A review on techniques for improving power quality: research gaps and emerging trends

Vasupalli Manoj[1], Prabodh Khampariya[2], Ramana Pilla[3]
[1]Department of Electrical Engineering, Sri Satya Sai University of Technology and Medical Sciences, Sehore, India
[2]Department of EEE, Sri Satya Sai University of Technology and Medical Sciences, Sehore, India
[3]Department of EEE, GMR Institute of Technology, Rajam, India

Article Info

Article history:

Received Jul 11, 2022
Revised Aug 15, 2022
Accepted Aug 25, 2022

Keywords:

Custom power device
Distributed generation
Hybrid filter
Power converters
Power quality
Power system
Total harmonic distortion

ABSTRACT

Many issues have arisen for the electricity sector because of the widespread use of gadgets that rely on electrical power. India's energy demands are rising rapidly due to the country's rapid economic development. These days, almost every industry makes extensive use of electrical machinery and equipment. Electronic gadgets add a non-linear demand to the power grid, which can cause power quality (PQ) problems such as voltage fluctuations that can damage electrical equipment and even knock the grid down. As the use of DG units becomes more commonplace, complications related to power conversion interfaces, load switching, and other factors emerge as potential bottlenecks in service. Power filters were first created several decades ago to address problems with PQ and to dampen harmonics caused by nonlinear loads. This document summarises previous studies that have investigated the effectiveness of power filters and other techniques for enhancing power quality. There are also descriptions of research that is still going on and where it stands, as well as a look ahead to what its possible future benefits might be.

Corresponding Author:

Vasupalli Manoj
Research Scholar, Department of Electrical Engineering
Sri Satya Sai University of Technology and Medical Sciences Sehore
466001, India
Email: manojv287@gmail.com

1. INTRODUCTION

Power quality (PQ) has emerged as a key issue in the power system in response to the increasing demand for electricity in modern society. Adjustable speed drives (ASD), energy-efficient lighting systems, and programmable logic controllers are examples of power electronics products that are increasingly in use and are blamed for degrading power quality [1]-[5]. Power quality is enhanced in several ways: dynamic voltage stability, decrease of harmonics distortion, lessening of used reactive power and an increase in power factor [6]-[13]. There are voltage waveform disturbances being generated because of the non-linearity of all these loads. Current harmonics are reduced by the filter and their efficiency is measured under both balanced & unbalanced nonlinear loads [14]-[20]. Technological progress, along with globalisation of the corporate sector, has led to a decline in the profitability of many business operations. Power quality concerns are becoming a major factor for acceptability in each activity area due to the increasing sensitivity of the processes engaged in in businesses, residences, and services. Industries and IT services that rely on continuous processes are particularly vulnerable to poor power quality [21]-[24]. In recent years, many solutions have been proposed to address power quality issues. Power conditioning systems, power filters, and other tools are used to improve the quality of the electricity [25]-[28].

The need for electricity in modern, always-on society is growing exponentially. Electricity is essential for everything, from meeting basic human needs to powering complex manufacturing processes. The current power system has its greatest challenge in meeting the need for both massive and constant electricity. Power quality enhancement can be done using APF, superposed control strategies, UV-PI and PR-R controller, DSTATCOM along with variable DC link, particle swarm optimization (PSO) assisted Kalman filter and hysteresis current control [29]-[35]. Distributed generation (also known as dispersed generation, decentralised generation, and embedded generation) is introduced and connected to the power grid to provide uninterrupted electricity to users. A procedure known as distribution generation must take place to generate energy at the consumer end, which may be coupled to the distribution grids. When properly integrated, the power from these decentralised sources may be supplied into the larger grid [36]-[38]. Grid operators face several challenges because of incorporating DGs into the existing power infrastructure. Negative impacts on power quality on the main grid can be attributed to several factors, including the incorporation of DGs, fluctuations in load, rapid changes in load, and electronic devices. Distributed generation (DG) penetration into the grid system is primarily motivated by the desire to meet peak load and customer demand. However, the client chooses the DGs' penetration point, which may not be optimal. As a result, it degrades power, safety, and power quality across the distribution network [39]-[45]. Voltage, frequency, and current that are not within the tolerances specified by IEEE standard 929-2000 are examples of power quality problems. Power quality enhancement can also be done using PSO, hybrid power filters, FPSO and voltage control technique [46]-[50]. About 22% of India's generated power is lost in transmission and distribution. As a result, many scholars, academics, and businesspeople have focused on these issues over the last fifteen years [51]-[57]. As part of the collected work done on the topic, this study provides a taxonomy of power performance improvement approaches and control tactics for distribution systems with and without DGs. Researchers interested in enhancing power quality might use this review of the relevant literature as a resource. The study came up with several ideas and approaches for the best control. It did this by putting together the work of the evaluated works done so far to advance the state of the art in power quality improvement (PQI). The purpose of this work is to conduct a literature review to ascertain the present status in the field of power systems that address power quality challenges.

