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ORIGINAL

The effects of various distributed generating types on the smart grid have been demonstrated using transient stability study and steady state voltage analysis

Los efectos de varios tipos de generación distribuida en la red inteligente se han demostrado mediante el estudio de la estabilidad transitoria y el análisis de la tensión en estado estacionario

Ruaa Aboalhawa[1], Hussein A. Taha[1], Muhammad Al-Badri[1]

[1]Department of Electrical Engineering, University of Wasit.

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ABSTRACT

Renewable energy and smart grid technologies are crucial in the modern era due to climate change and the need for secure energy sources. To address concerns regarding energy security, efficiency and aging energy infrastructure, it is necessary to move away from centralized power generation and embrace decentralized distributed generation and smart grid technologies. This transformation will meet the increasing demand for electricity, improve the quality of service, and reduce pollution. However, there are technical challenges to overcome, such as maintaining system stability when incorporating distributed generation into the smart grid. This research focuses on evaluating the impact of distributed generation on the smart grid, especially the system stability after integrating distributed generation. System stability was evaluated and confirmed using Dig-SILENT Power Factory V 13.2 software, which simulates connection issues and failures.

Keywords: Smart Grid; Future Grid; Distributed Generation; Mode Stability Analysis; Static VAR System (SVS).

RESUMEN

Las energías renovables y las tecnologías de redes inteligentes son cruciales en la era moderna debido al cambio climático y a la necesidad de fuentes de energía seguras. Para hacer frente a las preocupaciones relativas a la seguridad energética, la eficiencia y el envejecimiento de las infraestructuras energéticas, es necesario abandonar la generación centralizada de electricidad y adoptar la generación distribuida descentralizada y las tecnologías de redes inteligentes. Esta transformación satisfará la creciente demanda de electricidad, mejorará la calidad del servicio y reducirá la contaminación. Sin embargo, hay retos técnicos que superar, como el mantenimiento de la estabilidad del sistema al incorporar la generación distribuida a la red inteligente. Esta investigación se centra en evaluar el impacto de la generación distribuida en la red inteligente, especialmente la estabilidad del sistema tras integrar la generación distribuida. La estabilidad del sistema se evaluó y confirmó utilizando el software Dig-SILENT Power Factory V 13.2, que simula problemas de conexión y fallos.

Palabras clave: Red Inteligente; Red del Futuro; Generación Distribuida; Análisis de Estabilidad de Modo; Sistema VAR Estático (SVS).

INTRODUCTION

Switching from centralized to decentralized generation is having a substantial impact on the contemporary electric power industry. The energy industry has become more attractive and competitive as a result of the rapid expansion of distributed generation brought on by technical advancements. Aside from that, the deregulation of the power market, environmental concerns, and government incentives have all encouraged interest in development among industrialized nations throughout the world thanks to this technology.(1) These problems have caused the conventional electric power business to be replaced with the Smart Grid platform. Due to vertical integration and industry congestion, energy prices were higher in the past.

At present, there are challenges for large, outdated power stations in remote areas that operate with central dispatch, mainly because they do not have intelligent interoperability devices. Moreover, problems like coordination or protection malfunctions and issues with human operation increase the system's susceptibility to utility abnormalities.(2) To improve the quality of electricity and smoothly incorporate advanced grid components like intelligent sensors and digital meters, it is necessary to transform the current model into a Smart Grid.

It is widely known that the future of the electrical industry will be built on the Smart Grid. The market for distributed generating technologies like fuel cells, photovoltaics, wind turbines, and energy storage is being stimulated by the growing scope of this issue. Future electricity technologies that enable the installation and embedding of modern power electronic devices and information and communication technologies (ICT) will be significantly impacted by this tendency. In order to meet this challenge, the current distributed and bulk generating will coexist with a smart grid that provides greater power quality and dependability.(3) This talk will give a fundamental knowledge of the difficulties posed by distributed generation and the design of the smart grid in order to emphasize this. It also examines how DG influences the transient stability of the Smart Grid.

