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Status Review on Stability Analysis of Solar and Wind Electrical Energy Resource Based Microgrids integration into a Multi-Machine Power System.

Chinda Amos[1], Visa Musa Ibrahim[2], Saidu Yerima Musa[3] and David Ayuba Mshelia[4]
Department of Electrical and Electronics Engineering, Modibba Adama University Yola, Adamawa State Nigeria[1, 2, 3], National Centre for Technology Management Yola Nigeria[4]

Abstract

The world's interest in producing large amounts of electrical energy from renewable sources is mostly driven by global warming. One of the most promising renewable energy sources for producing large amounts of power is solar PV and wind energy, thanks to developments in converter technology. Wind and solar PV power could change the electrical grid in several ways and have an impact on its stability if the current commissioning rate persists. This paper provides a thorough analysis of the technological difficulties, including the stability concerns related to the integration of wind and solar PV on a large scale into the electricity system. The paper also analyzes solar PV for stability studies, HVDC, DFIG, FACTS devices, and generators' dynamic models. This report concludes by summarizing the research findings regarding the technical solutions to address the issues with power system stability.

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I. Introduction

Electrical power system stability is a critical aspect of modern electrical grids, ensuring that power systems can withstand disturbances and continue to operate reliably. As electricity demand grows and the integration of renewable energy sources increases, maintaining system stability becomes more challenging and essential. Understanding and managing power system stability is vital for ensuring the reliable operation of electrical grids, accommodating the growing use of renewable energy sources, and supporting the evolving demands of consumers and industries (Adebayo *et al.,* 2022). As power systems continue to evolve, the importance of stability will only increase, driving ongoing research and development in this critical field. Solar and wind energies are among the most common and used sources in recent decades, compared to other sources (Khare *et al*. 2016). Unlike the wind energy, solar energy can only be available during the day time. Wind and solar energy are stochastic nature, however, the uncertainty associated with wind energy variation can be much greater than that of the solar energy. This is due to the repetitive patterns of the solar energy in form of irradiance, which occur during the day time. Furthermore, wind and solar resource undergo seasonality, and are greatly affected by the weather conditions (Leung and Yang 2012). When deployed in small scale, the impact of solar and wind generators on power system stability is minimal, but when the penetration level increases, the dynamic performance of the power system can be affected.

Demand of electricity is increasing swiftly, while the huge amount of fossil fuel like gas coupled with the operational and maintenance required to produce sufficient electricity to meet the ever-increasing demand results in an enormous cost. As time passes, the operational and maintenance cost may increase exponentially resulting at higher electricity production cost. In this regard, the hunt for alternative energy sources has been sparked by environmental concerns, the exhaustibility of fossil fuels, and rising energy demands (Satymov *et al.,* 2022). Renewable energy resources now have more chances for integration into power system networks due to the recent advancements in renewable energy technologies and a decline in the cost of their unit energy production. Moreover, renewable energy resources are everywhere, unlike conventional energy sources, which are concentrated in a small number of places throughout the globe (IEA, 2012). Renewable energy is clean, reusable, sustainable, and beneficial to the environment. Examples of renewable energy sources include wind, sun, tidal, small hydro, geothermal, refuse-derived fuel, and fuel cells. Renewable energy has grown in importance as a result of pollution issues and the growing scarcity of fossil fuels (Bigerna *et al.,* 2021). Wind and solar energy have shown to be two of the most cost-effective renewable energy sources. Because fossil fuels produce power at a low cost per unit, a sizable portion of the world's electricity is still produced in this way. Due to the negative effects of this dependence on the environment, such as pollution and global warming, it is now necessary to explore and develop clean energy alternatives in order to produce electricity.

The wind and solar renewable resource uncertainty may result in higher loss of load probability (LOLP), especially during longer load demand supply periods. In the presence of critical loads, conventional non-renewable energy sources such as fossil fuel based generating systems are required to cover the base loads. Looking at the nature of each of the two sources, it is clear that each of them complements the other, so they are among the most common integrated energy systems (Yao *et al*. 2020; Shaker *et al*. 2016). Despite the merging of the wind and solar energy together, there are still some problems in eliminating fluctuations in the produced energy completely, especially with systems that are not connected to the grid, where the integration process cannot be completely controlled. Due to the aforementioned issues associated with wind and solar renewable energy sources, their integration into conventional grid system gives rise to questions on transient stability problem which is due to small signal stability and also due to weather conditions.

II. Renewable energy outlook

Renewable energy is the energy that is replenishing and non-deplete-able. It could guarantee energy security, promote national economic development, reduce or eliminate Green House Gas (GHG) emissions, conserve non-renewable energy, and eliminate or reduce their cost price, (Okoye *et al*., 2016). Africa has enormous potential for renewable energies, which are primarily unutilised and Nigeria is not exempted. Meeting the rising need for energy from secure, environmentally friendly, and safe sources has been one of the top priorities for world leaders, researchers, and educators since the Kyoto Protocol's commencement in 1992, (Przychodzen and Przychodzen, 2020) and (Miyamoto and Takeuchi, 2019). To meet up with the demand and lower GHG emissions, governments began to replace traditional fossil fuel-based energy sources with non-traditional and renewable ones. In addition, the renewable energy resources (RER) can improve energy security and contribute to the global energy economy (Zhu *et al.*, 2020), (Bigerna *et al.*, 2021). As a result, RER-based energy production has been rapidly expanding in recent years, and this trend is expected to continue in the decades to come (Gulagi *et al*., 2021), (Maruf, 2021) and (Wang *et al*., 2019). The global generation capacity from substantial RER, such as solar PV and wind energy resources, has expanded to over 95-fold and 8-fold, respectively. In 2020 compared to the capacity of 2007 according to research by the Renewable Energy Policy Network for the 21st Century (REN21, 2021), the growth in PV and wind power installation capacity over the past ten years is seen in figure 1. As may be observed, in terms of overall installation capacity, solar PV technology beat wind technology in 2020.

