

KWARA STATE UNIVERSITY, MALETE, NIGERIA

SCHOOL OF POSTGRADUATE STUDIES (SPGS)

ENHANCEMENT OF VOLTAGE STABILITY ON NIGERIAN ELECTRICITY TRANSMISSION NETWORK USING STATIC SYNCHRONOUS COMPENSATOR

PREVIEW

Ahmed Babatunde OLAOYE

19/67MEC/00006

June 2023

SCHOOL OF POSTGRADUATE STUDIES (SPGS)

ENHANCEMENT OF VOLTAGE STABILITY ON NIGERIAN ELECTRICITY TRANSMISSION NETWORK USING STATIC SYNCHRONOUS COMPENSATOR

A MASTER THESIS SUBMITTED

BY

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PREVIEW

In Partial Fulfilment of the requirement for the award of Master of Engineering (M.Eng.) in Electrical and Electronics Engineering

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING,

FACULTY OF ENGINEERING AND TECHNOLOGY,

KWARA STATE UNIVERSITY, MALETE

NIGERIA

June 2023

DECLARATION PAGE

I hereby declare that this thesis "Enhancement of Voltage Stability on Nigerian Electricity Transmission Network Using Static Synchronous Compensator," is a record of my research. It has neither been presented nor accepted in any previous application for higher degree.

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_____ _____

Ahmed Babatunde OLAOYE Date

APPROVAL PAGE

This is to certify that this thesis by Ahmed Babatunde **Olaoye** has been read and approved as meeting the requirements of the Department of Electrical and Computer Engineering for the award of the degree of Masters (M.Eng.) in Electrical and Electronics Engineering Department.

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DEDICATION

I dedicate this work to Almighty Allah. I thank Him for his blessings, guidance and sustenance. Also, the Kwara State University community, whose commitment to excellence in education and research has provided an enabling environment for me to pursue my academic goals.

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List of Acronyms

AC	Alternating Current
FACTS	Flexible Alternating Current Transmission System
FIDVR	Fault-Induced Delayed Voltage Recovery
IM	Induction Motor
IPFC	Interline Power Flow Controller
NNG	Nigerian National Grid
SPST	Static Phase Shifting Transformer
SSSC	Static Synchronous Series Compensator
STATCOM	Static Synchronous Compensator
SVC	Static Var Controller
TCSC	Thyristor Controlled Series Capacitor
TS	Transmission Station
UPFC	Unified Power flow Controller
VSC	Voltage Source Converter

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ABSTRACT

The rapid increase in electricity demand, coupled with inadequate infrastructure and system planning, has resulted in severe voltage stability issues. The voltage stability issues in Nigeria's power system caused by inadequate infrastructure and system planning, resulting in frequent blackouts, voltage collapse, and system disturbances, with significant impacts on the economy and quality of life of the population. Installation and optimal placement of a Static Synchronous Compensator (STATCOM) device in the transmission network can mitigate severe voltage stability issue. However, analysis of electric power system for network planning and operation requires the knowledge of the network parameters to examine system behavior. Power flow and contingency analysis is an essential tool in power system operation. In this research, a case study of Osogbo regional transmission network was analyzed by carrying out power flow solution and contingency analysis using power system simulation (PSS) software. The analysis was used to make decision on optimal location of STATCOM in the network by simulating its effect on the bus voltage during disturbance. Reactive-Voltage (QV) curve of the vulnerable buses were plotted to examine the proximity of the operating point to the point of voltage collapse and to study the effect of different outage on the reactive power margin with respect to the specified voltage with and without STATCOM. The result shows that optimal location of Flexible Alternating Current Transmission system (FACTS) device does not only regulate the bus where it is connected to but also stabilize the voltage of the whole network during N-1 contingency. The 33% voltage violations that occur during the most severe N-1 contingency case were reduced to 0% by placing the STATCOM at Ibadan North bus, thereby improving the voltage stability of the network. The study highlights the potential benefits of using STATCOM technology in enhancing the voltage stability and reducing the risks associated with transmission networks.

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CHAPTER ONE

INTRODUCTION AND RESEARCH BACKGROUND

1.1 Introduction

In recent times, transmission lines are heavily loaded, and power system instability becomes a power transfer limiting factor in the transfer of energy from sending end to receiving end. Owing to increase in power demand, the transmission line has been significantly stressed while the expansion of power generation and transmission stations has been severely hampered due to limited resources and environmental restrictions. This could have adverse effect on the security of power system. The power system security is described as ability of the network to remain at equilibrium after perturbation (Debasish *et al*., 2014). Perturbation can result to cascading failure and this should be avoided for a system to be secure, otherwise the system as a whole or its major part may completely collapse. This is normally referred to as system collapse. However, it is essential that power system is operated such that any single contingency will not leave other part of the network heavily overloaded, thus cascading failures are avoided.