2. METHOD REASONS FOR DEGRADATION IN POWER QUALITY

As we've seen, the non-linear load introduced into the power source by electronics and drives can cause problems with power quality, which in turn can cause electrical devices used by end users to malfunction, fail, or simply stop working. Therefore, power quality degradation impacts sensitive equipment for a variety of reasons. The few causes of poor power quality are as follows (as shown in Figure 1). The various reasons for degradation in power quality are depicted in Table 1 (in appendix).

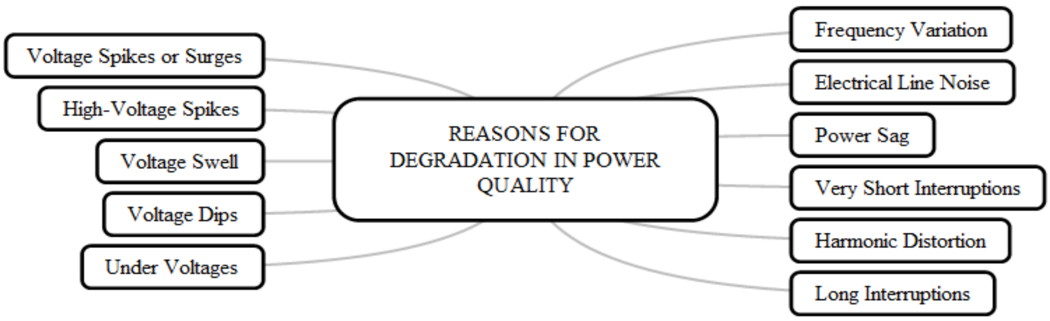


Figure 1. Causes of poor power quality

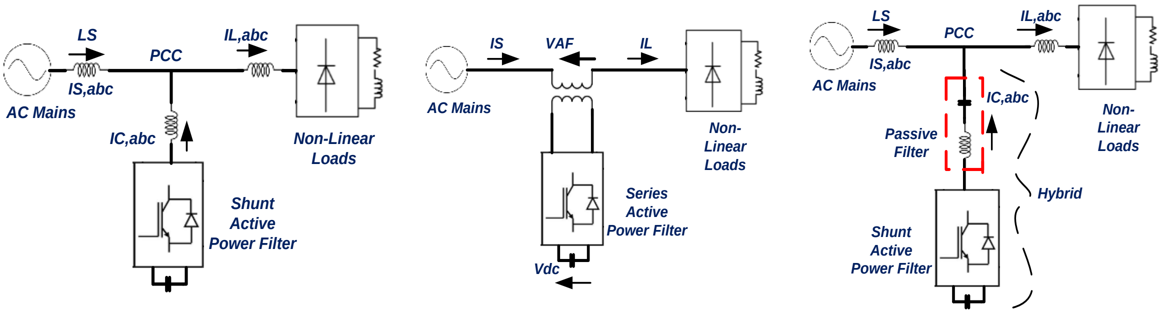
3. SOLUTIONS TO POWER QUALITY PROBLEMS

Power quality problems can be solved by utilising distributed generation and energy storage technologies. Isolating the power disturbances can be aided by using the correct interface devices. Power conditioners, such as surge suppressors, power filters, and so on, are explored in more detail below. After a decade of study, scientists have developed a wide variety of PQ enhancement devices that are crucial in addressing the issues [17], [21], [29], [33]. The solutions to power quality problems are listed in Table 2.

Classification of power filters such as shunt active power filter (APF), series APF, and hybrid filter are illustrated in Figures 2(a) to (c).

Table 2. Solutions to power quality problems

Power quality issue	Remarks
Surge suppressors	Surge suppressors for electric current are the cheapest and least complicated way to improve power quality. Transient voltage can be restrained by the suppression before it affects the load or equipment, which is why these devices are typically used to integrate with a power supply and other sensitive loads. Non-linear resistance in a transient voltage suppressor controls the surge and grounds the system.
Filters	Power quality is enhanced by using the filter, which is one of them. Filters for noise and harmonics are crucial in helping to eliminate interference from undesired currents and voltages of different frequencies. The noise filter has a low impedance channel between frequencies thanks to its integrated circuit comprising a capacitor and an inductor, which prevents the undesired signal from reaching the equipment.



(a) (b) (c)

Figure 2. Classification of power filters, (a) shunt APF, (b) series APF, and (c) hybrid filter

4. EXISTING RESEARCH METHODOLOGIES FOR POWER QUALITY IMPROVEMENT

Recently developed and introduced methods for improving power quality are highlighted. Recent journal papers are considered from IEEE publications to complete the review. Hybrid power filters (HPF) are being used in novel ways to solve the problem of poor power quality (PQ). Table 3 (in appendix) provides a summary of the methods employed and a review of the literature on power quality concerns.

5. RESEARCH GAP

After looking at the research that has been done and is being done in the field of improving power quality and reducing harmonics, several research gaps have been found.