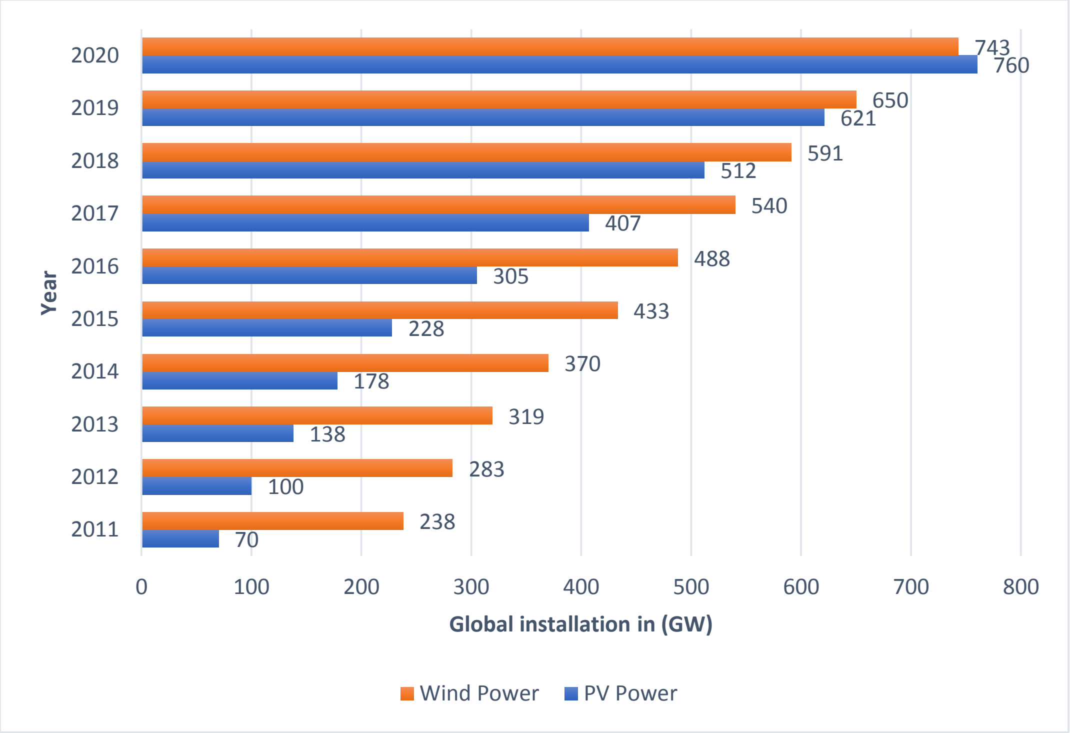

Figure 1: Global wind and PV installed capacity for 2011 – 2020, (REN21, 2021)

III. Power system stability

A power system's capacity to sustain operating equilibrium under normal conditions and to quickly return to a stable equilibrium state after network interruptions is known as power system stability (Kundur, 1994). These interruptions in the power network can range in size from small ones like progressive load changes, controller operation, etc. to significant ones like the loss of a large generator or load, a short circuit on a power line, etc. (Kundur *et al*., 2004).

3.1 Classification of Power System Stability

Power system stability is a single issue, but it is not possible to address it as such. Power system's instability can assume many different shapes, and is influenced by a large number of variables. As seen in figure 2, classification of stability into the proper categories substantially facilitates the analysis of stability issues, including the identification of critical contributors to instability and the development of techniques to enhance stable operation (Leonard L. Grigsby, 2012). These are founded on the following factors:

1. The physical characteristics of the ensuing instability in relation to the primary system parameter where instability is visible.
2. The size of the disturbance taken into account shows the best way to calculate and predict stability.
3. The tools, procedures, and time frame that must be considered in order to assess stability.