Overview of Smart Grid, and Distributed Generation technologies

Distributed Generation technology is used to provide electricity to widely dispersed systems connected close to the consumer load. This is achieved through the use of different applications such as synchronous generators, fuel cells, microturbines, photovoltaic systems, and energy storage. Democratic governance is increasingly important because it contributes to electrical system reliability and helps reduce greenhouse gas emissions. Developed countries, including Australia, are actively promoting the use of electrical distribution systems as a domestic source of power to avoid the need for additional power transmission and distribution infrastructure.(4) The increasing incorporation of democratic governance into grids in the past decade has shown its many advantages in terms of technology, finance and environment for users, utilities and energy providers. However, the presence of DG affects the configuration and performance of current power systems. Integrating DG turns the grid into an active system where both DG and conventional energy sources can be operated. Many studies have been carried out to analyze the impacts of distributed solar energy on the power system, highlighting important aspects of its connectivity and operation. These studies examine the change in power flow direction during DG integration, the impact of DG on system reliability and stability, system protection, voltage variation, and protection. They also explore the effects of direct distribution on the distribution system, with special emphasis on improving voltage quality, reducing losses, and improving reliability. Moreover, research shows that the direct distribution system can operate in island mode while connected to the distribution network, enhancing supply security and quality. The research also indicates that with increased DG penetration, the transient stability of the system improves. However, these studies mainly focus on medium and low voltage levels, and there is a lack of scenarios that address the issues from a smart grid perspective.(4) It is necessary to conduct a comprehensive evaluation of the system performance taking into account the availability of smart grid concepts and the rapid development of democratic governance and smart grid technologies. Through effective implementation of smart grid design and guidelines, declines in electrical quality and reliability can be avoided. The smart grid represents a future energy infrastructure that combines electricity and communications, providing real-time digital information on grid operation to the operator and consumer. This intelligent automation on the electrical distribution network can lead to changes in the grid model and thus impact the operation of the electrical grid.

A smart grid has many benefits, including its ability to recover from disruptions, provide users with more control, and improve electricity quality. One of its main advantages is its flexibility in accommodating different methods of producing electricity in different locations. To support the smart grid, important technologies are used such as SCADA systems, digital sensing, measurement and advanced control methods. SCADA systems are essential for the operation and regulation of power networks.(5) Despite these advantages, there are obstacles to widespread adoption of the smart grid, such as the lack of a unified framework, difficulties in connecting different components, and challenges in energy transmission and communications. To make the grid smarter, it is necessary to address seven main sectors: bulk generation, transmission, distribution, customers, operation, market area and service providers. These segments are classified based on the smart grid architectural design, as shown in figure 1. This diagram effectively illustrates the interconnected nature of the smart grid and emphasizes the need for a coordinated deployment strategy. Interdisciplinary research in communications, automation, sensing and control enhances our understanding of the energy industry.

Figure 1 depicts the structure of the Smart Grid.(6)

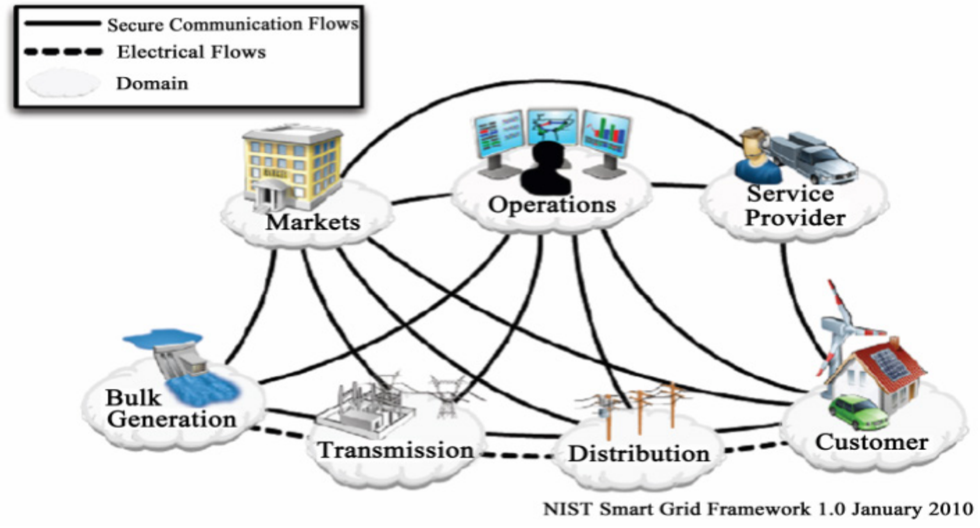


Figure 1. Structure of the Smart Grid(6)

