International Journal of Power Electronics and Drive Systems (IJPEDS)
Vol. 15, No. 1, March 2024, pp. 404~411
ISSN: 2088-8694, DOI: 10.11591/ijpeds.v15.i1.pp404-411

Review on various voltage stability issues in AC distribution network

Attaullah Khidrani[1], Raja Masood Larik[2], Ahsanullah Memon[3], Irfan Ahmed Bajkani[3], Sajid Hussain Qazi[3]
[1]Faculty of Electrical Engineering, Balochistan University of Engineering and Technology, Khuzdar, Pakistan
[2]Department of Electrical Engineering, NED University of Engineering and Technology, Karachi, Pakistan
[3]Department of Electrical Engineering, Mehran University of Engineering and Technology, Khairpur, Pakistan

Article Info

Article history:

Received Mar 29, 2023
Revised Jun 7, 2023
Accepted Jun 25, 2023

Keywords:

AC distribution
Distribution networks
Optimization
Renewable energies
Voltage control
Voltage stability

ABSTRACT

With the rapidly depleting natural energy resources and increasing population worldwide, the calls for more energy demand have risen globally. In this vein, the world is transitioning from traditional to renewable energy sources (RES) to meet the required demands. However, the (RES), due to its variable nature, has voltage stability and power quality issues that need to get minimized to enhance the reliability of the (RES) system. This paper reviews the voltage stability and quality issues in the AC distribution system based on renewable energy sources (RES). Initially the renewable energy sources and problems associated with renewable energy sources are discussed. This article gives an overview of voltage control strategies based on local as well as communication-based phenomenon for distribution networks. In this review a hybrid solar photovoltaic and wind system is used to generate the power of 3-5 kW. A voltage controller topology is suggested using MATLAB/Simulink for enhancing voltage stability of the system. It is suggested that a voltage stability controller can be designed using recommended topology by using Arduino with pulse width modulation technique. Thus, by measuring and correcting real-time voltage instability values of the system, the system can be made more reliably secure, efficient, and stable than the previously proposed renewable AC distribution systems.

Corresponding Author:

Sajid Hussain Qazi
Department of Electrical Engineering, Mehran University of Engineering and Technology
Shaheed Zulfiqiar Ali Bhutto Campus, Khairpur Mirs 66020, Pakistan
Email: sajidhussain@muetkhp.edu.pk

1. INTRODUCTION

The utilization of renewable energy sources (RESs) for generation of power has drawn in impressive consideration all throughout the world. This is because of the negative natural effect of consuming petroleum for energy generation, which delivers a tremendous measure of carbon dioxide and other toxic gases in the atmosphere [1]. The expanding interest for energy and the requirement for atmospheric safety calls for effective and harmless power generation system. The use of environmental friendly power is generally considered as a promising option in contrast to customary non-renewable energy source framework and in this way draws more consideration [2]–[7]. Keeping up voltage balance of the power system is one of the serious issues because of the voltage failure caused by various disturbances in the power system. Since past few decades the stability of the power system has proved to be a major problem. Various studies has been performed and analysis is done to study the effect of PV system injection in power system stability [8], [9].

Fast improvement has enabled presence of extensive knowledge related to general power system control and stability. Number of IEEE standards and books [10]–[13] cover modelling issues in depth [13]. High injection of PV generation on the power system may cause negative impacts in the power system operation due to variable voltages [8]–[14]. New research on the smart grids considers voltage balance of the power system of very much importance. The variable nature of the renewable energy may cause instability in the power system and this may lead to power quality issues [15], [16]. A review paper is written on the distributed energy generation and its control techniques, which focus on microgrid control, and voltage control methods [17].

Now a days the distributed energy generation is getting much more acceptance. Although the cost of electricity production is very high, but it provides the power near the customer end rather than a faraway generator [18]–[22]. Distributed energy resources (DERs) are getting so much reputation in the grids and these sources are utilized in achieving so many objectives [23], [24]. Chakravorty and Das in [25] to express the sensitivity of buses, a voltage stability index for distribution network planning was proposed. Murty and Kumar in [26], for DER optimal settlement a voltage stability margin index was expressed and also in this paper evaluation of voltage stability improvement was performed.

Voltage stability problem was very important topic for the power distribution networks and was broadly investigated in 1990s [27], [28]. Voltage stability studies have been extended to the distribution systems just with the arrival of new DG expertise [23]. In this paper the long term voltage dependability will be considered to uncover the system’s capacity to keep up consistent voltage followed by variable changes in the load [29]. In this review paper a comprehensive analysis is done on effects of DGs injection on the power system voltage stability.

