Sustainable Power Flow: Voltage Distribution Strategies for Renewable Energy Integration

Boya Divya[1], *Gopal* Kaliyaperumal[2*], *Lavish* Kansal[3], *Abhishek* Saxena[4], Praveen[5], *Q.* Mohammad[6], *K* RajaSri[7]

[1]Department of CSE, GRIET, Bachupally, Hyderabad, Telangana, India.
[2]Institute Department of Mechanical Engineering, New Horizon College of Engineering, Bangalore, India.
[3]Lovely Professional University, Phagwara, India.
[4]Department of Mechanical Engineering, ABES Engineering College, Ghaziabad - 201009, UP, India.
[5]Lloyd Institute of Engineering & Technology, Knowledge Park II, Greater Noida, Uttar Pradesh, India.
[6]Hilla University College, Babylon, Iraq.
[7]Department of Electrical and Electronics Engineering, MLR Institute of Technology, Hyderabad, Telangana, India-500089

Abstract- The rapid expansion of green energy resources (RER) into existing electrical networks necessitates an evolved approach to voltage distribution. This study explores the challenges and solutions associated with integrating green energy into high and low voltage distribution systems (HVDS and LVDS). The research evaluates various protection schemes for dynamic fault currents, voltage control systems for mitigating power quality issues, and optimal planning strategies for distributed generation. Innovative methodologies for integrating solar and wind energy, such as centralized-decentralized control approaches and demand response mechanisms, are proposed. The study demonstrates, through MATLAB simulations, that HVDS configurations significantly improve system efficiency and reduce technical losses compared to LVDS, particularly when interfacing with green energy sources.

Keyword-:– Green energy, electrical networks, LVDS, HVDS, power quality.

1 Introduction

Green energy sources like wind and solar power promise to meet future electricity demands. Usually, they are integrated at distribution utilities or run in an island mode, which has an impact on network layouts and failure levels. Because failure stages in renewable integrated power systems are intermittent and set circumstances might cause existing protection schemes to fail, it is imperative that an appropriate protection scheme be designed and chosen for dependable management and operation .For power networks with dynamic fault currents, bulk renewable infeed forces adaptation of current protection techniques to account for current fault change, necessitating either reactive and inflexible relay schemes. Thus the

* Corresponding author: vkgopalme23@gmail.com

study conducted in [1] evaluates protection schemes, its benefits and drawbacks, and also highlights the range of cutting-edge methods for green integrative energy networks, that encompass distribution, transmission, and island systems .While variable renewable or green energy, such as solar and wind energy, are essential for decolonization, their growing proportion in power networks presents risks that might compromise system stability .In order to improve transparency, solve problems related to green energy, rank cost-effective solutions, and find organizations that might reduce obstacles, [2] classifies different technologies according to their potential .Distribution network planning is changing as a result of distributed generation's quick expansion, but poor integration might present both technical and financial difficulties. Power quality, voltage stability, reducing power loss, dependability, and profitability all depend on optimal planning. The study in [3] examines traditional and meta heuristic approaches to optimum distributed generation planning, with a particular emphasis on analytical techniques for power system modelling and numerical approach assurance, as well as metaheuristic algorithms for adaptability .Distributed generation resources are increasingly appealing to power companies as a consequence of advancements in renewable energy technologies and modifications of their infrastructures. Although their applicability is restricted by regulatory and technological limitations, planners, regulators, and legislators profit from them. Research on line-loss reduction, reliability enhancement, economic benefits, and environmental pollutant optimization—among the technical, environmental, and financial rewards associated with renewable energy integration [4]. It also examines operational issues and the current state of renewable energy production technology.

2 Integration of Green Energy with electrical networks

When integrating green energy sources (GES) into traditional electrical networks, this study explores control solutions for minimizing regulation of voltage issues. It draws attention to the technological difficulties in preventing renewable distribution generators from expanding too far within the network .The study conducted in [5] assesses voltage control systems for distribution networks that include more renewable distributed energy sources. The technical obstacles of integrating green energy into the grid include harmonics generated by power electronic equipment used in renewable energy generation, which have an important impact on power quality, and swings in voltage and frequency caused by unpredictable un predictability. With an emphasis on windmills and photovoltaic solar panels, [6] examines new power quality issues in the combination of alternative power sources. It also examines current techniques for enhancing power quality, emphasizing control technology-based enhancement, and suggests future lines of inquiry.