Furthermore, in order to fully utilize the grid's "Smart Grid" potential, contemporary technology is also necessary. Given the system's complexity, it might be difficult to describe a network as "smart" if certain of its core traits are disregarded. The "Smart Grid" should ideally be viewed as a chance to improve the efficiency and usefulness of the electrical system.(7,8)

Experimentation

This study aims to simplify the management of the electricity system to make it more "intelligent". Previous research has shown that integrating dispersed generation into a smart grid environment can be successful, leading to the development of a single-line system network. However, this study does not prioritize concerns about the stability of the system, but instead focuses on the islands. In order to create an accurate and useful model, a typical grid analysis studies how distributed generation affects the voltage profile, stability, or dynamic behavior of the smart grid. For example, an ideal smart grid system should be able to handle short circuits with a maximum capacity of 5000 MVA and 4000 MVA over a 132 kV, 50 Hz grid. This network is connected to a 33 kV distribution system through 132 kV/33 kV Yg transformers with rated capacity T = 90 MVA and short circuit voltage of 13,18 %. The two main technologies used for distributed generation in the system are DG I and DG II, which are connected to the 11 kV bus through 33/11 kV transformers with a rated power of 28,1 MVA. The maximum load of the distributed generators is 23 MW, while the load on the network in the smart grid area is only 1 MW, as shown in figure 2.

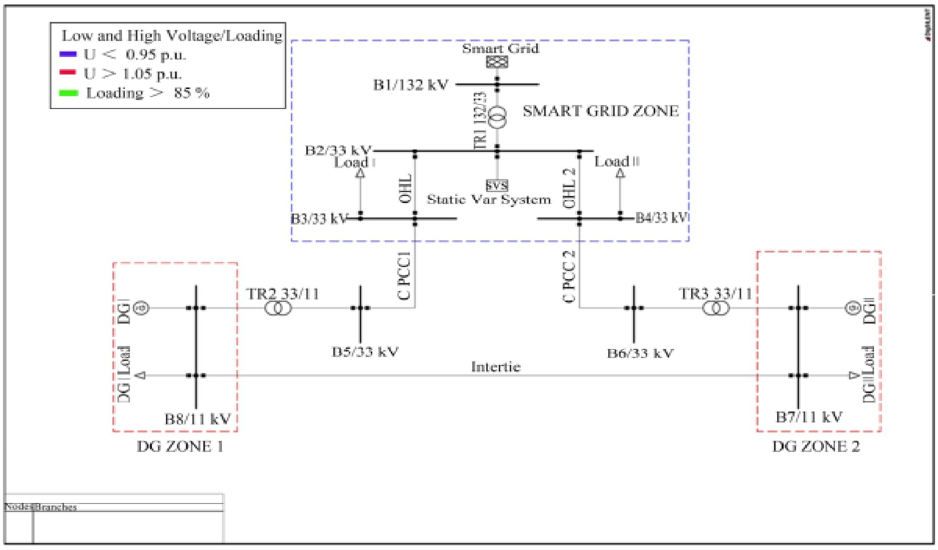


Figure 2. Topology of the smart grid

This section usually contains the case studies and significant study premises. The effects of various distributed generating types on the smart grid have been demonstrated using transient stability study and steady state voltage analysis. The following details have been taken into consideration:

The voltage pattern and potential overloading were analyzed by evaluating the steady state voltage profiles using the "Newton-Raphson" method. The analysis of transient stability was conducted when DG I and DG II were connected to a smart grid. The variables being observed during this analysis were frequency, power angle, and voltage. An experiment on transient stability was performed to carefully examine the initial signs of system flaws.(9) The variables being monitored during this experiment were frequency, power angle, and voltage.

A modified method has been used to analyze the impact of distributed generation (DG) on the smart grid. The Newton-Raphson load flow method was used to evaluate steady-state profiles, considering both PQ and PV nodes with distributed generation models. The smart grid's voltage and frequency were initially controlled, resulting in DG I operating in PQ mode at 11 kV bus, while DG II operated autonomously in PV mode. However, operating DGs in PV mode when connected to the grid is generally not recommended due to security concerns. In this case study, DG II continued to operate in PV mode while connected to the grid to evaluate their effectiveness as PV nodes for integration into the smart grid. At time t = 4 s in each case study, the link line between GT I and GT II, as well as the point of common coupling (PCC) on bus 7, was closed. To avoid system collapse caused by reactive energy injection or absorption from distributed generation, the SVS was converted To the reactive power control mode (Q mode).