Nigeria's power network has been plagued by a series of challenges that have led to power instability in the country. The grid has experienced over two hundred system collapse between 2010 and 2021 (Ogunbiyi *et al*., 2022). One of the key factors attributed to this is the inadequate power generation capacity, which has resulted in frequent power outages and blackouts. Another major challenge is the poor maintenance of the power infrastructure, which has resulted in the degradation of the transmission and distribution systems. Additionally, there are issues of electricity theft and vandalism, which have led to the loss of significant amounts of power (Dahunsi *et al*., 2021). The lack of investment in the power sector and inconsistent government policies have also contributed to the power instability in Nigeria. These challenges have had a significant impact on the country's economy and the quality of life of its citizens and addressing them remains a critical priority for the Nigerian government.

The satisfactory operating state of any power system is described when the frequency and voltage at all energized bus bars of the power system is within the normal operating range, except for brief

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tolerance outside the normal operating band. It is essential that the frequency and voltage at any node on the network remains constant while the voltage waveform at any bus is free from harmonics and the phases are balance. Similarly, the tendency of a power system to develop restoring forces equal to or greater than the disturbing forces - when the operating parameters of any bus bar is outside the tolerance band - to maintain the state of equilibrium is described as stability (Ismail *et al*., 2014).

One of the indices to evaluate the state of security of a power system is voltage stability (Ayodele *et al*., 2016) which is described as the ability of the system to remain at operating voltage band at every single bus of the network after being subjected to disturbance. The causes of failure of power system transient stability can be attributed to sudden disconnection of lines or generator, reactive power imbalance, short-circuit fault etc. Accurate and fast voltage stability assessment method is important to the security operation of power system. Challenges such as complex cascading failure and power shortage accident further rise the difficulty of power system stability control and analysis (Wang and Li, 2019).

The level of integrity of a power system is determined by security level of the network based on transient stability (Ayodele *et al*., 2016). Appropriately, it is imperative to device a means of improving steady state stability of a system for enhancement of grid integrity (Ashraf *et al*., 2013). This associated problem with transmission network can be effectively tackled by introduction of power electronic device for the regulation of power flow and voltage. This allows controllability of Alternating Current (AC) transmission system such that the changes can be accommodated in operating condition simultaneously, maintaining steady state and transient stability (Padiyar, 2007).

Power electronics-based system and other static equipment that provide flexible operation of AC transmission system, and controllability of power flow and voltage are described as Flexible AC Transmission System (FACTS) controller. FACTS controllers have the capability of balancing the transmission of AC in a power system by regulating the power flow in specific lines of the network, thus mitigating the power stability problems. The system relies on the principle of regulating power flow on critical lines and hence ease congestion on electrical network. This usually results in trading of energy between different stations (Kadandani and Maiwada, 2015). Furthermore, FACTS controllers can provide ancillary services such as voltage control to the grid network that

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is connected with Wind Power Plant. The controller can regulate the voltage in real-time by injecting or absorbing reactive power from the grid. This help to stabilize the voltage of the grid, improve power quality, and reduce losses.

FACTS refers to a wide range of controllers such as Static Var Compensator (SVC), Thyristor Controlled Series Capacitor (TCSC), Static Phase Shifting Transformer (SPST), and newer controllers based on Voltage Source Converters (VSC), including Static synchronous Compensator (STATCOM), Static Synchronous Series Compensator (SSSC), Unified Power Flow Controller (UPFC), Interline Power Flow Controller (IPFC). The introduction of FACTS controllers has had a significant impact on power delivery systems, with a primary function being power oscillation damping to prevent low-frequency oscillations that can threaten system security during peak power flow conditions (Padiyar, 2007). FACTS controllers also offer the advantage of flexible power scheduling under various operating conditions, and their fast controllability helps to improve dynamic security of power systems during contingency conditions where system stability is at risk.

During the development program of FACTS technology, it became apparent that determining the controllers' effectiveness on a network-wide basis would require upgrading most of the system analysis tools used by power engineers to plan and operate their systems. As a result, researchers have given considerable attention to enhancing and refining several analysis tools, such as: Positive sequence power flow, Three-phase power flow, Optimal power flow, State estimation, Transient stability, Dynamic stability, Electromagnetic transients, Power quality.

