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# VOLTAGE SECURITY IMPROVEMENT IN TRANSMISSION SYSTEMS UNDER HIGH PENETRATION OF RENEWABLES

## DOCTORAL THESIS SUMMARY

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# Abstract

When transmitting at ultra-high voltages, the operational power and reactive power ranges are substantially greater, or voltage control and reactive power balancing are more difficult to handle than at lower voltages.

Voltage management and reactive power correction in ultrahigh voltage (UHV) systems rely heavily on cooperation across voltage levels such as UHV, EUV, and others. An in-depth look into UHV AV systems' operating characteristics, voltage management, and reactive power compensation were conducted as part of this Thesis's contribution to the development of the applicable standard.

UHV system security and stability are aided by operational voltage management, which aims to maintain appropriate operating voltage, regulate reactive power distribution, as well as reduce grid losses. Many different types of reactive compensation equipment exist, including generators, synchrocons, controlled UHV reactor OLTC, shunt capacitor/reactor svc, as well as other reactive compensation equipment. There has been some discussion of using an automatic voltage regulation method, such as Automatic Voltage Control (AVC) or Voltage/Reactive Power Control (VQC).

Before adding additional power plants to a grid, it is vital to analyze long-term grid sufficiency, system balance, and dynamic stability. Throughout the day, we looked at various load and generation situations. The administration, economics, and efficiency of power systems are all impacted by the usage of renewable energy sources like wind and solar. With increased wind and solar power, the optimum conventional power generation mix may be altered. Preserving the safety and dependability of operations may need certain actions.

Transient stability may be improved by increasing the penetration of renewable energy sources (RES), we employed AVRs, PSSs, Governors, as well as SVC devices.

The Thesis deals some topics specific of Voltage security improvement for transmission systems, which have been of great interest since the beginning times of the interconnected power systems. Classical and modern methods of voltage regulation were addressed, and the SVC device was used among the FACTS devices, the best answer to a variety of technical issues with the power system's functioning. The thesis aims to enhance the voltage level and stability of the power system in steady state, emergency and post-emergency situations. Transient stability can be improved even in cases of high penetration of Renewable Energy Sources (RES), through the use of AVRs, PSSs, and governors as well as the SVC device.

In this study, NEPLAN, DIgSILENT PowerFactory and MATPOWER of the MATLAB environment were used in the steady state calculations, and DIgSILENT PowerFactory in the dynamic simulation.

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# CHAPTER 1: Introduction

## 1.1 Overview

Several similar voltage collapse catastrophes have occurred throughout the globe in recent decades, resulting in significant power system losses. Voltage difficulties will grow more problematic as more random as well as unknown factors are introduced to the grid in the future. Maintaining voltage stability and a good design of reactive power compensation are essential to ensure the stable and secure running of the power system when more UHV (Ultra High Voltage) transmission lines are installed. The standardization of voltage management and power compensation in UHV AC transmission is critical [1].

Power systems include three main parts: producing units, loads, as well as transmission & distribution networks. Generating units provide the energy, while loads use it. and carries power through the transmission & distribution network to the load sites[2]. The load demand has expanded rapidly in a competitive electrical market with the fast expansion of civilization. As a consequence, transmission networks are becoming overburdened, posing a danger to the power system's security, dependability, and stability, as well as making some generating patterns economically unviable. Though constructing additional transmission lines might alleviate the dire situation, it is difficult to do so owing to a variety of constraints, including environmental, right-of-way, and expense [3][4].

Renewable energy is becoming more essential in the production of power these days. Fossil fuels are not a viable future choice since they are non-Renewable Energy Sources that pollute the environment.

The availability of solar resources across the globe has made photovoltaic energy the most extensively used Renewable Energy Source (RES). Renewable energy is a reality in today's electrical landscape. The reduction of CO2 emissions and the improved efficiency for renewable technologies are two of the most important factors in their integration into energy networks.

As a result, non-renewable resource usage must be reduced, with renewable energy playing a vital role in the future [5]. Congestion management, security, transfer capabilities, as well as dependability may all benefit from FACTS devices[6]. Since the initial appearance of FACTS devices, continuous research and development has been carried out, from pioneering ideas to today's mature devices. The benefits of deploying FACTS devices in a network are already obvious, and they include improved power flow management and voltage support, as well as improved network stability and oscillation damping [7]. With the introduction of controlled thyristors devices based on power electronics, new avenues for improving power system stability were opened [8].

In power networks, static VAr compensators (SVCs) are the most often used shunt FACTS devices, since their prices are lower while still providing considerable system benefits. The SVC, which first appeared roughly two decades ago, is primarily used for voltage support as well as, when properly built, may help decrease power losses [9]. The reactive power support in the system is critical for maintaining an appropriate system voltage profile and assisting in the enhancement of security [6].

Power system stability has been a critical study topic in recent years, and it is a critical concern for large-scale systems. The transient stability of a long transmission system may be greatly improved by the management of excitation systems, which commonly comprises an automated voltage regulator (AVR) and a power system stabilizer (PSS)[10]. Elec. power grids are getting more stressed and complex as efficiency and reliability standards rise [11]. The power system is becoming more unstable and more difficult to manage as renewable energy are progressively incorporated into power transmission[12].

An electric power system's ability to operate safely and reliably is a must. Transient stability analysis is a critical component of power system design and operation[13]. To analyse the system's transient phenomena, the time-domain simulation can be divided into three phases: pre-fault, fault-on, and post-fault. Before a problem occurs, the pre-fault systems is really in a stable state. When a problem occurs, the system is indeed in fault-on state, as well as the protective function of the system clears it. In order to isolate the problem, circuit breakers must be opened to ensure that the system remains stable once it has been isolated. To ensure that the electric grid could resist and recover from large disturbances, transient analysis is required[14][15].

The necessity and opportunities of the subject of my thesis are coming from development of the Renewable Energy Sources (number and installed power) connected to power systems and increasing their penetration into the system due to the economic and environmental benefits of renewable energies. Where the new trend is to reduce carbon emissions and find an alternatives to classic fuels.

In this condition, we must have the impact studies of this trend and develop strategies to increase the security of energy supply and maintain the system, for security, economic and environmental necessities and to supply the end user with energy within the standard specifications.

## 1.2 Literature reviews

Since the issue of Voltage security improvement and power system security is important, researchers have taken care of this issue and developed algorithms for power flow, which include inexpensive FACTS devices and controllers (AVR-PSS-Governor), in order to provide safe and reliable power to customers within the specifications and without exceeding applicable power system restrictions. Research is still going on to meet the challenges with the help of the SVC device. The aim of this review is to gather information from the previous literature on voltage regulation and its security, the effect of renewable energies on the system and improving transient stability.

## 1.3 Problem Statement

Voltage stability may be determined using a number of various methods in the literature. They're all trying to figure out how likely a collapse is. However, these techniques have a number of flaws that have been uncovered. It is important to keep the voltage within acceptable limits according to the standard used for the power system because of its effects on the system. In addition, the penetration of Renewable Energies into power systems at a high level has become a necessity and a reality, so the power flow is not unidirectional anymore. Which leads to a change in voltage in high and medium voltage networks due to changing active and reactive power responses. Changes in the voltage-power property may affect the behavior of the system, so we will address in this Thesis also the effect of this high penetration of Renewable Energy Sources on power systems, and therefore the identification of our problem is to improve the voltage safety of transmission networks in power systems under the high penetration of renewable energies and we will address The traditional methods for improving the voltage level such as ( Tap changer, Shunt Capacitors and Reactors, Generator Regulator) in the steady state and modern methods such as the use of SVC device in the steady state and transient. Also, here in this Thesis we consider security criteria for the purpose of network security.

## 1.4 Objective

The objectives of the work in this thesis are to regulate and improving the voltage security of transmission networks by classical and modern methods with the presence of Renewable Energies and their high penetration.

Thus, controlling voltage levels under steady state as well as transient conditions and maintaining the security of the power system, and this is important in terms of meeting consumer needs and in terms of economic security, reducing maintenance costs and preserving equipment from damage. These goals will be achieved through:

1. Study of Voltage Regulation methods in Transmission Networks using Classic methods
2. Study of Voltage Regulation methods for transmission networks including RES
3. Understanding the Voltage regulation for transmission networks using FACTS devices
4. Improving transient stability as well as voltage control in the power system by combining SVC, AVR, PSS, and a governor.

## 1.5 Methodology

In order to achieve the above-mentioned objectives, briefly explain the steps for each section, starting with the first chapter, which represents the introduction and literary reviews that will provide us with information and experiences that have been implemented previously, and passing through the second chapter, which represents the general definitions of the electric power system, the power system stability, the security of the power system, and knowing the limits and restrictions For the power system to be taken into consideration, from Chapter Three to Chapter Six, they present the solutions to the problems that were mentioned in the problem statement.

# CHAPTER 2: Definitions and characteristics of power system

## 2.1 Generalities

It is possible to divide the power system into three major divisions: generating stations; transmission and distribution systems [44]. Power is generated by generators, consumed by loads, and delivered from generators to loads via the transmission system. Transmission systems serve as the connecting links between producing stations and distribution systems, and they also provide access to other power systems via interconnections with other power systems[45].

The term "transmission power system" usually refers to the high-voltage grid system of transmission lines and power transformers. “Distribution system” refers to the lower-voltage transmission lines and MV/LV transformers that are used to provide electricity directly to consumers. An electric power system is shown in Fig. 2-1, which shows the major components.

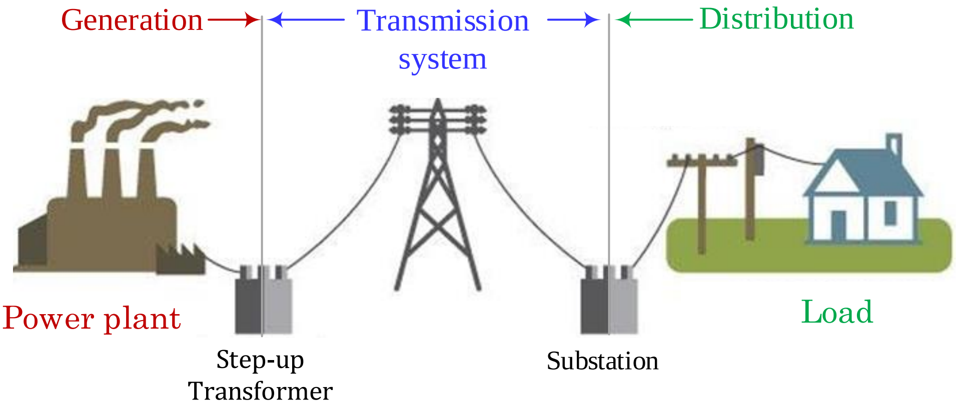


Figure 2-1. The main components of the power system[45].

The main function of the power system is to assemble power stations and load centers in order to provide the active and reactive powers required by the different loads connected to the system at a lower cost, with the required reliability and most efficiency as possible.

## 2.2 Definition of transfer capacity

In the field of electric power transmission, transfer capacity is a measure of an interconnected electric system's ability to reliably transmit or transfer power from one location to another via all transmission lines (or pathways) between those locations under defined system circumstances[47]. The units of transfer capacity are measured in terms of electric power, which is often stated in megawatts [MW]. Each individual electric system, power pool, control area, and sub region (or any combination of these) is considered to be a "area," as is any component of any one of these. The capacity to transfer information is also directed in nature. The transfer capacity from area A to B is not always equal to the transfer capability from area B to A, which is a common occurrence[48][49].

## 2.3 Power system stability

Power system stability is 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 system variables bounded so that practically the entire system remains intact[61][62].

We would also like to point out that the topics covered in this chapter were:

- ✓ Power system stability & Classification of power systems stability (Voltage stability and voltage collapse).
- ✓ Grid Hierarchical Voltage Regulation (Primary, Secondary and tertiary voltage regulation).
- ✓ Power System Security & Classification of system states and security control.

# CHAPTER 3: Voltage Regulation in Transmission Networks using Classic methods

## 3.1 Introduction

In order to guarantee the safety and reliability of the electric power system, voltage regulation services are essential. It's got to be on all the time. An ongoing effort to identify and monetize this auxiliary service is under way [99]. Current and voltage consumption must be managed in order to keep the voltage stable for system dependability. Voltage control may be performed by reactive power control because of the direct link between voltage as well as reactive power. Voltage can be kept constant at a nominal value no matter how so much power factor is required if adequate reactive power supplies are available. Regulating the voltage at a node may be used to regulate the amount if reactive power injection at that node. This raises the question of how voltage control differs from reactive power regulation, which is an important consideration. Each of the aforementioned process control has its own set of drawbacks. It is impossible to adjust voltage using reactive power because it is restricted by the reactive power resources available and by the realistic voltage restrictions at each node. If reactive power supplies are an issue, it is conceivable to regulate both voltage as well as reactive power, but just not at the same moment. If you're dealing with a transmission system, you'll need to adjust the voltage.

The voltages must be maintained within acceptable limits in the typical operating condition of the reactive power balancing [100]. When it comes to the quantity of reactive power generated and consumed, there is no difference. As a consequence, if the system's reactive power production and consumption are too high or too low, the voltage profile will be incorrect. Utility as well as transmission system operators (TSO) are clearly interested in enhancing reliability, security as well as an effective solution that has little effects on investment in terms of quality of supply.

Controlling the reactive power–voltage in power systems is essential both in regular operation and in an emergency. Electricity transmission at the requisite voltage quality and under ideal circumstances for both providers and customers is ensured during normal operation by this system. System security is enhanced in an emergency by increasing the margin of safety with regard to voltage instability limitations, therefore assuring uninterrupted operation and correct operational conditions for the biggest number of customers. Voltage control is a critical component in securing these outcomes. When dealing with voltage control as well as reactive power compensation issues at the transmission as well as distribution level, it is necessary to use a different strategy. There are two ways in which the high-voltage (HV) system may take use of the big generators' voltage–reactive power support: by allowing each distribution region to manage its own voltage; and by allowing each distribution area to manage its own voltage. Last but not least, the generation & distribution levels are controlled by distinct dispatching centres, which have a significant influence on the voltages in the distribution region, but not on the voltages in the EHV system [101].