2. RENEWABLE ENERGY RESOURCES

Due to the world's population's rapid growth, energy demand is rising quickly. The production of energy becomes a significant global issue. A significant development in energy generation is the utilization of renewable energy sources. Energy that is produced using resources that are replenished naturally is known as renewable energy. Water, wind, solar, and biomass are the most popular renewable energy sources. These energy sources have historically been used for transportation fuels, heating, and power generation. Because they can be sustained, renewable energy sources are appealing. As a result, there is now an alternative to the declining use of traditional energy sources including coal, oil, and nuclear power. Compared to conventional energy sources, renewable energy sources are clean energy sources with significantly reduced environmental impact [30].

The microgrid uses photovoltaic and wind power as promising sources of energy to generate electricity. The microgrid's ability to generate electricity is dependent on the strength of the sun and the wind, which creates some difficult requirements for the technology used to regulate the microgrid [31]. Figure 1 shows the percentage of renewable energy, which represents the condition of the rate at which energy has been produced from renewable sources in the past, present, and future [32].

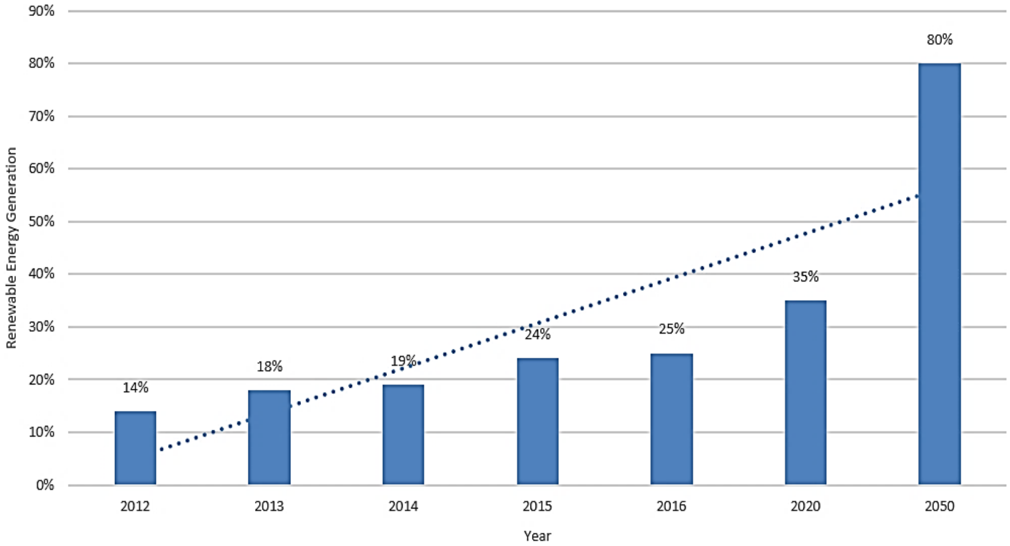

Figure 1. Increasing rate of energy generation from renewable energy sources in present and future

Overall, conventional fossil fuels are a sort of nonrenewable energy that could be dangerous due to resource depletion [33]. The most advanced RESs for electrical power generation are solar photovoltaic (PV) and wind, which have been extensively connected with the primary power grid in numerous locations across the world [34]. However, due to their intermittent availability, wind, and solar energy sometimes required energy storage devices [35]. The utility grid's quality, stability, and dependability may be impacted by the incorporation of RESs that are weather-dependent. The grid codes (GCs) and other standards of many nations have so imposed and updated a variety of rules, restrictions, and regulations regarding the functioning and connection of these RES [36]. GC contains a variety of technical specifications that describe important rules and restrictions associated with the generation units and their integration into the power grid to ensure the stable and appropriate operation of the power system [37].

3. PROBLEMS ASSOCIATED WITH RENEWABLE ENERGY RESOURCES

Power quality issues are related to the main challenge in integrating RESs with the traditional grid. High levels of solar PV and wind system penetration could pose serious problems for system stability overall. Voltage variations, flickering, unbalanced voltage and current harmonics, and frequency fluctuation are some of the issues with power quality. These issues are brought on by the switching elements (firing angle control) utilized in power electronics devices, which are now an essential part of RESs technology. The placement of the PV module, the distributed system configuration, and the level of solar PV penetration all affect how strong these problems are in the context of solar PV. In the case of wind, it is based on the kind of turbine, wind density, and wind speed. Power quality problems have been discovered in the literature to affect all RES integrated networks on the distribution, generating, and transmission sides. Rapid changes in sunshine and clouds produce voltage fluctuations and unbalance in solar PV, which has intermittent characteristics. In contrast, fluctuating wind speeds have an impact on wind power output [38]. Sensitive electrical and electronic equipment have a shorter lifespan due to voltage fluctuations.

