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Title:

Optimal Sizing and Allocation of Static Var Compensator in a Power network

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Last but by no means least, thanks go to our parents for their love, prayers, caring, and sacrifices for educating and preparing us for the future. They are the most important people in our world and we dedicate this work to them. Also, we express our thanks to our sisters, brothers, and all our families for their support and valuable prayers.

Dedication

I would like to dedicate this work to my father and my mother for their support, to my brother and my sister and all my family and friends.

Megari Mouhsen El Bachir

I would like to dedicate this work to my parents for their support and my beloved grandmother, may God protect them.

Azzeddine Hadjersi

Abstract

The power system transformation brings new challenges and opportunities due to changes and uncertainties in electricity consumption and generation. High integration of intermittent solar and wind generation requires fast ramping resources to satisfy the growing demand, triggered by the electrification of the transportation sector.A smart grid has also emerged as one of the solutions to the technical issues, hence allowing the usage of renewable and improving the energy efficiency of the electrical grid. The challenge is to develop an intelligent management system to maintain the balance between generation and demand. As part of the smart grid, the deployment of energy storage systems (ESS) and the Static Var compensator (SVC) plays a critical role in stabilizing the voltage and frequency of the networks with renewable energy sources and electric vehicles (EV).

In recent years, many voltage instability incidents have occurred in power systems, the main cause of the voltage instability is the reactive power limit of the system. Flexible Alternative Current transmission systems (FACTS) devices can play a very important role in preventing voltage instability. SVC as a FACTS device can significantly provide continuous voltage control under various operating conditions.

In this context, this report proposes a new algorithm to find the optimal location and size of SVC controllers in order to increase the voltage security of power systems during large disturbances. The optimal location and size of SVC are determined based on the sensitivity of the voltage magnitude dV/dQ. The simulated tests were made using a model of an IEEE 9-bus power network to see the positive impacts of a well implemented SVCs.

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Figure 4.10: Case 4: Load bus voltages (After SVC installation)

List of Abbreviations

SVC	Static Var Compensator
TCSC	Thyristor control series capacitor
STATCOM	Static Synchronous Compensator
HV	High Voltage
MV	Medium Voltage
LV	Low Voltage
ESS	Energy Storage System
EV	Electrical Vehicles
DR	Demand Response
FACTS	Flexible Alternative current transmission System
PV	Photovoltaics
RES	Renewable Energy Sources
COFR	Continuous operating frequency range
DG	Distributed Generation
ICT	Information and communication technology
OPF	Optimal Power flow
OLL	Overloaded lines
STD	Short-term dynamics
LTD	long-term dynamics
HMI	Human-Machine Interface
HS	Harmony search
PSO	Particle Swarm Optimization
PSS®E	Power System Simulator for Engineering

General Introduction

Electrical power systems are undergoing a metamorphosis. The future power networks will have greater unpredictability due to the increased share of renewable generation either as bulk installations connected to high voltage (HV) / medium voltage (MV) electricity networks or as distributed generation and new loads such as EV connected to low voltage (LV) electricity networks.

The power system is under change and the transition has started to a more decentralized and complex power system, with more distributed generation and active end-users, and it is generally acknowledged that the need for flexibility is increasing, even the conventional power generation which has been used for decades now is suffering from increasing demand in power consumption and sequentially losing stability and more precisely, it is losing reactive power in the system. In this context, the concept of flexibility has been defined in a variety of ways, for instance as "the modification of generation injection and/or consumption patterns, on an individual or aggregated level, often in reaction to an external signal in order to provide a service within the energy system or maintain stable grid operation".Flexibility services can be provided by flexible resources in distribution systems, such as EV, and demand response. These flexible resources are believed to play an important role in the planning and operation of the power system in the future.

In this report, we show how application of FACTS technologies such as SVC, is an effective solution to avoid instability problems and prevent the apparition of voltage collapse and improve the overall stability of the power system.

For this, the report is organized into four chapters, an overview of the conventional and renewable energies and their negative impact on the electrical system are illustrated in the first chapter. Then in the second chapter, we mention the SVC and we go deeper into smart grids stating its components and the infrastructure needed for the system. After that, we discussed the SVC controller model and different techniques for placement and why we chose our algorithm in the third chapter. The fourth chapter is devoted to the PSS®E and Matlab simulation of the IEEE 9-bus power network model. A general conclusion summarizes the outcomes of this project.

Chapter 1

Overview of Renewables and Conventional Power Generation

Chapter 1 : Overview of Renewables and Conventional Power generation

1.1 Introduction :

At first hand we have the Conventional power generation, mostly are fossil fuel stations, which represent almost 75% of world electricity usage in the world be it steam, Gas turbine, and combined gas/steam or Reciprocating engines using different types of fuels such as coal, gas, and oil. For environmental and security reasons, the generation stations are not built near cities where people live but rather in isolated areas which are leading to a deficiency in the reactor power generation because of the distance.

On the other hand, Renewable energy resources (RESs) and other significant opportunities for energy efficiency exist over wide geographical areas, in contrast to other energy sources, which are concentrated in a limited number of countries. The existing bottleneck in transmission lines continuous contamination of the environment due to heavy reliance on fossil fuels and the highly fluctuating cost of fuel are few reasons for the widespread use of renewable energy technologies whose energy storage are the need of time and range from low capacity mobile storage batteries to high capacity batteries connected to the intermittent renewable energy sources which are causing the instabilities in the power grid. We will look into that in this chapter.

1.2 Conventional Power Generation:

A fossil fuel power station is a thermal power station that burns fossil fuel, such as coal or natural gas, to produce electricity. Fossil fuel power stations have the machinery to convert the heat energy of combustion into mechanical energy, which then operates an electrical generator. The prime mover may be a steam turbine, a gas turbine, or, in small plants, a reciprocating gas engine. All plants use the energy extracted from expanding gas, either steam or combustion gases. Although different energy conversion methods exist, all thermal power station conversion methods have efficiency limited by the Carnot efficiency and therefore produce waste heat.

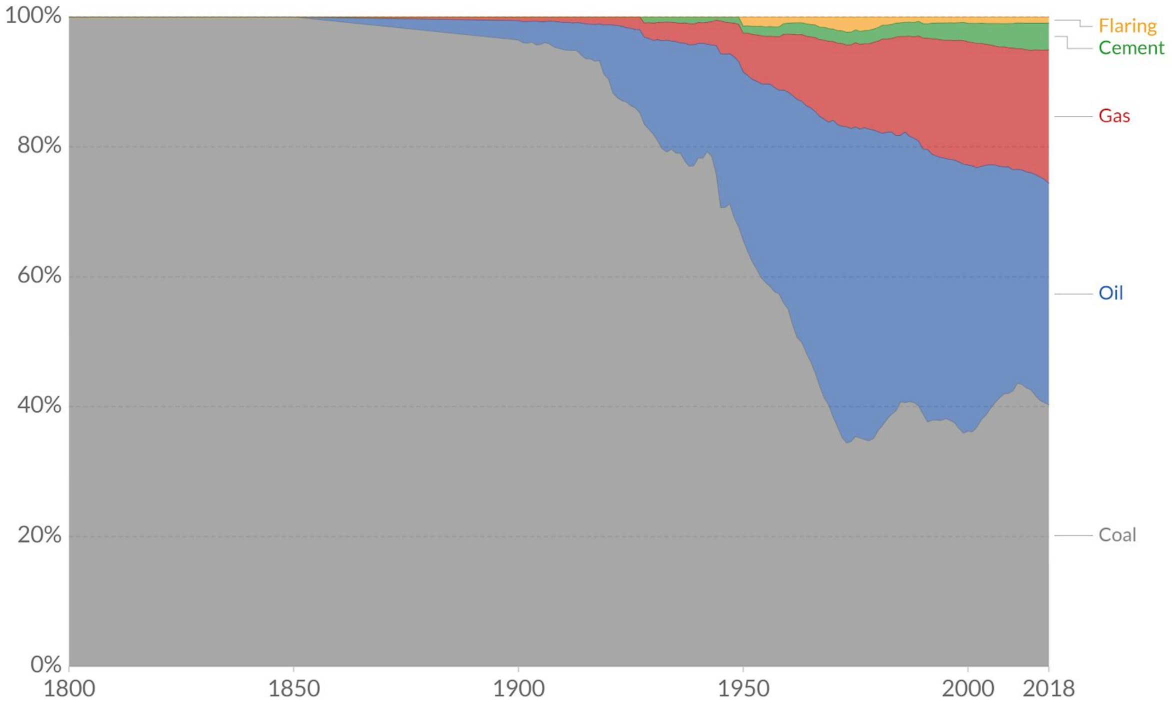


Figure 1.1: Different kinds of power generation and their percentage in a worldwide generation. [1]

1.2.1 Steam Turbine :

In a steam turbine power plant, fuel is burned in a furnace and the hot gasses flow through a boiler. Water is converted to steam in the boiler; additional heating stages may be included to superheat the steam. The hot steam is sent through controlling valves to a turbine. As the steam expands and cools, its energy is transferred to the turbine blades which turn a generator. The spent steam has very low pressure and energy content; this water vapor is fed through a condenser, which removes heat from the steam. The condensed water is then pumped into the boiler to repeat the cycle. Emissions from the boiler include carbon dioxide, oxides of sulfur, and in the case of coal fly ash from non-combustible substances in the fuel. Waste heat from the condenser is transferred either to the air; or sometimes to a cooling pond; lake, or river. [2]

Figure 1.2: Coal fueled Steam turbine power plant.

1.2.2 Gas turbine and combined gas/steam :

One type of fossil fuel power plant uses a gas turbine in conjunction with a heat recovery steam generator. It is referred to as a combined cycle power plant because it combines the Brayton cycle of the gas turbine with the Rankine cycle of the heat recovery steam generator. The turbines are fueled either with natural gas or fuel oil.

Figure 1.3: 480 MW GE H series power generation gas turbine.

1.2.3 Reciprocating Engines :

Diesel engine generator sets are often used for prime power in communities not connected to a widespread power grid. Emergency (standby) power systems may use reciprocating internal combustion engines operated by fuel oil or natural gas. Standby generators may serve as emergency power for a factory or data center, or may also be operated in parallel with the local utility system to reduce peak power demand charge from the utility. Diesel engines can produce strong torque at relatively low rotational speeds, which is generally desirable when driving an alternator, but diesel fuel in long-term storage can be subject to problems resulting from water accumulation and chemical decomposition. Rarely used generator sets may correspondingly be installed as natural gas or Liquefied petroleum gas to minimize the fuel system maintenance requirements.

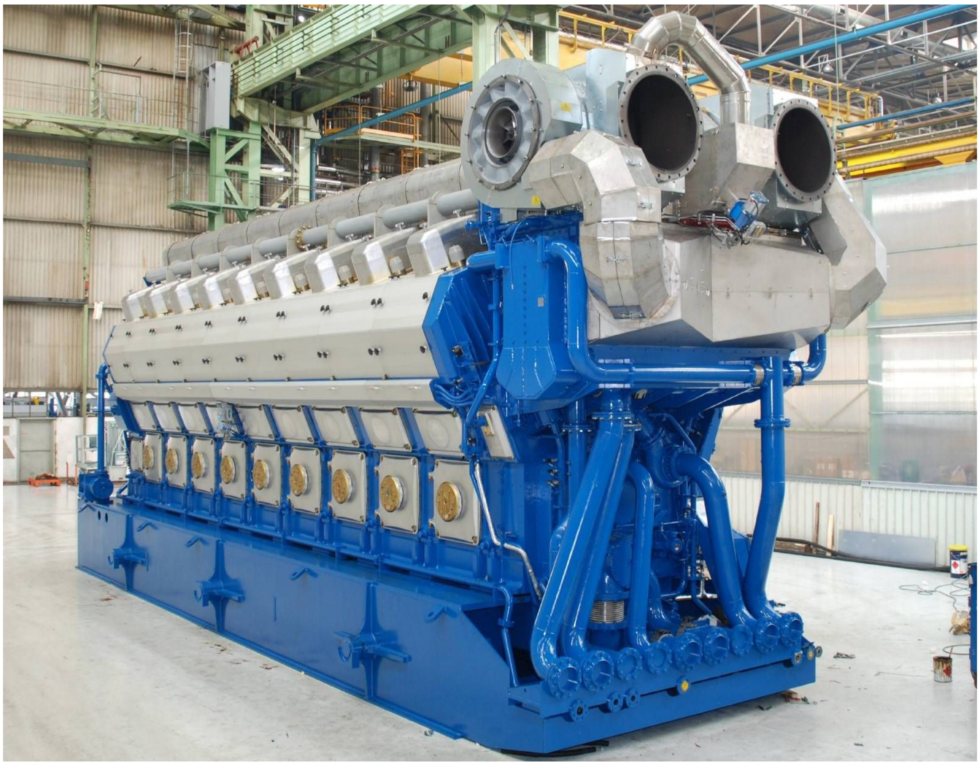


Figure 1.4: 130 MW Reciprocating engine using gas.

1.3 The Vulnerability of The Modern Power System :

Modern power systems are becoming more vulnerable to operating limit violations and voltage instability problems due to large transmission networks, deregulation of the electricity industry, and utilization of various renewable energy sources as well as different load patterns. The power system, at this stage, can become insecure and prone to voltage collapse due to a lack of reactive power support. Generators have the capability of providing reactive power but are limited to a certain extent. Furthermore, the reactive power produced by the generators cannot be effectively utilized if the demand for reactive power is far from its location. Therefore, it is an important issue to be addressed in the electricity industry because all of these problems may lead to a power outage also known as a “blackout”.

1.4 Power outage :

Power outages or blackouts can cause major problems at home and business. Data loss, productivity, security, and even profits can all be consequences. But in addition to the related inconvenience, the cause of power interruptions can also put sensitive electrical equipment at risk.

And though modern electronics have several safeguards making them less susceptible to damage that may be caused by power outages, surges, spikes, brownouts, and electrical interference, there are still risks and precautions that users can and should be aware of, especially if their businesses rely on their continued operation.

