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Par
OUAIL MOHAMED

Thème :

Stabilité des réseaux de distribution en présence de la génération distribuée

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Distribution network stability with presence of distributed generations (DGs)

by

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Abstract

For several reasons, the future electric distribution network is likely to include more distributed generation with different types and sizes, located on the load side. With the increasing power demand, DGs could be intended as a voltage support or power supplying support according to the economic and technical constraints. With the growth of penetration level, distribution network (DN) stability with the presence of distributed generation (DGs) must be deeply analyzed and investigated from all the sides. The aim of this thesis is to contribute to the investigations of Steady State and Transient Stability of Radial Distribution Network with the presence of DGs. An Overview regarding matters tied to integrating DGs is presented first, including a short investigation about the future electrical network of Algeria with integrating DGs. The investigation has required the presentation of the different methods used for transient and steady state stability evaluation and the effect of location and capacity of DGs on the steady state network parameters (voltage stability, power losses). The main contributions of this work consist of: investigation on the optimal placement and sizing of DGs using strength pareto evolutionary algorithm (SPEA) for voltage stability enhancement, active and reactive power losses reduction taking into account the number and types. Furthermore, for several reasons, DGs penetrations appear to be destined to escalate in DNs. This thesis has investigated some effect of DGs on DNs that were not addressed before, like the effect of installing new DGs on the transient stability of DNs considering (location, type, DGs size and number), and the effect of sudden under capacity, caused by losing DGs or excess demand, on the transient and steady state voltage stability and quality. Furthermore, the impact of DGs locations and power generation on the transient stability of micro-grid, subsequent to fault triggered islanding, have been investigated in this work. In addition, this thesis has investigated the potential of applying SPEA algorithm for both transient stability and steady state parameters improvement. The thesis has also proposed and analyzed methods for transient stability improvement of synchronous DGs and micro-grids that could reduce the effect of the small inertia problem of DGs.

ملخص

لعدة أسباب، من المرجح أن تتضمن شبكة التوزيع الكهربائية المستقبلية المزيد من التوليد المتوزع بانوع ومقاسات مختلفة، وتقع هذه المولدات بجانب المستهلك. مع زيادة الطلب على الطاقة، يمكن أن يكون الاستخدام الموضوعي لدعم الطاقة أو الجهد وفقًا لضوابط اقتصادية وتقنية. مع زيادة مستوى الادماج يجب تحليل ودراسة استقرار شبكة التوزيع مع وجود التوليد الموزع (DGs) بعمق والتحقيق فيها من جميع الجوانب. الهدف من هذه الأطروحة هو التحقيق في حالات الاستقرار في المرحلة الانتقالية والحالة المتوازنة لشبكة التوزيع الكهربائي مع وجود التوليد المتوزع (DGs). يتم تقديم نظرة عامة حول المسائل المرتبطة بدمج DGs أولاً، بما في ذلك التحقيق حول دمج DGs في الشبكة الكهربائية المستقبلية للجزائر.

تطلب التحقيق عرض الطرق المختلفة المستخدمة في تقييم استقرار الحالة الانتقالية و الحالة لمتوازنة وتأثير موقع ومقاس التوليد المتوزع على معلمات شبكة التوزيع في الحالة المتوازنة (استقرار الجهد ، فقدان الطاقة).

تتكون المساهمة الرئيسية لهذا العمل من: التحقيق في تحديد الموضع الأمثل والمقاس الأمثل للتوليد المتوزع باستخدام خوارزمية باريتو التطورية (SPEA) لتعزيز ثبات الجهد ، وتقليل ضياع الطاقة النشطة والمتفاعلة مع الأخذ في الاعتبار العدد والأنواع. علاوة على ذلك ، ولعدة أسباب ، يبدو أن عملية ادماج اختراق التوليد المتوزع مقدر لها أن تتصاعد في شبكات التوزيع الكهربائية. بحثت هذه الأطروحة في بعض تأثيرات اختراق التوليد المتوزع (DGs)على شبكات التوزيع الكهربائية التي لم يتم تناولها من قبل ، مثل تأثير تثبيت التوليد المتوزع الجديد على استقرار شبكات التوزيع في المرحلة الانتقالية مع وجود مولدات متوزعة أخرى مع الأخذ في الاعتبار (الموقع والنوع و المقاس والعدد) ، وتأثير قدرة توفير الطاقة المفاجئ بفقدان المولدات المتوزعة أو الزيادة في طلب الطاقة على استقرار وجودة الجهد الكهربائي. بالإضافة إلى ذلك بحثت هذه الأطروحة في إمكانية تطبيق خوارزمية (SPEA) لتحسين كل من الاستقرار في المرحلة الانتقالية و معلمات الحالة الثابتة. اقترحت وحللت هذه الأطروحة أيضًا طرقًا لتحسين الاستقرار ر في المرحلة الانتقالية للمولدات المتوزعة المتزامنة والشبكات الصغيرة والتي يمكن أن تقلل من تأثير مشكلة العطالة الصغيرة للمولدات المتوزعة (DGs).

Résumé

Pour plusieurs raisons, l’intégration des générateurs distribués(GEDs) dans le réseau de distribution électrique deviendrai plus important au futur, l’intégration va prendre différents types et tailles de GEDs située au côté des charge. Avec l'augmentation de la demande de puissance, les GEDs pourraient être conçues comme un support de tension ou un support de puissance en fonction des contraintes économiques et techniques. Avec la croissance du niveau de pénétration, la stabilité du réseau de distribution en présence des productions distribuées doit être profondément analysée. L'objectif de cette thèse est de contribuer à l’investigation de la stabilité, en régime permanent et transitoire, des réseaux de distribution de forme radiale en présence des GEDs. Premièrement les problèmes liés à l’intégration de GEDs les réseaux de distribution est présenté, y compris une brève étude sur les GEDs recommandées pour les réseaux électriques en l'Algérie.

L'étude a nécessité la présentation des différentes méthodes utilisées pour l'évaluation de la stabilité en régime permanent et transitoire et l'effet de l'emplacement et de la capacité des GEDs sur les paramètres du réseau en régime permanent (stabilité de la tension, pertes de puissance). La contribution principale de ce travail consiste en : une étude de l’emplacement et le dimensionnement optimaux des GEDs en utilisant l'algorithme génétique « Strength Pareto Evolutionary Algorithm(SPEA) » pour l'amélioration de la stabilité de la tension et la réduction des pertes de puissance active et réactive en tenant compte du nombre et des types. De plus, pour plusieurs raisons, l’intégration des GEDs semblent d’être augmenté dans les réseaux de distribution. Cette thèse a étudié certains effets des GEDs sur les réseaux de distribution qui n'étaient pas abordés auparavant, comme l'effet de l'installation des nouvelles GEDs sur la stabilité transitoire des réseaux en présence des autre GEDs en considérant (l’emplacement, le type des GEDs, la taille et le nombre de GEDs), et l'effet de la sous-capacité brusque, causée par déconnexion forcé des GEDs ou une demande excessive de puissance, sur la stabilité et la qualité et la stabilité de la tension. De plus, cette thèse a étudié le l'application de l'algorithme (SPEA) pour l’intégration et gestion des puissances des GEDs afin d'améliorer les paramètres des réseaux à l’état stable et la stabilité transitoire de réseaux en présence des GEDs. La thèse a également proposé et analysé des méthodes d'amélioration de la stabilité transitoire, qui pourraient réduire l'effet du problème lié à l’inertie, des GEDs et des micro-réseaux.

DEDICATION

I dedicate my dissertation work to my family and many friends. A special feeling of gratitude to my loving parents, whose words of encouragement and push for tenacity ring in my ears.

I also dedicate this dissertation to my many friends who have supported me throughout the process.

I dedicate this work and give special thanks to my supervisor. Professor MATALLAH Mohamed who has supported me. And Professor KANSAB Abdelkader, Professor Djilali Benyoucef and professor Abdallah Zegaoui for their advices

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List of Abbreviations

DG : Distributed Generation

DN : Distribution Network

DSG : Distributed synchronous generation

SCIG : Squirrel cage induction generator

VSI : Voltage stability Index

SPEA : Strength Pareto Evolutionary Algorithms

APL : Active Power Level index

RPL : Reactive Power Level

RP, AP : Reactive Power, Active Power

CCT : Critical clearing time

VI : Voltage profile index

TPAS : Transient Power Angle Shifting Control

PV: photovoltaic

AVR: Automatic Voltage Regulator

EAC : Equal Area Criterion

EEAC: Extended equal area criterion

COI : Center of Inertia

OMIB: One-machine infinite bus

CMs : Critical machines

u.e.p : Unstable equilibrium point

SIME: Single Machine Equivalent Method

PEBS: Potential Energy Boundary Surface

VSC: Voltage Source Converter

GA**:** Genetic Algorithm

SOPs: Soft Open Points

PLL : Phase-locked loop

PST: Phase shifting transformer

DC: Direct sources

ESS: Energy storage system

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1. CHAPTER 1: Introduction

1.1 General introduction

Regardless of the historical changes and developments that are submitted on the electrical network according to the energy policy, the principal operation aims to meet the electricity demand at all the locations within the power network as economically and reliably as possible. The evolution of the network was based on the economy, system security and the quality of energy supply. Conventional power system operation is based on centralized utility control of a relatively small number of large generators, delivering power through the transmission, network connecting the large generators, to the distribution network to meet a specified demand. The power network has been designed according to a specified demand in terms of capacity, location of the large generators, location of dispersed users…. etc. Nowadays, the specified parameters have been widely changed leading the network to its limits where meeting ever the demand need the total system upgrading. However, the high cost of network expansion (adding large central power plants, new transmission and distribution grid) and the shortage of conventional resources lead to the development of decentralized generation on distribution networks).

Recently, with electricity load increased, stochastic changes of day's power consumption, technological developments of DGs and attention to sustainable development and environmental pollution, investment in integrating distributed generation in distribution network becoming as necessary, so as to reduce the large power transmission, reduce the losses of transmission, support the local power grid and enhance the system reliability and quality. Therefore, the concerns of researcher rise more and more concerning the problems about integrating DGs in distributed network with high penetration level.

DG is a competitive power generation in the future electricity market. And it is incorporated into the distribution networks side as flexible power supply support for electric power system, and according to the desired advantages and the inevitable negative effect, DGs is incorporated using renewable energy sources (such as wind, photovoltaic) as well as nonrenewable sources [such as high efficiency small-scale Combined Heat and Power (CHP) schemes] to generate electric power. Incorporating DG in distribution network has been studied from the positive point of view and the negative point of view, DGs have a positive side for improving the quality and reliability of energy supply. However, a high level penetration of DGs brings a negative effect on power system stability, power system control and protection. The advantages and disadvantages of incorporating DGs in distribution network have been discussed and analyzed in [1].

The rapid growth of power demand has forced the power system to operate near to its stability limit, and according to the modern power system scenario and automation of systems in the world leads to increasing the penetration level of DGs. Despite the number of its advantages like increase in voltage profile, transmission and distribution lines cost reduction and line losses reduction if its penetration level becomes higher, distributed generation start to influence the dynamic behavior of the power system. The impact of distributed generation technology and penetration level on the dynamics of system have been investigated in [2]and it is found that the effects of distributed generation on the dynamics of a power system strongly depend on the technology of the distributed generators. In case of significant amount of DG, distribution systems may be subjected to unstable operation in the event of a large perturbation in the grid. Transient stability in distribution systems has gained special interest because of continuous increase of distributed generation which change the distribution networks from passive to active character of DNs. Various investigations conducted by industry and academia have shown that DGs could affect negatively the host distribution network in a number of ways. Analysis study of the transient stability at the distribution network level have been conducted in [3], where it is concluded that DG under voltage protection settings can be determined based on transient stability analysis, and this is an important issue as some types of DG units can remain connected and support the grid during and after a disturbance. Connecting DGs to distribution network are based generally on synchronous generator interface, induction generator interface and inverter interface according to the different DG types. Steady state and transient impact of Distributed Synchronous Generators (SDG) on a real Italian distribution network have been investigated in [4] and the influence on the quality of electricity supply and on the network stability have been analyzed. In [5] the influence of (SDG) and Distributed Induction Generators on stability of a generic distribution system is investigated and the dynamic behavior of the network with high penetration of different DSGs is analyzed in [6].

In contrast to large synchronous generators, distributed generation have relatively light or low-inertia turbine such as wind energy generators, small-scale Combined Heat and Power (CHP) schemes or do not have rotating kinetic energy at all such as PV systems or DGs connected via power electronic converters which hide the intrinsic rotational inertia.

Therefore, the overall system inertia will significantly decrease. Such low inertia may lead to loss of synchronism during abnormal fault conditions and large disturbances, the disturbance may be associated with an outage of a generator, transformer, line or loads and short circuit fault. Beside the angular stability of the conventional synchronous generator, instability can also occur when voltages reduce uncontrollably due to tripping or loss DGs for large-scale presence in distribution network. It stems from the attempt of load dynamics to restore power consumption beyond the capability of the combined transmission and generation system. Therefore, Distribution network stability is associated with the need for DGS to remain in synchronism in order to deliver power. This aspect of stability is governed by the ability of the system to maintain a balance between the demand and supply of reactive power in the network.

DGs penetrations are destined to escalate. Therefore, attention is shifting towards considering the cumulative effect on the bulk power system due to significant levels of DGs capacity. It can be expected that such large-scale presence will have impacts on the steady and transient stability of the distribution network and even on the whole system. Therefore, maintaining DGs connected at the network before and after disturbance will be necessary for the future distribution grid to assure the grid support and preventing the negative effect on the stability and reliability of total system.

Integrating DG units can have an impact (positive or negative) on the distribution systems, such as the voltage profile, power flow, power quality, stability, reliability, and protection. The impact is more important with the increasing penetration level compared to central power plants. Hence studying and analyzing the problems due to integrating DGs have become the topic of recent researches. Besides the voltage stability problem was known before in the passive distribution network (DNs). DGs, by transferring DNs from passive to active have introduced some problems which were known before only at the transmission level. Generally, DGs are directly connected to the grid using induction generators or synchronous generators or indirect interfacing using power electronics converters. The different nature of energy sources, mode of connection, and used technologies gives opportunities to the researchers to start large investigations on distribution network in presence of distributed generation regarding network stability, reliability, service quality, optimization and improvement techniques to use DGs etc…….

For several reasons, the future electric distribution network is likely to include more distributed generation, located on the load side. Currently DGs penetration is only a small percentage of the total load or generation. For small penetration, it is required to isolate the DGs from the grid when a disturbance occurs, and reconnect them when normal operation is restored. However, the cumulative impact of these disconnections on system stability may become important with the growth of penetration level. And the impact will be more important when the DGs take part in voltage and frequency control. Investments in DGs will lead progressively to increasing the level of penetration. Therefore, attention of researchers is shifting towards considering the cumulative effect on the stability, reliability and quality of power system due to significant levels of DG capacity. In this thesis we interested on the steady state and transient stability of radial distribution network with presence of DGs.

1.2 Recent studies and investigations regarding integration of DGs in distribution networks

The continuous increasing of DGs penetration in distribution network requires re-planning of the power system and this requires full knowledge about the concept of the new system, analyzing the several factors could be used in the planning and network management such as: impact of DGs in system operating characteristics, type of integrated DGs, the number and the capacity of the units, the best location, the best technology to be used, the type of network connection etc….. . many works, concerned the integration of distributed generation on the distribution network, aims to evaluate the impact of integrating DGs in distribution network considering the different types, the penetration level, the source nature and control strategy. Further investigation on using DGs in order to improve the network characteristics, such as steady state stability, transient stability, electric losses, voltage profile and reliability is the objective of many works [7], [8].

1.2.1 Impact of distributed generation on distribution system

The significant interest in Integrating distributed generation (DG) into a distribution network lead researcher to concentrate the work on evaluating the impact on the network characteristics, DGs penetration will change the electric system characteristics and will have various impact on the technical parameters based on its size type, the used energy sources, and location in the network. the impact of three different types of distributed generation (diesel generator, wind turbine and photovoltaic (PV)) on distribution networks' voltage profile and power losses is studied in [9]. Where NEPLAN software and the extended Newton-Raphson method have been used in the analysis. Where they find that different types of DG influence differently the distribution network and that their precise location and size are vital in reducing power losses and improving the voltage stability. beside various benefits could be provided by Interconnecting DG to distribution system as an enhanced in power quality, and a higher reliability, the integration of DG into existing networks has associated several technical, economic and regulatory questions. The authors in [10] investigates the impact of DGs on the power system for enhancing the power system quality by improve the voltage profile and power losses reduction. where others have studies the Impact of Distributed Generation on the Protection of Distribution Networks. In [11] the impact of distributed generation technology and penetration level on the dynamics of a test system is investigated. It is found that the effects of distributed generation on the dynamics of a power system strongly depend on the technology of the distributed generators and DGs penetration level.

1.2.2 Optimization on integrating DGs in distribution network

One of the most recent carried out research work regarding DGs are vised the optimal planning of distributed generation (DGs) systems under different aspects. several optimization techniques have been used to optimize distributed generation integration. These methods can be classified into three types: analytical, numerical (Linear Programming and Nonlinear Programming approach) and heuristic such as Genetic Algorithm (GA) and Artificial Bee Colony (ABC). The Genetic Algorithm (GA) presents the advantage to explore the space of the feasible solutions from a set of solutions created in a random manner. A multi-objective technique based on a genetic algorithm have been widely proposed for optimal location, sizing, type and number of DGs considering different objectives as cost minimization, voltage stability, power loss reduction, quality and reliability improvement. [12], [13].

The use of an optimization method capable of indicating the best solution for a given distribution network can be very useful for the system planning engineer, when dealing with the increase of DG penetration that is happening nowadays. The selection of the best places for installation and the preferable size of the DG units in large distribution systems is a complex combinatorial optimization problem, some aspects have been treated in [14]-[19].

1.2.3 stability of distribution network with presence of DGs

The continuous increase of connecting distributed generation to distribution network(DN) increase the interest on the DN Transient stability, there are many technical aspects and challenges that are still not properly understood or addressed. Among the numerous issues associated with distribution systems containing DGs, stability analysis is of significant interest [20]. The authors in [21] see that distribution network have extensive branches and unbalanced loads, with a specific set of equipment, which increasing the complexity of the numerical analysis of transient stability. They propose a new methodology for transient analysis in distribution networks with distributed generation. distributed Synchronous generator (DSGs) have a large involving thy are mainly used in the distribution network with the application in cogeneration and in self-producers of large industries, it is therefore necessary to investigate the angular stability of this type of generation units. Dynamic of the distribution network in presence of decentralized productions based on synchronous machine have been analyzed in [22]. the transient stability analysis of a 10-kV distribution network with wind generators, micro turbines, and CHP plants have been described in [23] using Matlab/Simulink to model and taking into account the detailed dynamic models of the generators for simulations and investigation of fault at various locations.

The high penetration of renewable energy and distributed generator based rotating machines with small inertia in distribution network will challenge the stable operation of the future distribution system, because the characteristics of converter-based resources differ from those of a synchronous generator and a short critical clearing time of small DGs based synchronous and induction generator with small inertia witch result a weak grid transient stability. To solve these problems, different methods have been proposed in literatures. One method to compensate for the reduced system inertia is to connect short-term energy storage to the DG bus. The entire unit is termed as virtual inertia or Virtual Synchronous Generator VSG [24], another approach is using The Virtual Synchronous Machine (VSM) concept, it is a flexible approach for controlling power electronic converters in grid-connected as well as stand-alone or micro-grid applications [25] [26].

1.3. Objectives and Outline of the Thesis

The objective of this theses is to investigate the stability of the future distribution network with presence of distributed generation. as the architectures of most of distribution network are in radial topology, our investigations are focuses on the radial topology. the objective is to determine the effect of penetration level, type of used DGs on the steady state stability as well as on the transient stability of distribution network. The important contribution is investigation about the optimal placement and optimal sizing of the distributed generation considering the DGs type, number of integrated DGs using the multi objective genetic algorithm (strength pareto evolutionary algorithms SPEA). The objective functions addressed in the optimization concern the steady state as well as the transient dynamic of the distribution network such as voltage stability, power loss and transient stability of DGs. The continuous increasing penetration level of DGs motivate us to investigate the effect of losing DGs on the steady state voltage stability as well as the transient stability of the others DG units and investigate the stability of distribution network with presence of distributed generation when integrating new DGs. Further due to the high impact of DGs inertia factor on the transient stability of synchronous DGs, which is generally very small for small units. We proposed an emergency control for transient stability improvement of synchronous distributed generator with small inertia, also with the growing deployment of micro-grids we proposed a connection topology with the main grid to improve the transient stability of the micro-grid when external fault is forcing the islanded mod. simulation and analyses of the results have been realized on radial distribution test systems using matlab code and Matlab/Simulink software.

1.4. Outline of the Thesis

After the general introduction presented in chapter 1, the remainder of this thesis is organized as follows:

Chapter 2 presents an overview on Distributed Generation (DG) and system stability. In this concept, at the first part different definitions and type of network stability with presence of DGs are discussed. Network and DGs modeling for stability assessment and impact of the DG units on power system are presented. types of DG units, types of interfacing and technologies are presented. The second part of the chapter is dedicated to discuss the distributed generation in the future algeria network with introducing the availability of different energy sources and its distribution on the country and the recommended DGs for algeria network are discussed.

Chapter 3 presents the different methods used for transient stability of power system and the methods could be used for transient stability analyses with presence of distributed generations. the steady state voltage stability of distribution system with presence of distributed generation are analyzed and the method could be used for voltage stability assessment are discussed.

Chapter 4 proposes to use optimizations method for transient and steady state improvement. At first the optimal placement and sizing of distributed generation using strength pareto evolutionary algorithms are investigated and discussed. the effect of losing DGs on the voltage stability and angle stability of DGs based- rotating machines are investigated. the effect of integrating new DGs on the transient stability of distribution network with presence of DGs are investigated considering the impact of the transient behavior between DGs and the impact on transient voltage. in addition, the impact of DGs location and power share on the transient stability of micro-grid subsequent to fault triggered islanding have been analyzed. At the last part of the chapter The optimal placement and sizing of different DGs type using SPEA for both steady state and transient improvement are investigated in radial distribution network and micro-grid.

Chapter 5 proposes emergency local control of connecting synchronous DGs and a topology to connect micro grid with the main grid in order to improve the transient stability. At the first we introduced the different methods used to improve the transient stability then the proposed local control of connecting synchronous DGs with small inertia are analyzed. At the last part the proposed topology base on using soft open points for connecting micro-grids with the the utility grid are investigated and analyzed.

Chapter 6 presents the thesis summary, and contributions.

2. CHAPTER 02: Overview on electrical network stability, DGs technologies, Types of DGs sources compatible with algeria network

2.1 introduction

With increasing penetration level of DGs in distribution network the Stability studies on this grid become a recent topic of study that should be treated extensively for the future electric generation. Traditionally, stability studies have been concerned only the transmission networks because they are the main network connecting the generators and distribution network was completely passive used for load supply with one direction of power flow. However with the introduction of distributed generation generators into the distribution networks, stability studies become essential to be carried out on this active distribution networks. In This chapter we treated and identified the different problems related to the stability of distribution networks with presence of DGs. The different types of stability are identified in this chapter and a general network modeling with presence of DGs are introduced. In contrast to the conventional generation power units, distributed generations are integrated to the network in small units with different types, different nature energy sources and technologies. In this part of study, we presented the different DGs classification according to their technologies, size, type off energy sources and power generation type. As the distribution generation become the future interest in the world we introduced the different type of energy sources existed in algeria and the recommended DGs could be used to support the future electrical network in algeria.

2.2. Definition of electrical system stability:

Power system stability considered as an important problem for secure system operation since the past, where the stability of whole system was relied on the transmission network connecting the power generators. However, introducing distributed generation have generalized the stability concern on the whole network.

Power system stability is defined as the ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most of the system variables bounded so that practically the entire system remains intact [27]. Disturbances of the system may be of various types like sudden changes of load, the sudden short circuit between line and ground, line-to-line fault, three line faults, generator outages, line outages, switching, etc. Power system stability can be broadly classified into rotor angle, voltage and frequency stability. Each of these three stabilities can be further classified into large disturbance or small disturbance, short term or long term. The classification is shown in Figure2. 1 [28]

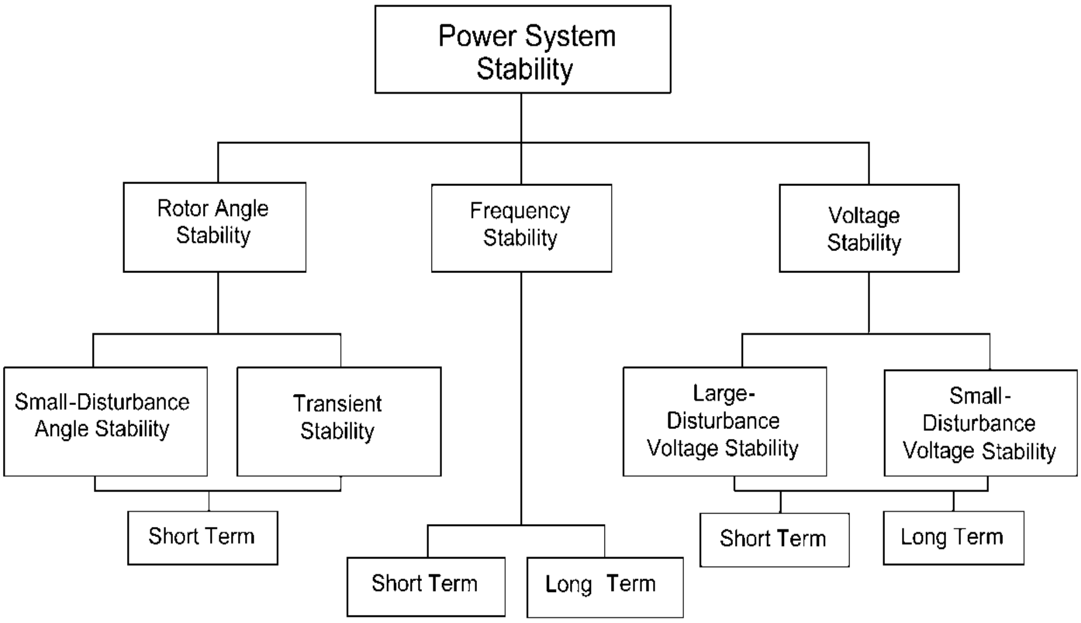


Figure 2.1:Classification of power system stability.

The power system is considered as nonlinear system that operates under continuous change of parameters and factors subjected to a disturbance level small or large disturbance, disturbance duration from short term to long term and the nature of the disturbance. Both voltage, frequency and angle stability system are depended on the initial operating condition.

2.3. Network stability with connecting DGs:

2.3.1.Angle stability:

At the transmission network it is considered as the ability of the system to remain in synchronism when subjected to a disturbance, means that all the generators still have the balance between the electromagnetic torque due to the generator electrical power output and mechanical torque due to the input mechanical power through a prime mover. Kipping the same electrical speed for all the generators. This still the same concern for a micro-grid based distributed synchronous generator in islanded mod. However the angle stability of distribution network with connecting synchronous DGs is concerned on the ability of the individual DGs to still synchronized to the utility grid. DGs is characterized by the small inertia compared to the main system inertia which make it very sensible for angle stability. Rotor angle stability is further classified into small disturbance angle stability and large disturbance angle stability.

With Integrating DGs in distribution network, the problem of angle stability has been introduced in distribution network which is concern the synchronization of each synchronous generator in connected mode and the synchronization of multi-DGs in islanded mode.

2.3.2. Voltage stability:

Voltage stability refers to the ability of a power system to maintain steady voltages at all buses in the system after being subjected to a disturbance from a given initial operating condition. Many definition of voltage stability have been used in literatures, According to IEEE [29], the definitions related to voltage stability are given as follow:

- Voltage Stability is the ability of a system to maintain voltage so that when load admittance is increased, load power will increase, and so that both power and voltage are controllable.
- Voltage Collapse is the process by which voltage instability leads to loss of voltage in a significant part of the system.
- Voltage Security is the ability of a system, not only to operate stably, but also to remain stable (as far as the maintenance of system voltage is concerned) following any reasonably credible contingency or adverse system change.

Maintain steady state voltages at all the system buses when subjected to a disturbance is the concern of Voltage stability studies. Either in small disturbances and large-disturbances. Unlike angle stability, voltage stability can also be a long term phenomenon. In case voltage fluctuations occur due to fast acting devices like induction motors, power electronic drive, HVDC etc… then the time frame for understanding the stability is in the range of 10-20 s. if voltage variations are due to slow change in load, over loading of lines, generators hitting reactive power limits, tap changing transformers etc… then time frame for voltage stability can stretch from 1 minute to several minutes. In contrast of transmission network with high X/R ratio, voltage stability depends on the balance of reactive power demand and generation in the system, radial distribution network has a small X/R ratio which make voltage stability depends ether on the balance of reactive power demand and generation and on the balance between real power generation of DGs generation and load demand.

2.3.3. Frequency stability

This type of stability represents the ability of the power system to maintain its nominal frequency following disturbances between generation and load. it can be caused by the loss of a large generator, or inefficient load shedding. Frequency instability may lead to sustained frequency swings leading to tripping of generating units or loads and it may be a short-term phenomenon or a long-term phenomenon according to the response of devices. The problem of frequency stability concerns Low frequency oscillations due to small disturbances in the system. for DGs connected mode the frequency stability is related to the transmission network where integrating high level of DGs can decrease the total inertia of the system which effect the whole system stability. The major frequency instability is generally associated with islanding scenarios. Where One or more sub-networks are isolated from the rest of the system. The generators of the sub-network try to keep synchronism with each other, but the subnetwork inertia is insufficient to cope with the isolated load. hence The frequency decreases rapidly leading to the system instability before reactions of controllers due to short term phenomenon. Frequency instability can also be a long term phenomenon, due unsuitable coordination between regulations and protections or due to a slow power response of power generation units. The problem of frequency instability due to the islanded mod is more delicate in distribution network in presence of DGs with small inertia.

2.4. Electrical networks modeling for Stability Studies

System modulation is depending to study objectives considering the needed time, the precision of the model and its complexity, local or global study concern. An appropriate choice of model is based on a compromise between the precision of the modeling and its complexity. Studding the electrical network stability with presence of DGs need to total modeling of the network as local modeling. Where a simplifications and hypotheses should be compatible with the purpose of the study. Angle, voltage and frequency stability study time interest is in the range from few milliseconds to several seconds. the electromechanical transients and long term dynamic of the system is the interest of our studies. Where the electromechanical modeling is used for transient and small signal stability and voltage stability. For purpose of Analyzing the influence of DGs on the stability of a distribution network and its effect on the whole power system stability.

In this part we presented the model a distribution network with DGs with adequative representation of the dynamics and significant reducing models used for performing the stability analysis of the large scale power system following small and large disturbances in order to improve the network stability with DGs integration.

2.4.1 Modeling system for power system transient stability study

With Increasing DGs level penetration, large synchronous generators will not more considered as the dominating generation unit. Without DGs penetration or small integration level transient stability of transmission systems analyzed with a simplified representation of the distribution systems. In future, distributed generation will affect the dynamic behavior of the system. For that DGs effect should be integrated in the dynamic models for transient stability analysis of power systems with high penetration of DGs.

Angle stability is remaining a necessary condition for satisfactory system operation in power system or distribution system based synchronous generators.

for transient stability studies of power system, the distribution system without DGs is represented only by the load at the main connections between the transmission system and the distribution systems. In case of small penetration of DGs, where DG power generation is less than the load at the main connections. We have to scenarios:

scenario1: DGs steel connected to the distribution during the transient phenomenon, it interaction could be represented by a negative load to be added to the load at the main connections.

Scenario2: the DG is disconnected from the network for protection raisons due to the limitations of the converter interface DGs or instability of DGs based rotating machines.

In case of large penetration of DGs, where DG can deliver power from feeder to others throw the transmission network , a simple approach proposed in [30] is used by representing the incorporation of DG in a distribution network as an equivalent load and generator. where Only one DG technology could be assumed to be connected at the main connection bus for each simulation scenario. the general model of connecting DG at a particular load bus is shown in Figure 2.2.

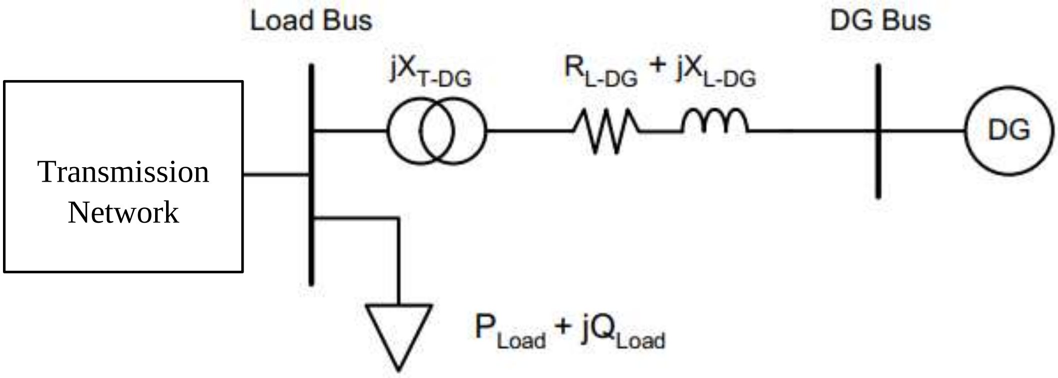


Figure 2.2: General model of connecting DG to transmission network

Where X_{T_DG} and X_{L_DG} represent the reactance of the transformer and the line between the DG and the transmission network respectively, and R_{L_DG} represents the resistance of the line.

Interconnection Network equations:

Interconnection Network modeled as a relation matrix between the currents and the voltages its main nodes, it is represented by a constant and symmetrical nodal admittance matrix

Ybus. As presented in equation (2.1).

$$\begin{bmatrix} I_1 \\ \vdots \\ I_n \end{bmatrix} = Y_{bus} \begin{bmatrix} V_1 \\ \vdots \\ V_n \end{bmatrix} \qquad 2\ .1$$

Where: $\begin{bmatrix} I_1 \\ \vdots \\ I_n \end{bmatrix}, \begin{bmatrix} V_1 \\ \vdots \\ V_n \end{bmatrix}$ are injected current and voltage vectors at nods, and Y_{bus} is the nodal admittance matrix.

Modeling the loads as constant impedance type, the power system with m nodes connecting generators, the nodal equation can be written as:

$$\begin{cases} \begin{bmatrix} I_1 \\ \vdots \\ I_m \\ 0 \\ \vdots \\ 0 \end{bmatrix} = Y_{busL} \begin{bmatrix} V_1 \\ \vdots \\ \vdots \\ V_n \end{bmatrix} \\ Y_{busL} = Y_{bus} + Y_L \end{cases} \qquad 2.\ 1$$

When the loads are considered as constant admittances, they can be included in the network admittance matrix as in the equation (2.2),find more detail in detail [31]

Where Y_L is the load admittance and $I_1 \dots . I_m$ are the complex injected generator currents at the generator buses.

Since there are no injections at buses m+1,.., n, we can eliminate them by reducing Y_{busL}.

Assuming that the Y_{busL} be partitioned as:

$$Y_{busL} = \begin{bmatrix} Y_{1_{m,m}} & Y_{2_{m,(n-m)}} \\ Y_{3_{(n-m),m}} & Y_{4_{(n-m),(n-m)}} \end{bmatrix} \qquad 2.\ 2$$

$$\begin{bmatrix} I_1 \\ \vdots \\ I_m \end{bmatrix} = Y_{red} \begin{bmatrix} V_1 \\ \vdots \\ V_m \end{bmatrix} \qquad 2.\ 3$$

Where $Y_{red} = (Y_1 - Y_2 Y_4^{-1} Y_3)$ is the desired reduced matrix and it has the dimensions (m x m).The reduced matrix are computed for every network condition (pre-fault, faulted and post-fault conditions).

Differential equations:

The differential equations of the synchronous machine of the system is depend on the order model of the synchronous machine, The impact of model detail of synchronous machines on real-time transient stability assessment is analyzed in [32] . 4^{th} order model, 3^{rd} order and classical model are expressed as follows:

4^{th} -order model:

$$\begin{cases} \begin{cases} T'_{d0}\frac{dE'_q}{dt} = -E'_q - (X_d - X'_d)I_d + E_{fd} \\ T'_{q0}\frac{dE'_d}{dt} = -E'_d - \left(X_q - X'_q\right)I_q \end{cases} \\ \begin{cases} \frac{d\delta}{dt} = w - w_s \\ \frac{2H}{w_s}\frac{dw}{dt} = p_m - p_e - D(w - w_s) \end{cases} \end{cases} \qquad 2.4$$

p_m is the mechanical power and $p_e$is The electrical power output expressed as follows:

$$p_m = E'_q I_q + E'_d I_d + \left(X'_q - X'_d\right) I_d I_q \qquad 2.5$$

Di: Damping constant of the machine.

$\mathrm{E}'_{\mathrm{dq}}$: Transient voltage in d-/q-axis.

E_{fd}: Field voltage.

H : Inertia constant.

$\mathrm{I}_{\mathrm{d,q}}$: Current in d-/q-axis.

$\mathrm{T}'_{\mathrm{d0,q0}}$: Transient time constant of d /q-axis.

$\mathrm{X}'_{\mathrm{d,q}}$: Transient reactance in d /q-axis.

$\mathrm{X}_{\mathrm{d,q}}$: synchronous reactance in d /q-axis.

δ: Rotor angle.

w : Rotor speed.

w_{s}: Synchronous rotor speed:

3^{rd} -order model:

In this model, the representation of the synchronous machine is reduced by another degree. Therefore, the damper windings dynamics represented by transient voltage E'_d are eliminated. This reduction is achieved by setting T'_{q0} equal to zero. The model is presented by the following equations:

$$\begin{cases} \begin{cases} T'_{d0}\frac{dE'_q}{dt} = -E'_q - (X_d - X'_d)I_d + E_{fd} \end{cases} \\ \begin{cases} \frac{d\delta}{dt} = w - w_s \\ \frac{2H}{w_s}\frac{dw}{dt} = p_m - p_e - D(w - w_s) \end{cases} \end{cases} \tag{2. 6}$$

$$p_m = E'_q I_q + \left(X_q - X'_d\right) I_d I_q \tag{2. 7}$$

2^{nd} -order model:(Classical model):

In is the classical model the voltage behind the transient reactance is assumed to be constant. For such a representation only the swing equation is needed to describe the dynamics of a synchronous machine.

$$\begin{cases} \frac{d\delta}{dt} = w - w_s \\ \frac{2H}{w_s}\frac{dw}{dt} = p_m - \frac{E'V_t}{-X'_d}\sin(\delta - \theta_T) - D(w - w_s) \end{cases} \tag{2. 8}$$

E':Internal voltage behind transient reactance.

$V_t\angle\theta_T$:Terminal voltage.

The synchronous machine model is selected depend on the needed precision and time of simulation limit. a comparison between the orders model have been realized in [32] to assess the transient first swing stability.

2.4.2. Molding of DGs:

Due to the variety of primary energy sources, DG can generate electricity by means of either rotating electrical machines or static electrical generators, If the DGs generate power at the system frequency, DGs can be directly coupled to the grid where a synchronous or an induction generator are used for generation. However, if the frequency deviates from the system frequency or DC sources as solar panels and fuel cells, due to the intermittent nature of energy sources, power electronic interface must be used. In term of DG connection to the power grid, we have two categories Direct grid-connected DG and Indirect grid-connected DG.

Since the incorporation of DGs in the stability studies become necessary, researchers have realized many works regarding static and dynamic models for the various DG technologies for stability analysis. For the high penetration level of DGS, Voltage and angle system stability studies with DGs penetration, both in the long- and short term, becomes necessary from local point of view or the global system point of view where the impact of DG is no longer restricted to the local load or distribution network where these units are connected, but may also have an impact on the transmission system. Developing models of DGs generally based on the DG’s primary energy source, generator, and type of connection to the network (direct or indirect grid connection).

2.4.3. Dynamic models of different DGs for stability studies.

2.4.3.1 GED connected through power electronics interface:

The General model presentation of this type of GEDs is illustrated in Figure 2.3, is concern the new technologies such as systems photovoltaics, fuel cells, some types of wind turbines…...
Modeling of the energy production structure interfaced with electronics power is a complex problem. However, these models are generally simplified according to the problem to be studied.

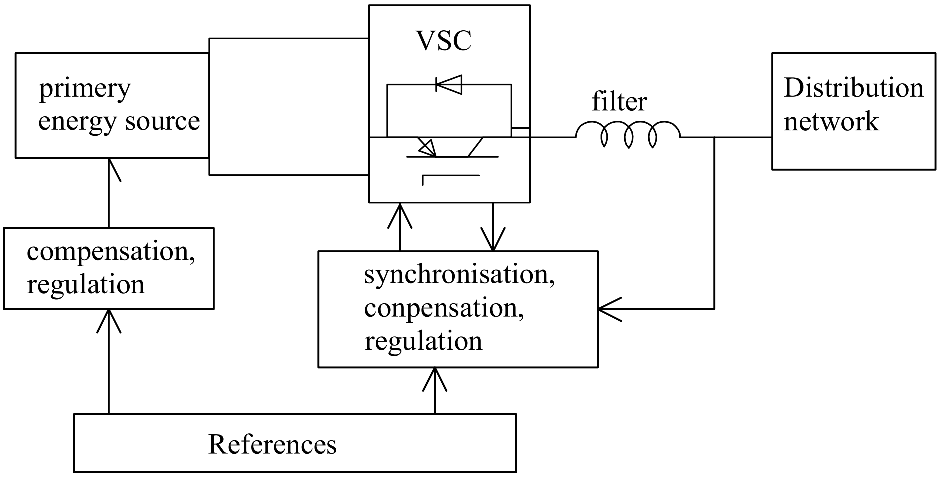


Figure 2.3: General diagram of grid connected GEDs using power electronics interface

Modeling assumptions and simplifications:

In order to create simple models, several assumptions considering the limits are made on the dynamics of different elements of the system. [33]
-Only the slow system dynamics is taken into account, the dynamics of the inverter for reactive power regulation or the dynamics of the production unit for the regulation of active power, an adequate first-order system should have inserted properly into the regulation and control system of the inverter.
-The production unit has fixed limit of active power output.
- The converters impose a limited on the amplitude of the transmitted current.
These simplifications in the park frame have been used to obtain the injected current simplified modeling, the energy source and the inverter have been modeled by a limitation and a delay to keep the system dynamic [34] as shown in Figure 2.4.

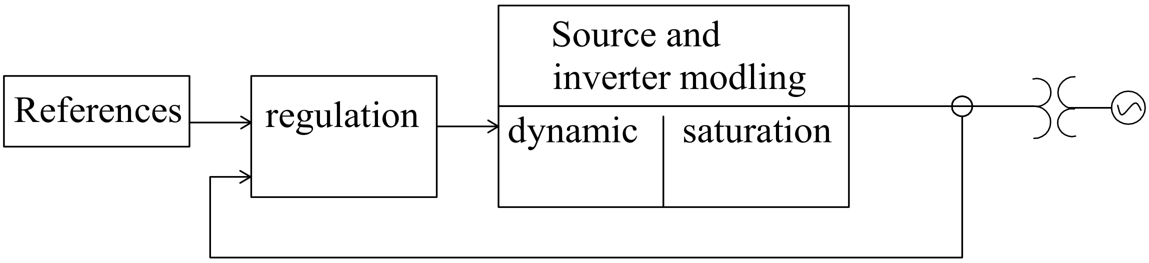


Figure 2.4: simplified modeling of the energy source and the inverter

Inverter control:

Several types of inverters control exist in the literature for DGs connection with the network. To decouple the control of the active and reactive power supplied by the inverter, park transformation is very often used. the active and reactive power supplied by the inverter at the current and voltage measurement point are represented as follow.

$$P = \frac{3}{2}\left(V_d I_d + V_q I_q\right) \qquad Q = \frac{3}{2}\left(-V_d I_Q + V_q I_d\right) \qquad 2.9$$

$$I_d = \frac{2}{3}\left(PV_d + QV_q\right) / \left(V_d^2 + V_q^2\right) \qquad I_q = \frac{2}{3}\left(PV_q - QV_d\right) / \left(V_d^2 + V_q^2\right) \qquad 2.10$$

Where:
P and Q are DG powers references.

$V_d$and$PV_q$are the direct and quadratic components of the voltage measured at the connection point, in the Park reference.

$I_d$and I_q are the direct and quadratic components of the DG current on the network connection.

To synchronize the Park transformation with the network using Phase Locked Loop or (PLL)is generally used. Where, at steady state, V_d take the amplitude of voltage network $V_d = V_{max}$ and $V_q = 0$.

Hence The currents $I_d$and $I_q$depend on the requested power as well as the measured voltage. at the network connection point. where I_d controls active power and I_q controls the reactive power.

The DGs based inverters could be controlled in (P/Q) mode or in (P/V) mode details in [34] according to the purpose of DGs integration, control power or control the voltage at the connecting node. The most simplified control mod is injecting only the active power where the reference current $I_q = 0$. The detailed (P/Q) control scheme is presented in figure 2.5

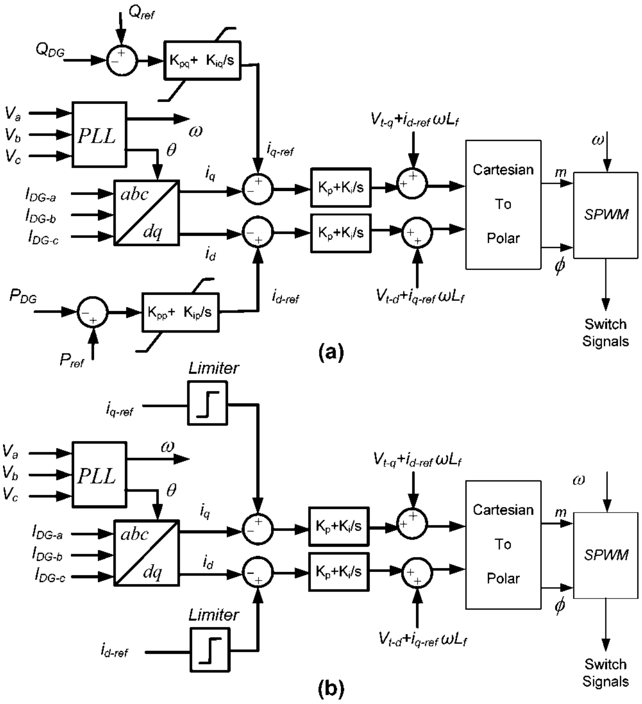


Figure 2.5:Control schemes of the inverter-based DG. (a) P&Q control scheme and (b) is current scheme control

L_f is the filter inductance; and V_{t-d} and $V_{t-q}$are the terminal voltage direct and quadrature component).

2.4.3.1 Modeling OF DGs based Synchronous generator:

Synchronous generators can be analyzed conveniently using the Park’s transformation, which results in a time-invariant nonlinear system. In the event that the system experiences a small perturbation, the linearized power system models can be used with advantage for both analysis and controller design. Such a linear design on a nonlinear system generally provides asymptotic stability over a small region about the equilibrium and is appropriate for the dynamic stability problem where the primary concern is providing damping following small disturbances. A simplification of the model could be used according desired studies, the author in [8] have used hypotheses to simplify the model where the behavior of the system by its dynamic characteristics and by its limitations. the slowest dynamic of the system is considered, that of the production source is the dynamic for active power generation and The reactive power depends only on the time response of the synchronous generator and the dynamics of the regulation system. the general diagram of synchronous generator system and its control block is presented in Figure 2.6.