The primary voltage control goals on the electricity network are as follows[51]:

- Ensure that the voltage is maintained at a suitable level.
- Reduce the amount of power system losses.
- Increasing the stability margin of the system voltage

A broad area voltage control and enough controlled reactive power reserves are essential to meet these goals. An operator's inability to keep track of the constantly changing operating circumstances of the energy systems has a significant impact on the voltage control issue.

Other topics covered in this chapter are:

- ✓ The relationship between voltage and active and reactive powers;
- ✓ Equipments for voltage and reactive power control;
- ✓ Voltage and reactive power continuous control devices.

## 3.2 Case Study

In this part, the voltage regulation in transmission networks was studied using the classical methods in two cases, the case I (four scenarios) about network (TEST2)[108], and the case II represent IRAQI- MAYSAN network (Part of the Southern Iraq Network) and all the calculations by using NEPLAN and DIgSILENT.

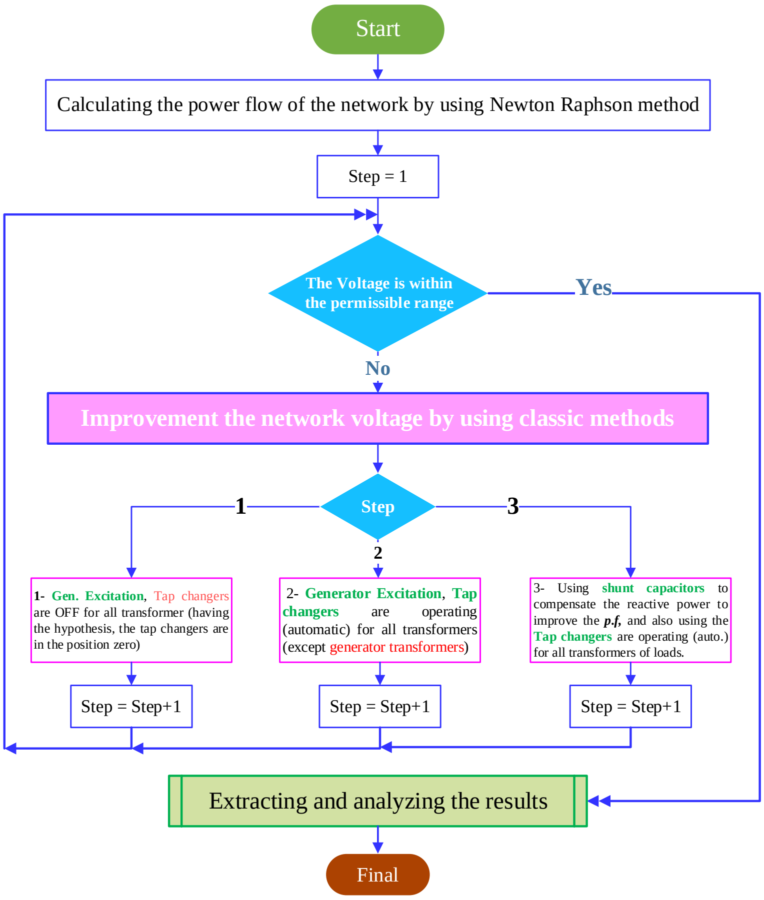


Figure 3-1. Flowchart of the case study Methodology

### 3.2.1 – Case 1: TEST 2 Network

### *3.2.1.A The first scenario:*

From NEPLAN and DIgSILENT, we calculate power flow and power losses through the branches of the network, assuming that all transformer tap changers are OFF for all transformers (having the hypothesis (the tap changers are in the position zero (0) for all transformers), and not use the generator excitation.

The Discussion of results S1

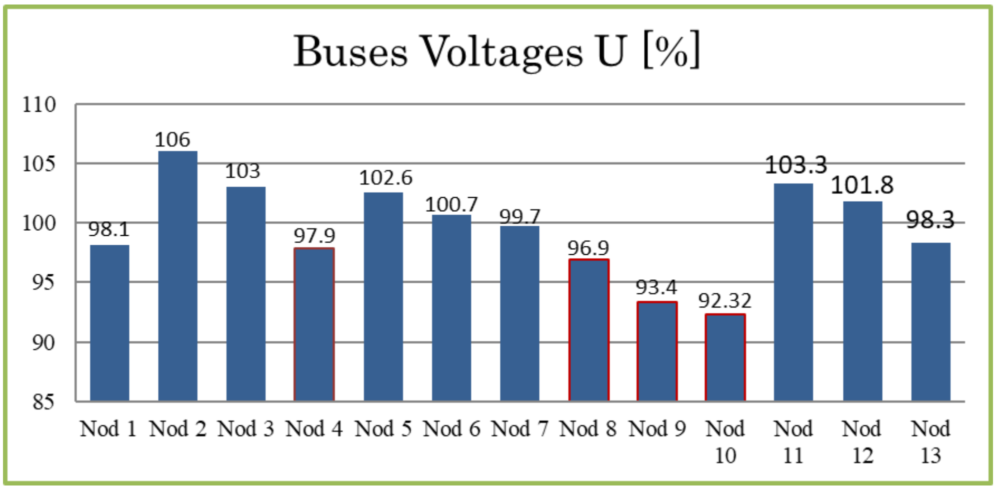


Figure 3-2. Nodes voltage (C1S1)

- Voltages are normal (i.e. within the permissible and recommended range) for generator nodes and line nodes as shown in figures 3-4 and 3-5.
- The generator voltage depends on the power factor of the load, the excitation voltage and the synchronous speed of the generator ($\underline{E} = \underline{U} + jX_S\underline{I}$ ); $X_S = \omega_0 L_s$ where $\omega_0$ is Angular velocity of the generator.
- In the Fig. 3-4, we can see a slight drop in the voltages of the Buses Voltages (4–8–9–10–13).
- We detect a big decrease at the nodes ( B-C2 ; B-C5 ; B-C6 ; B-C7 ; B-C8), as in shown in Fig. 3-5., Voltages angle to these nodes are big and ranging between (-10.9 to -16.4).

This is due to the increased impedance of the lines of these nodes, which is connected to the nodes above, in addition to the high current passaging to feeds the loads linked to the nodes above, causing the drop voltage between the sending and receiving nodes according to the relationship below:

$$\Delta \underline{V}_{AB} = \underline{V}_{send} - \underline{V}_{Receive} = \underline{ZI} \qquad \text{... (3.2) [51]}$$

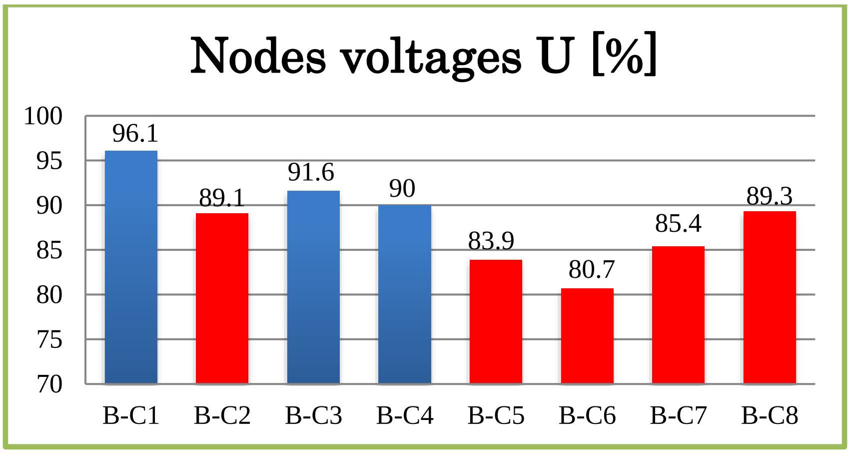


Figure 3-3. Loads Voltages U [%]

- The active total losses in network (30 MW), i.e. within the allowable and represents proportion 2.3% of total active generation
- While the reactive total losses in network (170 MVAr), is high and higher than the allowable and represents proportion 18.8% of total reactive generation, because there are inductive loads in the network, which cause drop voltage and therefore passing high-current, which leads to rise reactive losses, also the MVAr resulting from the transformers.

### *3.2.1.B The second scenario*

We will improve the network voltages by using the generators excitation and the Tap changers are not operating for all transformers, having the hypothesis (the tap changers are in the position zero (0) for all transformers), and From NEPLAN or DIgSILENT, we calculate power flow and power losses through the network.

Discussion of the results S2

The results above in the case of steady-state, and not operating the tap changer for all network transformers.

In this case, the network voltage was regulated by raising the voltage on the generating side via the excitation of generators.

- All nodes except N2–N11 have normal voltages (i.e., within the permissible and recommended ranges), as shown in Fig. 3-9.
- Voltages of generators nodes they are the same excitation value, voltages angle for these nodes are small;
- All the nodes Voltages within the allowable level, but less than 100%, because it depends on the type of load (inductive or capacitive) except BC1, it is higher than 100% because it has $P.f = 0.87$; as shown in below Fig. 3-8.

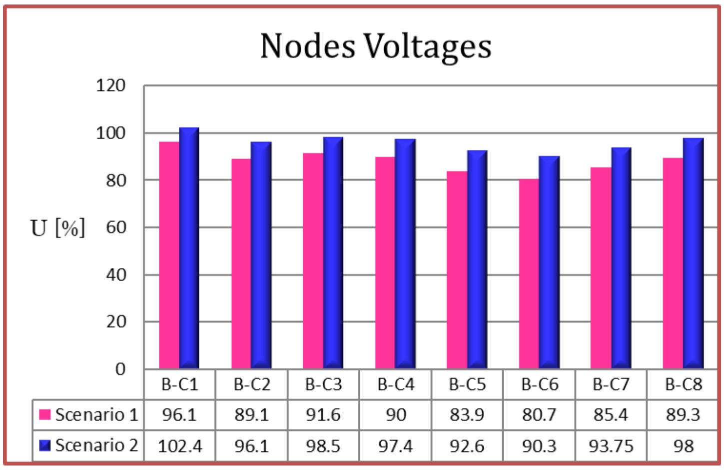


Figure 3-4. Loads Voltage (C1S1)

- We notice that a significant increase at the nodes (N2 – N11) more than allowable limit, this is because these nodes linked to generation, and connected lines in these nodes it's not loaded more than half capacity;

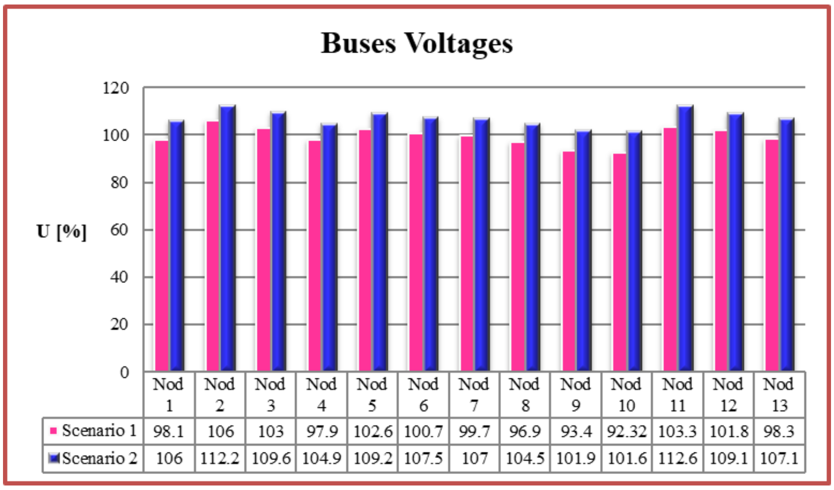


Figure 3-5. Nodes Voltages (C1S2)

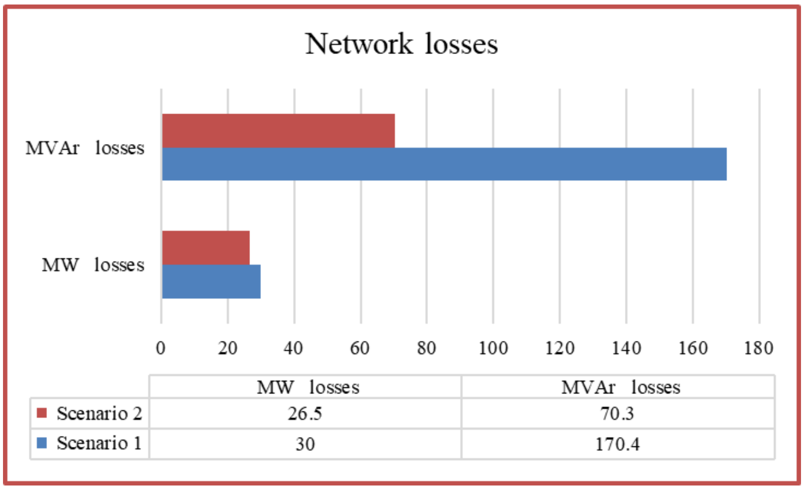


Figure 3-6. Network losses (C1S2)

According to Fig. (3–12), the active losses incurred in the network (26.5 [MW]) are normal, i.e. within acceptable limits, and represent 2.06% of total active generation. The reactive total losses in network (70.3 MVAr), s normal, i.e. within the allowable and represents proportion 8.2 % of total reactive generation.

We notice that the total losses $(P_{Losses}\ ,Q_{Losses})$ Less than losses $(P_{Losses}\ ,Q_{Losses})$ in the first scenario and that because of improved voltages by generators by excitation, increasing voltages leads to lower losses

### *3.2.1.C The Third Scenario:*

We will improve the network voltages by using the **generators excitation** and the **Tap changers** are operating (automatic) for all transformers (except generators transformers, having the hypothesis (the tap changers are in the position zero (0)), and From NEPLAN or DIgSILENT, we calculate power flow and power losses through the network.

Discussion of the results S3

In this scenario, we will operate all the Tap changers (automatic) for all transformers (except generators transformers) and using the excitation of generators to raise the voltage in generation side.

- We note that all the voltages in the all nodes are well as shown in figures (3-13) and 3-14;

- All the voltages of generators nodes are the same the proportion of generators excitation;
- All the Buses Voltages are well and ranging between 100% to 109%;
- The nodes Voltages are very excellent and they all about 100%.