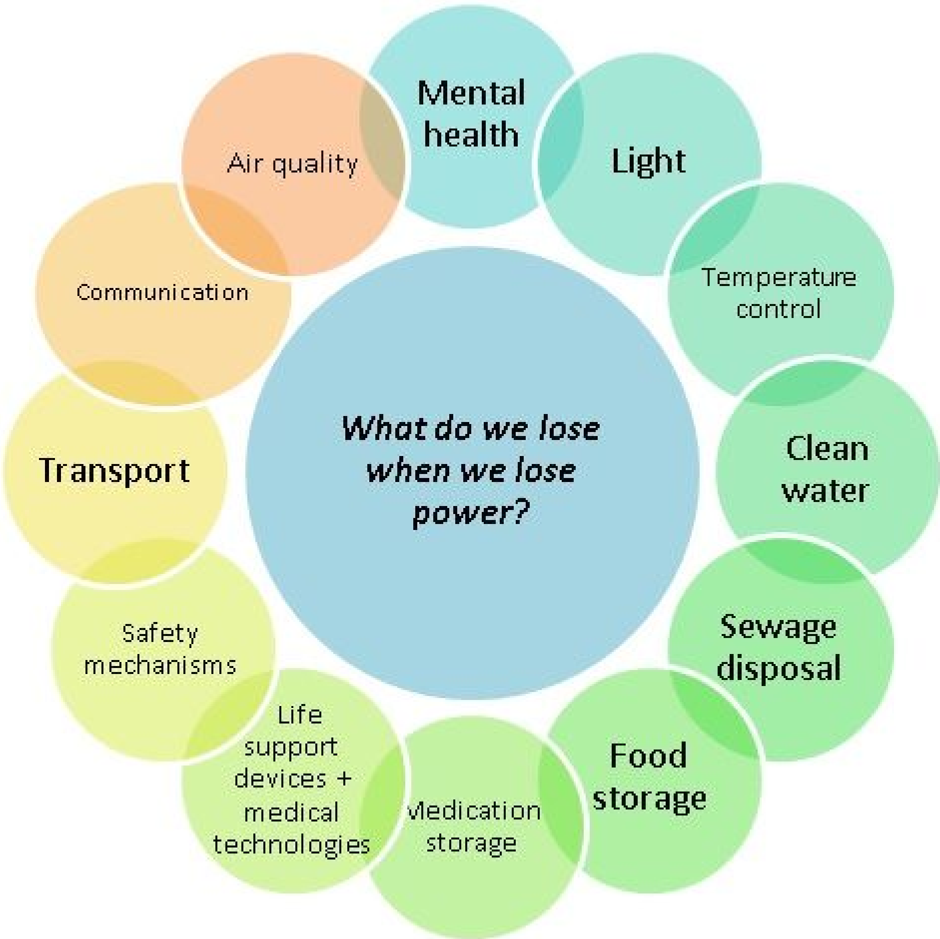


Figure 1.5: Power outage consequences.

1.5 Renewable Power Generation :

1.5.1 Solar Power :

Solar power is the conversion of energy from sunlight into electricity, either directly using photovoltaics (PV), indirectly using concentrated solar power, or a combination. Photovoltaics were initially solely used as a source of electricity for small and medium-sized applications, from the calculator powered by a single solar cell to remote homes powered by an off-grid rooftop PV system. As the cost of solar electricity has fallen, the number of grid-connected solar PV systems has grown into the millions and utility-scale photovoltaic power stations with hundreds of megawatts are being built. Solar PV is rapidly becoming an inexpensive, low-carbon technology to harness renewable energy from the Sun.

Figure 1.6: ALGERIA: 5600 MW of solar power plants under construction. [3]

1.5.2 Wind Power :

Wind power or wind energy is the use of wind to provide mechanical power through wind turbines to turn electric generators and traditionally to do other work, like milling or pumping.

Wind power is sustainable and renewable energy and has a much smaller impact on the environment compared to burning fossil fuels.

The wind is an intermittent energy source, which cannot make electricity nor be dispatched on demand. It also gives variable power, which is consistent from year to year but varies greatly over shorter time scales. Therefore, it must be used together with other electric power sources or storage to give a reliable supply. As the proportion of wind power in a region increases, more conventional power sources are needed to back it up.

Figure 1.7: Algeria is seen as an African leader for renewable energy. [4]

1.6 The impact of renewable energies on the electrical grid

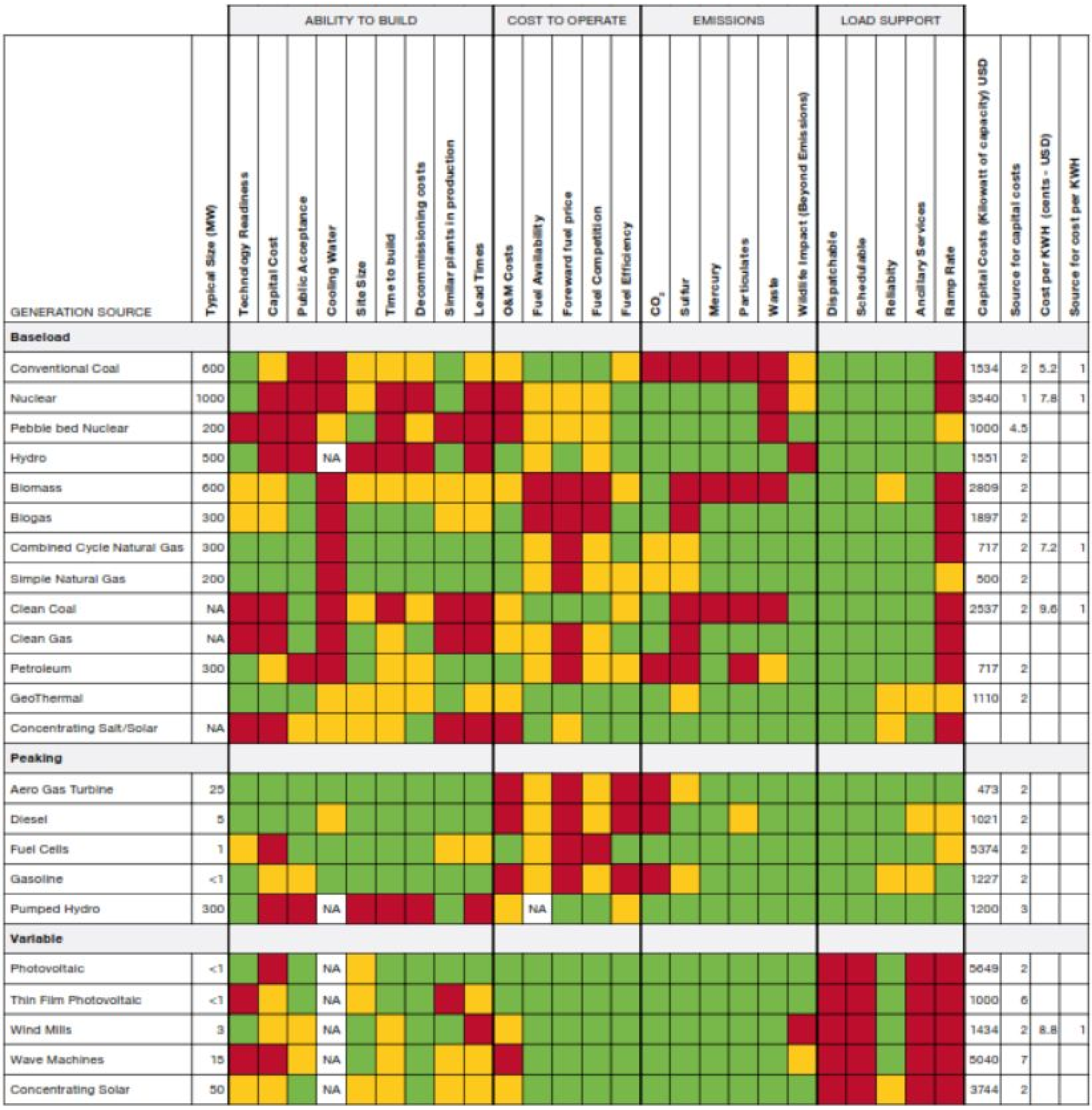
1.6.1 The instability of the solar and wind energies:

Unlike classical sources of energy, wind farms supply real power variations into the upstream grid, and at the same time, in some types of wind generation systems, the reactive power consumption is related to the real power production. These power variations cause voltage variations with consequences for the electrical power system and the customers.

On the other hand, the increasing use of power electronics in wind generation systems introduces voltages and current harmonics into the power system. As wind energy is a non-controllable energy source, it can cause problems with voltage stability and transient stability. Due to the rapid increase in the number of wind farms connected to the grid, the increasing rate of power of single wind farm and the weakness of the upstream power grid, where the wind farm connects, the importance and necessity of the study of wind farms connected to power systems is clear.

And for solar, one major problem is reliability. At best, a solar panel can produce electricity for 12 hours a day, and a panel will only reach peak output for a short period around midday. Tracking panels that follow the sun can extend this prime generation period somewhat, but it still means that panels spend very little of the day producing at maximum capacity. Storage batteries can charge during peak generation and provide a trickle of power at night, but they can be expensive, contain toxic materials, and wear out quickly due to repeated charge and discharge cycles.

Not only is the generation capacity of the PV resources variable, when interconnected at the grid edge they can give rise to distribution challenges such as over-voltage and reverse power flow and even drive negative prices in wholesale markets. Even though power generation from solar energy is more environmentally sustainable, high reliance on it can make power distribution systems less reliable.



GENERATION SOURCE	Typical Size (MW)	Capital Costs (Kilowatt of capacity) USD	Source for capital costs	Cost per KWH (cents - USD)	Source for cost per KWH
Baseload					
Conventional Coal	600	1534	2	5.2	1
Nuclear	1000	3540	1	7.8	1
Pebble bed Nuclear	200	1000	4.5		
Hydro	500	1551	2		
Biomass	600	2809	2		
Biogas	300	1897	2		
Combined Cycle Natural Gas	300	717	2	7.2	1
Simple Natural Gas	200	500	2		
Clean Coal	NA	2537	2	9.6	1
Clean Gas	NA				
Petroleum	300	717	2		
GeoThermal		1110	2		
Concentrating Salt/Solar	NA				
Peaking					
Aero Gas Turbine	25	473	2		
Diesel	5	1021	2		
Fuel Cells	1	5374	2		
Gasoline	<1	1227	2		
Pumped Hydro	300	1200	3		
Variable					
Photovoltaic	<1	5649	2		
Thin Film Photovoltaic	<1	1000	6		
Wind Mills	3	1434	2	8.8	1
Wave Machines	15	5040	7		
Concentrating Solar	50	3744	2		

Figure 1.8: Electricity generation costs and investment decisions. [5]

1.6.2 The Necessity of Integrating The Renewable System With a Complex Smart Grid System :

RESs are becoming integrated into electric power systems around the world, connected to existing transmission grids at a range of voltage levels.

The changes brought about by these new power sources are certain to have a significant impact on system performance and efficiency and to necessitate advances in the planning and operation of electric grids. However, as discussed earlier, wind and solar generation are unpredictably intermittent. That's why adding an unpredictable supply to the mix makes grid management very complex and increases the danger that the grid will become unstable and fail. The problem is even multiplied as wind and solar generation become a larger percentage of the total power sources.

RESs and ESSs are the key technologies for smart grid applications and provide great opportunities to decarbonize urban areas, regulate frequency, voltage deviations, and respond to severe time when the load exceeds the generation. ESSs such as battery energy storage systems enable the power grid to improve the acceptability of intermittent renewable energy generation. To do so, successful coordination between renewable power generation units, ESSs, and the grid is required.

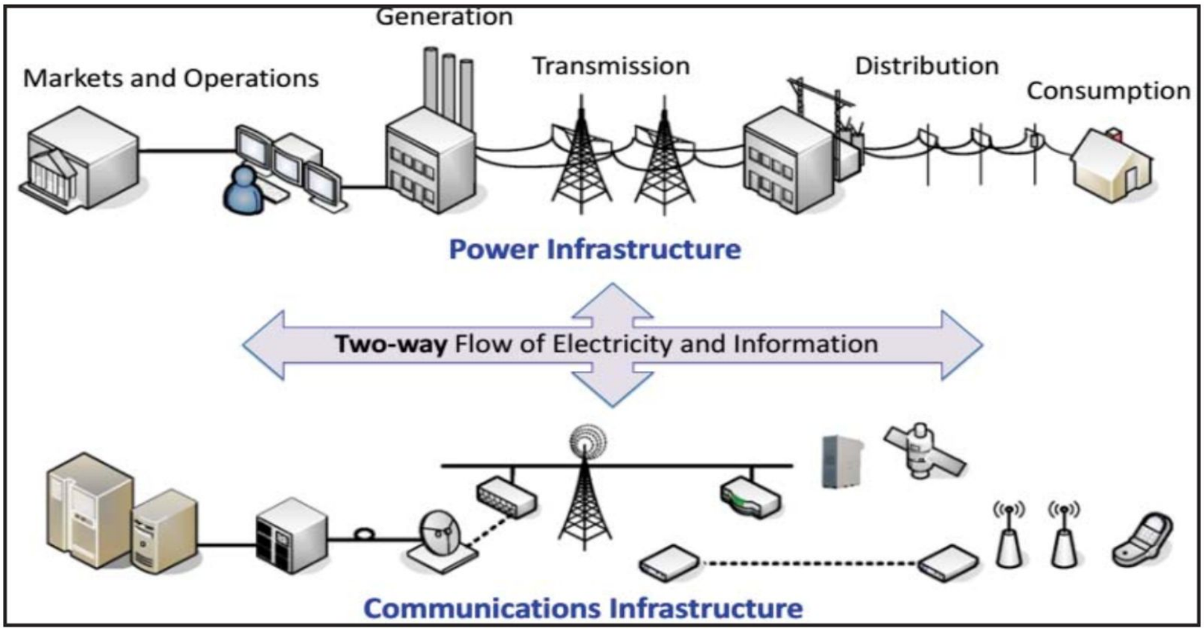


Figure 1.9: Smart grid infrastructure.[6]

Nonetheless, with the existing grid architecture, achieving the aforementioned targets is intangible. In this regard, coupling renewable energy systems with different generation characteristics and equipping the power systems with the battery storage systems to require a smooth transition from the conventional power system to the smart grid.

Indeed, this coordination requires not only robust but also innovative controls and models to promote the implementation of the next-generation grid architecture.

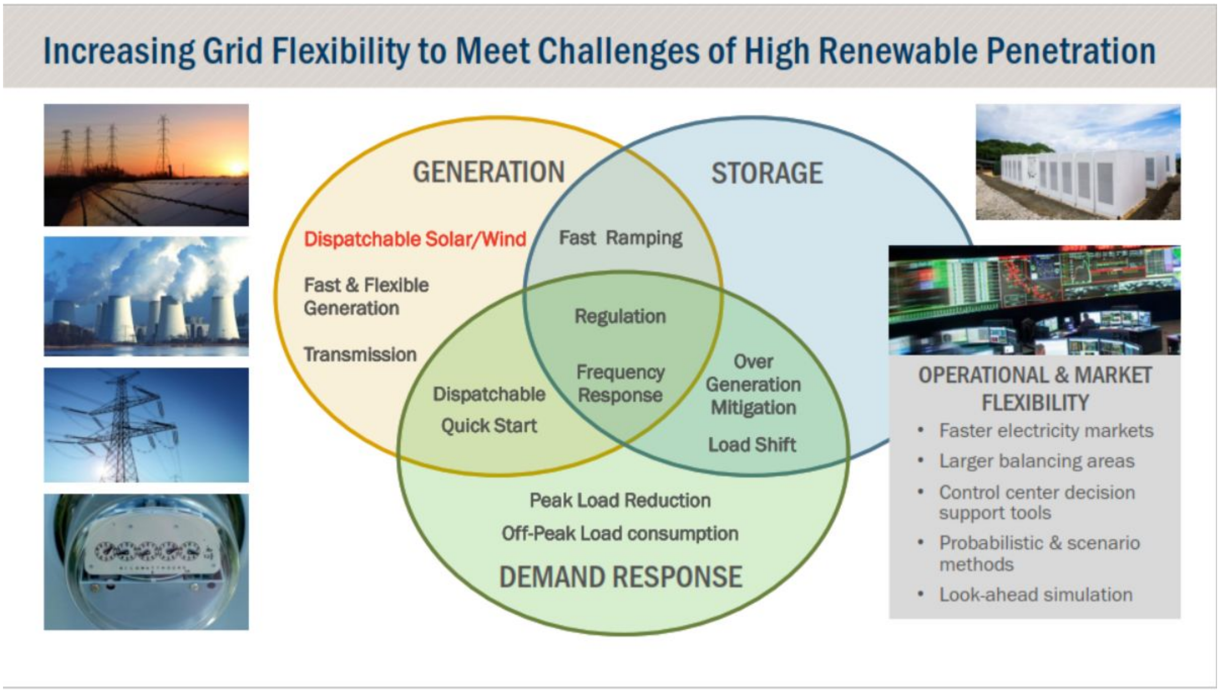


Figure 1.10: Demonstration of Essential Reliability Services.[7]

1.7 The four main types of stability:

Voltage stability: Power systems can sustain fixed tolerable voltage at every single bus of the network under standard operating conditions as well as after being subjected to disruption, the old wind turbines and solar PV panels are unable to support their local voltage or even control their reactive power output. Even so for the conventional generation method if the consumer is far away from the generation station.