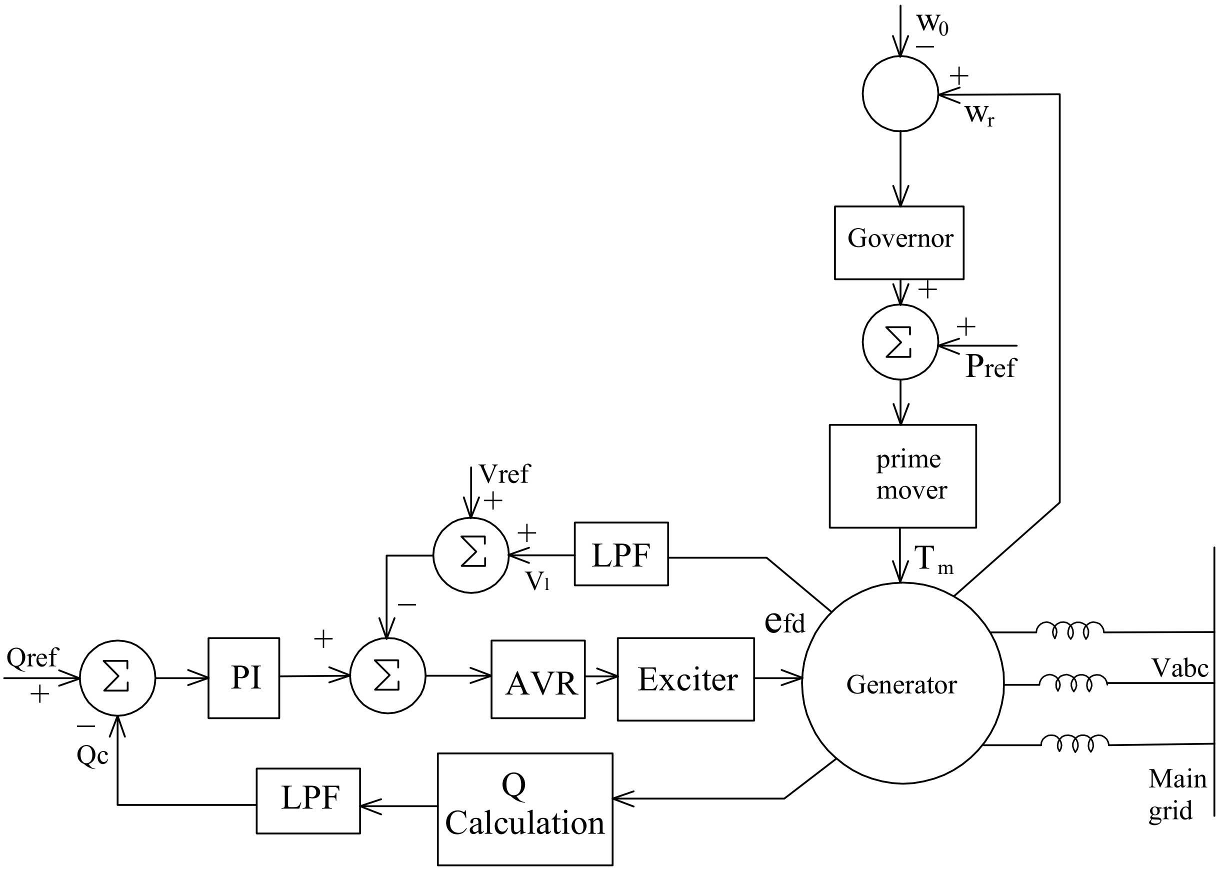


Figure 2.6: diagram of synchronous generator system and its control block

The dynamics of the synchronous machine can be described by a set of nonlinear differential equations. Typically, the states can be associated with each machine's armature currents, rotor currents resolved through the Park's equations, rotor dynamics, automatic voltage regulator (AVR) and the turbine governor dynamics.

General excitation system model and reactive power regulation:

Generally, two excitation regulation systems could be used, when Synchronous generators is connected to a distribution network, depending on the size of the generator and the stiffness of the connecting utility bus. using either automatic voltage regulation (AVR) or reactive power/power factor regulation (VAR/PF. A simplified model of the excitation system have been used in [35] for simplicity of the analysis in the time frame involved, the excitation system is represented as a tuned PI controller. The parameters of the circuit model could be approximated from the aggregate response of terminal voltage of a generator. the model of the excitation system is shown in Figure 2.7. A PI controller is cascaded with the exciter to regulate the reactive power of the machine. Therefore, when the grid is connected, the reactive power output of the machine will follow the desired reference value.

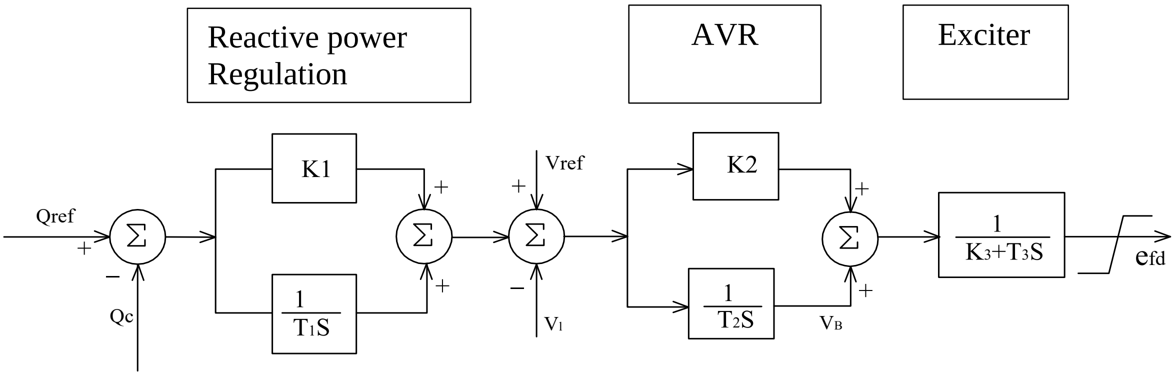


Figure 2.7: Diagram of excitation system control

Governor (prime mover) and Active Power Regulation Model:

A simplified model present the production source by a limitation and dynamic of active power generation, a simplified model used in [35] is presented in Figure 2.8

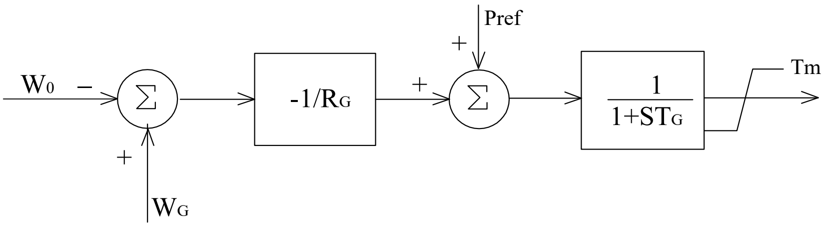


Figure 2.8: Figure: diagram of governor/prime mover control [10]

The governor dynamics including the prime mover is simplified to the equation below:

$$T_{\dot{m}} = \frac{1}{T_G}\left(P_{ref} + \frac{W_0 - W_r}{R_G} - T_m\right) \qquad 2.\ 11$$

Where T_G is the time constant of the prime mover of the generator and R_G is the governor droop.

Molding of Fixed-Speed Wind Turbine Generating Units

wind renewable energy could be used in deferent turbine unit as Fixed speed wind turbine with direct-grid connected induction generator, variable speed wind turbine with variable rotor resistance induction generator directly connected to the grid, Variable speed wind turbine with direct-grid connected doubly fed induction generator and dc/ac rotor convertor and Variable speed wind turbine with synchronous machine and full scale ac/dc/ac converter. Due to economical raisons the fixed speed wind turbine with direct-grid connected induction generator is the most commonly used in distribution systems as a DGs. The different types are presented in figure 2.9. [36]

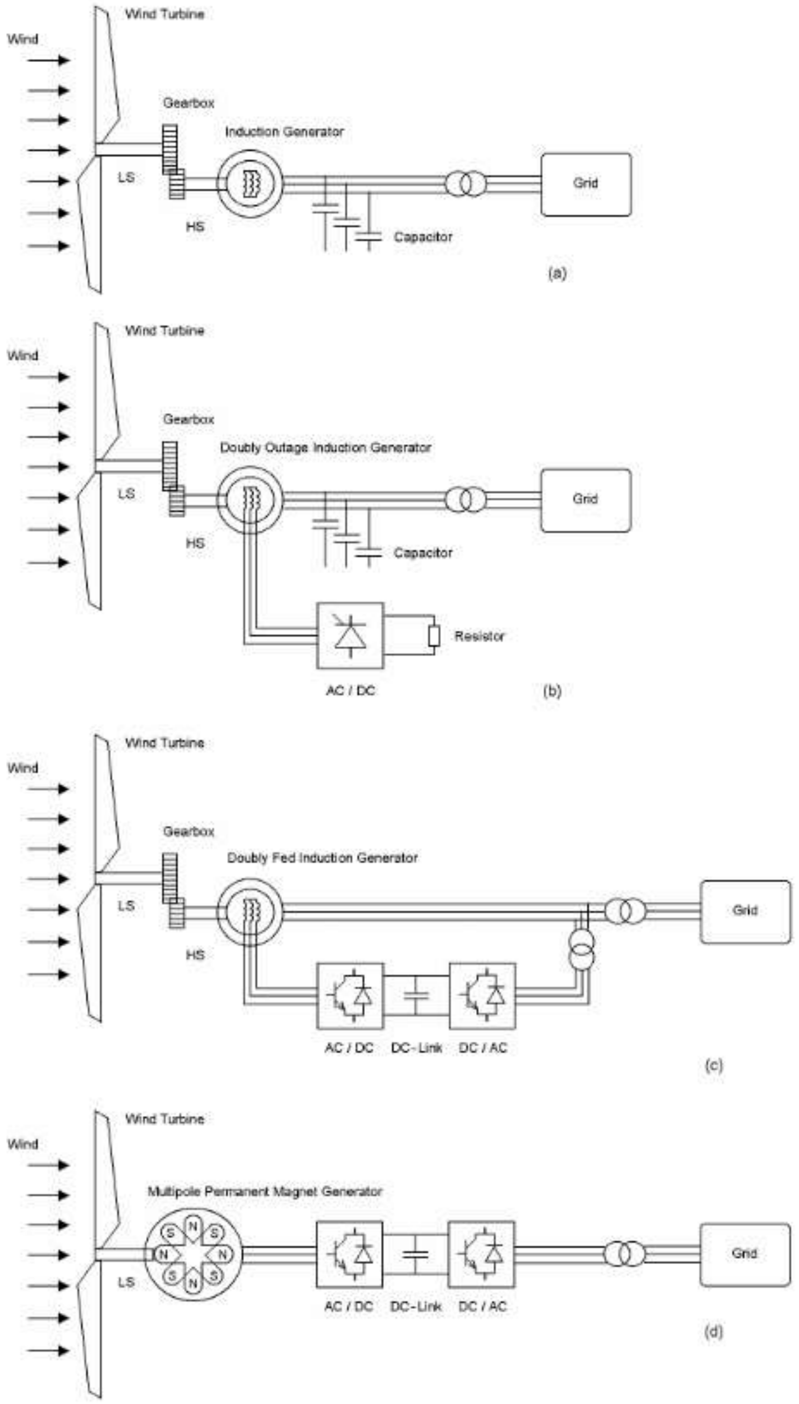


Figure 2.9: technologies of wind turbine generators:(a)Fixed speed wind turbine with direct-grid connected induction generator,(b)variable speed wind turbine with variable rotor resistance induction generator directly connected to the grid,(c)Variable speed wind turbine with direct-grid connected doubly fed induction generator and dc/ac rotor convertor, (d) Variable speed wind turbine with synchronous machine and full scale ac/dc/ac converter.

Fixed-Speed Wind Turbine is normally equipped with a squirrel-cage induction generator(SCIG), most squirrel-cage conventional IGs are usually used in small and medium scale hydros and wind farms with direct connection to sub-transmission and distribution networks as DGs [37]. a squirrel-cage induction generator is connected to the rotor through a gearbox, and a reactive source. Since the rotor of the squirrel-cage induction generator often runs at constant speed, the wind turbine of this type is sometimes called a fixed-speed wind turbine system. In order to prevent the induction generator from being damaged at high wind speed, the angle of the blades can be actively adjusted according to the wind speed (pitch angle control).

Wind turbine model:

In the literatures, the mechanical power and the aerodynamic torque developed by a wind turbine are given by:

$$P_w = \frac{\pi\rho r^2}{2} v_{wind}^3 C_p(\gamma, \beta) \tag{2. 12}$$

$$T_w = \frac{\pi\rho r^5}{2\gamma^3} w_m^2 C_p(\gamma, \beta) \tag{2. 13}$$

where $\mathrm{P_w}$ is the power extracted from the wind, $\mathrm{T_w}$ is generator electrical torque, ρ is air density, r is the area covered by the rotor, $\mathrm{v_{wind}}$is the wind speed, and $\mathrm{C_p}$ is the performance coefficient or power coefficient. Within $\mathrm{C_p}$, β is the pitch angle of rotor blades, λ is the tip speed ratio for which $\lambda = \frac{\mathrm{r\, w_m}}{\mathrm{v_{wind}}}$, where $\mathrm{w_m}$ is the angular speed of turbines (rad/s).

In the majority of investigations, the bitch and the active stall controlled wind turbine are modelled using $\mathrm{C_p}\text{-}\lambda - \beta$ curve where commonly the curve is given by the wind turbine manufacturer [36].

squirrel-cage IGs model

The induction generator can be represented by the detailed differential equations in the two-axis reference frame (d–q frame) as follow:

$$\begin{cases} V_{sd} = -R_s i_{sd} - w_s \psi_{sq} + \dot{\psi}_{sd} \\ V_{sq} = -R_s i_{sq} + w_s \psi_{sd} + \dot{\psi}_{sd} \\ \ 0 = -R_r i_{rd-} s w_s \psi_{rq} + \dot{\psi}_{rd} \\ \ 0 = -R_r i_{rq-} s w_s \psi_{rd} + \dot{\psi}_{rq} \end{cases} \tag{2. 14}$$

Where the used subscripts are defined as follows: d: d-axis quantity, q: q-axis quantity, r: rotor quantity, s: stator quantity, w_s is the synchronous speed, s is the sleep between the rotor and stator. and w_r is the rotational speed of the rotor.

$$s = \frac{w_s - w_r}{w_s} \qquad 2.\ 15$$

The constitutive flux linkage current relationships are:

$$\begin{cases} \psi_{sd} = -L_{ss}i_{sd} - L_m i_{rd} \\ \psi_{sq} = -L_{ss}i_{sq} - L_m i_{rq} \\ \psi_{rd} = -L_m i_{rd} - L_{rr}i_{rd} \\ \psi_{rq} = -L_m i_{rq} - L_{rr}i_{rq} \end{cases} \qquad 2.\ 16$$

Where L_{ss} and L_{rr} are the summation of leakage inductance $L_{s,r}$ and mutual inductance L_m of the stator and rotor winding respectively.

The electromagnetic torque, T_e can be expressed as:

$$T_e = \psi_{sd}i_{sq} - \psi_{sq}i_{sd} \qquad 2.\ 17$$

The rotating equation of the of the asynchronous machine rotor is given by:

$$\frac{d}{dt}w_r = \frac{1}{2H}(T_m - T_e) \qquad 2.\ 18$$

More detail of DGs molding could be found in the literatures ,On overview of the dynamic and static modeling of various DG technologies for stability analysis, allowing studying systems with DGs both in the long- and short term, have been realized in [38] such as Diesel Generator model, Micro Turbine Generator, Fuel Cell and photovoltaic generator.

Load modeling:

In general, modeling of load is a complex problem, due to the dependencies of load's active and reactive power with the voltage and frequency of connection bus, the static approaches are the most used techniques to model the

loads in power systems studies. In the static models, the load where P and Q are depended of bus bar voltage and scales factors. Generally, in the power systems literature two classical static approaches are used to model the loads. [39]

a)-exponential model defined as:

$$\begin{cases} P = KpP0(\frac{U}{U0})^{\alpha p} \\ Q = KqQ0(\frac{U}{U0})^{\alpha q} \end{cases} \qquad 2.\ 19$$

Where: Kp Kq are scaling coefficients (equal with 1 in the base case) and $P0$, $Q0$, $U0$ are the reference active and reactive power, respectively the reference voltage. αp and αq are coefficients which describe the type of load and determine the sensitivity of active and reactive power with the voltage.

Depending of the values of the coefficients αp and αq , three types of load models can results as presented in table 2.1.

Load model	αp	αq
Constant impedance (Z)	2	2
Constant current (I)	1	1
Constant power (P)	0	2

Table 2-1: Exponential load model

b)- polynomial model defined as:

$$\begin{cases} P = KpP0\left(ap\left(\frac{U}{U0}\right)^2 + bp\left(\frac{U}{U0}\right) + Cp\right) \\ Q = KqQ0\left(aq\left(\frac{U}{U0}\right)^2 + bq\left(\frac{U}{U0}\right) + Cq\right) \end{cases} \quad 2.\ 20$$

Where ap, bp, Cp, aq, bq, Cq represent the weighs of each model in table 2.1 and satisfies the condition below:

ap+ bp+ Cp=1 ; aq+ bq+ Cq=1 2. 21

The used load model is depending of network simplification and the type of studies.

2.6. Distributed generations types and technologies

Over recent years the penetration of distributed generation in distribution network was witnessing a dramatic growth in the world and it considered as the first researches interest. this increasing is due to the advancement in small generation technologies and the various type of energy sources. The emergence of new technological alternatives allows the DG technologies in distribution network to achieve immense technical, economic and environmental benefits. These benefits could be maximized by proper planning i.e. placement of DGs at optimum locations with optimum size and suitable type under certain constraints for benefits. the distributed generation could be classified according to their size, technology and sources of energy which briefly presented below:

The different types of traditional and nontraditional DGs are classified and described in [40]from the constructional, technological, size, and power time duration point of view. The DGs may also be grouped into four major types based on terminal characteristics in terms of real and reactive power delivering capability.

2.6.1. Type of DGs according to technologies and sources:

There are different types of DGs from the technological points of view are developing based on traditional production, renewable energy system or cogeneration:

- Traditional combustion distributed generators:

combustion small turbines, Micro-turbine, gas and diesel generators which can operate using natural gas, propane, and fuel oil. They are characterized by low installed costs, but have higher operational costs than other DG technologies The Micro-turbines are a relatively new technology for the generation of electric power ***it*** has evolved from early systems of 30 kW to 70 kW to today's systems, which can have individual ratings of 200 kW to 250 kW. A multi-unit could be assembled to provide power up to 10 MW. Gas turbines could be particularly useful for combined heat and power (CHP) applications, Their size ranges from 1 MW to as large as 40 MW for DG applications.

- Nontraditional sources distributed generators:

It consists of electrochemical and renewable devices such as photovoltaic, Wind turbines, small hydropower plant, fuel cell generator, geothermal power plant, tidal energy generator and bio power plants. Wind power technology is one of the most important renewable technologies with production power of multi-megawatt-size, wind turbines are being installed today. The wind power generation technology is used to convert wind energy into electrical energy where The solar photovoltaic technology is directly converting solar energy into electrical energy by photovoltaic effect of semiconductor material, the ranges of electrical rating Photovoltaic and solar thermal is a few W to few MW. Fuel cell is a generation facility which can directly convert the chemical energy stored in the fuel and oxidizer into electricity power, Fuel cells work like a storage battery. However, it does not store energy and will provide electricity as long as they are supplied with fuel. The current power of fuel cells has been developed to reach range of 1MW and more. Fuel cells can be classified as renewable (using hydrogen) or non-renewable (using natural gas or petrol).

2.6.2 Type of DGs according to the size and active-reactive power generation:

The DGS is also categorized by its size, small, medium, and large capacity, and it is classified by researchers according to their studies investigation. the four major types considered for comparative studies are described as follows:

Type1: DG is capable of delivering only active power such as photovoltaic, micro turbines, fuel cells, which are integrated to the main grid with the help of converters/inverters. However, according to current situation and grid codes the photovoltaic can and in sometimes are required to provide reactive power as well.

Type2: DG capable of delivering both active and reactive power. DG units based on synchronous machines (cogeneration, gas turbine, etc.).

Type3: DG capable of delivering only reactive power. Synchronous compensators such as gas turbines are the example of this type and operate at zero power factors, capacitor bank compensator.

Type4: DG capable of delivering active power but consuming reactive power. Mainly induction generators, which are used in wind farms, come under this category. However, doubly fed induction generator (DFIG) systems may consume or produce reactive power i.e. operates similar to synchronous generator.

2.6. Distributed generation for future algeria network:

Distributed generation based on conventional energy sources and renewable energy sources have played a vital role throughout the world. Algeria is one of countries should be investigate in and develop its distribution grid based on DGs.

2.6.1. Source of Energies in algeria

Algeria is an emerging economy whether in agriculture or industry where economic development need to develop the other sectors where lead to increase in energy consumption. The fact that there is a causal relationship between economic growth and energy consumption make the energy sector classed as first to be developed. beside the environmental concern researchers support that renewable energy consumption has positive impacts on economic growth. In terms of energy use in algeria, natural gas is the largest source of electricity production as it accounts for almost the complete source of total electricity due to its availability from the past. However, this conventional sources are not renewable, since their quantity is finite. While its production process is too slow to replenish these fuels as quickly as humans use them, so these sources will run out sooner or later. it is not considered as energy source for future economic. it is not considered as energy source for future economic. For that Algerian government should realize the importance of renewable energy and invest in the renewable energy projects such as solar, biomass, photovoltaic, geothermal and wind, which could be used as distributed generation for the management of the new projects and sustainable development.

2.6.2. Renewable Energies in algeria

It is worthy to mention that, in all the world, it is desirable to exploit the renewable energy sources for electric generation. In Algeria it is favorable for developing solar energy due to the abundant sunshine throughout the year, especially in the Sahara region. Many studies have estimated The solar radiation intensity and duration of sunshine on south and north of the country as presented in table 2.2 [41] [42].

Site	Latitude	Longitude	Altitude	SS (h)	Ghm
Tamanrasset	22.78 Nord	5.51 Est	1378	9.12	6457
CDER-Bouzareah	36.80 Nord	3.00 Est	345	7.19	4352
CDER-Bouzareah	36.80 Nord	3.00 Est	345	7.20	4459
ONM Dar El Beida	36.68 Nord	3.22 Est	25	7.35	4838
Bechar	31.50 Nord	2.25 Ouest	809	9.56	6369
URAER-Ghardaia	32.40 Nord	3.80 Est	468	9.13	5949
Oran-Sénia	35.63 Nord	0.60 Ouest	90	7.89	4952

Table 2-2 Daily solar radiation for cities in Algeria

SS is the annual average of the measured daily sunshine duration (hours). Ghm is the annual average of the measured daily global irradiation received on a horizontal surface (Wh/m^2).

Algeria ranges in latitude from 18.96° to 37.09° north, and in longitude from 8.68 west to 11.95 east. it is characterized by the important solar irradiation on a great part of the country. It represents highest solar reservoir region in the world with an important insolation time over the quasi-totality of the national territory mainly in the desert region. The daily obtained energy on a horizontal surface of 1 m2 is of 5 kW h over the major part of the national territory, it is evaluated about 1700 kW h/m2/year for the North and 2263 kW h/m2/year for the South of the country [42] . which is reasons for recommending the solar irradiation to be source of energy in Algeria which could be developed in in distributed generations with small or medium size. The researchers in [42] have presented the Solar maps illustrating the geographical distribution of solar irradiation, Figure 2.10, which could help to Investing in photovoltaic DGs with optimum installation and design units.

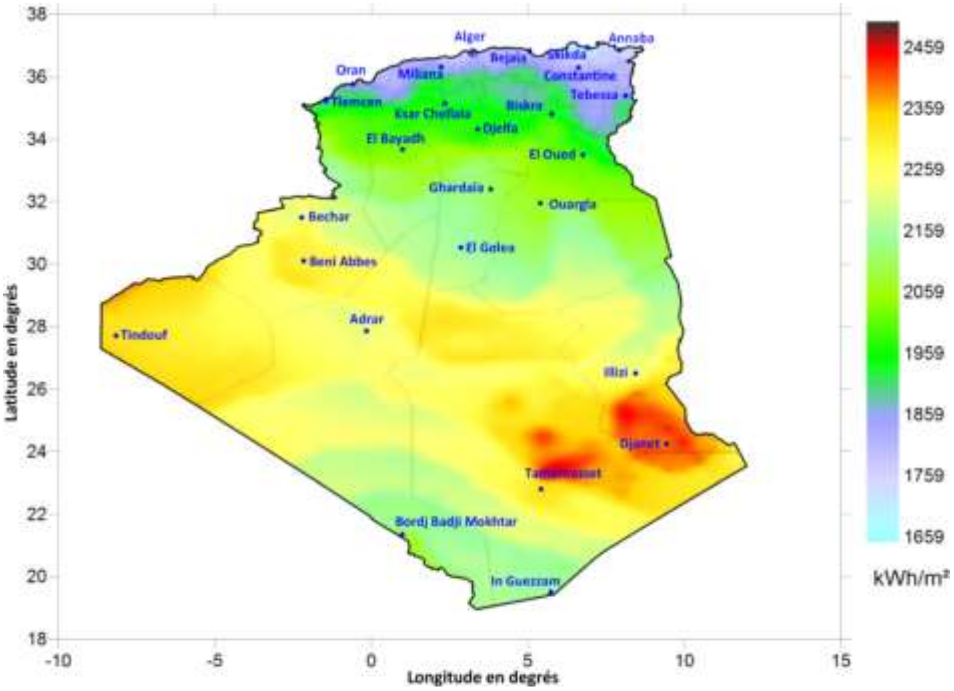


figure 2.10: Mean annual global irradiation estimated on the horizontal plane

Beside the Solar energy, wind and hydrogen power can be considered as potential renewable energy sources in Algeria. its geographic location has several advantages for extensive use of both solar and wind energies. Studies of indigenous wind resources in Algeria performed by Centre of Development of Renewables Energies (CDER) during recent years show that the climatic conditions in Algeria are favorable for wind energy utilization. The average speed of the wind is presented in This wind map figure 2 [43], it shows that Almost half of the country experience significant wind speed where the southwestern region present an considerable average speed of the wind and considered as The best wind energy potential, Where the wind velocity is higher than 6 m/s. Technological advancements over the last years have increased the wind energy potential.

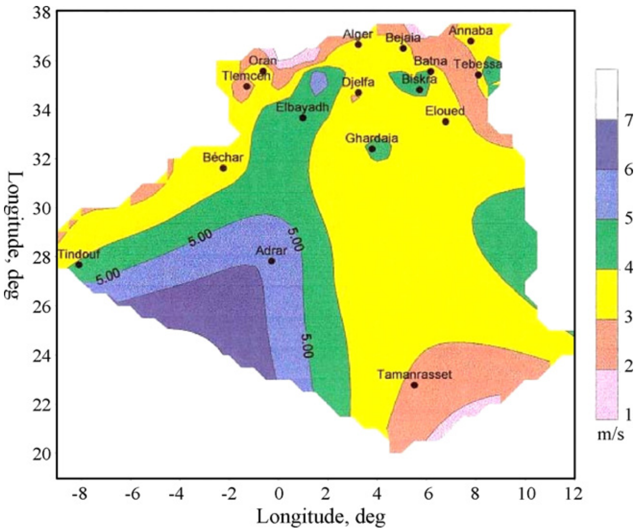


figure 2.11: Wind map evaluation in Algeria

The country’s first wind farm is being built at Adrar with installed capacity of 10MW with substantial funding from state-utlity Sonelgaz. And steel many other suitable sites should be exploit to realize distributed generation based on wind energy.

2.6.3. Recommended DGs for Algeria electric network

Solar and wind energy are the most abundant natural resource in Algeria. It becomes imperative for Algeria to exploit this important energy resource. It Still to evaluate the opportunities applicable to both renewable and non-renewable forms of distributed generation. the robustness, sustainability, reliability and stability are the main objective of distribution network operator (DNO). the main task is to achieve a better integration of DGs for flexible electric generation as demand response, Therefore, determination the best type of DG is an essential problem that requires economic and technical parameters analyses, these parameters may depend on, environmental and resource availability. DG technologies can provide energy solutions that are more cost-effective, more environmentally friendly, or provide higher power quality or reliability than conventional power plant. Understanding the possible DG types options to be installed in our network will lead to more benefit from these technologies. Some of these DG technologies offer high efficiency, resulting in low fuel costs, but emit a fair amount of pollutants such as carbon mono oxide and nitrogen oxide and others are environmentally clean but are not currently cost-effective. it is often difficult for decision makers to determine which technology is best suited to meet their specific energy needs.

For algeria case, the energy solar cover all the area which make photovoltaic DGs the first candidate to be developed in algeria, the small unit size with storage devices is recommended to be installed in the north region where large size of Hybrid Solar PV and Gas Turbine DGs is recommended to be installed in the south region of the country. DGs based on wind energy is have a chance to be used in medium size or hybrid large size unit such as hybrid photovoltaic and wind turbine system, Hybrid Wind/Photovoltaic and Fuel Cell system, hybrid wind and gas turbine system……..

Many remote communities around the world cannot be physically or economically connected to an electric power grid. South of algeria is a large area with diverse industrial bases and villages. Most of The electricity demand in these areas is conventionally supplied by small isolated diesel generators. The operating costs associated with these diesel generators may be unacceptably high due to discounted fossil fuel costs together with difficulties in fuel delivery and maintenance of generators. , renewable energy sources, such as solar photovoltaic (PV) and wind turbine generator will provide more benefit for electricity generation in off-grid areas. where hybrid energy systems can significantly reduce the cost of standalone power supplies in many off-grid situations, while at the same time providing a reliable supply of electricity using a combination of energy sources with minimization in the full consumption.

In case of grid connected mode, DGs could be used for voltage support and power reinforcement where the type of DGs is determined depending on the desired objectives, generally all the type, in terms of output generation, are needed.

3. CHAPTER 03: Electrical network stability evaluation in presence of DGs

3.1. Introduction

Transient stability studies include the entire analysis of the network disturbances such as equipment outages, load changes or faults disrupt the prevailing steady state operating conditions, causing a redistribution of power flows. The studies address The ability of the network to cope with these disturbances and to re-establish steady-state operation with permissible line flows and voltage levels for the planning utility in terms of security and reliability of power grids. The analysis identified the network transient stability limits, defined as a specified power demand and generator loading scenario, beyond which it cannot cope with a specified set of contingencies. The assessment of transient stability was considered before in the transmission networks that connect the large production plants in order to ensure a good operation and estimate the fragility of the network when it is submit to different events of a disturbance. However as DGs penetrations increase, their cumulative impact on bulk power systems will increase in severity and importance, and today the integration of DGs into the distribution networks is so motivated. And its penetration level increase in respect of years further DGs must have the capacity to withstand against severe disturbance for a sufficient time till the security and protection elements can stabilize the system.

synchronous generators in certain networks will take a sufficient rate which it’s stability is to influence its stability, its security and its reliability. the security planning of distribution network with integration of DGs require the studies of transient stability whether in connecting operating mode or as an island mode. In fact, synchronous machines, with small size, connected to the distribution network is very sensitive during a network disturbance due to their low inertia and because the relatively long of fault clearance times in distribution network they are not suitable for maintaining the angular stability. losing their transient stability, with high penetration level, will eventually lead to a collapse of a large part of consumers by consequences the reliability of the networks is affected. further it could lead to a cascade losing of generation leading to a total black out.

3.2. Methods of Transient stability assessment in power systems

Ensuring secure and stable operation of large scale power systems exposed to a variety of uncertain stresses, and experiencing different contingencies are among the most formidable challenges that power engineers face today. Security and more specifically stability assessment is an essential element of the decision making processes that allow secure operation of power grids around the world. Transient stability assessment analyzes the system's ability to sustain large transient disturbances such as loss of generation or failure on transmission facilities. These disturbances lead to large excursion of the machines rotor angle, which are described by the strongly non-linear relations governing the dynamics in power systems and a rigorous analytical study is hardly possible. Consequently, different methods of evaluating transient stability limits have been developed. They can be classified into three main categories:

3.2.1. Numerical integration methods:

This method is considered as a reference method in terms of precision and reliability, she can give almost all the important information on the dynamics of the system with any component modeling and adapt to any stability scenario. It is a time simulation method based on the step by step resolution of the non-linear differential equations set, which govern the transient stability phenomenon, using numerical integration methods. it allows to assess the robustness of the network against large disturbances by determining its temporal evolution. usually the principal objective from the transient assessment is to determine the Critical clearing time(CCT) of the synchronous machines for a defined scenarios of disturbances. Execution of this method is practically slow car estimating CCT need to perform several simulations of the network during and after disturbance clearance.

3.2.2. Direct methods

The most straightforward approach to the post-fault stability assessment problem is based on direct time-domain simulations of transient dynamics following the contingencies. Rapid advances in computational hardware made it possible to perform accurate simulations of large scale systems in real-time [44]. In order to allow fast transient stability assessment in the modern electrical network with high size and complexity, direct methods were developed. These methods try to avoid solving the system differential equations for analyzing power system transient stability in reduced time which are particularly attractive to be used in the area of power system planning, operation, and control. They can be used, for example, for predicting critical clearing times, for real-time security assessment and in developing strategies for emergency state control. One of the main approaches is based on Lyapunov’s method [45]and a second main approach is applying the equal area criterion [46].

Swing Equation:

For the classical model the following simplifications and assumptions were considered. The synchronous machine (SM) is represented by a constant voltage magnitude behind the synchronous reactance and the mechanical power input is assumed to be constant. the loads are represented by constant impedances [47]. the classical model is presented in Figure (II.3). For such a representation only the swing equation is needed to describe the dynamics of a synchronous machine.

Single Machine Infinite Bus system:

In case of Single Machine Infinite Bus system, the swing equation is defined as:

$$\begin{cases} M\dot{w} = P_m - P_e - P_D \\ \dot{\delta} = w \end{cases} \tag{3. 1}$$

Assume there is no damping in the system. Consider classical model Where $P_e = P_{emax}\sin(\delta)$

$$M\dot{w} = P_m - P_e = P_m - P_{e\,max}\sin(\delta) \tag{3. 2}$$

where $P_{emax} = E * V\sin(\delta)$, δ is the angle relative to the infinite bus, and ω is the relative rotor angle velocity.

Multi-machine system:

Center of inertia (COI): for multi machines systems an alternative method uses the center of inertia (COI) as the reference angle since it is a representation of the ’mean motion’ of the system. It allows to obtain more symmetric and more compact expressions for the differential equations of the network. The center of inertia for whole system is defined by:

$$\delta_0 = \frac{\sum_{i=1}^{n} M_i\,\delta_i}{M_T} \quad ; w_0 = \frac{\sum_{i=1}^{n} M_i\,w_i}{M_T} \tag{3. 3}$$

Where: $M_T = \sum_{i=1}^{n} M_i$

δ_i , w_i are rotor angle and speed successively.

Neglecting the damping system, the swing equation of COI can be defined as:

$$M_T\dot{w}_0 = \sum_{i=1}^{n}(P_{mi} - P_{ei}) = P_0 \tag{3. 4}$$

P_{mi} and P_{ei} are the mechanical and electrical power respectively.

The generators' angles and speeds relative to the COI are now defined by:

$$\tilde{\delta_\iota} = \delta_i - \delta_0 \quad ; \quad \widetilde{w_\iota} = w_i - w_0 \qquad 3.\ 5$$

The system equations of motion in the new reference become:

$$\begin{cases} M_i \dot{\widetilde{w_\iota}} = P_{m\iota} - P_{e\iota} - \frac{M_\iota}{M_T} P_0 \\ \dot{\tilde{\delta_\iota}} = \widetilde{w_\iota} \end{cases} \qquad 3.\ 6$$

3.2.2.1. Methods based on the Equal Area Criterion (EAC)

The equal area criterion (EAC) allows assessing transient stability of one-machine infinite bus (OMIB) systems without explicitly solving the swing equation [48]. The criterion essentially states that the system needs to be capable of absorbing the kinetic energy of the generator gained during the fault. The gained kinetic energy and the energy absorbing capability are represented by areas defined by the mechanical power and the power angle curve, which describes the non-linear relation of the electric power injection and the rotor angle.

After manipulation on OMIB swing equation, The equation determines the quadrature of the relative speed of the machine (with respect to a reference frame moving at a constant speed is presented as follow: [49]

$$\left(\frac{d\delta}{dt}\right)^2 = \frac{W_r}{H}\int_{\delta 0}^{\delta} Pa\, d\delta \qquad 3.\ 7$$

$$Pa = P_m - P_e \qquad 3.\ 8$$

The condition of stability is that this speed becomes zero, or negative, causing the motor to slow down. In other words, the increasing of angle $\delta$is restricted and after reaching some maximal value, δmax, the angle decreases. Thus, we may conclude that, δmax, exists and it is given by the condition

$$\int_{\delta 0}^{\delta} Pa\, d\delta \ \leq 0 \qquad 3.\ 9$$

In the opposite case $d\delta/dt$ does not become zero, the rotor will continue to move and synchronism is lost (the angle increases unlimitedly).

The integral of Pa dδ represents an area on the $p - \delta$ diagram. The integral can be split up into two areas, which could be expressed as the acceleration area A1 and deceleration area A2:

$$A1 = \int_{\delta 0}^{\delta c} Pa\, d\delta \qquad 3.10$$

$$A2 = -\int_{\delta c}^{\delta m} Pa\, d\delta \qquad 3.11$$

The stability is assured if the acceleration area A1, characterized by the kinetic energy stored by the rotor due to its acceleration during the disturbance, is less than that of deceleration A 2, characterized by the potential energy during its deceleration after fault clearance, presented in the power angle trajectory Figure 3. 1.

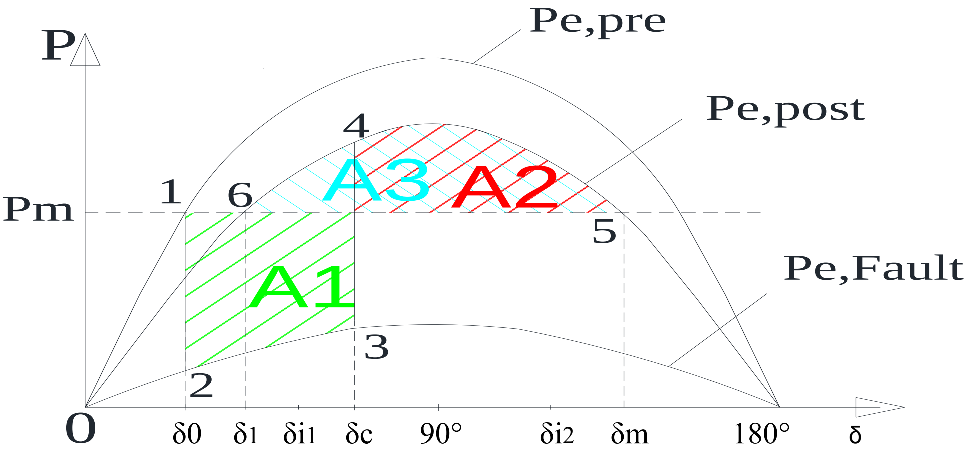


Figure 3.1: P-δ curve

A stability margin η can then be determined as follows, where δu is the rotor angle at the UEP.

$$\eta = -\int_{\delta 0}^{\delta u} Pa\, d\delta = \text{Ades}(\delta m = \delta u) - Aacc \qquad 3.12$$

A positive margin represents a stable case, a negative an unstable and in the case that η =0 it is a critical case where the limit of stability could be determined and could be characterized by the critical clearing time (CCT) as an index of stability. This approach was further developed with the extended equal area criterion [50]and most recently with the hybrid method Single Machine Equivalent Method (SIME) [51].

Single Machine Equivalent (SIME) Method

Transient stability assessment with a single Machine Equivalent (SIME) is based on the Equal Area Criterion and considered to be a hybrid method, since it combines the advantages of a direct method and time-domain simulation to get the flexibility with respect to power system model line of time-domain methods, speed and richer information of the direct method. In the following a summary of the method is given. and A detailed description of the method can be found in [47] and [51].

Principle of SIME:

As The extended equal area criterion(EEAC) developed to determine the critical machines by decomposing the multi-machine system into a set of critical machine(s) and a set of the ’remaining’ generators. The split set is based on the machine rotor angles at the initial time of the disturbance inception considering a sinusoidal variation $p-\delta$ curve. The machines in the two groups are aggregated and then transformed into two equivalent machines to form an OMIB system. using the classical simplified machine and network modeling.

The fundamental difference between the EEAC and SIME is that SIME relies on a time-variant OMIB, where the $p-\delta$ variation is no longer sinusoidal where the machine parameters is varying with the time domain simulation. The SIME method determines in each simulation step a set of candidate one-machine infinite bus (OMIB) system, which describes the dynamics of a critical generator group and a group of remaining (non-critical) generators. The machines in the system is split up into the critical and the non-critical group corresponding to their rotor angles. The machines in each group are aggregated and the parameters of the candidate OMIB system are determined. the transient stability of the resulting candidate OMIB can be assessed using the equal area criterion.

SIME FORMULATION

Considering unstable scenario, the temporal simulation during the disturbance should carried out firstly and after fault elimination and, in each simulation step, the candidates of OMIB is formed as the following steps:

1 -Critical machines identification for each candidate

Using the electrical angular deviation(distances) between two adjacent machines classified in descending order of their rotor angles, a candidate OMIB is correspond for each distance. the critical machines(CMs) for each candidate are those which are above of the corresponding distance and the remaining are those at the other side.

2 -Parameters calculation of a candidate OMIB:

-The two groups of (CMs) designated (I) And the remaining machines designated (s) are aggregated into two equivalent machines using the partial angular inertia center of each group:

The partial angular inertia center of the two groups are:

$$M_I = \sum_{j\in I} M_j \quad ; \quad M_S = \sum_{k\in S} M_k \qquad 3.\ 13$$

The angular rotor for the equivalent two machines are:

$$\begin{cases} \delta_I(t) = \frac{\sum_{j\in I} M_j\, \delta_j(t)}{M_I} \\ \delta_S(t) = \frac{\sum_{k\in S} M_k\, \delta_k(t)}{M_S} \end{cases} \qquad 3.\ 14$$

Then The candidate OMIB are formed as follow:

Angular rotor of a candidate:

$$\delta(t) = \delta_I(t) - \delta_S(t) \qquad 3.\ 15$$

Angular velocity of a candidate:

$$w(t) = w_I(t) - w_S(t) \qquad 3.\ 16$$

The Inertia coefficient and power of candidate OMIB is calculated as:

$$M = \frac{M_I\, M_S}{M_I + M_S} \qquad 3.\ 17$$

$$P_e = \frac{M_S\, P_e^I - M_I\, P_e^S}{M_I + M_S} \qquad 3.\ 18$$

$$P_m = \frac{M_S x P_m^I - M_I x P_m^S}{M_I + M_S} \qquad 3.\ 19$$

$$P_a = P_e - P_m \qquad 3.\ 20$$

3- Checking the instability conditions of OMIBs:

The procedure is carried out until a candidate OMIB reaches the unstable conditions sorted from CEA, an unstable OMIB trajectory reaches the unstable angle δ_u at time t_u at the condition defined by:

$$P_a(t_u) = 0 \;\; ; \;\; \dot{P}_a(t_u) = \frac{dP_a}{dt}(t = t_u) > 0 \qquad 3.\ 21$$

with $w > 0$ for $t > t_0$

These unstable conditions determine the termination conditions of the T-D program and identify the critical OMIB.

4-Instability margin determination:

After developing of equivalent swing equation of the critical OMIB [47] the unstable margin is assessed by:

$$\eta_u = -1/2\, M\, W_u^2 \qquad 3.\ 22$$

Where u correspond to unstable equilibrium point of the critical OMIB trajectory and

$$W_u = w(\delta = \delta_u). \qquad 3.\ 23$$

In case of a stable scenarios correspond to $\delta < \delta_u$, $\eta_u > 0$,the termination stable conditions where the T-D simulations can be stopped is expressed by:

$$W(t_r) = 0 \;\; ; \quad P_a(t_r) < 0 \qquad 3.\ 24$$

Where t_r correspond to the return angle δ_r, δ stops increasing then decreases.

the corresponding stable margin is defined as: η_{st}

$$\eta_{st} = \int_{\delta r}^{\delta u} |Pa|\, d\delta \qquad 3.\ 25$$

In stable case, $P_{e-}\delta$ curve "returns back" at $\delta = \delta_r$, so neither δ_u nor , $P_{e-}\delta$ curve can be computed at $\delta_u > \delta > \delta_r$. In this case approximate method is used to estimate the stability margin [47]. One of the approximate method used the accelerating power and the rotor angle from at least three successive data sets, to estimate the curve $\mathrm{P}_a - \delta$ as follows:

$$\mathrm{P}_a\,(\delta) = a\delta^2 + b\delta + c \qquad 3.\ 26$$

The constants can be determined using the three acquired successive data sets and, and The angle δ_u at the unstable equilibrium point is determined by solving $\mathrm{P}_a\,(\delta_u) = 0$ and by checking if the instability conditions of equ (3.26) are met.

$$P_a(\delta_u) = 0 \;\; ; \quad \dot{P}_a(\delta_u) > 0 \qquad 3.\ 27$$

3.2.2.2. Lyaponov's method.

As the simulation time of numerical integration methods is relatively long an alternative set of approaches using direct energy methods were proposed and developed to the level of industrial deployments over the last three decades [52]– [53]. These approaches are based on rigorous analysis of the dynamical equations and mathematical certification of safety with the help of the so-called energy functions. Energy functions are a specific form of Lyapunov functions that guarantee the system convergence to stable equilibrium points. These methods allow fast screening of the contingencies.

Transient energy function

In order to apply Lyapunov's method the system is described by a transient energy function, This function is used in scalar Lyapunov approaches to assess transient stability in the power system. [54], [55] [56].