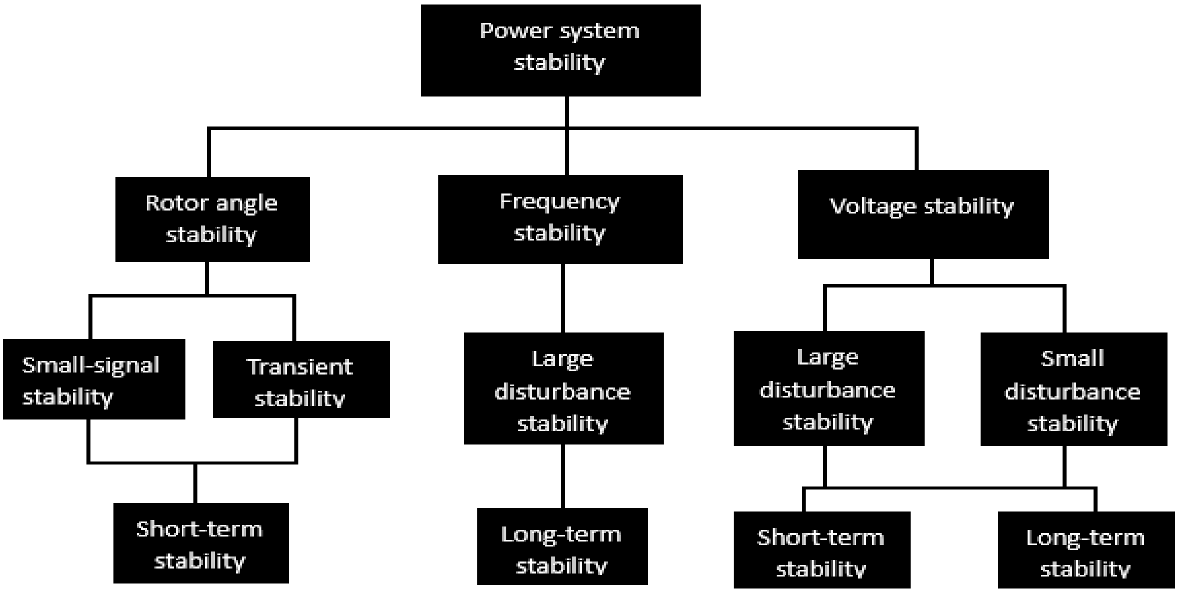

Figure 2: Classification of power system stability

3.1.1 Rotor Angle Stability

Rotor angle stability is concerned with the ability of interconnected synchronous machines of a power system to remain in synchronism under normal operating conditions and after being subjected to a disturbance (Leonard L. Grigsby, 2012). It depends on the capacity of each synchronous machine in the system to maintain or restore equilibrium between electromagnetic torque and mechanical torque. Some generators' rising angular swings, which cause them to lose synchronism with other generators, are one sort of instability that could result. An important aspect affecting this category of system stability is the way in which the power outputs of synchronous machines vary when their rotor angles change. This category of system stability is known as the "rotor angle stability problem," which involves the study of the electromechanical oscillations inherent in power systems. Restoring forces, which take effect whenever there are forces causing one or more machines to accelerate or decelerate relative to other machines, are the process by which networked synchronous machines maintain synchronism with one another (Leonard L. Grigsby, 2012).

Each machine's input mechanical torque and output electrical torque are in equilibrium under steady-state conditions, keeping the speed constant. If the system is disturbed, this equilibrium is thrown off, causing the machines' rotors to accelerate or decelerate in accordance with the laws of motion for rotating bodies. If one generator temporarily runs faster than another, the angular position of its rotor relative to that of the slower machine will advance. The resulting angular difference transfers part of the load from the slow machine to the fast machine, depending on the power–angle relationship (Leonard L. Grigsby, 2012). As a result, the angular separation and speed difference tend to decrease. The change in electrical torque of a synchronous machine following a perturbation can be resolved into two components:

1. Synchronizing torque component, in phase with a rotor angle perturbation

ii. Damping torque component, in phase with the speed deviation

System stability depends on the existence of both components of torque for each of the synchronous machines. Lack of sufficient synchronizing torque results in aperiodic or non-oscillatory instability, whereas lack of damping torque results in oscillatory instability. Rotor angle stability in terms of the following two subcategories: Small disturbance (or small-signal) rotor angle stability and Large disturbance (transient) rotor angle stability

3.1.2 Voltage Stability

Voltage stability refers to a power system's capacity to maintain constant voltages at all of its buses both during routine operation and in the event of a disturbance. The potential for instability manifests as a gradual decrease or increase in voltage on particular buses. Voltage instability may result in either a loss of load in the region where voltages drop to unacceptable levels or in the integrity of the power system. Progressive drop in bus voltages can also be associated with rotor angles going out of step. For example, the gradual loss of synchronism of machines as rotor angles between two groups of machines approach or exceed 180° would result in very low voltages at intermediate points in the network close to the electrical centre where rotor angle stability is not a concern, a prolonged voltage decline associated with voltage instability takes place (Kundur, 1994).

High levels of active power and reactive power flow through inductive reactance connected to the transmission network, limits the capacity of the transmission network for power transfer, and this results in higher reactive power losses followed by the voltage drops. When some of the generators reach their field current limits, the power transfer and voltage support are further constrained. It is useful to classify voltage stability into the following subcategories according to (Leonard L. Grigsby, 2012):

i. Large disturbance voltage stability is concerned with a system’s ability to control voltages following large disturbances such as system faults, loss of generation, or circuit contingencies. This ability is determined by the system-load characteristics and the interactions of both continuous and discrete controls and protections.

ii. Small disturbance voltage stability is concerned with a system’s ability to control voltages following small perturbations such as incremental changes in system load. This form of stability is determined by the characteristics of loads, continuous controls, and discrete controls at a given instant of time. This concept is useful in determining, at any instant, how the system voltage will respond to small system changes.

A criterion for small disturbance voltage stability is that, at a given operating condition for every bus in the system, the bus voltage magnitude increases as the reactive power injection at the same bus is increased. A system voltage is unstable if, for at least one bus in the system, the bus voltage magnitude (V) decreases as the reactive power injection (Q) at the same bus is increased. In other words, a system voltage is stable if V–Q sensitivity is positive for every bus and unstable if V–Q sensitivity is negative for at least one bus (Leonard L. Grigsby, 2012). A requirement for small disturbance voltage stability is that, for each bus in the system, at a given operating condition, the magnitude of the bus voltage rises as the reactive power injection at the same bus is raised. If the bus voltage magnitude (V) declines as the reactive power injection (Q) at the same bus increases for at least one bus in the system, the system is said to be voltage unstable. In other words, a system is voltage stable if every bus has positive V-Q sensitivity, and unstable if at least one bus has negative V-Q sensitivity.

Both large and small disturbance voltage stability are classified based on the duration of the resulting phenomenon as Short-term voltage stability involves dynamics of fast-acting devices such as induction motors, electronically controlled loads, and HVDC converters. A common scenario is when the power system is working under stress during hot weather with a high level of air-conditioning loads, and there is a significant disturbance, such as a malfunction, close to a load centre. The second one is the Long-term voltage stability involves slower acting devices such as tap-changing transformers, thermostatically controlled loads, and generator field current limiters. When the EHV network is running under stress, with many of the lines being heavily loaded and reactive power reserves at their lowest, a common scenario is the loss of a heavily laden transmission line. Following the disturbance, there would be a significant drop in voltage at nearby EHV buses, which would then be reflected into the distribution system.