Voltage fluctuations and unbalance, current and voltage harmonics, grid islanding protection, and other power quality issues, such as flicker and stress on distribution transformer, could be identified as the main effects of PV integration. These effects can be categorized as either dynamic or steady-state in nature: i) Variation of voltage in the feeder, which includes imbalanced voltage and voltage surge or fall; ii) Equipment used to regulate voltage, such as capacitor banks, on-load tap changers, and line voltage regulators, operating improperly; iii) The potential for distribution feeder overload; iv) Islanding identification and operation in the event of grid disconnect; and v) Distribution system security and dependability.

Power systems often have spinning reserves to avoid activation of load shedding. This will result in the production of high-quality sustainable energy. Power electronics converters, which are used to produce electricity from renewable energy sources, produce harmonics. We first talked about the features of renewable energy. Due to the semi-unpredictable characteristics and uncontrollable changes of wind and solar PV, both wind and PV power generation are prone to periodic variations that might cause deviations in performance. One way to lessen some of the unexpected aspects of wind and solar resources is to improve weather and power generation forecasting systems targeted at more precisely predicting the weather and power generation output of wind and solar resources at various time scales [39].

IEEE standard 1547a updated its voltage sags requirements in 2014. This included updated settings that make it easier for devices to withstand voltage drops steadily. These settings, which are listed in Table 1, are intended to reduce power quality difficulties brought on by disturbances brought on by tripping as a result of voltage dips [40].

Table 1. IEEE standard 1547a-2014 [40]

Range of voltage (base voltage % age)	Time of clearance (default) (s)	Maximum settings clearing time: adjustable up to and including (s)
V<45	0.16	0.16
45<V<60	1	11
60<V<88	2	21
110<V<120	1	13
V>120	0.16	0.16

4. CONTROL STRATEGIES USED IN DISTRIBUTION NETWORKS

SCADA are frequently used for power distribution system monitoring, while distribution management systems and energy management systems are employed for connecting to and communicating with remote devices. The main explanation for this move is the requirement for a significant increase in distributed generation, especially renewable energy sources, in order to achieve ecological priorities for emission reduction and sustainability. The integration of distributed generation (DG) into distributed networks has gained significant significance in the modern period in terms of the progress of quality and effectiveness. In any event, the large-scale penetration of DG into the current distribution systems was not envisaged for. Due to a growth in the injection of distributed generation into the system, numerous technical issues, including voltage management, power quality, and system protection, arise. In order to examine the distribution system and the impact of DG on the distribution system, additional components had to be combined with outdated distribution system devices. Significant efforts have been made in recent years to develop the optimal advanced control distribution system plan. The main goal of power distribution planning (PDP) is to build a power system that will enable cost-effective, dependable, and efficient operation. Recently, a few theories and tactics have been put out for the solution of sophisticated PDP problems [41]. Generally, there are total three types of control configurations: centralized control, distributed control, and decentralized control. All these controls are comparatively analyzed in Table 2.

Table 2. Comparison of different control techniques in electrical distribution network [42]

S. No.	Parameter	Distributed control	Centralized control	Decentralized control
1	Management	Distributed network	Centralized and structured network	Every entity considered
2	Response	Faster and more flexible	Slow	Fast exchange of information
3	Signal processing	Large signal processing is involved	Traffic and load prediction is needed	Control components have technical limits
4	Maintenance	Difficult to develop and maintain	Easier to develop and maintain	Less complexity in Software development
5	Dependability	Doesn’t depends on single computer	Depends on single computer.	Each unit controlled by its local controller
6	Size of system	Suitable for large systems	Suitable for small systems	Suitable for large systems
7	Coordination	No need to shut down whole system.	Whole system is to be shut down	Easily managed

5. POWER SYSTEM INSTABILITY PROBLEMS

The broadest definition of power system stability is the capacity of a power system to return to a stable operating point after exposure to a physical disturbance. This section has covered four types of power system stability: Rotor angle stability, converter stability, frequency stability, and voltage stability. Two further classifications for this division are small disturbance angle/voltage stability and high disturbance angle/voltage stability. Figure 2 displays the commonly used classification of power system stability. Long transmission lines, which restrict the amount of power that can be transferred between generators and loads in conventional power systems, are a primary contributing factor to voltage instability. However, because the feeders in microgrids are very short, only a small voltage difference exists between their transmitting and receiving ends. Depending on the time scale, voltage instability may develop over a short or extended period of time. Short-term voltage instabilities are brought on by a lack of control coordination or swift dynamical changes in the active and/or reactive power imbalance.