Transient stability: It is the ability of the power system to return to its normal conditions after a large disturbance. The large disturbance occurs in the system due to the sudden removal of the load, line switching operations; fault occurs in the system, sudden outage of a line, etc. A network fault, e.g. a tree branch short-circuiting an overhead line, may result in the flow of large (damaging) currents which requires wind and solar power plants to 'ride-through'.

Small-signal stability: It refers to the ability to maintain synchronism when small disturbances happen. The disturbances are considered very small, so the equations to present the system state need to be linearized when study, Single generators, or groups of generators, may slowly oscillate against each other for a period of seconds to minutes following a small disturbance. Wind and solar power plants are unlikely to initiate or contribute to such oscillations.

Frequency stability: It refers to the ability of a power system to maintain steady frequency following a severe system upset resulting in a significant imbalance between generation and load, If an online generator suddenly trips off, the system frequency will quickly start to fall. If the frequency can't be restored within several seconds, there is a danger of system collapse and a blackout. Frequency stability can be more challenging for smaller systems, especially when the instantaneous wind (and solar) share of generation is more than 50% of the system demand. If the worst does indeed happen and a disturbance results in the blackout of an entire power system, then generators with black start capability are required to restart the system. Wind and solar generation have not traditionally been associated with such a role.

1.8 Conclusion:

In this chapter, we have started with an overview of both conventional and renewables energies (solar and wind in particular) explaining the negative impact of these energies on the electric power grid system and why integrating a smart grid into the system would be a crucial step to have all those energies go along and fix the situation, nevertheless, we are going to discuss all of that in-depth in the upcoming chapters.

Chapter 2

SVC and Smart grids

Chapter 02: SVC and Smart grids

2.1 Introduction :

The smart grid paradigm for the electric power systems is encompassing an increasing adoption of distributed generation all over the world. This trend requires the input from FACTS devices, which can be used to increase transmission capacity, improve stability and dynamic behavior, and ensure a better quality of energy by controlling several parameters. This chapter addresses the issue of power quality influence by assessing the SVC operation mode on the smart grid in order to assess the power quality limitations imposed by PV sales and wind energy farms plants operation on sensible loads.

2.2 Static Var Compensator

Smart Grid requires advanced technology to make the grid ideal and smart. Nevertheless, due to the complexities of the system, it is unclear and even confusing to define the networks being “smart” if a few of its key characteristics are neglected. Instead, it is preferable to consider the term “Smart Grid” as the chance to enhance the power system performance and improve operational capabilities. One of FACTS devices used to do this is the SVC which is an advanced technology used for power system compensation. SVC as a control device offers fast response time and much faster than traditional mechanically switched reactors or capacitors. For the most ideal smart grid achievable, we must consider ESSs, FACTS, and implementing a 2-way information flow in the system. The SVC will be more detailed in the next chapter

2.3 Smart Grids

2.3.1 Introduction:

A Smart grid is a term that refers to the smart options that could transform the ways energy is produced, delivered and consumed, and potentially the way we conceive of these services.

Delivering energy more intelligently is fundamental to decarbonizing the electricity system at least possible cost while maintaining security and reliability of supply. Smarter energy delivery is expected to allow the integration of more low carbon technologies and to be much more cost-effective than traditional methods, as well as contributing to economic growth by opening up new business and innovation opportunities and increasing the savings by innovating new options for energy system management.

2.3.2 What is a Smart Grid

A Smart Grid is an electricity network that can intelligently integrate the actions of all users connected to its generators, consumers, and those that do both to efficiently deliver sustainable, economic, and secure electricity supplies. A Smart Grid employs innovative products and services together with intelligent monitoring, control, communication, and self-healing technologies to better facilitate the connection and operation of generators of all sizes and technologies, allow consumers to play a part in optimizing the operation of the system, provide consumers with greater information and choice of supply, significantly reduce the environmental impact of the whole electricity supply system and finally deliver enhanced levels of reliability and security of supply. [8]

2.3.3 The Vision Behind Smart Grids

Every developing technology is driven by a vivid vision, by which the success of the project is measured, and the aims of smart grids happen to be the following:

- Provide a user-centric approach and allow new services to enter into the market.
- Establish innovation as an economical driver for the electricity network renewal.
- Maintain security of supply, ensure integration and interoperability.
- Enable distributed generation and utilization of renewable energy sources.
- Ensure the best use of central generation, Consider appropriately the impact of environmental
- limitations; Enable demand side participation (demand-side response(DSR),demand-side management(DSM)).

2.3.4 Components of the Smart Grid [9]

The basic components of the smart grid are:

- Phasor Measurement.
- Supervisory Control And Data Acquisition. (SCADA)
- Centralized Remedial Action Scheme. (CRAS)
- FACTS.
- Advanced conductors.
- Substation automation.
- Distribution automation.
- Advanced metering for the consumers.
- Demand response.
- Distributed resources.

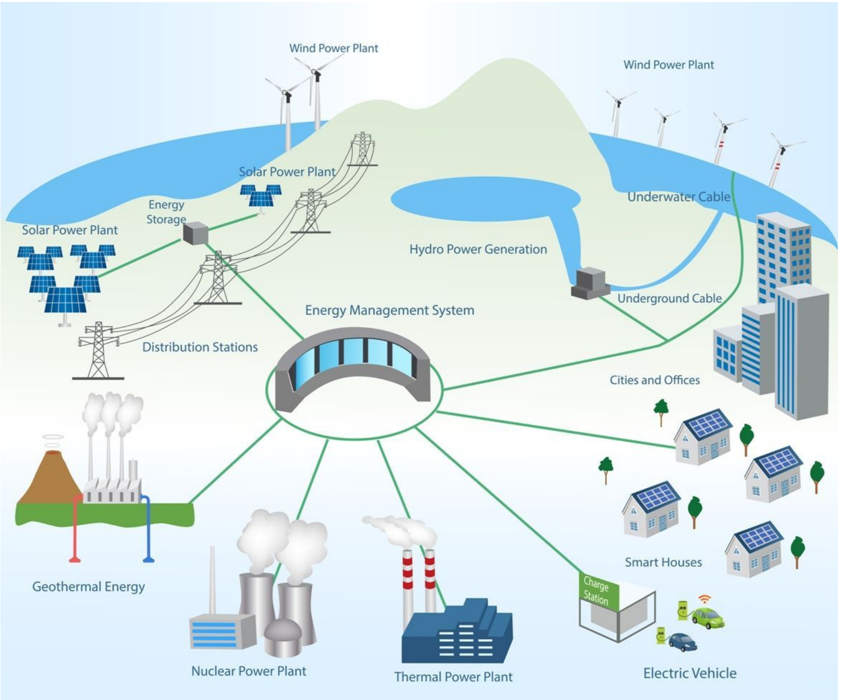


Figure 2.1: Components of the Smart Grid.[10]

2.3.5 A Model Set-Up

Figure (2.2) shows a model set-up of Smart Grid including smart generation, smart transmission, smart storage as well as smart sensors to isolate the fault.

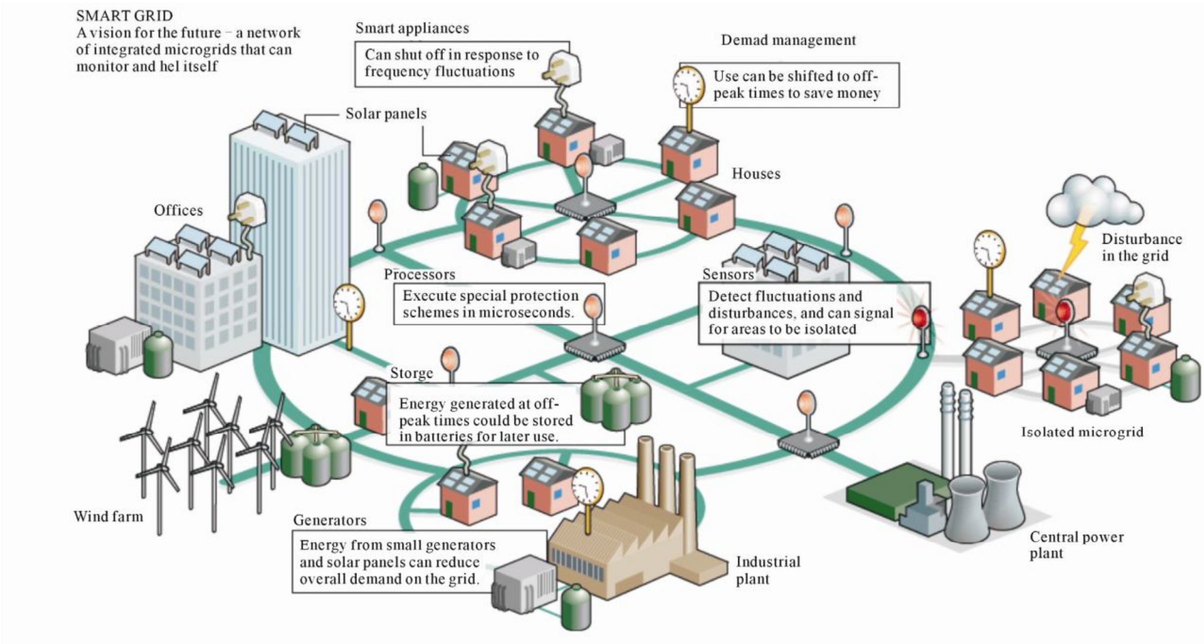


Figure 2.2: A model set up of a smart grid network.[11]

2.3.6 Optimizing Grid Operation and Use

In order to manage the ever-increasing demands for energy trading and security of supply, the existing transmission and distribution networks require improved integration and coordination. To control electric power flows across the states of Algeria, advanced applications and tools that are already available today should be deployed to manage the complex interaction of operational security and trading and to provide active prevention and remedy of disturbances. The main key elements and priority components are:

- Wide Area Monitoring (WAM) and Wide Area Control (WAC) systems with the regulation of SVC, optionally in a closed-loop, to maximize the use of available transmission capacity while reducing the likelihood of disturbances.
- Distributed state estimators for large synchronous areas with real-time power system security assessment and optimized dispatching with dynamic constraints.
- Coordinated ancillary services, including the integration of balancing markets and coordination of reserves throughout the grids/control areas, the integration of balancing markets is of particular importance both, for enhanced power system security and improved market liquidity.

- Steady-state and dynamic (transient) simulators with modeling of RES and nonlinear devices.

- Coordinated operation of power flow control systems (FACTS, phase shifters, etc.) with devices for automatic countermeasures/system defense. These applications exist in the component form today, Further work is urgently required to understand how to deploy and validate these solutions in a “closed-loop” operation.

- Regulatory issues of relevance for the defined targets should be re-considered to ensure innovative technological solutions are adequately promoted and deployed.

2.3.7 Optimizing Grid Infrastructure

New and efficient asset management solutions for the transmission and distribution grids are required, as well as coordinated and coherent grid infrastructure planning should be done. coordinated planning should be based on scenarios and include the necessary elements of risk management in order to cope with the increased volatility and uncertainty in location and size of generation and growing intermittent generation.

The key elements and priority components

- Expanding the grids (notably transmission) with new infrastructure (e.g. HV direct current) will depend on accelerating permitting procedures and making them much more efficient than today.

- New overhead line configurations to increase capacity and reduce electromagnetic fields are required.

- Refurbishment/enforcement of the existing HV lines by innovative network assets including superconductivity technology.

- New asset management and grid planning methods for transmission and distribution.

- Development of systems and components to maintain power quality at acceptable levels while encouraging the integration of new types of generators.

2.3.8 Integrating Large Scale Intermittent Generation

Large-scale forms of generation, e.g. wind farms and solar thermal generation require networks to enable efficient collection of the power generated and enable system balancing, either by energy storage, conventional generation, or by demand-side participation.[12]

Key elements and priority components

- Technically viable and commercially affordable solutions for the required networks for the collection of wind power.
- Grid connection from renewables networks should consider security and quality of supply, economy, and environmental sustainability.
- Transnational and cross-border grid reinforcements should be considered. The present long licensing procedures should be shortened.
- Solutions should be developed to allow for efficient and secure system operation of future grids with significant intermittent generation; heavy bulk power is not easily dispatchable.

2.3.9 Information and Communication Technology

This is about defining the tasks and implementing the necessary standards for Information and Communication Technology (ICT) solutions in future Smart Grids. The application of ICT is a prerequisite for data exchange between the different market players in the electricity supply chain and for the secure, economic, and environmentally benign operation of Smart Grids. [13]

Today ICT is applied at the transmission and sub-transmission level and ends at the bus-bars of the sub-transmission (110 kV)/MV substations. Different standard protocols at various voltage levels and for different kinds of equipment are used. By large, the medium and LV levels are characterized by limited ICT for economic reasons.

Standardized, open information models and communication services for all data exchange within the whole electricity supply chain and an electric power supply system is needed.

Different ICT technologies should be investigated and tested on-site with the goal of the introduction of ICT into the distribution level relying on the existing communication infrastructure (radio, power line, copper, or fiber optics), applied in a cost-effective way. The challenge will be to coordinate all these databases through one overlaying data warehouse based on common information models. The data warehouse concept interconnects to all other databases ensuring this way the necessary data consistency. The main key elements and priority components:

- Simple, robust, secure, and flexible communication infrastructure to allow monitoring, management, control and, dispatching operations at all levels down to the distribution and customers.
- Common information and data models for all information building blocks, in order to ensure consistent database management, need to be defined at all levels of the power system and electricity supply chain.
- Well functioning ICT solutions are essential for maintaining the security of supply and for the efficient interaction of the market players
- A truly competitive situation for all kinds of products relying on multi-vendor strategies can only be achieved with well defined and standardized ICT solutions.

Figure 2.3: What is ICT?[14]

2.3.10 Active Distribution Networks :

Transmission networks have always provided a balancing and management role in the electric power supply chain, whereas distribution networks have been designed to be passive "fit-and-forget" in operation. The challenge now is to provide many of the services found in transmission grids, such as power flow and constraint management, contingency analysis, and balancing in distribution networks [15]. This is required not just because of the increasing deployment of distributed generation, but also because of emerging intelligent building services in both residential and commercial premises, the need for utilizing local generation to support the local network at times of stress on the main grid, and because of the anticipated future wide usage of EV for the sake of transportation. Distribution networks will need to be able to respond or adapt in real-time to the complex interactions of all of these challenges and provide enhanced information to various actors to enable the real-time trading of the various services being provided.