Power quality and dependability may be improved by distributed generating units, but proper location is essential. In order to incorporate scattered generation, optimizing instruments have been created and current research is concentrating on these methods .Recent optimization techniques for scaling distributed generating units powered by renewable energy sources are covered in [7]. It examines the obstacles of integrating dispersed production and the factors that influence them, including economic, technological in nature, ecological, and regulatory variables. In an effort to investigate novel hybrid approaches, the research additionally addresses Pro-Con lists and popular heuristic methods for optimization .Demand response (DR), which is promising and economical for boosting smart grids and exploiting resources that are flexible, may be used to alleviate over- and under-voltage problems in low-voltage distribution networks with significant PV and EV generation. The work introduced in [8] presents a hierarchical control structure for a number of sub-CEMSs and an integrated community energy management system (CEMS) in order to employ FR-based two-stage strategies for voltage regulation. The models reduce voltage violations, customer power prices, and on-load tap changer tap operations. They have been demonstrated in an actual distribution network in Japan.Global solar energy production has increased, making photovoltaic penetration a noteworthy renewable energy source. But for a smooth integration into the power system, it poses problems including harmonics, voltage fluctuation, voltage increase, and voltage balancing. The work in [9] provides important insights on PV penetration for academics and utility designers by examining islands concerns, remote and local approaches, and their benefits and drawbacks. By examining the shortcomings of conventional reactive power compensation techniques in PV imbalance scenarios, the research in [10-13] hopes to further access the integration of green and renewable solar energy resources into power networks by highlighting the necessity for an electrical sensitivity look at to thoroughly analyse these problems. To address the issues with controlling voltage caused on by Solar imbalance, a novel combination centralized-decentralized approach is created [14]. By scheduling the inverter's reactive power response to fluctuations in PV power adaptively, it prevents inter-phase Voltage-Reactive Power interaction. validated using Australian low-voltage distribution systems that are in operation and time-series models .By incorporating additional solar power plants into distribution networks and ensuring voltage regulation within permitted bounds, the suggested approach helps to reduce carbon dioxide emissions in the future [15].

3 Applications of Green Energy in Power Generation

With an emphasis on the increasing use of green energy sources and generation uncertainty in power systems, [16] examines the historical evolution of power system adaptability as well as its features, sources, and assessment criteria. Climate change, green energy applications, and environmentally friendly energy systems are responsible for the sharp increase in renewable energy resources and the sharp decrease in fossil fuels [17-20]. Nuclear fusion and synthetic photosynthesis are two important objectives for batteries to store energy as they aid in the switch to renewable energy sources [21].As they absorb light and convert it into chemical energy, plants help us shift from using fossil fuels to alternative power sources. For locations with temperatures below freezing, thermal solar devices and systems for storing heat and energy are also practical options [22].It could be done to have a 100% sustainable grid in a number of nations, including Canada, Iceland, Norway, Coats Rice, Uruguay, and Brazil. Although they are an inexpensive, clean power source, hydro power plants are constrained by topography and variations in precipitation in the surrounding environment [23].Globally, significant hydro power sites have been established; but, in order to attain 100% renewable grids, less expensive variable renewable energy (RE) sources such as windmills and solar power systems are needed [24].Significant rooftop photovoltaic generation, sometimes with 40-year design lives, was deployed in electricity distribution networks within the last five years. Power electronic options for controlling voltage profiles in networks with significant solar power installation are the main topic covered in [25]. Using a focus on topological options and converter selection, this study investigates converter options, including finish converters with significant storage of energy at a DC bus, reduced store scenarios, or storage-free gadgets such grid converters .Distribution networks should be modified to minimize outages, pursuant to the best contingency assessment approach, which also incorporates wind power generation and an ordinary storage of energy system [26-30].

4 Proposed Methodology

Operational losses are higher in low-voltage (LV) distribution systems (DS) because they employ several loads from an enormous power transformer, prolonged low tension lines, and a total of four wires. In LVDS, high current leads to substantial losses [31]. Heat dispersion, magnetizing losses, losses-based on resistivity and energy-metering device losses are examples of technical losses. In a software named SIMULINK, part of MATLAB, applications, LVDS and high-voltage (HVDS) are implemented, and comparative evaluation is carried out at loading locations [32].