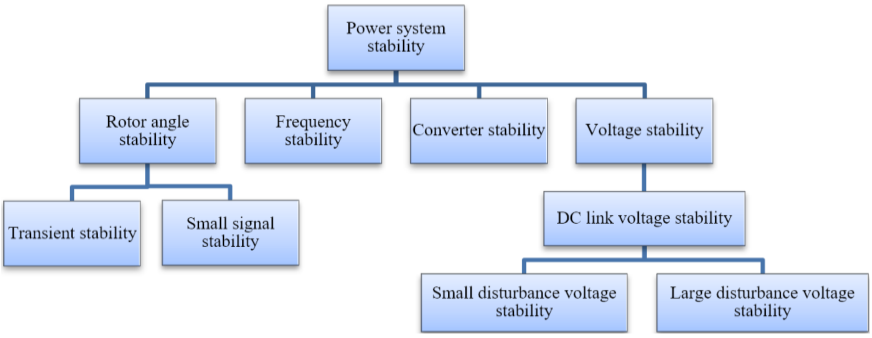

Figure 2. Classification of power system stability [44]

Voltage stability can be split into two categories in the report: small disturbance voltage stability and high disturbance voltage stability. When a system maintains its ability to maintain voltage stability following a little disruption, such as an increase in system load, this is referred to as small disturbance voltage stability. It is impacted by the load characteristic as well as the continuous and discontinuous control impacts over the allotted time. Large disturbance voltage stability is the capacity of all system buses to retain voltage stability after the system experiences a significant disturbance such a system failure, cutting machine malfunction, or line fault. Due to this reason undamped power oscillations are produced in the system, which increase beyond allowable operating range. On contrary to this, undamped oscillations are generated in heavily loaded microgrids due to small load changes for long term [43].

6. COMMUNICATION-LESS (LOCAL) VOLTAGE CONTROL STRATEGIES IN DISTRIBUTION NETWORKS

A low-voltage network's functionality is altered when distributed energy resources (DERs) are present in the system. With a large number of photovoltaics, which were formerly just conceivable at advanced voltage stages, bidirectional power flows in the system may be possible. One result of this is an increase in voltage at the ends of the lines. This occurrence can raise the level of the electricity by minimizing voltage drops, but it can also, in bad situations, result in the highest allowable voltage limit being surpassed. The ability of the grid to host PV devices is constrained by these phenomena, also known as "overvoltage" or "voltage boosting".

Techniques for controlling voltage locally don't require any kind of communication. The point of common coupling (PCC) measurement data, including voltage, frequency, and other measurement information, as well as the inverter's internal settings and internal algorithms determine how the PV source will respond. The limitation of using local approaches is that the network as a whole cannot be coordinated. Local control, on the other hand, is quick and doesn't need a lot of money up front. Autonomy is the fundamental tenet of local voltage regulation techniques. Low-voltage networks in the Polish electricity system typically lack communication infrastructure. Because they won't require the system operator to bear the high initial expenditures of creating the full network infrastructure, local techniques may end up being the greatest solution to improve the network hosting capacity. Different communication less local voltage control strategies are compared at Table 3.

Table 3. Different local control techniques comparison

Methods	Features	
Local control strategies		
Generation curtailment (in PV inverter)	Decrease in the PV installation's profit, ineffectiveness lacks boosting hosting capacity, Network-wide negative dynamic effects, simple in both execution and use.	There is no network coordinating provision. Simple to implement, requires no communication, is less expensive to implement and operate, has a low failure rate, operates quickly, and has little latency in control algorithms.
Reactive power control (in PV inverter)	Efficiency is influenced by reactance of network, and voltage drops brought on by network reactance necessitate high efficiency inverters and unstable parameterization, respectively.	
Voltage control in transformer OLTC	Unwanted voltage dip for consumers at network startup, higher-than-average transformer failure rates, and control discontinuity (in steps), Asymmetry in the network reduces efficiency.	
LVRs usage STATCOM usage	High device costs, the necessity for appropriate parameterization and the best network parameter selection, high efficiency (with asymmetries included), and good operating dynamics.	

7. COMMUNICATION-BASED VOLTAGE CONTROL OF DISTRIBUTION NETWORKS

Power is delivered to the loads from the substation and transformer in conventional distribution networks. Power flows in both ways when DER is linked to the network, increasing the voltage along the feeders. A voltage profile that satisfies legal requirements is advantageous for utilities and customers since it lowers network power losses and raises supply quality. The two main types of voltage control techniques are communication-based and local (autonomous) control. Local quantities taken at the point of common coupling (PCC) serve as the basis for autonomous control. There are five categories of communication-based schemes: local, centralized, decentralized, distributed, and hybrid (combination of centralized and local). Table 4 (see Appendix) depicting the comparative analysis of communication-based voltage control strategies.

8. CONCLUSION

In the paper thorough review on control of voltage stability issues have been carried out and found that decentralized and distributed controllers are viable to be implemented in the distribution system to tackle stability issues. Furthermore, it has been analysed that with the implementation of those controllers with availability of renewable energy resources the behaviour of such controllers has impact of distribution network. Hence, a detailed simulation will be carried out in MATLAB environment to exactly check the response of all the discussed controllers.