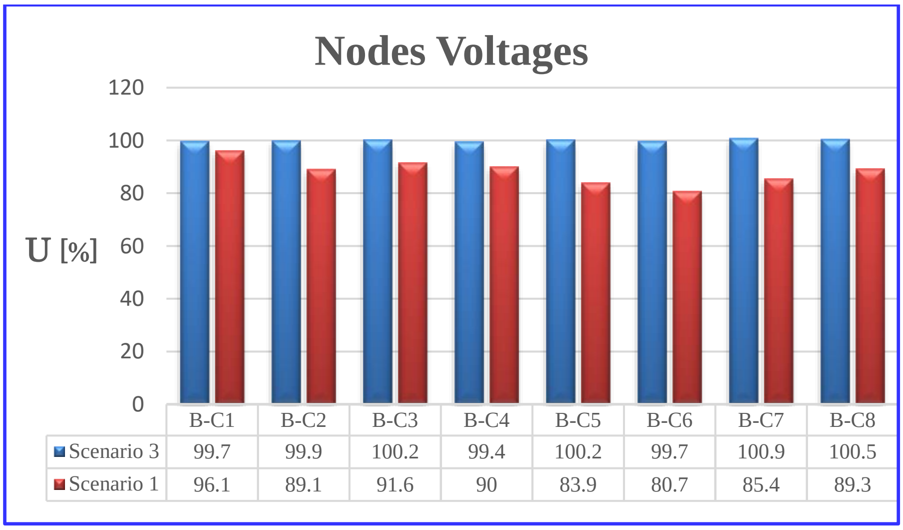


Figure 3-7. Loads Voltages (C1S3)

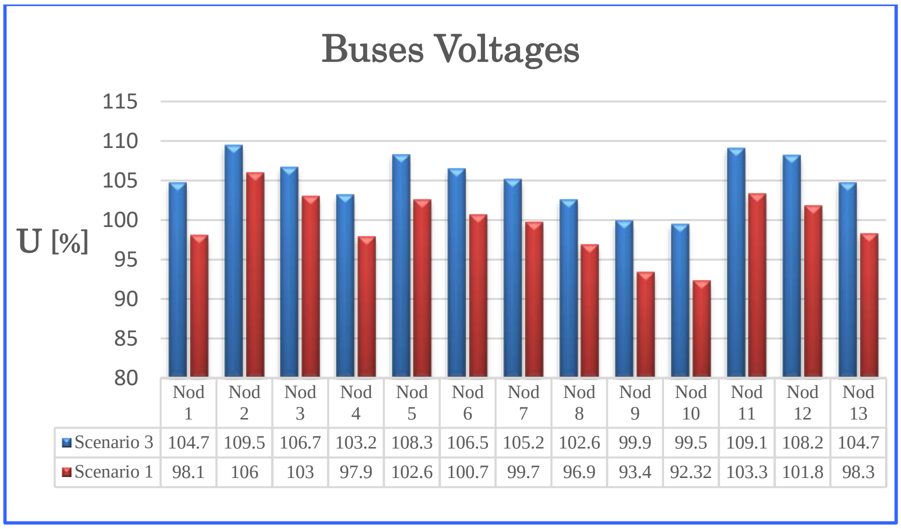


Figure 3-8. Nodes Voltages (C1S3)

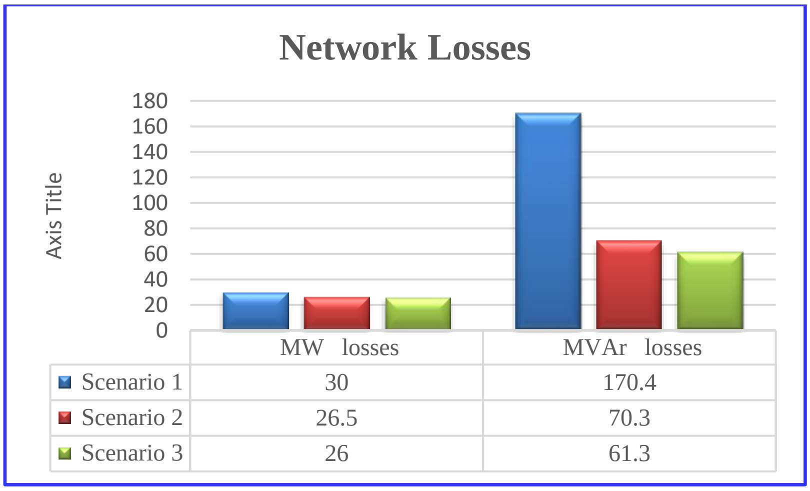


Figure 3-9. Network losses (C1S3)

- Active losses in the network are typical, i.e. within permissible limits, and account for 2% of total active generation, as shown in Fig. 3-15.
- The reactive total losses in network (61 [MVAr]), is normal, i.e. within the allowable and represents proportion 4.7 % of total reactive generation.
- ✓ We notice that the total losses ($P_{Losses}$ , $Q_{Losses}$) Less than losses in the first scenario and that because of improved voltages. The reason for the improved the voltages and regularity is to excitation of the generator and operates the tap changers, as the generator generates power with voltages higher than (100% of V operating) in order to compensate for voltage drops that happens at lines, and the tap changer is regulates the recommended voltages for loads.

### *3.2.1.D The fourth Scenario:*

In this scenario, we will improve the network voltages by using improving the power factor for the industrial and urban networks which that has the power factors are less than (0.92) by compensate reactive power by adding shunt capacitors. as well using the Tap changers are operating (automatic) for all transformers (except transformers of generators), and we do not use the generators excitation, and From NEPLAN or DIgSILENT, we calculate power flow and power losses through the network.

**Discussion of the results S4:** After improving the power factor, tap-changers (automatic) for all load transformers and not using generator excitations.

- We note that adding static capacitors depending on the power factor for the load;
- We note that values of voltages for all nodes voltages are excellent at about 100%, as shown in Fig. 3-16;
- We note that values of voltages for generators nodes are the same generation voltages 100%;

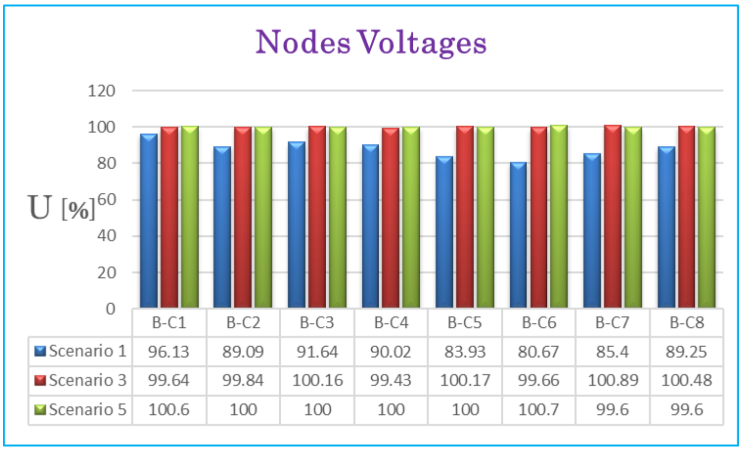


Figure 3-10. Loads Voltages (C1S4)

- We see that the voltage values for bus voltages are all OK and range between (100% - 108%) as shown in Fig. 3-17.

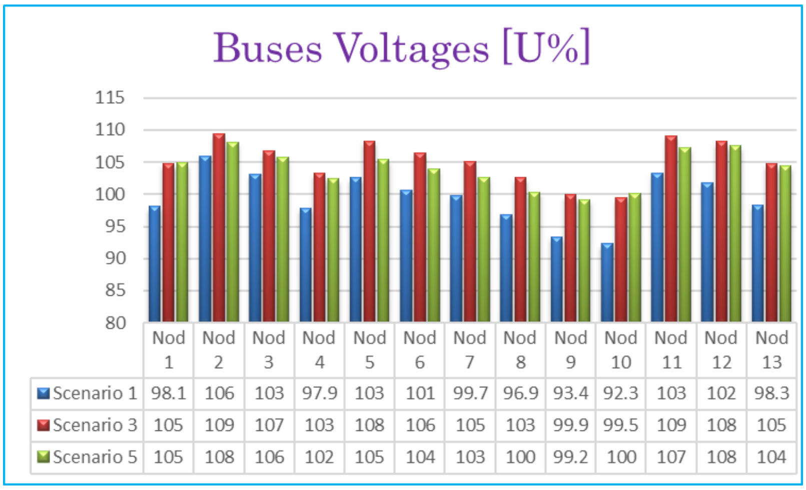


Figure 3-11. Nodes Voltages (C1S4)

- The active total losses in network 22.6 [MW], is little, i.e. within the allowable and represents proportion 1.75% of total active generation as shown in Fig. 3-21;
- The reactive total losses in network 18.7 [MVAr], is normal, i.e. within the allowable and represents proportion 2.95 % of total reactive generation, as shown in Fig. 3-21;
- ✓ We notice that all the voltages are very well and the total losses ($P_{Losses}$ , $Q_{Losses}$) are it is the least case for the network and represents the best operation of the network, and the reason is the improved power factors capability that improves voltages and thus increase load carry capabilities, in addition to operating the tap changer, which improves the voltages with required value for loads

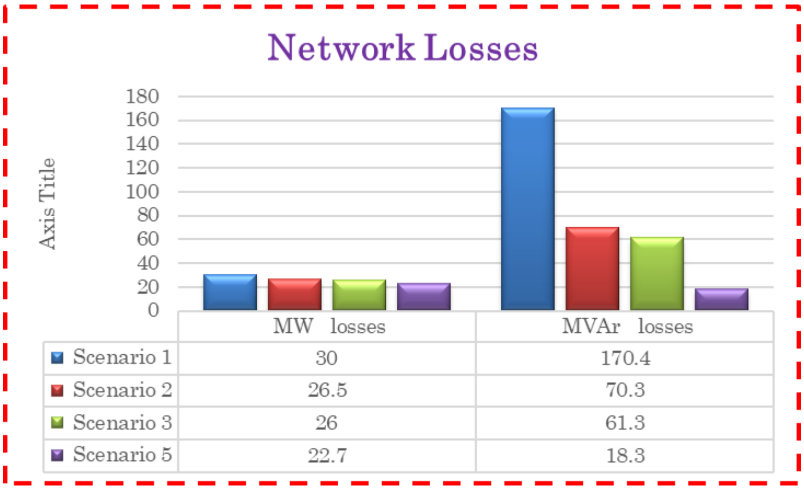


Figure 3-12. Network losses (C1S4)

We connected the Capacitors directly to the busbar, to minimize the losses and voltage drops. The Capacitors compensate locally the reactive power (MVAr) of the consumers and are distributed throughout the power system. The major features of shunt capacitors are their low cost and flexibility of installation and operation.

A lower power factor causes a higher current flow for a given load. As the line current increases, the voltage drops in the conductor increases, which may result in a lower voltage at the equipment. With an improved power factor, the voltage drop in the conductor is reduced, improving the voltage at the equipment. System conductor losses are proportional to the current squared and, since the current is reduced in direct proportion to the power factor improvement, the losses are inversely proportional to the square of the power factor.

# CHAPTER 4: Voltage Regulation and Renewable Energy Sources

## 4.1 Introduction

The voltage regulation service is a crucial auxiliary function that all system operators rely on to keep the power system safe and dependable. It has to be always running. On-going research is being carried out in order to better clarify how to measure and offer this added service. Voltage stability and system reliability need regulation of both current and voltage use[109]. Due to the close connection between reactive power and voltage, it is feasible to modify voltage by altering reactive power[100].

At the transmission as well as distribution level, a separate approach is needed to examine voltage management and reactive power compensation. When it comes to high-voltage (HV) grids, they can take full advantage of a voltage–reactive power support provided by large power generators, ability to control the overall grid, however when it comes to distribution grids, voltage control is typically applied to each area separately, every one of which is just a minor part of the whole distribution system. Finally, various dispatching centres and operators regulate transmission and distribution levels, and although EHV system functioning has a significant influence on distribution area voltages, the reverse is less so.

The following are the key voltage control goals on the transmission grid:

- Reducing power system losses is a priority, as is ensuring a constant high-voltage profile.
- Boosting the voltage stability range in the systems.

Both must be readily available at the distribution level in order to meet these objectives.

a) Reactive power reserves that can be controlled in the event of a contingency.
b) Wide-area voltage management system that is both efficient and automatic.

Some precautions may be required to maintain operational security and dependability at an acceptable level. The research typically looks at a variety of consequences with varying time scale resolutions, and both system-wide as well as local-level impacts (see Fig. 4-1). Distributed generation (DG) grid integration concerns focus on local and regional effects, rather than transmission and system-wide issues, because of the widespread use of DG and PV generation[18].

## 4.2 Renewables (Photovoltaic and wind turbines)

In the age of civilized technology, development and industrialization, the rapid and increasing growth of electric energy is saturated with fossil fuels[112], which are expensive, which are rapidly depleting and pollute the environment (the atmosphere). Reducing carbon dioxide emissions and increasing the efficiency of renewable technologies is one of the reasons for their incorporation into electric power systems [113]. This leads to a shift to clean, cheap, and carbon-free renewables[114]. which have also been divided into controlled Renewables (hydro, geothermal, biomass) and variant Renewable Energy Sources (VRES), represented by (wind turbines and photovoltaic). Variable renewable energy sources (VRES) show an increasing growth in the supply of electric energy over the past decade, specially in Europe, USA, and China. In the recent period. The China has become a world leader in Renewable Energy Sources generation as it has surpassed the United States of America as well as Europe and aims to consume 35% of electricity by 2030[115]. However, these RES are semi-variable due to their dependence on climate and location. It brings uncertainty which causes system instability and may lead to successive failures[116].

Through studies, it has been shown that the stability may be significantly influenced by high photovoltaic (PV) penetration considering total power rating, voltage drop, analysis of faults, and transient stability[124]. The increasing integration of RES increases the complexity of controlling in voltage in transmission networks due to uncertainty in weather-based forecasting of power generation[125][126][39][127][128].

Studies of WT/PV integration, on the other hand, need knowledge of other power plants, loads, and the structure and characteristics of the transmission and/or distribution system. These factors will impact the conclusions of an integration study aimed at estimating the likely consequences in a future year of high quantities of wind and PV power. There will be a wide range of data kinds and quantities needed for the many simulations that may be part of a study. The transmission grid, for example, may be represented in certain unit commitment and dispatch models by merely net transfer capacity between balancing zones constraining transmission flow.