3.1.3 Frequency Stability

Frequency stability is concerned with the ability of a power system to maintain steady frequency within a nominal range following a severe system fault resulting in a significant imbalance between the overall system generation and load (Kundur, 1981). It depends on the ability to restore balance between system generation and load, with minimum loss of load.

Severe system faults generally result in large excursions of frequency, power flows, voltage, and other system variables, thereby invoking the actions of processes, controls, and protections that are not modelled in conventional transient stability or voltage stability studies. These processes may be very slow, such as boiler dynamics, or only triggered for extreme system conditions, such as volts/hertz protection tripping generators. In large interconnected power systems, this type of situation is most commonly associated with islanding. Stability in this case is a question of whether or not each island will reach an acceptable state of operating equilibrium with minimal loss of load. It is determined by the overall response of the island as evidenced by its mean frequency, rather than relative motion of machines. Generally, frequency stability problems are associated with inadequacies in equipment responses, poor coordination of control and protection equipment, or insufficient generation reserve. Examples of such problems are reported by (Kundur *et al*., 1985), (Chow *et al*., 1989), and (Kundur, 1981). Over the course of a frequency instability, the characteristic times of the processes and devices that are activated by the large shifts in frequency and other system variables will range from a matter of seconds, corresponding to the responses of devices such as generator controls and protections, to several minutes, corresponding to the responses of devices such as prime mover energy supply systems and load voltage regulators. Three main reasons behind the stability issues According to (Gopakumar *et al*., 2014) are:

i. Decreased system inertia, resulting in angular instability and frequency instability.
ii. Lower voltage stability as a result of reduced energy distribution; and
iii. Lower frequencies' oscillations as a result of a shift in the power-sharing ratio.

IV. Wind energy conversion system

A wind-based power system is dependent on the availability of fluctuating wind from the environment, whereas a traditional power system may be controlled for power output. However, with advancements in technology and increased economic competition, wind power is now a significant source of energy. These advantages over other renewable energy sources make wind energy a clear choice for utility-scale power generation. The kinetic energy of the wind is transformed into electric energy or other energy types via a wind energy conversion system. Wind power has grown significantly over the past ten years due to its environmental friendliness and advantages over conventional alternatives (Chang, 2023). In addition to lowering the unit cost of producing electricity, technological innovation has increased the wind turbines' dependability and capacity (Bamisile *et al;* 2020).

A basic wind energy conversion system (WECS) comprises of a wind turbine, an electric generator, power lines, and loads. Wind turbines can be divided into two types: horizontal wind turbines and vertical wind turbines, depending on how the turbine spins. The most prevalent type of wind turbines is a horizontal one, which spins on a horizontal axis, as opposed to a vertical one, which has the main rotor shaft positioned vertically. The majority of the grid-connected wind farms use horizontal wind turbines (Bamisile *et al;* 2020). The mechanical components of a WECS according include the rotor, the main shaft, gearbox, mechanical breaks, nacelle, pitch and yaw drives, and wind measuring equipment. Whereas the electrical components of a WECS include the generator, power converter, step-up transformer, and wind farm collection points or points of common coupling.

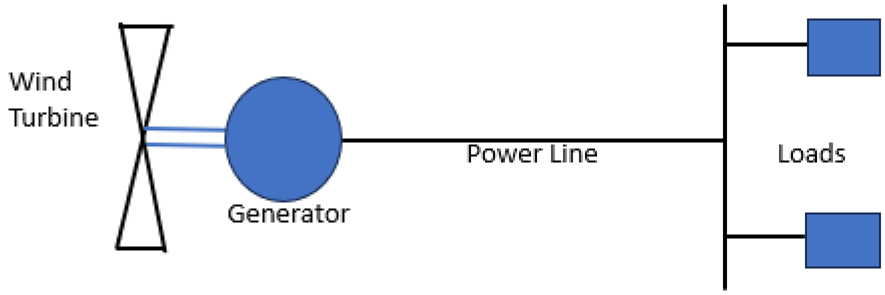

Figure 3: wind energy conversion system.

These wind turbines can also be divided into fixed-speed and variable-speed categories. A rotor is connected to the generator in fixed-speed wind turbines, while the stator winding is directly connected to the grid. The squirrel cage induction generator (SCIG) and wound rotor induction generator coupled wind farms are two examples of wind farms with fixed-speed turbines. The fixed-speed turbines have a simple construction and are relatively cheap. However, they cannot track fluctuating wind speeds, which means they may not be as efficient as variable-speed turbines. On the other hand, variable-speed turbines can operate at varying speeds depending on the wind speed, maximizing their energy capture for the wind source. But it was also learned that they require a complex power electronics converter, which makes them more expensive compared to fixed-speed turbines (S. Mathew, 2006). In the variable speed wind turbines, the permanent magnet synchronous generator, the DFIG-based generator, and the wound rotor synchronous generator are used (Adetokun and Muriithi, 2021). It's important to note that variable-speed wind turbines have a significant advantage in energy capture, but cost should also be considered. The DFIG-based generator is a popular option for variable-speed wind technology

V. Solar-Grid integration

The technique known as solar-grid integration enables large-scale solar power generated by PV systems to enter the already-existing electrical grid. This technique necessitates considerable thought and study in all aspects, including the production, installation, and use of solar componentry. Effectively connecting the levels of solar energy penetration onto the transmission grid necessitates a thorough understanding of the effects on the grid at various locations. The inverter is probably the most crucial component for integration in a photovoltaic plant that uses PV modules to input into the grid. Other components are also present. As depicted in Figure 4, the components include the PV generator (solar modules), the Generator Junction Box (GJB), the Metres, the Grid connection, and the DC and AC wiring. Solar energy system depends on inverters, which are frequently referred to as a project's brains. The primary purpose of an inverter is to convert direct current (DC) output into alternating current (AC), which is the industry standard for all appliances. Despite variable load conditions, inverters must maintain constant voltage and frequency and, in the case of reactive loads, must either supply or absorb reactive power (WEC. Energy Resources, 2023). A network that permits significant integration of photovoltaic (PV) power into the national utility grid is known as solar-grid integration. This is a crucial technological advancement since the integration of standardised PV systems into grids optimises building energy balance, enhances the PV system's economics, lowers operational costs, and adds value for both consumers and utilities (Sterling *et al.*, 2013). As there is an increasing need for the use of alternative clean energy sources instead of fossil fuels, solar-grid integration is now a widespread practise in many nations throughout the world (Akubude *et al.*, 2019).