Energy Function Formulation:

- Case of Single-machine infinite-bus system:

Consider a single-machine infinite-bus system (SMIB), The energy function is always constructed for the post fault system. In the SMIB case, the post fault equations are

$$M\frac{d^2\delta}{dt^2} = P_m - P_{emax}\sin(\delta) \qquad 3.28$$

The lyaponov function is obtained with development in the swing equation, details in [57], as follow:

At the stable equilibrium point δ_s:

$$P_{emax}\, sin(\delta_s) = P_m \qquad 3.29$$

$$\frac{d}{dt}\left[\frac{M}{2}\left(\frac{d\delta}{dt}\right)^2 - \int (P_m - P_{emax}\, sin(\delta))\, d\delta\right] = \frac{d}{dt}\left[\frac{1}{2}Mw^2 - \int_{\delta_s}^{\delta}(P_m - P_{emax}\, sin(\delta))d\delta\right] = 0 \quad (3.30)$$

Then the energy function V (δ, ω) can be written as:

$$V\,(\delta,\omega) = \frac{1}{2}Mw^2 - \int_{\delta_s}^{\delta}\left(P_m - P_{emax}\, sin(\delta)\right)d\delta \qquad 3.31$$

$$V\,(\delta,\omega) = \frac{1}{2}Mw^2 - P_m(\delta - \delta_s) - P_{e\,max}(cos(\delta) - cos(\delta_s)) = V_{KE} + V_{PE}\,(\delta,\delta_s) \qquad 3.32$$

where $V_{KE} = \frac{1}{2}Mw^2$ is the transient kinetic energy and

$V_{PE}\,(\delta,\delta_s) = -P_m(\delta - \delta_s) - P_{e\,max}(\cos(\delta) - \cos(\delta_s))$ is the potential energy. V (δ, ω) is equal to a constant represents the total energy presented in the system at $t = t_{cl}$ once the fault is cleared. And $\delta_s = sin^{-1}(\frac{P_m}{P_{e\,max}})$, This is a stable equilibrium point surrounded by two unstable equilibrium points;

$$\begin{cases} \delta^u = \pi - \delta_s \\ \delta^u = -\pi - \delta_s \end{cases} \quad 3.33$$

The critical value of the Lyapunov function V (δ, ω) at the nearest stationary point which, for the system considered here, is equal to the second equilibrium point ($\pi - \delta_s$, $\omega = 0$). Substituting these values into equation (3.32), to obtain the critical energy function as:

$$V_{cr} = 2cos(\delta_s)P_{e\,max} - P_m(\pi - 2\delta_s) \quad (3.34)$$

The generator-infinite bus bar system is stable for all initial conditions after fault clearance (δ_0, w_0) satisfying the condition:

$$V\,(\delta_0, w_0) < V_{cr} \quad 3.35$$

- **Case of multi-machine system**

The transient energy function V is always defined for the post-disturbance system. It can be derived from the n acceleration equations in the COl frame. Using the simplification of classical model with Internal-node model where the loads are assumed to be constant impedances. details in [57], [54] The resulting network is shown schematically in Figure 3.2

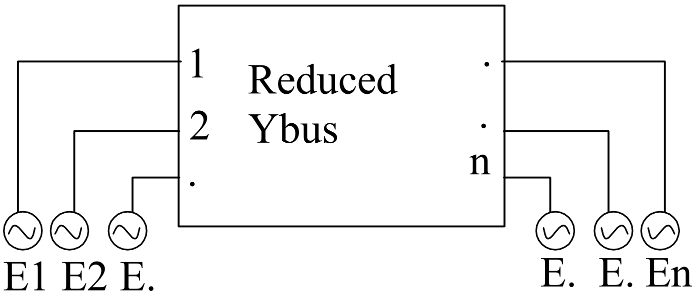


Figure 3.2: classical model with Internal-node model simplification of network

The admittance matrix reduced to the internal nodes of the generators governing the currents and electrometric forces of generators as:

$$[I] = [Y_{bus}][E] \quad 3.36$$

Where $Y_{ij}\angle\theta_{ij} = (G_{ij} + jB_{ij})$ is the element ij in reduced bus admittance matrixY_{bus}.

$[E]$ is constant voltage vector behind the direct axis transient reactance

The electrical power of generator i ,in the simplified model, is defined by

$$P_{ei} = Real(\bar{E}_i\bar{I}_i^*) = Real\left(\sum_{j=1}^{n} Y_{ij}\,E_iE_j\angle(\delta_i-\delta_j - \theta_{ij})\right) \quad 3.37$$

$$P_{ei} = E_i^2 G_{ii} + \sum_{\substack{j=1 \\ j\neq i}}^{n} (C_{ij}\, sin\delta_{ij} + D_{ij} cos\delta_{ij}) \qquad 3.38$$

$$C_{ij} = E_i E_j Y_{ij} sin\theta_{ij} \quad ; D_{ij} = E_i E_j Y_{ij} cos\theta_{ij} \qquad 3.39$$

The equations of motion of the synchronous generators,$(i = 1, \ldots, n)$, are given by:

$$M_i \dot{w_\iota} = P_{mi} - P_{ei} = P_{mi} - E_i^2 G_{ii} - \sum_{\substack{j=1 \\ j\neq i}}^{n} (C_{ij}\, sin\delta_{ij} + D_{ij} cos\delta_{ij}) \qquad 3.40$$

$$\dot{\delta_\iota} = w_i \quad ; i = 1,2, \ldots, n \quad ; \qquad 3.41$$

The equations of motion referred to the center of inertia (COl) are done by:

$$M_i \dot{\widetilde{w_\iota}} = P_i - \sum_{\substack{j=1 \\ j\neq i}}^{n} (C_{ij}\, sin\widetilde{\delta_{\iota\jmath}} + D_{ij} cos\widetilde{\delta_{\iota\jmath}}) - \frac{M_i}{M_T} P_0 \qquad 3.42$$

$$\dot{\widetilde{\delta_\iota}} = \widetilde{w_\iota} \qquad 3.43$$

The transient energy function V can be derived from the n motion equations in the COl frame reference.

The individual machine energy function is given by :

$$v_i(\tilde{\delta}, \widetilde{w}) = \frac{1}{2} M_i \widetilde{w_\iota}^2 - \int_{\delta_i^s}^{\delta_i} \left(P_i - \sum_{\substack{j=1 \\ j\neq i}}^{n} (C_{ij}\, sin\widetilde{\delta_{\iota\jmath}} + D_{ij} cos\widetilde{\delta_{\iota\jmath}}) - \frac{M_i}{M_T} P_0 \right) d\delta \qquad 3.44$$

The total transient energy of the network is equal to the sum of the individual energies, and considering the constraints satisfied by the centre of inertia variables given by:

$$\sum_{i=1}^{n} M_i\, \widetilde{\delta_\iota} = \sum_{i=1}^{n} M_i\, \widetilde{w_\iota} = 0 \qquad 3.45$$

The transient energy of the system is simplified to:

$$V(\tilde{\delta}, \widetilde{w}) = \sum_{i=1}^{n} \frac{1}{2} M_i\, \widetilde{w_\iota}^2 - \sum_{i=1}^{n} P_i \left(\widetilde{\delta_\iota} - \widetilde{\delta_\iota}^{s} \right) - \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \left(C_{ij} \left(cos\widetilde{\delta_{\iota\jmath}} - cos\widetilde{\delta_{\iota\jmath}}^{s} \right) + \right.$$

$$\left. \int_{\widetilde{\delta_\iota}^{s} + \widetilde{\delta_\jmath}^{s}}^{\delta_i + \delta_j} D_{ij} cos\widetilde{\delta_{\iota\jmath}}\, d(\delta_i + \delta_j) \right) \qquad 3.46$$

The physical representation of the transient energy function components are as follows:

$\sum_{i=1}^{n} \frac{1}{2} M_i\, \widetilde{w_\iota}^2$: total change in rotor kinetic energy relative to COI;

$\sum_{i=1}^{n} P_i\, (\widetilde{\delta_\iota} - \widetilde{\delta_\iota}^{s})$: change in rotor position energy relative to COI;

$C_{ij} \left(cos\widetilde{\delta_{\iota\jmath}} - cos\widetilde{\delta_{\iota\jmath}}^{s}) \right)$: change in magnetic stored energy of branch ij;

$\int_{\widetilde{\delta_\iota}^{s} + \widetilde{\delta_\jmath}^{s}}^{\delta_i + \delta_j} D_{ij} cos\widetilde{\delta_{\iota\jmath}} d(\delta_i + \delta_j)$: change in dissipated energy of branch ij

The total potential energy relative to COI is represented by:

$$\sum_{i=1}^{n} P_i \left(\widetilde{\delta_i} - \widetilde{\delta_i}^{s}\right) - \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \left(\mathrm{C}_{ij} \left(cos\widetilde{\delta_{ij}} - cos\widetilde{\delta_{ij}}^{s} \right) + \int_{\widetilde{\delta_i}^{s}+\widetilde{\delta_j}^{s}}^{\delta_i+\delta_j} \mathrm{D}_{ij} cos\widetilde{\delta_{ij}}\, \mathrm{d}(\delta_i + \delta_j) \right) \qquad 3.47$$

To avoid calculating the actual system trajectory. A linear trajectory in the angle space is assumed to allow the transfer conductance terms to be analytically evaluated between the limits $\tilde{\delta}^{s} + \tilde{\delta}$: [54],where the term below could be approximated as :

$$\int_{\widetilde{\delta_i}^{s}+\widetilde{\delta_j}^{s}}^{\delta_i+\delta_j} D_{ij} cos\widetilde{\delta_{ij}}\, d(\delta_i + \delta_j) \approx \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \left(D_{ij} \frac{\widetilde{\delta_i} - \widetilde{\delta_i}^{s} + \widetilde{\delta_j} - \widetilde{\delta_j}^{s}}{\left(\widetilde{\delta_i}^{s} - \widetilde{\delta_j}^{s}\right) - \left(\widetilde{\delta_i}^{s} - \widetilde{\delta_j}\right)} \left(sin\left(\widetilde{\delta_i}^{s} - \widetilde{\delta_j}^{s}\right) - sin\left(\widetilde{\delta_i}^{s} - \widetilde{\delta_j}\right) \right) \right) \qquad 3.48$$

In order to determine the stability of the system, the critical energy has to be computed. The stability analysis is Performed by comparing the system energy V (δ, ω) at the initial state of post fault system with the critical energy Vcr. If system energy is less than the critical energy then the post-fault trajectory will be stable; otherwise, it is unstable.

Methods of Critical Energy calculation:

The evaluation of critical energy is the most difficult part. significant progress has been made for transient stability analysis and Several practical attempts were made to identify the critical energy. a straightforward theoretical approach to identify the critical energy is described in [56],in this part Three Bases approaches to determining critical energy could be found in several literatures are given below:

- **Closest u.e.p method**

This method aims to determine The critical energy Vcr, which is the value of V (δ, ω) at the closest u.e.p, ie, Vcr = V (xuc), where x uc is the unstable equilibrium point (u.e.p) resulting in the lowest value of Vcr among the u.e.p’s inside in the stability boundary. details in [58]. algorithm for determination of the closest unstable equilibrium point is explained in [59]

The stability is determined by Calculating the value of V (δ, ω) at the time of fault cleared, and If V (δ, ω) < Vcr then the post-fault system is stable, otherwise it is unstable.

- **Potential Energy Boundary Surface ”PEBS”**

In case of SMIB system, the stable equilibrium point surrounded by two unstable equilibrium points ,zero-dimensional PEBS, $\delta^u = \pi - \delta_s$ and $\delta^u = -\pi - \delta_s$ and Vcr = VPE(δ^u).

In case of multi-machine systems a number of unstable equilibrium points u.e.p's surround the stable equilibrium point of the post fault system. The potential energy boundary surface constitutes a multidimensional surface passing through the u.e.p's. detail of BEBS theory in [60] [61].

In this method To find the critical value of V $(\tilde{\delta}, \widetilde{w})$, the fault-on trajectory is monitored until it crosses the PEBS at a point $\tilde{\delta}^*$close to $\tilde{\delta}^u$corresponds to the controlling u.e.p, so that $\mathrm{Vcr} = \mathrm{VPE}(\tilde{\delta}^u) \approx \mathrm{VPE}(\tilde{\delta}^*)$. The PEBS crossing is detected at the point at whichVPE(δ)) achieves a local maximum along the faulted trajectory. The critical clearing time tcr is good estimated from the fault-on trajectory when V $(\tilde{\delta}, \widetilde{w}) =$ Vcr.

- **Boundary Controlling u.e.p (BCU) Method**

Considering the equations of the post fault system referred to the center of inertia (COl) done by:

$$M_i \dot{\widetilde{w_i}} = f_i(\tilde{\delta}) \qquad 3.\,49$$

$$\dot{\tilde{\delta_i}} = \widetilde{w_i} \qquad 3.\,50$$

Find the controlling u.e.p. relative to a fault-on trajectory by Use the point $\tilde{\delta}^*$After the PEBS is crossed as the initial condition and integrate the post-fault reduced system (3.49) to find the first local minimum of $\sum_{i=1}^{n} ||f_i(\tilde{\delta})||$. At this minimum $\tilde{\delta} = \tilde{\delta}^u{}_{app}$ is almost the relevant or the controlling u.e.p. and $Vpe(\tilde{\delta}^u{}_{app}) = Vcr$ is a good approximation to the critical energy of the system.

The exact u.e.p can be obtained by solving $\sum_{i=1}^{n} ||f_i(\tilde{\delta})|| = 0$ and using $\tilde{\delta}^u{}_{app}$
as a starting point to arrive at $\tilde{\delta}^u$. Details of the method exist in [62] [57].

3.3. Transient stability analyses in distribution network with presence of distributed generation

With the integration of DGs in distribution networks, the transient simulation of distribution networks become necessary function for the management, and security planning. a rapid dynamic simulation is needed to assess the DGs stability for preventive and emergency's actions. such simulation is often difficult due to the large size of the distribution network with its radial topology. Generally, to simplify the system management the distribution network is divided in subdivisions. And The simulation is carried when the network is separated into two subnetworks: the network to be studied and the rest of the network which represented by static or dynamic equivalent model [22]. [63].

Distributed generators (DGs) is embedded in distribution networks using deferent technologies include synchronous generators, induction generators and inverter based generation, therefore the transient stability in distribution network does not related only on the angle stability of synchronous generators. hence it will be of interest to consider distributed non-synchronous generating sources in the transient stability study The authors in [64] have addressed the impact of increased penetration levels of distributed non-synchronous generation on global transient stability of the power system.

For transient stability investigation, due to the complexity of the numerical analysis of transient stability, the dynamic equivalent model is generally used for Network simplification. Where the network is divided to the subnetwork to be studied and an equivalent model of an external network using aggregation and simplification methods [39]. The authors in [65] have analyzed the Transient Stability of a Distribution Network With Distributed Generators where The external system, to which the DN is connected, is assumed to behave as an ideal voltage source. Distribution subnetworks with equivalent main grid is presented in Figure 3.3.

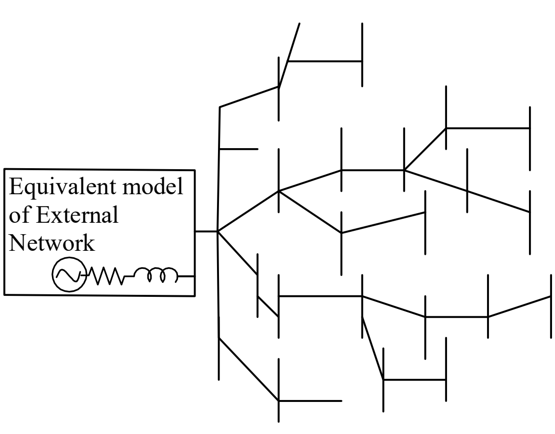


Figure 3.3: Distribution subnetworks with equivalent external model of the main grid

Besides the dynamic behavior of the generation system, the distribution networks present extensive branches with a specific set of equipment, what increases the complexity of the numerical analysis of transient stability. And simulation of the entire network could lead to convergence problems. a proposed methodology in [21] aims to reduce the original network into a simplified network with compatible dynamic response. The simplified model contains only the representative elements in steady state representation of the network is obtained with the following steps:

1) Identify and maintain, in the model, the equipment in the main feeder: distributed generators, fuses, reclosers, and voltage regulators. and divide the feeder into small areas among each identified equipmen.

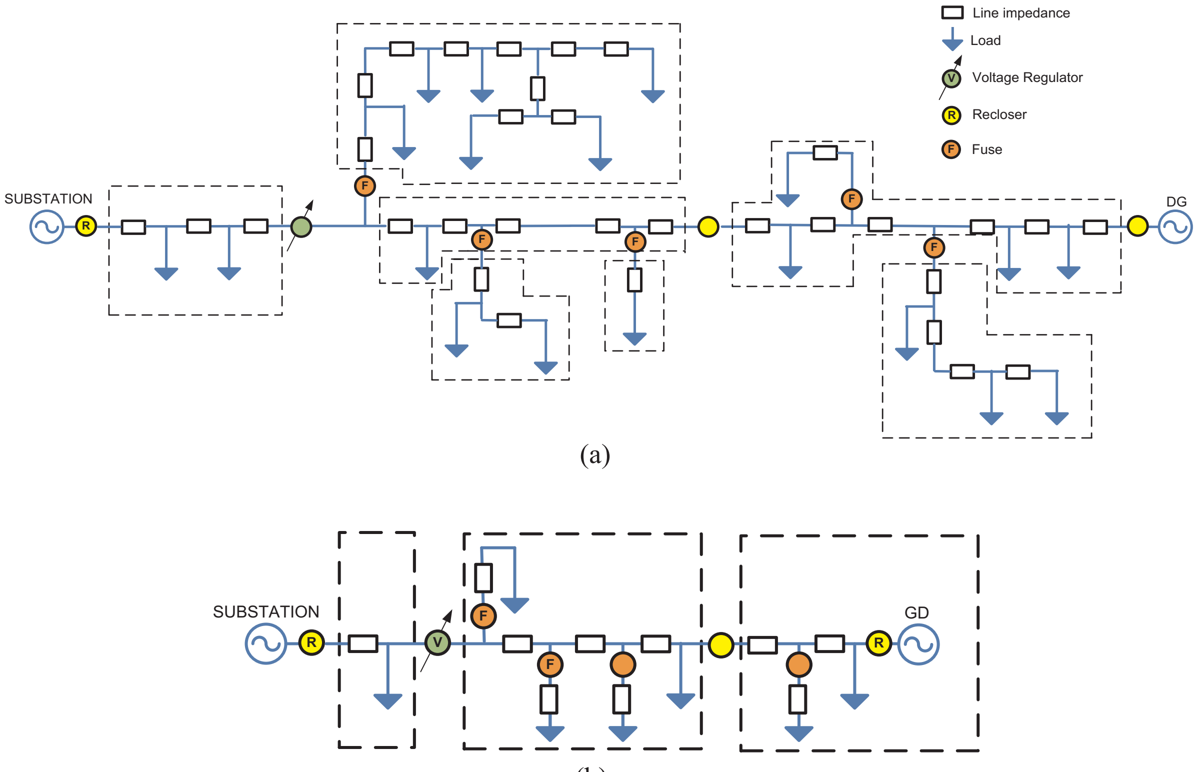
2) Calculate the total line impedance among each equipment and the total line impedance of each branch that derives from the main line. For convenience of calculation, all line impedances in each section or branch are concentrated.

3) In each area, the number of branches should be reduced. Branches that have the following characteristics shall be preserved in the simplified network:

-The branch with lower accumulated impedance. This branch will present the
lowest short circuit;

- The branch with higher accumulated impedance just after the fuse of the main feeder branch. This branch has the largest short-circuit current;
- The branch with higher rated current fuse at the main feeder derivation. This fuse will have the longest time of operation.

4) Calculate the concentrated load of each section or branch. The loads are modeled as constant impedance, where the equivalent impedance per phase is calculated by considering the voltage obtained with the power flow of the full network in steady state, keeping the original voltage drops in the simplified network. more details in [21].An example of a network reduction is shown in Figure 3.4.



(a)

(b)

Figure 3.4: network simplification: A, original network; B, simplified network [38]

3.3.1. Methods of transient stability assessment in distribution network:

In contract to the transmission network where the concerned transient stability is the angle stability of the synchronous generator as first and the frequency deviation suit to a large disturbance, distribution network connecting different type of DGs based on synchronous, induction generators and inverter based DGs, hence the transient stability is no longer concern only the angle stability.

In fact, the DGs is integrated in small unit form dispersed in the distribution network, for that the stability should be evaluated locally considering a subnetwork where the stability of each DGs in the subnetwork and its contribution to the system suit to a disturbance is the first interest.

The transient stability study of a subnetwork connecting distributed generation with small inertia and low power interaction does not cause a total grid instability. for that the angle stability simulation study of the subnetwork is referred to an external equivalent system.

3.3.1.1. Angle stability assessment of DGs based on synchronous generators:

for real systems, the time domain simulation is widely used where several works use the simplified network reduced to the substation [22]. The author in [22] propose hybrid PEBS individual to assess the stability of each synchronous machine using the individual energy function and time domain simulation of the system dynamic. Its principal based on:

-calculation of the system trajectory with maintaining the fault during a time higher than the critical clearing time, using time domain simulation program.

-calculation of the critical energy of each machine, which is equal to the potential energy, using the trajectory of each machine.

-calculation of stability indices as critical clearing time(CCT) and the stability margin.

CCT corresponds to the moment when the total transient energy is equal to the critical energy.

Referring to center of inertia (COI), the individual machine energy function is given by:

$$v_i(\tilde{\delta}, \widetilde{w}) = \frac{1}{2} M_i \widetilde{w_i}^2 - \int_{\delta_i^s}^{\delta_i} \left(P_{mi} - P_{ei} - \frac{M_i}{M_T} P_0 \right) d\delta \qquad 3.\,51$$

Beside the critical clearing time and margin stability indexes, The transient stability of a system can be assessed by means of certain indicators As:

a) Rotor Speed deviation: is the maximum amount of deviation in the rotor speed during fault.

b) Oscillation duration: is the time taken by the oscillations to reach a new equilibrium after the clearance of the fault.

c) Rotor angle: The response of the rotor angle of the generator to different types of faults is considered.

d) Terminal voltage: The variation in the terminal voltage of the DG due to different fault conditions is monitored. The voltage stability is analyzed by taking into consideration the drop in voltage level during fault and the time taken by it to settle down after the clearance of the fault.

3.3.1.2. Transient Stability of DGs based on Induction Generators:

Induction machine considered as the most robust element in industrial use, where it takes a large part of the loads. And with introduction of DGs in the electrical network, it has received an augmented attention even in transmission network as doubly-fed induction generator used for a large wind turbine connected through electronic interface, or in distribution networks where most squirrel-cage IGs are usually used in small and medium scale hydros and wind farms with direct connection to distribution networks as DGs due to ability to produce power at varying rotor speeds. The prime mover can be a steam turbine and gas turbine with constant mechanical torque or wind turbine with variable mechanical torque. due to lower cost, smaller size, and less maintenance [37]. Beside the transient stability of small inertia synchronous generator When a short-circuit fault occurs in a distribution network, the small inertia of induction generator (IG) lead the to the increasing of its speed, which may cause system transient stability problems.

With increasing DGs penetration in distribution network, DGs based IG tends to increasing as generator element. Therefore, IG could contribute in grid instability, it is important to assess the transient stability of IGs and their impacts on stability of distribution networks.

The transient stability of IG could be assessed based on the critical speed defining the transient stability limitation and critical clearing time (CCT). An investigation of a single IG in a distribution system were realized in [66]. The real challenge for researchers was determination the CCT of a distribution network with multiple IGs in reduced simulation time. It can be determined by using simulation techniques through the trying-error method, where very long computation time is required [67]. the Transient Stability Study of Distributed Induction

Generators Using an Improved Steady-State Equivalent Circuit Method have been realized in [37]. The critical speed and critical fault clearing time (CCT) for maintaining system stability are determined using the proposed technique. And The factors affecting transient stability of a multi-IG distribution system have been investigated.

The torque-slip or Torque-speed characteristic as shown in Figure 3.6 is used for transient stability analysis of induction generator. assuming that steady state operating point is (w=w0, Te=Tm), when a disturbance occurs the induction generator terminal voltage falls to a set value according to various disturbances where the corresponding torque characteristic changes into a new characteristic. The torque-slip characteristic with respect of input voltage is deduced from the equivalent circuit of IG Figure 3.5.

The electromagnetic torque Te and rotor motion equation of an IG are presented as follow:

$$\begin{cases} T_e = \frac{R_r}{S} I_r^2 = \frac{R_r}{S} \frac{V_e^2}{(R_e+\frac{R_r}{S})^2+(X_e+X_r)^2} \\ \frac{dw_r}{dt} = \frac{1}{2H}(T_e - T_m \end{cases} \tag{3.52}$$

Where R_r and X_r are the rotor resistance and leakage reactance, respectively. S is the rotor slip. T_m and H are the mechanical torque and IG inertia coefficient respectively.

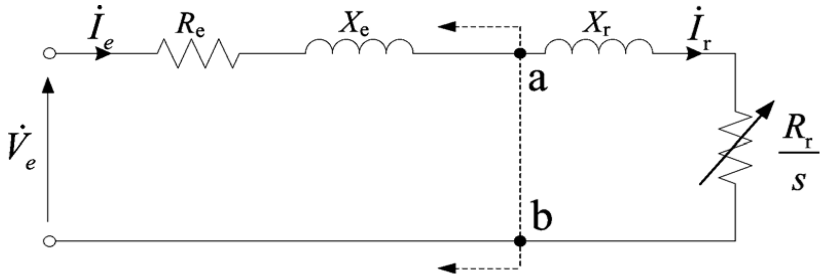


Figure 3.5: Simplified thevenin equivalent circuit of an IG.

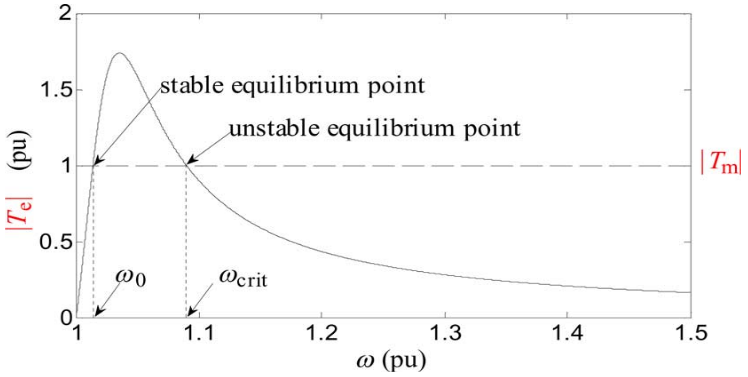


Figure 3.6:Torque-speed curve of an IG.

During the fault the rotor speed accelerate, and depending on the torque-speed characteristic after clearance of disturbance, if the IG speed is high than the critical speed w_{crit} the will lose the stability. and the CCT is defined at the stability limit (w $= w_{crit}$).

3.3.1.2. Transient stability of distribution network including DGs based on inverter interface

In contrast to synchronous generators inverter based DGs does not intrinsically have the frequency and phase reference. In grid connection case the synchronization is carried out by detecting the ac voltage at a point of common coupling (PCC) with a phase-locked loop (PLL) and using it as the reference phase signal of the inverter control system. Inverter-based DGs can be used as power sources or voltage sources by adopting the PQ Control strategy, more usually used in case of network connection, or Droop Control strategy in case of islanded mod of a micro-grid.

Compared to synchronous generators Inverters do not permit large short-circuit currents, power converters can only cope with few percent of overcurrent 20% to 40%. Therefore, power converters have to be protected against extreme events as short circuits but also other events which may induce small overcurrent: phase shift, connection of large loads and tripping of a line. In case of no existing of current limiter the inverter based DGs should be disconnected, other way, the current is limited via current limitation algorithms, such as the virtual impedance. [68]. Many control strategies have been proposed for grid-forming converter in order to limit the current during transients. One strategy is to limit the current with a saturated control algorithm. Recently innovative concepts based on Virtual Impedance have been implemented to emulate the effect of a physical impedance when the current exceeds its nominal value. These methods have shown their effectiveness to limit the current transients in case of lines tripping [69].

The transient stability problem related to inverter based DGs is depend on the control type: using PLL-based current control, only physical constrains related to the over current is presented, however Using voltage control based on the droop control, DGs based inverter have not only to cope with current limitation but also maintain the post-fault synchronization of the VSC based on droop control. some papers proposed to switch from voltage control based on the droop control to the PLL-based current control in order to maintain the synchronism and to ensure a transient stability. [70] Where others focus on enhancing critical clearing time of Voltage Source Converter (VSC) based on droop control embedding virtual impedance as current limitation algorithm.

3.4. Steady state Voltage stability analyses of distribution systems in the presence of distributed generation

Voltage stability refers to the ability of a power system to maintain steady voltages at all buses in the system after being subjected to a disturbance from a given initial operating condition. The voltage stability phenomenon has been well recognized in distribution systems. Radial distribution systems having a high resistance to reactance ratio cause a high power loss so that the radial distribution system is one of the power systems which may suffer from voltage instability [71]. In certain industrial areas, it has been observed that under certain critical loading conditions, the distribution system experience voltage collapse. Voltage collapse is a local phenomenon. it occurs at a node within the area with high loads and low voltage profile [72]. With integration DGs in distribution network, the impact on the voltage stability could be positive as well as to be negative. Depending the type and the capacity and the location to be installed.

3.4.1. Types of DGs used for voltage stability analyses:

In this study, four major types of DG have been considered. DG classification is based on their terminal characteristics in terms of real and reactive power delivering capability; Different types of the DG's can be characterized as [73]:

Type1: DG capable of injecting both real and reactive power, e.g. synchronous machines.

*Type2:*DG capable of injecting real but consuming reactive power, e.g. induction generators used in the wind farms.

Type3: DG capable of injecting real power only, e.g. photovoltaic panels.

Type4: DG capable of injecting reactive power only, e.g. kvar compensator, synchronous compensator, capacitors etc.

To have an idea about the effect of distributed generators capacity of each type on the system behavior, the active Penetration Level (APL) and the reactive Penetration Level (RPL)parameters are respectively defined as the ratio of the total active power and reactive power generation from DGs ($\sum P_{dg}$,$\sum Q_{dg}$) to the active and reactive power peak load demand ($\sum P_{peak}$) , ($\sum Q_{peak}$).

They can be calculated as:

$$\begin{cases} APL = \frac{\sum p_{dg}}{\sum P_{peak}} * 100\ \% \\ \mathrm{RPL} = \frac{\sum \mathrm{Q_{dg}}}{\sum \mathrm{Q_{peak}}} \ * 100\% \end{cases} \qquad 3.\ 53$$

Voltage stability is depending on the system and load characteristics, the generating units' behavior, and the interactions of controls and protections. It is tending to be a more challenging issue in distribution systems with presence of distributed generation and the large power fluctuations. Where integrating DGs in distribution network can affect the voltage profile, voltage stability, power flow, power quality, reliability, and control and protection, due to its intermittent nature, of renewable energies, and its smaller inertia during transients and system faults. its effects are depending on the level of penetration.

3.4.2. Used Method for voltage stability evaluation:

Steady state voltage stability analysis is traditionally done using power flow methods. in order to determine the load ability limits of the power system, Conventional analysis techniques usually detect saddle-node bifurcations, or voltage collapse points using continuation power flow methods, or Point of Collapse methods [74]. In many paper researchers used voltage stability indexes as a practical tools to evaluate and improve the voltage stability.

Voltage collapse:

The continues increasing demand of power from a high loaded area increase the power transfer of electrical line with voltage decline at the receiving node. The sending node, line and receiving node are characterized by a maximum loadability point figure3.7, the rise of power demand higher than the maximum loadability lead to a voltage collapse. The voltage decline is often monotonous and small at the onset of the collapse and difficult to detect. A sudden and probably unexpected increase in the voltage decline often marks the start of the actual collapse.

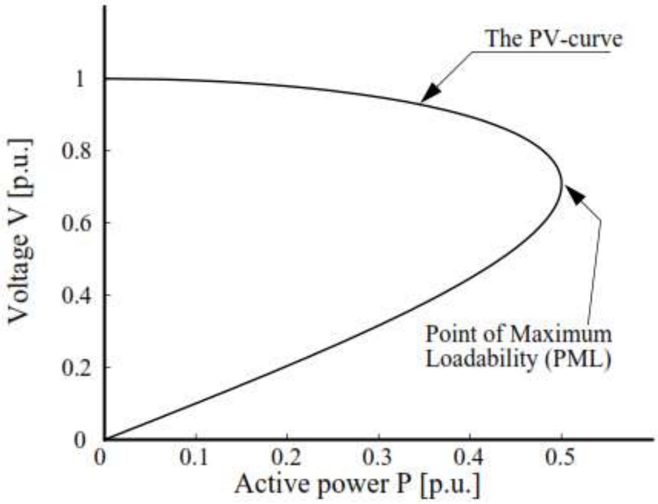


Figure 3.7: A voltage-power curve characteristic of electrical line

The Point of Collapse (PoC) is a point where a bifurcation occurs and is indicated in Figure3.7. If the power is increased for the load there will be a bifurcation in the system when reaching the PoC.

3.4.2.1. Voltage Stability Index used in this study:

A steady state voltage stability index is proposed by M. Charkravorty et.al in [75] and has been used in many papers for identifying the node which is most sensitive to voltage collapse.

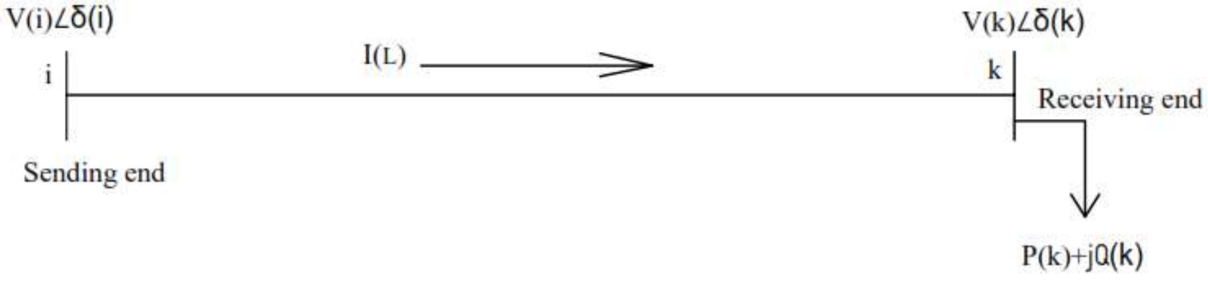


Figure 3.8:*Electrical equivalent of two-node system*

Using the Electrical equivalent of two-node system as shown in figure 3.8 and after developing the power flow equations we get:

$$I(j) = \frac{\mathrm{V(i)-V(k)}}{\mathrm{r(L)+jX(L)}} \qquad 3.\ 54$$

$$|v(k)|^4 - b(L)|v(k)|^2 + c(L) = 0 \qquad 3.\ 55$$

Where:

$$b(L) = \{|v(i)|^2 - 2P(k)r(L) - 2Q(k)x(L)\} \qquad 3.\ 56$$

$$C(L) = \{|P(k)|^2 + |Q(k)|^2\}\{r(L)^2 x(L)^2\} \qquad 3.\ 57$$

The condition to have a solution for equation (3.55) is defined as:

$$b(L)^2 - 4C(L) \geq 0 \qquad 3.\ 58$$

And after simplification of (3.58) we obtain a voltage stability index as presented below:

VSI=

$$\{|v(i)|^4\} - 4\{\mathrm{P(k)x(L) - Q(k)r(L)}\}^2 - 4\{\mathrm{P(k)r(L) + Q(k)x(L)}\}|v(i)|^2 \quad (3.\ 59)$$

Where:

SI (k) = voltage stability index of node k.

L = branch number,

i = sending end node,

k = receiving end node,

I(L) = current of branch L ,

V(i) = voltage of node I ,

V (k) = voltage of node k,

P (k) = total real power load fed through node k,

Q (k) = total reactive power load fed through node k.

For stable operation of the radial distribution networks, SI (k) must be ≥ 0.

The node at which the value of the stability index is minimum is more sensitive to the voltage collapse.

3.4.3. Effect of active and reactive power injection on voltage stability and power losses

The Effect of active and reactive power injection on objective functions are evaluated in the test 33-bus radial distribution network; a constant power load model has been used in the simulation. The detailed data for this system is given in table 1 in the Appendix [76]. Figure 3.8 illustrates the network structure of the system.

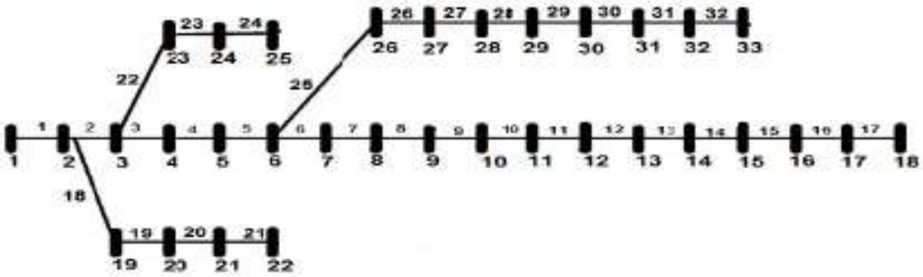


Figure3.9: modified 33-bus test distribution system

A mesh plot has been used to evaluate the stability index, the total active power losses and the total reactive power losses in the 33-bus distributed network versus the location and size of both active and reactive power injection. Figure 3.10 shows that the active power injection affect the stability index more than the reactive power injection and the improvement level increase as the penetration level increase. However, the constraints in voltage and current limit the penetration level of DGs. The location and the size have the principal effect on the objective functions. Figure 3.11 and 3.12 show the total active and reactive power losses of the system for different locations and sizes of the DG units.

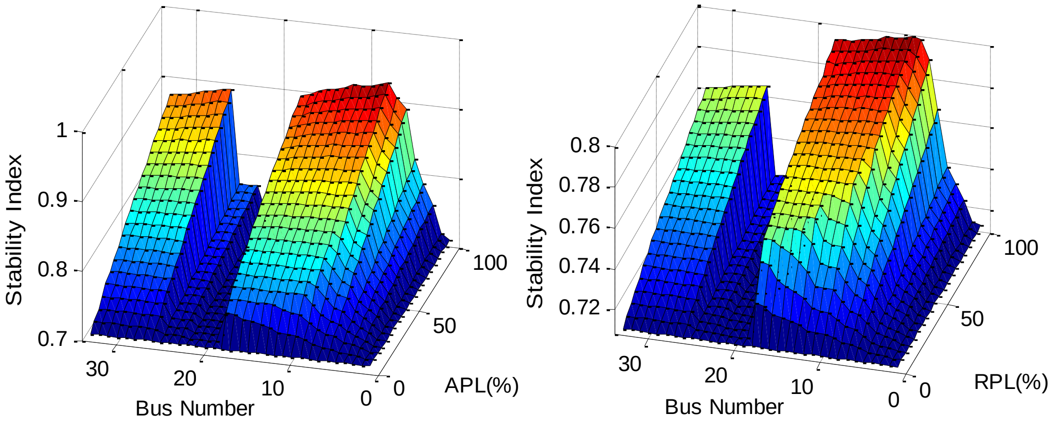


Figure 3.10:Effect of capacity and location of DG on Stability Index

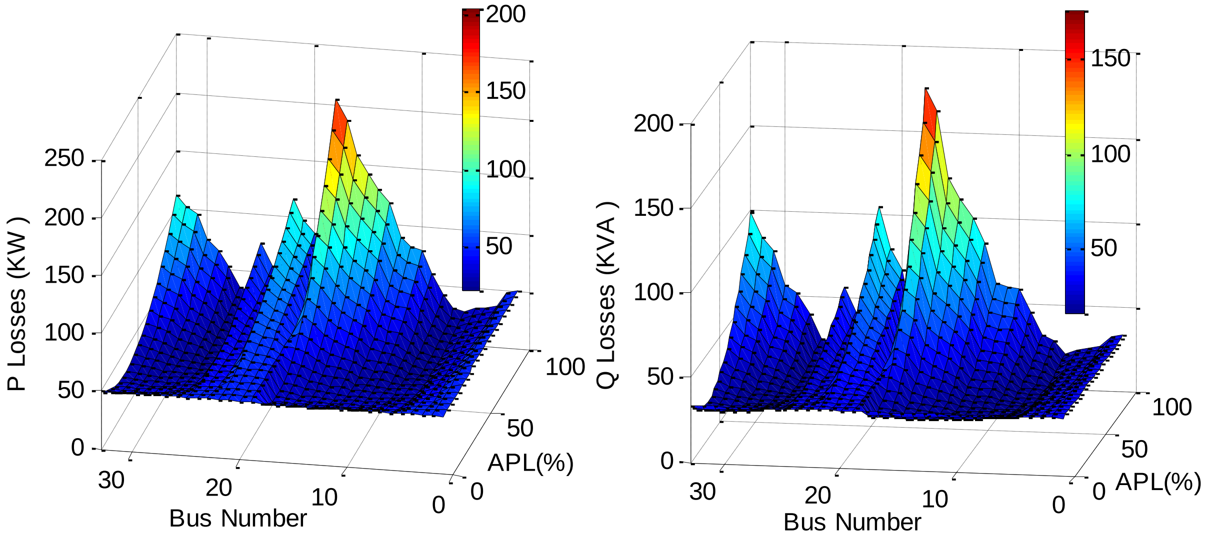


Figure3.11: Effect of Active power injection capacity and location of DG on active and reactive power losses

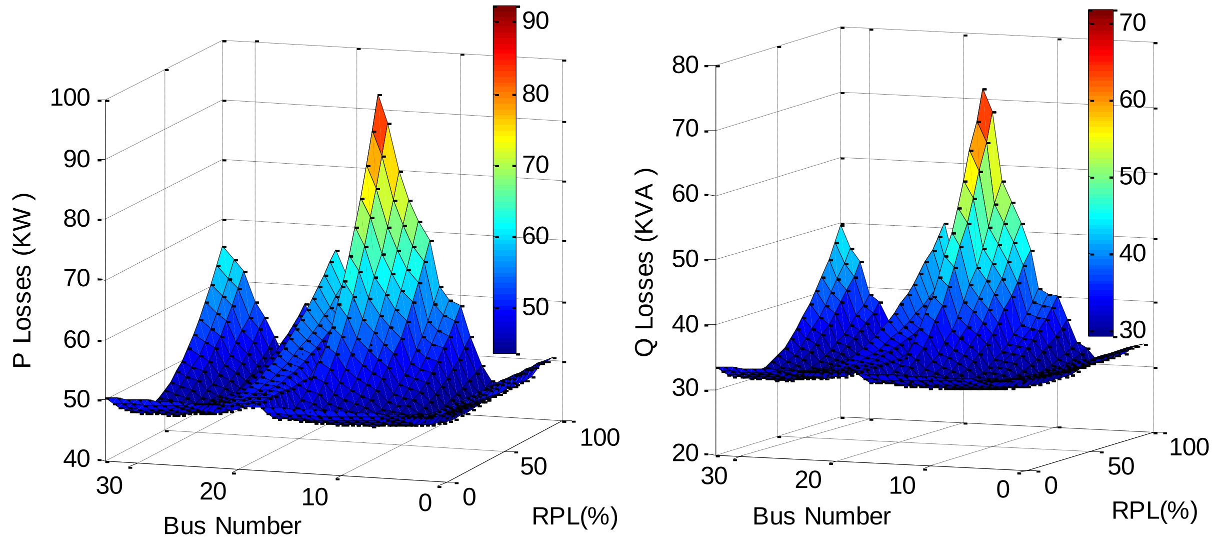


Figure3.12: Effect of Reactive power injection capacity and location of DG on active and reactive power losses

In contrast to transmission networks where voltage stability is depending mainly on the balance of reactive power, we observe from the mesh plot in figure 3.10 that both active and reactive power injection effect differently and significantly the voltage stability with respect of the capacity and installing location due to the high resistance to reactance ratio characteristic of the radial network.

We note from the mesh plot figure 3.11 and figure 3.12 that the active and reactive power injection have important effect on network active and reactive power losses. where the active and reactive power capacity injection are effecting differently the losses with respect of the locations of connecting DGs units.

From this analyses we deduce that The installing location, size and type of DGs can play an important role on reducing power losses and voltage stability improvement of distribution networks. And that optimization techniques are required for planning, design and management of distribution network with presence of DGs.

It can be observed that the highest reduction in power losses does not take the same location and size where the highest improvement in system stability. If the system faces a critical problem of stability, it is better to consider only one objective function to prevent the voltage collapse. If the interests are to enhance different parameters such as stability and power losses, optimization technique should be used as techniques base on genetic algorithms. In this study we used the SPEA algorithm to realize an optimization work regarding voltage stability and power loss.

3.5. Summary

In this chapter, the deferent method used for angle stability evaluation in power system have been presented, the methods could be used could be used for a large network using aggregation and simplification, in distribution network it is more practical and simple to evaluate the angle stability on a sub portion using aggregation and dynamic equivalent for the external network. Transient stability in distribution systems become the recent topic due to the continuous increase of distributed generation. Besides the extensive branches distribution networks the dynamic behavior of DGS increasing the complexity of the numerical analysis of transient stability. In this part a simplified methodology for transient analysis in distribution networks with distributed generation have been presented. the hybrid PEBS individual have been recommended to assess the stability of each synchronous machine using the individual energy function and time domain simulation of the system.

Beside the synchronous machine, induction machine has high part in distribution network even as motor or recently as generator. a short-circuit fault in a distribution network lead to increasing the speed of induction generator, which may cause system transient stability problems. In this part an improved SteadyState equivalent circuit method to determine transient stability of a distribution system with (IGs) based on the torque –speed characteristic have been presented where The critical speed and critical fault clearing time (CCT) for maintaining system stability could be determined using the technique.

Regarding the steady state stability, we have introduced a voltage stability index to predict voltage collapse in distribution system, which could be used in voltage stability analyses and optimal studies. The index is based on maximum loading capability of each bus. The index has been used in simulation on 33 bus radial distribution network presenting the effect of DGs penetration and location to be installed on the voltage stability. The simulation has also illustrated DGs effect on the power losses.

4. CHAPTER 04: Investigation on the Steady State and Transient Stability of Distribution Network with presence of DGs

4.1. Introduction:

The increase in electricity demand, technological advancements in the grid integration of renewable energy sources, environmental concerns and the restructuring of electricity market have significantly motivated the network integration of DG units. Moreover, DGs are available in modular units, and are characterized by ease of finding sites for smaller generators, shorter construction times, and lower capital costs. Distributed Generation (DG) is defined as ‘‘an electric power source connected directly to the distribution network or on the customer site of the meter’’. DGs should be strategically placed in distribution networks for grid reinforcement, reducing power losses and on-peak operating costs, and improving voltage profiles and load factors [77].DGs also affect power quality, stability, reliability, and protection. Since DG units have a small capacity compared to central power plants, the impacts are minor if the penetration level is low (1%–5%). However, if the penetration level of DG units increases to the anticipated level of 20%–30%, the impact of DG units will be profound [15]. hence investigation and analyzing studies concerned the stability, quality and enhancement of distribution network with presence of DGs should be the objective of the recent research.

4.2. Optimal placement and sizing of DGs for steady state improvement

The planning of the electric system with the presence of DGs requires defining several factors including the best technology to be used, the size, location and capacity of each unit, the interconnection method, and uncertainty of power generation and time varying load .etc. [78].

Optimal location, size, type and number are the design variables that are alternatively computed for each DG. The authors in [18] introduce a review about several investigations on this subject. The selection of the best places for installation and the size of the DG units in large distribution system is a complex combinatorial optimization problem [79]. The optimal installation of DGs into existing distribution networks is subjected to electrical network operating constraints, DG operation constraints and investment constraints. The distribution network must be kept within operational and design limits at all times to provide good-quality energy and avoid damage to the equipment.

Different methods have been used to keep the network within operational limits and to optimize the steady state impacts of DGs integration. These methods can be classified into three types: analytical, numerical and heuristic. Analytical methods have been used in [16] to find the optimum size and location of a single DG and the optimal size and power factor of different types of DGs respectively.

Numerical Methods such as Linear Programming used in [14] and Nonlinear Programming used in [80] have been proposed to solve the optimal DG placement. Heuristic Methods such as Genetic Algorithm (GA) and Artificial Bee Colony (ABC) are required for optimization problems that try to satisfy either one or several objectives with discrete or continuous decisions variables. The Genetic Algorithm (GA) presents the advantage to explore the space of the feasible solutions from a set of solutions created in a random manner. GA have been used to solve multi-objective Optimal DG placement problem in [17], [81]. It is also used in [19] to minimize power loss cost. In [82], a non-dominated sorting GA (NSGA) is used to maximize the distributed wind power integration.