## 4.5 The Case Study

In this part (Case Study), we will study the Voltage Regulation in Transmission networks including the Renewable Energy Sources about (NORDIC 32-Bus) power system represents large system.

The goal of the chapter is to study the effect of renewable energy sources (RES) on power systems in terms of planning, operation and improving the voltage level of the NORDIC 32-Bus power system, which suffers from problems in the voltages of some buses, as well as the high percentage of power losses.

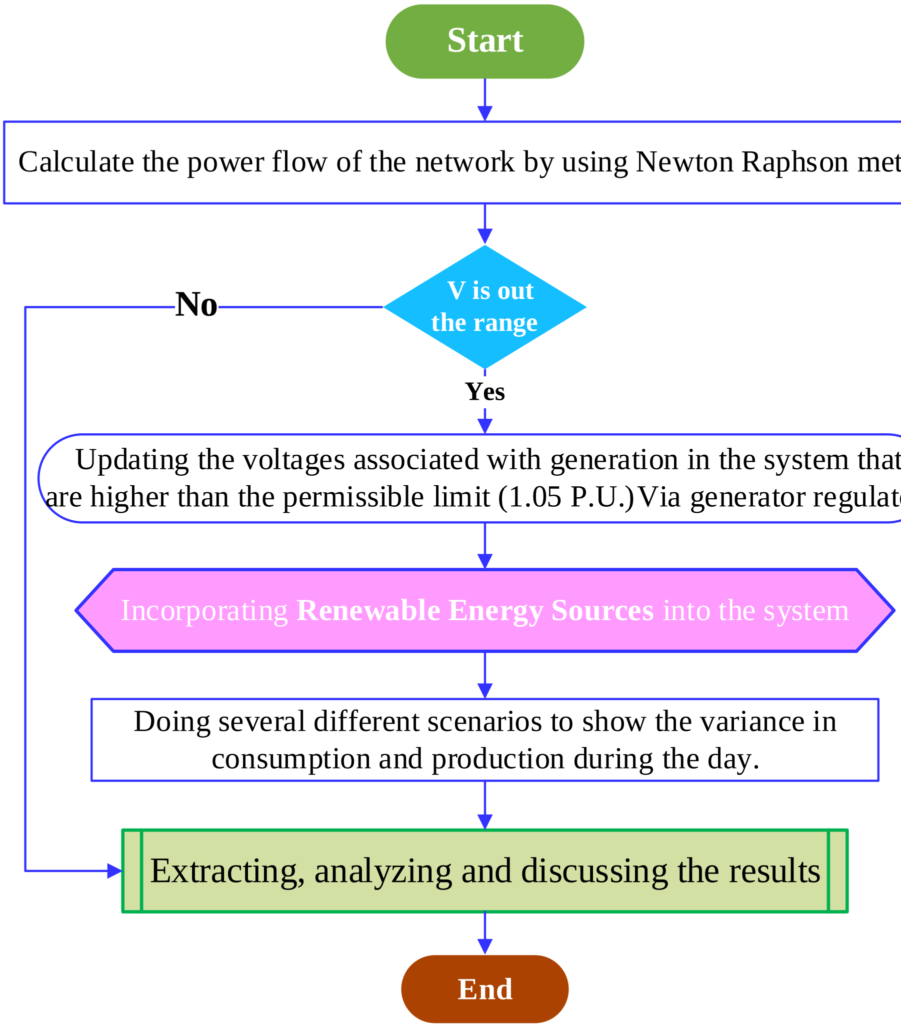


Figure 4-1. Flowchart of Methodology of the Case study

### 4.5.3 Outline of the Case Study part

***4.5.4 Initial case:*** contains a study of the power flow in the system and the results of the voltages in the buses and the total losses (analyze and explain the results)

***4.5.5:*** Incorporating Renewable Energies (RES) into the NORDIC 32-Bus power system, including WT and PV. and make several scenarios that show the variation in consumption and generation during the day.

***4.6 At last, Presents the conclusions***

### 4.5.4 Initial case - Base case:

In this case, we simulated the Nordic32 power system with the DIgSILENT and MATLAB programs. The results DIgSILENT PowerFactory (15.1) and MATLAB were completely similar, the results are similar in all respects in terms of voltages at all buses, as well as the total losses.

## Discussion of the results :

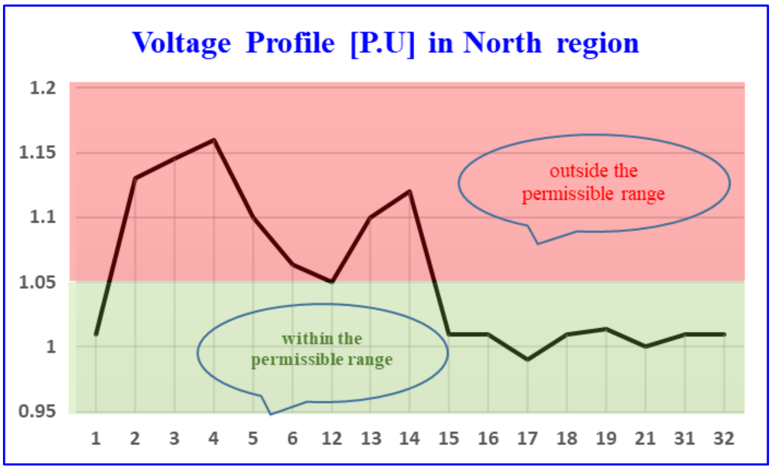


Figure 4-2. Voltage Profile in North region (Base case)

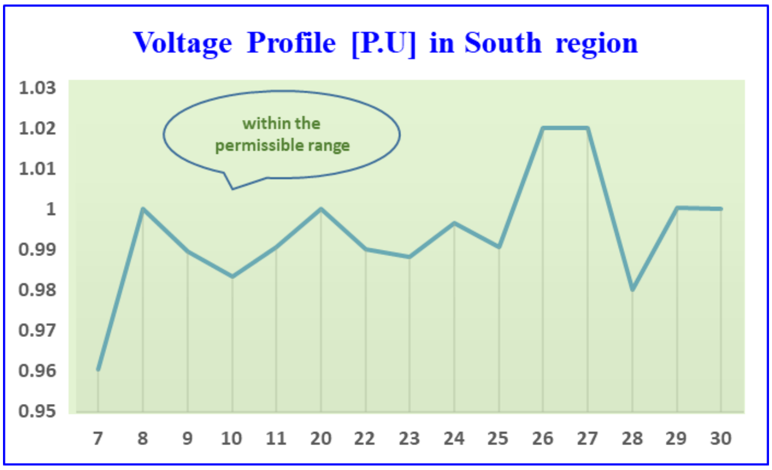


Figure 4-3. Voltage Profile in South region (Base case)

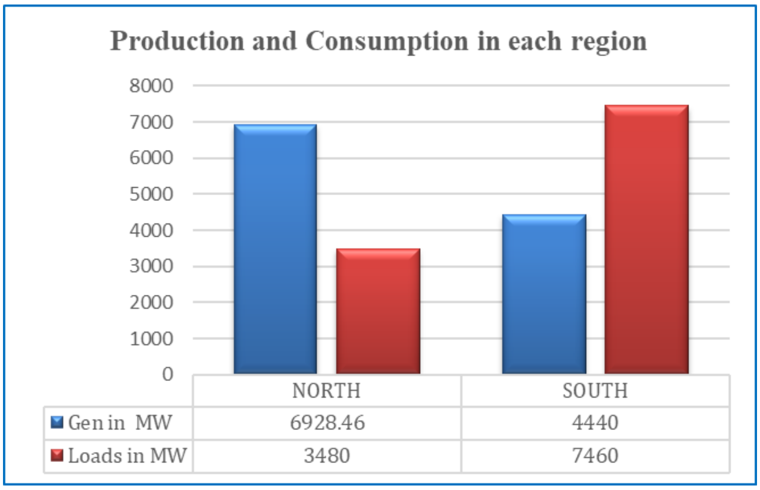


Figure 4-4. Production and Consumption in each region (Base case)

Fig. 4-8. above shows (in North Region) the voltages are normal (i.e., within the allowable and the recommended range) for some buses and the other buses having significant increase.

As for the South Region, the voltages are all within the permissible limit, but some buses are less than 1 p.u, as shown in Fig.4-9.

Fig. 4-10. shows in the North region that the total generation is high (6928.46 MW) while the consumption is small (3480 MW). also, in the South region that the total generation is low (4440 MW) while the total load (7460 MW) is high, the system is heavily loaded with large transfers essentially from the North region to the South region.

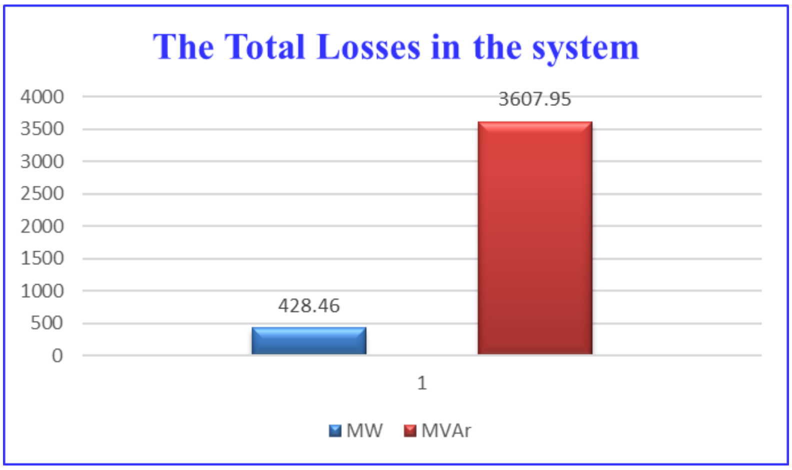


Figure 4-5. Production and Consumption in each region (Base case)

The total active losses represent 3.77% of the total real generation and is within the permissible limit as shown in Fig 4-11. whereas the total losses of reactive power in the system is (3607.9 MVAr), It represents 49.37% of the total generation of the reactive system, which is very high and above the permissible percentage as shown in Fig 4-11.

This needs to develop a solution to the problem in the system (improving voltage and minimizing losses) by using one of the voltage regulation methods, as we see in the following cases.

### 4.5.5 Incorporating Renewable Energies and doing several scenarios

In this case, we are incorporating renewable energies (RES) into the NORDIC 32-Bus power system, including wind turbines (WT) and photovoltaic (PV) farms. and make several scenarios that show the variation in consumption and generation during the day, as shown in the tables below.

**In all scenarios**, we will update the voltages associated with generation in the system that are higher than the permissible limit (1.05 P.U.), which is bus voltages 2, 3, 4, 5, 6, and 13 and make it 1.05 P.U. by generator regulator, and the results from MATPOWER of Matlab.

Table 4-1. Scenarios in percentage

| | The case | The Time | Percentage change in Loads and Generation | Generation Type | Scenarios | The Load | | The Generation | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Classical generation | | Renewable Energy Sources | |
| | | | | | | | | *70% of Total Gen* | | ***30% of Total Gen*** | |
| | | | | | | | | | | PV | WT |
| | | | | | | **$P_L$ [MW]** | **$Q_L$ [MVAr]** | **$Q_{gen}$ [MVAr** | **$P_{gen}$ [MW]** | ***3410.5 MW*** | |
| 0 | Basic Case | | | | | 10940 | 3689 | 1458.64 | 7957.92 | 75% RES | 25% RES |
| 1 | **First Scenario** | **The Noon** | 90 % | **Classical Gen + RES** | **Scenario 1.1** | 90 % $P_L$ | 90 % $Q_L$ | 90 % of [70% $Q_{gen}$] | 90 % of [$P_{gen}$] | | |
| | | | | | | | | | 90 % of [70% $P_{gen}$] | 90% of **[75% RES]** | 90 % of **[25% RES]** |
| | | | | **Classical Generation** | **Scenario 1.2** | 90 % $P_L$ | 90 % $Q_L$ | 90 % of [$Q_{gen}$] | 90 % of [$P_{gen}$ ] | 0 | 0 |
| 2 | Second Scenario | The Evening | 100% | **Classical Gen + RES** | **Scenario 2.1** | 100 % $P_L$ | 100 % $Q_L$ | 100 % of [70% $Q_{gen}$ ] | 100 % of [70% $P_{gen}$ ] | 0 | [100% WT] **=30 % $P_{gen}$** |
| | | | | **Classical Generation** | **Scenario 2.2** | 100 % $P_L$ | 100 % $Q_L$ | 100 % of [$Q_{gen}$ ] | 100 % of [$P_{gen}$] | 0 | 0 |
| 3 | Third Scenario | The Night | 75 % | **Classical Gen + RES** | Scenario 3.1 | 75 % $P_L$ | 75 % $Q_L$ | 75 % of [70% $Q_{gen}$] | 75 % of [$P_{gen}$] | | |
| | | | | | | | | | 75 % of [70% $P_{gen}$] | 0 | **75% of [30% $P_{gen}$ ]** |
| | | | | Classical Generation | Scenario 3.2 | 75 % | 75 % | 75 % of [$Q_{gen}$] | 75 % of [$P_{gen}$] | 0 | 0 |