The sixth iteration of the experimental analyses and findings

The following section presents the results and analysis of the simulations performed. Each simulation case study carefully defines how electricity flows and the initial properties of the system.(10) The simulations initially show that there were no problems encountered in the system design, such as overcurrent, undervoltage, or high voltage. Section 6.1 of Case 1 provides the default information in figure 3 for analyzing the smart grid voltage while it is in a steady state. An important advantage of integrating distributed power into electrical networks is the improvement of the system voltage profile when it is stable. Voltage violations or fluctuations that may occur while connecting distributed generators can significantly affect the overall stability of the network. Therefore, it is important for power system operators (PSOs) to ensure that, even in the worst-case scenario, the variation in grid steady-state voltage remains below 5 %. This section examines how distributed generation affects the steady-state voltage of the smart grid.

After achieving a stable system bus voltage of 1 p.u., the Smart Grid proceeds to introduce DG I and DG II, taking into account different case studies that examine the voltage profile in a steady state. It is determined that a maximum voltage difference of 5 % is acceptable. As a result, Table 1 provides the steady state voltage profiles for each specific bus by incorporating DG I and DG II.

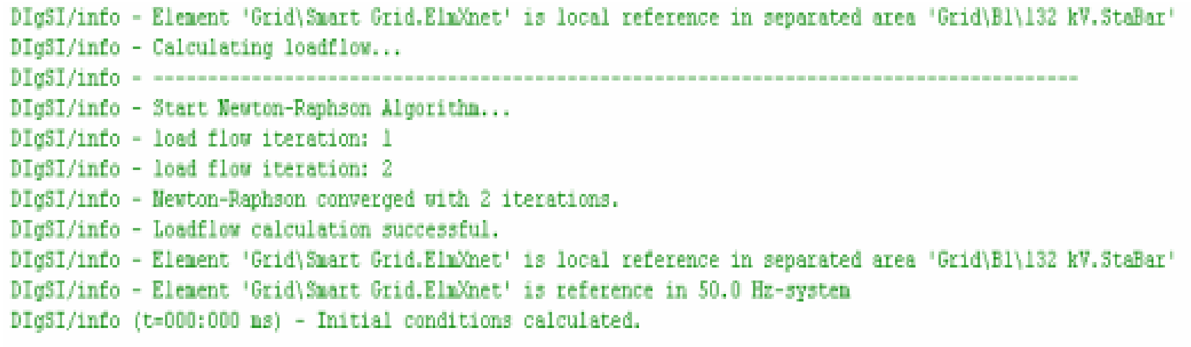
Based on the information in table 1, the introduction of Distributed Generators (DGs) to the Smart Grid leads to voltage inconsistencies due to an unequal distribution of reactive power generation. However, this issue only affects specific points, and there are no significant voltage problems observed elsewhere. Currently, the overall voltage level of the Smart Grid is at 0,996 per unit (p.u.), which falls within the acceptable range of 0,95 to 1,05 p.u. The data from table 1 indicates that the employment of DG I and DG II units in the Smart Grid has a minimal impact on the sensitivity of bus 1 (SG zone).

Analysis of transient stability in the smart grid

Researchers have investigated the impact of incorporating distributed generation into the current configuration of the Smart Grid. The Smart Grid operates within a specific voltage range, but there is no guarantee that the system will function correctly in the event of a failure. Therefore, it is vital to assess the Smart Grid's ability to withstand sudden disturbances. This evaluation of transient stability focuses on determining how the integration of distributed generation affects the Smart Grid and how the system reacts to problems. The voltage's magnitude, frequency, and power angle in the Smart Grid are used as indicators to determine whether a stability analysis is necessary.

Section (Case 1) of the Grid Connected Mode Stability Analysis

This paragraph will discuss the stability of the Smart Grid (Case 2) in two scenarios - when distributed generation is added and when grid linked mode stability is analyzed. According to figure 4, when DG II is incorporated, the voltage stability of the Smart Grid at bus 132 kV decreases. However, after being connected to DG II for five seconds, the variance shows that the voltage stabilizes and remains within acceptable limits. Figure 5 reveals that in an effort to regain power and synchronize the system, scattered generation consistently increases its operating slip or speed, leading to voltage instability. Due to the high rotor slip, DG II now requires a significant increase in reactive power. Without a reactive power controller, this could further worsen voltage instability. Hence, when connected to the grid, the SVS functions in Q mode to supply and control reactive power. After evaluating the voltage imbalance, an additional assessment of the smart grid's frequency stability was carried out. Figure 6 demonstrates a slight frequency increase at the switching point when DG units are connected to the smart grid.