- Lack of adequate approaches: existing research in a variety of fields has been shown to be somewhat ineffective when subjected to nonlinear, dynamically fluctuating loads.
- Insufficient use of methods based on fuzzy logic: the majority of the already published research is concerned with more conventional approaches, such as PI controllers. According to the survey findings, the use of fuzzy logic in the development of works is quite uncommon.
- Insufficient use of neuro-fuzzy methods: a lot of focus in recent research has been placed on either fuzzy or neural network techniques. Recent studies have shown less interest in neuro-fuzzy methods.
- More APF-based strategies: the focus of modern research has been on APFs, not hybrid power filters.
- Total harmonic distortion (THD) minimization is the subject of almost no research.
- Hardware implementation using FPGA and the neuro-fuzzy logic approach is quite unusual.

6. THE STATE OF THE ART IN THE RELATED AREA OF RESEARCH

An in-depth analysis of the latest advances in power quality improvement and harmonics reduction is conducted using metadata from IEEE Xplore publications between 2010 and the present. The results of an investigation using the keywords "power quality + harmonics" and "power quality + active power filter" are presented in Table 4. Figure 3 provides a graphical depiction of the computed research status, which may be seen in Table 4 as an abundance of journals, conferences, early access articles, standards, books, magazines, and courses. devoted to IEEE-published research. The current state of the art in the area of power quality is outlined in Table 4.

Table 4. Current state of the art in the research domain

Type of publications	Power quality (harmonics)	Power quality (APF)
Journals	2056	518
Conferences	10468	2560
Early access articles	93	29
Standards	56	03
Books	20	05
Magazines	19	04
Courses	01	--

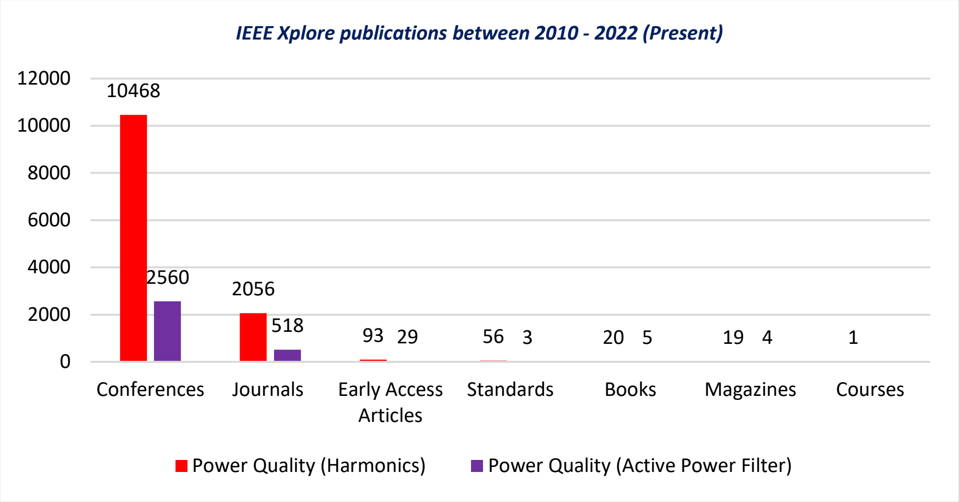


Figure 3. Histogram of current research status

7. CONCLUSION AND FUTURE WORK/SCOPE

The current global power supply is inadequate and cannot keep up with the ever-increasing demand for electricity. Furthermore, complexity at the load end is becoming more of an issue as electronic gadgets become increasingly commonplace. The poor quality of the electricity also causes power equipment to malfunction or the power system to fail. It is crucial for customers to take preventative measures to overcome these issues and avoid financial losses due to PQ issues. This paper presents several contributors to power quality deterioration, as well as recent studies aimed at improving power quality, the research gaps revealed by this analysis, and the existing state of the art in this research domain, which includes many issues that have yet to be adequately addressed. In addition, this review paper might be used as a springboard for further study in the future: i) applying analytic techniques to the design of a hybrid power filter, ii) a neuro-fuzzy based controller has been designed for a hybrid power filter to improve power quality, lower THD, and suppress harmonics, iii) a FPGA with the neuro-fuzzy logic method may be used to develop a prototype of hardware.

APPENDIX

Table 1. Reasons for degradation in power quality

Power quality issue	Remarks
Voltage spikes or surges	Non-linear loads can cause a spike in demand that lasts for a short period of time (known as a surge) Huge power equipment may be shut off if the voltage suddenly rises over the standard. Surge suppressors, voltage regulators, and power conditioners can be used to mitigate the damaging effects of such spikes and surges.
Voltage swell	Voltage swell is a phenomenon when voltage increases rapidly, beyond the typical range in a matter of seconds. Due to inefficient management, this increase in demand has resulted in a few related problems. It's possible that the system will malfunction, resulting in broken sensors, and lost data.
Voltage dips	Voltage sags and dips describe temporary periods of low voltage. Consumers may notice annoying things like lights that flicker or loads that trip. Voltage sags occur when the supply voltage drops and then quickly recovers. These drops originate from the beginning of large loads and the provision of inductive loads.
Under voltages	Undervoltage is an electrical problem where equipment needs to draw more current to keep the output voltage constant. Problems with overloading are caused by low voltage, which is caused by loads with low power factors. This can be caused by improper tapping of transformers and a faulty voltage regulator.