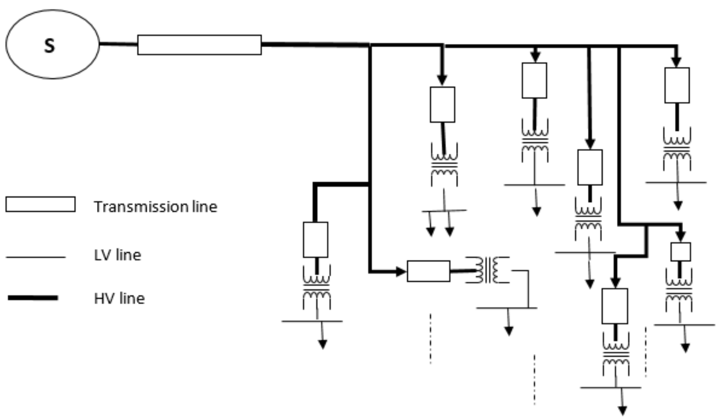

Fig. 1: Modelling of HVDS system on software

A MATLAB simulation of a HVDS with relatively-small electrical transformers rated at 65 KVA is shown in Fig. 1. After reaching the loading sites, the high tension lines drop down to the requisite 230-Volt phase to ground voltages for load effectiveness. To lower distribution losses, enhance supply performance, and minimize tampering with electricity, HVDS are used [33-37].

HVDS uses insulation based aerial bunched cables (ABC) instead of lower-tension (LT) wires to minimize energy tampering issue and illegal-wiring based connections. This increases authorized connections, decreases errors, while also rendering direct tapping more difficult, all of which increase dependability. In order to distribute electricity near to load locations, the system redefines pre-existing LV-networks into HVDS, each individual feeder splitting into an independent one. Durability along with quality concerns are also taken into consideration while integrating energy from green sources [38].

5 Result and Discussion

The scope of investigating of how loading reflects on electrical power networks has increased. In this case, hybrid green energy systems supply additional power to the network [39]. In this case, the transformed function of the phase voltage is computed in order to assess the power waveform and ascertain the degree of distortion. Long before mass transformers were used in LVDS, research was conducted on the power transmission bus. The buses prior to the micro converters in the case of a HVDS were selected for analysis.

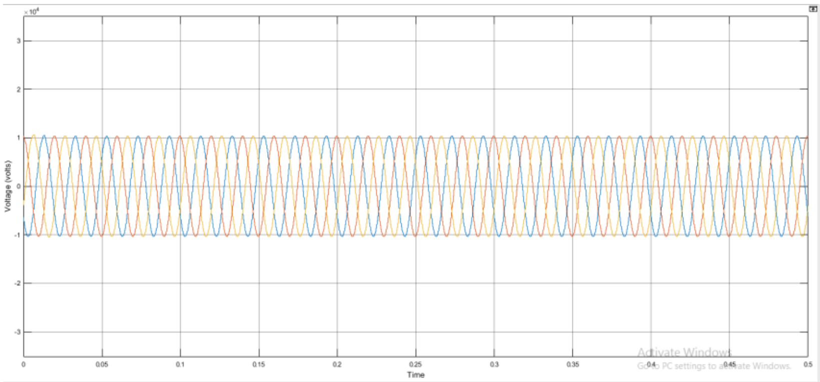

Fig. 2: Voltage at transmission line for HVDS with the green energy

According to Fig.2, integrating green energy into an 11kV HVDS involves the use of inverters to transform the renewable energy source's output to match the 11kV AC required for the distribution network [40]. This allows for the direct supply of green energy to the grid, reducing transmission losses and supporting distributed generation.

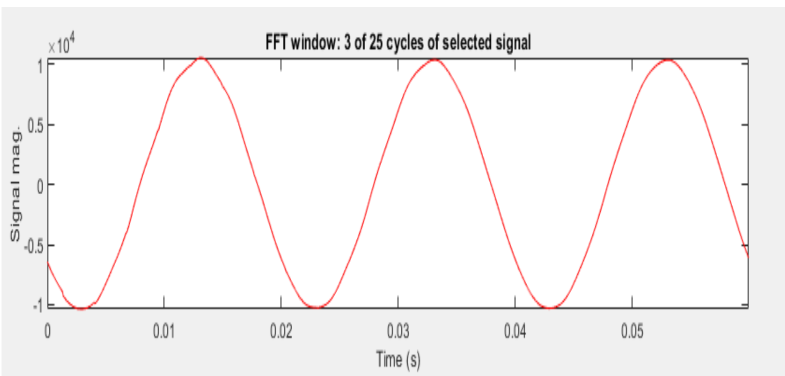

Fig. 3: Voltage at transmission line by FFT transform for HVDS using green energy

Fig. 3 will help in identifying the harmonic content added by way of inverters used for connecting green energy resources to the AC grid, and making sure that the voltage remains in the desired quality standards, by detecting and mitigating any deviations from the essential 50/60 Hz frequency, depending on the local grid standard.