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DIgSI/info - Element 'Grid\Smart Grid.ElmXnet' is local reference in separated area 'Grid\B1\132 kV.StaBar'
DIgSI/info - Calculating loadflow...
DIgSI/info - ------------------------------------------------------------------------------------
DIgSI/info - Start Newton-Raphson Algorithm...
DIgSI/info - load flow iteration: 1
DIgSI/info - load flow iteration: 2
DIgSI/info - Newton-Raphson converged with 2 iterations.
DIgSI/info - Loadflow calculation successful.
DIgSI/info - Element 'Grid\Smart Grid.ElmXnet' is local reference in separated area 'Grid\B1\132 kV.StaBar'
DIgSI/info - Element 'Grid\Smart Grid.ElmXnet' is reference in 50.0 Hz-system
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Figure 3. Data on the initial load flow and system configuration

Table 1. Voltage profile of the Smart Grid improves when distributed generation is implemented

Bus No	Before (p.u)	After (p.u)
1	1,0	1,0
2	1,0	0,966
3	1,0	0,966
4	1,0	0,966
5	1,0	0,966
6	1,0	0,966
7	1,0	0,966
8	1,0	0,966
9	1,0	0,966

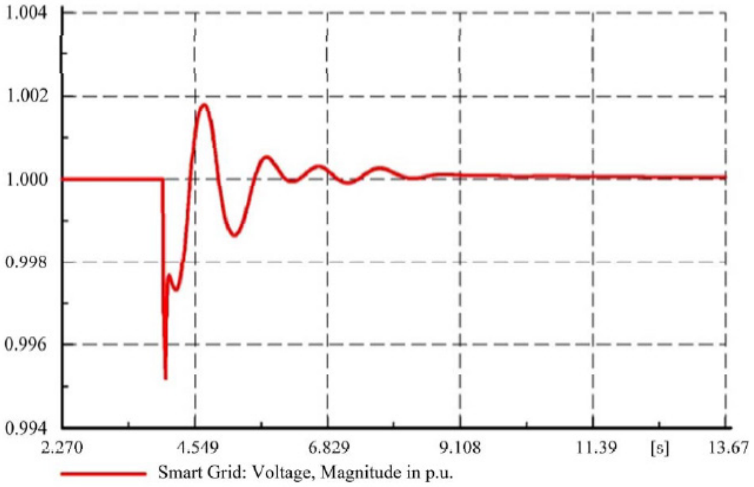

Figure 4. Voltage of the Smart Grid is indicated by p.u. when integrating DGs

This passage will cover the examination of stability while connecting to the grid or incorporating distributed generation in the Smart Grid. Figure 4 reveals that the addition of DG II has little effect on the voltage stability of the Smart Grid at bus 132 kV. The difference indicates that the voltage becomes stable and remains within acceptable limits after five seconds of being connected to DG II. Figure 5 illustrates how distributed generation continuously raises operating slip or speed in order to recover power and synchronize the system. Instability in voltage results from this. The significant rotor slip means that DG II now needs additional reactive power. Without a reactive power controller, voltage instability could get worse. The SVS creates and manages reactive power in Q mode when it is linked to the grid. Voltage imbalance was followed by a more thorough investigation of the smart grid's frequency stability.

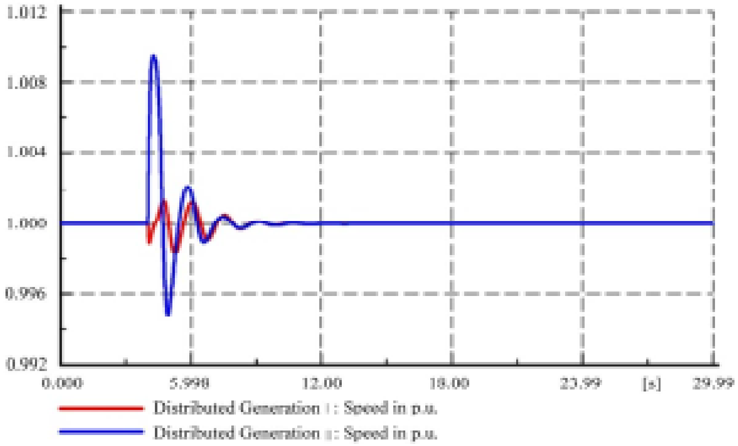

Figure 5. Proportion of generated electricity that is distributed in per unit (p.u.) measurements when connected to the smart grid