APPENDIX

Table 4. Comparative analysis of different voltage control strategies

Ref	Characteristics	Advantages	Disadvantages
Centralized			
[45], [46]	– Controlling voltage between the substation and the rest of the network – Sensors along the feeders collect data. – The control system is sophisticated. – Require a communication pathway – Broad coherence – Hardware implementation is simple. – Solid – Requires communication network – Significant outlay – Strict control – Data sharing is challenging – Complexity of computation – Challenges is limited – Redesigning is necessary frequently	– Broad coherence – Hardware implementation is simple. – Solid – Possibility of achieving both local and global goals	– Requires a robust and extensive communication network – Significant outlay – Strict control – Data sharing is challenging – Single point failures are possible – Complexity of computation – Challenges when access to global information is limited – Redesigning is necessary frequently
Decentralized			
[47], [48]	– Local control that regulates voltage on an autonomous basis utilising local data – Capable of offering support for local voltage – Each unit is controlled by a local controller that is unconnected to other controllers and is only partially aware of system-wide problems – There is poor coordination, and some gadgets might be often activated – Plug and play functionality is possible – Economically viable	– Lack of cohesion – Cost-cutting - decreasing the requirement for significant investment – Local factors determine control actions – Independent of wide-area communication systems – Capable of supporting voltage – Eliminates the requirement for sophisticated data management	– Insufficient coordination – Ignores the overall goal – Concentrates on the regional goal – The potential for disputes when there are many local controls
Distributed			
[49], [50]	– To reach a control decision, local controllers communicate with one another – Independence from centralised control. – Less computation work required compared to centralised EMS – Dependability is preserved – Making the best choice is feasible	– Solid – Generous – Versatile – Accurate frequency and voltage regulation	– Delays in signal transmission – Communication systems may cause security issues

ACKNOWLEDGEMENTS

Author thanks Sindh Higher Education Commission for research grant under grant no. SHEC/SRSP/ET-4/21/2020-21 and also acknowledge the support of Mehran UET SZAB Campus, Khairpur Mirs for providing condusive environment to carry out this research.

REFERENCES

[1] A. Q. Al-Shetwi, M. A. Hannan, K. P. Jern, M. Mansur, and T. M. I. Mahlia, "Grid-connected renewable energy sources: review of the recent integration requirements and control methods," *Journal of Cleaner Production*, vol. 253, p. 119831, Apr. 2020, doi: 10.1016/j.jclepro.2019.119831.

[2] S. Guo, Q. Liu, J. Sun, and H. Jin, "A review on the utilization of hybrid renewable energy," *Renewable and Sustainable Energy Reviews*, vol. 91, pp. 1121–1147, Aug. 2018, doi: 10.1016/j.rser.2018.04.105.

[3] A. Memon, M. W. Bin Mustafa, T. A. Jumani, M. O. Obalowu, and N. Malik, "Salp swarm algorithm–based optimal vector control scheme for dynamic response enhancement of brushless double-fed induction generator in a wind energy conversion system," *International Transactions on Electrical Energy Systems*, vol. 31, no. 12, Dec. 2021, doi: 10.1002/2050-7038.13157.

[4] T. Yusaf, S. Goh, and J. A. Borserio, "Potential of renewable energy alternatives in Australia," *Renewable and Sustainable Energy Reviews*, vol. 15, no. 5, pp. 2214–2221, Jun. 2011, doi: 10.1016/j.rser.2011.01.018.

[5] G. Kelly, "History and potential of renewable energy development in New Zealand," *Renewable and Sustainable Energy Reviews*, vol. 15, no. 5, pp. 2501–2509, Jun. 2011, doi: 10.1016/j.rser.2011.01.021.

[6] A. Memon, M. W. Mustafa, M. N. Aman, M. Ullah, T. Kamal, and A. Hafeez, "Dynamic low voltage ride through detection and mitigation in brushless doubly fed induction generators," *Energies*, vol. 14, no. 15, p. 4461, Jul. 2021, doi: 10.3390/en14154461.

[7] O. Nematollahi, H. Hoghooghi, M. Rasti, and A. Sedaghat, "Energy demands and renewable energy resources in the Middle East," *Renewable and Sustainable Energy Reviews*, vol. 54, pp. 1172–1181, Feb. 2016, doi: 10.1016/j.rser.2015.10.058.

[8] A. Memon, M. W. Mustafa, M. N. Aman, A. Hafeez, and M. Ullah, "Improving transient behavior of a brushless doubly fed induction generator through reactive current control of grid-side converter," *Electronics*, vol. 10, no. 12, p. 1413, Jun. 2021, doi: 10.3390/electronics10121413.