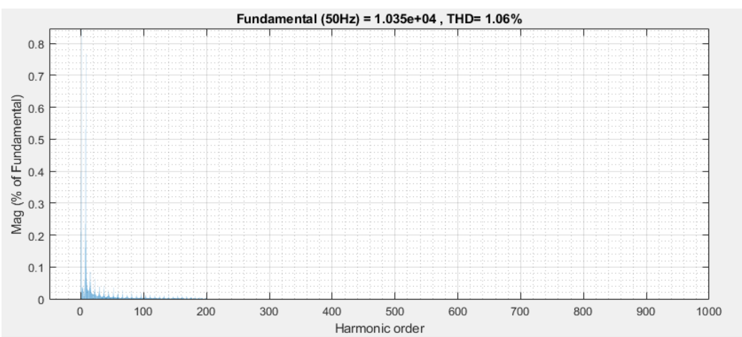

Fig. 4: The harmonic distortion in voltage of transmission line for HVDS with the green energy.

Inverters and converters, which are critical for integrating renewable energy sources into the grid, Fig.5 can introduce harmonic currents that distort the voltage waveform. Acceptable THD levels for distribution systems are typically below 5% as per IEEE standards, ensuring efficient operation and minimizing adverse effects on both the grid and connected equipment.

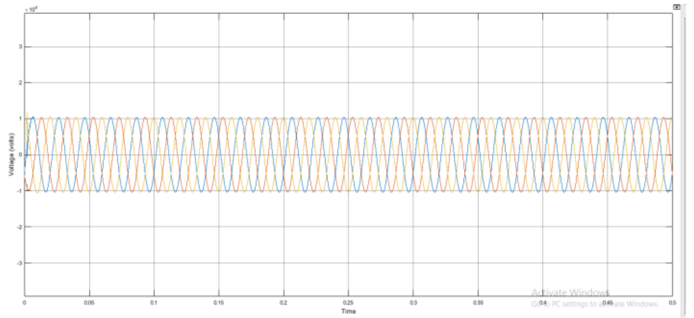

Fig. 5: Voltage at transmission line for LVDS with the green energy resources

According to Fig. 5, when incorporating green energy resources into an LVDS, the voltage from renewable sources would be stepped down using transformers to match the lower distribution voltage levels suitable for local distribution usually 240V to 480V in many countries for residential and light commercial use.

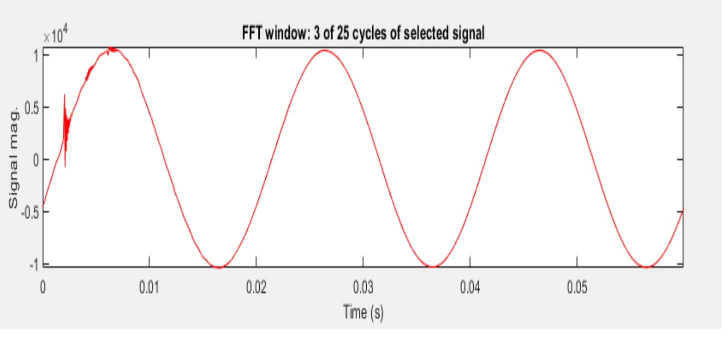

Fig. 6: Voltage at transmission line by FFT transform for LVDS using green energy

Power quality may be monitored with the use of an FFT analysis of an 11kV transmission line for a LVDS employing renewable energy sources. Fig. 6 determines the voltage's frequency components, including its harmonic content, which is essential for controlling harmonics and fluctuating voltages in renewable energy sources like wind and solar power.