Table 1. Reasons for degradation in power quality (continue)

Power quality issue	Remarks
High-voltage spikes	Surge suppressors, voltage regulators, and power conditioners may all be used to dampen down these spikes. It's possible that the fault in the electrical system may cause data loss and malfunction.
Harmonic distortion	Welding equipment, DC brush motors and other high-intensity loads are major contributors to harmonic distortion. Increased distortion results from the usage of nonlinear load producing devices, such as electronic equipment. This might lead to cable overheating, performance degradation, erroneous metre reading, and other undesirable outcomes.
Frequency variation	Frequencies vary from 50 Hz–60 Hz in different parts of the world. Devices like surge suppressors, voltage regulators, power conditioners, and so on can mitigate this. Frequency drift is the result of incorrect frequency sources or the unexpected behaviour of generators.
Electrical line noise	Electromagnetic interference (EMI) and radio frequency interference (RFI) are to the circuits of electronic devices what static electricity is to electrical wiring. EMI and RFI can be tamed with surge suppressors, voltage regulators, power conditioners, and other similar tools.
Power sag	System failures are the most common cause of sages, which can trigger load switching that requires substantial starting currents. Surge suppressors, voltage regulators, power conditioners, and other similar tools are all good ways to stop this kind of power change in a PQ.
Very short interruptions	The opening and shutting of protective devices during the decommissioning of a malfunctioning network causes brief interruptions that, on the great scale of things, can be deemed negligible. Since this happened, we've had insulation problems, lightning strikes, and so on. This disruption might cause problems with the protection system, and data integrity.
Long interruptions	Disruptions that last longer than two seconds fall under this category. Power outages can occur for a variety of reasons, including mechanical failure, the contact of foreign items with electrical wiring, human error, and many others.

Table 3. Summary of existing research

Reference	Considered issue	Technique used	Outcomes
[1]	Power quality	DVR	The suggested DVR-based control technique effectively compensated for the distorted load voltage & kept the voltage profile smooth and constant with little harmonic content.
[2]	Power quality	APF	Better PQ
[3]	Voltage profile + power losses	Distribution generation units	Reduction in voltage deviation and faults
[4]	Power quality	RL algorithm	The current-base controller sends signals through the q-axis and zero-axis of VSC current controllers to compensate for uneven DR load current, while the voltage controller monitors PCC voltage magnitude and DSTATCOM's reactive power setting point.
[5]	Power quality	Fuzzy logic	After compensating for the non-linearity of the load, the source current is sinusoidal, and the DC link voltage is stable, as demonstrated by the steady-state response of the suggested filter.
[6]	Harmonics	Fuzzy based vector PI controller	Comparing the results of the three schemes presented in this paper—one without a filter, one with a hybrid power filter, and one with a fuzzy interface.
[7]	Power quality	Solar-DSTATCOM	Overvoltage, VU, Dip, swell, and harmonics were all identified as being negatively impacted by PV units.
[8]	Power quality	DVR	Load voltage remained stable at its nominal value.
[9]	Power quality	D-FACTS	Dynamic voltage stability
[10]	Power quality	FACTS technologies	This study provides a complete review of FACTS/D-FACTS technology as well as its implementation in new electric utilities that integrate RESs using power electronic converters.
[11]	Power quality	Fault current limiter (FCL) and a dynamic voltage restorer (DVR)	The FCL is able to keep the DG-short-circuit grid's magnitude at a safe level. When it comes to supplemental compensation, the proposed DVR is a cost-effective compensator.
[12]	Power quality	Dual voltage source inverter	The suggested approach can correct for local imbalanced and nonlinear load in addition to exchanging power between DGs.
[13]	Power quality	custom power devices such as D-STATCOM, UPQC, UPS, TVSS, and DVR.	Issues with DC power quality are the primary topic of this study, along with related standards, potential solutions, and a brief history of the subject.
[14]	Power quality	PI controlled SAPF	Harmonic reduction in balanced & unbalanced nonlinear loads.
[15]	Power quality	Hysteresis current control technique	Adaptive reduction of higher cognitive harmonics and suppression of dominant harmonics make HAPF one of the most effective methods for delivering clean electricity to end users.
[16]	Power quality	Power electronic generation	Better power quality
[17]	Power quality	Unified power quality conditioner	Enhanced power quality

Table 3. Summary of existing research (continue)