[9] H. Liu, L. Jin, D. Le, and A. A. Chowdhury, "Impact of high penetration of solar photovoltaic generation on power system small signal stability," in *2010 International Conference on Power System Technology*, Oct. 2010, pp. 1–7, doi: 10.1109/POWERCON.2010.5666627.

[10] P. M. Anderson, *Analysis of faulted power systems*. Wiley-IEEE Press, 1995.

[11] P. M. Anderson and A. A. Fouad, *Power system control and stability, second edition*. IEEE press power engineering series, 1994.

[12] J. W. D. Stevenson and J. J. Grainger, *Power system analysis*. McGraw-Hill Education, 1994.

[13] A. Memon *et al.*, “Dynamic response and low voltage ride-through enhancement of brushless double-fed induction generator using Salp swarm optimization algorithm,” *PLOS ONE*, vol. 17, no. 5, p. e0265611, May 2022, doi: 10.1371/journal.pone.0265611.

[14] M. Yagami, S. Ishikawa, Y. Ichinohe, K. Misawa, and J. Tamura, “Power system transient stability analysis in the case of high-penetration photovoltaics (part 2),” in *2015 IEEE Eindhoven PowerTech*, Jun. 2015, pp. 1–6, doi: 10.1109/PTC.2015.7232320.

[15] R. A. Walling, R. Saint, R. C. Dugan, J. Burke, and L. A. Kojovic, “Summary of Distributed resources impact on power delivery systems,” *IEEE Transactions on Power Delivery*, vol. 23, no. 3, pp. 1636–1644, Jul. 2008, doi: 10.1109/TPWRD.2007.909115.

[16] A. Memon, M. W. Mustafa, A. Khidrani, F. Hafeez, S. K. Baloach, and T. A. Jumani, “Internal mode control based coordinated controller for brushless doubly fed induction generator in wind turbines during fault conditions,” *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 23, no. 2, p. 650, Aug. 2021, doi: 10.11591/ijeecs.v23.i2.pp650-656.

[17] M. Yazdanian and A. Mehrizi-Sani, “Distributed control techniques in microgrids,” *IEEE Transactions on Smart Grid*, vol. 5, no. 6, pp. 2901–2909, Nov. 2014, doi: 10.1109/TSG.2014.2337838.

[18] M. Kezunovic, J. D. McCalley, and T. J. Overbye, “Smart grids and beyond: achieving the full potential of electricity systems,” *Proceedings of the IEEE*, vol. 100, no. Special Centennial Issue, pp. 1329–1341, May 2012, doi: 10.1109/JPROC.2012.2187131.

[19] Y. She, X. She, and M. E. Baran, “Universal tracking control of wind conversion system for purpose of maximum power acquisition under hierarchical control structure,” *IEEE Transactions on Energy Conversion*, vol. 26, no. 3, pp. 766–775, Sep. 2011, doi: 10.1109/TEC.2011.2159607.

[20] Y. Jiang and Z.-P. Jiang, “Robust adaptive dynamic programming for large-scale systems with an application to multimachine power systems,” *IEEE Transactions on Circuits and Systems II: Express Briefs*, vol. 59, no. 10, pp. 693–697, Oct. 2012, doi: 10.1109/TCSII.2012.2213353.

[21] A. Memon, M. W. Mustafa, S. K. Baloch, A. Khidrani, and T. Ahmed, “Dynamic response enhancement of BDFIG using vector control scheme based internal model c ontrol,” *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 23, no. 1, p. 90, Jul. 2021, doi: 10.11591/ijeecs.v23.i1.pp90-97.

[22] B. A. Kalwar, W. Fangzong, I. Ahmed, and M. H. Saeed, “Ti atom doped single vacancy silicene for hydrogen energy storage: DFT study,” *Journal of the Chinese Chemical Society*, vol. 68, no. 12, pp. 2243–2253, Dec. 2021, doi: 10.1002/jccs.202100369.

[23] R. S. Al Abri, E. F. El-Saadany, and Y. M. Atwa, “Optimal placement and sizing method to improve the voltage stability margin in a distribution system using distributed generation,” *IEEE Transactions on Power Systems*, vol. 28, no. 1, pp. 326–334, Feb. 2013, doi: 10.1109/TPWRS.2012.2200049.

[24] L. Wang, H. Gao, and G. Zou, “Modeling methodology and fault simulation of distribution networks integrated with inverter-based DG,” *Protection and Control of Modern Power Systems*, vol. 2, no. 1, p. 31, Dec. 2017, doi: 10.1186/s41601-017-0058-9.

[25] M. Chakravorty and D. Das, “Voltage stability analysis of radial distribution networks,” *International Journal of Electrical Power & Energy Systems*, vol. 23, no. 2, pp. 129–135, Feb. 2001, doi: 10.1016/S0142-0615(00)00040-5.