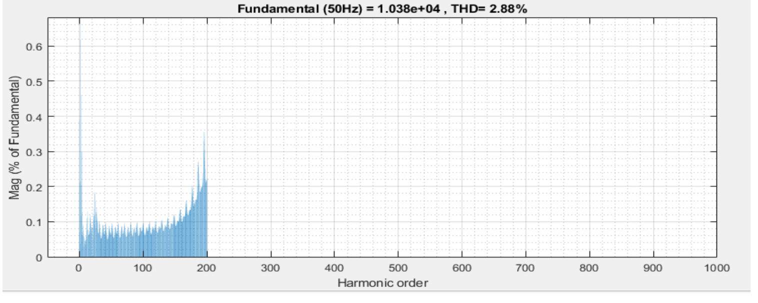

Fig. 7: The harmonic distortion for LVDS using green energy sources

HVDS are more efficient than the transmission and distribution systems, according to study, even in this situation whenever the networks are made up of different green energy resources. The total harmonic distortion of system reflects both the voltage being applied and the loads. The HV system's distortion in the voltage waveform was found to be 1.08 percent less than the LV system's 2.78 percent distortion.

Table 1: Comparative analysis of LVDS and HVDS systems in terms of improvement

Research factors for the comparative evaluation	Factors at LVDS	Factors at the HVDS	Identifying the Improvement
Total harmonic distortion of voltage at the load line	3.54 %	1.89%	Decreased by 1.64
Highest Value of voltage recuperated	215.7 V	218.4 V	2.7 V retrieved
Total harmonic distortion of current at the load line	3.74 %	1.69%	Reduced by 1.63
Magnitude of current available at the terminal	2.615 A	2.75 A	Minimized current loss
Active Power presented (Watts)	625 W	645.3 W	2.2 % upsurge in power
Reactive Power	0 Var	0 Var	-
Impact of loading on 11KV line in terms of THD% in voltage	2.78%	1.08%	Decreased by 1.79

The waveforms of currents and voltages were found to become less distorted when generating electricity to a great extent employing a HVDS for specific dimensions of time. However, when employing a bulk transmitter and then continuing to drive loads at one particular location, the waveforms became more distorted but certain failures occurred as the spacing here between transmitter and the supply elevated. The distortions were made worse by a number of green power loading factors. The final obtained values are listed in Table 1. Whenever the HV line is virtually extended to the maximum load of the customer, line losses are decreased.

6 Conclusion

The integration of green energy resources into distribution networks presents both challenges and opportunities. Our study's comparative analysis reveals that HVDS configurations, with their smaller transformers and aerial bunched cables, offer substantial advantages over LVDS in terms of efficiency and reliability when connected to renewable sources. The FFT analyses confirm that appropriate inverter technologies can effectively manage harmonic distortions, maintaining power quality within IEEE standards. The innovative voltage regulation strategies proposed not only enhance the stability and sustainability of the power grid but also pave the way for a more extensive adoption of renewable energy. In conclusion, this research contributes a robust framework for the integration of RER into the power grid, promoting a sustainable energy transition with significant technical, environmental, and economic benefits.

References

1. Yogananda, H. S., Basavaraj, R. B., Darshan, G. P., Prasad, B. D., Naik, R., Sharma, S. C., & Nagabhushana, H. (2018). New design of highly sensitive and selective MoO3:

Eu3+ micro-rods: Probing of latent fingerprints visualization and anti-counterfeiting applications. Journal of colloid and interface science, 528, 443-456.
2. Xie, Qiangqiang, Hongxun Hui, Yi Ding, Chengjin Ye, Zhenzhi Lin, Peng Wang, Yonghua Song, Ling Ji, and Rong Chen. "Use of demand response for voltage regulation in power distribution systems with flexible resources." IET Generation, Transmission & Distribution 14, no. 5 (2020): 883-892.
3. Wang, Licheng, Ruifeng Yan, and Tapan Kumar Saha. "Voltage regulation challenges with unbalanced PV integration in low voltage distribution systems and the corresponding solution." Applied Energy 256 (2019): 113927.
4. Vijayakumar, Y., Nagaraju, P., Yaragani, V., Parne, S. R., Awwad, N. S., & Reddy, M. R. (2020). Nanostructured Al and Fe co-doped ZnO thin films for enhanced ammonia detection. Physica B: Condensed Matter, 581, 411976.
5. Vandana, C. P., & Chikkamannur, A. A. (2021). Feature selection: An empirical study. International Journal of Engineering Trends and Technology, 69(2), 165-170.
6. Telukunta, Vishnuvardhan, Janmejaya Pradhan, Anubha Agrawal, Manohar Singh, and SankighattaGarudacharSrivani. "Protection challenges under bulk penetration of renewable energy resources in power systems: A review." CSEE journal of power and energy systems 3, no. 4 (2017): 365-379.
7. Telagam, N., Kandasamy, N., & Nanjundan, M. (2017). Smart sensor network based high quality air pollution monitoring system using labview. International Journal of Online Engineering (iJOE), 13(08), 79-87.
8. Parashuram, L., Sreenivasa, S., Akshatha, S., & Udayakumar, V. (2019). A non-enzymatic electrochemical sensor based on ZrO2: Cu (I) nanosphere modified carbon paste electrode for electro-catalytic oxidative detection of glucose in raw Citrus aurantium var. sinensis. Food chemistry, 300, 125178.
9. Awasthi, A., Saxena, K. K., & Dwivedi, R. K. (2021). An investigation on classification and characterization of bio materials and additive manufacturing techniques for bioimplants. Materials Today: Proceedings, 44, 2061-2068.
10. Suganthi, S. T., Vinayagam, A., Veerasamy, V., Deepa, A., Abouhawwash, M., & Thirumeni, M. (2021). Detection and classification of multiple power quality disturbances in Microgrid network using probabilistic based intelligent classifier. Sustainable Energy Technologies and Assessments, 47, 101470.
11. Sridhara, V., Gowrishankar, B. S., Snehalatha, & Satapathy, L. N. (2009). Nanofluids—a new promising fluid for cooling. Transactions of the Indian Ceramic Society, 68(1), 1-17.
12. Sinsel, Simon R., Rhea L. Riemke, and Volker H. Hoffmann. "Challenges and solution technologies for the integration of variable renewable energy sources—a review." renewable energy 145 (2020): 2271-2285.
13. Ramu, G. (2018). A secure cloud framework to share EHRs using modified CP-ABE and the attribute bloom filter. Education and Information Technologies, 23(5), 2213-2233.
14. Ram, J. P., Pillai, D. S., Ghias, A. M., & Rajasekar, N. (2020). Performance enhancement of solar PV systems applying P&O assisted Flower Pollination Algorithm (FPA). Solar Energy, 199, 214-229.
15. Raghu, M. S., Kumar, C. P., Prashanth, M. K., Kumar, K. Y., Prathibha, B. S., Kanthimathi, G., ... & Osman, S. M. (2021). Novel 1, 3, 5-triazine-based pyrazole derivatives as potential antitumor agents and EFGR kinase inhibitors: Synthesis, cytotoxicity, DNA binding, molecular docking and DFT studies. New Journal of Chemistry, 45(31), 13909-13924.
16. Awasthi, A., Saxena, K. K., Dwivedi, R. K., Buddhi, D., & Mohammed, K. A. (2023). Design and analysis of ECAP Processing for Al6061 Alloy: a microstructure and