Reference	Considered issue	Technique used	Outcomes
[18]	THD	Battery energy storage system (BESS)	Better THD
[19]	Power quality	Fuzzy controller	Better PQ
[20]	Harmonics and power quality	ANFIS based STATCOM	Reduced harmonics and better PQ
[21]	Power quality	SAPF	Enhanced power quality
[22]	Power quality	Transformer integrated filtering system	Improved power quality
[23]	Power quality	Power factor corrections	Better PQ
[24]	Power quality	Grid integrated renewable distributed generation	Improved power quality
[25]	Voltage disturbances	Control method of grid-connected PWM voltage source inverters	Reduction in voltage disturbances
[26]	Power quality	DVR	Better power quality
[27]	Power quality	Evolutionary computing techniques	Enhanced power quality
[28]	Power quality	Optimized direct control method	Better PQ
[29]	Power quality	APF	Improved power quality
[30]	Power quality	Superposed control strategies	Enhanced power quality
[31]	Power quality	uv-pi and pr-r controller	Improvement in PQ
[32]	Power quality	icosΘ control algorithm	Refined power quality
[33]	Power quality	DSTATCOM along with variable DC link voltage control	Improved power quality
[34]	Power quality	PSO assisted kalman filter - based SAPF	Enhanced power quality
[35]	Voltage regulation	Power theory hysteresis current control scheme	Improved voltage regulation
[36]	Load growth	WIPSO-GSA algorithm	Optimal DG installation problem was solved
[37]	Power quality	SAF	Harmonics are eliminated
[38]	Power quality	Fuzzy controller	Enhanced power quality
[39]	Power quality	Centralized energy management approach	Improved power quality
[40]	Power quality	ANFIS-UPQC	Enhanced power quality profile
[41]	Wind farm power quality	ANN-controlled hybrid filter	Improved power quality
[42]	Power quality	Switched filter compensator	Enhanced power quality
[43]	Power quality	PMSM based adjustable speed drive (ASD) load	Enhanced power quality
[44]	Power quality	UPQC	Enhanced power quality
[45]	Power quality	Adaptive noise reduction control	Enhanced power quality
[46]	Capacitor placement and power quality	PSO	Optimized capacitor placement and improved power quality
[47]	Power quality	Voltage regulation techniques	Improved power quality
[48]	Power quality	Hybrid power filters	Improved power quality
[49]	APF	FPSO	Improved APF
[50]	Voltage stability	Voltage control technique	Enhanced voltage stability and maximized DG utilization
[51]	THD	SEPIC controlled rectifier	SEPIC-controlled rectifier is applicable for a wide variety of loads
[52]	Power quality THD	AC to DC ĈUK converter	Proposed arrangement regulates the output voltage and maintains a high-power factor
[53]	Power quality	DSTATCOM PQ theory	Diode-clamped structure makes the power quality of a multi-level DSTATCOM structure better
[54]	Power quality	Dynamic voltage restorer Gray wolf optimizer Butterfly optimizer	Ideal placement of FACTS devices in IEEE 33 and 57 bus s ystems is determined using a sophisticated GWO and DSTATCOM with BO that adjusts for DVR
[55]	Power quality issue mitigation	Vehicle-grid (V2G) grid-vehicle (G2V)	analysis of current power quality problems and possible solutions
[56]	Hybrid active power filter (HAPF)	SRF theory P-Q theory SVPWM	HAPF is designed so that the VA rating of the active filter goes down while the filtering efficiency of the passive filter goes up
[57]	Power quality Harmonic elimination	Multilevel inverter PSO Cascaded H-bridge	Summary of the advantages of the three primary types of multilevel inverters, including cascaded h-bridge, neutral point clamped, and flying capacitor designs

REFERENCES

[1] N. Abas, S. Dilshad, A. Khalid, M. S. Saleem, and N. Khan, "Power quality improvement using dynamic voltage restorer," *IEEE Access*, vol. 8, pp. 164325–164339, 2020, doi: 10.1109/ACCESS.2020.3022477.

[2] A. H. M. Abu-Jalala, T. Cox, C. Gerada, M. Rashed, T. Hamiti, and N. Brown, "Power Quality Improvement of Synchronous Generators Using an Active Power Filter," *IEEE Trans. Ind. Appl.*, vol. 54, no. 5, pp. 4080–4090, 2018, doi: 10.1109/TIA.2018.2828789.

[3] I. Ahmad, G. Fandi, Z. Muller, and J. Tlusty, "Improvement of voltage profile and mitigation of power losses in case of faults using DG units," *19th Int. Sci. Conf. Electr. Power Eng. EPE 2018 - Proc.*, pp. 1–6, 2018, doi: 10.1109/EPE.2018.8395984.

[4] M. Bagheri, V. Nurmanova, O. Abedinia, and M. S. Naderi, "Enhancing power quality in microgrids with a new online control strategy for DSTATCOM using reinforcement learning algorithm," *IEEE Access*, vol. 6, no.1, pp. 38986–38996, 2018, doi: 10.1109/ACCESS.2018.2852941.

[5] R. Balasubramanian, R. Sankaran, and S. Palani, "Simulation and performance evaluation of shunt hybrid power filter using fuzzy logic based non-linear control for power quality improvement," *Sadhana - Acad. Proc. Eng. Sci.*, vol. 42, no. 9, pp. 1443–1452, 2017, doi: 10.1007/s12046-017-0697-6.

[6] S. C. Behera, G. K. Choudhary and R. K. Mandal, "Fuzzy based vector PI controller to mitigate the harmonics issue of a distribution system using three-phase hybrid power filter," *2nd International Conference on Advances in Electrical, Electronics, Information, Communication and Bio-Informatics (AEEICB)*, 2016, pp. 610-616, doi: 10.1109/AEEICB.2016.7538362.