It is more practical using DGs to solve the most critical problems as voltage stability, especially with the development of their technologies including photovoltaic, wind turbine, fuel cells, small and micro-sized turbine packages, internal combustion engine generators, and reciprocating engine generators. A literature survey shows that a lot of work has been conducted on the optimization of design variables (number, type, location and size and reconfiguration of the network) in distributed networks in order to improve proposed objective functions (min power loss, min cost, max profit, max DG capacity, max benefit/cost ratio, voltage stability) [83], [84]. According to the existing reviews, more investigations are needed in this subject, a combination between voltage stability and active and reactive power loss are considered as very important objective functions.

In this part of theses, a multi-objective GA, strength pareto evolutionary algorithms (SPEA), has been used to find the optimal DG location and size considering the type and number of installed DGs in a radial distribution system. The problem is solved to improve the voltage stability, reducing active power loss and reactive power loss. A comparison between optimal design variables of two different load states has been conducted in order to demonstrate the effect of the load state on the optimization process. A comparison between integrating a single DG and a multiple DGs with the same power injection in a distributed network has also been conducted where a steady state voltage stability index, four assessing the voltage stability at each node, is used to assess the network stability.

4.2.1. Problem formulation

The optimization problem is formulated to improve the distribution network stability while reducing power loss by optimally selecting the location, number and size of different types of DGs using a Genetic Algorithm, Strength Pareto Evolutionary Algorithm (SPEA). The backward / forward sweep method of distribution load flow [85] has been used to evaluate the desired objective. The constraints of the proposed problem include voltage limits at each bus, and the feeder and DG capacity limits.

A. Objective Function

1. Voltage Stability Index: the steady state voltage stability index developed before aid to identifying the node which is most sensitive to voltage collapse. For stable operation of the radial distribution networks, SI (i+1) must be ≥ 0. The node at which the value of the stability index is minimum is more sensitive to the voltage collapse. The minimum SI is considered as an objective function in this investigation.

2. Minimizing the total active and reactive power losses.

Minimise

$$\{P_L = \sum_{k=1}^{n} |I_k|^2 R_k\} \quad 4.1$$

Minimise

$$\{Q_L = \sum_{k=1}^{n} |I_k|^2 X_k\} \quad 4.2$$

Where: n= nbus- 1

B. Constraints

1. Voltage limits on each bus:

Make sure that the voltages $|v_i|$ along the feeder are well within the tolerable range, ± 5 % of the nominal value [26].

$$0.95 \leq |v_i| \leq 1.05 \quad i = 1,2, \dots \dots nbus \quad 4.3$$

2. Feeder capacity limits:

$$0 \leq I_{ij} \leq I_{ijmax} \quad \forall\, i, j \quad 4.4$$

3. DG Power Limits:

$$p_{DG,i}^{P} \leq P_{DG,i}^{MAX}, Q_{DG,i}^{P} \leq Q_{DG,i}^{MAX} \qquad 4.5$$

Where$P_{DG,i}^{MAX}$and $Q_{DG,i}^{MAX}$are the allowable maximum active and reactive powers for the ith DG unit.

4.2.2. Strength pareto evolutionary algorithms

This approach has been proposed par Ziztler [86]; it is implemented with the help of genetic algorithm and is based on the maintenance of elitism in the population by the constitution of an external set of non-dominated solutions. The elitism techniques try to keep the non-dominated solutions along the procedure of research of the solutions.

To every generation, the set is actualized according to the new non-dominated solutions. The algorithm starts with a population of size N generated in an uncertain manner with an empty external set. To every t generation, the set is filled and actualized by the non-dominated solutions gotten from the current population.

The notion of dominance permits us to identify the optimal Pareto solutions forming the border of Pareto. For a problem of minimization, a solution xi dominates a solution xj if and only if:

$$\forall m \in [1, n],\ f_m(\ x_i\ )\ \leq f_m(\ x_j\ )\ et\ \ \exists m\ \in [1, n], f_m(\ x_i\ )\ < f_m(\ x_j\ ) \qquad 4.6$$

f_m : Objective function.

Algorithm of SPEA [87]**:**

The principle of Genetic algorithms is well detailed in [88]the author have described with details all the type of genetic algorithms. in this work we give a simple algorithm defining the principle of SPEA.

Step 1: **Initialization**: an initial population P_t will be created as well as an empty external set $\bar{p}_t$. (t = 0; N=Population size). The initial population is randomly generated (The set of candidate buses and DGs size are limited).

Step 2: **Updating of the external set**: All individuals of P_t whose decision vectors are no dominated will be copied into a current version of the external set$\overline{\mathrm{P}}'$. Individuals that become weakly dominated will be removed. Finally, the new external set can be defined as $\bar{P}_{t+1}$ =$\bar{\mathrm{P}}'$

Step 3: **Fitness assignment**: to all the individuals of the external set $i \in \bar{P}_t$, the strength value will be assigned firstly: $(i) \in [0, 1]$. The strength is measured by the number of dominated solutions, divided by the population size N + 1, and thus proportional to the population size ($n_i$number of solutions dominated by i):

$$S_i = \frac{n_i}{N+1} \qquad 4.7$$

Once the strength values (i) are defined, the fitness values can be calculated. For the external set the fitness value of $i$is equal to the strength value: $(i) = (i)$ .For $j \in P_t$ the fitness is the sum of all strength values of the dominated items in the external set, plus one, to ensure that the external set is having a lower value than the population:

$$(j) \ = \ 1 + \sum_{i \in \bar{P}_t} (i) \ (i \text{ dominate } j) \qquad 4.8$$

Step 4:**Selection**: for this, two random individuals of both sets are chosen $(i, j) \in \bar{P_t} + P_t$and compared. The one with the lower fitness value will be included in the next generation.

Step 5& 6: **Recombination** and **mutation**: the individuals inside the population will be modified depending on recombination and mutation probability parameters. The recombination recombines two individuals into new solutions, while the mutation is flipping genes randomly.

Step 7: **Constraints check**: the new individuals will be checked against the constraints. In this work, it have been proposed to replace those genes randomly by others surviving the constraint.

Step 8: **Termination criterion**: if stopping criteria are satisfied (fixed number of iteration), the algorithm will stop here: The best solutions are stored in the external set. Otherwise, the algorithm continues on to Step 2 with the next generation.

4.2.3. Results and analysis

The simulations have been carried out in MATLAB environment**.**

SPEA investigation progress for two objective functions

The SPEA investigation progress for two objective functions has been tested for 12-bus radial distribution network; a summary of system data is presented in Table 2 in the Appendix A [89]. Figure 6 illustrates the network structure of the system.

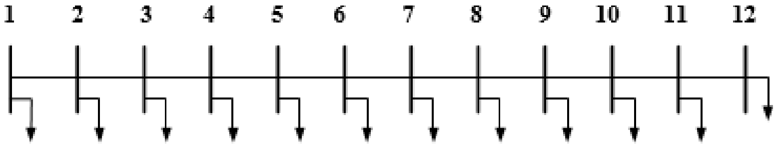


Figure 4.1 : 12-bus and 11 branches system

Figure 4.2 represents SPEA progress on the 12 Bus system, to select optimal location and size of one DG type 1 to minimize the total active power loss and maximize the stability index.

In order to show clearly the progress of population selection, a minimization problem has been taken. In this test, two objective functions have been used, the total active power loss and the parameter $\frac{1}{1+\mathrm{SI}}$ instead of the SI (the stability index). It is observed from figure-7- that the no dominated solution has been selected among the total population. It is also noted that the search for the solution does not sweep all the area because of the constraints that have been taken in consideration.

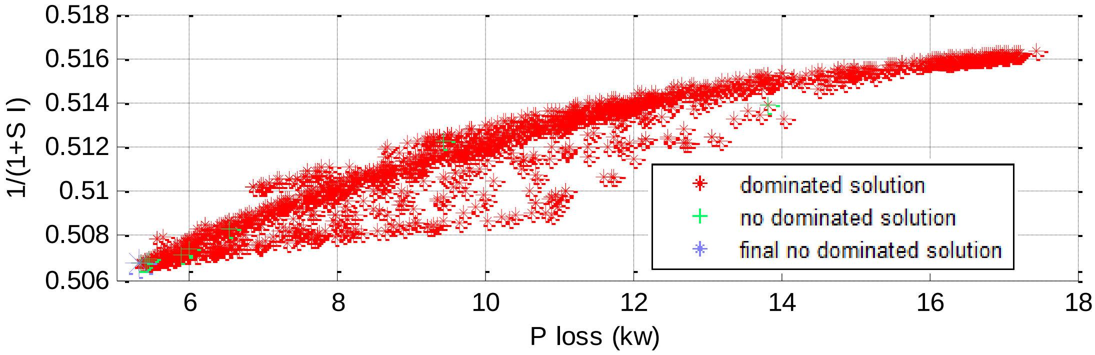


Figure 4.2: SPEA progress in selecting optimal location and size of DG type 1

A. Selecting optimal location and size of different types of DGs using SPEA algorithm

The parameters of the genetic algorithm, SPEA, selected for optimization are Population size (N=10), recombination probability (Pr=0.8) and mutation probability (Pm=0.03). The GA is set to stop when 150 iterations are evaluated.

In this study, after validation of the program, three cases have been analyzed depending on the number and type of DGs to be installed. The first case considers only one connected DG type. The second case, four different connected DGs are considered to be installed optimally. For the two cases, the algorithm is applied on a modified 33-bus distribution system. This system works at the nominal voltage of 12.66 kV and the base apparent power is 10 MVA. In addition, the maximum currents limit of the system branches is selected to be 255 A.

The third case considers two connected DGs to a 119-bus network. This system functions at 11 kV nominal voltage. The detailed data for this system is given in table 3 in the AppendixA [90]

Validation of the program:

In order to validate the implementation of the SPEA algorithm in our MATLAB program, a comparison with the results presented on figure 3.9 where only the voltage stability index is considered as objective function. The case of one DG of type 3, active power injection, and type 4, reactive power injection, is used for validation purposes.

The SPEA algorithm is meant to find the optimal placement and size for this case. From table 4.1, it can be noted that the optimal location and size presented by the algorithm are the parameters presenting the highest voltage stability index among all other locations and sizes.

DG	Optimal location	Optimal size		Stability Index
		(APL%)	(RPL%)	
type 3	8	99.89	0	0.92
type 4	9	0	99.50	0.79

Table 4-1: Optimal location and sizes of DG using SPEA algorithm.

Case-I: One DG is connected Considering two load states of the 33-bus distribution system, SPEA algorithm was used to find the optimal location and size for type 1, type3 and type 4 independently. The maximum penetration of DG in the network is limited: APLmax=30%, RPLmax =30%. Theoptimal size and locations obtained for each type in the first and second load state are given in Table 4.2 and Table 4.3.

The objective functions without DG integration:

First load state: Stability index=0.71, Active power loss=493.07 kW, Reactive power loss=328.178 kvar.

Second load state: Stability index=0.68, Active power loss=579.18 kW, Reactive power loss=391.42 kvar.

DG type	Optimal location	Optimal size (APL%) (RPL%)	Stability Index	Power loss (KW) (KVAR)
type 1	10	27.44 29.49	0.81	227.09 150.61
type 3	11	29.90 0	0.80	268.95 178.94
type 4	13	0 29.94	0.76	440.65 293.42

Table 4-2: Optimal location and sizes of DG in the first load state.

DG type	Optimal location	Optimal size (APL%) (RPL%)	Stability Index	Power loss (KW) (KVAR)
type 1	30	29.77 28.54	0.79	203.90 139.58
type 3	31	29.439 0	0.77	259.01 174.37
type 4	31	0 29.41	0.73	507.96 343.35

Table 4-3:Optimal location and sizes of DG in the second load state.

Table 4.2 and 4.3 show that the SPEA algorithm can find the optimal location and size of each DG type integration, and The network stability and energy losses depend on the network load state. It can be noted that the stability index is improved and the system power losses are reduced in each load state after the integration of DG especially for type 1. It can be observed that when a DG unit of type 1is considered, the stability index is improved over 10%, and the active and reactive power losses are reduced over 55% in the two load states. The optimal placement and size at the first state is not the same as the second. Therefore, to benefit more from DGs integration, the optimal location and size should be investigated according to different load variations data during one year.

Figure.5.3 show the impact of DG on voltage profile considering only one type optimally installed. It can be observed that the greatest improvement on voltage profile is achieved when the DG units of type 1 is integrated.

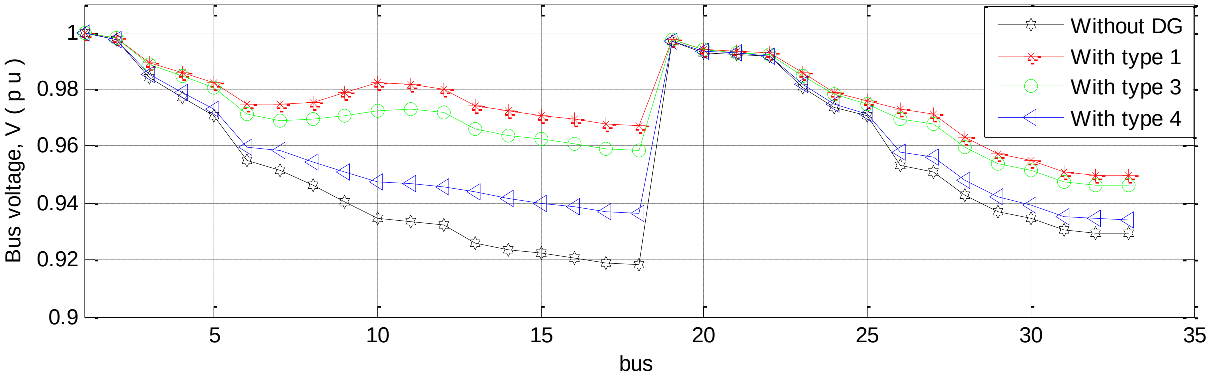


Figure 4.3: Voltage profile before and after integrating of DGS in the first load state

Case-II: four DGs are connected: in order to compare with the first case, the total active and reactive penetration of DGs are limited to 30 %. (The first load state has been used in the investigation).

In this case, three scenarios have been investigated to show the effect of DGs number on the voltage stability and the power losses.

Scenario1: four DG units of type 3 have been installed. Maximum penetration of each unit is APLmax= (30/4) % , RPLmax = (30/4) %.The optimal sizes and locations obtained are given in Table 4.4.

Scenario2: four DG units of type 4 have been installed. Maximum penetration of each unit is APLmax= (30/4) % , RPLmax = (30/4) %. The optimal sizes and locations obtained are given in Table 4.5.

Scenario3: two DG units of type 3 with two DG units of type 4 have been installed. Maximum penetration of each unit is APLmax= (30/2) %,RPLmax =(30/2)%. The optimal sizes and locations obtained are given in Table 4.6.

Optimal location				Optimal size			
DG unit 1	DG unit 2	DG unit 3	DG unit 4	DG unit 1 (APL%)	DG unit 2 (APL%)	DG unit 3 (APL%)	DG unit 4 (APL%)
31	29	18	13	7.50	7.49	7.46	7.50
Stability Index				Power loss (KW)	Power loss (KVAR)		
0.84				212.11	138.62		

Table 4-4: Optimal locations and sizes of the four DG units of type 3.

Optimal location				Optimal size			
DG unit 1	DG unit 2	DG unit 3	DG unit 4	DG unit 1 (RPL%)	DG unit 2 (RPL%)	DG unit 3 (RPL%)	DG unit 4 (RPL%)
29	13	18	31	7.50	7.50	7.50	7.50
Stability Index				Power loss (KW) (KVAR)			
0.795				410.24 273.33			

Table 4-5: Optimal locations and sizes of the four DG units of type 4.

Optimal location				Optimal size			
DG unit 1 (Type 3)	DG unit 2 (Type 3)	DG unit (Type 4)	DG unit 4 (Type 4)	DG unit 1 (APL%)	DG unit 2 (APL%)	DG unit 3 (RPL%)	DG unit 4 (RPL%)
15	31	30	18	14.22	13.83	12.88	13.15
Stability Index				Power loss (KW) (KVAR)			
0.87				164.34 106.29			

Table 4-6: Optimal locations and sizes of the four DG units of type 3 and 4.

The optimal location and size of each DG unit for different scenarios are shown in table 4.4 to 4.6. Comparing with the first case, table 4.4 and 4.5 show that the number of DGs affects significantly the stability and the power losses. It is observed from the results that four optimally installed DGs present better voltage stability and less power losses than one installed DG with the same total size. It is also observed from the results in table 6 that when DGs of different types are installed optimally, a higher loss reduction and stability improvement can be achieved.

A comparison between the voltage stability index obtained by integration of one DG type1 and the one obtained in the scenario 3 is illustrated in figure 4.4.

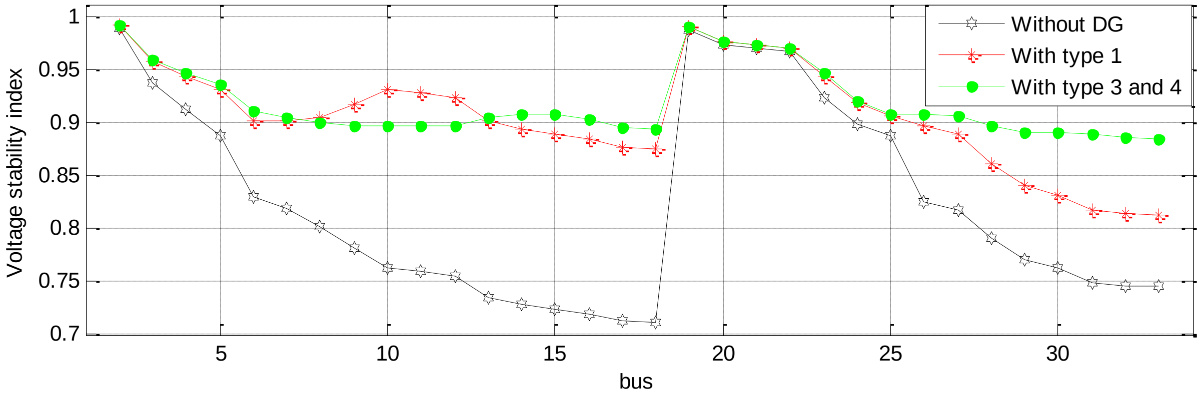


Figure 4.4:Voltage stability index before and after integrating of DGs

It is noted from the results given in case-I and case-II that an optimal integration of several small DGs with deferent types improves the stability of the network and reduce the energy loss more than the use of one DG of important size. Moreover, the reliability of the power injection is increased.

Case III:

Two different DGs are connected to the modified IEEE 119-node test feeder (Figure (5.5) [90]. The first one is a type 3 DG with a maximum capacity of 1,9 MW and the second one is considered as a set of reactive compensators (type 4 DG) of 0.2MVA. This test system is an 11 kV distribution system.

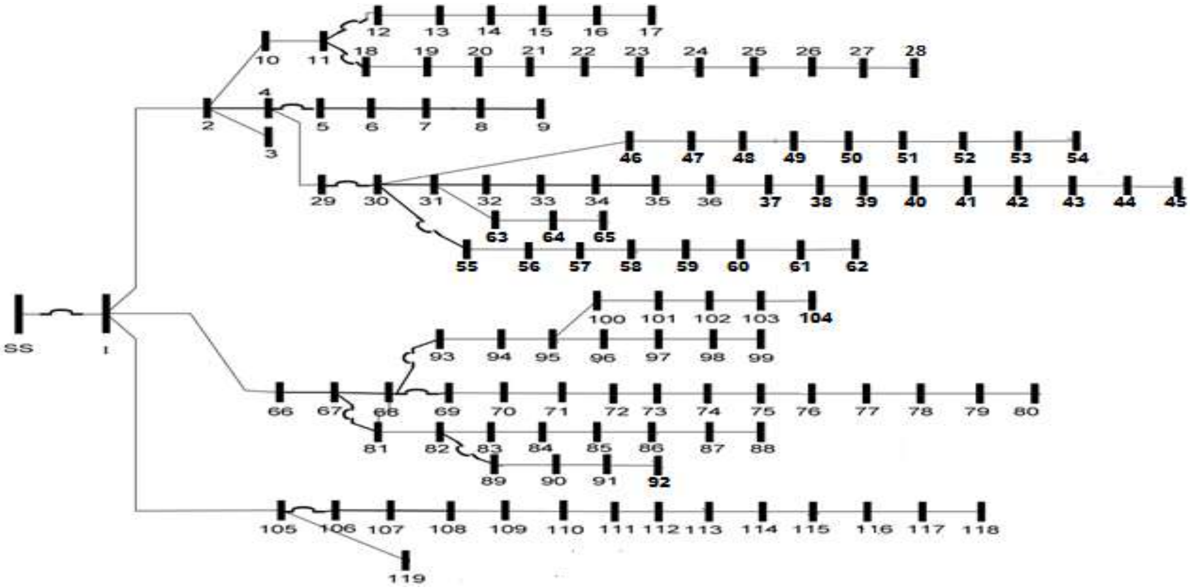


Figure 4.5:The modified 119-bus test system [90]

Optimal location		Optimal size	
DG type 3	DG type 4	DG type 3 (APL%)	DG type4(RPL%)
79	80	9.985	35.794
Stability Index		Power loss	
		(KW)	(KVAR)
0.7954		1577.7	1206

Table 4-7: Optimal locations and size of the two DG units of type 3 and 4.

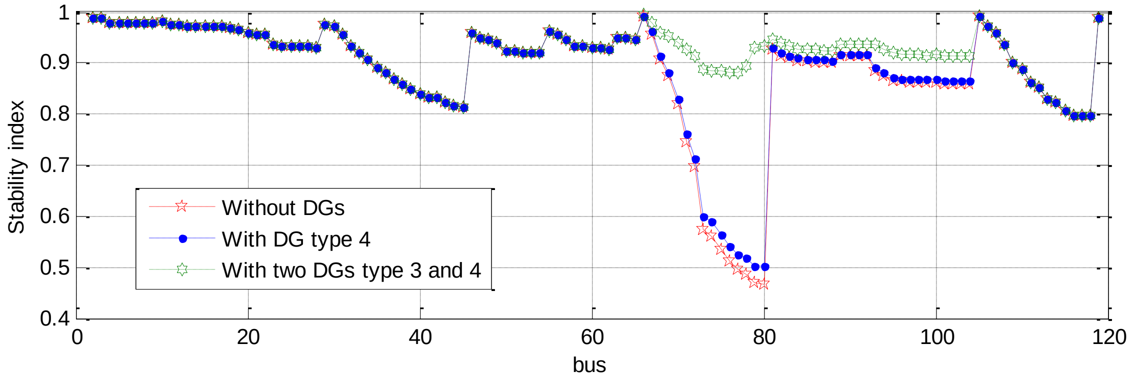


Figure 4.6:Voltage stability index before and after integrating DGs

The optimal locations and size of the two DGs are presented in table 4.7. Results show that the optimal placement is situated at a node within the area with high loads and that the optimal size of DGs is their full capacity. The voltage stability index of all buses before and after integrating DGs is presented in Figure 4.6. it can be noticed that only the feeder of buses 66 to 104 had it stability index effected by the integration of DGs. This can be explained by the fact that the DGs are present only on this feeder branch and that the different feeders are separated. Under these circumstances, the effects of the DGs are limited to this feeder branch.

It can also be noticed that the integration of the type 4 DG did not improve much the stability index of the affected set of buses while a great improvement of the index occurred with integration of a type 3 DG. It is worth mention that our algorithm operates normally with large systems.

4.3. Potential voltage instability of distribution network including DGs:

For stable operation of a distributed system, the power flows and bus voltages should be maintained within acceptable limits throughout the network despite changes in load or available transmission and generation resources. assuming future load growth to be met largely by large-scale DG, the system with presence of DGs should have the ability to remain in a state of operating equilibrium under normal operating conditions and after being subjected to a disturbance.

Beside the stochastic changes of power consumption and fluctuation of renewable power generation, losing high part of DGs, due to disturbance occurrence, could have the large impact on the network stability. Passive distribution network has slow actuation time of voltage controller due to its mechanical devices; as the mechanical tap changer which take time to move from one position to the next, commonly this time period is about 5–10 s. In a large power system, every voltage level has its own tap changer. In order to reduce the possibility of the tap changers hunting each other and establishing a better coordination, the common practice is to make the higher voltage-level tap changers respond faster than those in lower voltage networks. Usually, the first tap time delay for distribution tap changers is from 30 to 60 s [91].in this study a simulation of the impact of power fluctuation on the voltage stability and quality of service before control actions or in case where the voltage controllers working near of its limit have been carried out for different scenarios, shown in Tables 2 to 7. The power fluctuation reasons could be refried to the cloud effect on the photovoltaic generation or losing DGs suit to a disturbance occurrence, and changes in power consumption. The Effect of sudden power changes on the network voltage are evaluated in the modified test 33-bus radial distribution network; a constant power load model has been used in the simulation. data for this system is given in table 1 in the Appendix. Fig1 illustrates the network structure of the system [92].

In order to have large analyses of Sudden under capacity impact due DGs disconnection taking into account the emplacement, number and the type of DGS, six DGs is considered connected to the network as presented in table 4.8.

DG bus connection	3	6	18	22	25	33
Active power penetration(%)	7	7	7	0	7	6
Reactive power penetration (%)	4	0	4	4	4	4

Table 4-8: location and penetration level of DGs integrated to 33-bus system used for sudden power fluctuation. analyses

The impacts of large bus power changes is illustrated throw the voltage profile and stability index (VSI). The parameters have been evaluated using back/forward sweep method to calculate power flow, modelling the loads and DGs as P, Q bus where the voltage at bus1 is considered as voltage reference.

For stable operation of the radial distribution networks, SI (i+1) must be ≥ 0. the node at which the value of the stability index is minimum is more sensitive to the voltage collapse.

The voltage profiles and stability index have been evaluated using back/forward sweep method to calculate power flow, modelling the loads and DGs as P, Q bus where the voltage at bus1 is considered as reference.

DG bus connection	Network load case	Senerio1	Senerio2	Senerio3	Senerio4	Senerio5	Senerio6
3	Max load	lost	maintained	maintained	maintained	maintained	maintained
6	Max load	maintained	lost	maintained	maintained	maintained	maintained
18	Max load	maintained	maintained	lost	maintained	maintained	maintained
22	Max load	maintained	maintained	maintained	lost	maintained	maintained
25	Max load	maintained	maintained	maintained	maintained	lost	maintained
33	Max load	maintained	maintained	maintained	maintained	maintained	lost

Table 4-9: different scenarios correspond to losing one DG.

DG bus connection	Network load case	Senerio1	Senerio2	Senerio3	Senerio4	Senerio5
3	Max load	lost	lost	lost	lost	lost
6	Max load	lost	maintained	maintained	maintained	maintained
18	Max load	maintained	lost	maintained	maintained	maintained
22	Max load	maintained	maintained	lost	maintained	maintained
25	Max load	maintained	maintained	maintained	lost	maintained
33	Max load	maintained	maintained	maintained	maintained	lost

Table 4-10:Table 3: correspond to losing two DGs.

3	Max load	lost	maintained	maintained	maintained	maintained
6	Max load	lost	lost	lost	lost	lost
18	Max load	maintained	lost	maintained	maintained	maintained
22	Max load	maintained	maintained	lost	maintained	maintained
25	Max load	maintained	maintained	maintained	lost	maintained
33	Max load	maintained	maintained	maintained	maintained	lost

Table 4-11:Table 4: correspond to losing two DGs

DG bus connection	Network load case	Senerio1	Senerio2	Senerio3	Senerio4	Senerio5	Senerio6
3	Max load	lost	lost	lost	lost	maintained	maintained
6	Max load	lost	lost	lost	lost	lost	lost
18	Max load	lost	maintained	maintained	maintained	lost	lost
22	Max load	maintained	lost	maintained	maintained	lost	maintained
25	Max load	maintained	maintained	lost	maintained	maintained	maintained
33	Max load	maintained	maintained	maintained	lost	maintained	lost

Table 4-12:Table 5: correspond to losing three DGs

DG bus connection	Network load case	Senerio1	Senerio2	Senerio3	Senerio4	Senerio5	Senerio6
3	Max load	lost	lost	lost	lost	lost	lost
6	Max load	lost	lost	lost	lost	lost	lost
18	Max load	lost	lost	lost	lost	lost	lost
22	Max load	lost	maintained	maintained	lost	lost	lost
25	Max load	maintained	lost	maintained	lost	maintained	lost
33	Max load	maintained	maintained	lost	maintained	lost	lost

Table 4-13:Table 6: correspond to losing four DGs, five or all DGs

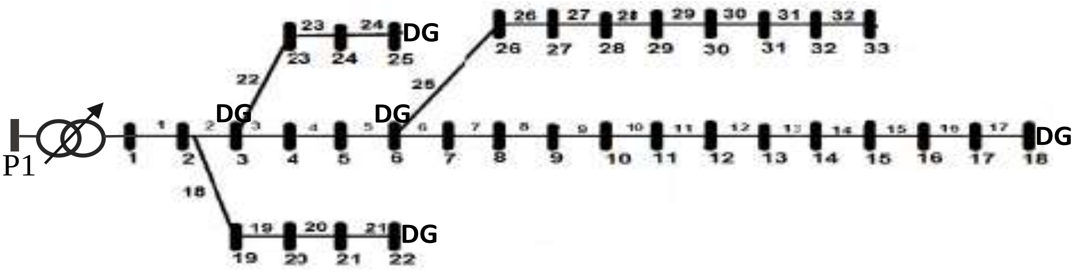


Figure 4.7: 33-bus test distribution system

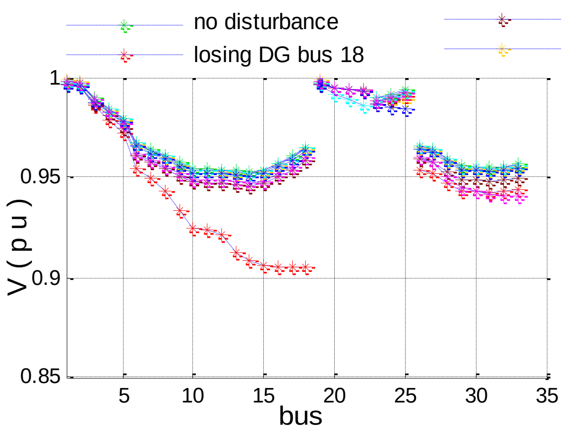


Figure 4.8:Voltage profile at the moment of losing one DG

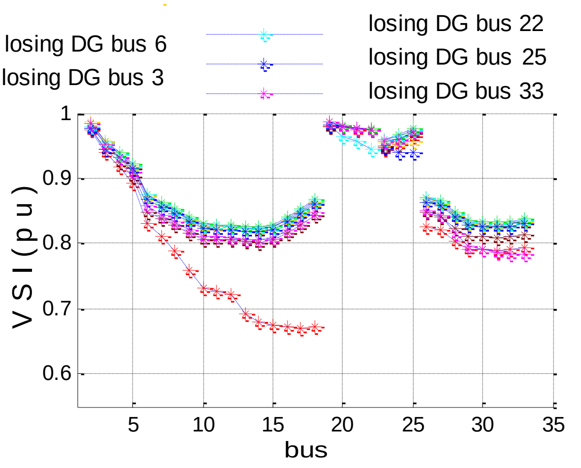


Figure 4.9:Voltage stability index at the moment of losing one DG

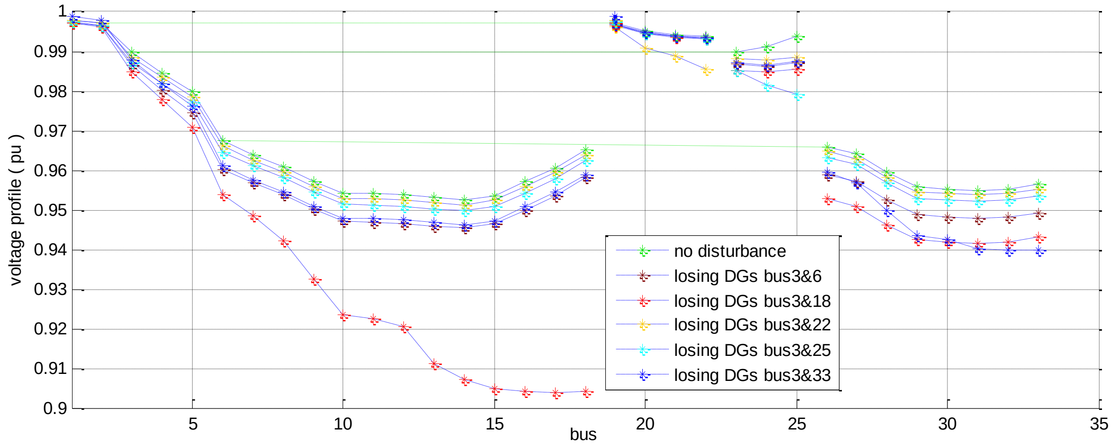


Figure 4.10: Voltage profile at the moment of losing DG3 & one other DG

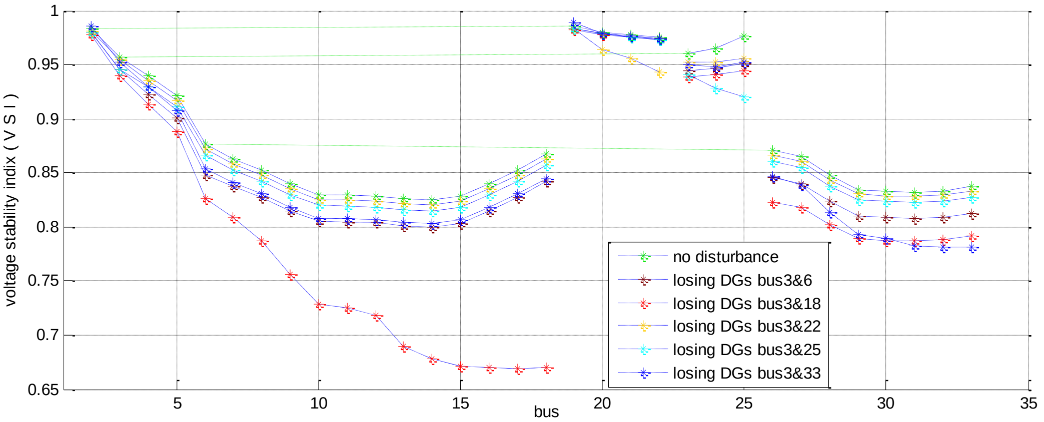


Figure 4.11: Voltage stability index at the moment of losing DG3 & one other DG

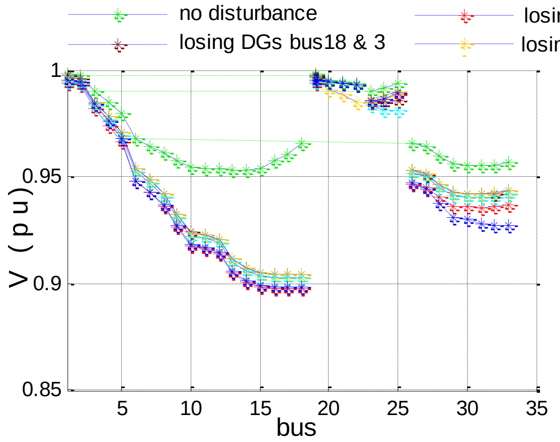


Figure 4.12: Voltage profile at the moment of losing DG18 & one other DG

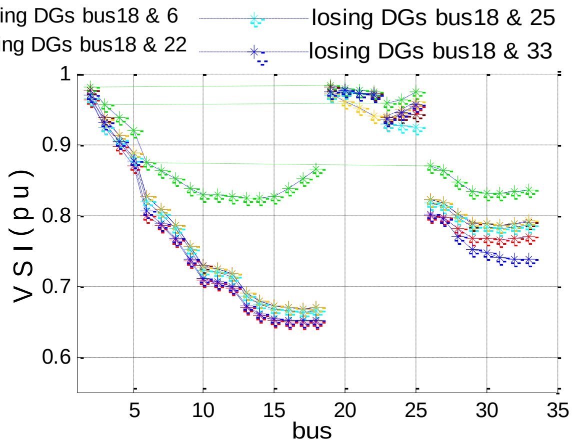


Figure 4.13: Voltage stability index at the moment of losing DG18 & one other DG

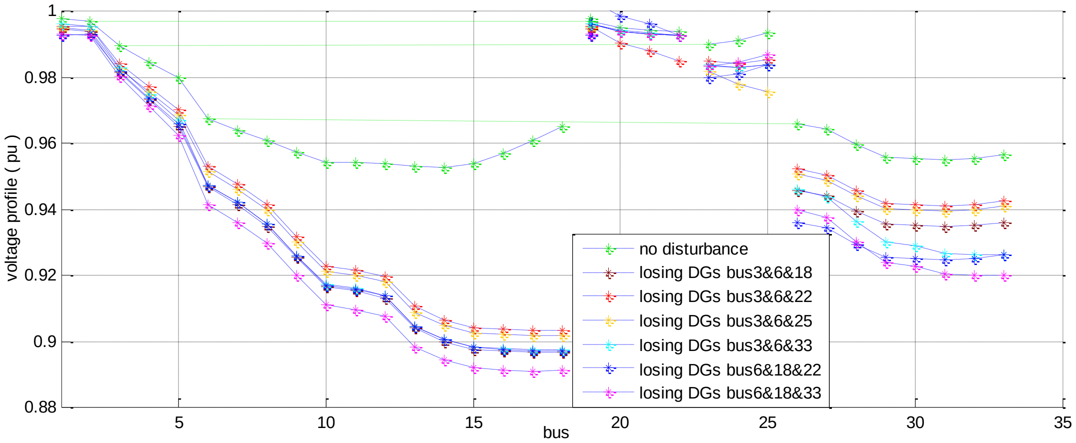


Figure 4.14: Voltage profile at the moment of losing three DGs

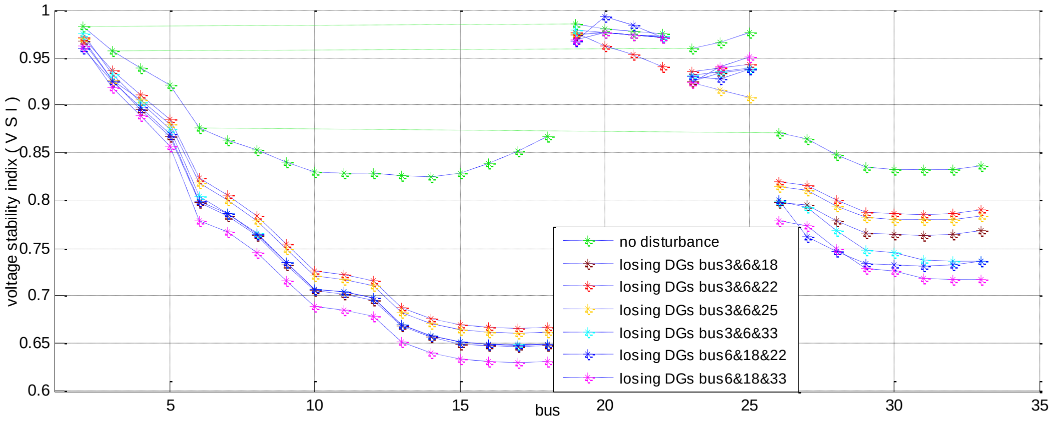
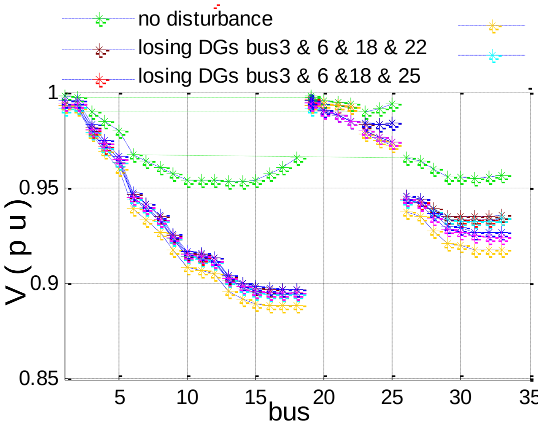


Figure 4.15: Voltage stability index at the moment of losing three DG3



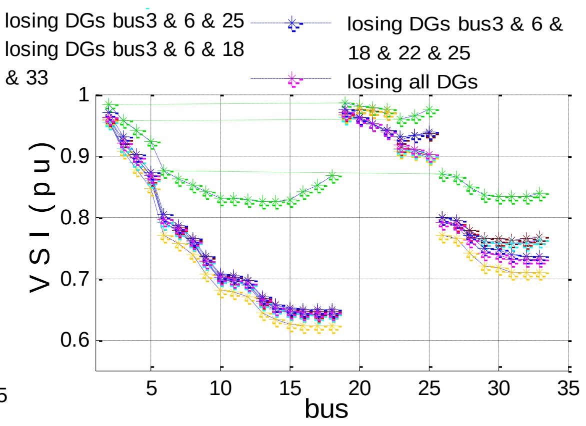


Figure 4.16: Voltage profile at the moment of losing of losing four, five or all DGs

Figure 4.17: Voltage stability index at the moment of losing four, five or all DGs

From the different simulated scenarios illustrated in figures (4.8 to 4.17), it is observed that the location of DGs, type of DGs and the numbers of lost DGs could affect the voltage service quality and stability, where the effects is deferent with the different disconnected units. In our case study losing DG connected to bus 18 have the high effect and the effect increase with disconnecting DGs number and power fluctuations.

Many studies on the optimal placement and sizing of DGs have been realized without considering the effect of losing DGs, however this effect should be considered in case of high level integration and must be integrated in the problems of optimization concerned integrating DGs in distribution network.

4.4. Transient stability problems in distribution network with presence of DGs

The ability of the network to re-establish steady-state operation, with large scale penetration of DGs, after submitting to disturbances is related to DGs withstand against these disturbances and to re-establish steady-state operation. for low penetration level, if a disturbance occurs on distribution network, DG trips and does not generate power until critical network conditions are removed. So, the control scheme of DG will wait to be restored and restart automatically. Nevertheless, if DGs is intended as a voltage support for critical Processes or power supplying support for remoted area then more care is required to try to ensure that DG does not trip for remote network faults [93]. islanded operation is not generally allowed for two major reasons [94] [95] [96]:

1-Restoring the outage circuits is complicated by having islanded generators; since automatic reclosing is generally used, switching requires synchronizing the islanded generator/load to the utility system.

2- In general, power quality cannot be always maintained within an acceptable level by the islanded generators, and this can result in damage to the customer equipment.

In contrast to large synchronous generators used in power system, distributed synchronous generators have usually standard characteristics such as small inertia constant (between 0.5 to 2 seconds), high reactance, short time constants, weak damping and simple automatic voltage regulators (AVRs**)** [97]**.** As the tripping time of protection system in the distribution is relatively long, it may not be possible to ensure stability for all faults in the distribution network.

4.5. Investigation on the transient stability of DGs

With the integration of DGs in distribution networks, the transient simulation of distribution networks become necessary function for the management, and security planning. a rapid dynamic simulation is needed to assess the DGS stability for preventive and emergency’s actions. such simulation is often difficult due to the large size of the distribution network with its radial topology.in this analyses studies the time domain simulation using individual transient function and torque – sleep characteristic for the transient stability assessment of SDGs and SCIGs.

4.5.1. Simulation approach in radial distribution network:

In radial distribution network, iterative techniques commonly used in transmission network power-flow studies are not used because of poor convergence characteristics. Instead, an iterative technique, buck word-forward sweep, specifically designed for a radial system is used. This technique could be used in linear systems where the loads are modeled by impedances, and nonlinear network where most of loads are assumed to be constant kw and kvar. For the ladder network it is assumed that all of the line impedances and load are known along with the voltage at the source. Details of the technique have been well explained in [85].

In order to realize our studies a simulations of transient stability have been carried out in matlab environment**.** Balanced three phase faults is considered and analyzed using an equivalent single phase circuit and the classical model of the synchronous generator. Therewith the following assumptions were considered. The synchronous machine (SM) is represented by a constant voltage magnitude(EMF) behind the synchronous reactance Xd’ and the mechanical power input is assumed to be constant. For such a representation only the swing equation is needed to describe the dynamics of a synchronous machine. The primary concern in the transient stability analysis is to verify the synchronism of the generator machines in a short period of time after the occurrence of a disturbance, during which the actions of the controllers do not have a significant effect. So the mechanical power is considered constant.

An approach Using back/forward sweep for transient stability simulation:

Back/forward sweep (BFS)method has advantages of easy programming, high computational efficiency and good convergence. The load buses are considered as PQ nodes where the load current used in BFS iteration is calculated as:

$$I = \left(\frac{S}{Vn}\right)^{*} \qquad 4.9$$

To simulate the dynamic of SDG, the angular velocity and The power angle between Induced EMF and the nod to be connected. Are evaluated where at each iteration the current at the SDG nod used in FBS iteration is calculated as:

$$\boldsymbol{I} = \left(\frac{\boldsymbol{Vn\angle\theta - EMF\angle\delta}}{\boldsymbol{Zeq\angle\emptyset}}\right) \qquad 4.\,10$$

Where:

Vn is the nod voltage and Zeq is single line impedance between EMF and terminal nod voltage including transformer impedance and connection line impedance

$$(Zeq = Xd' + Z_{TRF} + Z_L) \qquad 4.11$$

Transient stability assessment of induction generator using (BFS) simulation:

In contrast of Synchronous generator SCIG does not have self-excitation, where the delivered power and electromechanical torque is depended of the terminal connected voltage. The voltage of distribution network nodes cannot be considered as constant where deferent parameters could affect the nodes voltage as nod load variation, node generation, disturbances. The effect is more important in radial network shame and weak networks. Hence this effect should be token in consideration during the transient stability simulation of induction generators**.**

To simulate the dynamic of SCIG, the first order steady state equivalent circuit could be modified to be introduced in BFS simulation method, this approach gives the real terminal voltage during the dynamic simulation. using induction generator sleep (S) and parameters of the equivalent circuit to calculate the current at the IG nod used in FBS iteration.

The current used in BFS iteration is calculated as:

$$\boldsymbol{I} = \boldsymbol{Is} = \left(\frac{\boldsymbol{Vn}}{\boldsymbol{Zeq(s)}}\right) \qquad 4.12$$

Where: Vn is the nod voltage and Zeq (s) is single line equivalent impedance of IG with respect of the sleep(s) as presented in figure 4.18.

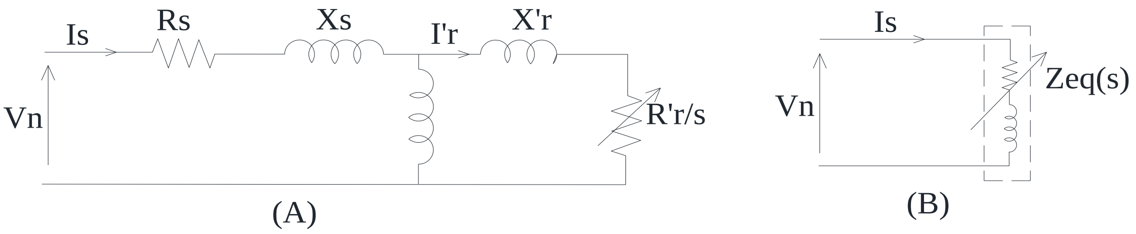


Figure 4.18: (A) Single line equivalent circuit of SCIG, (B) Equivalent impedance representing SCIG

Critical clearing time determination:

The electromagnetic torque and rotor motion equation of an IG are as

$$T_e = \frac{R'r}{s} T'_r{}^2 \quad ; \quad \frac{dw_r}{dt} = \frac{1}{2H_i} = T_e - T_m \qquad 4.13$$

Assuming unstable case (t>= CCT), for each dynamic simulation iteration during the short circuit fault we use the generator sleep to calculate Zeq(s) to be used in BFS iteration for determining the terminal voltge (Vn) and the generator torque $Te(Vn)$. CCT is determined when $Te(Vn) \leq Tm$ & $w(t) > w0$.