The main key elements and priority components

- An active network requires effective and coherent visibility of the various devices connected to it to allow timely decision making and information flow.
- Centralized manual control needs to be replaced by a distributed control architecture which will be coordinated and integrated into existing control methodologies in order to take advantage of the intelligence that will enhance the networks of the future.
- It is necessary to ensure compatibility of all functions and devices also during the transition from the present to the future active distribution grids.
- Besides on-line control and management, the active distribution network will introduce new functionalities, enabled by new tools and solutions relying on dynamic and multifaceted optimization. Modeling of uncertainties in planning and operation required to achieve that will build upon: [16]

- Standardization of the data models and communication protocols to ensure minimum overhead and capacity to expand and encompass future requirements.
- Communication systems capable of coping with the needs in terms of capacity, reliability and, costs induced by the new functions.

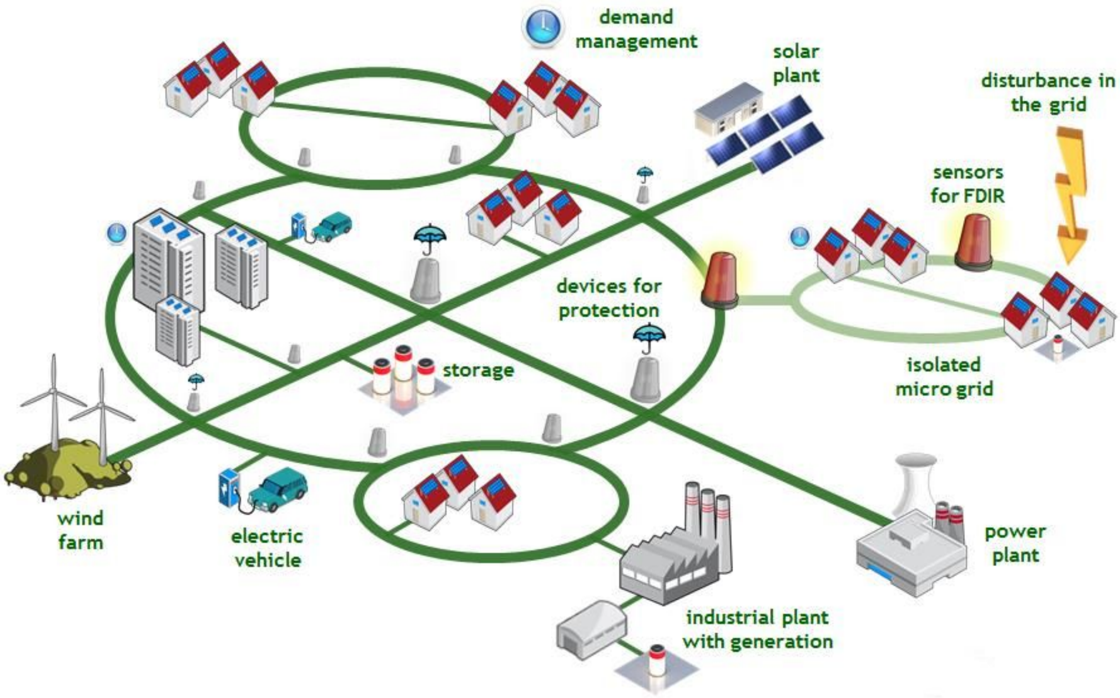


Figure 2.4: Active distribution networks.[17]

2.3.11 New MarketPlaces, Users, and Energy Efficiency

Diminishing the differences between transmission and distribution in areas such as ancillary services, grid connection, and access, but also quality and security of supply is one of the important characteristics of the whole Smart Grids concept. At the same time, such as “democratization” and “decentralization” requires enhanced and strengthened control and management. This is necessary to operate the grid securely, control and management solutions are also required to deploy several new and emerging concepts successfully and effectively such as the Virtual Power Plants and end-user energy management concepts. To meet future customer needs, a range of new market participants will evolve.[18]

Key elements and priority components

- Innovative Customer Interface Devices as bidirectional smart communicators between the customers and the market.
  - To give the customer choice in energy supply, it is necessary to develop solutions to increase and optimize information related to energy consumption, improving the interaction between customers and market players
  - Such devices shall be able to provide the relevant energy information stored in digital or electronic meters to stimulate the consciousness and generate a virtuous new behavior toward energy savings, increasing end-user energy efficiency.
  - Such devices can also work as “energy data providers” for all the smart appliances installed in a house, to enable load management services.
- Intelligent Smart Home Controller, providing information on patterns of behavior, useful for raising awareness of energy consumption and to foster efforts towards real energy conservation/savings.
  - Encouraging the customers’ active role requires advanced ICT tools able to manage the complexity of multiple inputs, take consequent intelligent actions, and provide easy and flexible interaction between the customers and the system.
  - The Smart Home Controller should represent the control point and counterpart to smart meters. They will interact closely in order to exchange data.
  - The customers’ active role will be focused on setting the rules and priorities of energy use in respect of availability and cost while the daily operations, information, and communication.

2.4 Conclusion :

In this chapter, we mentioned the importance of the FACTS device SVC and we went a bit deeper into smart grids where we showed the vision behind future smart grids, its main components and we showcased a Model set up of it as well,we clarified how to optimize its infrastructure, operation, and use so that we can manage the ever-increasing demand for energy and supply security. We furthermore explained how to integrate intermittent generations into the system, until now we have just gone through general concepts about smart grids, in the next chapters we will specify the methods and algorithms that should be used and discuss how to apply that in a power system.

Chapter 3

SVC controllers placement

Chapter 3 : SVC controllers placement

3.1 Introduction :

The electric power industry, in the present, is very complex and undergoes unforeseen rapid changes in terms of demand/generation patterns and trading activities that hinder the system security. For example, a steep rise in load or a certain critical line/equipment outage can cause line overload or undesirable voltage profile, and such events can push the system towards instability and possibly even a blackout. In order to cope with such situations, it is common practice to purchase the right of asking for a reduction of the load from certain customers. However, it is not an ideal situation from a reliability perspective as well as having a critical load in the power system. Load curtailment is the collection of control strategies employed to reduce the electric power loading in the system and the main aim is to push the disturbing system towards a new equilibrium state. Load curtailment may be required even when voltages at some buses deviate from their acceptable voltage limits.

In such cases, reactive power is supplied locally to keep the voltages within limits. The main disadvantage of the reactive power over the active power is that it cannot be transmitted over long distances and hence, must be provided locally by some means. FACTS controllers can be a suitable alternative to provide such reactive power locally. Generators have the capability of controlling reactive power but the location of the reactive power demand can hinder their effects considerably. Due to the high costs of FACTS devices, their proper location in the system must be ascertained. The impacts of Thyristor control series capacitor (TCSC) and SVC on system load curtailments based on optimal power flow (OPF) is studied by placing the devices in the system on a hit and trial basis. But a “hit and trial” method is not a mathematical approach to find the optimal location of these controllers and a proper mathematical method is suggested, in this thesis, as the costs of these devices are reasonably high. SVC is chosen for this purpose since it is cheaper. However, the cost of SVC has not been considered in this thesis.

3.2 System modeling :

3.2.1 Static representation of SVC :

SVC is a shunt connected Var generator or absorber whose output is adjusted to exchange capacitive or inductive current to maintain or control specific parameters of the electric power system, typically bus voltage. It includes separate equipment for leading and lagging Vars [19]. A simple connection diagram of SVC has been given in Figure (3.1).

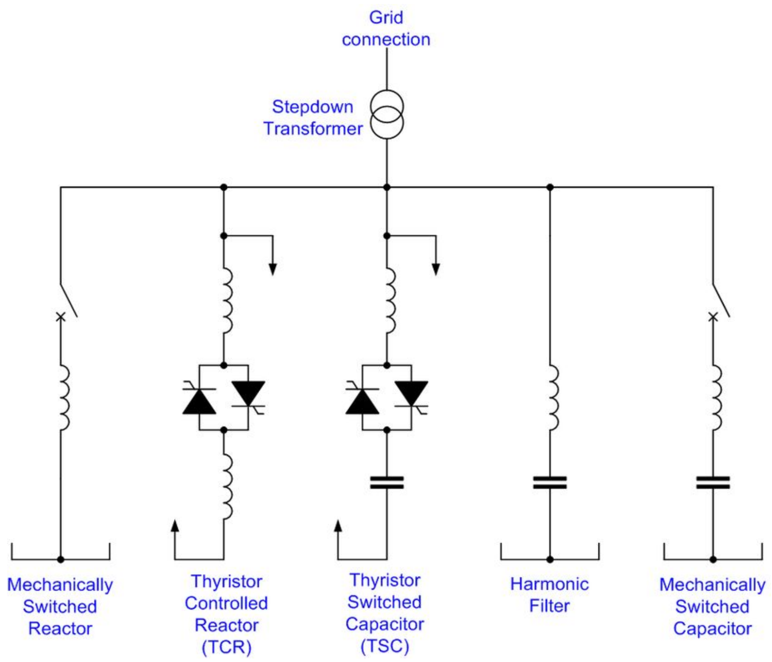


Figure 3.1: SVC connection to a bus.

1. Thyristor Controlled Reactor (TCR): In this type of SVC a reactor with thyristor valves is incorporated in each phase. Reactive power is varied by controlling the current through the reactor using the thyristor valves. This type of SVC is characterized by smooth and continuous control.

2. Fixed capacitor Thyristor Controlled Reactor (FC-TCR): In this type of SVC a TCR is used in combination with a fixed capacitor bank when reactive power generation is required. This is often the optimum solution for sub-transmission and distribution applications.

The main characteristics of this type of SVC are smooth and continuous control, elimination of harmonics by tuning the fixed capacitors, and compact design.

3. Thyristor Switched Capacitor (TSC): In this type of SVC a shunt capacitor bank is divided into an appropriate number of branches. Each branch is individually switched on or off through anti-parallel connected thyristors. The main characteristics of this type of SVC are step and smooth control, no harmonics, low losses, and flexibility.

4. Thyristor Controlled Reactor–Thyristor Switched Capacitor (TCR–TSC): In this type of SVC the TCR and the TSC is combined to get an optimum solution in many cases. With a TCR–TSC SVC, continuously variable reactive power can be obtained across the entire control range, with full control of both the inductive and the capacitive parts of the compensator. The principal benefit is an optimum performance during major disturbances in the system such as line faults and load rejections. This type of SVC is characterized by continuous control, elimination of harmonics through TSC control, low losses, redundancy, and flexibility.

A Shunt FACTS device has been represented as an injection at one node to which it is connected whereas a series FACTS device is generally taken as power injection at two nodes connected at both the ends of a line in which a series FACTS controller exists.

In the active control range, the susceptance (*Bsvc*) and, hence, the reactive current is varied according to the voltage regulation slope characteristics shown in Fig. (3.2). The slope value depends upon the desired voltage regulation, the desired sharing of reactive power among various sources, and other needs in the system. Typically, it varies between 1-5%. The SVC behaves like a shunt capacitor of the maximum value (*BCsvc*) at the capacitive limit, and as a fixed shunt reactor at the minimum value *(-BLsvc*) corresponding to the inductive limit. These limits are reached when there are large variations in the bus voltage. The inductive limit is reached when the bus voltage exceeds the upper limit, whereas the capacitive limit is reached when it falls below the lower limit.

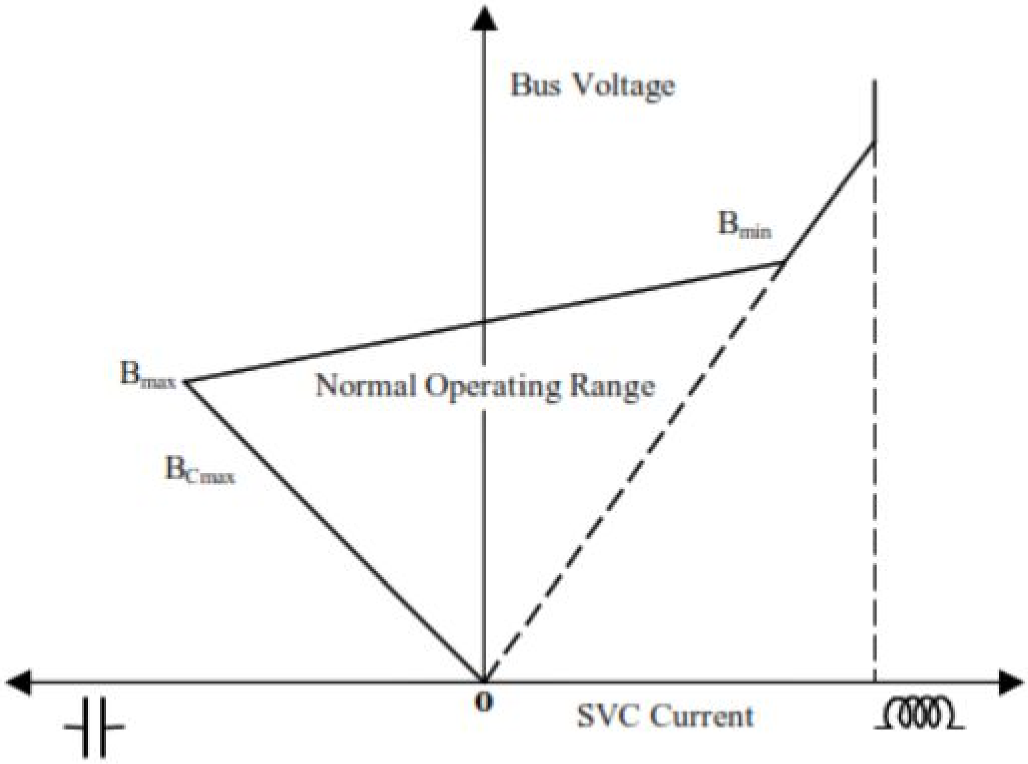


Figure 3.2: SVC output characteristics.

The SVC can be represented by its shunt current injection model. The current injection (*ISVC*) into the bus, where the SVC is connected, can be written as

$$\overline{I_{svc}} = jB_{svc}V \tag{3.1}$$

$$B_{svc} = B_c - B_{TCR} = \frac{1}{X_c X_l}\left\{X_l - \frac{X_c}{\pi}\left[2(\pi-\alpha) + \sin 2\alpha\right]\right\},$$

$$X_L = \omega L,\ X_c = \frac{1}{\omega C}, \tag{3.2}$$

where, B_{SVC}, α, X_L, X_C are the shunt susceptance, firing angle, inductive reactance, and capacitive reactance of the SVC, respectively. $\omega = 2\pi f$, where f is the frequency of the supply.

The reactive power injected into the bus due to SVC can be expressed as :

$$Q_{svc} = B_{svc} V^2 \tag{3.3}$$

where V is the voltage magnitude of the bus at which the SVC is connected.

SVC is still considered as a lower-cost alternative to a static synchronous compensator (STATCOM). A comparative study between STATCOM and SVC is given in the following table (3.1).

STATCOM	SVC
1. It acts as a voltage source behind a reactance 2. It is insensitive to transmission system harmonics 3. It has a larger dynamic range 4. It generates fewer harmonics 5. It has faster response (within ms) and better performance during transients 6. Both inductive and capacitive regions of operation are possible. 7. It can maintain a stable voltage even with a very weak AC system. 8. It can be used for small amounts of energy storage. 9. Temporary overload capacity translates into improved voltage stability.	1. It acts as a variable susceptance. 2. It is sensitive to transmission system harmonic resonance. 3. It has a smaller dynamic range. 4. It generates more harmonics. 5. Its performance is slow during the transients 6. It operates mostly in the capacitive region. 7. It has difficulty in operating with a very weak AC system.