[26] V. V. S. N. Murty and A. Kumar, “Optimal placement of DG in radial distribution systems based on new voltage stability index under load growth,” *International Journal of Electrical Power & Energy Systems*, vol. 69, pp. 246–256, Jul. 2015, doi: 10.1016/j.ijepes.2014.12.080.

[27] J. A. D. de Leon and C. W. Taylor, “Understanding and solving short-term voltage stability problems,” in *IEEE Power Engineering Society Summer Meeting*, vol. 2, pp. 745–752, doi: 10.1109/PESS.2002.1043412.

[28] T. Cutsem and C. Vournas, *Voltage Stability of Electric Power Systems*. Boston, MA: Springer US, 1998.

[29] K. Vu, M. M. Begovic, D. Novosel, and M. M. Saha, “Use of local measurements to estimate voltage-stability margin,” *IEEE Transactions on Power Systems*, vol. 14, no. 3, pp. 1029–1035, 1999, doi: 10.1109/59.780916.

[30] E. Hossain, E. Kabalci, R. Bayindir, and R. Perez, “A comprehensive study on microgrid technology,” *International Journal of Renewable Energy Research*, vol. 4, no. 4, pp. 1094–1104, 2014.

[31] Y. Liu, A. P. Meliopoulos, L. Sun, and S. Choi, “Protection and control of microgrids using dynamic state estimation,” *Protection and Control of Modern Power Systems*, vol. 3, no. 1, p. 31, Dec. 2018, doi: 10.1186/s41601-018-0104-2.

[32] F. R. Badal, P. Das, S. K. Sarker, and S. K. Das, “A survey on control issues in renewable energy integration and microgrid,” *Protection and Control of Modern Power Systems*, vol. 4, no. 1, p. 8, Dec. 2019, doi: 10.1186/s41601-019-0122-8.

[33] M. Bhattacharya, S. R. Paramati, I. Ozturk, and S. Bhattacharya, “The effect of renewable energy consumption on economic growth: Evidence from top 38 countries,” *Applied Energy*, vol. 162, pp. 733–741, Jan. 2016, doi: 10.1016/j.apenergy.2015.10.104.

[34] S. Qazi, M. W. Mustafa, and I. A. Bajkani, “Simulation of PMSG based wind energy system with Multi Level NPC Converter,” in *4th International Multi-Topic ConferenceAt: MUET, Pakistan*, 2015, no. February.

[35] J. P. Barton and D. G. Infield, “Energy storage and its use with intermittent renewable energy,” *IEEE Transactions on Energy Conversion*, vol. 19, no. 2, pp. 441–448, Jun. 2004, doi: 10.1109/TEC.2003.822305.

[36] M. A. Mahar, A. S. Larik, and I. A. Bajkani, “TCSC integration in national transmission system of Pakistan to enhance transmission capability: A case study of Hub Jamshoro section,” in *2019 Proceedings of the International Conference on Industrial Engineering and Operations Management*, 2019, vol. 2019, no. MAR, pp. 630–641.

[37] M. R. Islam, H. Lu, M. J. Hossain, and L. Li, “Mitigating unbalance using distributed network reconfiguration techniques in distributed power generation grids with services for electric vehicles: A review,” *Journal of Cleaner Production*, vol. 239, p. 117932, Dec. 2019, doi: 10.1016/j.jclepro.2019.117932.

[38] G. Mokhtari, G. Nourbakhsh, F. Zare, and A. Ghosh, “Overvoltage prevention in LV smart grid using customer resources coordination,” *Energy and Buildings*, vol. 61, pp. 387–395, Jun. 2013, doi: 10.1016/j.enbuild.2013.02.015.

[39] N. A. Amoli and A. P. Sakis Meliopoulos, “Operational flexibility enhancement in power systems with high penetration of wind power using compressed air energy storage,” in *2015 Clemson University Power Systems Conference (PSC)*, Mar. 2015, pp. 1–8, doi: 10.1109/PSC.2015.7101694.

[40] IEEE Standards Coordinating Committee, *IEEE 1547 standard for interconnecting distributed resources with electric power systems*, no. July. The Institute of Electrical and Electronics Engineers, Inc, 2003.

[41] S. H. Qazi, M. W. Mustafa, U. Sultana, and N. Hussain, “Enhanced power quality controller in anautonomous microgrid by pso tuned pi controller,” *Indian Journal of Science and Technology*, vol. 10, no. 18, pp. 1–9, May 2017, doi: 10.17485/ijst/2017/v10i18/108925.

[42] A. R. Boccella, P. Centobelli, R. Cerchione, T. Murino, and R. Riedel, “Evaluating centralized and heterarchical control of smart manufacturing systems in the era of industry 4.0,” *Applied Sciences*, vol. 10, no. 3, p. 755, Jan. 2020, doi: 10.3390/app10030755.