Summary for all scenarios

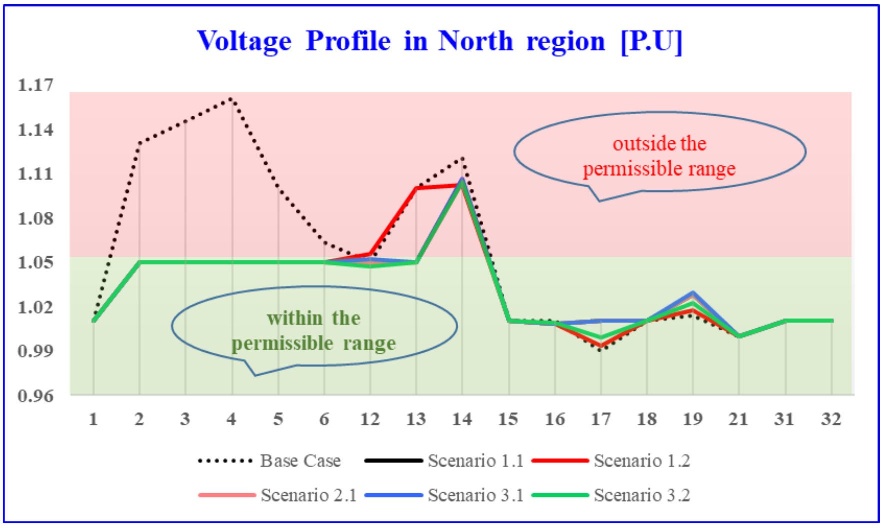


Figure 4-6. Voltage profile in North region for all Scenarios

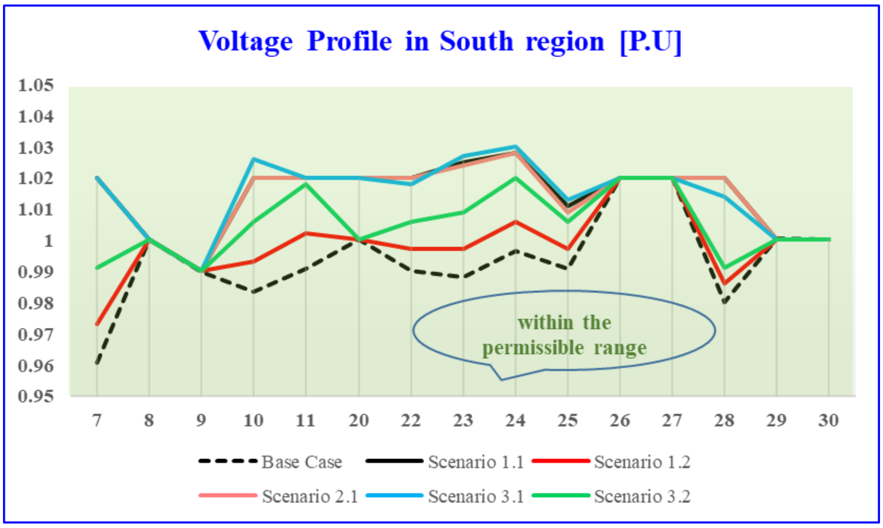


Figure 4-7. Voltage profile in South region for all Scenarios

If we look at the Fig. 4-36 & 4-37, we can see that the voltages improved in all scenarios;

- In the scenarios **(Noon S1.1, Evening S2.1**, and **Night S3.1**) in which renewable energies were added to the system, the voltages improved in all buses, especially in the south region, and this is due to the addition of renewable energies to the south region, which is characterized by low generation and high load.
- In the scenarios (**Noon S1.2** and **Night S3.2**) for which we did not add renewable energies, the voltages improved in most of the buses, due to the updating of voltages for the generation, as well as the decrease in loads in the system.

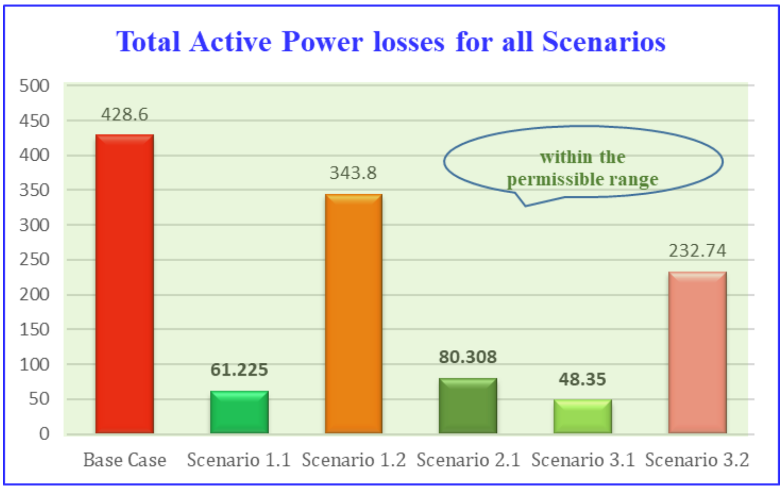


Figure 4-8. Total Active losses in the system for all Scenarios

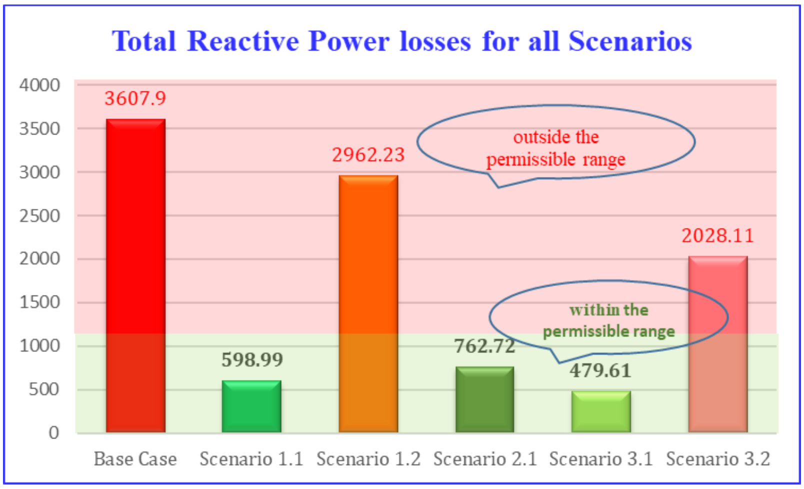


Figure 4-9. Total Reactive losses in the system for all Scenarios

We have to remember that in the base case, large transfers, mostly from the North to the South area, have placed a heavy burden on the system. And that the north region has high generation and low loads, and the south region has high loads and low generation

## From the Fig. 4-40 and 4-41

- we notice that the losses in the at **Noon** - first scenario were significantly reduced due to the addition of renewable energies to the south area with low generation, also due to the reduction of loads by 10% of the system, because the loads are concentrated in the South region.

  As for the **Noon**-second scenario, the losses were also slightly reduced because the load was reduced by 10%.

- In the **Evening** - first scenario, the losses decreased significantly despite the fact that the loads remained constant, because we reduced the classic generation by 30%, and replaced it with renewable energy source, which is only wind Turbine, and Wind Turbine was added to the **SOUTH** region, which is characterized by its low generation and loads high, so the losses decreased dramatically.
- In the **Night** - the first scenario, the losses decreased dramatically, and it is considered the best among the scenarios as well as the best operating condition of the system and this is due to two reasons, the first is a decrease in consumption by 25% of the system loads and the second is to add renewable energies in the South area, where in the previous case the **SOUTH** region was few Productions and a lot of consumption and generation come to it from the North.

  In the **Night** - second scenario, the losses are almost halved, due to loads being reduced by 25%.

# CHAPTER 5: Voltage Regulation for Transmission Networks Using FACTS Devices [SVC]

## 5.1 Introduction in Voltage Regulation by SVC

Scientific and technological advancements in electric power transmission networks are improving the manageability, stability, as well as reliability of power systems while maintaining a high quality of electricity delivery. Flexible alternating controlled transmission systems (FACTS) with current multifunction devices may produce the best and most complete outcomes for these goals, and in particular, reactive power control devices–SVC. The SVC is a controlled static device configured by an inverter voltage, set in parallel within the electric network[109].

Implementation of the SVC can be similar to other FACTS devices: controlled by the longitudinal compensation (TCSC), The static compensator as well as the static synchronous series compensator (SSSC) (STATCOM). Control algorithms of such converters must be able to ensure high quality of the converter in steady-state mode conditions (low losses, satisfying the requirements of the voltage harmonic distortion standards) and also to ensure the efficiency and high performance of SVC in emergency and post-emergency conditions of network.

This chapter main objective is to maintain and manage voltage at power grid substations in normal as well as fault conditions, finding location for SVC installation as well as provide information on energy flow, reactive power compensation, as well as subsequently reduce damage by utilizing optimization process to discover the optimal FACTS devices are also the subject of this investigation because they have the potential to enhance voltage stability, increase line capacity, and decrease power system operating costs [149][150][151].

Before adding additional new power plants to the electrical grid, long-term grid adequacy and short-term effects on system balance and dynamic stability must be evaluated. Power system management, economics, as well as efficiency are all affected by WT/PV power implementation. At larger percentages of wind and solar, the best conventional generating mix may alter[152].

The voltage profile must be improved for the power system's reliability and to supply high-quality electricity. Voltage instability and line overloading are two of the primary issues that the electrical system faces today. Reactive power generation, transmission, and consumption all contribute to voltage stability. Voltage profile instability is caused by unbalanced reactive power. As a result, a power electronics device called FACTS has been created to improve controllability and power transfer capabilities. The need to find solutions to these issues and restrictions prompted technological progress to be focused on flexible AC transmission (FACTS). For maximum output, power production as well as transmission is a complex process involving many different parts of the power system. When it comes to reactive power, heavy inductive loads are still a critical component of the system. Active electricity can only be sent via wires if a constant voltage is maintained. Loads such as motors as well as other electrical appliances demand reactive power.

Benefits of installing FACTS are presented in below Fig. 5-1 [153][154][155][156].

Figure 5-1. Advantages of installing FACTS

Some precautions may be required to maintain an appropriate degree of operational security and dependability. It is common for the studies to focus on a broad range of implications, ranging from system-wide to local. Grid integration problems at the distribution side tend to focus further on the local and regional repercussions of solar and wind power growth than on transmission as well as system-wide concerns. To regulate the flow of energy systems, the FACTS innovation uses a collection of numerous controllers for use either individually or in conjunction with one another. This includes but is not limited to shunt and series impedance, voltage and current and also phase angle.

This chapter focuses on the usage of the Static VAr Compensator (SVC) to rectify voltage regulation as well as dynamic performance concerns in this system

## 5.8 The Case Study

This Part (case study) focuses on power system voltage regulation (NORDIC 32-Bus) using FACTS devices (SVC devices).

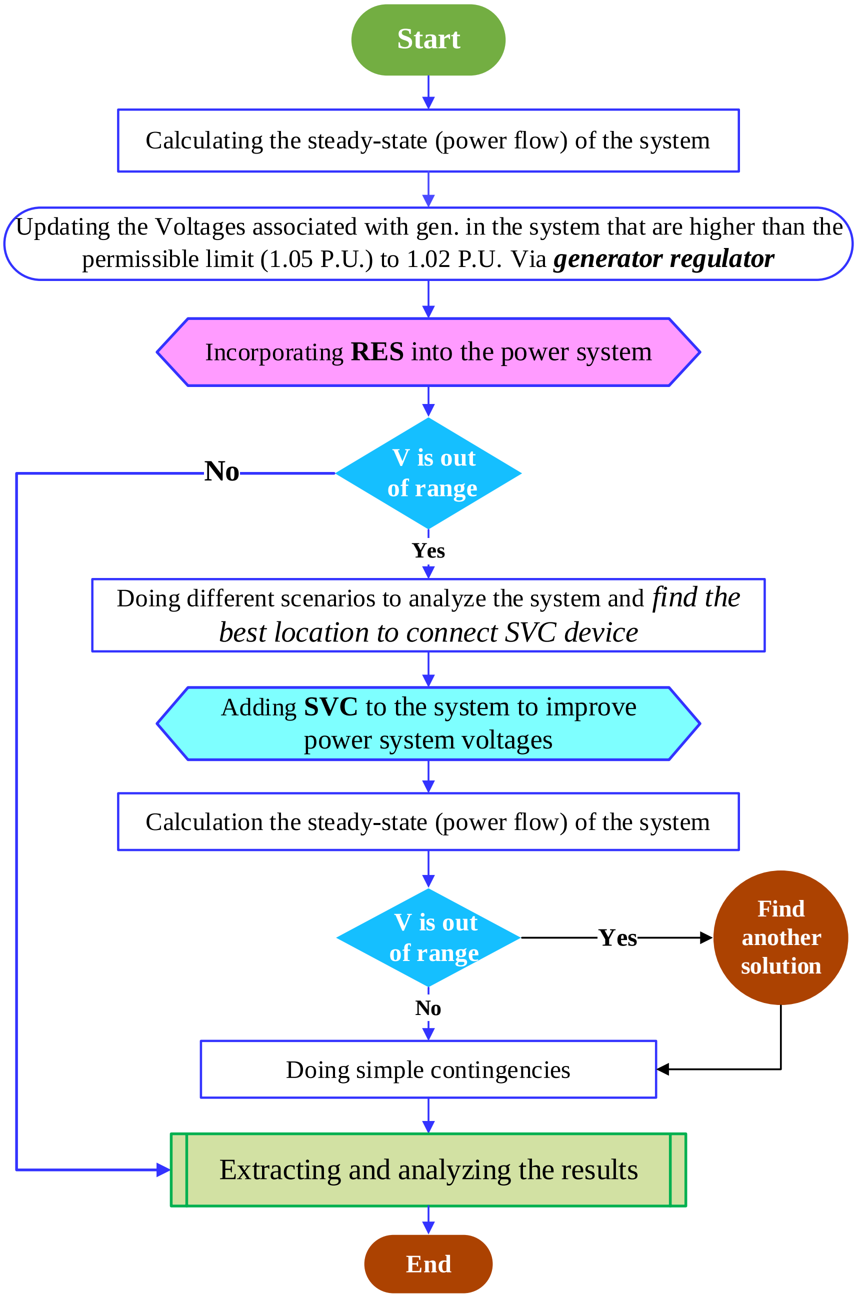
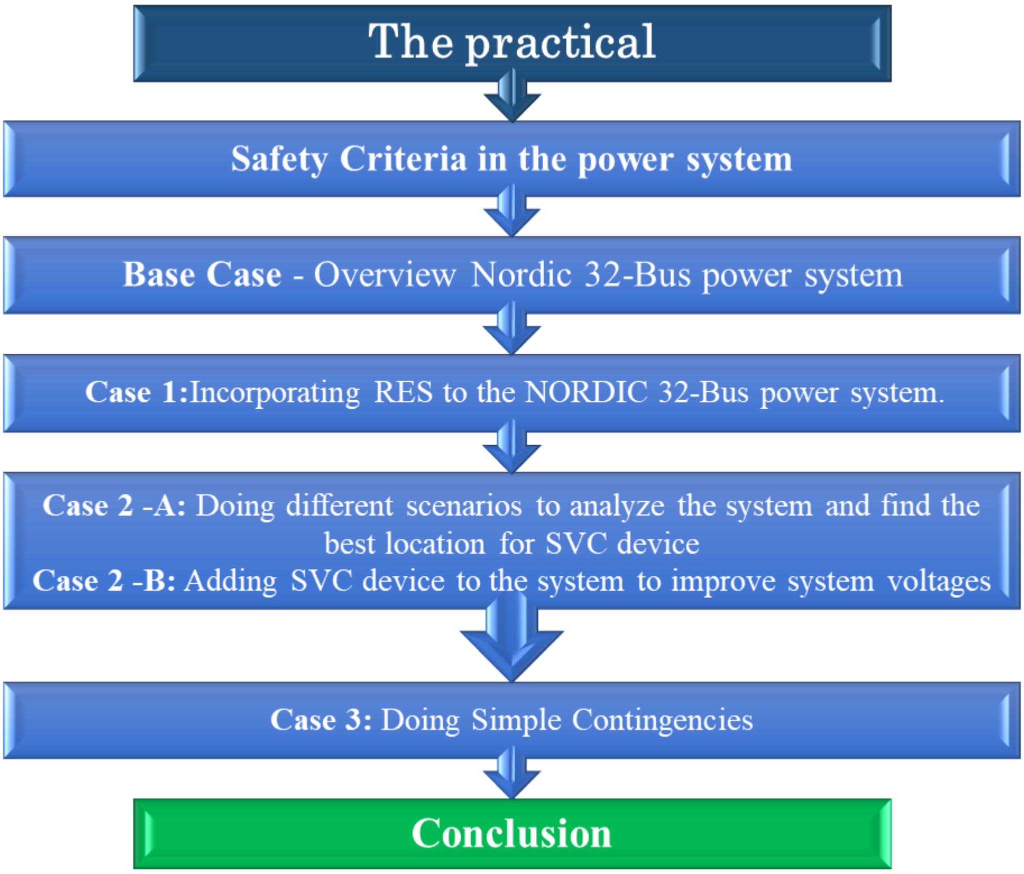


Figure 5-2. Flowchart of Methodology of the Case study

Outline of the Case Study part



### 5.8.1 Initial case - Base case:

The results of this case are presented in the third chapter (the basic case).