mechanical property study. International Journal on Interactive Design and Manufacturing (IJIDeM), 17(5), 2309-2321.
17. Prakash, S., Somiya, G., Elavarasan, N., Subashini, K., Kanaga, S., Dhandapani, R., ... & Sujatha, V. (2021). Synthesis and characterization of novel bioactive azo compounds fused with benzothiazole and their versatile biological applications. Journal of Molecular Structure, 1224, 129016.
18. Cheruvu, A., Radhakrishna, V., & Rajasekhar, N. (2017, May). Using normal distribution to retrieve temporal associations by Euclidean distance. In 2017 International Conference on Engineering & MIS (ICEMIS) (pp. 1-3). IEEE.
19. Awasthi, A., Saxena, K. K., & Arun, V. (2020). Sustainability and survivability in manufacturing sector. In Modern Manufacturing Processes (pp. 205-219). Woodhead Publishing.
20. Padmaja, B., Prasad, V. R., & Sunitha, K. V. N. (2018). A machine learning approach for stress detection using a wireless physical activity tracker. International Journal of Machine Learning and Computing, 8(1), 33-38.
21. Malagavelli, V., Angadi, S., Prasad, J. S. R., & Joshi, S. (2018). Influence of metakaolin in concrete as partial replacement of cement. Int J Civil Eng Technol, 9(7), 105-111.
22. Mahmud, Nasif, and A. Zahedi. "Review of control strategies for voltage regulation of the smart distribution network with high penetration of renewable distributed generation." Renewable and Sustainable Energy Reviews 64 (2016): 582-595.
23. Liang, Xiaodong. "Emerging power quality challenges due to integration of renewable energy sources." IEEE Transactions on Industry Applications 53, no. 2 (2016): 855-866.
24. Kumar, K. Y., Saini, H., Pandiarajan, D., Prashanth, M. K., Parashuram, L., & Raghu, M. S. (2020). Controllable synthesis of TiO2 chemically bonded graphene for photocatalytic hydrogen evolution and dye degradation. Catalysis Today, 340, 170-177.
25. Kumar, K. U., Babu, P., Basavapoornima, C., Praveena, R., Rani, D. S., & Jayasankar, C. K. (2022). Spectroscopic properties of Nd3+-doped boro-bismuth glasses for laser applications. Physica B: Condensed Matter, 646, 414327.
26. Awasthi, A., Saxena, K. K., & Arun, V. (2021). Sustainable and smart metal forming manufacturing process. Materials Today: Proceedings, 44, 2069-2079.
27. Kroposki, Benjamin, Brian Johnson, Yingchen Zhang, VahanGevorgian, Paul Denholm, Bri-Mathias Hodge, and Bryan Hannegan. "Achieving a 100% renewable grid: Operating electric power systems with extremely high levels of variable renewable energy." IEEE Power and energy magazine 15, no. 2 (2017): 61-73
28. Karimi, Mazaher, H. Mokhlis, Kanedra Naidu, Sohel Uddin, and AH Abu Bakar. "Photovoltaic penetration issues and impacts in distribution network–A review." Renewable and Sustainable Energy Reviews 53 (2016): 594-605.
29. Ali, MdSawkat, MdMejbaulHaque, and Peter Wolfs. "A review of topological ordering based voltage rise mitigation methods for LV distribution networks with high levels of photovoltaic penetration." Renewable and Sustainable Energy Reviews 103 (2019): 463-476.
30. Adefarati, Temitope, and Ramesh C. Bansal. "Integration of renewable distributed generators into the distribution system: a review." IET Renewable Power Generation 10, no. 7 (2016): 873-884.
31. Abdmouleh, Zeineb, Adel Gastli, Lazhar Ben-Brahim, Mohamed Haouari, and Nasser Ahmed Al-Emadi. "Review of optimization techniques applied for the integration of distributed generation from renewable energy sources." Renewable Energy 113 (2017): 266-280.
32. Kalyani, G., Janakiramaiah, B., Karuna, A., & Prasad, L. N. (2023). Diabetic retinopathy detection and classification using capsule networks. Complex & Intelligent Systems, 9(3), 2651-2664.

33. Kalair, Anam, Naeem Abas, Muhammad ShoaibSaleem, Ali Raza Kalair, and Nasrullah Khan. "Role of energy storage systems in energy transition from fossil fuels to renewables." Energy Storage 3, no. 1 (2021): e135.
34. Jayabal, R., Subramani, S., Dillikannan, D., Devarajan, Y., Thangavelu, L., Nedunchezhiyan, M., ... & De Poures, M. V. (2022). Multi-objective optimization of performance and emission characteristics of a CRDI diesel engine fueled with sapota methyl ester/diesel blends. Energy, 250, 123709.
35. Impram, Semich, SecilVarbakNese, and Bülent Oral. "Challenges of renewable energy penetration on power system flexibility: A survey." Energy Strategy Reviews 31 (2020): 100539.
36. Ehsan, Ali, and Qiang Yang. "Optimal integration and planning of renewable distributed generation in the power distribution networks: A review of analytical techniques." Applied Energy 210 (2018): 44-59.
37. de Quevedo, PilarMeneses, Javier Contreras, Marcos J. Rider, and JavadAllahdadian. "Contingency assessment and network reconfiguration in distribution grids including wind power and energy storage." IEEE Transactions on Sustainable Energy 6, no. 4 (2015): 1524-1533.
38. Chaudhury, S., Krishna, A. N., Gupta, S., Sankaran, K. S., Khan, S., Sau, K., ... & Sammy, F. (2022). Effective image processing and segmentation-based machine learning techniques for diagnosis of breast cancer. Computational and Mathematical Methods in Medicine, 2022.
39. Bhukya, L., Kedika, N. R., & Salkuti, S. R. (2022). Enhanced maximum power point techniques for solar photovoltaic system under uniform insolation and partial shading conditions: a review. Algorithms, 15(10), 365.