[7] A. Chidurala, T. K. Saha and N. Mithulananthan, "Power quality enhancement in unbalanced distribution network using Solar-DSTATCOM," *Australasian Universities Power Engineering Conference (AUPEC)*, 2013, pp. 1-6, doi: 10.1109/AUPEC.2013.6725394.

[8] C. Benachaiba and B. Ferdi, "Power Quality Improvement Using DVR," *American Journal of Applied Sciences*, vol. 6, no. 3, pp. 396-400, 2009, doi: 10.3844/AJASSP.2009.396.400.

[9] A. H. Elmetwaly, A. A. Eldesouky and A. A. Sallam, "An Adaptive D-FACTS for Power Quality Enhancement in an Isolated Microgrid," *IEEE Access*, vol. 8, pp. 57923-57942, 2020, doi: 10.1109/ACCESS.2020.2981444.

[10] F. H. Gandoman *et al.*, "Review of FACTS technologies and applications for power quality in smart grids with renewable energy systems," *Renew. Sustain. Energy Rev.*, vol. 82, no. September 2017, pp. 502–514, 2018, doi: 10.1016/j.rser.2017.09.062.

[11] T. Ghanbari, E. Farjah, and F. Naseri, "Power quality improvement of radial feeders using an efficient method," *Electr. Power Syst. Res.*, vol. 163, no. May, pp. 140–153, 2018, doi: 10.1016/j.epsr.2018.05.027.

[12] S. Gomathi, S. Tharanya and T. Venkatesan, "Enhancement of power quality on grid connected dual voltage source inverter," *Online International Conference on Green Engineering and Technologies (IC-GET)*, 2015, pp. 1-6, doi: 10.1109/GET.2015.7453800.

[13] E. Hossain, M. R. Tür, S. Padmanaban, S. Ay and I. Khan, "Analysis and Mitigation of Power Quality Issues in Distributed Generation Systems Using Custom Power Devices," *IEEE Access*, vol. 6, pp. 16816-16833, 2018, doi: 10.1109/ACCESS.2018.2814981.

[14] A. A. Imam, R. S. Kumar, and Y. A. Al-Turki, "Modeling and simulation of a pi controlled shunt active power filter for power quality enhancement based on p-q theory," *Electron.*, vol. 9, no. 4, 2020, doi: 10.3390/electronics9040637.

[15] P. N. Babu, B. Kar and B. Halder, "Modelling and analysis of a hybrid active power filter for power quality improvement using hysteresis current control technique," *7th India International Conference on Power Electronics (IICPE)*, 2016, pp. 1-6, doi:10.1109/iicpe.2016.8079381.

[16] N. Jelani and M. Molinas, "Power quality enhancement by power electronic generation interface under non-ideal voltage conditions," *IEEE 23rd International Symposium on Industrial Electronics (ISIE)*, 2014, pp. 2161-2166, doi: 10.1109/ISIE.2014.6864952.

[17] T. Jin, Y. Chen, J. Guo, M. Wang, and M. A. Mohamed, "An effective compensation control strategy for power quality enhancement of unified power quality conditioner," *Energy Reports*, vol. 6, pp. 2167–2179, 2020, doi: 10.1016/j.egyr.2020.07.027.

[18] J. Krata and T. K. Saha, "Real-Time Coordinated Voltage Support With Battery Energy Storage in a Distribution Grid Equipped With Medium-Scale PV Generation," *IEEE Transactions on Smart Grid*, vol. 10, no. 3, pp. 3486-3497, May 2019, doi: 10.1109/TSG.2018.2828991.

[19] T. P. Kumar, N. Subrahmanyam and M. Sydulu, "Control strategies of a fuzzy controlled solid oxide fuel cell/battery distributed generation system for power quality enhancement," *International Conference on Circuits, Power and Computing Technologies [ICCPCT-2014]*, 2014, pp. 64-69, doi: 10.1109/ICCPCT.2014.7055009.

[20] T. B. Kumar and M. V. G. Rao, "Mitigation of Harmonics and power quality enhancement for SEIG based wind farm using ANFIS based STATCOM," *International Conference on Smart Electric Grid (ISEG)*, 2014, pp. 1-7, doi: 10.1109/ISEG.2014.7005595.

[21] S. Kumaresan and H. H. Sait, "Design and control of shunt active power filter for power quality improvement of utility powered brushless DC motor drives," *Journal for Control, Measurement, Electronics, Computing and Communications*, vol. 61, no. 3, pp. 507–521, 2020, doi: 10.1080/00051144.2020.1789402.

[22] Q. Liu, Y. Li, S. Hu, and L. Luo, "A Transformer Integrated Filtering System for Power Quality Improvement of Industrial DC Supply System," *IEEE Trans. Ind. Electron.*, vol. 67, no. 5, pp. 3329–3339, 2020, doi: 10.1109/TIE.2019.2916383.