In this scenario, we used NEPLAN, DIgSILENT, as well as MATLAB to model the Nordic32 power system.

In terms of voltages as well as angles at all buses, and also power flow as well as total losses, the findings are same for NEPLAN (5.5.5), DIgSILENT PowerFactory (15.1) and MATLAB.

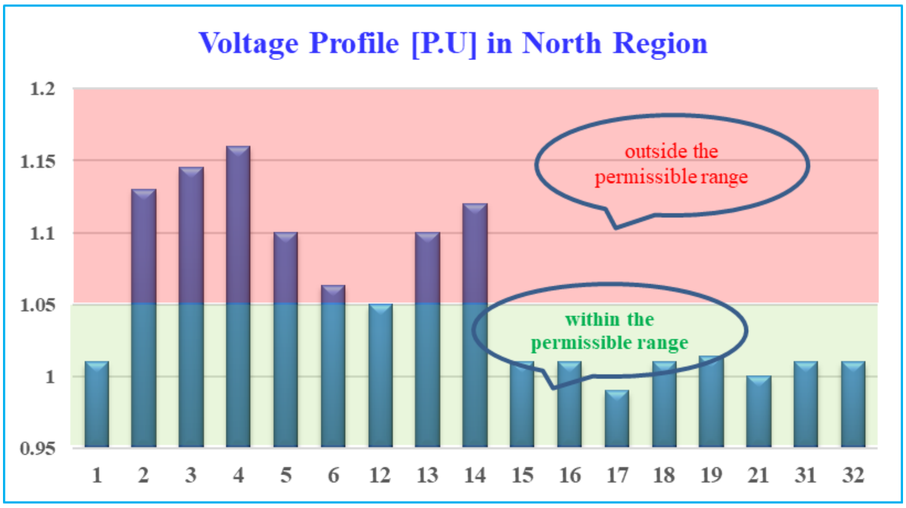


Figure 5-3. Voltage Profile in North region (C0)

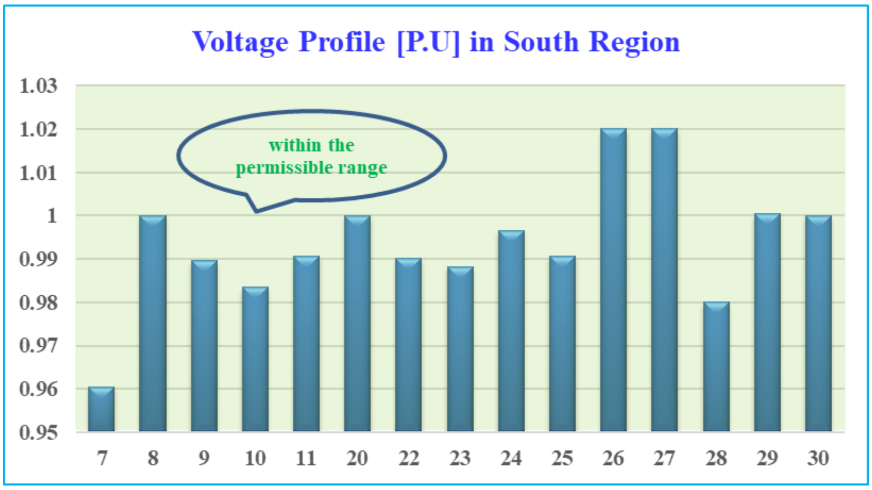


Figure 5-4. Voltage Profile in South region (C0)

Here, we're talking about the steady-state situation of network functioning, which is what we're seeing here.

Fig. 5-10 shows the voltages are normal (i.e., within the allowable and the recommended range) for some buses and the other buses having a significant increase ($U > 1.05\ p.u$) (out of the permissible limit), and Fig. 5-11 shows the voltages in the South Region are all within the permissible limit. In this chapter we will improving the voltage using the SVC device.

### 5.8.2 Case 1 - Incorporating Renewable Energies Sources (RES)

In this case, we will update the voltages associated with generation in the system that are higher than the permissible limit (1.05 P.U), which is buses voltage 2, 3, 4, 5 ,6 and 13, and make it 1.02 P.U. Via generator regulator.

Now, we reduce the generation by 15% of the total generation in the system, and we add Renewable Energy Sources (RES) instead. and we are incorporating Renewable Energies Sources (RES) into the NORDIC 32-Bus power system, including Wind Turbines (WT) and photovoltaic (PV) farms, as shown in the tables 5-1 below.

Table 5-1. The location and capacity of RES C1

| | The Location | The Capacity [MW] | RES Type | The Region |
|---|---|---|---|---|
| 1 | Bus 7 | 600 | WT | South region |
| 2 | Bus 11 | 505.3 | PV | |
| 3 | Bus 17 | 300 | WT | North region |
| 4 | Bus 19 | 300 | PV | |
| Total | | 1705.3 | RES | |

Discussion of the results

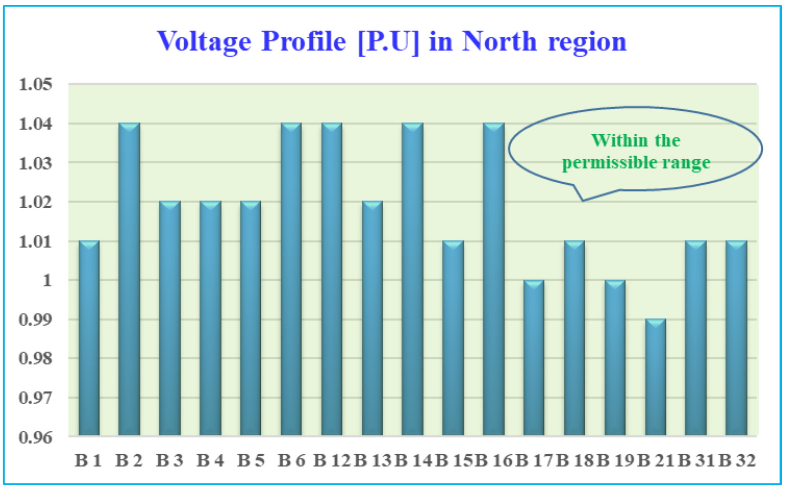


Figure 5-5. Voltage Profile in North Region C1

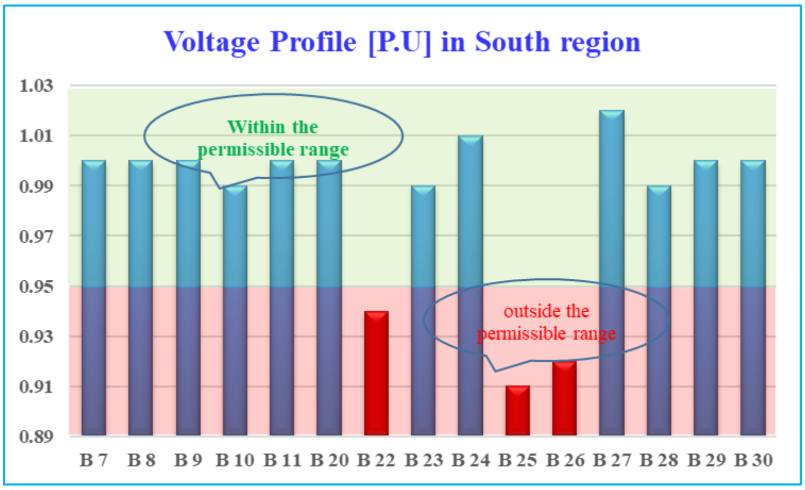


Figure 5-6. Voltage Profile [P.U] in South region C1

After updating the voltages associated with the generation, which was higher than 1.05 P.U and making it 1.02 P.U Via generator regulator and adding RES to the system, we notice that the voltages in the North region are all within the permissible limit, as shown in Fig. 5-13.

While in the south region, all voltages are within the permissible limit except for Buses 22, 25 and 26, which will need to be regulated, as shown in Fig. 5-14, and we will add SVC as we will see in the next steps.

### 5.8.3 Case 2 – Analyze the system and adding SVC to the system

#### *5.8.3.A Case 2- A: Doing different scenarios for the system to find the appropriate location for the SVC device*

In this case, we will do a full system analysis to know the stability of the system as well as the weak areas and weak buses in the system. The purpose of this case is to find the appropriate location for the SVC device. We will do five Cases, and each case represents area, in each area, there are several events:

1- The first area: In the Northwest Region of the system
2- The second area: In the Northeast Region of the system
3- The third area: In the Southwestern Region of the system
4- The fourth area: In the center of south Region of the system
5- The Fifth area A: In the Southeastern Region
6- The sixth area B: In the Southeastern Region

Fig. 5-15 below shows the regions in the system

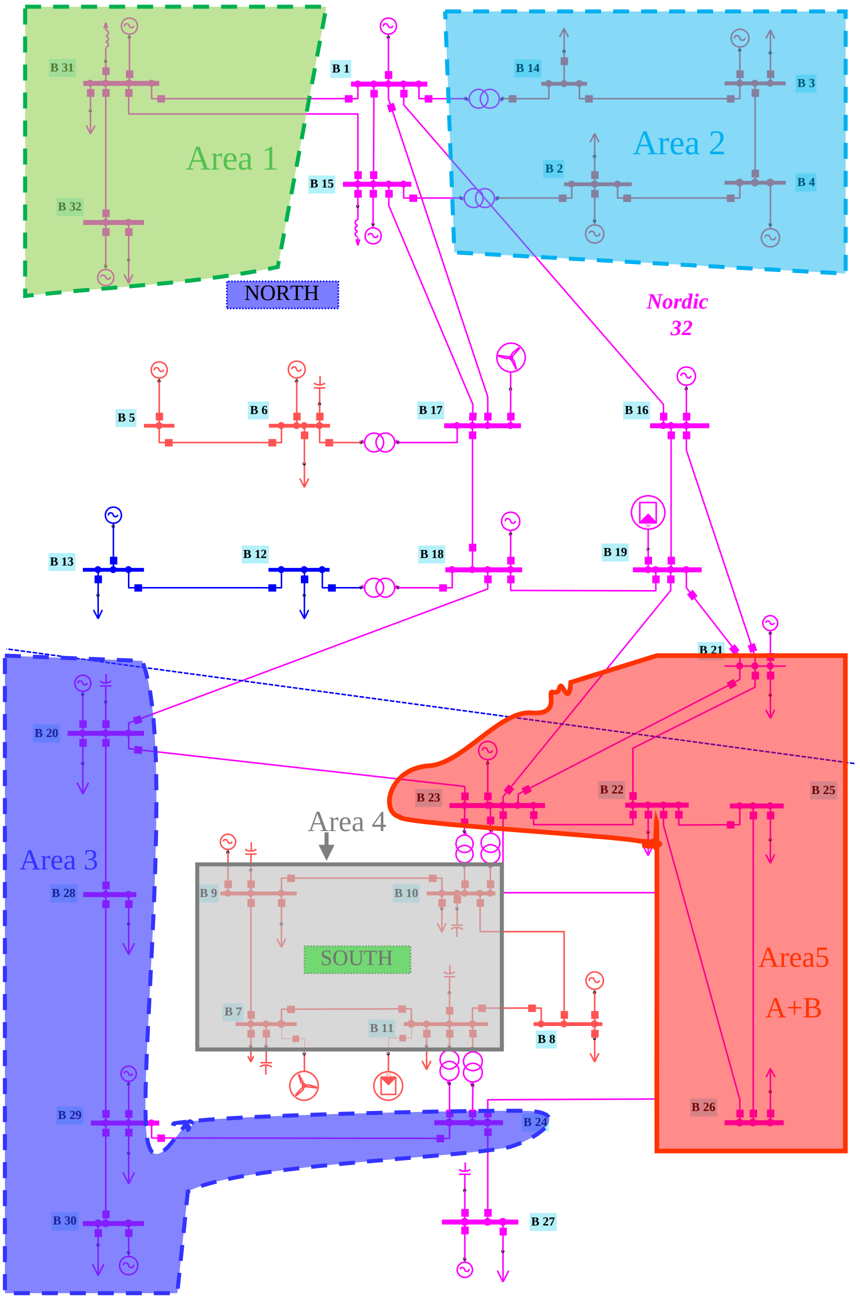


Figure 5-7. Single line diagram of NORDIC 32-Bus power system divided to several Area C*2*

**System Analysis Summary:** We did a complete analysis of the system to know the stability of the system as well as to know the weak areas and buses in the system. We analyzed the system in five regions:

In the northwest region (Area1) and in the northeast region (Area2), and in the southwestern region (Area3) and in the center of the south region (Area 4) as a region with high loads and low generation. As well as in the southeastern region (Area5-A and Area5-B).