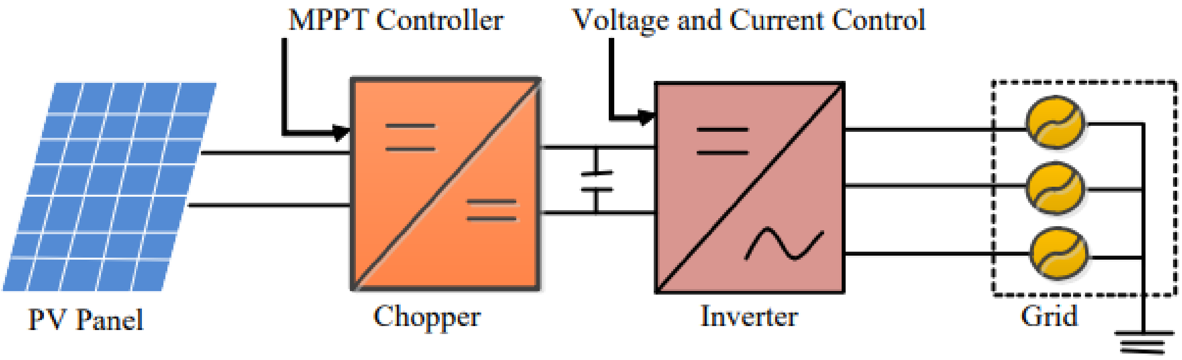

Figure 4. Main components of grid connected solar system (GCSS)

Power typically travels from centralised generators to substations, then to consumers, in most electric utility systems. Power can be generated using solar energy in both directions. The majority of electrical distribution systems, however, were not created to support two-way power delivery. If the load and PV generation are not closely matched, even tiny amounts of PV may have an influence on system parameters for distribution feeder circuits that are long and serve rural or developing areas (Coddington *et al.*, 2023). The likelihood of harm to the utility grid and effects on other utility customers served by the same distribution circuit increases when PV generation exceeds local energy demand (Coddington *et al.*, 2023), as a result energy will migrate through the distribution feeder and possibly through the local substation.

VI. Power System Components

Power system components constitutes traditional synchronous generator, a wind generator based on DFIG, loads, FACTS devices, an HVDC link, and a power oscillation damping controller. For the stability studies, a thorough mathematical description of those power system components will be produced. When a power system's stability is assessed by model-based analysis, the system can be thought of as a mathematical model. The system's eigenvalue property is used to assess the stability of the system. Participation factor, mode form, polarity, controllability, observability, and sensitivity are among the indices for the assessment of the system's eigenvalues. However, in power system, the eigenvalues are usually not real, they contain imaginary part. When eigenvalues are real, the negative value stands for decaying oscillation which is the stable state. The positive value means the instability of the system. Whereas when the eigenvalues are conjugate, the real part of eigenvalue represents damping magnitude, when it is positive, the system is stable. The imaginary part provides the frequency of oscillations (Song *et al*., 2020). When an eigenvalue $\lambda <, =, \text{or} > 0$, it signifies that the system is stable, is at critical position and not stable at all.

VII. Review of Fundamental Concepts

In this section, reviews of the works presented by researchers in the areas including, wind power generation; solar power generation; renewable microgrids comprising of solar and/or wind and storage systems; renewable energy integration into the utility or large-scale power system; stability analysis; power system cost minimization and performance optimization; etc are presented.

S/N	Authors/Year	Title	Sources	Information obtained	Limitations
1.	Abhinav and Ratnesh, 2019	Small Signal Stability of a Power System	*International Journal of Recent Technology and Engineering (8)3*	SVC dampens power system oscillations, enhancing stability, as shown by the eigenvalues plot	Future scope includes the impact of renewable energy penetration on system modes (eigenvalues).
2.	Karthikeyan and Dhal, 2015	Small Signal Stability Enhancement using STATCOM based on Eigen Value Analysis	*Indian Journal of Science and Technology, Vol 8(34), DOI:10.17485/ijst/2015/v8i34/86119*	The performance of stability improvement has been achieved by STATCOM and the Eigen values has been changed from 2 to 0.	STATCOM alone improved small signal stability eigenvalues. Future work can use computational algorithms aside PSAT
3.	Abhinav and Pindoriya, (2016).	Grid Integration of Wind Turbine and Battery Energy Storage System: Review and Key Challenges	*2016 IEEE*	The paper reviews issues in active and reactive power management, including power fluctuation, frequency regulation, dispatchability, reactive power support, voltage stability, and low voltage ride-through. It also covers control strategies and battery technologies	Wind turbines connect to the grid via power electronics, requiring better converter control for efficient power management. Considering the dynamic behavior of each component is crucial for system stability and security.
4.	Liang et al., 2022	Analytical Methods of Voltage Stability in Renewable Dominated Power Systems: A Review	*Electricity 2022 (MDPI)*	Review of voltage stability analyses of power systems with high levels of renewable energy penetration was carried out.	To coordinate the expanding asynchronous power supplies with the current synchronous generation.
5.	Bi and Gao, 2014	Power System Dynamic Voltage Stability Analysis Considering Wind Power	*2014 IEEE 12th International Conference on Dependable, Autonomic and Secure Computing*	This paper analyzes the impact of wind power on voltage stability under various operating conditions and fault locations.	It is important to analyze the coordinated control of multiple types of renewable energy
6.	Patil and Thosar, 2016	Steady State and Transient Stability Analysis of Wind Energy System	*2016 2nd International Conference on Control, Instrumentation, Energy & Communication (CIEC)*	This work analyzes the transient and steady-state response of a wind energy system using a two-mass model, examining the effects of generator inertia, spring constant, viscous friction, and gear ratio through pole-zero study under fault conditions	This study is useful to design fault tolerant control system in future.
7.	Limei *et al.*, 2022	Small Signal Stability Analysis and Optimize Control of Large-Scale Wind Power Collection System	*IEEE Access, 2022*	This paper uses the Weibull distribution to describe wind speed uncertainty, calculates its shape and scale parameters using the maximum likelihood approach with measured data, and analyzes small signal stability with large-scale wind power integration.	The effect of wind speed and wind farm capacity variation on parameter optimization and damping ratio needs to be investigated. Considering annual increase in wind power penetration
8.	Singh *et al.*, 2019	A Comprehensive Review on Enhancement of Voltage Stability by using Different FACTS	*2019 IEEE*	This paper presents survey of various methods for enhancement of voltage stability by using	In the future, hybrid techniques with various FACTS controllers will enhance voltage stability, address multi-task objectives, handle