[23] V. M. Lopez-Martin, F. J. Azcondo, and A. Pigazo, "Power quality enhancement in residential smart grids through power factor correction stages," *IEEE Trans. Ind. Electron.*, vol. 65, no. 11, pp. 8553–8564, 2018, doi: 10.1109/TIE.2018.2813965.

[24] T. Matlokotsi and S. Chowdhury, "Power quality enhancement in sub-transmission and distribution networks using grid-integrated renewable distributed generation," *52nd Int. Univ. Power Eng. Conf. UPEC 2017*, vol. 2017-Janua, pp. 1–6, 2017, doi: 10.1109/UPEC.2017.8232011.

[25] Y. A. R. I. Mohamed and E. F. El-Saadany, "A control method of grid-connected PWM voltage source inverters to mitigate fast voltage disturbances," *IEEE Trans. Power Syst.*, vol. 24, no. 1, pp. 489–491, 2009, doi: 10.1109/TPWRS.2008.2006996.

[26] A. B. Mohammed, M. A. M. Ariff, and S. N. Ramli, "Power quality improvement using dynamic voltage restorer in electrical distribution system: An overview," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 17, no. 1, pp. 86–93, 2019, doi: 10.11591/ijeecs.v17.i1.pp86-93.

[27] M. I. Mosaad and H. S. Ramadan, "Power quality enhancement of grid-connected fuel cell using evolutionary computing techniques," *Int. J. Hydrogen Energy*, vol. 43, no. 25, pp. 11568–11582, 2018, doi: 10.1016/j.ijhydene.2018.02.001.

[28] Y. Naderi, S. H. Hosseini, S. G. Zadeh, B. Mohammadi-Ivatloo, M. Savaghebi, and J. M. Guerrero, "An optimized direct control method applied to multilevel inverter for microgrid power quality enhancement," *Int. J. Electr. Power Energy Syst.*, vol. 107, pp. 496–506, 2019, doi: 10.1016/j.ijepes.2018.12.007.