When the network includes several DGs of type SDG and IG the critical time of each unit could be determined using the same method where the time of disturbance should be high than of CCT of each DG (individual transient function is used for determining CCT of SDGs and torque/sleep characteristic to determine CCT of SCIGs).

4.5.2. Parameters and factors effecting Transient stability of distributed generation with presence of DGs:

Deferent factors could affect the network transient stability of GGs as emplacement of DGs, short circuit location, the operating regime as network reconfiguration, load change, DGs power generation and the influence of different types of DGs on others. investigating in this factors can give a solution for improving the transient stability of distribution network with presence of DGs.

4.5.2.1. Effect of installing new DGs on the transient stability of the DN with presence of DGs:

In this part we present the different parameters and factors should be considered when installing new DGs to prevent negative effect on the transient stability of DNs. the studies are carried out on a modified real radial distribution network located in Sicily (Italy). The single line diagram of the distribution system, without DGs, is presented in Figure 4.19.

The considered distribution network consists of two principal lines, 32 buses fed through a 132/20 kV transformer with rated power equal to ST=35MVA, Vcc= 13.18%, with total network load (real power only) during maximum demand is 4.38 MW of which line 1 takes 3.29 MW, and line 2, 1.09 MW. During the minimum demand period, total load is 1.39 MW, of which line 1 carries 0.89 MW and line 2, 0.50 MW. The distribution lines and the feeder are modelled as series connection of resistance and inductance and the loads are represented by constant power model (Tables 4 in Appendix A).

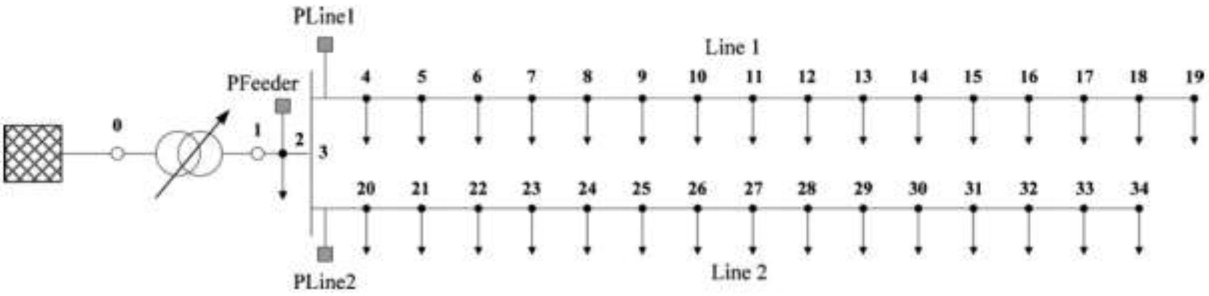


Figure 4.19: Real Italian distribution network. [93]

For the investigation, the bellow scenarios are considered:

- **Scenario1**: integrating new DG based on synchronous generator(SDG) in DN with presence of SDGs

Assuming that the distribution network (34-bus system) includes two DGS (SDG1 at node 19, SDG2 at nod 34, and a new synchronous DG (SDG3 or SDG1) will be integrated, three short circuit is supposed to be at the load connected at node 2. DGs parameters are presented in (Appendix B).

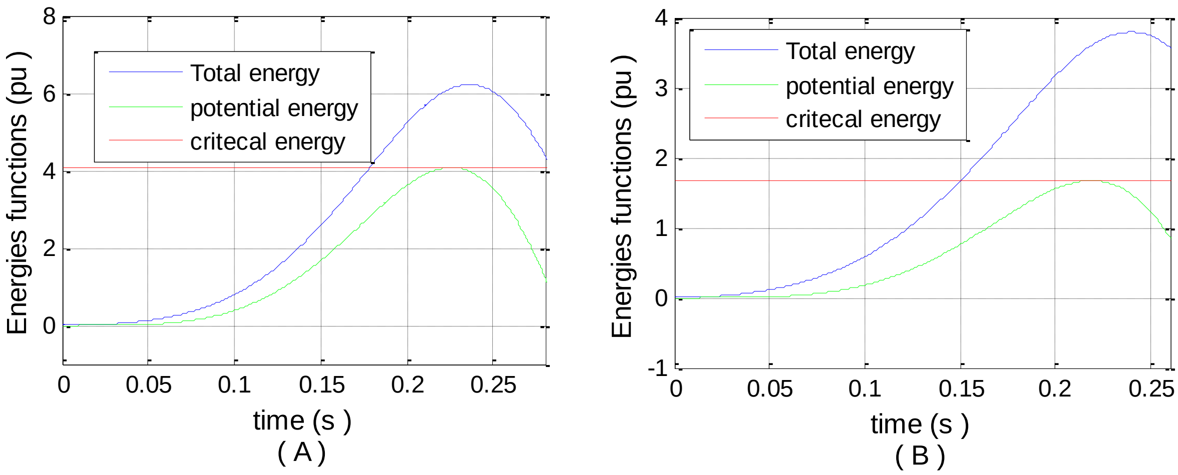


Figure 4.20:Transient Energies of SDGs before integrating the new one : (A) for SDG1,(B) for SDG2.

Operation time is generally needed to disconnecting unstable SDGs, this time rely on communication, computation program, security and protection control devices. The critical times of the generators is close together, hence the critical clearing time of SDGs is determined where assuming all the DGs still connected during the transient calculations.

Using hybrid individual transient energy function as clear in figure 4.20 we find the critical clearing time of the connected SDGs: CCT (SDG1) = 0.1785 s and CCT (SDG2) =0.1505 s.

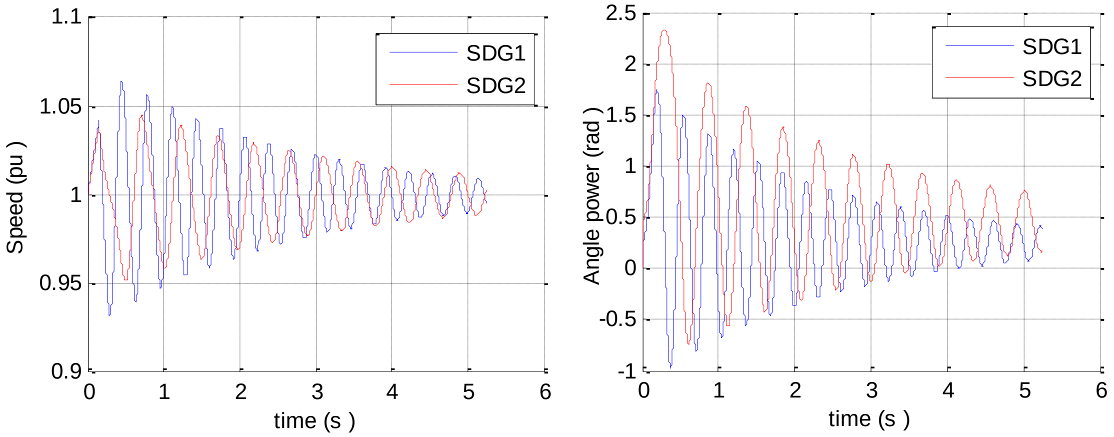


Figure 4.21: Rotor speed and power angle of SDG1 and SDG2 assuming that the disturbance is cleared at t=1.5s .

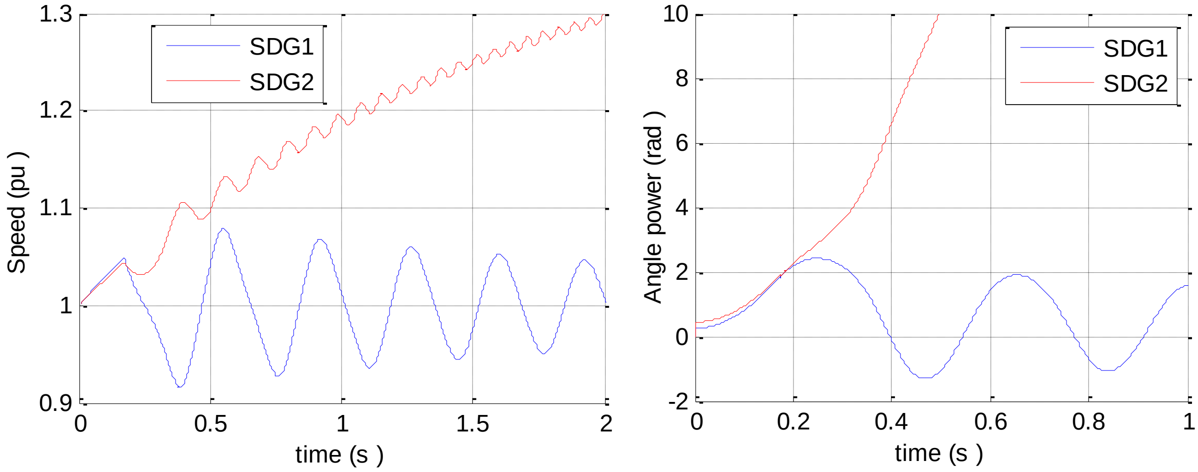


Figure 4.22: Rotor speed and power angle of SDG1 and SDG2 assuming that the disturbance is cleared at t=160ms.

As simulation of three phase short circuit is realized to verify the CCT determination considering self-clearing time after 150 ms and 160 ms, figure4.22 show that both SDGs still stable for clearing time of 150 ms while SDG2 lose synchronism for disturbance clearing time of 160 ms.

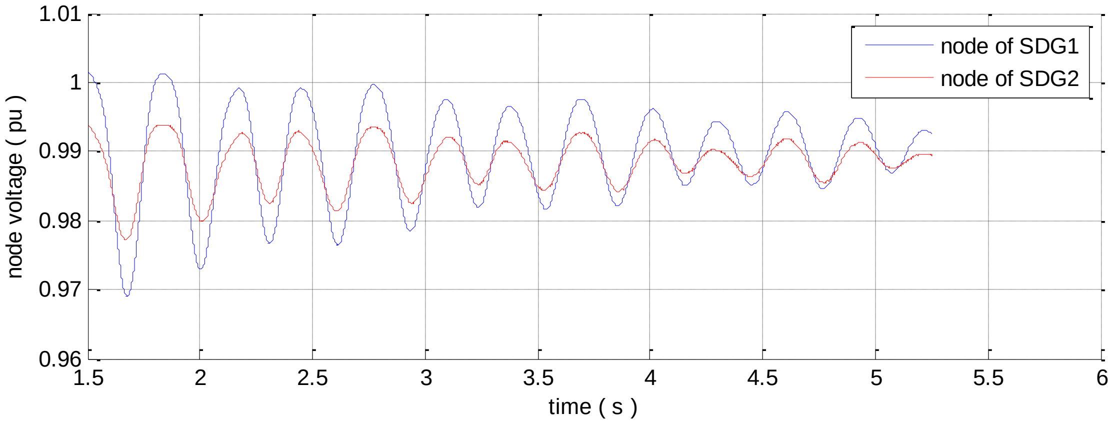


Figure 4.23:Transient Voltage of node connecting DGs for fault elimination time of 150ms

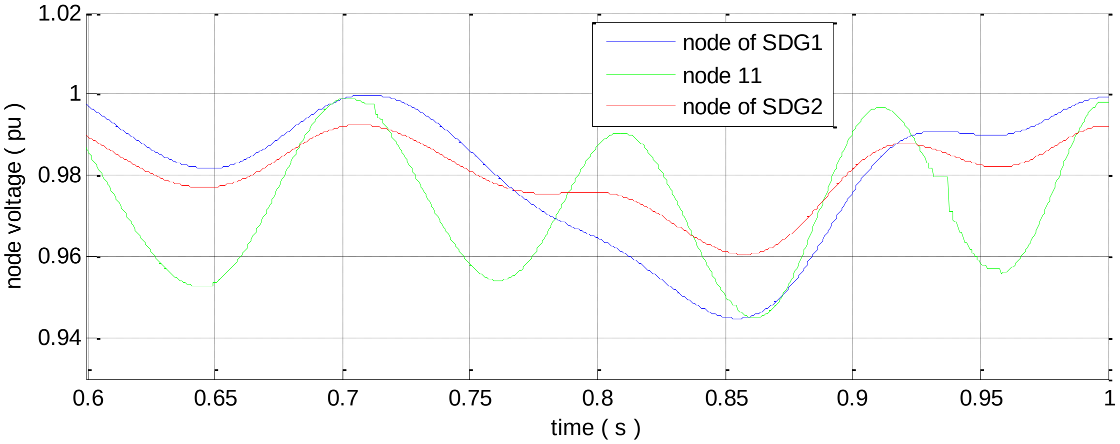


Figure 4.24:Transient Voltage of node connecting DGs for fault elimination time of 160ms

Integrating DGs in weak feeders for voltage or power support is one of the solution proposed by researchers, however beside the effect on the steady state voltage stability caused by losing DGS, the transient effect of DGs dynamic on nodes voltage after a disturbance could have a negative effect on the loads and the other DGs stability. The transient voltage after elimination the disturbance is shown in figure 4.23, when the SDGs still stable, and, figure 4.24 when one SDG lose its synchronism. The effected voltage will affect power generation and consumption where the effect is more important for weak networks.

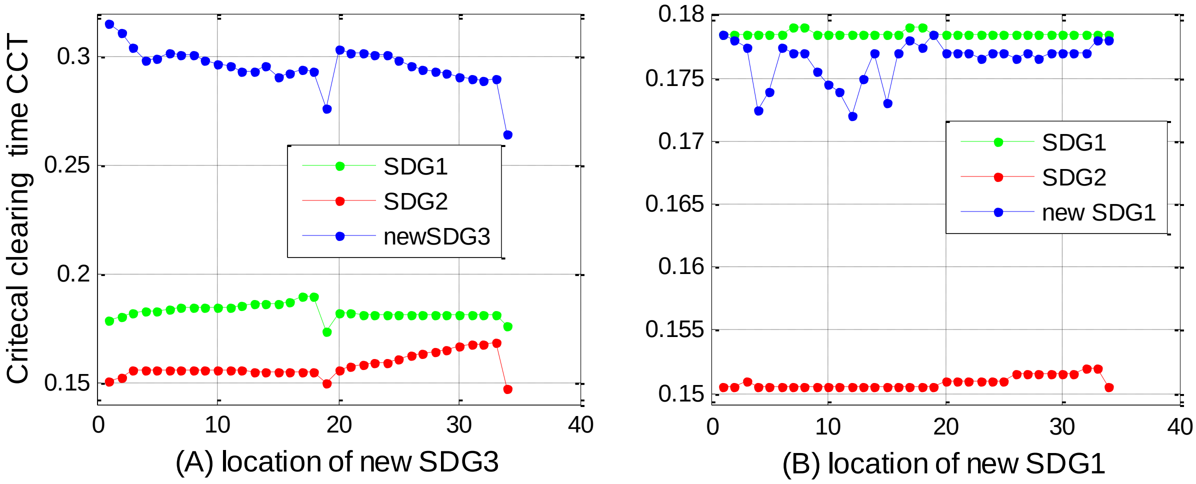


Figure 4.25: location Effect of integrating new SDG on CCT of SDGS :(A) integrated new SDG3, (B) integrated new SDG1

The graph in figure 4.25 confirms that Beside the effect of size of the new connected DG and its parameter as its inertia coefficient and its transient reactance (Xd') on its critical time and CCT of the others , the connected location of new SDG affect the critical clearing time of SDGs and the effect is more important when connecting SDG with high capacity.(A) show that connecting location of SDG3 have large effect on its CCT and the CCT of SDG1 and SDG2. (B) show that connecting location of new SDG1 have large effect on its CCT and small effect on CCT of the existed SDG1 and SDG2. The effect is due to the transient dynamic behavior of the new connected generators and the effect is depending of network topology, the connected SDGs, and the X/R ratio of the network lines.

- **Scenario2:** integrating new DG based on SCIG in DN with presence of SDGs

Assuming that the distribution network (34-bus system) includes three DGS (SDG1 at node 19, SDG2 at nod 10, and SDG1 at nod 34) and a new SCIG2 will be integrated. For the reason of the short circuit location effects on the transient stability of SCIG due to the direct relation between the electromagnetic torque and the terminal voltage of the induction generator we suppose that the short circuit is occurred at the nodes connecting DGs in order to investigate the effect of integrating SCIG on the CCT of the existed SDGs independently of short circuit location effect.

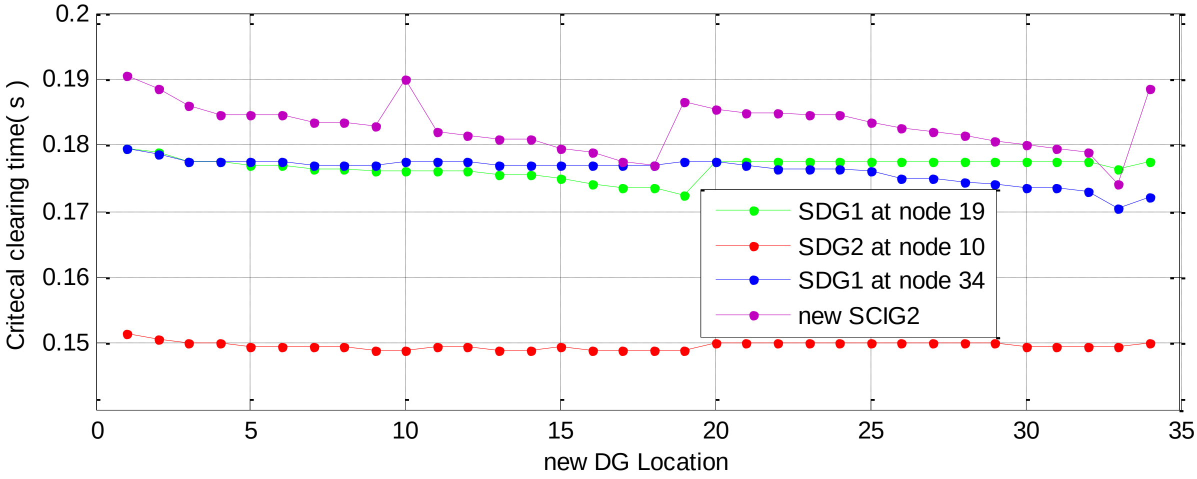


Figure4.26: location effect of installing new SCIG on CCT of SDGs

In contrast of synchronous generator, Squeal cage induction generator need to be excited throw the stator terminals, and the torque (delivered power) is directly related to the terminal voltage. For this raison the disturbance location, type of disturbance (short circuit fault or open circuit) on one phase, two phase or three phase are effecting differently the dynamic and the stability SCIGs. In this part we investigate the location effect of installing a new SCIG in distribution network with presence of synchronous generators where the dynamic effect of SCIG on the critical clearing time of three SDG placed at different place have been simulated as clear in figure 4.26. The result shows a small effect on the CCT of SDG at the different locations, because the short time disturbance (short circuit) without losing SCIG stability cause a small increasing of the generator speed leading to small increasing in reactive power consumption where its effect has been compensated by the increasing of generated power between the stable and unstable limits could be seen at the torque-sleep characteristic. The effect will be more important in weak feeders and on SDGs with high CCT if the instable SCIG will not quickly disconnected due to the increasing in their reactive power consumption. The simulation shows an effect of SCIG location on its CCT due to the effected terminal voltage at the connected node and the effect will be more important at week feeders.

- **Scenario3:** integrating new SDG in DN with presence of SCIGs

Considering the modified 33-bus test system that includes two SCIGs (SCIG1 at node 19, SCIG2 at nod 33 and a new SDG1 will be integrated. we suppose that the three phase short circuit is occurred at the nodes connecting DGs in order to investigate the location effect of integrating SDG on the CCT of the existed SCIGs independently of short circuit location effect.

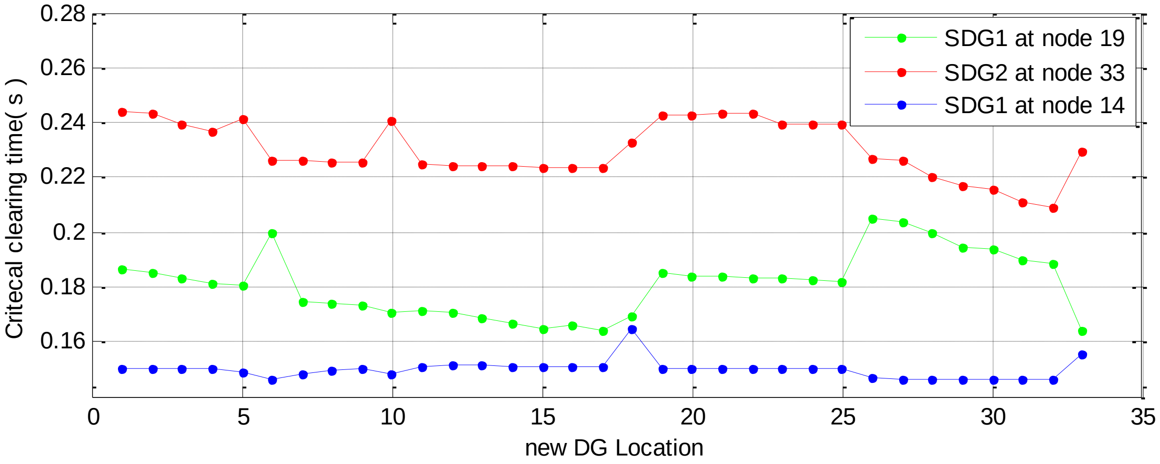


Figure 4.27: location effect of installing new SDG on CCT of SCIGs

It is evident that losing DGs affect the voltage profile in weak feeders which cause a decrease in the CCT of SCIG, if the feeder includes SDGs with small CCT the effect is more important due to dynamic effect of SDG on the voltage profile before its disconnection. The location effect of installing new SDG on the CCT of existed SCIGs have been simulated on the modified 33-bus test system where the results presented in figure 4.27 show a difference of 40 ms, this impact confirm the need to take into a count the effect to install new DGs.

4.5.2.2. Effect of losing DGs during disturbance on the transient stability of the other DGs:

For analyzing the power change effect, during the disturbance, on CCT of SDGs we consider the case where SDG1 is connected to node 19 and SDG1 is connected to node 34. The effect of location and level of power change have been simulated and analyzed.

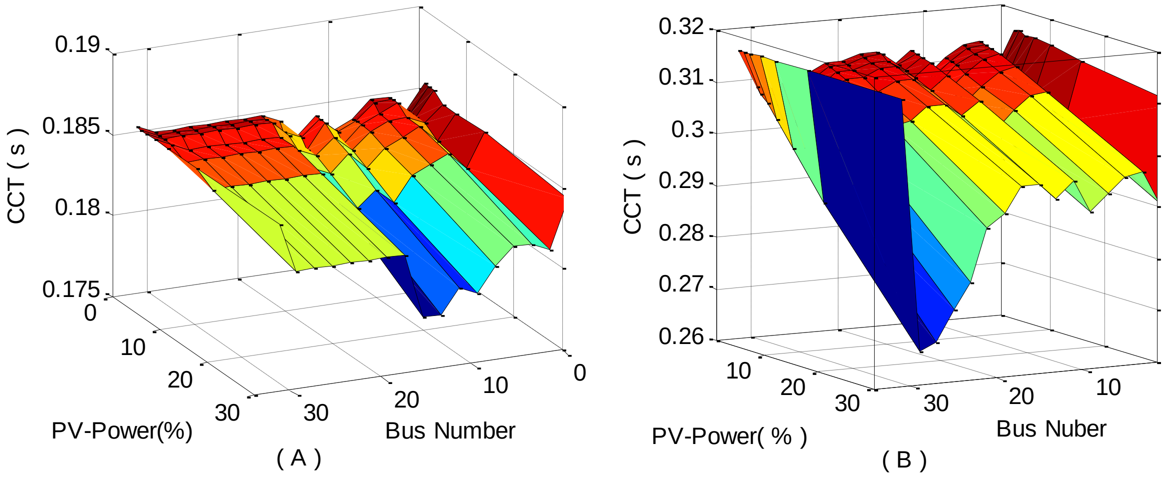


Figure 4.28: Effect of power change during the disturbance on CCT of SDGs: (A) CCT of SDG1, (B) CCT of SDG3,

The power change could be caused by losing generators or increasing loads, in this analyses we consider that a generated power debited by system without inertia, as example photovoltaic generation, will be decreased after 100 ms of the disturbance, Figure 4.28. Show that the location and decreasing in generated power effect the CCT of SDGs, the graph in (A) illustrate the effect on CCT of SDG1 and (B) CCT of SDG3. The effect is more important on CCT of SDG3 due to its high CCT which make it subject to the power change disturbance for long time before losing stability compared to SDG1 (from 100 ms till CCT).

4.5.3. Transient Stability Analysis of Radial Micro-Grid Subsequent to Fault-Triggered Islanding

A micro-grid typically consists of DGs, energy storage units, and distributed loads that may operate in grid-connected mode or in island mode. system stability in the case of disturbances or sudden changes are the main concern for micro-grid operation. In grid-connected mode, both the frequency and voltage magnitude are mainly determined by the main grid. In island mode, frequency and voltage magnitude at all locations within the micro-grid have to be maintained at acceptable limits. Micro-grids stability is depending on the system's proper design and control. In this part of work, we investigate the impact of DGs location and power generation during the connected mode on the Large-Signal stability of micro-grid Subsequent to Fault-Triggered Islanding Incident. we consider a micro grid constitute from conventional synchronous generators(SGs). The SGs are capable of injecting the kinetic potential energy preserved in their rotating parts to the power grid in the case of disturbances However the small size of DGs provide less inertia and damping than conventional SGs used in power system. Hence, they are unable to maintain of system stability for large disturbances.

Micro-grid has become a popular way to integrate DGs to the grid in low and medium voltage distribution networks. A typical micro-grid system includes a small gas turbine, wind turbine, photovoltaic arrays, energy storage system, and different kinds of loads. There are two kinds of islanded micro-grids, SG-dominated islanded micro-grid and DG-dominated islanded micro-grid. this study focuses on the transient stability of SG-dominated islanded micro-grid.

The researches on transient stability of grid connected Micro-grid are mainly about the dynamic response of different DGs during large disturbances and transient process simulations of Micro-grid when subjecting to faults. While for the islanded Micro-grid, the transient stability analyses are mainly focused on the fault current and transient process simulations [98].

The transition from the grid-connected mode to autonomous operation subsequent to a transient grid is the main challenge, where the micro-grids are more vulnerable to lose stability even with typical fault clearance timings. The aim of this part of work is analyzing the impact of some parameters and factors on the stability of the system during the transition and investigating on using optimization method for improving the stability.

4.5.3.1. Modeling and Simulation of Micro-grid

Traditional power systems based on synchronous generators have a distinct difference in time constants between the frequency and voltage regulation, with turbines (T=10 s) and governors (T=1 s) operating on a much higher time scales than the exciter (T=50 ms). systems dynamics is well described through time scale separation illustrated in 4.29 [99] .The transient stability of micro grid subsequent to large disturbance is evaluated at the first swing. For the case of changing to islanded mode the voltage and power control have a great effect on maintaining system stability. In this analyses study we consider only the voltage control because the response time of power control is grate than the voltage control.

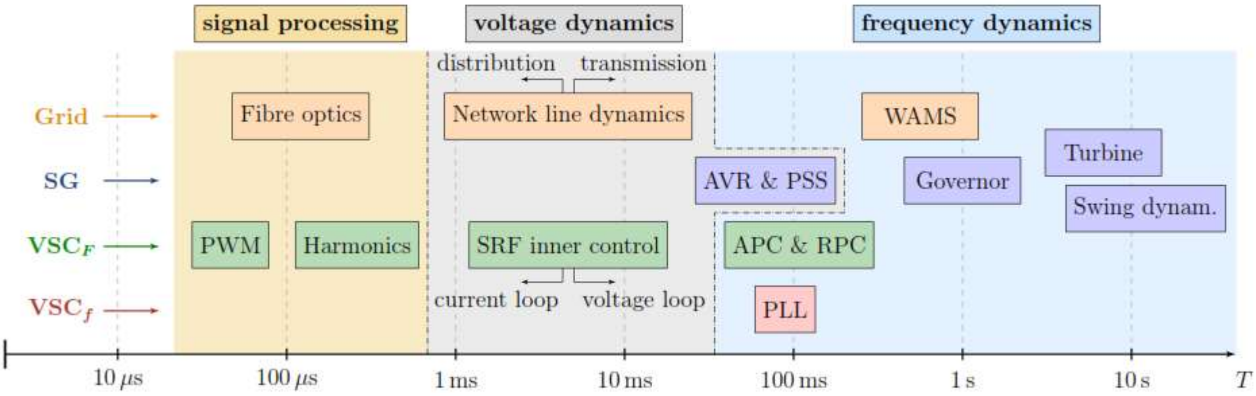


Figure 4.29: Timescale separation between different physical and control dynamics in a low inertia system

4.5.3.2. Control strategy

Control During Grid Connected Mode: During grid connected mode the objective of the synchronous machine controller is to control constant output power. Since the frequency is determined by the grid and is held stiff, the rotor speed is constant. As a result, the power output depends directly on the torque exerted by the prime mover on the shaft. Thus the mode of operations is referred to as Constant Power Mode.

Control During Islanded Mode: During islanded mode, the objective is to ensure that the required amount of power is delivered at the nominal voltage and frequency. Generally, two type of control are used During Islanded Mode (Droop control and master slave control) in this investigation the master slave control has been used where the generator with higher capacity is considered as the master.

The transient stability subsequent to large disturbances are evaluated at the first swing, for that only the systems with small response time are considered in the system modeling as the voltage control and reactive power control.

The IEEE Type-I system is The simplified model of the excitation system most used in dynamic analyzes which has an exciter function of the first order, a first order of amplifier function, corrector function and a stabilization loop which improves the stability of the system. the excitation system model is presented blow in figure 4.30 and 4.31. [22].

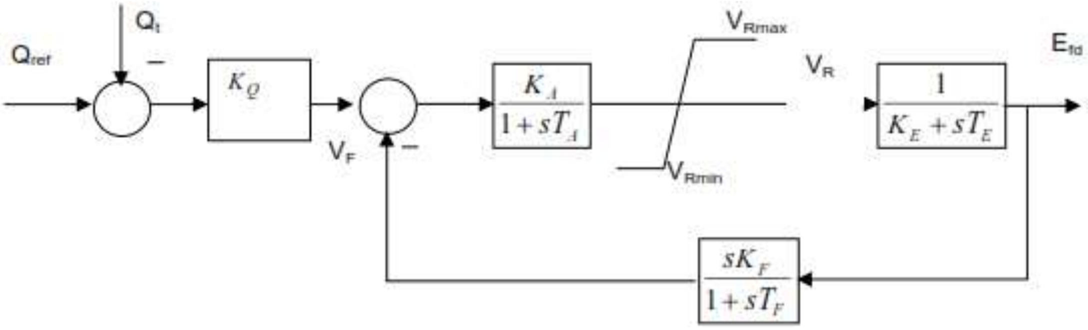


Figure 4.30: Reactive power regulator model

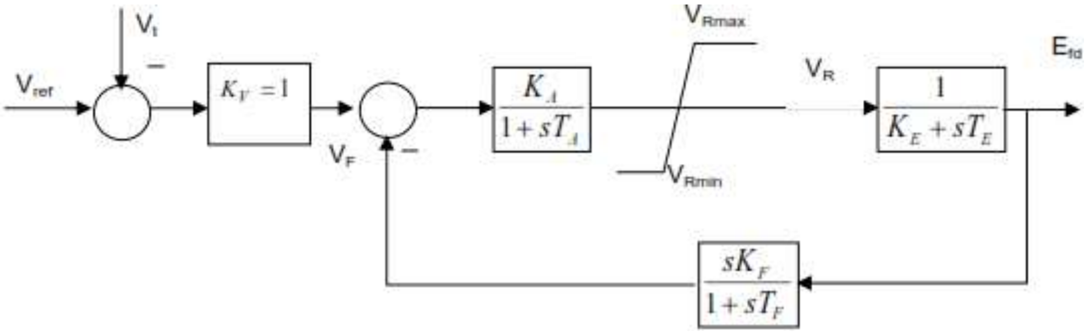


Figure 4.31: Automatic voltage regulator

The state space representation of the regulation system is given by Eqs. 4.14 and 4.15, where E_{Fd} is the field voltage. K_F, T_F are the self / separately excited gain and stabilizer time constant. K_A, T_A are the amplifier gain and time constant. The VAR parameter used in this simulation are presented in table 4.17.

$$\begin{bmatrix} \dot{V}_F \\ \dot{V}_R \\ \dot{E}_{fd} \end{bmatrix} = \begin{bmatrix} -1/T_F & K_F/(T_E T_F) & K_E K_F/(T_E T_F) \\ K_A/T_A & -1/T_A & 0 \\ 0 & 1/T_E & -K_E/T_E \end{bmatrix} \begin{bmatrix} V_F \\ V_R \\ E_{fd} \end{bmatrix} + \begin{bmatrix} 0 \\ K_A/T_A \\ 0 \end{bmatrix} \Delta Vt \qquad 4.14$$

$$E_{fd} = \begin{bmatrix} 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} V_F \\ V_R \\ E_{fd} \end{bmatrix} \qquad 4.15$$

Where:

ΔVt= $K_Q(Q_{ref} - Q_t)$ for reactive power regulator using automatic voltage regulator

ΔVt= $K_V(V_{ref} - V_t)$ for automatic voltage regulator

Voltage regulator	gain Time constant	300 0.02 S
Exciter	gain Time constant	1 0.8 S
Damping filter	gain Time constant	0.03 1 S
Output limit	Upper Lower	3 pu 0 pu

Table 4-14: Voltage Regulator parameters [100]

One-axis model of synchronous machine is used in for the simulation, the representation of the electrical model is given in the following equation Eq. 4.17 [101].

$$\boldsymbol{T'_{d0}} \frac{\boldsymbol{d\acute{E}_q}}{\boldsymbol{dt}} - \boldsymbol{\acute{E}_q} - (X_d - \boldsymbol{X'_d}) I_d + E_{fd} \qquad 4.16$$

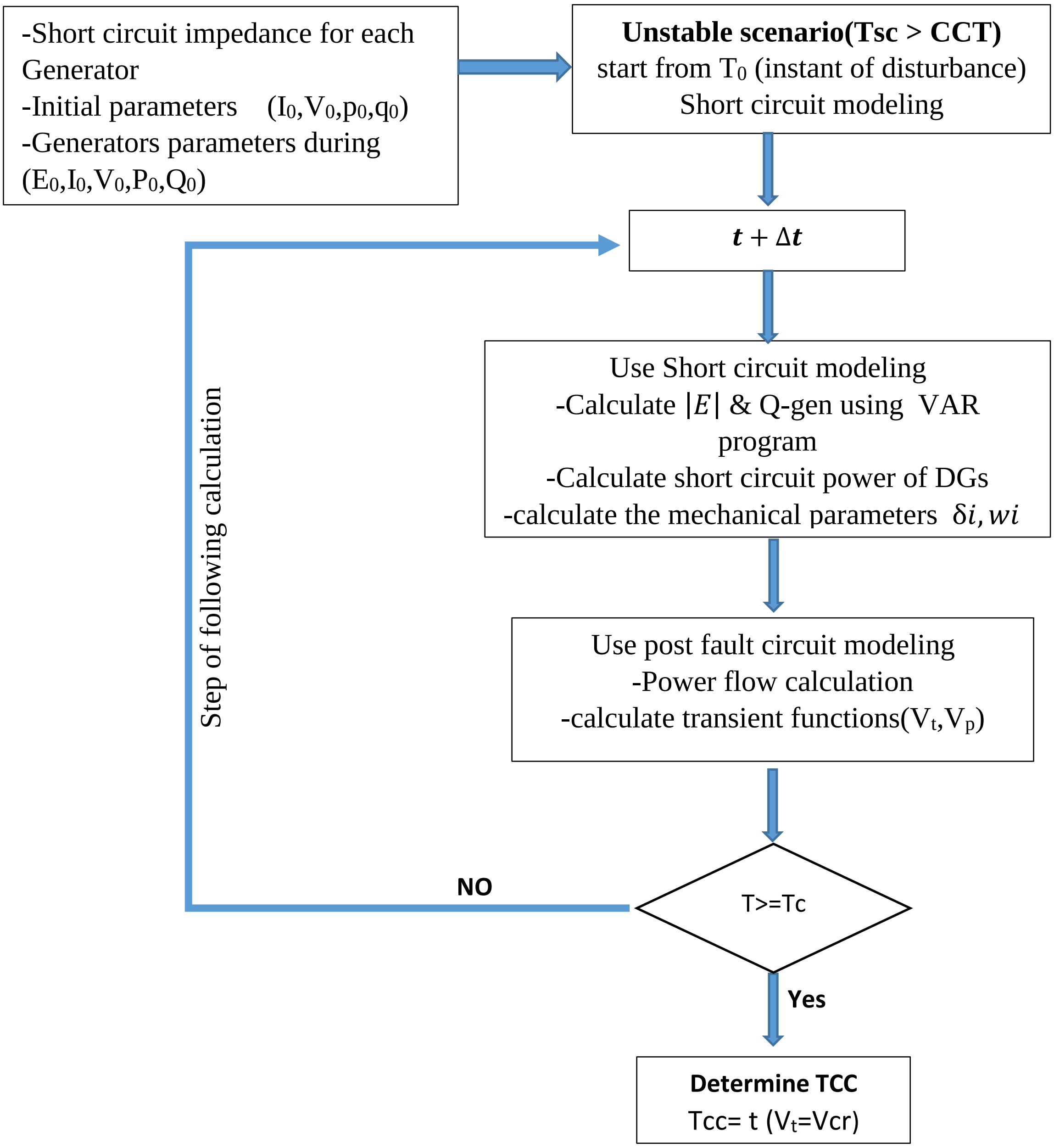
4.5.3.3. Simulation method of micro-grid after Islanding:

This work aims to model Microg-rids for study their transient responses subsequent to fault-triggered islanding.

- a single line network representation and equivalent transient FEM with series transient impedance for the generators have been used to calculate the power flow and generated power using buck ward forward sweep.

- During the integrated mode all the parameters of the micro grid are referred to the Point of Common Coupling (PCC) bus 1, where the buses and lines parameters are in per unit value, voltages of bus1 is “V1=1pu”. In the islanded mode, for applying the buck ward forward sweep to calculate the power flow, all the parameters are referred to the Fem of one DGs (in this study we conceder the master generator as the reference voltage Fem (DGs1) =1pu.

4.5.3.4. Simulation Algorithm:



4.5.3.5. Simulation and analyses:

The 33-bus radial network have been used in this study, for all the simulation SDG3 is considered connected at the PCC node 1, DSG2 is connected at nod 18 and DSG1 is connected at node 33.

Initial Parameters during the connected mode:

- Total load is P=3 pu ;
- DSG3: P=1.25 pu ; Q=0.1pu ;
- DSG2: P=1 pu ; Q=0.1 pu ;
- DSG1: P=0.75 pu ; Q=0.1 pu ;
- $(V_{ref=}1pu,$ for Automatic voltage regulator of DSG3.
- $Q_{ref1}, = 0.25\ pu, Q_{ref2} = 0.3$ pu for reactive power regulators.

- **Simulation of the micro-grid after disconnection without disturbances:**

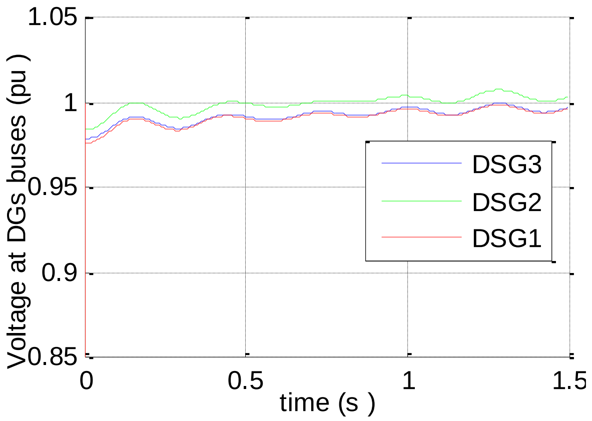


Figure 4.32:Transient voltage after islanding

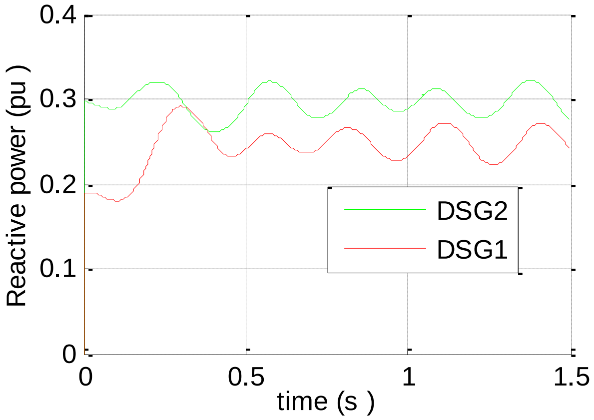


Figure 4.33:Reactive power injection after islanding

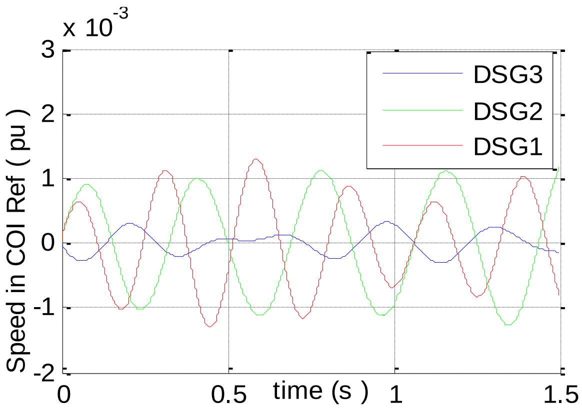


Figure 4.34: DGs speeds after islanding in COI reference

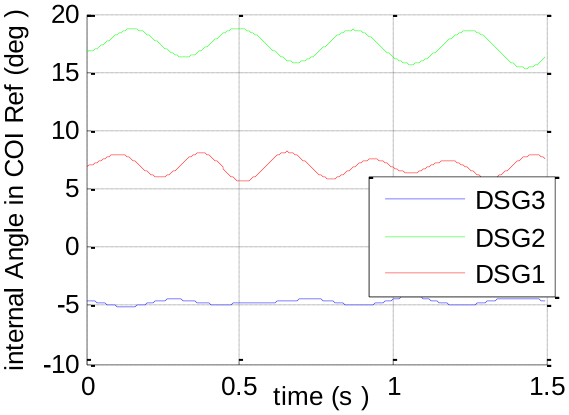


Figure 4.35: DGs angles after islanding in COI reference

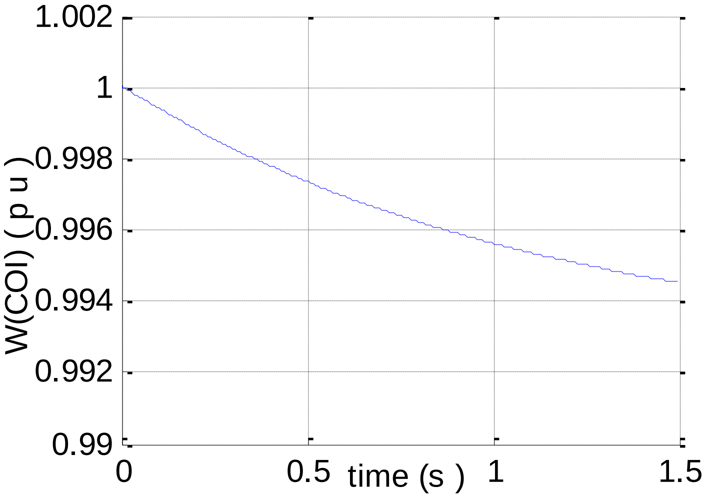


Figure 4.36:COI speed after islanding

In this case the we simulated and analyzed the scenario of micro-grid disconnection from the main grid without disturbance event, the figures from 4.32 to 4.35 show that the system with VAR control is remain stable where the mechanical power is considered constant and the loads are supposed as constant impedance during the transient simulation. the simulation of speed and the rotors angles of DSGs is referred to the center of inertia. figures do not show a large perturbation of DGs speeds and angles due to the small difference between the generated power from DGs and load power before and after disconnection. Figure 4.36 give an image of the frequency variation compared to the main frequency.

- **Simulation of the micro-grid after disconnection with disturbances:**

In this part to scenarios (stable und unstable) have been simulated considering a three phase short circuit disturbance occurred at the at the Point of Common Coupling (node 1).

- **Stable scenario:**

The simulation illustrates the dynamic behavior of DGs after the disturbance event at t=0s.The micro- grid is disconnected from the main grid at t=125ms and the disturbance is considered to be at main grid side and cleared from the micro-grid side at the same time of disconnection.