		Controllers Planning in Power Systems		different FACTS controllers	dynamic and static load modes, and improve environmental friendliness
9.	Machabe *et al*., 2020	A Review of Power System Instability Prediction Methods Using Phasor Measurement Unit Data	*2020 IEEEXplore*	This research presents a review of instability prediction methods using phasor measurement unit (PMU) data including neural networks, auto-regression, FFT, One Class Support Vector as well as Parallel Detrending Fluctuation Analysis.	Future work should compare neural network performance with autoregressive approaches for stability prediction and explore eigenvalue prediction using data from Phasor Measurement Units at various network locations.
10.	Zhang *et al*., 2021	A critical review of data-driven transient stability assessment of power systems: principles, prospects and challenges	*Energies 2021 (MPDI)*	This paper makes a comprehensive review from the following four aspects: feature extraction and selection, model construction, online learning and rule extraction.	Obtaining large-scale, balanced, and accurately labelled data is challenging and costly. Existing data-driven TSA methods often lack interpretability and adaptability to topological changes, limiting their practical application in power systems.
11.	Bamisile et al., 2020	An approach for sustainable energy planning towards 100 % electrification of Nigeria by 2030	*Elsevier Energy 197 (2020)*	This study presents a sustainable and economically viable plan for achieving 100% electrification in Nigeria by 2030, analyzing the use of natural gas, onshore and offshore wind, photovoltaic, concentrated solar power, and hydro-power, with pumped hydrostorage as the sole storage system.	In future research, the integration of electric vehicles to solve the CEEP challenges in some of the cases presented will be studied. In addition, the transmission and distribution requirements to achieve 100% electrification of Nigeria is yet to be analyzed.
12.	Adetokun and Muriithi, 2021	Impact of integrating large-scale DFIG-based wind energy conversion system on the voltage stability of weak national grids: A case study of the Nigerian power grid	*Elsevier Energy Reports 7 (2021)*	This paper examines the impact of integrating large-scale DFIG-based wind energy systems on the voltage stability of the 52-bus, 330 kV Nigerian power grid, using indices from PV and QV analyses to assess stability limits, including maximum active power margin, minimum reactive power margin, and critical voltage-reactive power ratio.	The impact of change in wind speed and reactive and active power injection during faults was not investigated
13.	Bamisile *et al*., 2020	Analysis of Solar PV and Wind Power Penetration into Nigeria Electricity System	*2020 IEEE Xplore.*	In the study, use of solar PV and wind power plants to solve Nigeria electricity problem was investigated to determine the maximum penetrable capacity of solar PV and wind power with/without critical excess electricity production (CEEP).	Future research will explore integrating storage systems and additional renewable energy sources like biomass, geothermal, and hydropower to meet Nigeria's current electricity demand alongside solar PV and wind power.
14.	Bamisile *et al*., 2019	Smart Micro-Grid: An Immediate Solution to	*2019 IEEE PES Innovative Smart Grid Technologies Asia*	In this paper, the potential utilization of smart micro-grid to solve the	The used of wind and solar PV for electricity generation for only 12

		Nigeria's Power Sector Crisis		power supply challenge in Nigeria is explored. The used of wind and solar PV for electricity generation for 12 different cities in Nigeria is also analyzed.	different cities in Nigeria was analyzed.
15.	Ikem *et al.*, 2016	Integration of Renewable Energy Sources to the Nigerian National Grid - Way out of Power Crisis	*International Journal of Engineering Research (2016)*	This paper suggests that the Federal government invest in alternative energy sources by reviewing the power sector and renewable energy potentials, using identified issues with power generation, transmission, and distribution as benchmarks to avoid past mistakes.	The limitations in this work is the lack of discussion on cost analysis benefit, Portfolio Standards, Feed-in-Tariffs and Renewable Energy Certificate to determine the best policy mechanism for renewable energy
16.	Khan *et al.*, 2022	A Review of Grid Code Requirements for the Integration of Renewable Energy Sources in Ethiopia	*Energies (MDPI) 2022,*	This article discusses Ethiopia's current grid code and its need, outlining technological requirements for integrating small and microgrids, crucial for renewable energy. It also identifies barriers to normalizing the grid code and testing grid compatibility for renewables.	Implementation of advanced controlling techniques such as artificial intelligence techniques is still not discussed in the grid code.
17.	Aluko *et al.*, 2020	A Review of the Control System Roles in Integrating Renewable Energy into the National Grid	*2020 IEEE PES/IAS PowerAfrica*	This paper presents the issues around the strategic importance of control systems in the integration of renewable energy sources (RESs) into the national grid to ensure a cost-effective transition to a lower-carbon energy system.	The design and integration of smart microgrids into the Nigerian national grid are the future works that need to be explored.
18.	Ahmed *et al.*, 2020	Grid Integration Challenges of Wind Energy: A Review	*IEEE Access 2020*	This article reviews challenges and proposed solutions related to wind energy integration, including generation uncertainty, power quality, stability, reactive power support, and fault ride-through. It also examines socioeconomic, environmental, and market challenges associated with integrating wind power into the grid.	Researchers should focus on improving storage capacity and duration, and explore new probabilistic methods to enhance prediction accuracy and reduce computational demands. Investigating the relationship between wind energy generation uncertainties and demand side management is also crucial for reliable grid integration. Future work should review similar challenges and their impacts on distribution grids, and consider detailed solutions for these issues.
19.	Coughlan *et al.*, 2007	Wind Turbine Modelling for Power System Stability Analysis—A System Operator Perspective	*@ 2007 IEEE TRANSACTIONS ON POWER SYSTEMS*	This paper examines model development and validation from the Irish grid operator's perspective, using a generic modelling approach for large-scale power system stability investigations.	Generic models representing the dynamics of relevance for power system stability analysis should be developed for large-scale studies.