We noticed the system remains stable and the voltages in the Buses are within the permissible limit. Except in the southeastern Area (Area5), which is considered the weakest Area in the system: The southeastern Area, which is represented by buses 22, 25 and 26, is an area that does not contain generation and has high loads and is connected to the system by only two transmission lines.

Therefore, the appropriate location for installing the SVC device is the southeastern Area (Area5) represented by Buses (22, 25 and 26).

Table 5-2. Choosing the best location of SVC C2

| SVC location | SVC size [MVAr] | Voltage results in p.u | | | |
|---|---|---|---|---|---|
| | | V B22 | V 25 | V 26 | V23 |
| Bus 22 | 729 | 1.00 | 0.97 | 0.98 | 1 |
| Bus 25 | 513.9 | 0.98 | 1.00 | 0.99 | 1 |
| Bus 26 | 386.3 | 0.97 | 0.96 | 1.00 | 0.99 |

From the table 5-9 above, the 25 Bus is the best location to install the SVC device, as the system voltages will be close to 1 and the size of the device is the smallest compared to the performance.

### 5.8.3.B Case 2 - B: NORDIC 32-Bus power system with SVC

In this case, we will install an SVC device in Nordic 32 power system, for the purpose of improving the voltage level in the system

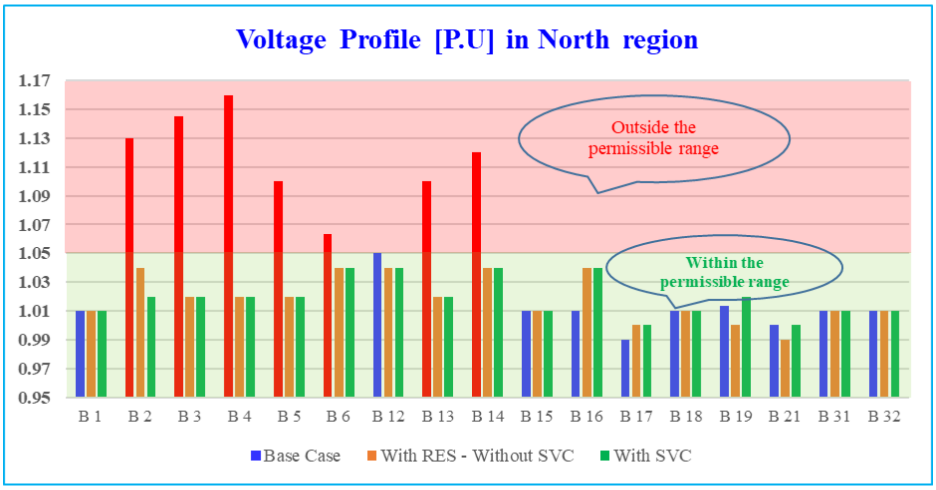


Figure 5-8. Voltage Profile in North region C2

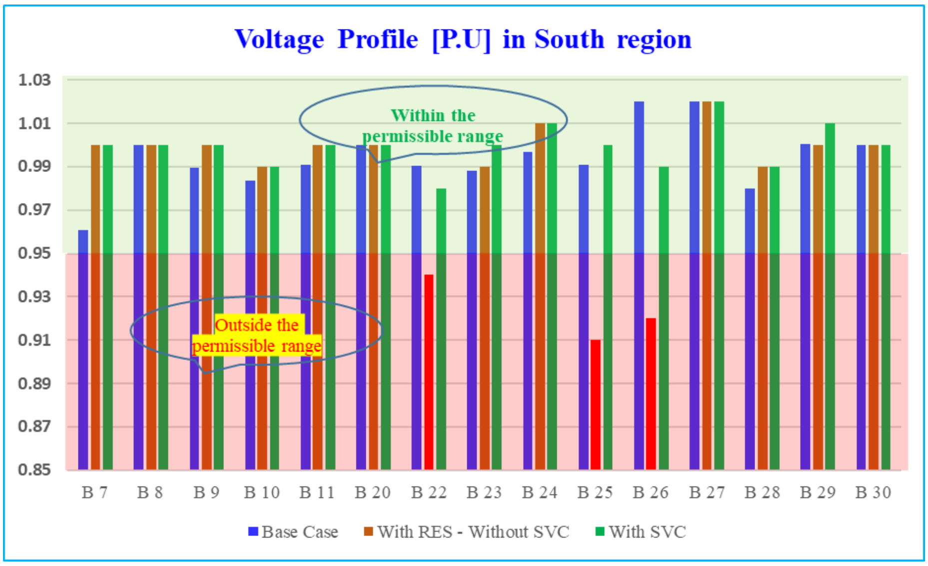


Figure 5-9. Voltage Profile in South region C2

From Figs. 5-16 and 5-17 above, it can be seen that after adding SVC to the system, all system voltages (in the North and South regions) are very good and within the permissible limit (0.95-105) P.U and all system voltages range from 0.99 P.U to 1.04 P.U.

# CHAPTER 6: Transient stability enhancement and voltage regulation using SVC with AVR, PSS and Governor

## 6.1 Introduction

Power system stability has been a major concern since the 1920s, when it was first recognized[187][188]. The relevance of power system instability has been shown by a number of large-scale blackouts[189]. In the past, transient instability is the most prevalent stability issue on most systems, which has been a major focus of industrial research [190]. Voltage control and transient stability have been more difficult to maintain in power systems over the past several decades due to rising demand for electricity and a variety of technological restrictions. Stability of the power system becomes a hot topic in this setting, and it is one of the most difficult challenges that the power community faces today[190][10].

The subsystems that make up a power system are all linked together. Synchronous machines are often employed in power systems as a source of electrical energy. In the literature, there are a variety of ways to regulate the situation. An automated voltage regulator (AVR) as well as a power system stabilizer (PSS) has traditionally been installed in synchronous generators integrated into a power system [10].

For years, flexible alternating current transmission system (FACTS) processors have been well recognised for their advantages, including better dynamic stability and improved power regulation. One of the most important shunt FACTS devices in power systems is the Static VAr Compensator (SVC)[191][192]. It regulates terminal voltage in a smooth, rapid, and exact manner. Unless an auxiliary control is included into the regulatory loop, the SVC usually has no effect.

## 6.5 The Case Study

In this part (The Case Study), we will study the Transient stability enhancement as well as voltage regulation in power system using AVR, PSS and Governor with SVC. We will work on regulating the voltage for the Nordic32 power system, we will analyze the voltage (Base case) and after that we add AVR, PSS and Governor and then add renewable energies (RES) (Photovoltaics and Wind turbine) to the Nordic32 power system and then we add an SVC device to the Nordic32 power system.

### Outline of the Case Study part about the NORDIC 32 power system

### 6.5.1 Case 0 - Base case:

This case represents the steady-state calculations of the system in the base case, and the results was presented in the fourth and fifth chapters in the results of the base case

### 6.5.2 Case 1 - Incorporating RES and adding SVC to the system

This case represents the calculations of the state of the system in the steady state after adding the sources of renewable energies to the system. The results are presented in the fifth chapter in the results of Incorporating RES.

#### *Analyze the system and adding SVC to the system*

As we studied in the previous chapter (the fifth chapter), and we knew how to determine the best location for SVC, and the Bus_25 was the best location for SVC, as well as knowing the size of the appropriate device for the system. Now we will install SVC device in Bus 25 to improving the system Voltage. The results are presented in the fifth chapter in the results of adding SVC.

### 6.5.3 Case 2 - Addition of Exciter (AVR, PSS) and Governor to generators

In this case, we will add an **Exciter** (Automatic Voltage Regulator (AVR), Power System Stabilizer (PSS)) and **Governor** for each generator in the network.

We will rely on the IEEE report in the AVR and PSS data, and the Governor data will be from the IEEE and the CIGRE reports[143][145][222].

### 6.5.4 Case 3 – Doing Disturbance in the power system

The disturbance of concern is a three-phase short-circuit on line 21 (between Bus 18 and 20), lasting 5 cycles (0.10 s) and cleared, and the fault location in 50% (in the middle of the line), knowing that the line is a double circuit.

**Discussion of the results:** Through the results of DIgSILENT, we will include the voltage and the active and reactive power of the transmission line, and the generators associated with the buses connected to the line as being more affected by the Disturbance, as well as the speed and angle of the rotor for the generators G12 connected to the Bus 18 and G9 connected to the Bus 1 (Slack Bus).

**Dynamic responses to contingencies:** After adding AVR, PSS and Governor, and installing the SVC at Bus 25 to improvement the system voltage, we did a model analysis for the system to see the stability of the system.