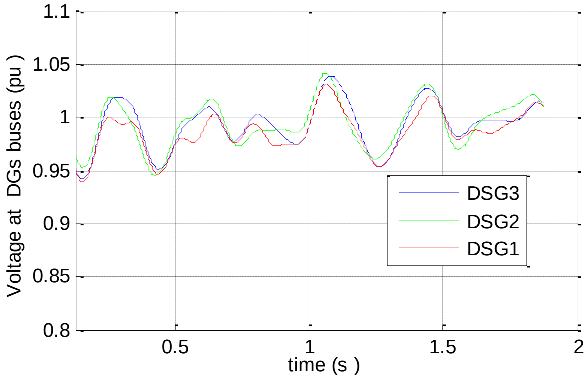


Figure 4.37:Transient voltage after islanding

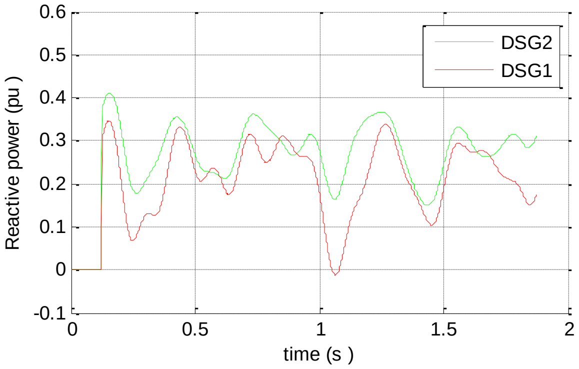


Figure 4.38:Reactive power injection after islanding

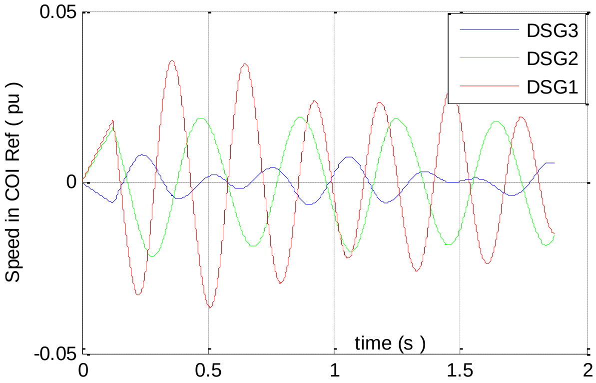


Figure 4.39:DGs speeds after islanding in COI reference

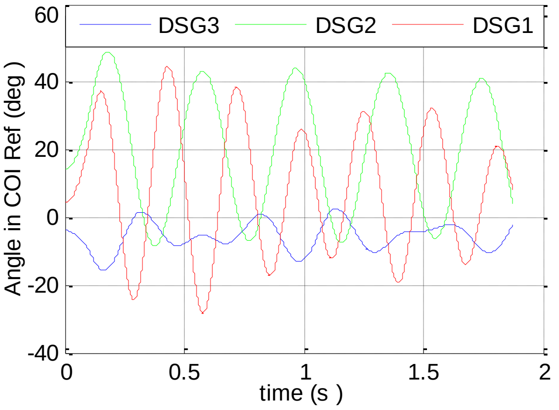


Figure 4.40:DGs angles after islanding in COI reference

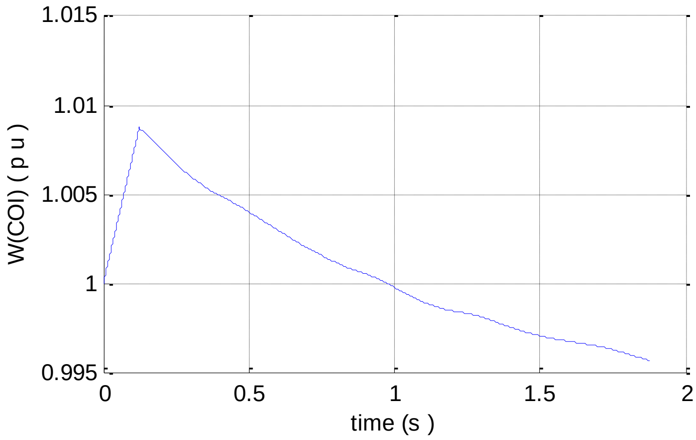


Figure 4.41:COI speed after islanding

Figure 4.37 show the voltage of nodes connecting DGs and DGs reactive power after the disconnection from the main grid, the figure show that the voltages of the node does not violate the allowable limits (∓5%) .the voltages are osculating around the equilibrium point. The perturbation of the nodes voltages has effect the reactive power injected by the distributed generations as it is cleared in figure 4.38. the VAR control the reactive power to the reference powers 0.3pu and 0.25pu of SDG2 and SDG1respectively. Figure 4.39 and figure 4.40 represent respectively the speeds and rotors angles of DGs in the COI reference describing the synchronization of DGs in the islanded mode, they are show that the system is remain stable in term of DGs synchronization. From the speed of center of inertia illustrated in figure4.41 we find that the image of the frequency have a variation in allowable limits (∓2%) .

Unstable scenario:

In this scenario we suppose that The micro- grid will be disconnected from the main grid at t=230ms after disturbance occurrence at t=0.0s.

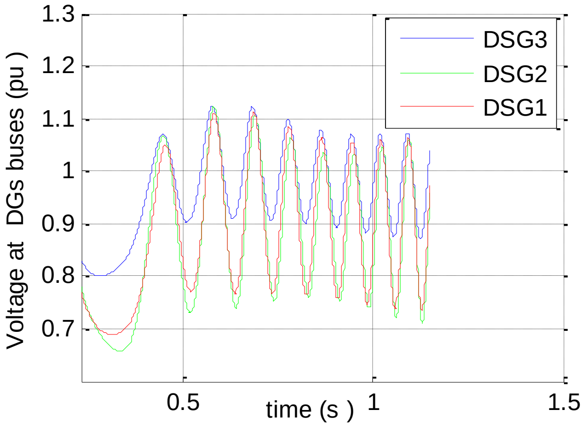


Figure 4.42:Transient voltage after islanding

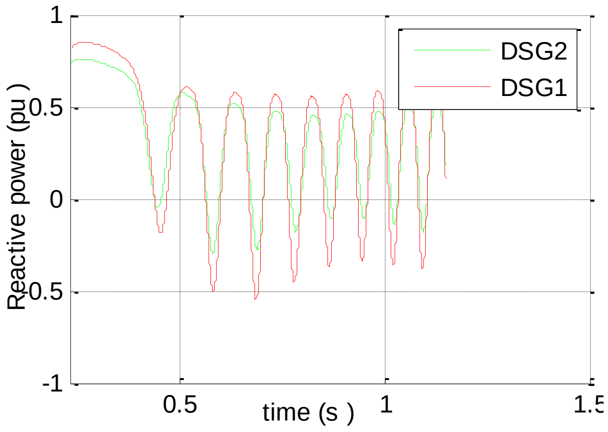


Figure 4.43:Reactive power injection after islanding

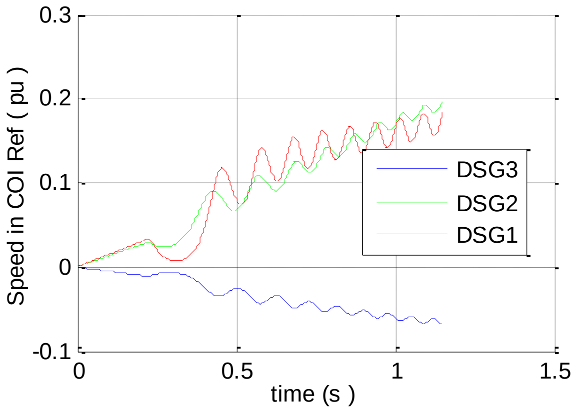


Figure 4.44:DGs speeds after islanding in COI reference

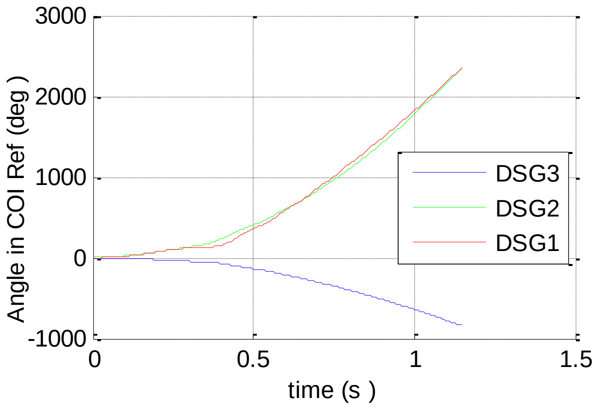


Figure 4.45:DGs angles after islanding in COI reference

For a clearing time of 230 ms (time before turning to islanding mode without disturbance at the micro-grid side), the micro-grid loses the synchronism between the DGs, and the voltage and reactive power are no longer controlled as it is clear in figure 4.42 and figure 4.43. The dynamic behavior of DSGs represented by the variation of speeds and rotors angles of DGs in the COI reference are presented in figure 4.44 and figure 4.45 respectively.

4.5.3.6. Impact of DGs Location and power generation during the connected mode on CCT of micro- grid after islanding

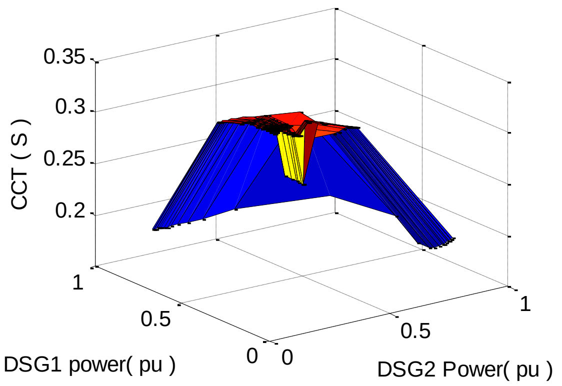


Figure 4.46: Impact of DSGs power during connected mode on CCT of micro-grid

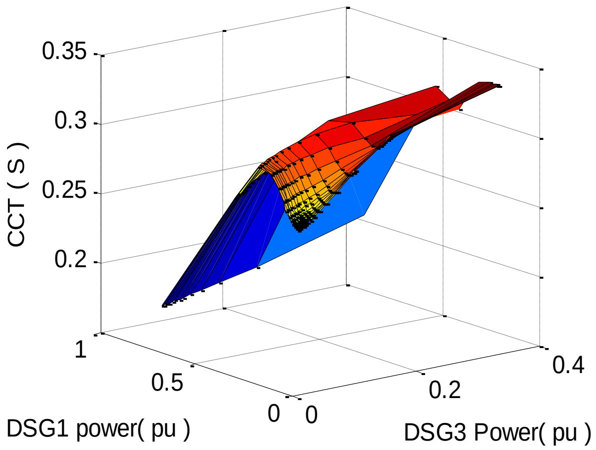


Figure 4.47:Impact of DSGs power during connected mode on CCT of micro-grid

The mash plot in figure 4.46 and figure 4.47 show the impact of the DSGs generation power at the steady state, where the micro-grid is in connected mode, on the critical clearing time of micro grid after islanding subsequent to a disturbance. To ignore the effect of short circuit impedances effect in our simulation we suppose a disturbance of three phase short circuit at each node connecting the DGs.

Figure 4.46 represent the impact of the generated power from DSG1and DSG12 at the connected mode before disturbance occurrence, where DSG1 is connected at node 33 and DSG2 at node 18. In this simulation DSG3 is assumed generate a power 1.25 pu. It is clear from the figure that the generated power of both DSGs have a considerable effect on the stability of the micro-grid defining by its critical clearing time(TCC).

The same investigation is realized considering that DSG2 generate a power 0.5pu and simulate the impact of power level generation from DSG 1 and DSG3 as it is clear in figure 4.47. Compared to figure 4.46 the impact of DSG1 is more important than the others.

In this case of simulation, we note that the critical time Subsequent to fault-triggered islanding incident decrease with respect of power generation level of DGs in figure 4.46 and increase with power generation of DSG3 in figure 4.47. these effects are tied to the generators inertia.

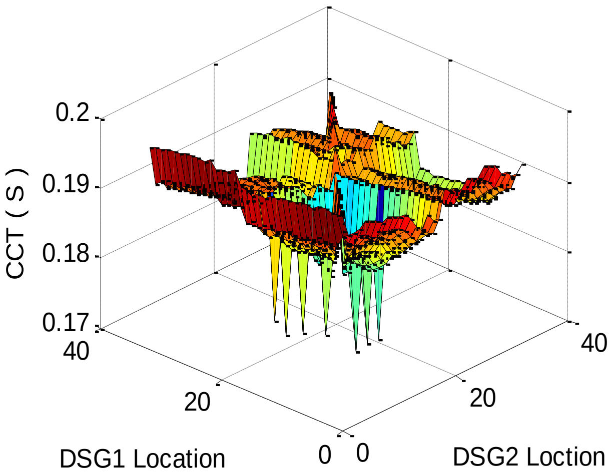


Figure 4.48: Impact of DSGs location on CCT of micro-grid after islanding

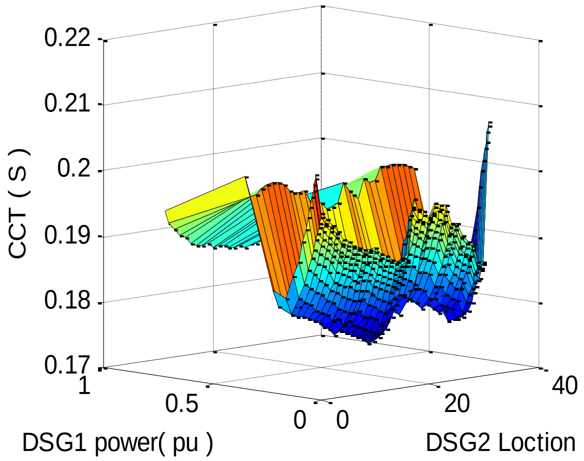


Figure 4.49:Impact of DG1power and DG2 location on CCT of micro-grid after islanding

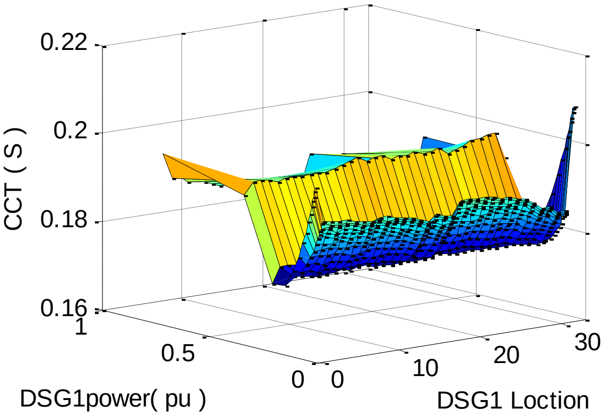


Figure 4.50: Impact of power and location of DG1 on CCT of micro-grid after islanding

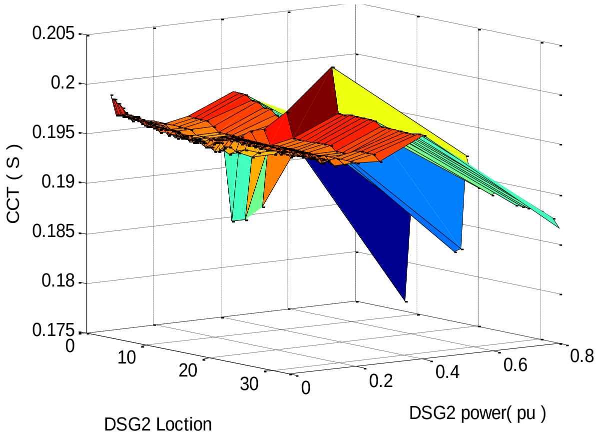


Figure 4.51: Impact of power and location of DSG2 on CCT of micro-grid after islanding

Beside the impact of power generation, the impact of DGs location have been considered in this part. The location impact of DSG1 and DSG2, with nominal power generation, are presented in figure 4.48, we note that the locations have also an important impact on the system stability.

Figure 4.49 shows the effect of DSG1 power and DSG2 location on the CCT of the micro-grid, where DSG1 is connected to node 33 and DSG2 generate its nominal power. From the mesh plot we note a different impact compared with the others cases.

Figure 4.50 and figure 4.51 show respectively the impact of location and power generation of DSG1, where DSG2 connected at node 33, and DSG2, where DSG1 connected at node 18. The mesh plot in this figure present a different effect compared to the others cases.

We conclude from this different cases of simulation that the DGs power generations and locations effect the transient stability of the micro-grid subsequent to fault triggered islanding. the impact could increase or decrease the disturbance critical clearing time of the islanded micro-grid more than 100 ms. This impact should be considered at the system design and Management. In this thesis we investigate the possibility of selecting the optimal locations and power sharing of SDGs in order to enhance the network steady state parameters and improve the transient stability of the micro-grid after the disturbance clearing and turning to islanded mode.

4.6. Optimal placement and power management of DGs in radial distribution network for transient and steady state enhancement using genetic algorithm (SPEA)

Beside the service quality and the steady state stability of distribution network, the service Continuity (network reliability) suit to a disturbance is always the wish of the network managers. losing distributed generation units due to a disturbance probably causes a technical problem which could have an important effect on the total system.

The objectives of integrating DGs in distribution network is diverse as power lost reduction, quality enhancement, voltage stability improvement, power or voltage support, network reliability…etc. one of the main interest is to ensure the continuity of the energy supplied by DGs units and their contribution to the system service. For properly benefit from DGs optimization studies is generally required. In This part investigation on optimization study is carried out for improvement of both the steady state parameters and the transient stability of distribution network with presence of DGs. In this study, the Strength pareto evolutionary algorithm (SPEA), a genetic algorithm, have been used for the optimization. the optimization could be even used in planning and designing the distribution network or preventive actions for system quality, reliability and stability management.

4.6.1. Problem formulation

As presented before the location and type and size of DGs effect the steady state parameters and the transient stability of the network. In this part The optimization problem is formulated to improve the voltage stability of the distribution network and reducing power loss with improvement in the critical clearing time of the integrated DGs by optimally designing and management of the system, considering the location, number and types of DGs, using (SPEA Algorithm). The constraints of the proposed problem include voltage limits at each bus, current limits of the feeders and DG capacity limits.

Objective Function: The minimum node voltage stability index (SI) , active power loss (PL) and critical clearing time (CCT)is considered as an objective function in this investigation.
Introducing CCT index in SPEA algorithm:

SPEA parameters:

The of the genetic algorithm, SPEA parameters selected for optimization are Population size (N=10), recombination probability (Pr=0.8) and mutation probability (Pm=0.03). The GA is set to stop when 150 iterations are evaluated.

In this study different cases have been analyzed depending on the number and type of DGs to be installed.

4.6.2. Optimal placement and power generation of DGs:

It is clear from the power-angle curve that the generated power of the synchronous generator at stable point during the steady state have the important effect on the CCT. Selecting optimal placement of SDG is needed for the network designing while finding optimal placement and power generation could be used for preventive actions and network reconfiguration.
one of the most used methods for transient stability improvement is to modify the power supplied from the generators and network reconfiguration. Different methods could be configured to have optimal solution, the CCT index is introduced in the SPEA algorithm according to the degree of severity suit to a DG instability, CCT could be introduced as a constraint relied to the network security or as a parameter to be improved. In this study we interested on voltage stability enhancement, active power loss reduction and critical clearing time improvement.

Two cases have been investigated in this study: optimal placement and power generation of one SDG, optimal power generation of multi-DGs. For the investigation The generated active power of DG represented by (AP) and the generated reactive power represented by (RP). These parameters are respectively defined as the ratio of the active power and reactive power generation from DG to the nominal power of DG.

- **Selecting optimal placement and power generation of one SDG:**

the simulations have been carried out in MATLAB environment**.**

The first case considers only one connected SDG type. We applied ASPEA algorithm on 119 bus system to select optimal solutions enhancing steady state voltage stability, power loss reduction as well as incising the critical clearing time. considering a modified state of charge which gives the voltage profile and stability index shown in figure 4.29. and figure 4.30 from the graphs, we can select the area effected by the change of load state to reduce time of simulation, in our case the feeder from the node 66 to 104 is the considered area.

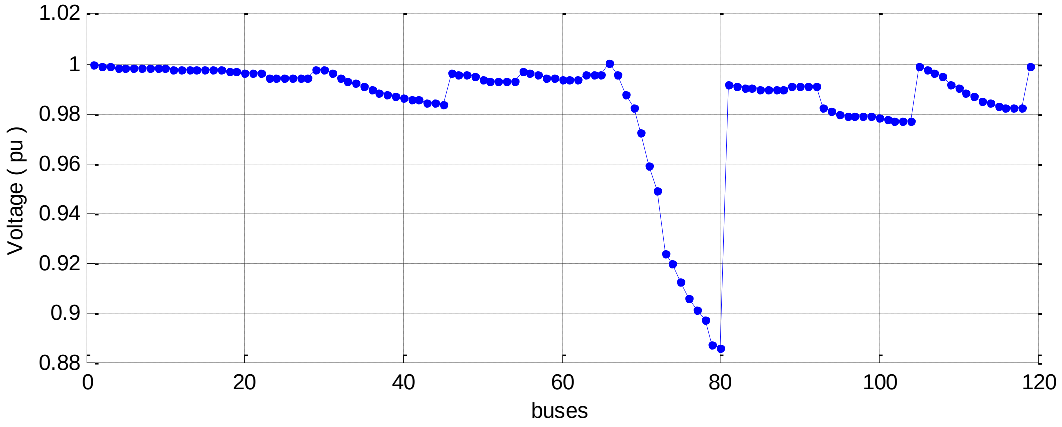


Figure 4.52: Voltage profile before integrating DG

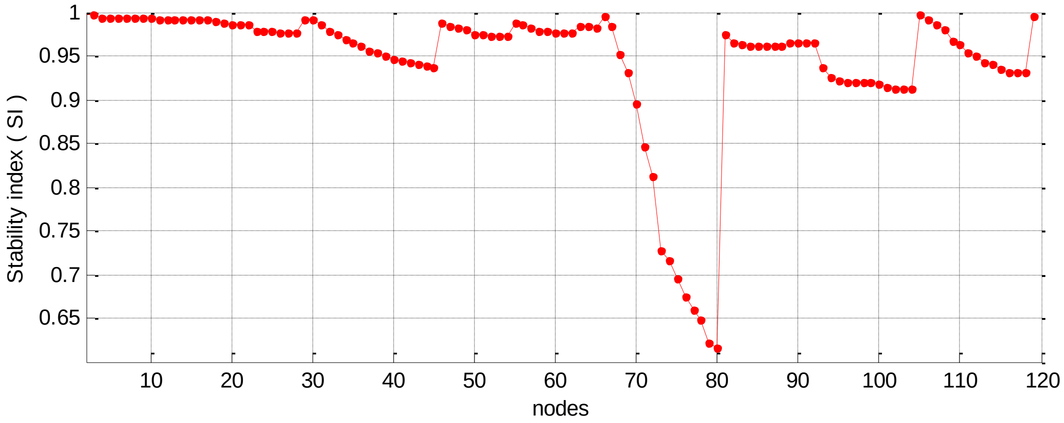


Figure 4.53: Stability index of each node before integrating DG

We supposed a case of increasing power at the feeder from bus 66 to 104. The voltage profile and voltage stability index presented in figure 4.52 and 4.53 illustrate a voltage drop problem at the feeder and a decrease in the voltage stability index. In this part SPEA have been used to find optimal placement and power generation of integrating synchronous distributed generation (SDG3), using SPEA have been realized.

Optimal location	Optimal power		Stability Index	Power loss (KW)	CCT (s)
	AP(%)	RP(%)			
79	79.372	11.437	0.86189	245.98	0.29
79	61.12	17.08	0.82432	323.14	0.354
79	77.5	7.72	0.85259	254.58	0.29
79	73.66	9.16	0.84503	268.6	0.31
79	71.08	23.16	0.85621	278.74	0.348
79	77.48	20.28	0.86839	252.48	0.32
79	78.76	12.2	0.86135	247.92	0.294
79	78.64	8.7	0.85662	249.83	0.288

Table 4-15:optimal locations and power generation of SDG

Considering a short circuit at the SDG connected node, The optimal selected solutions are presented in table 4.15, SPEA gives a no dominated solution. Where a solution x dominates a solution xx when all the objective functions of candidate x is best then of the candidate xx.

The result in the table show the candidate present enhancement in the stability index with difference at the range from 0.82432 to 0.86839 and power loss from 245.98 kva to 323.14 for critical clearing time of the SDG from 0.29s to 0.354 s.

Using the same selected location (bus 79) for integrating the SDG at its nominal power and unit power factors gives the objective function as: CCT=0.266 s and power loss = 251.68 kw, SI=0.812 . compared to the selected optimal candidate, we find that the SPEA gives different solutions with different enhancement in the objective functions. The solutions are with acceptable steady state enhancement as well as an increasing in the critical clearing time of the SDG or with acceptable CCT and good enhancement in the steady state parameters.

As the state of network load is a daily varying, the optimal candidate is depending of state of load. If we need a candidate with a required minimum of the critical clearing time, a constraint on the CCT mast be made in the algorithm. The optimal location and generated power could be used for power management as well as network reconfiguration for security and improvement objective.

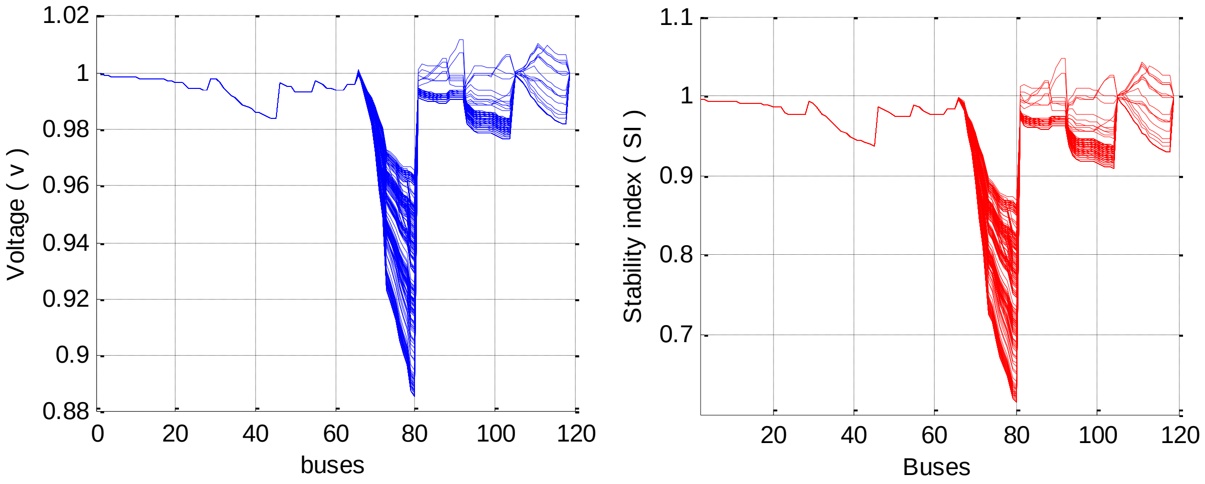


Figure 4.54: Voltage profile and stability index for different candidate of (location and generated power)during different iterations

Figure 4.54 show the voltage profile and stability index of some candidate during the execution of the SPEA algorithm, it is clear that all the possible objective function has been swept during the selection.

- **Selecting optimal power generation of multi-DGs**

In this part, finding optimal power generation of different DGs is investigated, the same feeder is considered for the investigation, assuming the same modified load state of the modified 119 test system include DGs (SDG1 connected to node 74, SDG2 connected to node 88, SCIG1 connected to node 92 and SCIG2 connected to node 80). The same objective functions are considered, steady state voltage enhancement, power loss reduction, maximizing the critical clearing time of the existed DGs.

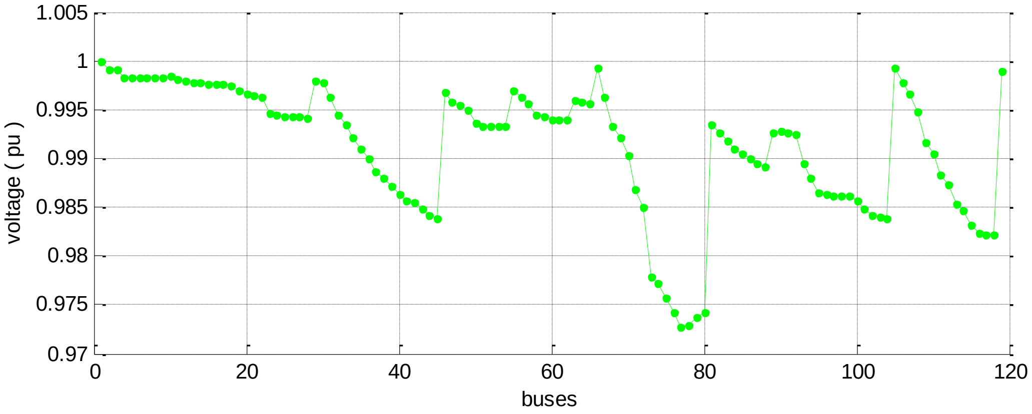


Figure 4.55: Voltage profile correspond to using DGs nominal power

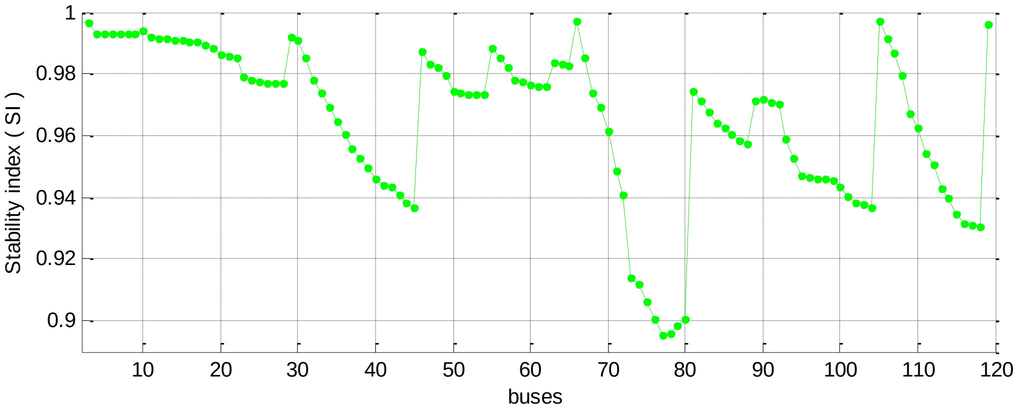


Figure 4.56: stability index correspond to using DGs nominal power

power loss (KVA)	Critical clearing time of DGs (s)			
	SDG1	SDG2	SCIG1	SCIG2
227.66	0.2345	0.1925	0.1085	0.14

Table 4-16: objective functions corresponding to use DGs at nominal power

The graphs in figure 4.55 and 4.56 represent the voltage profile and stability index at each bus corresponding to integrating the DGs with its nominal power. the corresponding power loss and critical clearing time of the different DGs are given in table 4.16. the result of nominal power generation show enhancement in stability index, voltage stability and power loss. However, the critical clearing time of DG based SCIG1 is very small which present transient stability weakness could lead to synchronism problem of SCIG1 even for small disturbances and could have an effect on the total network transient stability.

Considering that the constraint of required minimum CCT limit (min(CCTs) >= 0.15s) is implemented in the applying SPEA algorithm, the selected candidates are given in table 4.16.

DSG1 Power		DSG2 power		SCIG2 power AP(%)	SCIG1 power AP(%)	Stability Index	Power loss (KW)	CCT (s)			
AP (%)	RP (%)	AP (%)	RP (%)					DSG1	DSG2	SCIG2	SCIG1
63.1	21.6	74.4	19.35	48.6	46.35	0.89945	194.94	0.151	0.385	0.3675	0.2625
81	12.1	97.95	9.6667	73.6	31.45	0.88673	225.84	0.273	0.1855	0.217	0.378
97.5	20.6	78.759	3.75	91.3	65.8	0.89527	228.53	0.2275	0.154	0.161	0.182
96.6	24.9	80.3	8.8333	87.5	57.55	0.89495	226.45	0.231	0.1575	0.1715	0.2135

Table 4-17: Objective functions corresponding to use the optimal candidate using SPEA algorithms

One of the advantages of SPEA algorithms that it gives different optimal solutions correspond to multi objectives and accept the different desired conditions and constraint Comparing the results selected by SPEA algorithm in table4.17 with the results of using nominal power of DGs in table 4.16, we find that integrating DGs in the network could enhance the steady state objectives with improvement in the transient stability of network if the generated power of the different DGs is optimally selected. The reasons for that is the different parameters which could affect the transient behavior of the different DGs as reactive power, active power, voltage profile, transient dynamic of DGs ……etc.

4.7. Optimal location and power generation of DGs in micro-grid for transient and steady state enhancement

In this part we investigate about the suitable location and DGs generation power, during the connected mode, for enhancing the voltage profile and power losses at the steady state and improving the transient stability of the micro-grid Subsequent to Fault-Triggered Islanding by increasing the critical clearing time. The same 33-bus radial distribution is used in this investigation.

4.7.1. Voltage profile index:

To evaluate the voltage profile, we propose an index (VI) collect all the nodes voltages.

$$VI = \frac{1}{nbus} * \sum_{j=1}^{nbus} |1 - Vbus| \qquad 4.17$$

The Voltage index represent the average value of the difference between the voltages at nodes and the nominal value (1pu). The voltage profile is more enhanced when the voltage index has Small value.

In this simulation study, The SPEA algorithm have been used to select the optimal location and generated power of DSG1and DSG2. the DSG3 is connected to the node 1 generated power p=1.25 pu at the steady state.

Optimal location		Optimal Power(P_{dg}/S_{dgMax})		CCT(s)	Power loss	V_profile Index
DSG2	DSG1	DSG2	DSG1		(KW)	
28	31	0.3275	0.276	0.116	36.105	0.0054
31	13	0.3075	0.279	0.114	25.905	0.0012
15	8	0.1075	0.121	0.351	15.532	0.0095
13	12	0.1341	0.121	0.273	18.401	0.0084
12	10	0.1208	0.156	0.208	17.957	0.0083
8	13	0.1541	0.121	0.264	15.361	0.0090
33	15	0.28	0.275	0.115	29.206	0.0015
14	6	0.1808	0.181	0.183	13.073	0.0068
30	12	0.1091	0.181	0.187	13.514	0.0083
15	12	0.1341	0.059	0.347	17.799	0.0094
13	33	0.2875	0.275	0.111	25.234	0.0015

Table 4-18: Optimal DGs locations and powers

Table 4.18 gives optimal candidates correspond to powers and locations of DSG1 and DSG2 selected by SPEA algorithm for the objective functions aim to minimize power losses, improve the voltage profile at the steady state and increasing the disturbance critical clearing time of the micro-grid subsequent to fault triggered islanding. SPEA algorithm have selected the no dominated solution with different enhancement in the objective functions. from the table we can select the candidate according to desired enhancement of each objective functions, control and network design parameters.

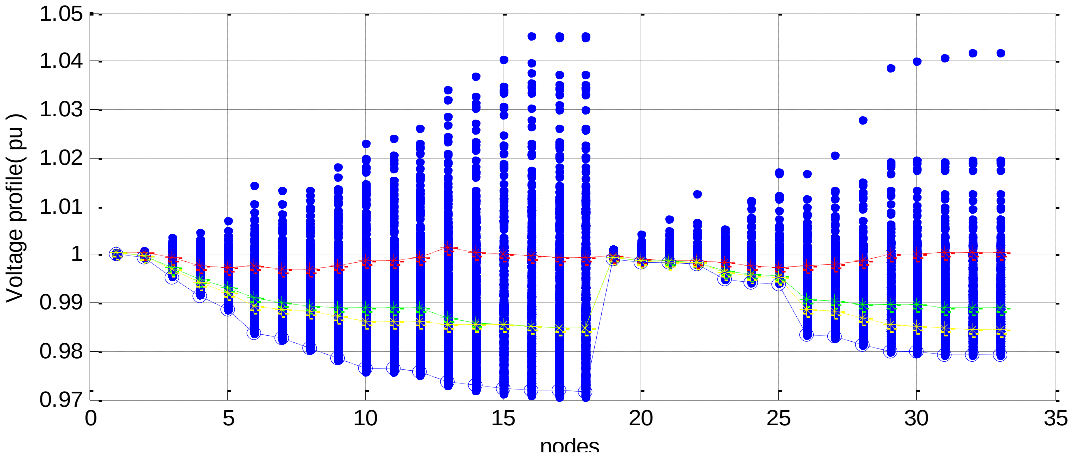


Figure 4.57: Voltage profiles correspond to different locations and generated powers of DGs 1&2

The figure 4.57 illustrate the voltage profile correspond to different locations and power generation during the searching process. The voltage profiles in yellow, green and red colors with star marks correspond to the selected candidate with maximum CCT, minimum losses and best voltage profile respectively. we note that all the corresponded voltage profiles are enhanced compared to the case of no DGs integration represented by the dashed line with small circles marks in blue color. The selected candidates could be used for power sharing management, and micro-grid protection designing and control.

4.8. Summary

In this chapter, SPEA algorithm has been used to investigate the optimal DG placement and size in a distributed network. The optimization problem has been formulated in order to improve voltage stability and minimize total active and reactive power losses for integration of different DG types. Penetration level of DG, voltage and current limit are considered as the constraints in the optimization process. A steady state voltage stability index has been used to assess the stability at each node. A 33-node distribution network has been used for the simulation. Illustrative mesh plots were given in this paper to show the impacts of DGs locations and sizes on the voltage stability and power losses. The proposed algorithm has been used in different scenarios to show the effect of the type and the number of DGs integration on the distributed network. The location, size and type of DGs significantly affect the voltage stability and the power losses. The algorithm proposed in this paper can find a compromise between different objective functions providing useful information for optimal DGs integration.

The problems of DGs integrated in distribution network have been investigated, analyzing the effect of DGs on the steady state and transient stability of the network, the transient effect of integrating new DGs on the transient stability of distribution network reinforced with DGs have been investigated and discussed, considering the type and number of the existed DGs in the network type number of the new ones. The impact of locations and steady state power generation of DSGs, connected to a micro-grid, on the transient stability of the micro-grid subsequent to a disturbance triggered islanding have been simulated and investigated.

SPEA algorithm has been investigate to be used for selecting optimal DG placement and sizing in a distributed network planning and management for steady state and transient stability improvement, in addition the algorithm has been used to select the optimal locations and steady state power generation of DSGs for the objective of enhancing steady state parameters and improve the transient stability of a micro-grid subsequent to a fault triggered islanding.

5. CHAPTER 05: Transient stability improvement of distribution network with presence of DGs

With presence of DGs, several variables could affect the transient stability of distribution network. And on the other hand, a number of methods and applications that can be used to improve the transient stability of distribution networks could be found in the literatures. These methods include high-speed fault clearing, regulated shunt compensation, dynamic braking, fast responding high gain exciters and reactor switching. According to [48] The different methods aim to:

-Reduction of the impact of the disturbance or the fault severity.

-Increase of the synchronization forces to support the restoration of steady state operation after a disturbance.

-Reduction of the acceleration or deceleration power through control of the prime mover to meet the equilibrium of mechanical and electrical power.

-Applying artificial load to SG to reduce accelerating power by increasing electrical power.

A Review and Comparison of Conventional and Renewable based Techniques for Preventive and Emergency Control used for transient stability improvement have been realized in [102] . the different techniques are presented as follow:

1-Conventional Techniques: the techniques are considered conventional when no renewable energy sources (RES) are involved.

-Preventive Transient Stability Control: based on SG Re-Dispatch, Load Shedding, Reduction of System Reactances, Upgrade of System Voltage, Variable Series Compensation……

- Emergency Transient Stability Control: based on Fast Excitation System, Braking Resistor, Fast valving, Generator tripping, Variable Shunt Compensation, Variable Series Compensation, Combined Variable Series and Parallel Compensation, Controlled System Separation, High Speed Circuit Breaker, Single-Pole Operation, Auto Re-Closing, Fault Current Limiter, HVDC Transmission Link Control.

2- Renewable Energy Source(RES) Based techniques: the techniques utilize RES based generators.

- Preventive Transient Stability Control: based on Increasing Voltage Set point,

-Emergency Transient Stability Control: based on advanced control strategies to complement and enhance the Low Voltage Ride-Through (LVRT) capabilities of DGs based RES, transient stability improvement by complementing wind power plants with FACTS, Virtual Inertia control strategy for penetration of converter-based RES.

Due to the high number of distribution network nodes, number of compounded device, number of charge in distribution network, the disturbances on distribution networks cannot be avoided where large disturbances are a big threat to the stability of distribution networks with DG. Despite the DGs benefit on distribution network, voltage enhancement, power loss reducing, power support and voltage support, the main concern is introducing DGs in distribution network without degrading the stability of system, It should rather be improved.in this regard the author in [22] have proposed emergency control, to maintain the stability of distributed synchronous generators, based on rapid disconnection and connection of the area including the generators using the high power demand of the isolated area to decelerate and reestablish the generator. However the stochastic nature of the load make difficulties to determining the optimal isolated area where the disconnection and connection time is rely on the isolated braking energy. Appling the methods need smart grids concept, incorporating automation technologies and real time communication using intelligent devices with instant control actions, with fast automatic reconfiguration scheme of distribution network. In this work a new method of improving transient stability of DSG connected in distribution network have been proposed and analyzed.

5.1. Transient stability improvement of DSGs using local control

5.1.1. Increasing the transient potential energy of DSG using local control:

The disturbance critical clearing time is directly proportional to the amount of kinetic energy gained by the generators during a fault. this energy is proportional to the fault duration. Where Protection fault clearing times on distribution networks are often in the order of 500msecs - 1.5secs, depending on the protection settings. For small DSG, critical fault clearing times of distributed generators can often be lower than the clearing times of typical distribution protection. Therefore, High-speed fault clearing will protect DSG from losing synchronism and further improve the power quality of the distribution network by reducing the voltage depressions.

Beside the high-speed fault clearing solution, we propose a local control based on fast reconfiguration of DSG connection, this technique aims to increase the critical transient energy (deceleration area), after fault elimination, over the entire positive swing of the rotor angle by shifting the transient power angle, witch aid the generator to evacuate more electrical power and to re-establish the equilibrium.

Assuming that, the synchronous generator is connected to an infinit busbar system. let's consider the steady-state operating point (δ_0, p_m) presented in Figure5.1, the disturbance in the system could cause the operating point to move away from the steady-state point and as a result changes the output power of the generator. After fault clearance the synchronizing torque component that increases with the power angle of the generator is responsible for the generator to remain in synchronism and that's possible as long as the area A1<A2 as illustrated in figure 5.1 and transient stability margin increase with increasing the deceleration area A2 and decrease with increasing the acceleration area A1.increasing and decreasing A2 and A1 can be achieved by fast action for mechanical power reducing, increasing electrical power evacuation during and after fault clearance. in this thesis a new technique to increase the deceleration area is investigated and simulated, it is based on the transient power angle offset using a local control system for shifting the power angle. Shifting the relative angle will change the post fault trajectory and the deceleration area will be increased to be A2+A2' which increase the electrical power evacuation after the disturbance. The increasing of deceleration area is depend on the switching point δswt and the shift angle Ø.

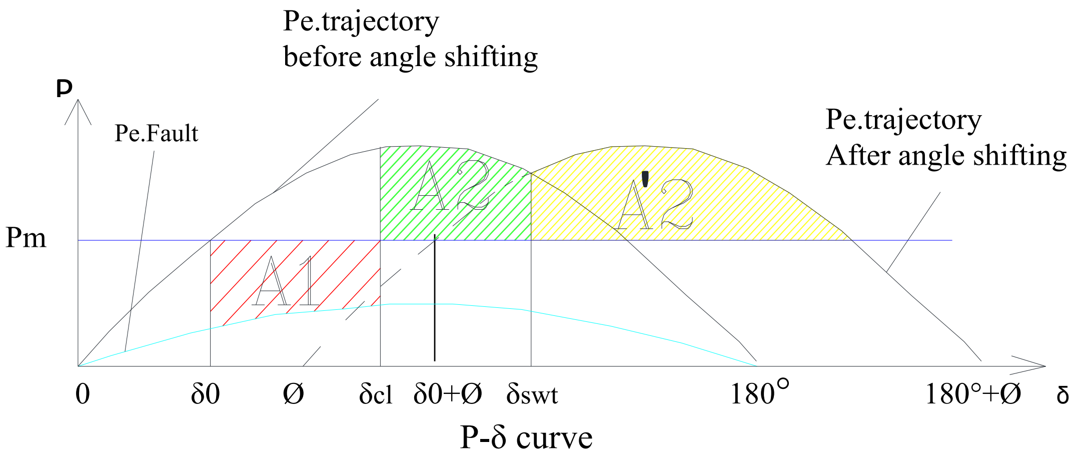


Figure 5.1: P-δ curve: Before and after angle shifting

5.1.2. Transient Power Angle Shifting (TPAS):

Generally, the phase shifting transformers (PST) is used to shift the voltage angle in order to increase and low the active power transmission in network. PST aims at introducing voltage phase shift between sending and receiving of transmission line; the voltage phase shift is controlled by adding to the voltage of one end of transmission line a quadrature voltage component. based on the same principal of PST, in this work we look to reduce the transient Power angle at the first swing, by shifting forward the angle phase of connected terminal. That could be carried out practically by using power electronic devices, solid state transformer, power electronic switches as fast transfer switches or using controlled thyristor switching circuit interface .

- **Static Transfer Switch:** A static transfer switch is a switch that can transfer power between two different sources in case of a fault in the feeding power source. An example of a static transfer switch consists of two parallel thyristors, during normal conditions, thyristor 1 is continuously fired and conducts the load current. When a disturbance occurs, the thyristor 1 is disabled from firing and the thyristor 2 is fired. The current commutates to the other source or supply in a very less time usually less than half a cycle after the disturbance is detected. In [103] a medium voltage static transfer switch with a transfer switch less than 4ms have been proposed.

Basic Principle of TPAS:

The power angle is principal element controlling the angle stability of DSG, it is estimated as the difference between the angle phase of the generator induced voltage (fem) and the generator terminal voltage. during a short circuit disturbance, the power angle is increased where it is very quick for generators with small inertia, and after fault clearance if the critical angle is exceeded then the stability of SDG will be lost. The purpose of the method is to reduce the start of power angle after fault elimination by shifting forward the phase angle of voltage terminal during the disturbance time as presented in figure 5.3.

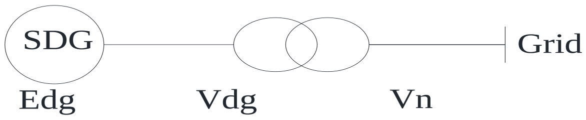


Figure 5.2: the voltages terminals used for transient power angle variation

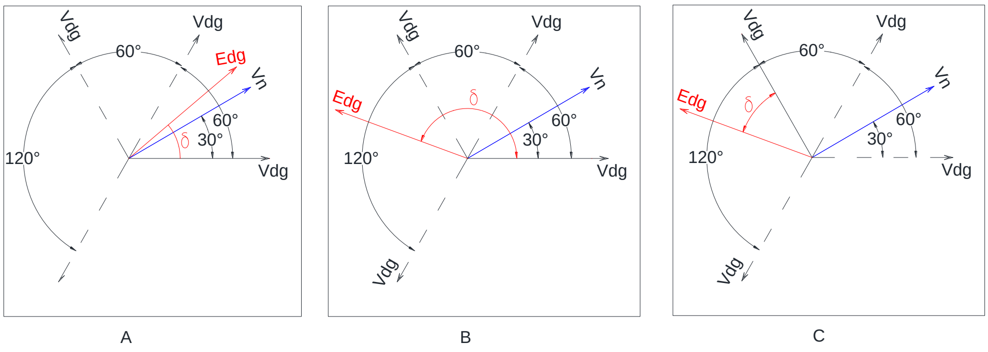


Figure 5.3: shifting angles of voltages terminal: A: angles at the steady state; B:angles at transient state before control action; C:angles at transient state after shifting control action;

Many topologies could be used to realize the reconfiguration using fast Tie Switches or the thyristor controlled switching circuit interface for shifting the relative transient angle. Because DGs is generally small units with small power generation, so we can use directly the thyristor controlled switching circuit interface for connecting the generator to the main grid. Ehe thyristor controlled switching circuit interface could be controlled for shifting the transient angle by permutation between the voltage terminals phases changing the sequences of the connected voltages which give a shifted angle of 120°. This method is more cost effective than using PSTs.

Changing voltage sequences at terminal connection (basic principle):

During normal operating conditions, the bypass switches are open and the disconnect switches are closed. The controller transfers the energy from the generator to the network throw a set of voltage phases sequences at connection terminal, in case of a short circuit disturbance the controller opens the switch of the primary reconfiguration and closing the switch corresponding to the alternate reconfiguration. For that reconfiguration we can reduce the angle power by shifting the angle phase of terminal connection by $2\pi/3$. As clear in figure5.4

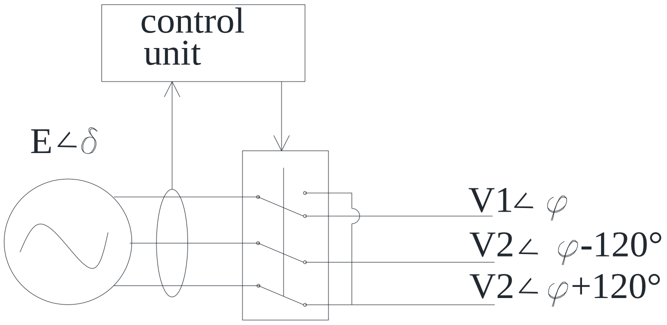


Figure 5.4:diagrame of SDG connection with local TPASC

Beside the commutation between the connected phases, we can get more step of angle shift as $\pi/3$ and $2\pi/6$ using vector group index of the transformer. with local intelligent control using phasor measurement unit, the power angle could be shifted more one time till the energy potential compensate the kinetic energy gained during the disturbance.