Table 3.1 : Comparison of SVC and STATCOM

3.2.2 SVC Model

In order to present the problem formulation, a brief view of the SVC model, and the way it influences the network are given in this section as an example. [20]

The SVC is modeled by a shunt variable admittance and can be placed either at the terminal bus of a transmission line or in the middle of a long line [21]. Considering the SVC without losses, the admittance only has its imaginary component and it can take values in a specified range (usually between 0 and the maximum SVC capacity studied, here 500 MVAR). This is denoted by:

$$\underline{y}_{SVC} = \underline{jb}_{SVC} \tag{3.4}$$

This part considers the case of an SVC installed in a node Figure (3.3) with a continuously variable set point. [16]

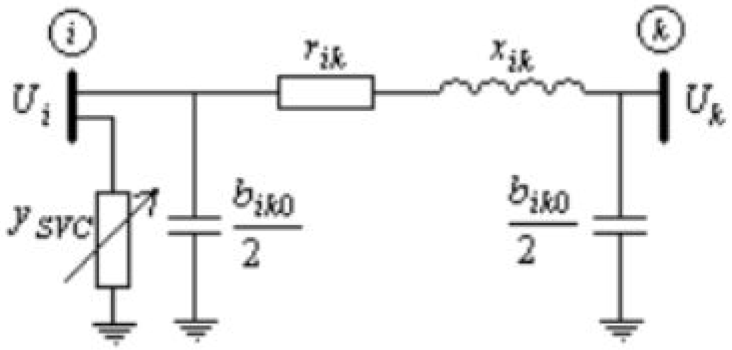


Figure 3.3: Equivalent circuit of an SVC connected to a bus terminal.

In this case, only one term of the nodal admittances matrix is modified, corresponding to the node where the SVC is connected:

$$\underline{Y}_{ii}' = \underline{Y}_{ii} + \underline{y}_{svc} \tag{3.5}$$

The matrix is therefore modified as follows :

$$[\underline{Y}'_{nn}] = \begin{pmatrix} \underline{y}_{ik} + \frac{\underline{y}_{ik0}}{2} + \underline{y}_{SVC} & -\underline{y}_{ik} \\ -\underline{y}_{ik} & \underline{y}_{ik} + \frac{\underline{y}_{ik0}}{2} \end{pmatrix} \quad (3.6)$$

3.2.3 Problem Formulation:

Consider a transmission network represented by its nodal admittance matrix *[Ynn]* and the vector of nodal powers *[S]*.

Let *Sv* be the vector of state variables (voltage phase and magnitude) and let *Cv* be the set of control variables (location, size, reference SVC values, the domain of variable *location* – consisting in a set of nodes where the SVC placement study is carried out).
The problem lays in determining *Sv* and *Cv* to minimize or maximize a certain objective function f (Sv, Cv) while verifying the following two types of constraints:

$$\begin{aligned} &g(Sv,Cv) = 0 \text{ (Kirchhoff's law)} \\ &h(Sv,Cv) \leq 0 \text{ (security constraints)} \end{aligned} \quad (3.7)$$

The domains of definition for the variables are also set as inequality constraints.
The objective function when searching for optimal SVC locations can include several optimization criteria. This thesis proposes a multi-objective function, searching for a solution consisting of both the SVC location and SVC size that minimizes the voltage deviations, active power losses, and installation costs.

01. The objective function

The objective function consists of three objectives, two of which are technical and one economical, as follows:

A.Minimize the active power losses:

$$O_1 = \sum_{l=1}^{b} R_l I_l^2 = \sum_{l=1}^{b} \left[V_i^2 + V_j^2 - 2V_i V_j cos\left(\delta_i - \delta_j\right)\right] Y_{ij} cos\varphi_{ij} \quad (3.8)$$

where b is the number of branches, R_l is the resistance of line l, I_l is the current through line l, V_i δ_i are the voltage magnitude and angle from node i and Y_{ij} , φ_{ij} are the magnitude and angle of the i-j line admittance

B. Minimize the voltage deviations

$$O_2 = \sum_{i=1}^{n} \left(\frac{U_{iref} - U_i}{U_{iref}}\right)^2 \quad (3.9)$$

Where n is the number of buses, U_{iref} is the reference voltage at bus i and U_i is the actual voltage at bus i.

02. Operational constraints

A. Power flow balance equations. The balance of active and reactive powers must be satisfied in each node:

$$P_{Gi} - P_{Li} =$$

$$= U_i \sum_{k=1}^{n} \left[U_k \left[G'_{ik} \cos(\theta_i - \theta_k) + B'_{ik} \sin(\theta_i - \theta_k)\right]\right]$$

$$Q_{Gi} - Q_{Li} =$$

$$= U_i \sum_{k=1}^{n} \left[U_k \left[G'_{ik} \sin(\theta_i - \theta_k) + G'_{ik} \sin(\theta_i - \theta_k)\right]\right] \quad (3.10)$$

where the conductance G'_{ik} and susceptance B'_{ik} represent the real and imaginary components of element Y'_{ik} of the [$\underline{Y}'_{nn}$] matrix, obtained by modifying the initial nodal admittance matrix when introducing the SVC

B. Power flow limits. The apparent power that is transmitted through a branch *I* must not exceed a limit value, S_{lmax}, which represents the thermal limit of the line or transformer in steady-state operation :

$$S_l \leq S_{lmax} \qquad (3.11)$$

C. Bus voltages. For several reasons (stability, power, and quality, etc.), the bus voltages must be maintained around the nominal value:

$$U_{imin} \leq U_{inom} \leq U_{imax} \qquad (3.12)$$

In practice, the accepted deviations can reach up to 10% of the nominal values.

03. SVC reference value

The size of an SVC is expressed as an amount of reactive power connected to a bus of voltage 1p.u. Sign conventions: a positive value indicates the fact that the SVC generates reactive power and injects it into the network through the node to which it is connected (capacitive state); a negative value characterizes the inductive state, where the SVC absorbs reactive power from the network.
The SVC size is a variable that can take *nv* discrete values from the interval:

$$QL\ max < Q\ svc < Qc\ max \qquad (3.13)$$

3.3 Modeling of SCV controllers:

The SVC in our case will be modeled as a reactive power generator connected to a bus in a system .

The reactive power generated by SVC is given by:

$$Q_{SVC}^{Min} \leq Q_{SVC} \leq Q_{SVC}^{Max} \tag{3.14}$$

If the SVC is operating outside the limits, so the bus becomes PQ-type and the reactive power Q is set and is expressed by Eq. (3.15):

$$Q = - B * U^2 \tag{3.15}$$

Where

B : equivalent susceptance of the SVC

U : the calculated voltage magnitude at the SVC node.

3.4 Some SVC location Algorithms:

3.4.1 The Particle swarm optimization Algorithms:

Particle Swarm Optimization (PSO) is population-based stochastic search algorithms approaches as the potential techniques for solving such a problem. For this study, SVC is chosen as the compensation device. The PSO provides a population-based search procedure in which individuals call particles and change their positions. The position of each particle is presented in the X-Y plane. Each particle moves to the new position using velocity according to its own experience, called Pbest. Gbest is the overall best value obtained so far by any particle in the population. From time to time, the PSO consists of velocity changes of each particle towards its Pbest and Gbest. Each particle tries to modify its current position and velocity according to the distance between its current position and Pbest, and the current position and Gbest. After finding the best values the particle updates its velocity and position. The velocity of each particle can be modified. The flowchart of is shown in Figure (3.4)

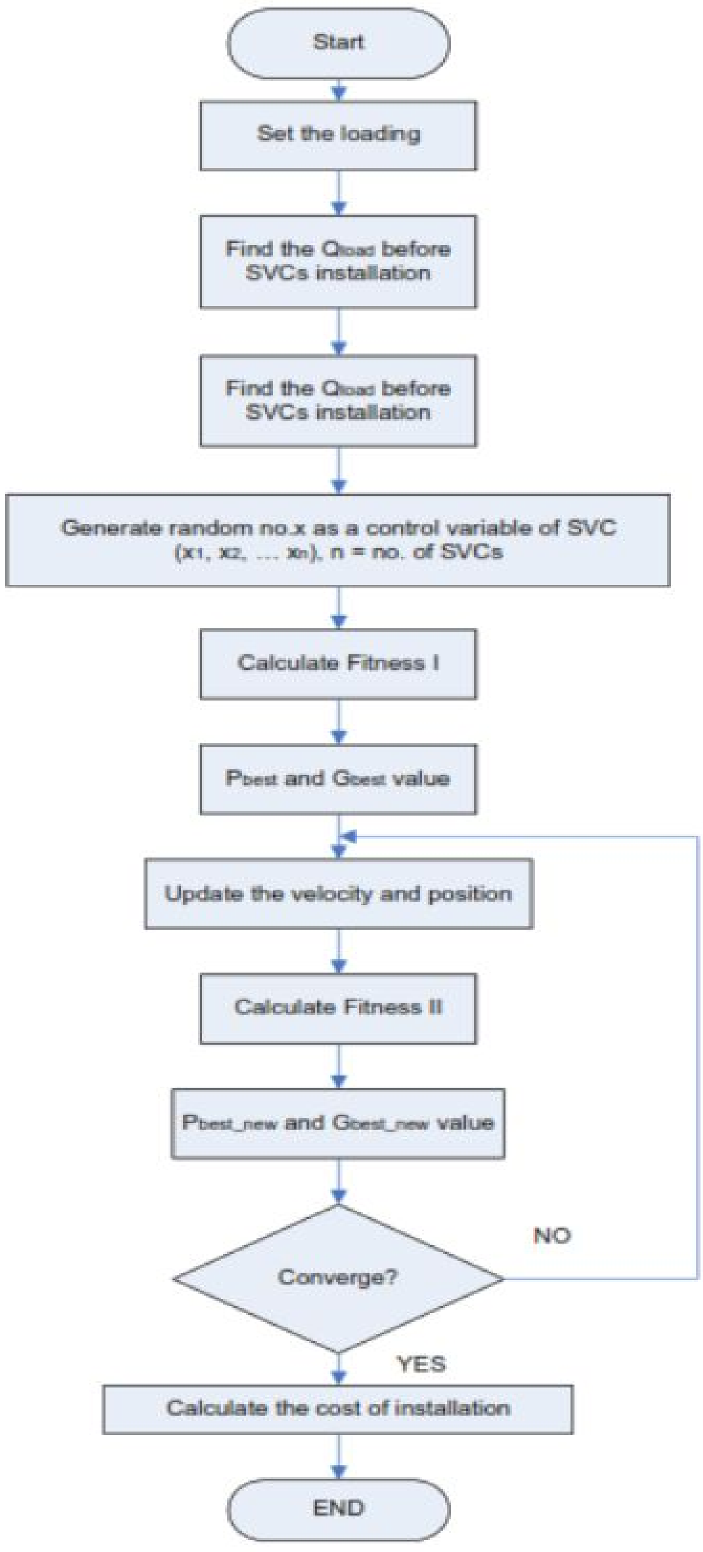


Figure 3.4: A flowchart of Particle swarm optimization. [23]

3.4.2 Genetic algorithm-based technique:

This technique proposes a genetic algorithm that tries to identify the optimal location and size of an SVC. A multi-criteria function is developed, comprising both operational objectives and investment costs. The computer program is run on multiple nodes test systems, assessing improvements in voltage profile, and reducing power losses. The purpose of this technique is to validate the solution method in order for it to be adapted for systems of higher dimensionality.

Genetic Algorithms are a way of solving problems by emulating the mechanism of evolution as found in natural processes. They use the same principles of selection, recombination, and mutation to evolve a set of solutions toward a “best” one. Before using any of the Genetic Algorithm models, the problem must be represented in a suitable format that allows the application of genetic operators. Genetic Algorithms optimize a single variable, the fitness function. Hence, the objective function and some of the constraints of the problem at hand must be transformed into some measure of fitness.

Encodings. The first feature that should be defined is the type of representation to be used so that an individual represents one and only one of the candidate solutions.

Fitness Function. This function measures the quality of chromosomes and it is closely related to the objective function.

Selection methods. The selection methods specify how the genetic algorithm chooses parents for the next generation. In this study, two selection methods were tested. The first method was Roulette Wheel Selection, which chooses parents by simulating a roulette wheel with different sized slots, proportional to the individuals’ fitness.

Crossover mechanism. The one-point crossover exchanges the genetic information found after a random position in the two selected parents. The scattered crossover mechanism is described in the following. For each pair of selected parents, the algorithm generates a set of binary components. The number of components is equal to the number of genes in an individual. This is a mask that will guide the crossover: if the mask value for the ith gene is 0, then this gene of the offspring will inherit the ith gene from the first parent.

Otherwise, the ith gene of the offspring will be the ith gene from the second parent. This mechanism is applied to each gene. For example, if the number of genes is set to 4, then a possible mask would be 0110. Let ABCD and XYZW be the two selected parents. The scattered crossover would lead in this case to the following two offspring: AYZD and XBCW. The scattered crossover proved to work better for the problem at hand. The crossover is applied in each successive generation with a certain probability, known as the crossover fraction or rate. A large crossover rate decreases the population diversity, but in this problem, a higher exchange of genetic material is needed.

Mutation Mechanisms. This mechanism is very important from the genetic diversity point of view, and it prevents landing a local, sub-optimal solution. The mutation rate is highly connected with the crossover fraction. [24]

3.4.3 Improved Harmony Search Algorithm:

Harmony search (HS) algorithm is a metaheuristic optimization algorithm inspired by the operation of orchestra music to find the best harmony between components that are involved in the operation process, for an optimal solution. It is based on rules and randomness to imitate natural phenomena. As musical instruments can be played with some discrete musical notes based on player experience or based on random processes in improvisation, optimal design variables can be obtained with certain discrete values based on computational intelligence and random processes. Among the advantages of the HS algorithm, it can consider discontinuous functions as well as continuous functions because it does not require differential gradients; it does not require an initial value set for the variables; it is free from divergence and may escape local optima. In the HS algorithm, it looks for vectors or the path of X which can reduce the computational function cost or shorten the path. The flowchart is given in figure (3.5).