20.	Liang *et al*., 2022	Analytical Methods of Voltage Stability in Renewable Dominated Power Systems: A Review	*Electricity (MDPI) 2022*	This paper provides a comprehensive literature review of voltage stability analyses of power systems with high levels of renewable energy penetration. A series of generalized evaluation schemes and improvement methods relating to the voltage stability of power systems integrated with various distributed energy resources are discussed.	Addressing the rising complexity and stability issues from increased renewable integration and asynchronous generation requires better coordination with synchronous generation. Additionally, there is a need for improved dynamic voltage stability analysis methods to enhance accuracy and effectiveness.
21.	Chepkania *et al*., 2020	Review of Frequency Stability Control Schemes in the Presence of Wind Energy Sources	*IEEE Xplore, 2020*	This paper reviews frequency stability control schemes for integrating wind turbines using the PSAT simulation tool in MATLAB/Simulink, finding it insufficient for accurate results in the IEEE 39 Bus system with time domain simulation.	It notes that the Newton-Raphson method can get trapped in local optima, suggesting the need for alternative metaheuristic or numerical methods, or reorganization of IEEE 39 Bus data, to improve time domain simulation of wind farms in the grid
22.	Ahmad *et al*., 2021	Transient Stability Assessment of IEEE 9-Bus System Integrated Wind Farm	*MATEC Web of Conferences (2021)*	In this research, the transient stability of the IEEE 9-Bus system integrated with Doubly Fed Induction Generator (DFIG) is analyzed.	Future work should consider using an optimized intelligent Power System Stabilizer (PSS) to provide additional damping.
23.	Sun *et al*., 2010	A Review on Analysis and Control of Small Signal Stability of Power Systems with Large Scale Integration of Wind Power	*IEEE 2010 International Conference on Power System Technology*	This paper chiefly focuses on the small signal stability problems of power systems with large scale integration of wind power.	Hybrid modulation of active and reactive power in variable speed wind turbine generators has been overlooked, and their design often ignores wind power's stochastic nature and fault ride-through issues.
24.	Deshmukh and Moorthy, 2013	Review on Stability Analysis of Grid Connected Wind Power Generating System	*International Journal of Electrical and Electronics Engineering Research and Development, 2013*	This paper reviews generator models for power system stability studies and analyzes the effects and enhancements of stability in grid-connected wind power systems.	In the future, the authors will focus on transient stability studies using MATLAB, considering three-phase faults, and adopting STATCOM to improve stability
25.	Ali *et al*., 2021	Offshore Wind Farm-Grid Integration: A Review on Infrastructure, Challenges, and Grid Solutions	*IEEE Access on Power & Energy Society Section, 2021*	This study aims to compare and relate previous and recent developments in PQ and stability challenges and their solutions, with a focus on low voltage ride-through (LVRT) schemes and grid codes for interconnecting offshore wind power plants.	UPFC and STATCOM are preferable for addressing PQ issues, with SVC and TCSC as secondary options. Countries have established grid codes for reliable system operation, and detailed codes are needed for integrating various ESS technologies to ensure smooth wind generation output and system flexibility during faults.
26.	Ncwane and Folly, 2020	A Review of the Impact of Integrating Wind	*2020 IEEE Explore*	The literature on wind power generation's impact on power system transient stability and	The authors advised to investigate the impact of wind power