5.1.3. Critical clearing time(CCT) of DSG using TPAS:

In order to realize our studies, the modified 33 nod radial distribution network is used. The single line diagram of the distribution system is presented in Figure 4.1. The distribution lines and the feeder are modelled as series connection of resistance and inductance and the loads are represented by constant impedances model (Table1 in Appendix A). an ideal case of TAPS is considered in this simulation.

Considering a scenario where DSG1 with specification in (Table 1 in Appendix B) connected at nod 18 and a three fault short circuit accrued at nod 33. We used the hybrid individual transient energy to estimate CCT.

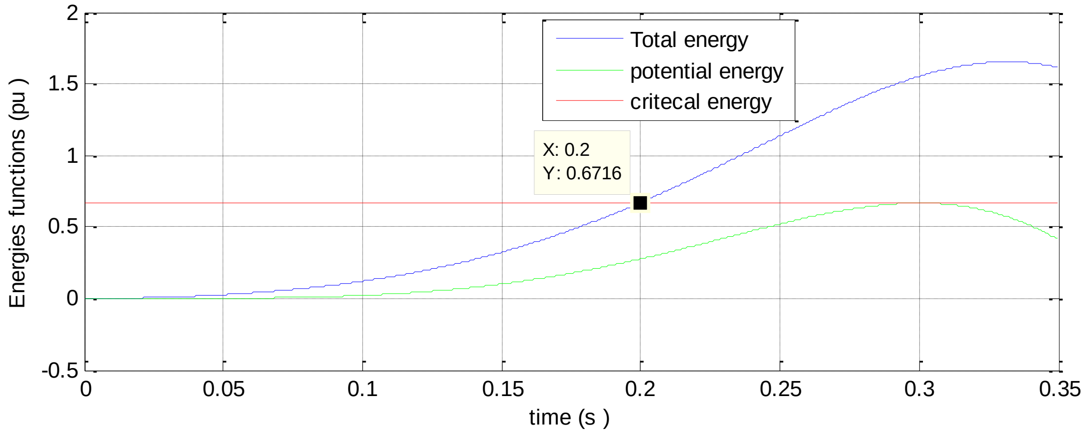


Figure 5.5: Critical clearing time(CCT) estimation using individual transient energy function, without control actions

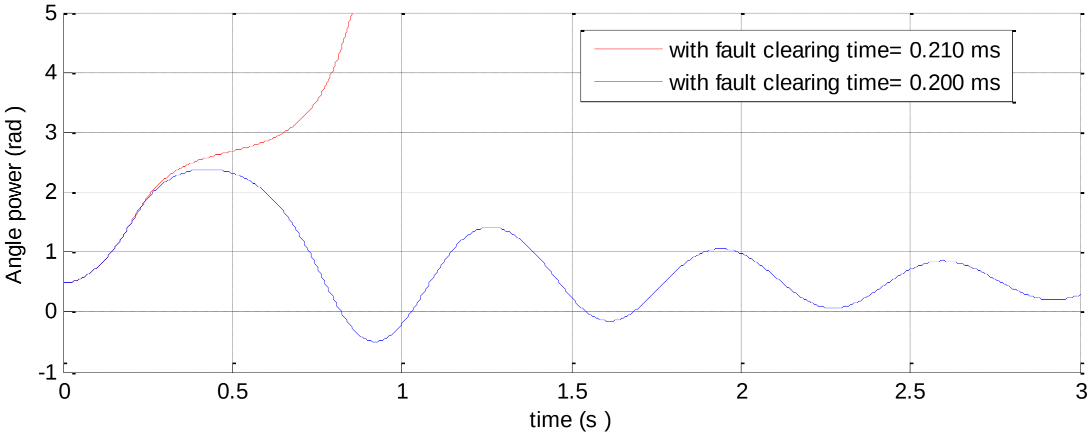


Figure 5.6: load angle at its stable point limit (CCT±Δt) without control actions

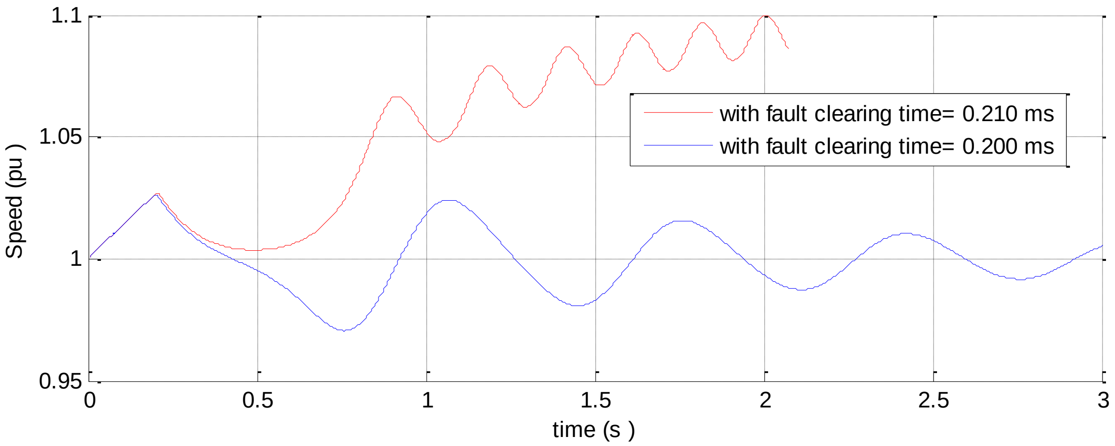


Figure 5.7:Rotor speed at its stable point limit (CCT±Δt) without control actions

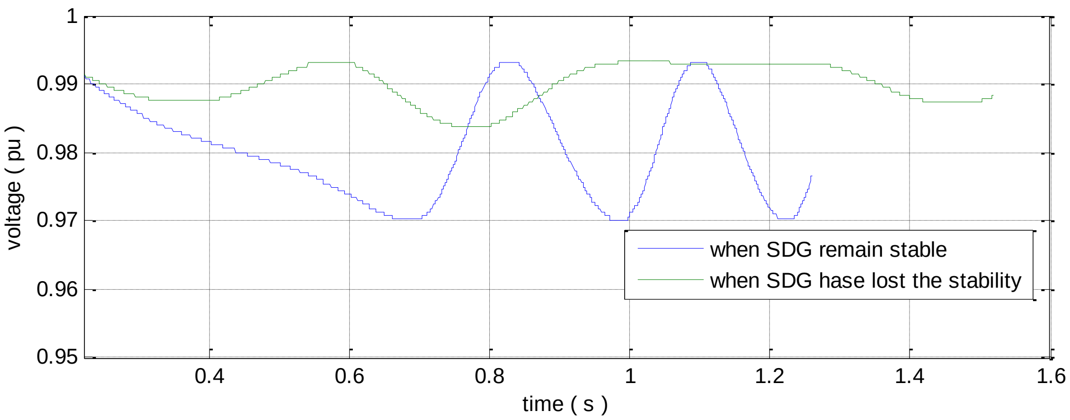


Figure 5.8:voltage at the node where SDG connected after fault clearing

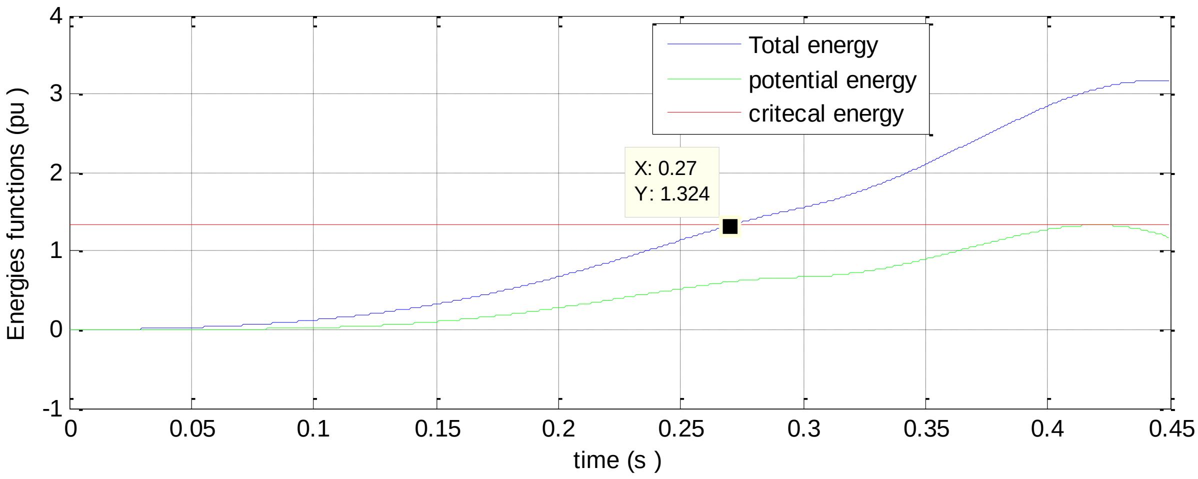


Figure 5.9: Critical clearing time(CCT) estimation using transient energy function, with TAPSC of 2π/3

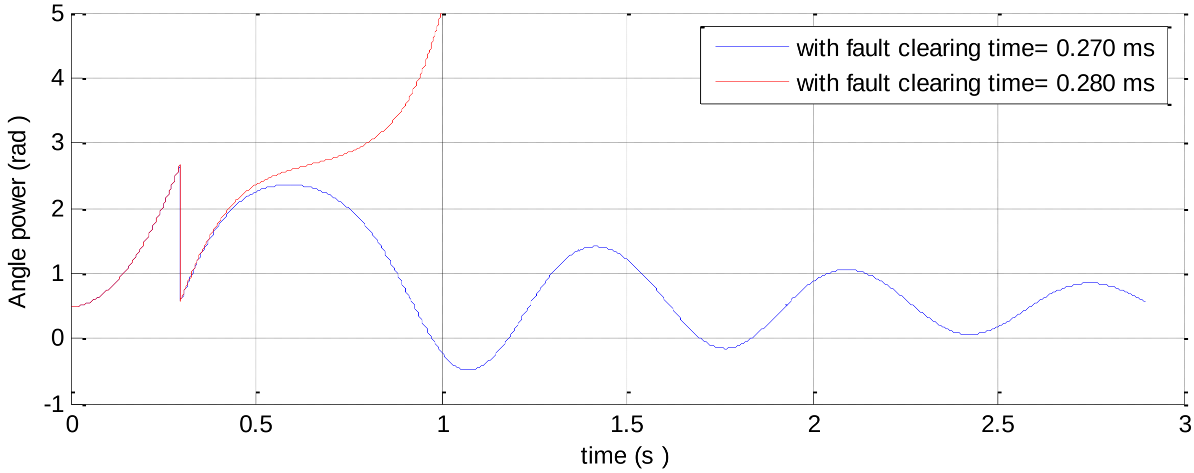


Figure 5.10: load angle at its stable point limit (CCT±Δt) , with TAPSC of 2π/3

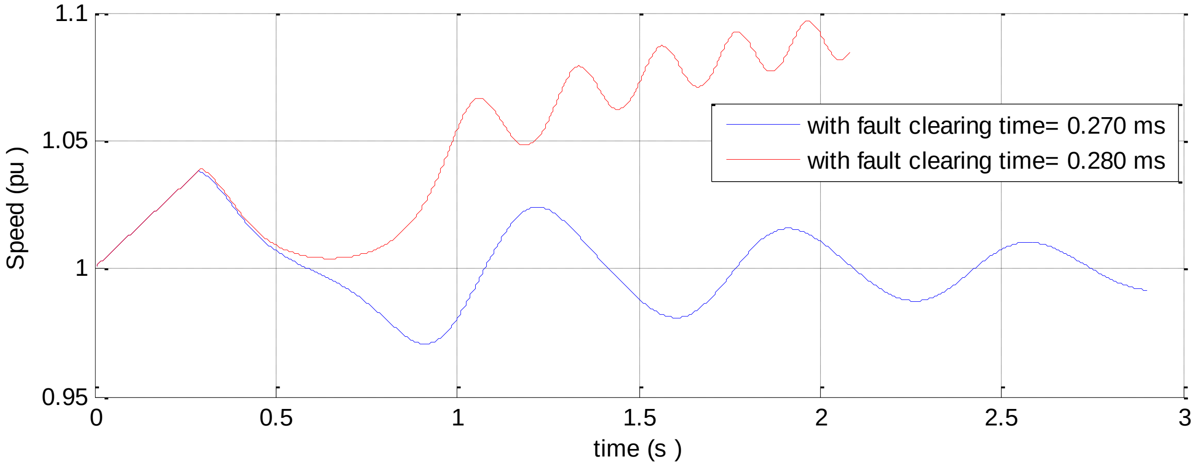


Figure 5.11: Rotor speed at its stable point limit (CCT±Δt) with TAPSC of 2π/3

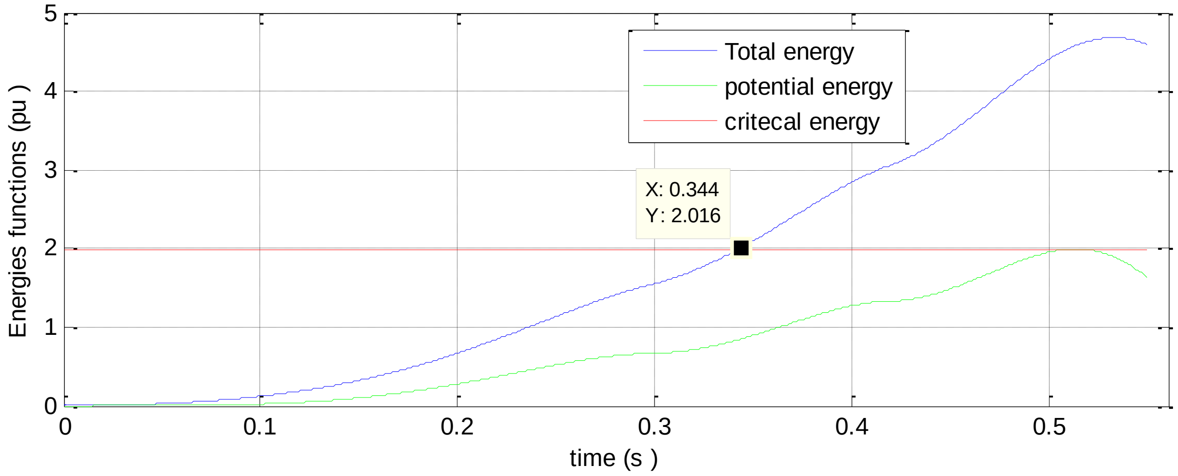


Figure 5.12: Critical clearing time(CCT) estimation using transient energy function, with two successive TAPSC of 2π/3

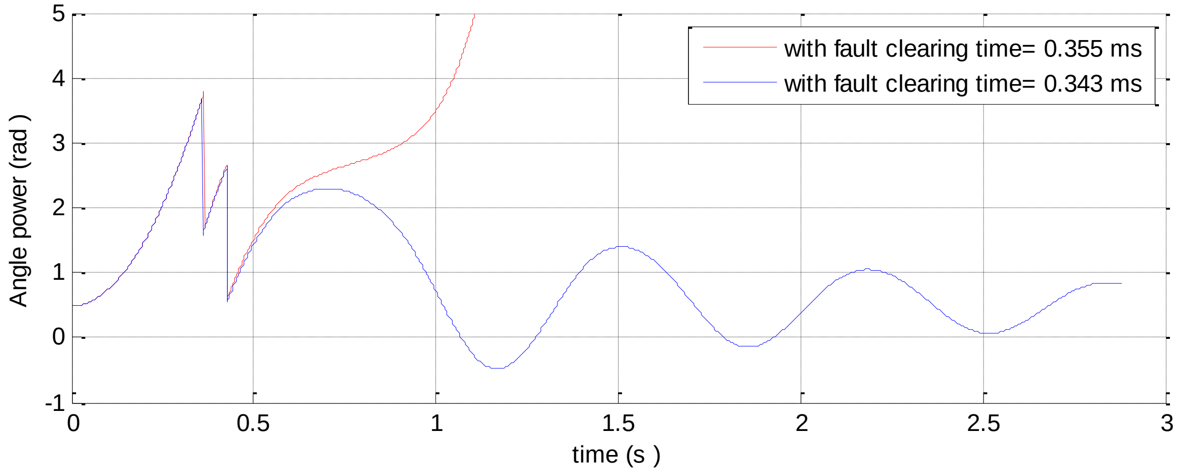


Figure 5.13: load angle at its stable point limit (CCT±Δt) , with two successive TAPSC of 2π/3

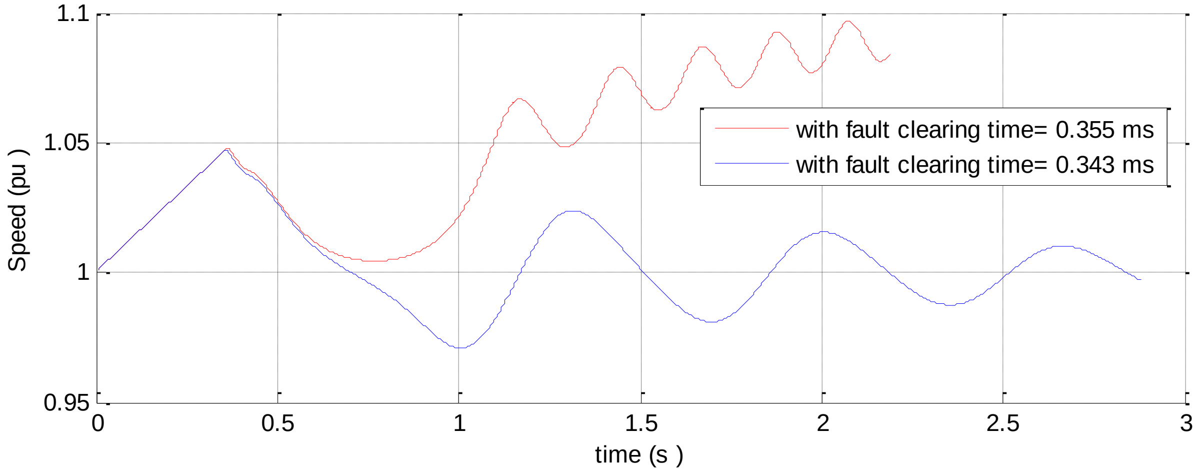


Figure 5.14: Rotor speed at its stable point limit (CCT±Δt) with two successive TAPSC of 2π/3

Considering the maximum potential energy as the critical energy to estimate the critical clearing time and assuming a self-fault clearance with the same potential energy trajectory before and after fault clearance, figure.5.5 illustrates the transient energies function and critical clearing time determination CCT=.0.2 ms

It is clear that CCT is small due to the small inertia of SDG, which could implicate a potential transient instability of the network if the SDG is used as voltage or power support. When the distributed generator loses its stability it would be disconnected from the network. Per consequence power quality are violated due to the unavailable DG support.

In the case of using DGs as voltage or power support, due to increasing power demand in radial distribution network, the transient stability represents the major problem when the network cannot withstand when losing DGs.as solution in case of using DGs for voltage support, upgrading the network and improve the strength of the weak network by reducing the network impedance. Hover this solution is not economical mainly with the continuous increasing in power demand. Therefore, the investigation on improvement of distribution network is the purpose of this study.

Results analyses of the proposed TPASC:

Firstly, a simulation of normal integration of SDG1 at the nod 33 of the test system have been simulated at a stable case and instable case. The graphs at figures from 5.6 to 5.14 show the dynamic behavior of the SDG (angle and speed) at the two cases and its effect on the transient voltage at the connected node after disturbance clearance due to the weak nature of the feeder. The individual transient energy function has been used to estimate the critical clearing time of the SDG referring to voltage angle of the first nod. according to conventional system protection of distribution network the CCT=0.2ms is considered very small for the network security.

Considering an ideal applying of the proposed local control, the graphs in figure from (4.35 to 4.36) show the effect of the control approach on the dynamic of SDG for angle shifting of 120° by commutation between terminal phases where the speed osculation are relatively increased and an incrimination in the critical clearing time of 0.07ms. and the graphs in figure from (4.36 to 4.38) show the effect of the control approach on the dynamic of SDG for two successive angle shifting of 120°, the critical clearing time has increased by 0.144ms compared to the normal connection.

5.2. Using soft open points SOPs for transient stability improvement of micro- grid

Several small-scale distributed generators DGs have been recently used in power and distribution systems, the increasing penetration of DGs as renewable or dispatchable gave rise to the concept of micro-grids due to its several advantages. A typical micro-grid can be viewed as a cluster of DG units capable of operating either islanded or connected to the main grid. Micro-grids can provide grid reinforcement without the need for more generation expansion and can increase the service reliability. Further, micro-grids can offer local power-quality (PQ) enhancement, voltage regulation, and power factor correction [100].

Maintaining the voltage and frequency within the standard permissible levels is an important requirement in micro-grid design procedures. transient stability issues represent the most problem due to the small inertia of the system and the changing of control mod when passing from the connected mod to the stand alone mod. In this theses we propose a method for connecting the micro-grid to the main grid could eliminate the transient problem related to the changing mod.

The proposed method is based on using Soft Open Points (SOPs) with multi-terminals. Soft Open Points (SOPs) are power electronic devices installed in place of normally-open points in electrical power distribution networks. They are able to provide active power flow control, reactive power compensation and voltage regulation under normal network operating conditions, as well as fast fault isolation and supply restoration under abnormal conditions. Operating principle of Soft Open Points for electrical distribution network operation have been well explained in [104].

Considering Back-to-back VSCs based Soft Open Point as the example in figure 4.48, the utility grid and the micro grid are interconnected with a back-to-back VSCs based SOP. Two VSCs are located connected via a common dc link. the dc link could connect others dc sources and storage devices as shown in figure 5.15.

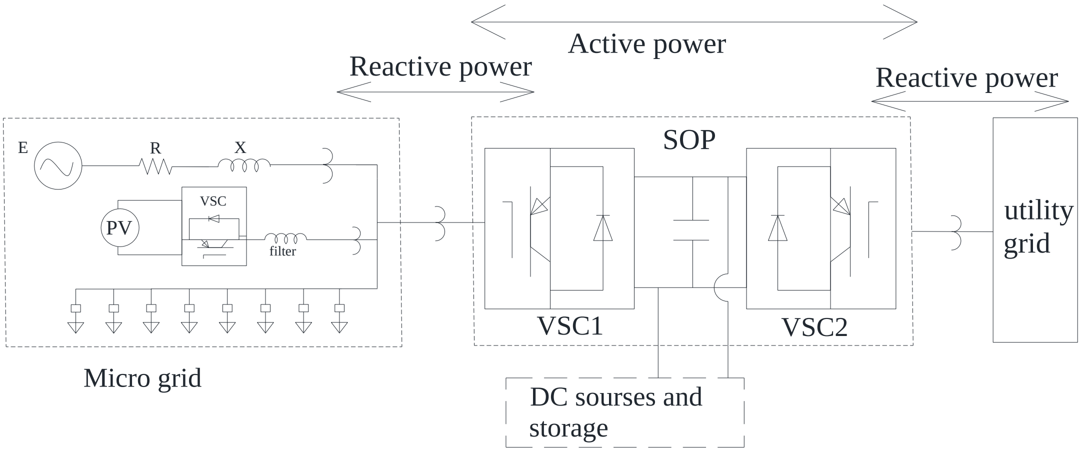


Figure 5.15: Basic configuration of connecting micro grid to utility grid based SOP

Soft open point gives an alternative solution to improve distribution network operation, without requiring network topology changes. Power electronic devices enable more efficient use of existing network capacity by controlling power flows in an accurate and flexible way. Recently, installing power electronic devices (SOPs) in place of normally-open points in a distribution network has been investigated [105] [106].

Instead of simply opening/closing normally-open points, SOPs devices has the following characteristics:

- Flexible active and reactive power control: it is able to control load transfer and optimize network voltage profile by providing fast dynamic and continuous real/reactive power flow control between two the two ends interfaced by SOP.

- fast dynamic and independent control: this device gives independent control of the micro grid from the main grid, where VSC1 is controlled according to the micro grid control strategy and VSC2 is synchronized to the main grid. And The control strategy of the micro grid does not change when connecting or disconnecting with the main grid avoiding the transient effect of changing control mod on the micro grid side with small inertia.

- fast isolation of disturbances and faults: the fault is instantaneously isolated using the VSC, which eliminating the impact of sever disturbances on the stability of the micro grid.

In this part we interest on the transient stability of micro grid with small inertia, for the investigation we consider a simple topology of micro grid connected to the utility grid using Back-to-back VSCs based Soft Open Point. The microgrid power sources consist of a 0.75-MVA diesel-based synchronous DG and a 0.75-MVA inverter-based DG connected to a DC sources, The microgrid designed to meet the local load requirements for a few hours.

A comparison between direct connection of micro-grid and connection using SOPs have been realized in this part, where three cases have been simulated and analyzed. The simulation are conducted in matlab-Simulink using the data listed in appendix C.

- **Case 1**:

The micro-grid is connected is direct connected to the micro-grid as the topology presented in figure 5.16 , the voltage source converter is synchronized with grid by PLL loop control using power and current loops as presented in figure 5.17.

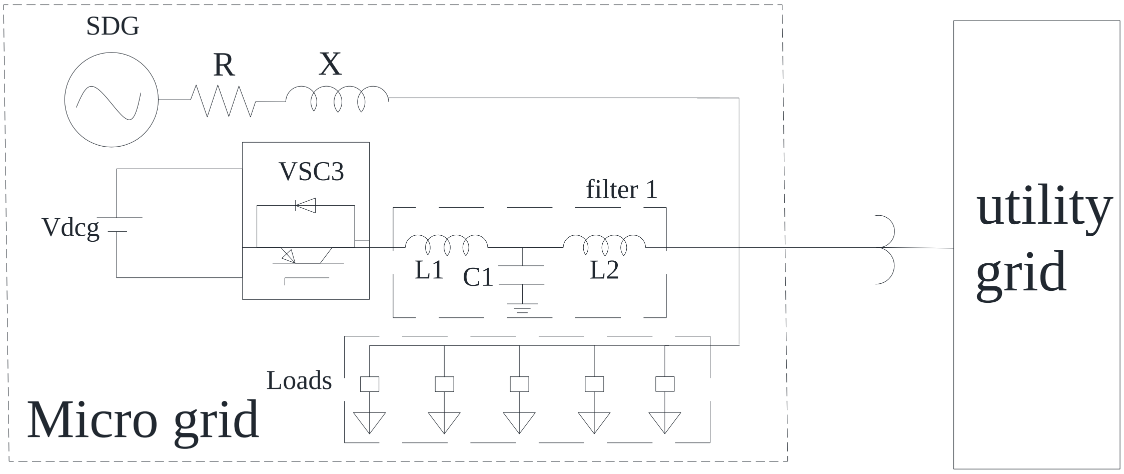
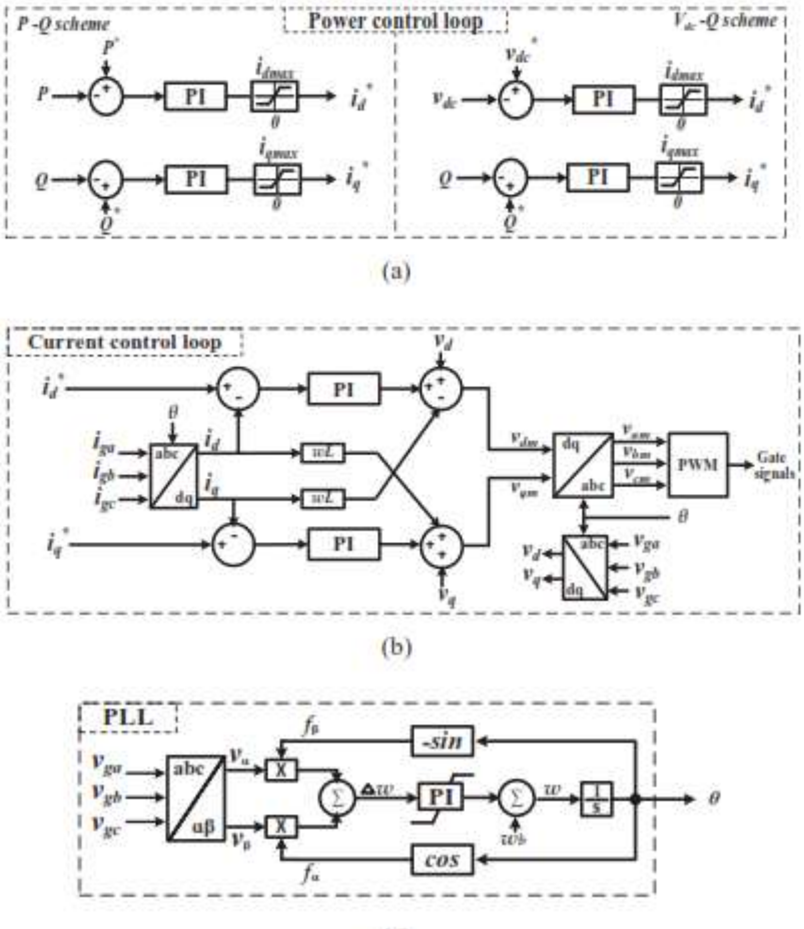


Figure 5.16: main topology of direct connection of micro-grid to the main grid



(a)

(b)

(c)

Figure 5.17: Control loops diagram of the VSC for power flow control mode

At the steady state we consider a Slave micro-grid Control Strategy where the generators deliver a constant powers, after the disturbance the micro-grid is switched to Master/Slave Control Strategy where the DSG is controlled to enforce frequency and voltage regulation.

The main simulation diagrams are presented as follow:

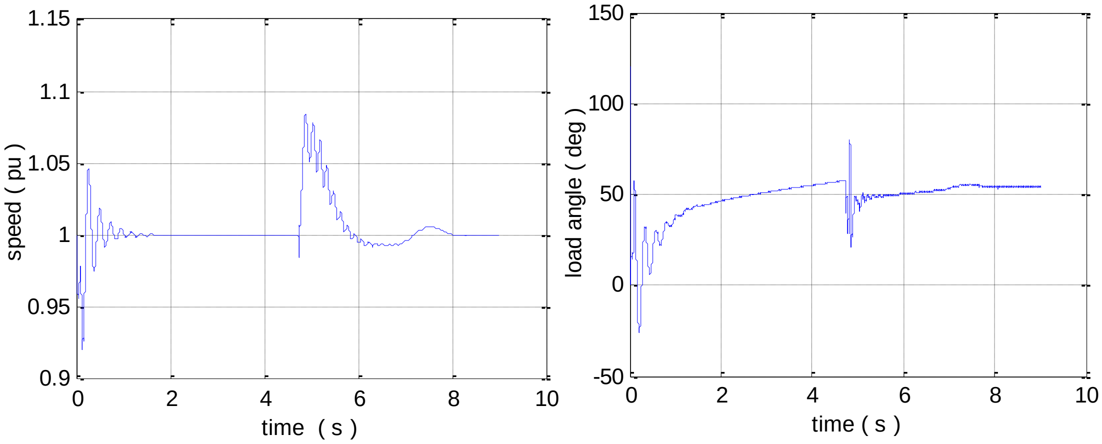


Figure 5.18: Rotor speed and load angle of synchronous generator based diesel DG

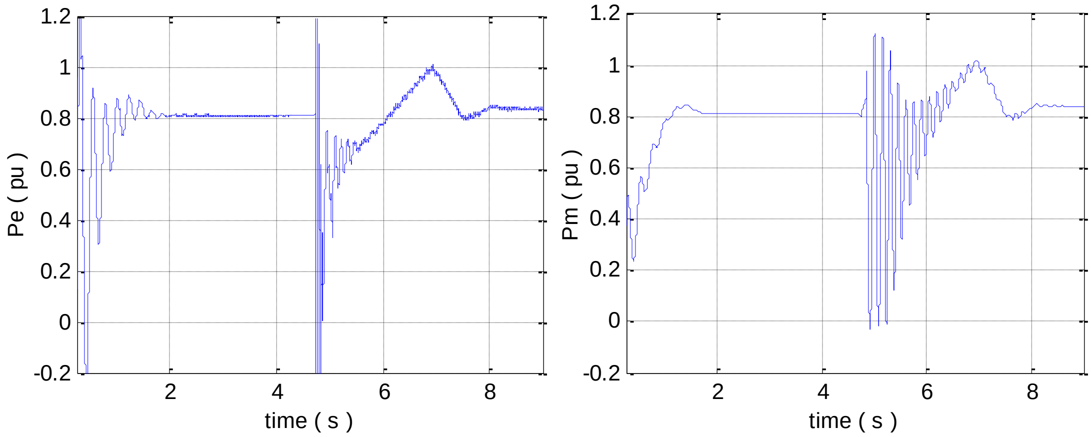


Figure 5.19: Electrical and Mechanical power of the synchronous generator

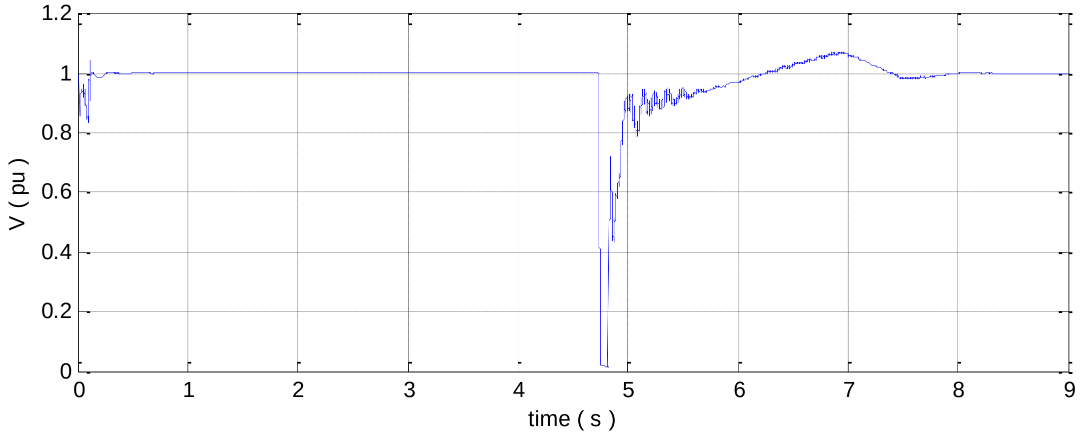


Figure 5.20: micro-grid voltage

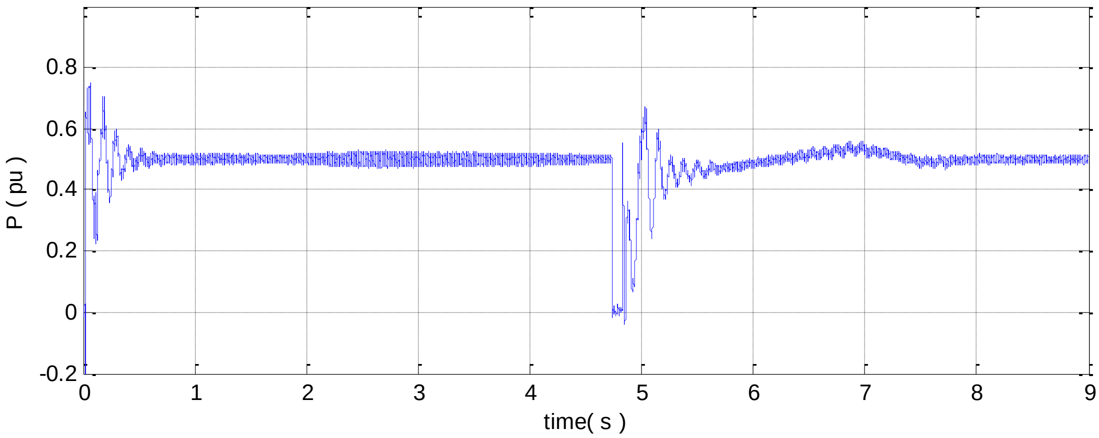


Figure 5.21: VSC3 power

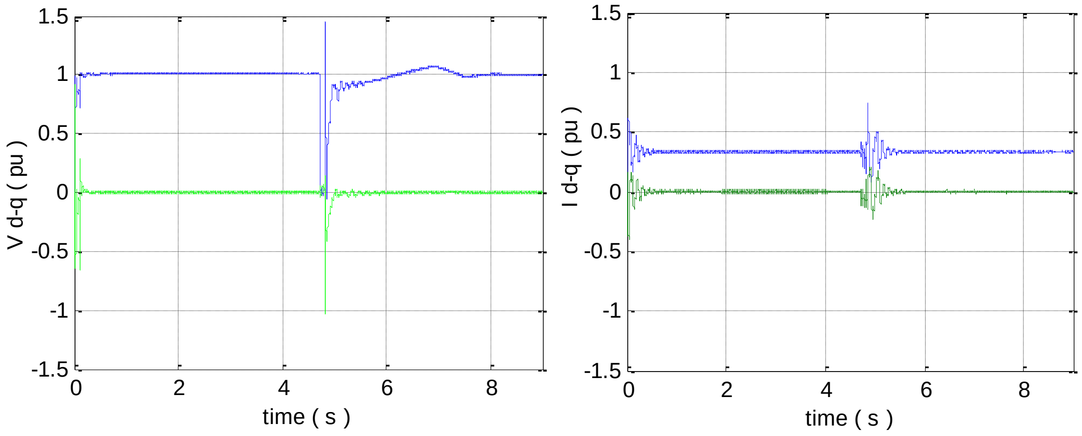


Figure 5.22: V d_q and I d_q of VSC3

The simulation of the micro-grid behavior using direct connection topology is realized considering a three phase short circuit at the main grid side, the micro-gid is isolated and switched to islanded mod after 100s. the simulated results show some perturbation when changing the function mode of the micro-grid before stabilizing at the new steady state operation. The most drawbacks of this topology is the voltage drop during the transient disturbance which could affect the loads as induction motor. The load angle and speed have been increased, this incising represent the big problems of transient stability when the micro grid contain many rotating machines with small inertia, the longtime disturbance lead generally to disconnect the inverters based DGs due to the current limits of its components.

- **Case 02:**

0.75-MVA Back-to-back VSCs based SOPs is interfaced The micro grid and the main grid. And a energy storage system (ESS) is connected to the dc link of the SOP. The proposed (ESS) is consists of a battery bank, For this study The battery is replaced by a DC sources for the simulation. the energy storage device with a rated voltage of 278 V have been considered. As the topology presented in figure 5.23.

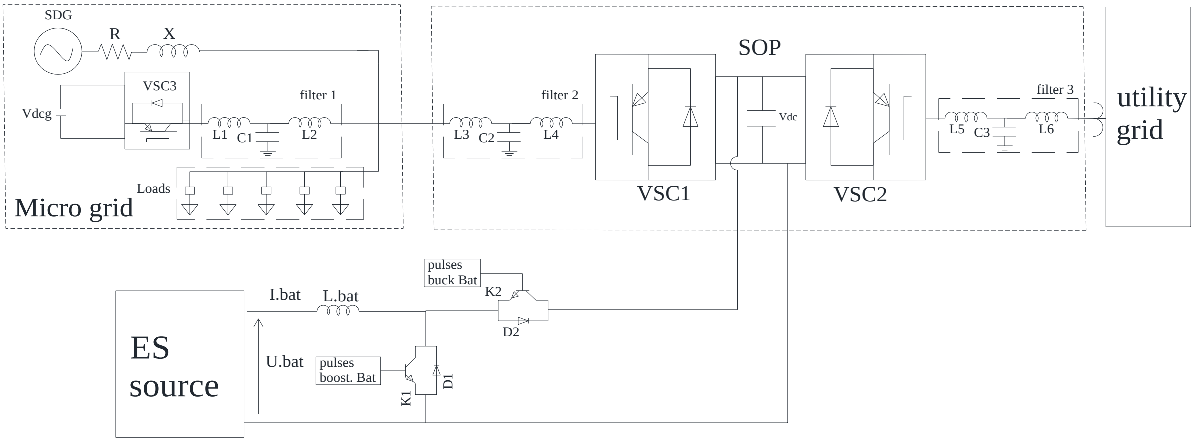


Figure 5.23: simple micro grid connected to utility grid based SOP with ESS

The DC-DC converters are linked to the DC-Link, it manages the battery power flow, as shown in Figure 5.23. Energy transfer is enabled between battery and the DC-Link bus and back in the aforementioned structure. DC-link current, IDC, can be positive or negative whereas voltage across the DC bus is always positive. The DC converter that interface the battery with the DC-Link give a good flexibility power management either when energy flow to DC-Link rising the voltage level which is boost behavior, or when energy flows from DC-Link to sources showing a typical buck behavior. In boost-mode, (K1) and (D2) are active. In the buck-mode, (K2) and (D1) are active [107].

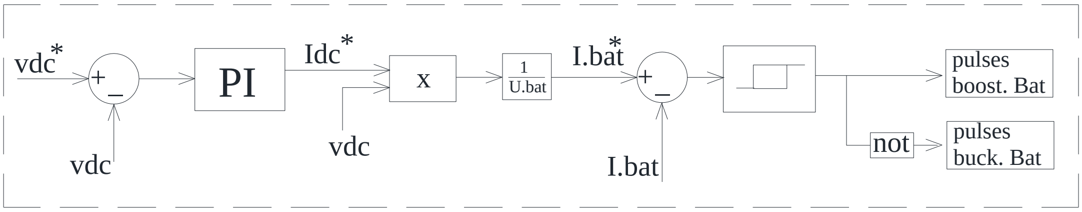


Figure 5.24: Control scheme of DC-DC converter connecting ES Sources to the DC-link

For this study the purpose is maintaining a constant reference value of DC bus voltage (UDC) during the transient event by controlling the process of charging and discharging of the of the battery. Generally, a supercapacitors is used with the battery for fast response time.

The control of the DC–DC converter is realized via a cascade configuration Figure 5.24. In order to upkeep the dc bus voltage, a main voltage loop with a proportional-integral (PI) controller generates the total current reference I ∗ DC that should be taken from the DC-link bus. The regulators of storage source converters are current-controller with hysteresis regulator [108].

In This part we focus on analyzing the benefit of using sop to improve transient stability of micro grid during and after islanding conditions caused by a sudden three-phase fault occurring at the main grid. The simulated case considers the follow steady state:

Master/Slave Micro-grid Control Strategy is used to enforce frequency and voltage or power factor regulation. the inverter-based DG delivers constant active power P=0.5 pu referring to its capacity. and the main grid gives active power support to the micro grid P=0.2pu referring to max power of SOP. the synchronous-based DG control the frequency and the voltage while the inverter-based DG and VSC of the SOP behaves as a slave unit and is controlled with *P&Q* control scheme. The main interest in this investigation is the micro grid side, hence we consider the control scenario where VSC1 controlled to ensure a constant voltage of the dc link (Vdc) and VSC2 and VSC3 are synchronized to the micro grid as slaves using (PLL) and controlled to deliver a specified power using power and current loops.