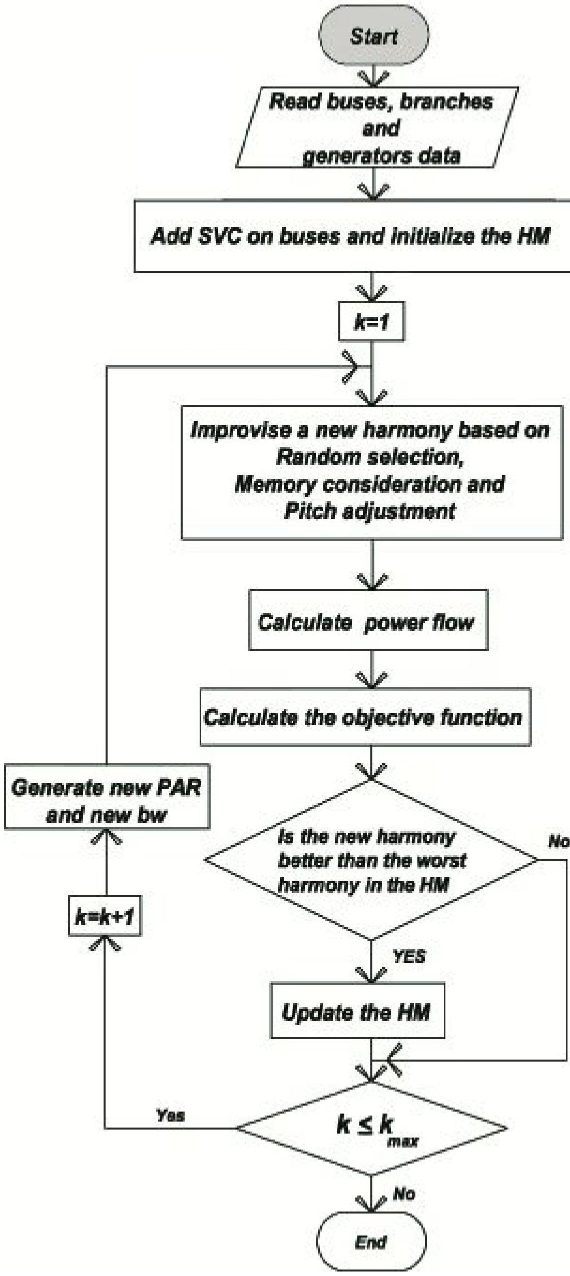


Figure 3.5: The IHS algorithm for solving the SVC placement problem. [25]

3.4.4 Suggested New algorithm:

3.4.4.1 Objective Function:

In this thesis, the main objective is to find the optimal location and determine the size of the SVC for enhancing voltage security during emergency operating conditions.
This can be achieved through minimizing the sensitivity of voltage magnitude (dV/dQ) under severe line contingencies. The objective function is given by :

$$F_1 = Minimize\,[F] \tag{3.16}$$

The term F represents the dynamic voltage deviation (dV/dQ) at each node. The minimum value of the sensitivity of voltage magnitude (dV/dQ) is used to find the best location of SVC. Dynamic voltage deviation is calculated as follows:

$$F = \sum_{k=1}^{N_{PQ}} \frac{(V i - V up)}{(Q - Q0)} \tag{3.17}$$

Where:
Vi is the voltage magnitude at node k.
Vup is the upper limit of the voltage at node i.
Vlow is the lower limit of the voltage at node i.

The equality and inequality constraints are:

-Load Flow :

$$Q_{Gi} - Q_{Di} - \sum_{j=1}^{N_{Node}} V_i V_{ij} Y_{ij} sin(\delta_{ij} + \gamma_j - \gamma_i) = 0 \tag{3.18}$$

$$P_{Gi} - P_{Di} - \sum_{j=1}^{N_{Node}} V_i V_{ij} Y_{ij} cos(\delta_{ij} + \gamma_j - \gamma_i) = 0 \tag{3.19}$$

-Reactive Power of SVCs :

$$Q_i^{min} \le Q_i \le Q_i^{max} \qquad (3.20)$$

Where Qi is reactive power injection at node i by SVC;

-Voltage

$$V_i^{min} \le V_i \le V_i^{max}; i \in N_{Node}$$

(3.21)

Where V_i^{min} and V_i^{max} are minimum and maximum voltage at node i respectively.

3.4.4.2 Optimal placements of SVC controllers :

The proposed algorithm for finding the optimal placement of SVC controllers involves the following steps:

- Create several critical contingencies such as line outage or generator outage. Then, load flow computation is done, and voltage magnitudes of several 220 kV nodes are computed for each contingency.

-Once the voltage magnitudes enter the specified dynamic limits (Vlower < Vi < Vupper), the voltage sensitivity dv/dq is computed for each contingency.

-The process is continued until the voltage magnitudes are less than the lower limit of the voltage at node i Then, nodes are ranked according to the dv/dq values.

The flowchart of the proposed algorithm is shown in Figure (3.6).

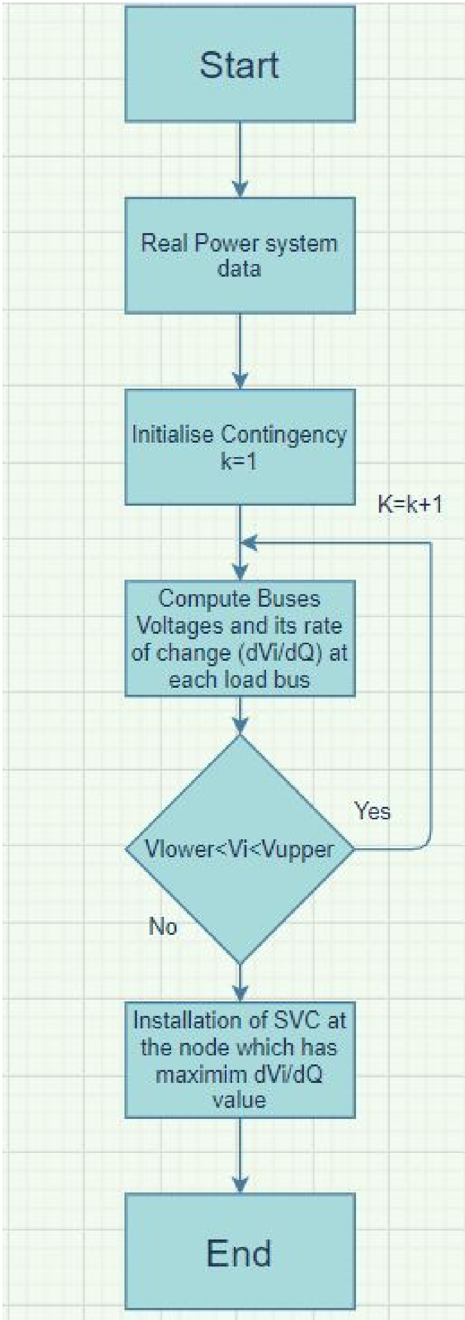


Figure 3.6: Flowchart of the proposed algorithm

This report proposes a new algorithm to find the optimal location and size of SVC controllers in order to increase the voltage security of power systems during large disturbances. The optimal location and size of SVC are determined based on the voltage magnitude sensitivity factor.

3.5 Conclusion :

In this chapter, we talked about different FACTS devices and controllers and why we chose the SVC for our case. We gave an overview of it with modeling and representation of the situation. We also included different techniques used to identify the best location for an SVC and why we chose the new algorithm as the technique used in this project which will be presented much better in the next chapter.

Chapter 4

Simulation Results and Discussion

Chapter 4 : Simulation Results and Discussion

4.1 Introduction :

The following chapter deals with the simulation and results of the proposed algorithm presented in the previous chapter. First, we have introduced the IEEE 9 bus model that has been used to test our algorithm as well as the PSS®E software that has also been used in the simulation. Then, we presented the four cases of study with the load bus voltages profiles for each case. Finally, we listed the observed points that can be drawn from the simulation results in a conclusion.

4.2 Power system simulator for engineering (PSS®E)

Power System Simulator for Engineering (PSS®E—often written as PSS/E) is a software tool developed by SIEMENS and used by power system engineers to simulate electrical power transmission networks in steady-state conditions as well as over timescales of a few seconds to tens of seconds. Since its introduction in 1976, it has evolved from a simple command-line interface, to an integrated, interactive program for simulating, analyzing, and optimizing power system performance, and it can provide probabilistic and dynamic modeling features.[26]

4.3 Test System Modeling in PSSE

For the testing and evaluation of the proposed algorithm, the test set up system IEEE 9 bus model is considered. The IEEE 9 bus system that is illustrated in Figure (4.1) consists of 3 generating units and 9 buses out of which one is the swing bus. Some of the data regarding the system are shown in the Figure (4.1). The detailed data of the system are illustrated in appendix A.

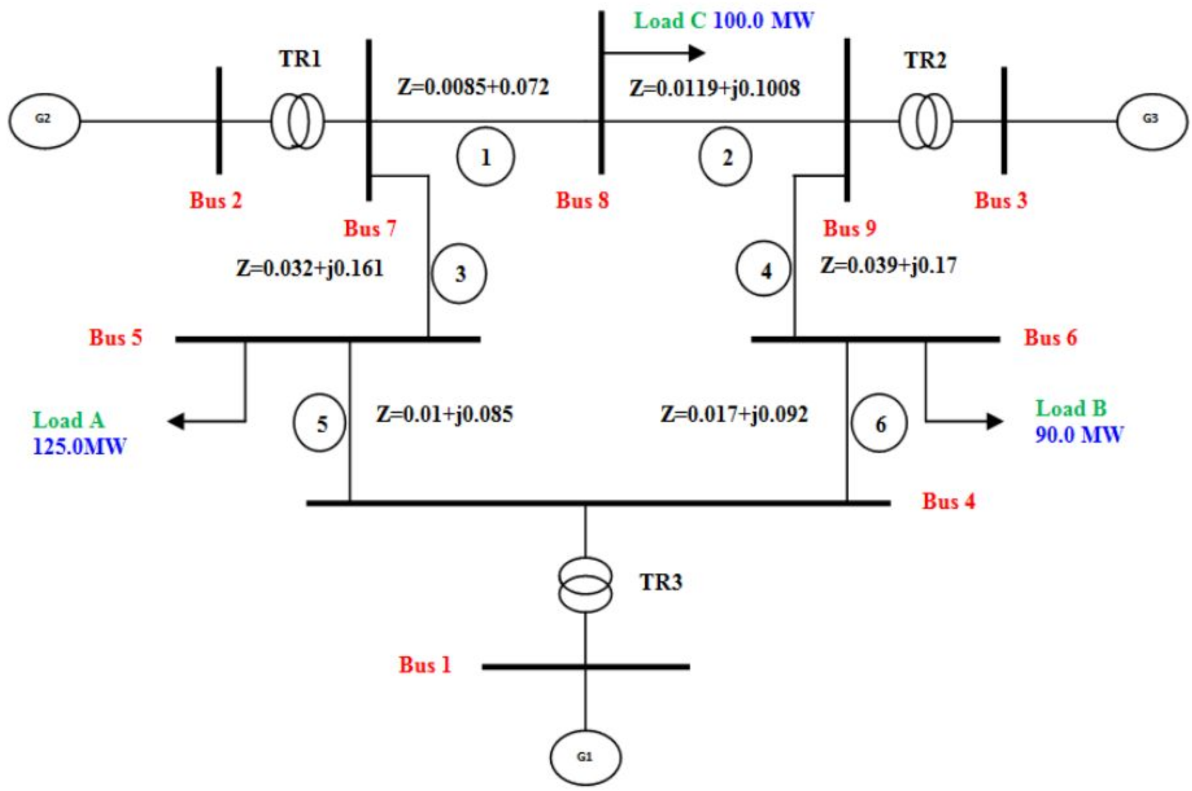


Figure 4.1: IEEE 9 Bus Power Network Model

The PSS®E software has been used in the simulation of a set up power grid and then its results have been used for testing our algorithm. Here is a short description of this powerful software in power systems.

Power System Simulation for Engineering (PSS®E) is a comprehensive set of programs for studies of power system transmission network and generation performance in both steady-state and dynamic conditions. Currently two primary simulations are used, one for steady-state analysis and one for dynamic simulations. One of the calculations and analyses facilities that could be offered by PSS®E is the Power flow and related network functions.

PSS®E software has been used for simulating the dynamic of the disturbance and presenting the frequency generators and load bus voltages plots before and after the implementation of the load shedding scheme.

An example of creating a disturbance for an IEEE 9 bus model using the PSS®E software is shown in figure (4.2).

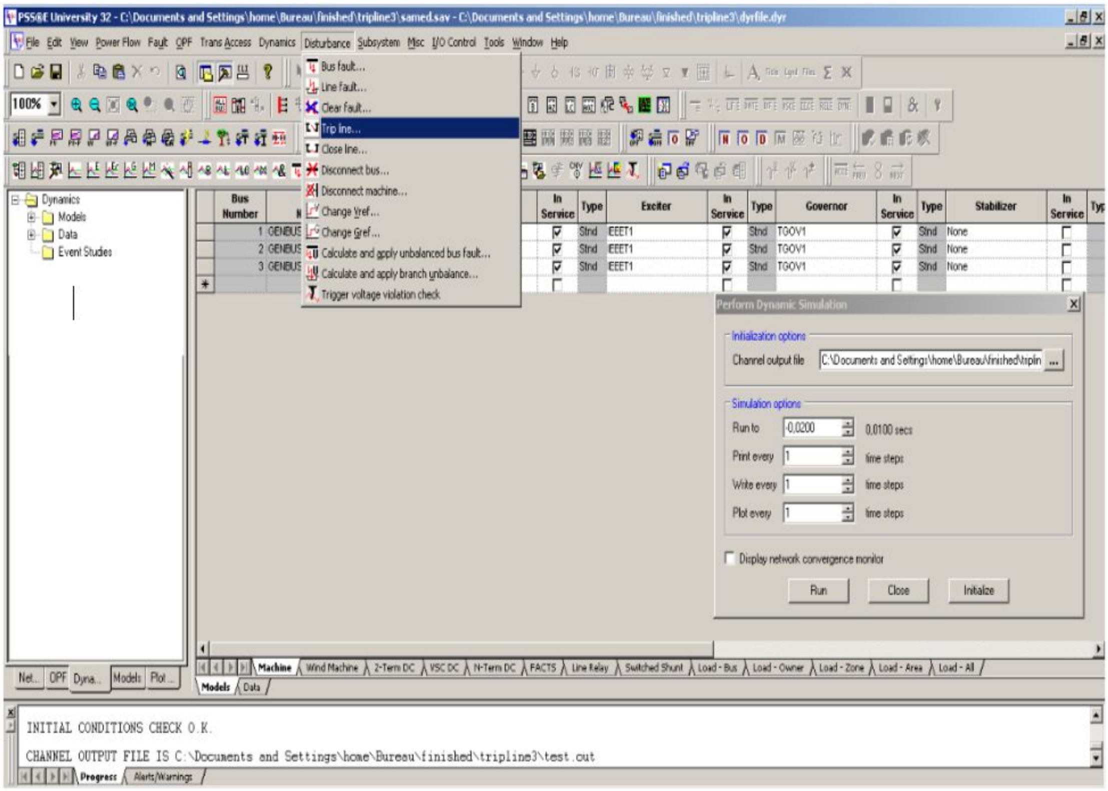


Figure 4.2: How to create a disturbance using PSS®E software

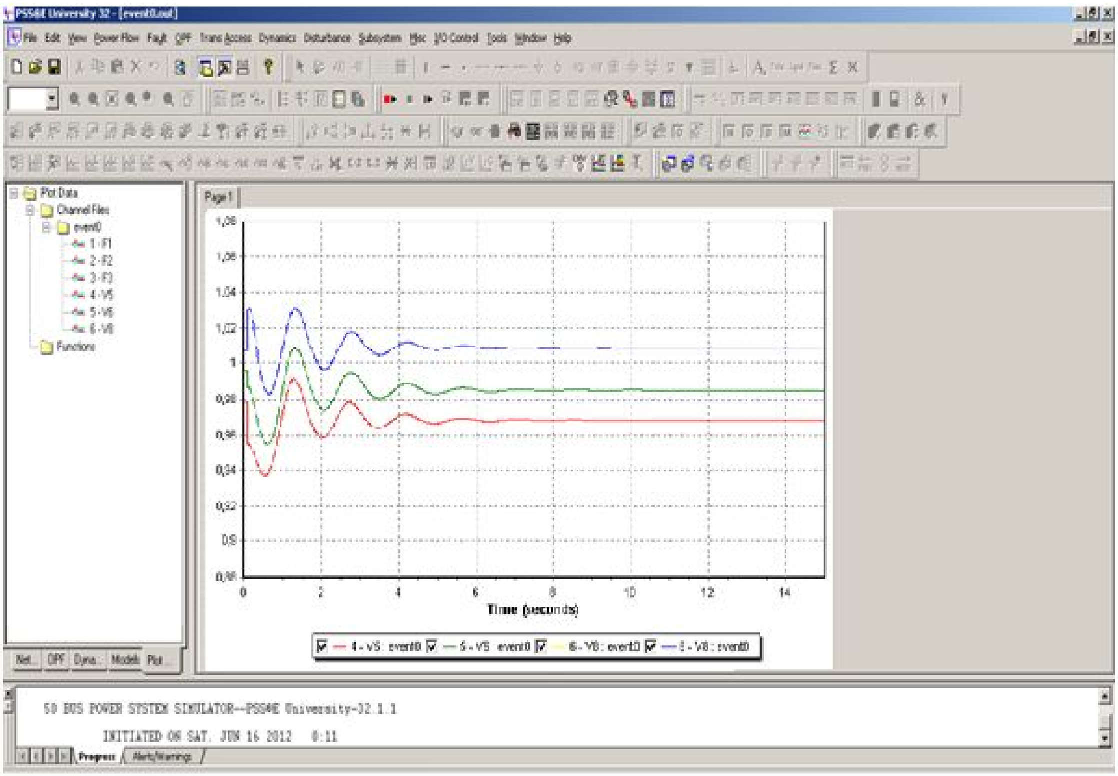


Figure 4.3: Plot of the load bus voltages

Another example of how to plot the load bus voltages is shown figure (4.3).