		Generation on Transient Stability		modelling considerations has been reviewed.	generation on transient stability.
27.	Idris *et al.*, 2020	The Status of the Development of Wind Energy in Nigeria	*Energies 2020*	Reviews the past and present studies on wind energy in Nigeria.	Focus should be given to hybrid systems combining wind, solar, battery storage, and diesel engines. Additionally, more research is needed on efficiency enhancement models for different turbine configurations.
28.	Bamisile et al., 2020	Analysis of Solar PV and Wind Power Penetration into Nigeria Electricity System	*IEEE Xplore 2020*	The use of solar PV and wind power plants to solve Nigeria's current electricity challenge has been analyzed in this study	Storage systems will be analyzed for their potential to use solar PV and wind power to meet Nigeria's electricity demand, with additional consideration of biomass, geothermal, and hydropower.
29.	Deshmukh and Deore, 2018	Impact of Wind Power Integration on Transient Stability of Power System	*2018 IEEE*	This study proposes examining a standard IEEE 14-bus test system to determine the minimum synchronous generation required for stability under specific loading and fault conditions, and discusses the optimal location for integrating wind energy to enhance system performance.	Effect of adding power system stabilizer and increasing the inertia of the wind generator can also be a subject of study
30.	Erlich and Brakelmann, 2007	Integration of Wind Power into the German High Voltage Transmission Grid	*2007 IEEE.*	This paper deals with the integration of wind power into the German high voltage grid	In the future further research is needed to identify new or improved approaches for enhancing the interactive behaviour of wind turbines and power systems.
31.	Zhanga *et al.*, 2022	Stability analysis of doubly-fed wind generation systems under weak power grid based on virtual synchronous control combined with adaptive robust control	*Elsevier Energy Reports 2022*	This paper proposes a stability analysis method for DFIGs using an adaptive control approach. It derives the DFIG impedance model with a power outer-loop based on virtual synchronous control and analyzes the effects of various power grid conditions and control parameters on system stability using the generalized Nyquist criterion	Future research should comprehensively address grid-connected stability and frequency characteristics of wind power, including the calculation and analysis of control parameters
32.	IRENA, 2023	Renewable Energy Roadmap, Nigeria	*International Renewable Energy Agency, Abu Dhabi*	Successfully integrating renewable energy sources in Nigeria will require addressing synchronization and variability issues to ensure a stable and reliable power supply.	The variability of wind speed and solar irradiance poses challenges for grid integration, requiring careful synchronization to avoid instability at the point of common coupling.
33.	Singh, *et al.*, 2023	Inter-area oscillation damping controls for wind power plants",	*IEEE Transactions on Sustainable Energy*	Mentioned other disturbances causing system instability, include faults from over/under voltage,	The analysis should account for dynamic interactions between wind turbines, solar

				surges, sags, swells, frequency changes, harmonics, noise, and switching heavy loads on or off.	photovoltaics, and other system components.
34.	Machabe *et al* . 2020	A Review of Power System Instability Prediction Methods Using Phasor Measurement Unit Data	*IEEE Explore, International Conference, Cape Town, South Africa*	Examine instability prediction methods using data from phasor measurement units.	Recommend comparing autoregressive approaches, such as eigenvalue prediction, to improve performance
35.	Eftekharnejad *et al*. 2013	Optimal generation dispatch with high penetration of photovoltaic generation	*IEEE Trans. Sustain. Energy*	Investigated the impact of rooftop and utility-scale PVs on small-signal stability in power systems.	They found critical modes with a damping ratio under 10%, introducing new oscillation mode.
36.	Movahedi *et al*., 2019	Designing SSSC, TCSC, and STATCOM controllers using AVURPSO, GSA, and GA for transient stability improvement of a multi-machine power system with PV and wind farm	*International Journal of Electric Power Energy System*	Worked on coordinated PSS-based FACTS controllers with PI controllers of solar PV and wind farms to enhance the stability of a multi-machine electric network.	The methodologies and solutions to address the problem of angular stability, however, were still in their infancy and need more research and development to reach technological maturity.
37.	Liang *et al*., 2022	Analytical Methods of Voltage Stability in Renewable Dominated Power Systems	*A Review. Electricity*	reviewed several methods of voltage stability analysis such as L-Index, Modal Analysis, V-Q sensitivity analysis, power flow-based method and dynamic voltage stability analysis.	Accuracy and efficiency remain challenges, as stability margins for each bus cannot be accurately calculated due to low accuracy and the consideration of too many system parameters.
38.	Khan and Go, 2019	Assessment of Malaysia's Large- Scale Solar Projects: Power System Analysis for Solar PV Grid Integration	*Global Challenges*	The probabilistic power flow method, combined with an optimization algorithm, addressed disturbances from PV output variability and managed load-supply imbalances and generation fluctuations due to environmental changes.	The probabilistic power flow algorithm addresses voltage and frequency fluctuations but does not fully mitigate the inherent variability in PV and other renewable sources
39.	Wang, *et al*., 2019	Integrating Model-driven and Data-driven Methods for Power System Frequency Stability Assessment and Control	*IEEE Transactions on Power Systems*	To address disturbances, they integrate model-driven and data-driven methods by combining the System Frequency Response (SFR) model with an Extreme Learning Machine (ELM) model. This approach maintains the physical causality of the SFR model while using ELM to correct errors and enhance predictions	ELM is sensitive to noise and outliers, prone to overfitting, and requires a large number of hidden neurons for high accuracy.
40.	Chen *et al*., 2020	Rotor Angle Stability Prediction of Power Systems with High Wind Power Penetration Using a Stability Index Vector	*IEEE Transactions on Power Systems*	They used the Extended Equal Area Criterion (EEAC) for rotor angle stability but struggled with large data volumes. To address this, they applied an ensemble decision tree algorithm to process SI vectors and	However, it struggles with handling large volumes of data and many features.

				identify optimal classifiers for rotor angle stability prediction in a one-machine-infinite-bus system.	

VIII. CONCLUSION

From the reviewed Literatures it shows that high Solar PV and wind energy penetration is influenced by factors such as size, location, type, system reserves, displacement of conventional generators, reactive power compensation, and control loops. Significant effort has been made to address stability constraints with large-scale solar and wind based microgrid integration into grid system. However, most studies focus on individual stability issues rather than a unified approach. Besides stability, dispatching strategies and spinning reserves are also crucial for future systems with high penetration, indicating the need for further research in these areas. However, integrating these sources into the grid poses challenges due to their inherent variability, leading to stability concerns, especially in systems not connected to the grid. There is a global push towards renewable energy to reduce greenhouse gas emissions and enhance energy security. The capacity of renewable energy sources, particularly solar PV and wind, has significantly increased over the past decade. To increase large-scale penetration in future power systems, it is crucial to address stability issues related to voltage, frequency, and rotor angle, and to develop standards for integration. Overall, the document underscores the need for comprehensive approaches and further research to effectively integrate renewable energy into power systems while ensuring stability and reliability.

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