[43] E. I. Ushakov, “On mechanism of voltage instability in power systems,” in *2005 IEEE Russia Power Tech*, Jun. 2005, pp. 1–8, doi: 10.1109/PTC.2005.4524766.

[44] H. Bulat, D. Franković, and S. Vlahinić, “Enhanced contingency analysis—a power system operator tool,” *Energies*, vol. 14, no. 4, p. 923, Feb. 2021, doi: 10.3390/en14040923.

[45] X. Luo, J. Wang, M. Dooner, and J. Clarke, “Overview of current development in electrical energy storage technologies and the application potential in power system operation,” *Applied Energy*, vol. 137, pp. 511–536, Jan. 2015, doi: 10.1016/j.apenergy.2014.09.081.

[46] H. Ji *et al.*, “A centralized-based method to determine the local voltage control strategies of distributed generator operation in active distribution networks,” *Applied Energy*, vol. 228, pp. 2024–2036, Oct. 2018, doi: 10.1016/j.apenergy.2018.07.065.
[47] P. N. Vovos, A. E. Kiprakis, A. R. Wallace, and G. P. Harrison, “Centralized and distributed voltage control: impact on distributed generation penetration,” *IEEE Transactions on Power Systems*, vol. 22, no. 1, pp. 476–483, Feb. 2007, doi: 10.1109/TPWRS.2006.888982.
[48] A. Bedawy, N. Yorino, and K. Mahmoud, “Optimal decentralized voltage control in unbalanced distribution networks with high PV penetration,” in *2017 Nineteenth International Middle East Power Systems Conference (MEPCON)*, Dec. 2017, pp. 1373–1377, doi: 10.1109/MEPCON.2017.8301362.
[49] S. K. Sahoo, A. K. Sinha, and N. K. Kishore, “Control techniques in AC, DC, and hybrid AC–DC microgrid: a review,” *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 6, no. 2, pp. 738–759, Jun. 2018, doi: 10.1109/JESTPE.2017.2786588.
[50] O. O. Mohammed *et al.*, “Assessment of the influence of wind energy incorporated capacity benefit margin in ATC computation,” *International Journal of Applied Power Engineering (IJAPE)*, vol. 11, no. 2, p. 145, 2022, doi: 10.11591/ijape.v11.i2.pp145-155.

BIOGRAPHIES OF AUTHORS

Attaullah Khidrani currently working as Assistant, prof, deptt. Of Electrical,Engineering Balochistan UET, khuzdar. Completed his M.Eng from MUET, Jamshoro Sindh and PhD in Electrical Engineering from University technology Malaysia in 2021. Area of interest is renewable energy, grid connected microgrid, and conrol. He can be contacted at email: khidraniatta@gmail.com.

Raja Masood Larik received his Bachelor of Engineering and Master of Engineering (Electrical) from NED University of Engineering & Technology Karachi, Sindh-Pakistan and PhD (Electrical Power Systems) from University Technology Malaysia (UTM) in the year 1998, 2006 and 2019 respectively. He is currently working as Assistant Professor at Department of Electrical Engineering NED University of Engineering and Technology Sindh, Pakistan. He can be contacted at email: rmlarik@neduet.edu.pk.

Ahsanullah Memon received his Ph.D. from Universiti Teknologi Malaysia in 2022. He did his B.E and ME in Electrical Engineering from Mehran University of Engineering and Technology, SZAB Campus Khairpur Mirs, Pakistan. His area of interest is machine learning, optimization, power system analysis, power quality, and grid integration of renewable energy sources. He can be contacted at email: ahsanmemon@ muetkhp.edu.pk.

Irfan Ahmed Bajkani has done his bachelors of Engineering in electrical engineering from Mehran University of Engineering and Technology Jamshoro in 2010. Then he did his Masters Electrical Power Engineering in FACTS technology from Mehran University of Engineering and technology in 2016. Then he did his Ph.D. (2022) in the design of Electronic materials for renewable energy. He has been teaching in MUET SZAB Campus Electrical department since 2013 as Assistant Professor. He can be contacted at email: irfanahmed@muetkhp.edu.pk.

Sajid Hussain Qazi currently working as Assistant Professor at Department of Electrical Engineering, Mehran UET SZAB Campus, Khairpur, Pakistan. Completed his M.Eng and Ph.D. in Electrical Engineering from Unviersiti Teknologi Malaysia in 2016 and 2018, respectively. Received his B.Eng from Mehran UET, Jamshoro, Pakistan. Area of interest is interconnecting renewabke energy sources with grid, optimization of controller, power quality, and microgrids. He can be contacted at email: sajidhussain@muetkhp.edu.pk.