4.4 Simulation Results

The simulation of our algorithm test is done using PSS®E software (that has been introduced in the section above) and Matlab that has been used to determine the main parameters of the algorithm which are the bus where the maximum value of dV/dQ can be obtained and the size of SVC. This section contains the results and plots before and after the installation of SVC with comments.
The simulation is done by considering the following cases:

Case Study 1: Loss of Transmission Line 3 :

The case study 1 of the IEEE 9 bus system considers the loss of transmission line 3 connecting bus 5 to bus 7. The resulting load bus voltages waveforms obtained from PSS®E during the disturbance without installing SVC are shown in the figure (4.4).

The most critical lines of the IEEE 9 bus model are the lines that are connecting the generator buses to the remaining buses of the system. If a generator has only one transmission line connecting to the power system, this becomes a crucial line as its loss can result in the isolation of the generator from the whole system which is equivalent to the studies that will be carried out in the next case studies.

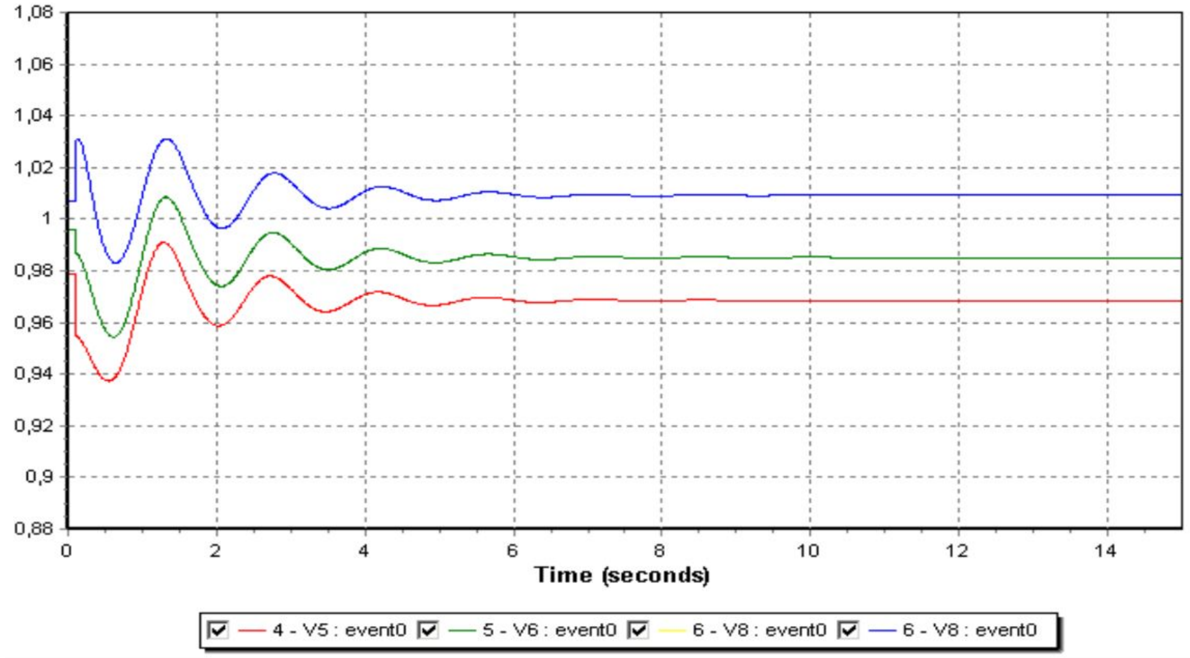


Figure 4.4: Case 1 : Load Bus voltages (without SVC)

In this case, tripping the line 3 is not really crucial since we still have line 1 that is connecting generator 2 to the power system. As a result, the load bus voltages are not really affected much by this disturbance. This latter is considered as a very small disturbance that does not require any compensation. However, the recovery of the very small decline of the system load bus voltages is done by the spinning reserve.

Case Study 2: Outage of Generator 3 :

The case study 2 that we considered for the IEEE 9 bus model is the loss of generator 3. This causes the load bus voltages to be reduced after the disturbance takes place and before installing any SVC, the load bus voltages behaviors are shown in the figure (4.5).

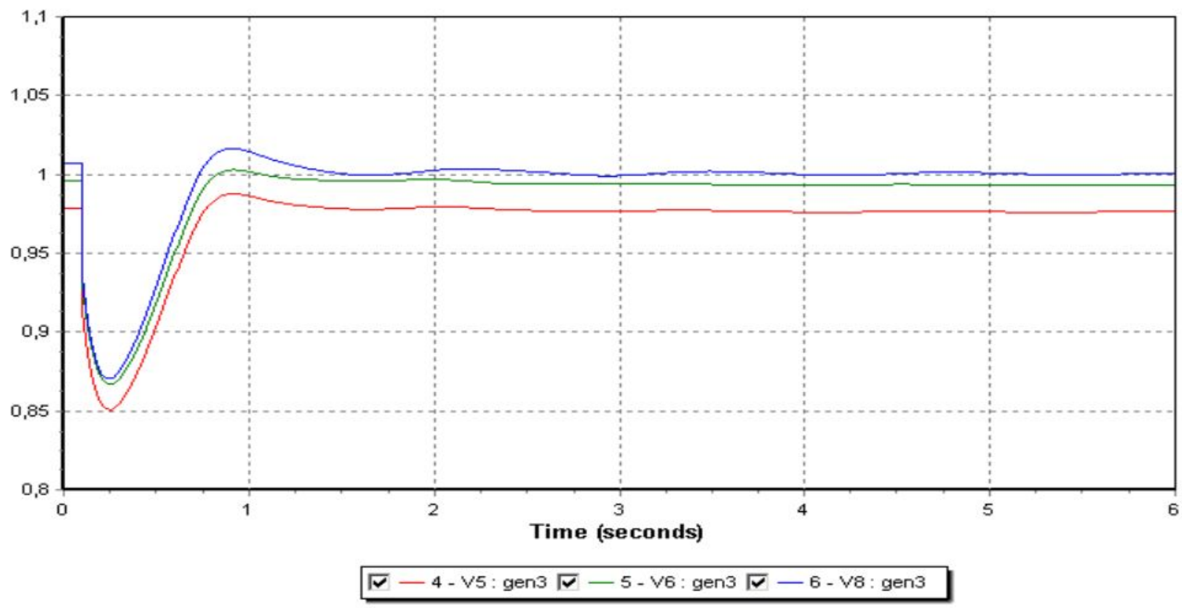


Figure 4.5: Case 2: Load Bus Voltages (Before installing SVC)

Figure (4.5) represents the load bus voltages before installing SVC. These voltages decrease below the rated value and they become stable at the following values:

Voltage at load Bus 5: 0.976 p.u

Voltage at load Bus 6: 0.993 p.u

Voltage at load Bus 8: 1.00 p.u

Now, the voltage sensitivities for each load bus under this case are represented in table (4.1).

Load bus Number	**dV/dQ**
5	0.000103188
6	0.000479844
8	0.000193001

Table 4.1: Voltage Sensitivities at each Load Bus (Case Study 2)

The maximum value of dV/dQ value is 0.000479844 at bus 6.

It can be noticed that the SVC with a range between 100 Mvar and 200 Mvar to be installed at any load bus gives good results. The load bus voltages experience a gradual improvement. This can be noticed in the figure (4.6).

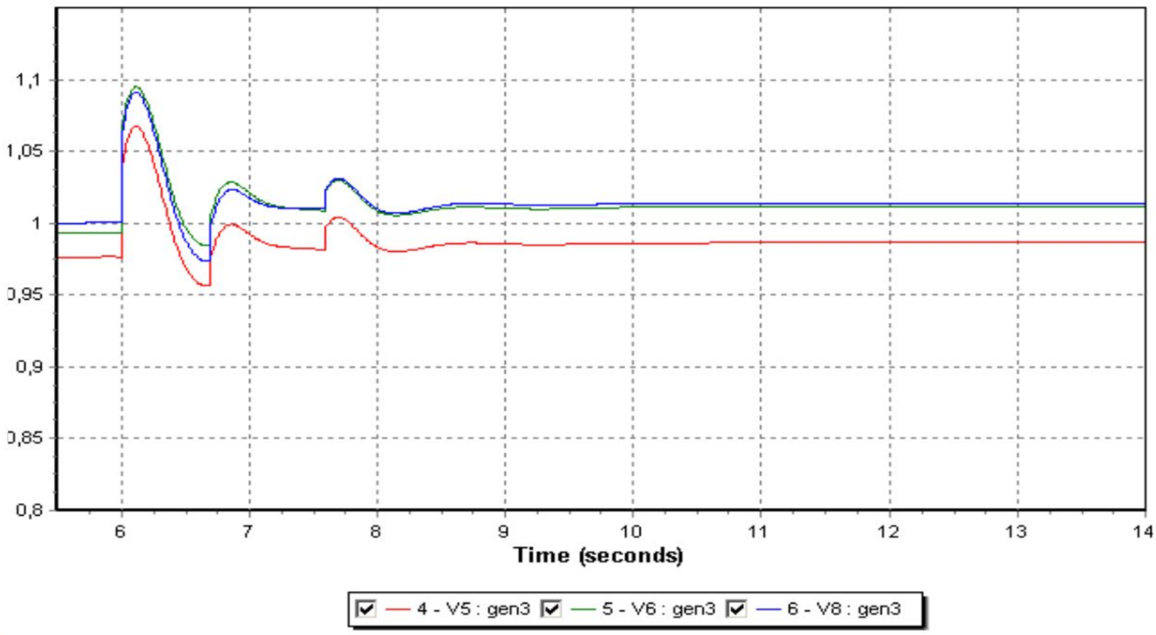


Figure 4.6: Case 2: Load Bus Voltages (After installing SVC)

<u>Case Study 3: Outage of Generator 3 with increase of load A & C by 50 % :</u>

The third case study of the IEEE 9 bus system considers the loss of a generator at bus 3 with an increase of load A & C by 50 **%.** This loss caused a reduction in the total generated power of the system by 196.6885 MW. The load bus voltages are also affected by the loss in the generated power. This can be seen in the plots of the load bus voltages in figure (4.7).

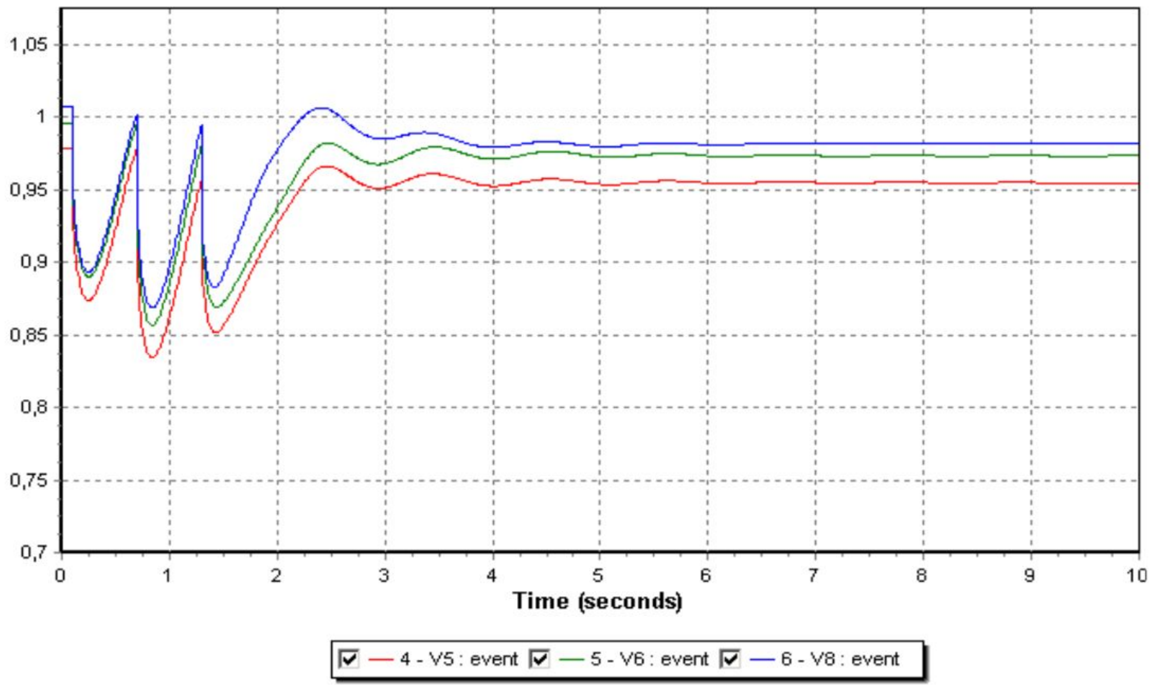


Figure 4.7: Case 3: Load Bus Voltages (Before load shedding)

Before installing SVC, the load bus voltages decrease below their predetermined standards and become stable at the following lower values:

Voltage at load Bus 5: 0.95477 p.u.

Voltage at load Bus 6: 0.97328 p.u.

Voltage at load Bus 8: 0.98175 p.u.

The voltage sensitivities; dV/dQ values are calculated individually for each load bus and the results are listed in the table (4.2).