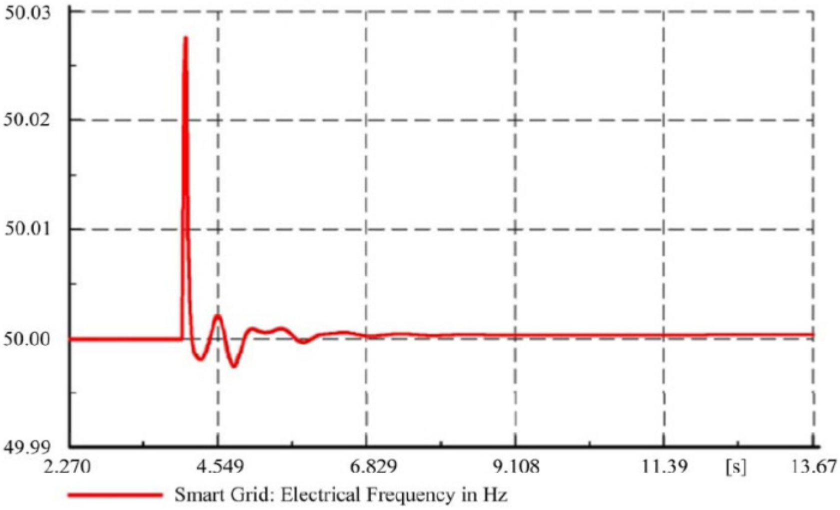

Figure 6. Frequency of the smart grid when integrating DGs in Hz

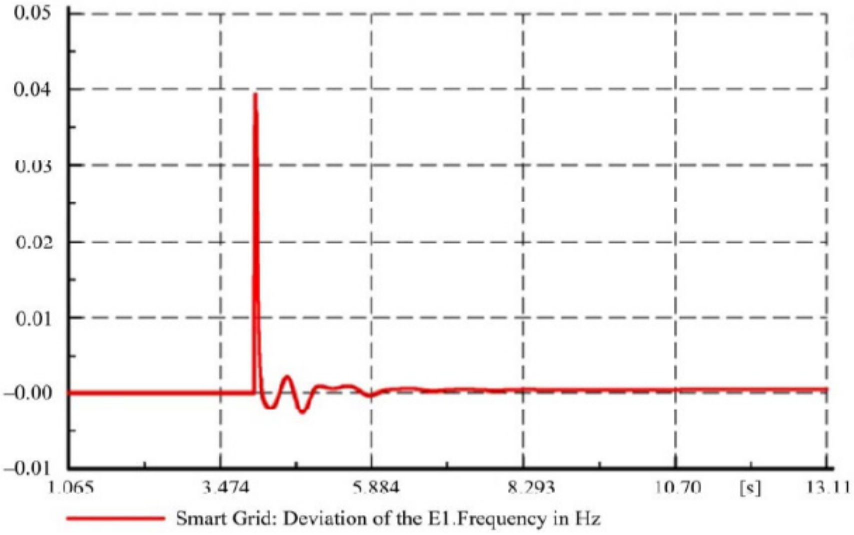

Figure 7. Total deviation of Smart Grid frequency during the integration of DGs is measured in hertz