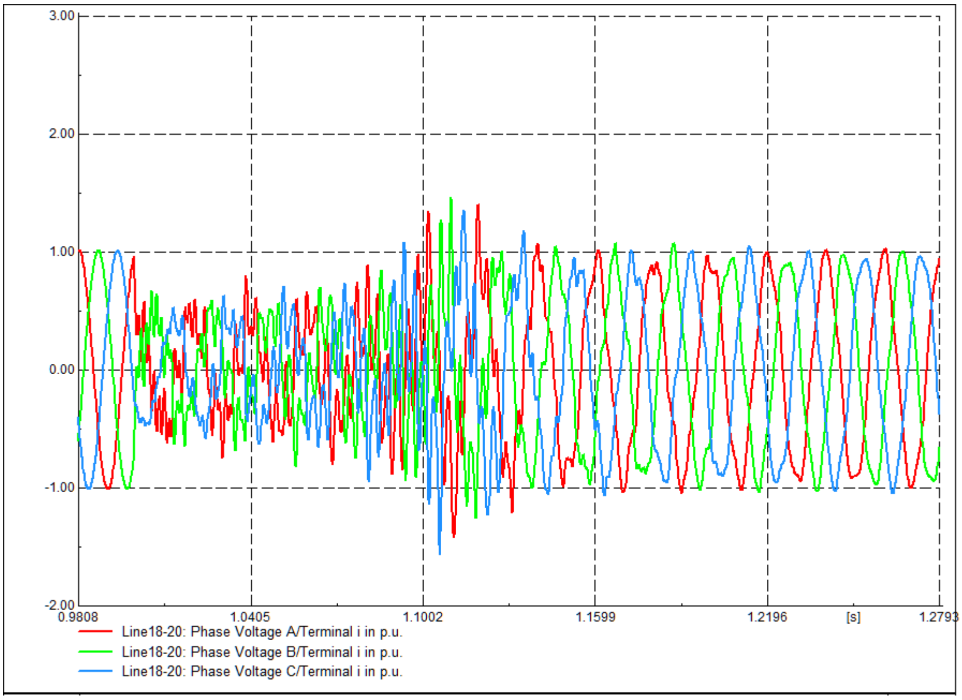


Figure 6-1. The voltage in transmission line 21

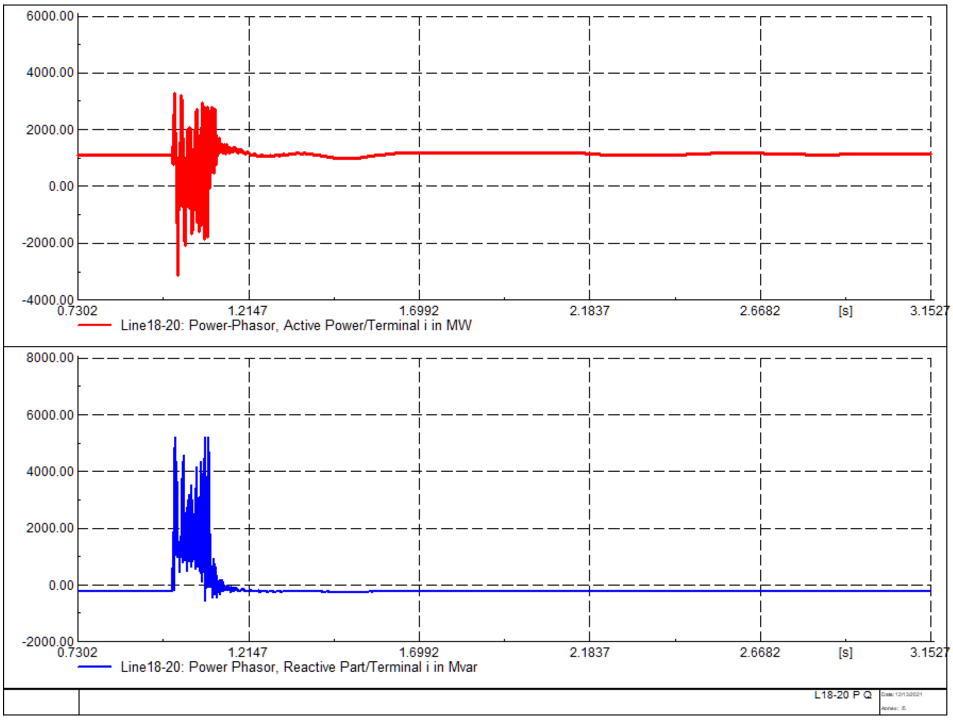


Figure 6-2. The active and reactive power in transmission line 21

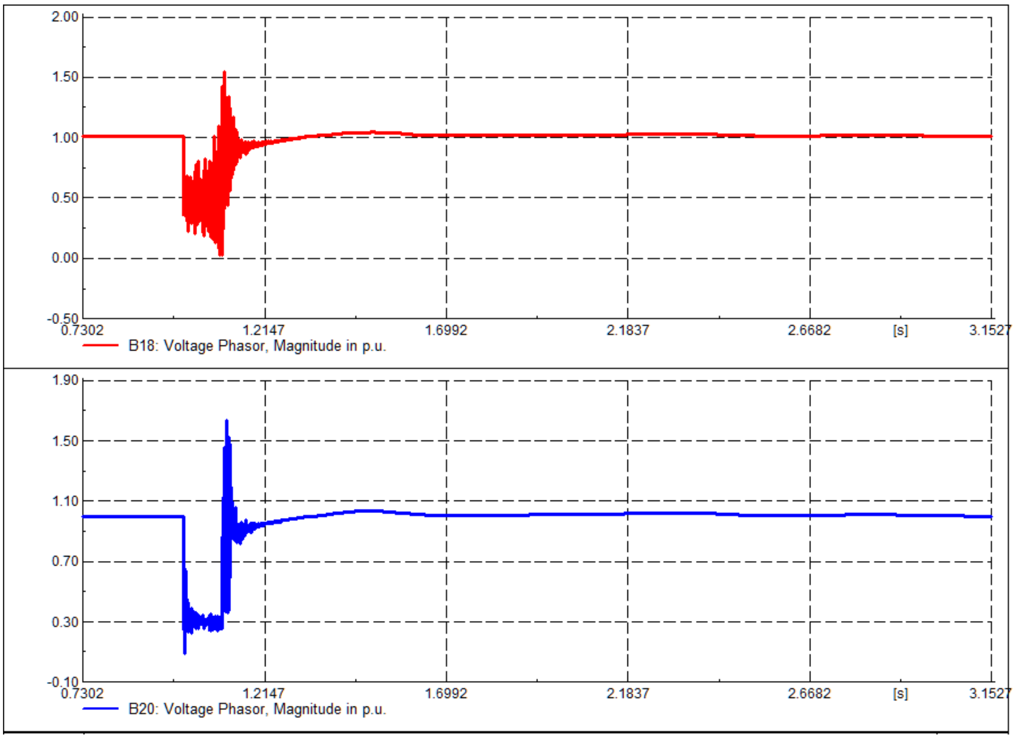


Figure 6-3. The Voltage magnitude p.u in Bus 18 and Bus 20

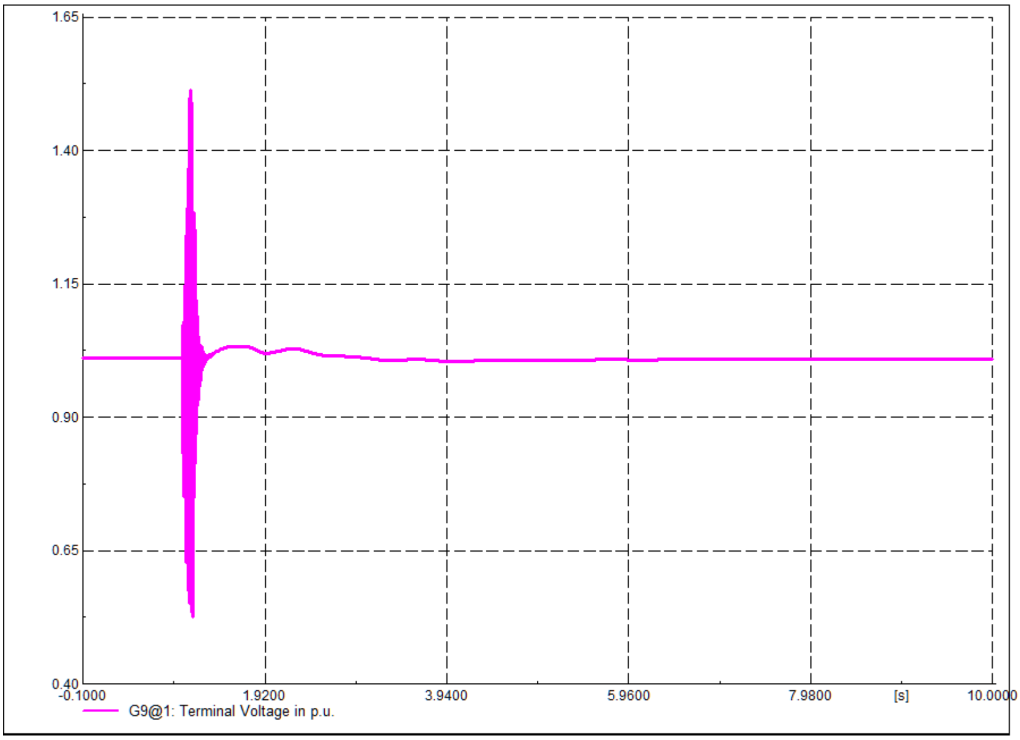
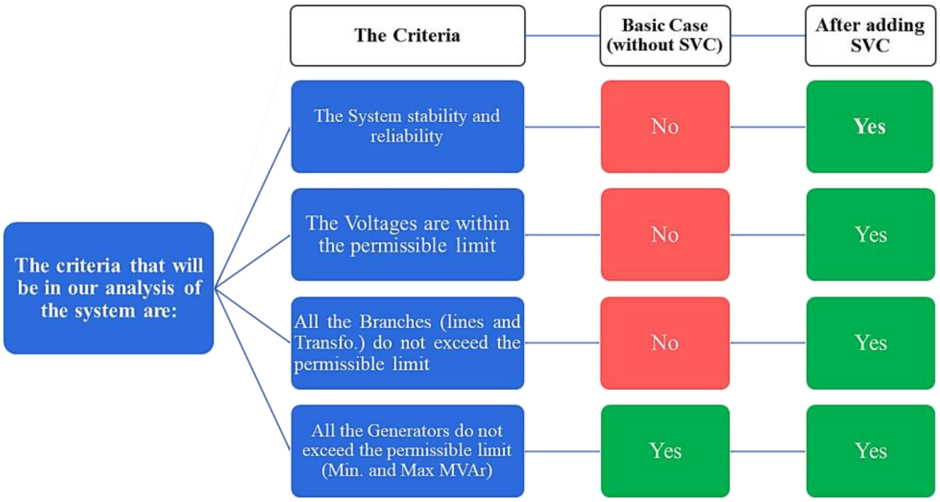


Figure 6-4. The Voltage magnitude p.u in Gen. 9

During the disturbance period, all parts of the system suffered from fluctuations, as the disturbance hit the system after 1 second of its operation and lasted for 0.10 seconds. This can be seen in Fig. 6-8, it can be seen that the voltage suffered from fluctuations during the disturbance period, Where it can be seen that the voltage decreased a lot during the disturbance period (the period from 1 sec to 1.1 sec), but soon the system returned to the state of stability, where it can be notice in the time 1.2 seconds that the voltage has stabilized as in Fig. 6-8, Fig. 6-10 and Fig. 6-13, Where these figures represent the voltages in transmission line 12 (between Buses 18 and 20), Buses 18 and 20 and generator9 connected to Bus1 (Slack Bus) respectively.

The focus was on the results above (line 21 (between Buses 18 and 20) and generator 12 connected to Bus 18) among the rest of the results of lines and generators because they are the most affected by disturbance. As for generator 9 connected to Bus 1 it represents the Slack bus. It is worth mentioning that all generators remained in the operating state and no generator went out of service due to the addition of controllers (AVR, PSS, Governor) and SVC device to the system. The criteria that will be in our analysis of the system are:



**The criteria that will be in our analysis of the system are:**

| **The Criteria** | **Basic Case (without SVC)** | **After adding SVC** |
|---|---|---|
| The System stability and reliability | No | **Yes** |
| The Voltages are within the permissible limit | No | Yes |
| All the Branches (lines and Transfo.) do not exceed the permissible limit | No | Yes |
| All the Generators do not exceed the permissible limit (Min. and Max MVAr) | Yes | Yes |

Figure 6-5. Stability criteria for the power system in our study

Therefore, the system is considered stable, reliable and safe, and all system equipment such as (Generators, transmission lines, and power transformers) did not exceed the permissible limits as shown in Fig. 6-16 above.

# CHAPTER 7: Conclusions and Recommendation

The main conclusions presented in this thesis are highlighted in this chapter and summarizes some ideas for future research work. Personal contributions to this work have also been included.

## 7.1 Conclusions

The necessity and opportunities of the subject of my thesis are coming from development of the Renewable Energy Sources (number and installed power) connected to power systems and increasing their penetration into the system due to the economic and environmental benefits of renewable energies. Therefore, the impact of this trend has been studied and strategies have been developed to increase the security of energy supply and maintain the system for security, economic and environmental necessities and to supply the end user with energy within the standard specifications.

This Thesis was an attempt to address the importance of improving voltage safety for transmission networks in power systems in light of the increasing integration of renewable energies and their impact on the system in the steady state and transient state. The traditional methods and the use of the SVC device were used to regulate the voltage level, and the effect of renewable energies on the system and the variation in production and consumption was studied. The system security improvement was also studied using the controllers, exciter, governor and SVC, and the safety standard was respected in this study for the system equipment. The overall conclusions of this Thesis are:

i) In this study, I researched the voltages regulation and their methods of regulation. In this studied the Classic methods of voltage regulating for two cases and regulating the voltages for each case depends on the nature of the network, and we used more than one way, but we got on the best solution in the system when we improved power factor (by using capacitors) and using Tap changers for the loads transformers.

ii) We analyzed several scenarios during the day in order to illustrate the variation in loads and generation, and how renewable energies can be exploited to improve system operation. Before incorporating new power plants into the power system, it is necessary to assess work adequacy over long time scales and implications for system balancing and dynamic stability in the shortest timescales. wind turbines and photovoltaic power implementation affect power system management and efficiency. The optimal conventional generation mix may fluctuate with larger shares of wind turbines and photovoltaic. To ensure the security of operational and the reliability at an acceptable level. We have observed the effect of renewable energies on the system and its usefulness on the entire system in improving voltages and minimizing losses.

iii) The proposed method of using the controllers, the exciter and the governor and the SVC provided a satisfactory solution for the stability of the system. Using a combination of the analysis system with the static device such as the SVC, it is possible to provide voltage control at the Bus to which the device is connected as well as provide system stability and reliability. The SVC device, AVR, PSS and governor increase the dependability as well as stability of the system. There is a discussion on how to use SVC for optimization. SVC improves power quality as well as stabilises power use. This effect might be utilised to compensate for a fluctuating load voltage in situations where this is necessary. It would increase power stability as well as reduce the danger of catastrophic events resulting from those sources of instability.

AVR/PSS and SVC controllers are used in the Thesis to improve power system stability. To improve transient stability as well as voltage control in Nordic32's power system, the SVC is linked. Because of our investigations in this Thesis. This underscores the robust performance of the SVC in emergency as well as post-emergency modes of the electrical system.

## 7.2 Personal contributions

### (i) Documentation

- *Integrating renewable RES into the Nordic 32 power system*; After that, several different scenarios were implemented to highlight the variation in consumption and production throughout the day.
- *I have identified and classified into power system topics the usefulness of the FACTS devices*. It was the third step of the work. They have been classified in terms of type of connection. Moreover, the benefits of installing FACTS for the power system was presented
- *I have developed the methodologies to improve voltage security or enhance stability to achieve maximum impact by finding the best SVC location and using the controllers (AVR, PSS, GOVERNOR*). From this perspective, the technical limits of the power system related to the power transfer capabilities have been identified. Connected to the security aspects of a power system, a brief description of the power system stability aspects was presented.
- *The criteria in the stability level of the power system's performance* were used to assess in our thesis.

### (ii) Simulations and calculations and Model development

- Calculation of the voltage performance index and power flow performance index was carried out on the TEST 2 and Maysan test networks and Nordic32 power system.
- Placement of capacitors group was added for the TEST 2 and Maysan test networks to improvement the power factors for industrial loads.
- Renewable energy sources (Photovoltaics and Wind Turbines) have been added to the Nordic 32 power system to see the variation in loads and generation and how it affects the system.
- Areas of influence were traced, using also graphical representation, for the Nordic 32 power system. These areas show the spread of influence that an SVC can have on the voltage level at the network buses around the bus where the SVC is placed.
- Placement of one SVC device was proposed for the Nordic 32 power system.
- Steady state calculations were performed on the Nordic 32 power system that includes an SVC device and RES
- Dynamic simulations were performed in DIgSILENT PowerFactory on the Nordic 32 power system. The system behavior to outage transmission line, outage generator, and short-circuit was determined.
- Added the Controllers (AVR, PSS, Governor with SVC device) to the Nordic 32 power system to improve transient stability.

### (iii) Publications associated with this thesis

- I have published the results of my research and published their results in Romanian and international conferences and journals; I have published one paper in ISI's Indexed Conference and three papers in the International Cataloged database (Scopus).

1- **Power Flow Analysis in Power System Planning. Case Study**
**Published in: IEEE**
Publisher: 2019 International Conference on ENERGY and ENVIRONMENT (CIEM)
**The authors: Murtadha SAMI** and Stefan Gheorghe

2- **Analysis of the Influence of Renewable Energy Sources on The Power System Operation**
**Published in: EMERG (www.emerg.ro)**
**The authors: Murtadha SAMI,** Stefan GHEORGHE and Lucian TOMA

3- **Voltage Security Improvement for Transmission Network In Power Systems Using Svc Device**
**Published in: UPB Scientific Bulletin** (https://www.scientificbulletin.upb.ro))
**The authors: Murtadha SAMI,** Stefan GHEORGHE and Lucian TOMA

4- **Transient Stability Improvement and Voltage Regulation In Power System Hosting Renewables By Svc**
**Published in: IEEE**
Proc. of the International Conference on Electrical, Computer and Energy Technologies (ICECET 2022). July 2022, Prague-Czech Republic
**The authors: Murtadha SAMI,** Stefan GHEORGHE and Lucian TOMA
**5- Scientific Research 2: Voltage Regulation in Transmission Networks Using Classic Methods.**
**Discussion date: 2020**

**6- Scientific Research 3: Voltage Regulation for Transmission Networks, including Renewable Source of Energy.**
**Discussion date: 2021**

**7- Scientific Research 4: Voltage Regulation for Transmission Networks, using FACTS Devise (SVC).**
**Discussion date: 2021**

**8- Scientific Research5: Transient stability enhancement and voltage regulation in Nordic32-Bus power system using SVC, AVR, PSS and Governor.**
**Discussion date: 2021**

## 7.3 Recommendation for future work

As there is always place for better, new ideas can be shaped to improve the work presented in the dissertation. Some of these ideas might be:

- ✓ Integrating artificial intelligence techniques in the methodology for optimal placement of FACTS devices;
- ✓ Selecting the best position for FACTS devices in a power system based on many other target functions;
  - ✓ Use of energy storage system (ESS) in the power system to minimize imbalances between energy demand and production.

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