Load bus number	**dV/dQ**
5	0.000926756
6	0.000103185
8	0.000850300

Table 4.2: Voltage Sensitivities at each Load Bus (Case Study 3)

The maximum value of the dV/dQ is 0.000926756. The SVC with a range between 100 Mvar and 200 Mvar to be installed at each load bus is obtained using the voltage sensitivity with maximum value according to the proposed algorithm. It can be noticed that the best results can be obtained when the SVC of 130 Mvar is installed at bus 5. The load bus voltages experience a gradual improvement. This can be noticed in the figure (4.8)

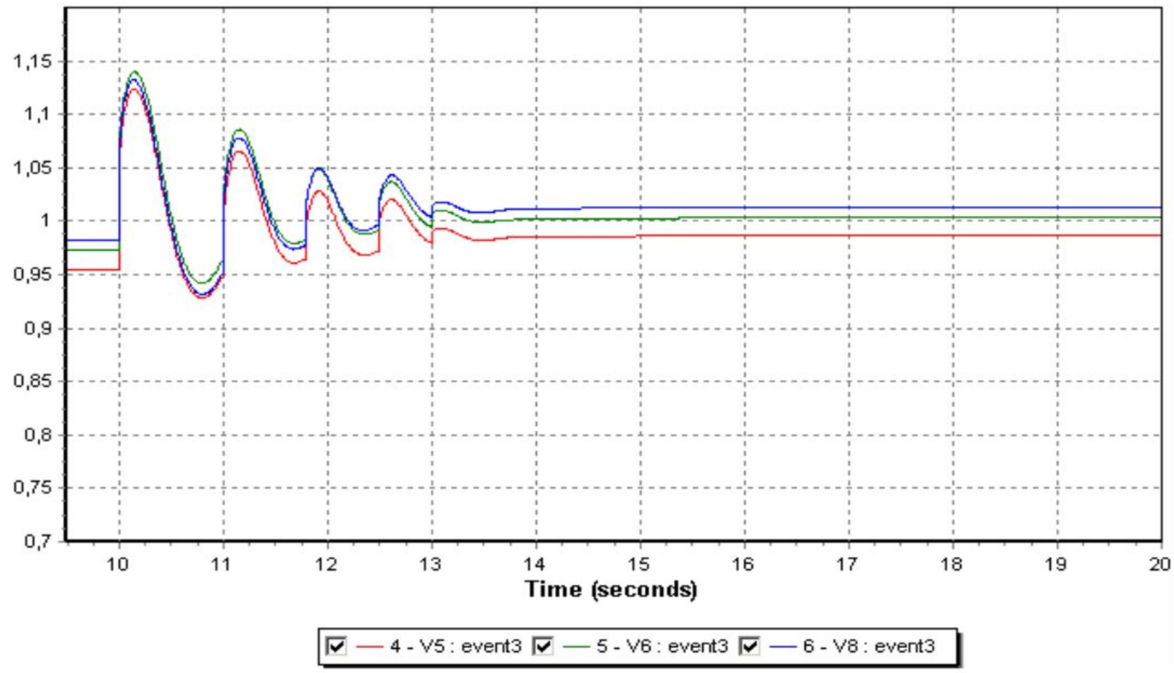


Figure 4.8: Case 3: Load Bus Voltages (After SVC installation)

Case Study 4: Increase of Load A, B & C by 100 % (Overload) :

The last case study of the IEEE 9 bus system is the overload that consists in an increase of load A, B & C by 100 %. The generation power loss due to this overload is 314.6885 MW. The load bus voltages plots after the disturbance and before installing SVC are illustrated in Figures (4.9).

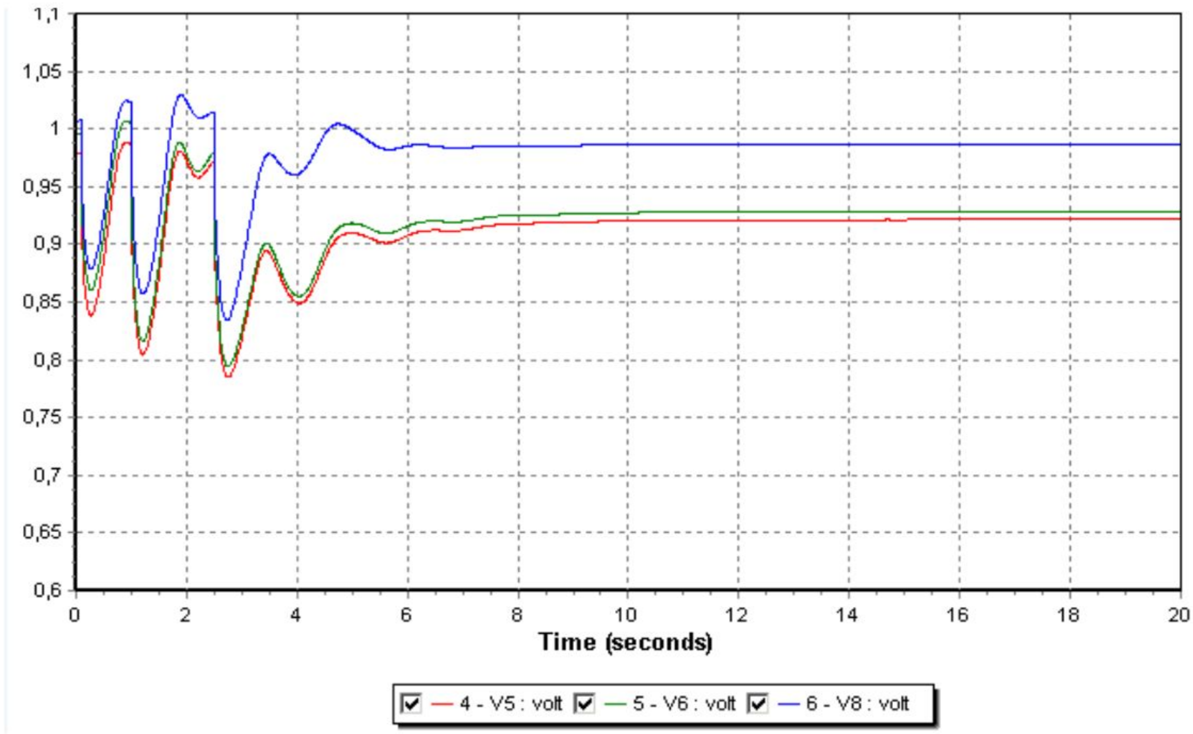


Figure 4.9: Case 4: Load Bus Voltages (Before installing SVC)

The load bus voltages are also changed due to the loss of some of the generated power. As it can be seen in the figure above. The load bus voltages are definitely lower than the acceptable values.

Voltage at load Bus 5: 0.924 p.u

Voltage at load Bus 6: 0.926 p.u

Voltage at load Bus 8: 0.9761 p.u

The voltage sensitivities for this case are calculated and tabulated in the table (4.3) below

Load bus number	**dV/dQ**
5	0.001194300
6	0.000859908
8	0.000955450

Table 4.3: Voltage Sensitivities at each Load Bus (Case Study 4)

The maximum value of the dV/dQ is 0.0011943. After installing SVC with 190 MVAr at bus 5 according to our proposed algorithm, the voltage profile has been improved very much; as shown in the figure (4.10).

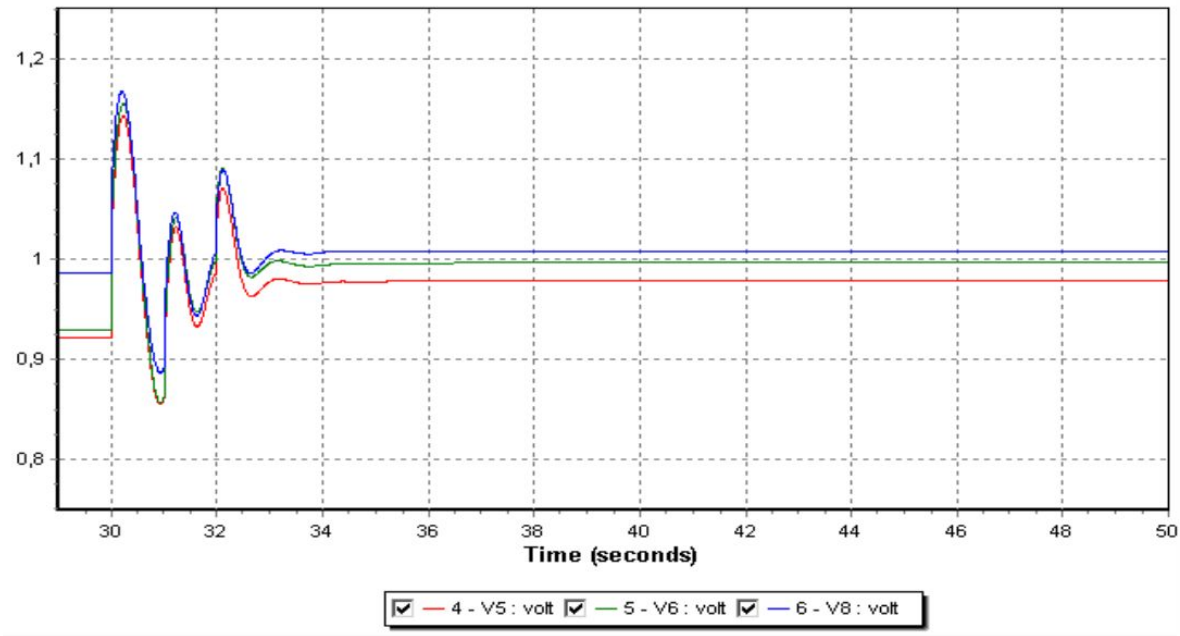


Figure 4.10: Case 4: Load bus voltages (After SVC installation)

4.5 Conclusion

The obtained simulation results for the four different disturbance sizes are really satisfactory and they are in concordance with previous research works. It can be said that SVC placement based on the voltage sensitivities definitely improves the voltage profile of the power system. We have considered several cases here. In the first case study, the disturbance was very small. The values of voltage were in the safe margin and the disturbance can be removed by the system using the spinning reserve with no need to install any SVC. The disturbance of the second case study was small and these results in the load bus voltages were slightly affected. For the third and the fourth cases, the disturbance was very large; as a result voltages settled at low unacceptable values.

However, after SVC installation has been investigated an improvement in the voltage profiles is observed. In totality, it takes around 20 seconds for the system to reach an acceptable value.

The most optimal location can be predicted by considering both voltage stability and real and reactive power losses. Hence, SVC application in power systems enhances voltage stability, minimizes line losses and improves voltage regulation.

General Conclusion

Smart grids represent a new era in the electrical sector, they are the definitive solution for managing the grids of the future, it benefits both companies and consumers, it increases efficiency and energy savings, so one of the key advantages offered by telemanagement systems is that bills are more accurate. reflecting the real consumption instead of estimations, reducing the cost of the old system of manual energy meter readings. In addition to that companies will be able to access information about the installation remotely, which leads to problems being diagnosed easily and solutions can therefore be implemented faster which will improve customer services.

Integrating renewable technologies to our current grid system will have a big failure, that's due to the unstable power they generate and the lack of reactive power as well, so with the existing grid architecture, coupling renewable energy systems with different generation characteristics and equipping the power systems with the battery storage systems to require a smooth transition from the conventional power system to the smart grid. Indeed, this coordination requires not only robust but also innovative controls and models to promote the implementation of the next-generation grid architecture. Therefore, the grid should be changed entirely.

Flexible AC transmission system devices (FACTS) are most promising controllers when it comes to power transmission in long distances in smart grids. FACTS devices provide system stability, midpoint voltage support and reactive power control in grid interconnections. And the FACTS device that we see suitable for the project is the Static Var Compensator SVC. In order to locate the SVC in the grid, there happen to exist four techniques, The Particle swarm optimization technique, Genetic algorithm-based technique, Improved Harmony Search Algorithm and the technique we suggest to use: New algorithm using PSS®E and Matlab.

The algorithm that we proposed identifies the optimal location for SVC placement based on the minimization of the rate of change of voltage magnitude sensitivity factor dV/dQ. The simulation showed that this method is a big success on papers waiting for it to be brought up into the real world. Future work is to verify the performance of the proposed method on a large power system and including other types of FACTS devices.

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Appendix A:

IEEE 9 Bus Power System Model Data

This appendix includes the IEEE 9 Bus power system model data that has been used in the simulation of our algorithm by the PSS®E software.

B.1.The generator parameters for the IEEE 9 bus system:

The three generators have identical dynamic characteristics.

Gen No.	H	X'd	X'q	Xd	Xq	T'do	T'qo	X1	Ra
1	9.55	0.6	0.8	1.8	1.75	6.5	0.2	0.15	0
2	3.33	0.6	0.8	1.8	1.75	6.5	0.2	0.15	0
3	2.35	0.6	0.8	1.8	1.75	6.5	0.2	0.15	0

Xd, Xq, X'd, X'q, X"d, X"q, Xl, H, and D are in pu, machine MVA base. X"q must be equal to X"d.

B.2.The Exciter parameters (for all generators):

TR(sec)	KA	TA(sec)	VR MAX	VR MIN	KE	TE(sec)	KF	TF(sec)	E1	SE(E1)	E2	SE(E2)
0.0	400	0.040	7.3	-7.3	1.0	0.8	0.03	1.0	2.47	0.035	4.5	0.47

B.3.The governor parameters (for all generators):

R	T1(sec)	V MAX	V MIN	T2	T3	Dt
0.050	0.05	1.050	0.3	1.0	1.0	0.0

B.4.Bus data:

Bus number	Bus KV	Bus code	Bus type	Voltage(pu)
1	16.5	3	Swing	1.040
2	18.0	2	P-V	1.025
3	13.8	2	P-V	1.025
4	230.0	1	P-Q	1
5	230.0	1	P-Q	1
6	230.0	1	P-Q	1
7	230.0	1	P-Q	1
8	230.0	1	P-Q	1
9	230.0	1	P-Q	1

B.5.Line and Transformer data:

From bus	To bus	R(pu)	X(pu)	Charging(pu)	magnitude	angle
4	5	0.0100	0.0850	0.17600	0.00	0.00
4	6	0.0170	0.0920	0.15800	0.00	0.00
5	7	0.0320	0.1610	0.30600	0.00	0.00
6	9	0.0390	0.1700	0.35799	0.00	0.00
7	8	0.0085	0.0720	0.14899	0.00	0.00
8	9	0.0119	0.1008	0.20900	0.00	0.00

Generator data sheet:

Data Type	Abbreviation	Unit
Data derived from equivalent diagram		
(as alternative to original data)		
d-axis:		
Subtransient short circuit time constant	Td"	sec
Subtransient reactance unsaturated (saturated)	xd" ($xd"_s$)	p.u.
Transient short circuit time constant	Td'	sec
Transient reactance unsaturated (saturated)	xd' (xd'_s)	p.u.
Synchronous reactance	xd	p.u.
q-axis:		
Subtransient short circuit time constant	Tq"	sec
Subtransient reactance unsaturated (saturated)	xq" ($xq"_s$)	p.u.
Transient short circuit time constant	Tq'	sec
Transient reactance unsaturated (saturated)	xq' (xq'_s)	p.u.
Synchronous reactance	xq	p.u.
for 3 winding model	xq" = xq'	p.u.
Open circuit characteristic: (no load curve)		
Generator voltage	U_G (based U_{Gn})	p.u.
Excitation current	I_f (based I_{f0})	p.u.