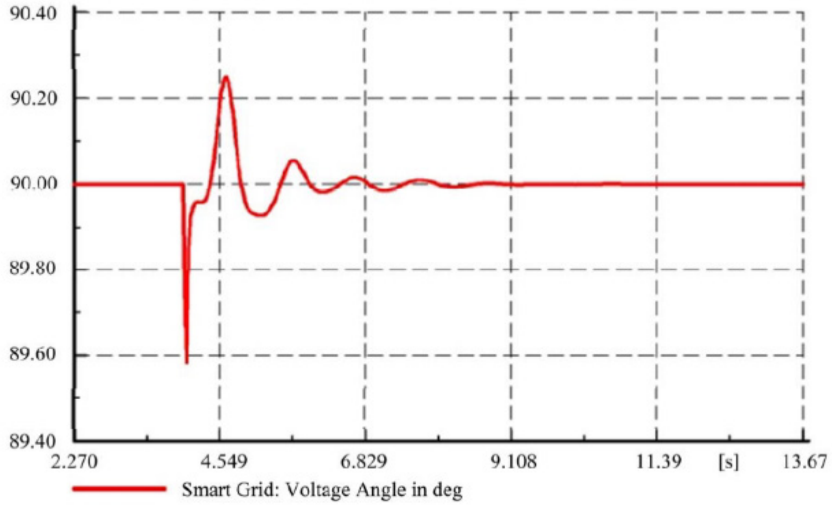

Figure 8. Voltage angle of the Smart Grid is measured in degrees when integrating DGs

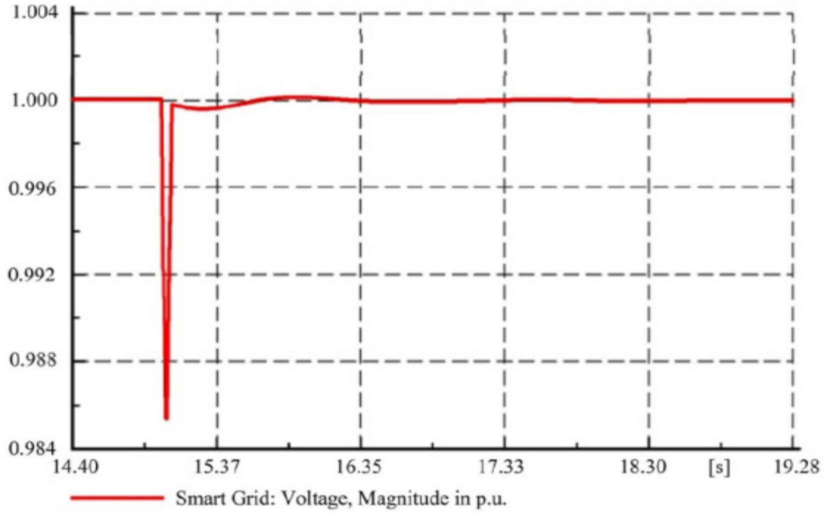

Figure 9. Voltage of the Smart Grid changes in response to a 3-phase fault in per unit

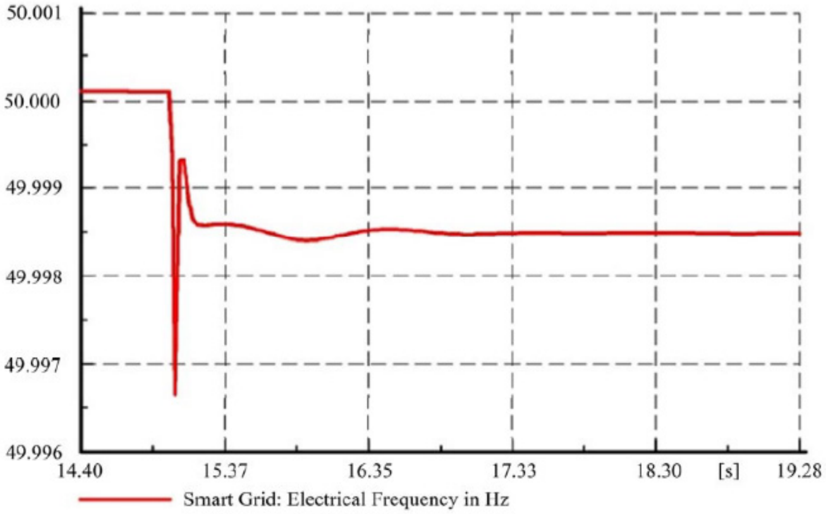

Figure 10. During a three-phase fault, the frequency response of the Smart Grid is measured in hertz

Fault Stability Analysis

This part of the text deals with the stabilization of the smart grid or the study of integrating distributed generation into the grid. According to figure 4, the stability of the smart grid voltage at the 132 kV bus decreases significantly when DG II is installed. However, the voltage stabilizes within five seconds of connecting it to DG II and remains within acceptable limits. Voltage instability is caused by a continuous increase in operational slip or speed of distributed generation as it tries to recover power and synchronize the system, as shown in figure 5. To solve this problem, it is necessary to have a reactive power controller to prevent further voltage instability. Therefore, the SVS operates in Q mode to supply and regulate reactive power when connected to the network. Furthermore, the frequency stability of the smart grid was evaluated after voltage imbalance. Figure 6 shows that adding DG modules to the smart grid leads to a slight increase in frequency at the switching point.