The main simulation diagrams as presented as follow:

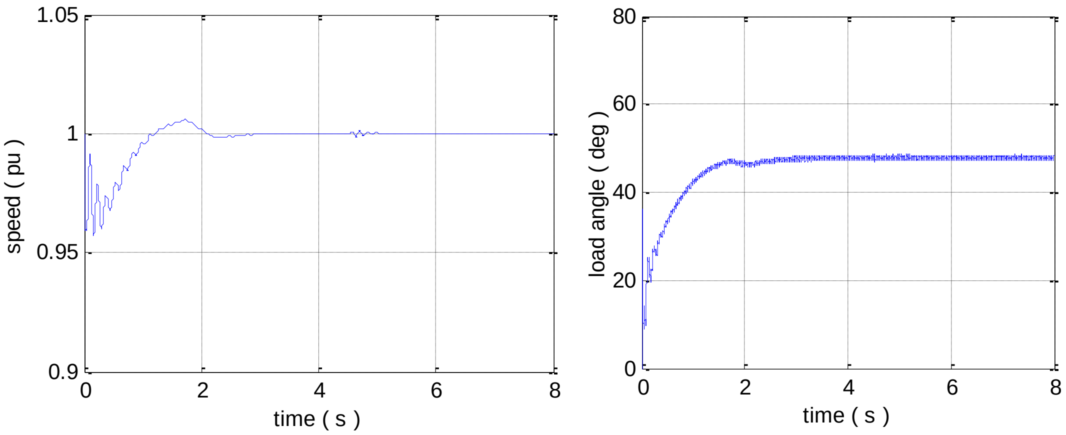


Figure 5.25:rotor speed and load angle of synchronous generator based diesel DG

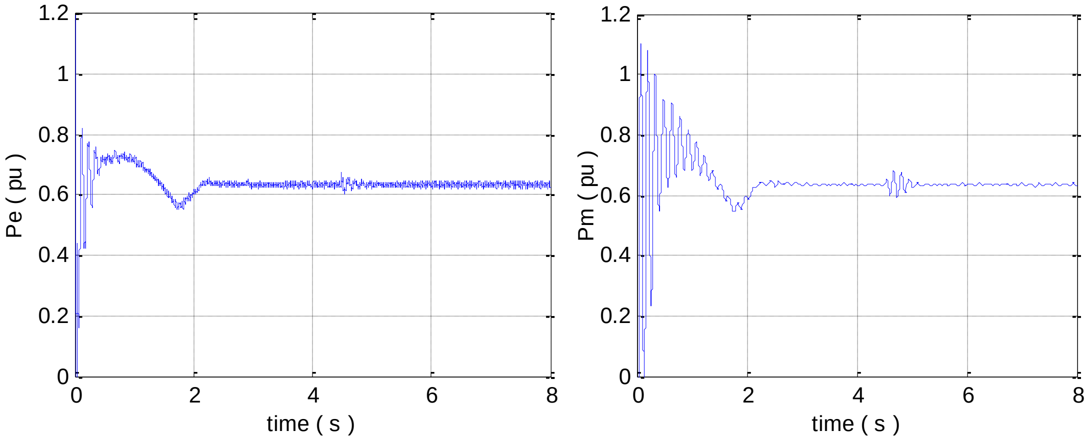


Figure 5.26:Electrical and Mechanical power of the synchronous generator

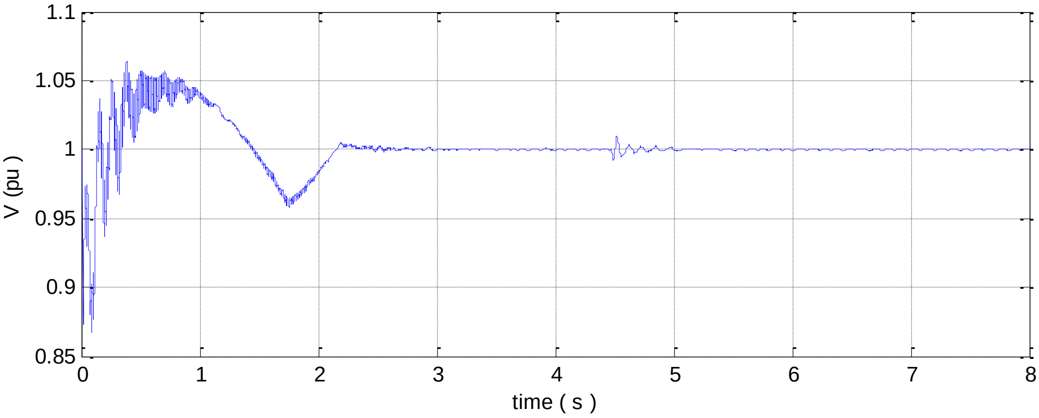


Figure 5.27:Micro-Grid voltage

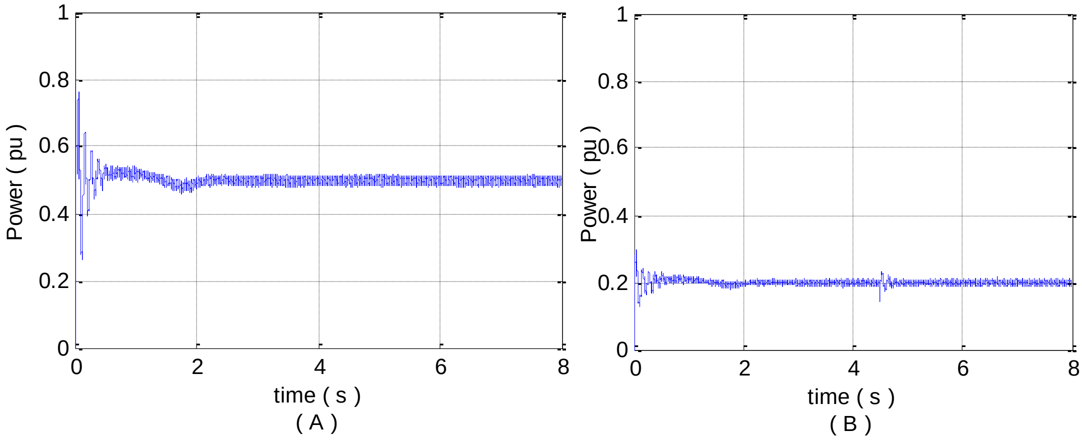


Figure 5.28: delivered power from VSC1 and VSC3

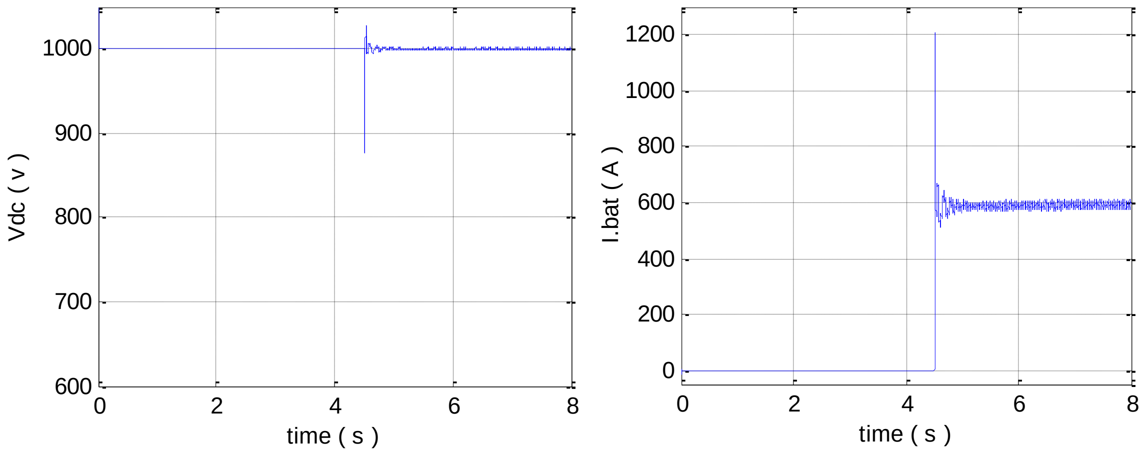


Figure 5.29:Voltage of DC link and Current of energy storage system

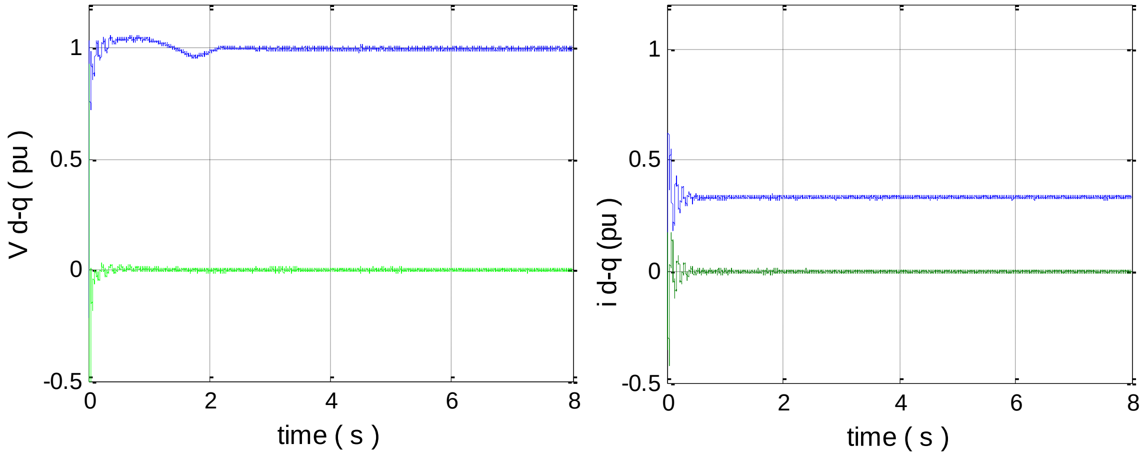


Figure 5.30: I d_q of VSC3

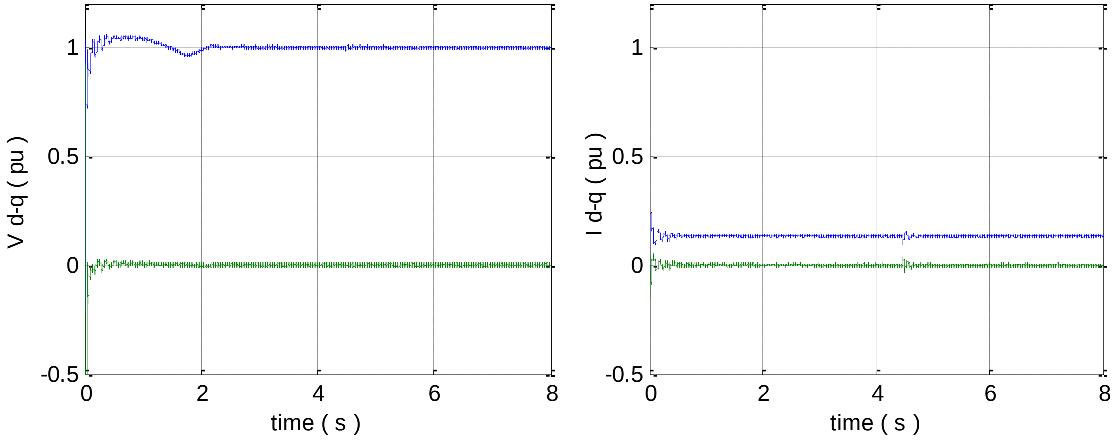


Figure 5.31: I d_q of VSC1

The simulation results show that using SOPs topology for connecting the micro grid to the main network gives a high improvement of the transient stability and the service quality. The same three phase short circuit is supposed to be at the main grid side, the accrued at t=4.5s and it is cleared after 10 ms using the fast response of the SOPs characteristic, the battery aims to maintain the dc-link voltage at a constant value. The effect of the fault on the micro-grid parameters is neglected. Hence the transient stability of the micro grid and the service quality at micro-grid side will not be affected by external disturbances. The energy storage system is used to sustain the power till the fault clearance or network reconfiguration reconnecting the micro-grid. If the power sources of the micro-grid can meet the loads than the power will be managed step by step without effecting the stability and the quality of the micro-grid.

- **Case 03:**

In this case we focus on analyzing the benefit of using sop to improve transient stability of micro grid during and after islanding conditions caused by a sudden three-phase fault occurring at the main grid. The same control strategy is considered for the simulation where the system does not have the energy storage system. the main topology is presented in figure5.31. the inverter-based DG delivers constant active power P=0.5 pu referring to its capacity. and the main grid gives active power support to the micro grid P=0.3pu referring to max power of SOP. the synchronous-based DG control the frequency and the voltage while the inverter-based DG and VSC of the SOP behaves as a slave unit and is controlled with *P&Q* control scheme.

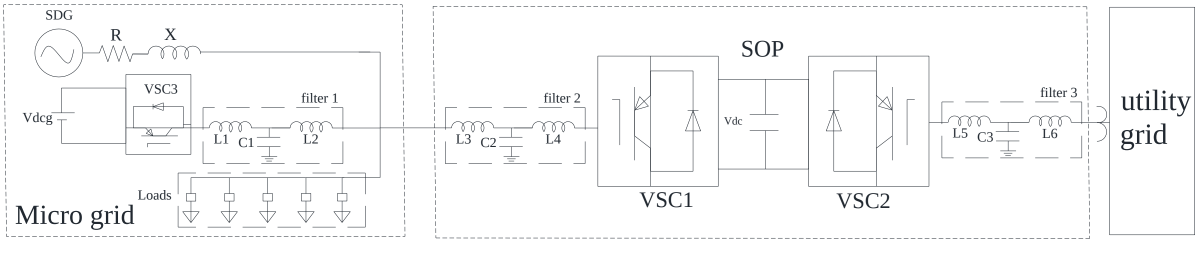


Figure 5.31: simple micro grid connected to utility grid based SOPs

The main Simulation diagrams are presented as follow:

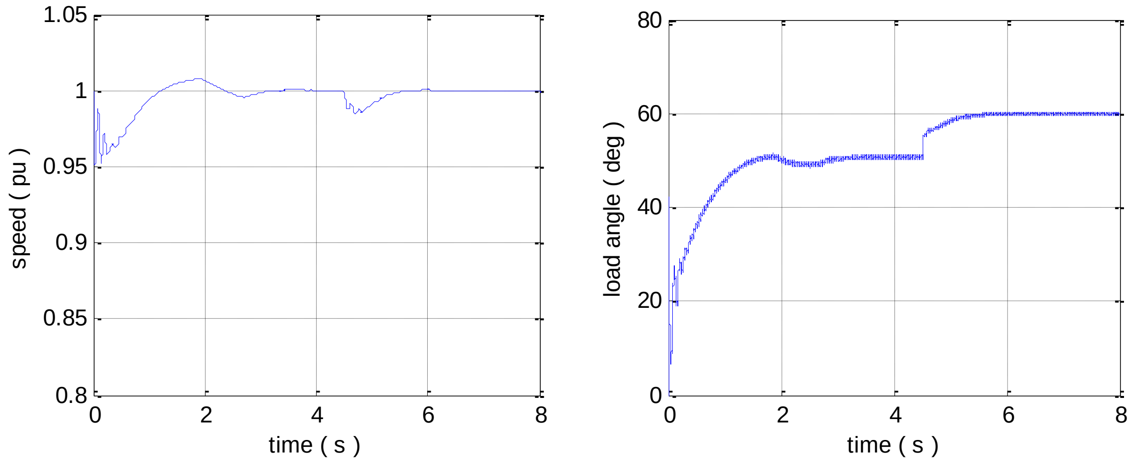


Figure 5.32: rotor speed and load angle of synchronous generator based diesel DG

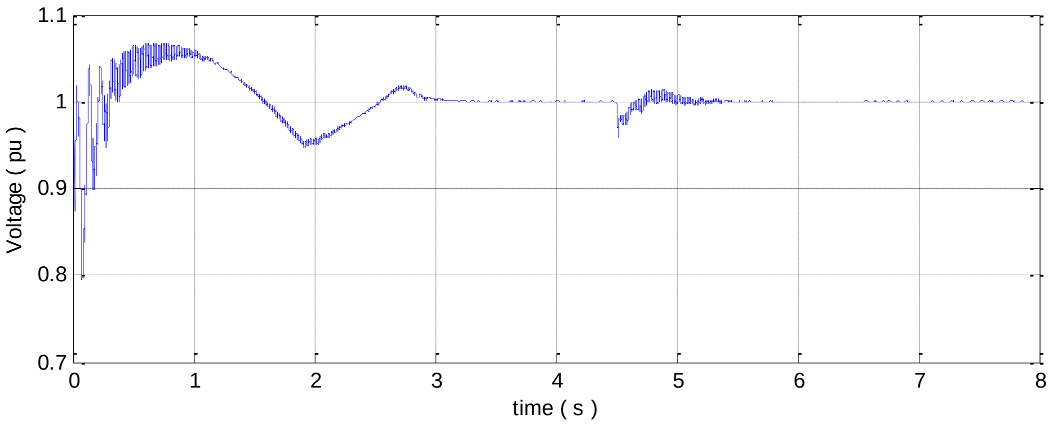


Figure 5.33: micro-grid voltage

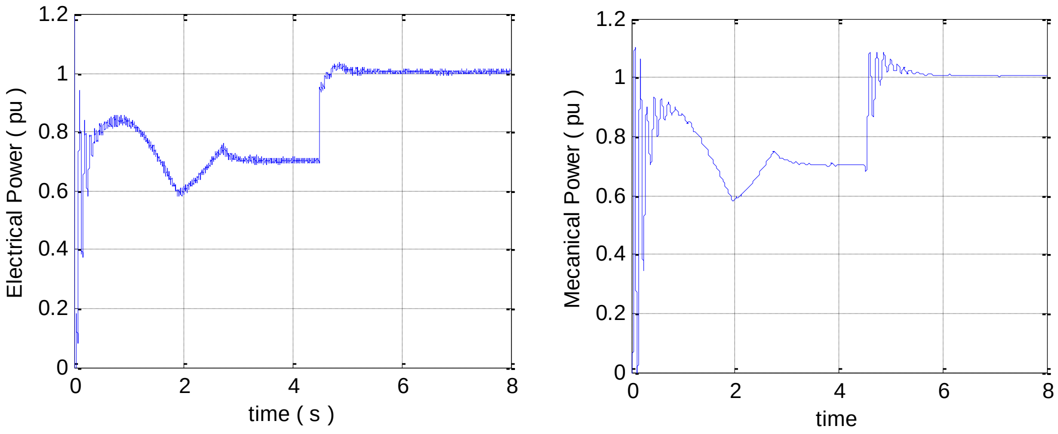


Figure 5.34: electrical and mechanical power of the synchronous generator

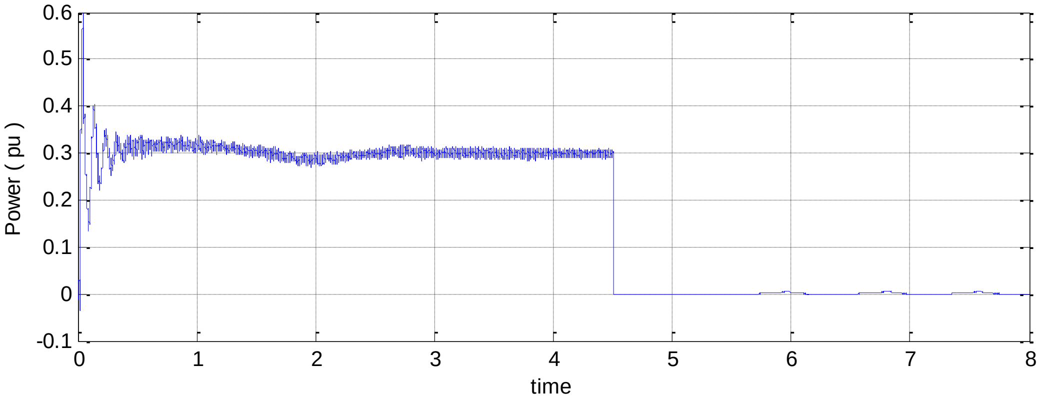


Figure 5.35: the delivered power from SOP to the micro grid

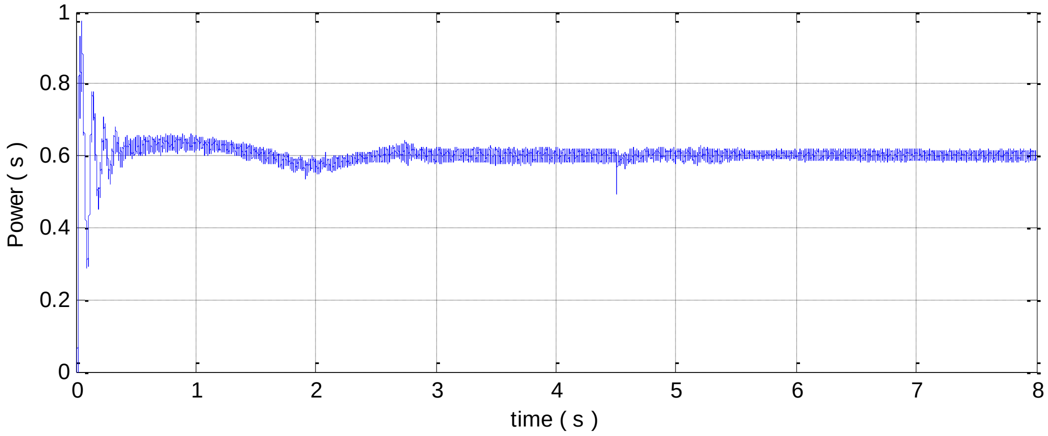


Figure 5.36:VSC3 delivered power from DC source to the micro grid

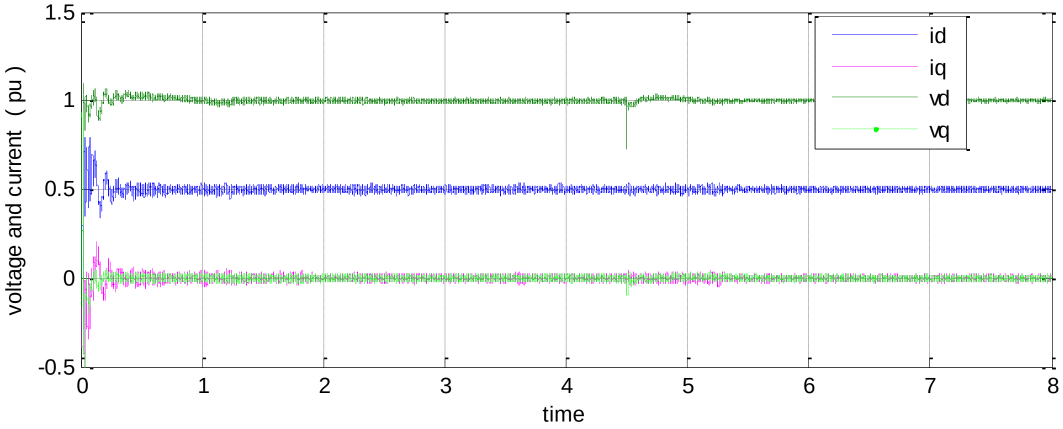


Figure 5.37: V d_q and I d_q of VSC3

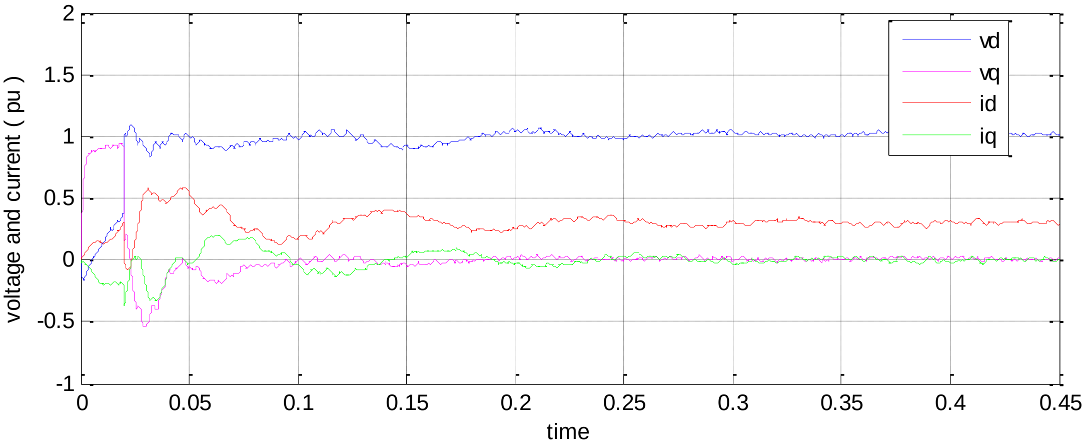


Figure 5.38:Vd_q and I d_q of VSC1 before disconnection mode

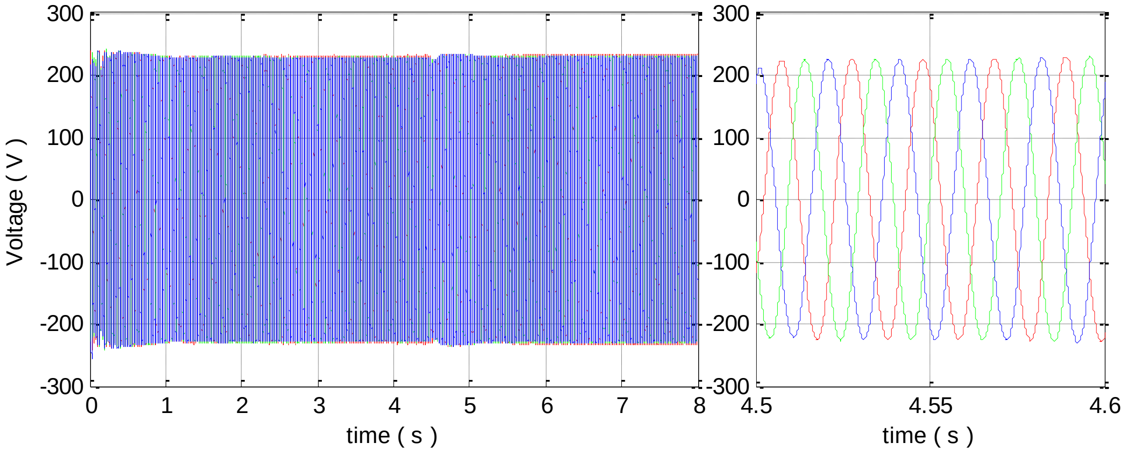


Figure 5.39: Voltage of VSC3 terminal

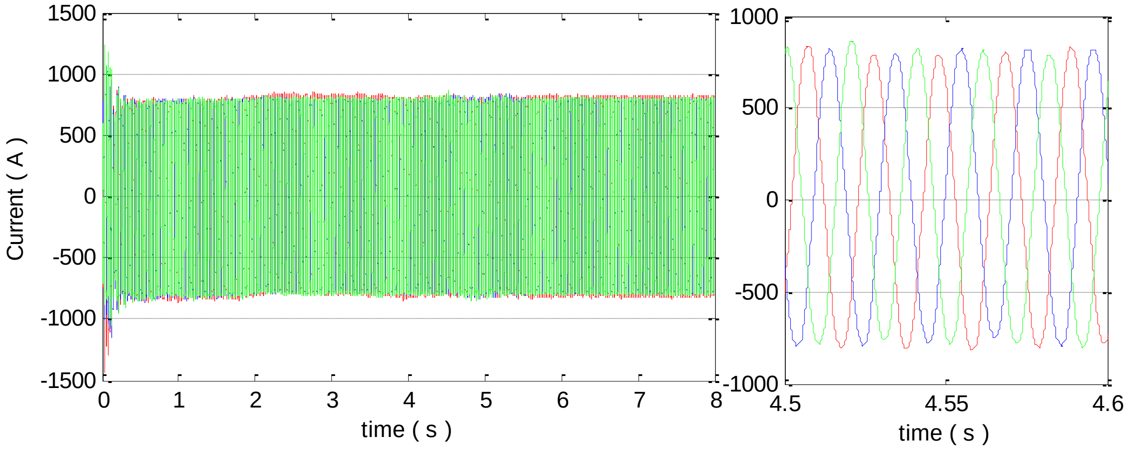


Figure 5.40: Current of VSC3 terminals

The same time of disturbance is considered in this case t=4.5s, the fault is fast isolated by disabling the faulted side VSC1 and VSC2, assuming that it is cleared after 10 ms. The simulation of connecting micro grid to the main grid using SOPs without energy storage system show that an external disturbance does not have a great effect on the micro-grid when the power transferred between them is not very important due to the fast disconnection characteristic of the SOPs. Where the only effect on the micro-grid is the change of power equilibrium.

The SOPs interface is proposed in many literatures to replace normal open loop in distribution network, it could be used to enhance the steady state as well as the transient stability of distribution network with presence of DGs, where it gives fast network reconfiguration, voltage control, power transfer control. Further network disturbances or faults on one connected feeder can be isolated from the other side by VSCs, and the transient overvoltage and overcurrent of VSCs are able to be limited by control strategies. Looking for this characteristic, we proposed to use SOPs for micro-grid and main grid interface, thus it beside the sited advantages it gives a high improvement of the micro-grid transient stability. Even for micro-grid with small inertia.

5.3. Summary

In this chapter local control strategy has been proposed for transient stability Improvement of synchronous distributed generation with small inertia, the basic principle of the proposed local control have been investigated and discussed using simulation and analyzing.

Modified topology for connecting DGs to the distribution network have been proposed and discussed using simulation, the analyses have been realized for the purpose of transient stability improvement of distributed generation with small inertia, the proposed topology is based on using soft open points as interface between micro grid and the utility grid.

The simulation results present the important of the proposed methods, this method will present a good advantage in smart grids.

6. Chapter 06: Conclusions and contributions

6.1. Conclusion

This thesis tackled the problem of distribution network stability with presence of distributed generations in the context of integrating new DGs or increasing penetration level. this work focused on the transient stability problems as well as voltage stability problems from side of the advantages and disadvantages of integrating DGs from side of effect on the network voltage, power losses and the effect between DGs, optimization and improvement in integration of DGs from different sides (voltage stability, voltage profile, power loss, critical clearing time of DGs). Chapter 1 introduced the stability problems in distribution network with presence of DGs. Chapter 1 introduced the problem of the impact of DG units on voltage stability. Chapter 2 provided an overview on the Distributed Generation and system stability, type of stability, impact of DGs on power system, general molding used for stability assessment, and then provided the different type and technologies of DGs and the recommended DGs for algeria future electric network. Chapter 3 provided the different method could be used for transient and steady state stability assessment of distribution network with presence of DGs. Chapter 4 utilized the DG units for steady state parameters improvement by proposing a method to locate and size the DG units. Then provided total analyses on the transient stability of DGs in distribution network and utilized the proposed method for both steady state and transient stability improvement. Chapter 5 provided transient stability improvement by proposing methods to control and to connect the DG units with the utility grid. The following points summarize the work presented in this thesis:

1. Distribution grids are being transformed from passive to active networks by integrating distributed generation (DG). Hence beside the voltage stability problem known in distribution network, DGs penetration have introduced the transient stability problem in distribution network, therefore analyzing the transient stability in DNs become necessaire function to insure the service continuity and network security. for this reason, chapter 3 is presented to introduce the different methods could be used to evaluate the steady state and transient stability of distribution network with presence of DGs. Many parameters have the ability to improve or worsen the voltage stability of the system, in this chapter we gave an example showing DGs location and sizing effect on the voltage stability and power losses.

2. The objective from integrating DGs in distribution network could be for voltage support or power support, however Placing DG units in distribution system can improve some parameters while worsen others if not well studied. for this reason, chapter 4 is presented to introduce method could be used to improve the all network parameters based on multi objective optimization genetic algorithms namely strength pareto evolutionary algorithms (SPEA), the proposed optimization technique was formulated to locate and size the DG units for voltage stability enhancement and power losses reduction. This formulation has considered the limits of distribution system such as voltage and current limits, the maximum penetration level. The proposed method is applied with different scenarios to consider different types and numbers of DG units. The method succeeded in placing and sizing the DG units based on their types and their numbers. the study conducted and formulated different cases and concluded that the optimal placement, size, type and numbers are depending of the state of loads in contrast to transmission network that have a greater sensitivity between $\Delta V/\Delta Q$ than $\Delta V/\Delta P$ due to high resistance to reactance ratio in radial distribution network.

3. Transient stability problem is one of the most drawbacks of integrating DGs in distribution network which limit its penetration level due to its small inertia. beside the disturbance location effect on the transient stability of DGs, chapter 4 have presented other factors effecting Transient stability of distributed generation with presence of DGs.in this study we analyzed the effect of installing new DGs on the transient stability of the other DGs, the effect of losing DGs during disturbance on the transient stability of the other DGs and the effect of sudden DGs disconnection on the steady state voltage of weak radial distribution network. In addition, the impact of locations and power share of DGs on the transient stability of a micro-grid during the transition mode subsequent to a disturbances have been simulated and discussed in this part of work. in this study we proposed to use the optimization method SPEA for both steady state and transient improvement. Different cases have been considered where the method was formulated to locate new DGs or size the DG units for voltage stability enhancement, critical clearing time increasing and reducing power losses. We concluded that the optimization technic using SPEA can optimally integrate DGs in distribution network (and in micro-grids) in term of steady state enhancement as well as transient stability improvement.

4. Small inertia of distributed generation presents a big problem of integrating DGs in distribution network in term of transient stability. Maintaining DGs synchronization with main grid and the stability of micro-grid suit to a disturbance is very important for the network stability, service quality and reliability. For that reasons chapter 5 introduced proposed methods for maintaining the synchronization of DGs-based synchronous machine with the utility grid suit to a short circuit occurrences using local control strategy based on transient power angle shifting where an ideal case has been analyzed. Further the chapter have introduced a proposed topology for connecting micro-grids with the main grid based on soft open points in order to improve the transient stability of the micro-grid when external disturbances are accrued.in this study we investigate the micro-grid behavior during transient faults-forced islanding conditions. In case of normal grid connection and the case of using the proposed topology. Analyzation study have been conducted on micro-grid including a mix of synchronous and inverter-based DG where a constant load is considered. We concluded that using power electronic technologies to integrate DGs in distribution network will improve the transient stability of distribution network with presence of DGs.

6.2 Contributions

The main contributions of this thesis can be highlighted as follows:

1. Investigation on using strength pareto evolutionary algorithms to place and size the DG units in radial distribution network to improve the voltage stability and reduce active and reactive power losses.
2. Investigate the effect of losing DGs on the voltage profile and stability in radial distribution network.
3. Modifying the buck word – forward sweep to be used for simulation the transient stability of radial distribution network with presence of DGs.
4. Investigate the effect of integrating new DGs on the transient stability of radial distribution network with presence of DGs, considering DGs based on synchronous machine. and squirrel cage induction generators.
5. Investigate the impact of DSGs locations and power share on the transient stability of a micro-grid subsequent to a disturbances triggered islanding.
6. Investigation on use SPEA algorithms to place and size DGs for both steady state and transient stability improvement.
7. Investigation on use SPEA algorithms to select the optimal locations and powers share of DSGs for both steady state and transient stability improvement of micro-grid subsequent to a fault triggered islanding.
8. Investigate the proposed control and connection topology of synchronous DGs and micro-grid with the utility grid to improve the transient stability.

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APPENDEXES

APPENDIX A:

TABLE 1: System data for modified 33-bus distribution network

Line #	**Node** *i*	**Node** *j*	**R (Ω)**	**X(Ω)**	**Load at node *j***		**Line** #	**Node*i***	**Node** *j*	**R (Ω)**	**X (Ω)**	**Load at node *i***	
					P(kw)	Q(kvar)						**P(kw)**	**Q(kw)**
1	1	2	0.0922	0.047	100	60	20	20	21	0.4095	0.4784	90	40
2	2	3	0.493	0.2512	90	40	21	21	22	0.7089	0.9373	90	40
3	3	4	0.3661	0.1864	120	80	22	3	23	0.4512	0.3084	90	50
4	4	5	0.3811	0.1941	60	30	23	24	25	0.8980	0.7091	420	200
5	5	6	0.8190	0.7070	60	20	24	24	25	0.8980	0.7071	420	200
6	6	7	0.1872	0.6188	200	100	25	6	26	0.2031	0.1034	60	25
7	7	8	0.7115	0.2351	200	100	26	26	27	0.2842	0.1474	60	25
8	8	9	1.0299	0.7400	60	20	27	27	28	1.0589	0.9338	60	20
9	9	10	1.044	0.7400	60	20	28	28	29	0.8043	0.7006	120	70
10	10	11	0.1967	0.0651	45	30	29	29	30	.5074	0.2585	200	100
11	11	12	0.3744	0.1298	60	35	30	30	31	0.9745	0.9629	150	70
12	12	13	1.4680	1.1549	60	35	31	31	32	0.3105	0.3619	210	100
13	13	14	0.5416	0.7129	120	80	32	32	33	0.3411	0.5302	60	40
14	14	15	0.5909	0.5260	60	10	-	-	-	-	-	-	-
15	15	16	0.7462	0.5449	60	20	-	-	-	-	-	-	-
16	16	17	1.2889	1.7210	60	20	-	-	-	-	-	-	-
17	17	18	0.7320	0.5739	90	40	-	-	-	-	-	-	-
18	2	19	0.1640	0.1565	90	40	-	-	-	-	-	-	-
19	19	20	1.5042	1.3555	90	40	-	-	-	-	-	-	-

TABLE 2: System data of 12 buses and 11 branches system

Branch no.	Sending end	Receiving end	R (ohms)	X (ohms)	**Load at node *i***	
					PL (kW)	QL(kVAR)
1 2 3 4 5 6 7 8 9 10 11	1 2 3 4 5 6 7 8 9 10 11	2 3 4 5 6 7 8 9 10 11 12	1.093 1.184 2.095 3.188 1.093 1.002 4.403 5.642 2.89 1.514 1.238	0.455 0.494 0.873 1.329 0.455 0.417 1.215 1.597 0.818 0.428 0.351	0 60 40 55 30 20 55 45 40 35 40 15	0 60 30 55 30 15 55 45 40 30 30 15

TABLE 3: System data for modified 119-bus distribution network

Line #	**Node *i***	**Node *j***	**R (Ω)**	**X(Ω)**	**Load at node *j***		**Line #**	**Node*i***	**Node *j***	**R (Ω)**	**X (Ω)**	**Load at node *i***	
					P(kw)	Q(kvar)						**P(kw)**	**Q(kw)**
1	1	2	0.036	0.01296	101.14	0.12	60	60	61	0.207	0.0747	90.758	0.69
2	2	3	0.033	0.01188	11.292	0.11	61	61	62	0.247	0.8922	47.7	0.823
3	2	4	0.045	0.0162	21.845	0.15	62	31	63	0.187	0.261	369.7	0.623
4	4	5	0.015	0.054	63.602	0.05	63	63	64	0.133	0.099	321.64	0.443
5	5	6	0.015	0.054	68.604	0.05	64	64	65	0.070	0.044	150.64	0.223
6	6	7	0.015	0.0125	61.725	0.05	65	1	66	0.028	0.0418	463.74	0.093
7	7	8	0.018	0.014	11.503	0.06	66	66	67	0.117	0.2016	52.006	0.39
8	8	9	0.021	0.063	51.073	0.07	67	67	68	0.255	0.0918	100.34	0.85
9	2	10	0.166	0.1344	106.77	0.553	68	68	69	0.21	0.0759	193.5	0.7
10	10	11	0.112	0.0789	75.99	0.373	69	69	70	0.383	0.138	26.713	1.277
11	11	12	0.187	0.313	18.687	0.623	70	70	71	0.504	0.3303	25.257	1.68
12	12	13	0.142	0.1512	23.22	0.473	71	71	72	0.4	0.1461	38.713	1.353
13	13	14	0.18	0.118	117.5	0.6	72	72	73	0.962	0.761	395.14	3.207
14	14	15	0.15	0.045	28.79	0.5	73	73	74	0.165	0.06	239.74	0.55
15	15	16	0.16	0.18	26.45	0.533	74	74	75	0.303	0.1092	84.363	1.01
16	16	17	0.157	0.171	25.23	0.523	75	75	76	0.303	0.1092	22.482	1.01
17	11	18	0.218	0.285	11.906	0.727	76	76	77	0.206	0.144	1614.775	110.687
18	18	19	0.118	0.185	78.523	0.393	77	77	78	0.233	0.084	129.817	110.777
19	19	20	0.16	0.196	351.4	0.533	78	78	79	0.591	0.1773	1122.43	111.97
20	20	21	0.12	0.189	164.2	0.4	79	79	80	0.126	0.0453	145.37	110.42
21	21	22	0.12	0.0789	54.594	0.4	80	67	81	0.559	0.3687	223.22	1.863
22	22	23	1.41	0.723	39.65	4.7	81	81	82	0.186	0.1227	162.47	0.62
23	23	24	0.293	0.1348	95.178	0.977	82	82	83	0.186	0.1227	437.92	0.62
24	24	25	0.133	0.104	150.22	0.443	83	83	84	0.26	0.139	183.03	0.867
25	25	26	0.178	0.134	24.62	0.593	84	84	85	0.154	0.148	183.03	0.513
26	26	27	0.178	0.134	24.62	0.593	85	85	86	0.23	0.128	119.29	0.767
27	27	28	0.1866	0.127	53.336	0.622	86	86	87	0.252	0.106	27.96	0.84
28	4	29	0.015	0.0296	522.62	0.05	87	87	88	0.18	0.148	26.515	0.6
29	29	30	0.012	0.0276	59.117	0.04	88	82	89	0.16	0.182	257.16	0.533
30	30	31	0.12	0.2766	99.554	0.4	89	89	90	0.2	0.23	20.6	0.667
31	31	32	0.21	0.243	318.5	0.7	90	90	91	0.16	0.393	11.806	0.533
32	32	33	0.12	0.054	456.14	0.4	91	91	92	0.16	0.393	11.806	0.533
33	33	34	0.178	0.234	136.79	0.593	92	68	93	0.669	0.2412	42.96	2.23
34	34	35	0.178	0.234	83.302	0.593	93	93	94	0.266	0.1227	34.93	0.887
35	35	36	0.154	0.162	93.082	0.513	94	94	95	0.266	0.1227	66.79	0.887
36	36	37	0.21	0.1383	42.361	0.7	95	95	96	0.266	0.1227	81.748	0.887
37	37	38	0.12	0.0789	51.653	0.4	96	96	97	0.266	0.1227	66.526	0.887
38	38	39	0.15	0.0987	57.965	0.5	97	97	98	0.233	0.115	15.96	0.777
39	39	40	0.15	0.0987	1205.1	0.5	98	98	99	0.496	0.138	60.48	1.653
40	40	41	0.24	0.1581	146.66	0.8	99	95	100	0.196	0.18	224.85	0.653
41	41	42	0.12	0.0789	56.608	0.4	100	100	101	0.196	0.18	367.42	0.653
42	42	43	0.405	0.1458	40.184	1.35	101	101	102	0.1866	0.122	11.7	0.622
43	43	44	0.405	0.1458	283.41	1.35	102	102	103	0.0746	0.318	30.392	0.249
44	44	45	0.405	0.1458	283.41	1.35	103	103	104	0.0746	0.318	30.392	0.249
45	30	46	0.33	0.194	55.134	1.1	104	1	105	0.0625	0.0265	47.572	0.208
46	46	47	0.31	0.194	38.998	1.033	105	105	106	0.1501	0.234	350.3	0.5
47	47	48	0.13	0.194	342.6	0.433	106	106	107	0.1347	0.0888	449.29	0.449
48	48	49	0.28	0.15	278.56	0.933	107	107	108	0.2307	0.1203	168.46	0.769
49	49	50	1.18	0.85	240.24	3.933	108	108	109	0.447	0.1608	134.25	1.49
50	50	51	0.42	0.2436	66.562	1.4	109	109	110	0.1632	0.0588	66.024	0.544
51	51	52	0.27	0.0972	39.76	0.9	110	110	111	0.33	0.099	83.647	1.1

52	52	53	0.339	0.1221	31.964	1.13	111	111	112	0.156	0.0561	419.34	0.52
53	53	54	0.27	0.1779	20.758	0.9	112	112	113	0.3819	0.1374	135.88	1.273
54	30	55	0.391	0.141	26.86	1.303	113	113	114	0.1626	0.0585	387.21	0.542
55	55	56	0.406	0.1461	88.38	1.353	114	114	115	0.3819	0.1374	173.46	1.273
56	56	57	0.406	0.1461	55.436	1.353	115	115	116	0.2445	0.0879	898.55	0.815
57	57	58	0.706	0.5461	332.4	2.353	116	116	117	0.2088	0.0753	215.37	0.696
58	58	59	0.338	0.1218	16.83	1.127	117	117	118	0.2301	0.0828	40.97	0.767
59	59	60	0.338	6	49.156	1.127	118	105	119	0.6102	0.2196	192.9	2.034

Table 4: System data for modified 34-bus distribution network

Line data			**Bus data**				
from bus To bus	**R (Ω)**	**X (Ω)**	Bus	*P*max (MW)	*Q*max (MVAR)	*P*min (MW)	Qmin(MW)
1- 2	0.3492	0.2034	1	0	0	0	0
2- 3	0.5572	0.3246	2	0	0	0	0
3- 4	0.1614	0.0602	3	0	0	0	0
4- 5	0.0424	0.0282	4	0.45	0.22	0.12	0.06
5- 6	0.1515	0.0352	5	0.30	0.15	0.04	0.02
6 -7	0.2861	0.0754	6	0.02	0.01	0.01	0.00
7- 8	0.0374	0.0193	7	0.06	0.03	0.03	0.01
8- 9	0.0683	0.0398	8	0.06	0.03	0.04	0.02
9- 10	0.0296	0.0196	9	0.17	0.08	0.05	0.02
10- 11	0.0463	0.0307	10	0.26	0.12	0.06	0.03
11- 12	0.0868	0.0576	11	0.28	0.14	0.06	0.03
12- 13	0.1962	0.0998	12	0.48	0.23	0.23	0.11
13 -14	0.0064	0.0026	13	0.23	0.11	0.03	0.01
14- 15	0.2288	0.0915	14	0.07	0.03	0.02	0.01
15 -16	0.1984	0.0794	15	0.41	0.20	0.08	0.04
16 -17	0.4847	0.1304	16	0.27	0.13	0.03	0.01
17- 18	0.2026	0.0652	17	0.02	0.01	0.01	0.00
18- 19	0.4071	0.0739	18	0.06	0.03	0.03	0.01
3 -20	0.0020	0.0007	19	0.11	0.05	0.04	0.02
20- 21	0.2432	0.0973	20	0.06	0.03	0.02	0.01
21- 22	0.0739	0.0276	21	0.03	0.03	0.01	0.00
22- 23	0.1750	0.0652	22	0.09	0.03	0.02	0.01
23 -24	0.0584	0.0218	23	0.09	0.05	0.04	0.02
24 -25	0.1544	0.1024	24	0.05	0.04	0.02	0.01
25- 26	0.4000	0.1600	25	0.09	0.03	0.03	0.01
26- 27	0.1848	0.0800	26	0.09	0.04	0.03	0.01
27- 28	0.1062	0.0704	27	0.08	0.04	0.03	0.01
28 -29	0.1980	0.0773	28	0.08	0.04	0.04	0.02
29- 30	0.2834	0.1128	29	0.06	0.04	0.03	0.01
30- 31	0.1152	0.0454	30	0.09	0.03	0.05	0.02
31-32	0.1280	0.0512	31	0.09	0.04	0.05	0.02
32 -33	0.0895	0.0334	32	0.05	0.04	0.03	0.01
33- 34	0.1293	0.0517	33	0.06	0.02	0.03	0.01
			34	0.05	0.03	0.04	0.02

APENDIX B:

DGS based SCIG specifications:

Based on machine nominal values, the following are in per unit:

parameters	SCIG1	SCIG2
nominal power (kW)	700	2000
nominal L-L voltage (kv)	0.690	0.690
nominal frequency (Hz)	60	60
stator resistance pu	0.0279	0.048
stator inductance pu	0.00086	0.00019
rotor resistance pu	0.016	0.018
rotor inductance pu	0.000304	0.0002
mutual inductance: pu	0.015	0.010
IG inertia (s)	0.5	0.8

Transformers characteristics: SCIGs are connected to the network using the following transformers

Parameters	**Trf1**	**Trf2**
Rated power (MVA)	1	2.5
Primary voltage (kV)	0.69	0.69
Secondary voltage (kV)	21	21
R (p.u)	0.015	0.015
X (p.u)	0.058	0.058

Synchronous generator characteristics:

Based on machine nominal values, the following are in per unit:

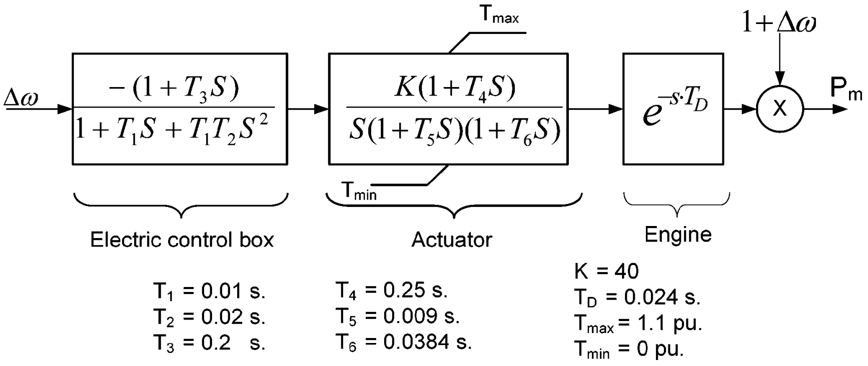
parameters	**SDG1**	**SDG2**	**SDG3**
Rated power (MVA)	1	1.2	5
nominal power (MW)	0.75	1	4
nominal L-L voltage (KV)	0.48	0.4	11
nominal frequency(Hz)	60	60	60
stator resistance (pu)	0.003	0.05	0.00012
leakage reactance (pu)	0.18	0.19	0.0765
Inertia coefficient (MW-S/MVA)	1.3	1.5	2
Axe d			
Reactance (pu)	1.305	0.94	0.89
Transient reactance (pu)	0.296	0.25	0.0193
sub transient reactance (pu)	0.252	0.22	0.0139
transient open circuit time constant – T'd0 (s)	3.5	1.75	0.67
Axe q			
Reactance (pu)	0.474	0.61	1.0478
Transient reactance (pu)	0.243	0.21	0.024
sub transient reactance (pu)	0.243	0.2	0.015

Transformers characteristics: **SGS are connected to the network using the following transformers**

Parameters	**Trf1**	**Trf2**	**Trf3**
Rated power (MVA)	1.25	1.6	6
Primary voltage (kV)	0.48	1	11
Secondary voltage (kV)	21	21	21
R (p.u)	0.011	0.012	0.016
X (p.u)	0.058	0.0637	0.078

TABLE : Transformers characteristics

Appendix C:



Schematic layout and parameters of the diesel generator governor model [100]

Excitation generator control:

parallel PI Voltage regulator: kp = 2, ki=50.

Output limits:

Upper 0 pu; lower 3.5 pu;

Synchronous generator characteristics:

Rated power (MVA)	1
nominal power (MW)	0.75
nominal L-L voltage (KV)	0.4
nominal frequency(Hz)	50
stator resistance (pu)	0.003
leakage reactance (pu)	0.18
Inertia coefficient (MW-S/MVA)	0.5
Axe d	
Reactance (pu)	1.305
Transient reactance (pu)	0.296
sub transient reactance (pu)	0.252
Axe q	
Reactance (pu)	0.474
sub transient reactance (pu)	0.243

Voltage source converters (VSC) parameters:

Power control: parallel PI with constant kp = 0.5, ki=50.
Current control: parallel PI, with constants kp = 0.5, ki=300.
Regulateur PI for PLL with constants kp =180 , ki=3200 .

Filters parameters:

R=0.0001 hom

L=0.0004 H

C=0.005mF

Regulateur PI for Control of DC–DC converters: kp =100 , ki=300 .