The economic and technical benefits of FACTS have garnered widespread support from electrical equipment manufacturers, operators, and research organizations (Johns, 2017). FACTS devices provide several economic and technical benefits for power transmission systems. From an economic perspective, FACTS devices can increase the overall efficiency of the power system and reduce energy losses, leading to cost savings for utilities and customers. The use of FACTS devices can also improve the power quality and reliability of the system, which can reduce the need for expensive maintenance and repair.

Technically, FACTS devices can help to stabilize the power system and improve its flexibility. By controlling the reactive power flow on the transmission line, FACTS devices can reduce voltage drops and power losses, thus improving the power transfer capability of the system (Padiyar, 2007). This, in turn, can allow for the integration of renewable energy sources, such as wind and solar,

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which often have fluctuating output levels. Another technical benefit of FACTS devices is their ability to improve the transient stability of the system, which is important for preventing voltage instability and blackouts. FACTS devices can rapidly respond to changes in system conditions and provide dynamic voltage support, allowing for more efficient operation of the power system.

1.2 Motivation

Based on the classification of system collapse indices on the Nigeria national grid, 88% of incidents are by fault-induced disturbances. This vulnerability to voltage instability makes the Nigerian National Grid (NNG) prone to system collapse. To improve stability and reliability, it is essential to address both the technical and political challenges associated with the system. This will require a committed effort from both the government and the management of Nigerian power utility organization (Samuel *et al*., 2014).

The expanding interconnected network, coupled with limitations on new line construction and economic considerations, have necessitated the use of controllable Var compensators to support voltage and maintain stability in transmission systems.

1.3 Problem Statement

The power system in Nigeria has been facing severe voltage stability issues due to the rapid increase in electricity demand coupled with inadequate infrastructure and system planning. These voltage stability problems have resulted in frequent blackouts, voltage collapse, and system disturbances, which have a significant impact on the economy and quality of life of the population. One potential solution to mitigate these issues is the installation of a Static Synchronous Compensator (STATCOM) device in the transmission network, which can regulate the voltage and provide reactive power support to the system.

Although, researchers have used different types of compensator and FACTS devices to improve the quality and control of voltage stability to which the performance has been great, yet the advantages of FACTS device have not been captured to improve the voltage stability of Nigerian National grid. Therefore, there is a need to evaluate the voltage stability of the Nigerian transmission network using a STATCOM device. This research will investigate the impact of a

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STATCOM device on voltage stability by analyzing different scenarios, such as different contingency cases and various locations of the STATCOM installation.

1.4 Aim and Objective

1.4.1 Aim:

The aim of this work is optimal placement of Static Synchronous Compensator for enhancement of voltage stability of Nigerian Transmission network using Osogbo regional network as a case study.

1.4.2 Objectives:

The objectives are to:

i. determine the bus variables using power flow analysis;
ii. carry out N-1 security analysis on the network using contingency analysis;
iii. identify the weak bus and its voltage stability margin; and
iv. evaluate the effectiveness of a STATCOM device in improving voltage stability in the transmission network.

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1.5 Scope

The Nigerian grid is interconnected across the whole country. The grid consists of several regional network in the country such as: Port-Harcourt, Kano, Lagos, Enugu, Benin and Osogbo regional network. This work focuses on Osogbo regional network which consists of 24 buses. The scope of this research includes optimal location of the STATCOM device in the Osogbo regional transmission network. The research involves modeling, simulation, and experimental validation to evaluate the voltage stability of the network. Focusing on the determination of bus parameter to know the state of the network and contingency analysis to analyze the effect of N-1 security on the network and identify the weak buses in the system. The research also includes voltage stability study to provide insight on the system proximity to system collapse.

1.6 Thesis Layout

Chapter one presents an overview of the dissertation, including the research problem, aim and objectives of the study, scope, and structure of the thesis. Chapter two presents a comprehensive review of the relevant literature on the research topic, including theoretical frameworks, and

previous studies. Chapter three explains the research design, data collection methods, data analysis techniques, and the project framework. The chapter also discusses the limitations of the methodology. Chapter four presents the findings of the study, including graphs, tables, and charts to illustrate the results. The chapter also provides a detailed analysis and interpretation of the data collected. It also interprets the results of the study in the context of the research questions and the existing literature. The concluding chapter discusses the implications of the findings and their contribution to the field. The chapter concludes with practical recommendations for policymakers, practitioners, and other stakeholders, as well as areas for further research.

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