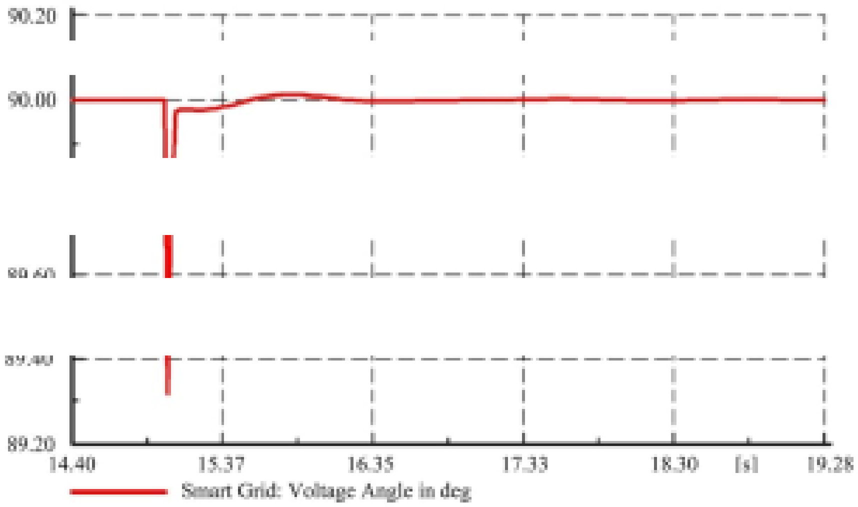

Figure 11. Voltage angle on the Smart Grid when a three-phase power unit fails

CONCLUSIONS

The effect of distributed generation is discussed in this work.

A study was carried out to evaluate the stability of smart grids. The study focused on voltage levels when integrating distributed generation and transient stability of the smart grid after a self-clearing fault. The same grid setup was used to evaluate the ongoing stability of the smart grid after integrating distributed generation and fixed Var system (SVS) interconnection. After 15 seconds, a transmission line failure occurred between buses 2 and 3, lasting for 200 ms. Figure 9 shows the response of the smart grid to this fault. Obviously, the fault caused a decrease in the alternating current voltage, which led to a decrease in electrical torque and an acceleration of the rotor slip of the distributed generation. This resulted in increased reactive power consumption. However, thanks to SVS's fast reactive power support, the system quickly regained stability, and the voltage returned to normal within 2 seconds of resolving the fault. The study also examined the stability of the smart grid's fault response frequency, as shown in figure 10. During the fault, the system's frequency decreased slightly. Unfortunately, after fixing the bug, the frequency remained slightly lower than expected. This discrepancy is attributed to the mismatch between the electromagnetic and mechanical torques of the distributed generation units. However, this mismatch usually does not cause major problems.

When the SVS gathers enough reactive power, the rotor's speed decreases gradually, resulting in the system eventually restoring its equilibrium. As a result, above 49,998 Hz, the frequency level remains the same after the fault. Figure 11 exhibits the occurrence of a three-phase short circuit failure and an 89,30 degree decrease in the voltage angle of the Smart Grid. This results in a decline in voltage, as shown in figure 9. The limitations on voltage and frequency fluctuations rely on the voltage angle. However, both prior to and following a failure caused by the use of SVC, the system can still operate in synchronization with DG. Figure 11 presents a fluctuation in voltage angle for a duration of two seconds, followed by a stabilization at 90 degrees. This leads to the establishment of a new constant value between the DG and the Smart Grid.

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CONFLICT OF INTEREST

None.

AUTHORSHIP CONTRIBUTION

Conceptualization: Ruaa Aboalhawa, Hussein A. Taha, Muhammad Al-Badri.
Research: Ruaa Aboalhawa, Hussein A. Taha, Muhammad Al-Badri.
Writing - original draft: Ruaa Aboalhawa, Hussein A. Taha, Muhammad Al-Badri.
Writing - revision and editing: Ruaa Aboalhawa, Hussein A. Taha, Muhammad Al-Badri.