[29] B. P. Narendra, R. B. Peesapati, and G. Panda, "An Adaptive Current Control Technique in Grid-tied PV System with Active Power Filter for Power Quality Improvement," *IEEE Reg. 10 Annu. Int. Conf. Proceedings/TENCON*, vol. 2019-Octob, pp. 187–191, 2019, doi: 10.1109/TENCON.2019.8929487.
[30] M. Ovaskainen, J. Öörni, and A. Leinonen, "Superposed control strategies of a BESS for power exchange and microgrid power quality improvement," *Proc. - 2019 IEEE Int. Conf. Environ. Electr. Eng. 2019 IEEE Ind. Commer. Power Syst. Eur. EEEIC/I CPS Eur. 2019*, pp. 3–8, 2019, doi: 10.1109/EEEIC.2019.8783764.
[31] S. K. Dash and P. K. Ray, "Power quality improvement utilizing PV fed unified power quality conditioner based on UV-PI and PR-R controller," *CPSS Transactions on Power Electronics and Applications*, vol. 3, no. 3, pp. 243-253, Sept. 2018, doi: 10.24295/CPSSTPEA.2018.00024.
[32] A. K. Panda, T. Penthia, M. Mangaraj, and A. R. Dash, "Power quality refinement by executing icosΘ Control Algorithm in Fuel Cell based DSTATCOM," *IEEMA Eng. Infin. Conf. eTechNxT 2018*, pp. 1–6, 2018, doi: 10.1109/ETECHNXT.2018.8385299.
[33] K. K. Prasad, H. Myneni, and G. S. Kumar, "Power Quality Improvement and PV Power Injection by DSTATCOM With Variable DC Link Voltage Control from RSC-MLC," *IEEE Trans. Sustain. Energy*, no. 99, pp. 1–10, 2018, doi: 10.1109/TSTE.2018.2853192.
[34] S. K. Prince, K. P. Panda, V. N. Kumar, and G. Panda, "Power quality enhancement in a distribution network using PSO assisted Kalman filter - Based shunt active power filter," *IEEMA Eng. Infin. Conf. eTechNxT 2018*, pp. 1–6, 2018, doi: 10.1109/ETECHNXT.2018.8385314.
[35] G. C. Pyo, H. W. Kang, and S. I. Moon, "A new operation method for grid-connected PV system considering voltage regulation in distribution system," *IEEE Power Energy Soc. Gen. Meet. Convers. Deliv. Electr. Energy 21st Century, PES*, pp. 1–7, 2008, doi: 10.1109/PES.2008.4596783.
[36] A. Rajendran and K. Narayanan, "Optimal Installation of Different DG Types in Radial Distribution System Considering Load Growth," *Electr. Power Components Syst.*, vol. 45, no. 7, pp. 739–751, 2017, doi: 10.1080/15325008.2017.1309721.
[37] R. S. Rani, C. S. Rao, and M. V. Kumar, "PSPWM based Five-Level Shunt Active Filter for Power Quality Improvement in Power System Network," *Energy Procedia*, vol. 117, pp. 794–801, 2017, doi: 10.1016/j.egypro.2017.05.196.
[38] P. K. Ray, S. R. Das, and A. Mohanty, "Fuzzy-controller-designed-pv-based custom power device for power quality enhancement," *IEEE Trans. Energy Convers.*, vol. 34, no. 1, pp. 405–414, 2019, doi: 10.1109/TEC.2018.2880593.
[39] B. Sahoo, S. K. Routray, and P. K. Rout, "A novel centralized energy management approach for power quality improvement," *Int. Trans. Electr. Energy Syst.*, vol. 31, no. 10, pp. 1–23, 2021, doi: 10.1002/2050-7038.12582.
[40] A. S. Kumar, S. Rajasekar, and P. A.-D.-V. Raj, "Power Quality Profile Enhancement of Utility Connected Microgrid System Using ANFIS-UPQC," *Procedia Technol.*, vol. 21, pp. 112–119, 2015, doi: 10.1016/j.protcy.2015.10.017.
[41] S. H. Shahalami and R. Hosseini, "Improvement of wind farm power quality by means of ANN-contorlled hybrid filter," *PEDSTC 2014 - 5th Annu. Int. Power Electron. Drive Syst. Technol. Conf.*, no. Pedstc, pp. 544–549, 2014, doi: 10.1109/PEDSTC.2014.6799433.
[42] A. M. Sharaf and A. A. Abdelsalam, "Power quality enhancement in wind-grid interface based on switched filter compensator," *INISTA 2011 - 2011 Int. Symp. Innov. Intell. Syst. Appl.*, pp. 404–409, 2011, doi: 10.1109/INISTA.2011.5946101.
[43] A. Sharma, A. K. Mishra, B. S. Rajpurohit, and K. N. Srivastava, "Power quality enhancement at PCC for PMSM based adjustable speed drive load," *7th Int. Conf. Power Syst. ICPS 2017*, pp. 364–369, 2018, doi: 10.1109/ICPES.2017.8387321.
[44] A. Shrivastava and P. Nene, "Power quality enhancement using UPQC connected with PV arrays," *Proc. - 5th Int. Conf. Commun. Syst. Netw. Technol. CSNT 2015*, pp. 1232–1237, 2015, doi: 10.1109/CSNT.2015.283.
[45] B. Singh, S. Goel, A. Singhal, A. Garg and C. Jain, "Power quality enhancement of grid integrated solar PV system based on adaptive noise reduction control," *IEEE Power & Energy Society General Meeting*, 2015, pp. 1-5, doi: 10.1109/PESGM.2015.7286619.
[46] P. M. H. Sonwane and B. E. Kushare, "Optimal capacitor placement and sizing for enhancement of distribution system reliability and power quality using PSO," *Int. Conf. Converg. Technol. I2CT 2014*, pp. 1–7, 2014, doi: 10.1109/I2CT.2014.7092338.
[47] A. A. Stonier, S. Murugesan, R. Samikannu, S. K. Venkatachary, S. S. Kumar, and P. Arumugam, "Power quality improvement in solar fed cascaded multilevel inverter with output voltage regulation techniques," *IEEE Access*, vol. 8, pp. 178360–178371, 2020, doi: 10.1109/ACCESS.2020.3027784.
[48] S. A. Temerbaev and V. P. Dovgun, "Improvement of power quality in distributed generation systems using hybrid power filters," *Proc. Int. Conf. Harmon. Qual. Power, ICHQP*, pp. 694–698, 2014, doi: 10.1109/ICHQP.2014.6842761.
[49] M. T. Esfahani, S. H. Hosseinian, and B. Vahidi, "A new optimal approach for improvement of active power filter using FPSO for enhancing power quality," *Int. J. Electr. Power Energy Syst.*, vol. 69, pp. 188–199, 2015, doi: 10.1016/j.ijepes.2014.12.078.
[50] T. Xu and P. C. Taylor, "Voltage Control Techniques for Electrical Distribution Networks Including Distributed Generation," *IFAC Proc. Vol.*, vol. 41, no. 2, pp. 11967–11971, 2008, doi: 10.3182/20080706-5-kr-1001.02025.
[51] M. S. Arifin and M. J. Alam, "Input switched closed-loop single phase SEPIC controlled rectifier with improved performances," *Int. J. Electr. Comput. Eng.*, vol. 11, no. 1, pp. 1–8, 2021, doi: 10.11591/ijece.v11i1.pp1-8.
[52] M. S. Arifin, N. Mohammad, M. I. Khalil, and M. J. Alam, "Input switched closed-loop single phase ĈUK AC to DC converter with improved power quality," *Int. J. Power Electron. Drive Syst.*, vol. 10, no. 3, p. 1373, 2019, doi: 10.11591/ijpeds.v10.i3.pp1373-1381.
[53] J. V. R. Babu and M. Kumar, "Multilevel diode clamped d-statcom for power quality improvement in distribution systems," *Int. J. Power Electron. Drive Syst.*, vol. 12, no. 1, pp. 217–227, 2021, doi: 10.11591/ijpeds.v12.i1.pp217-227.
[54] M. Chiranjivi and K. Swarnasri, "A novel optimization-based power quality enhancement using dynamic voltage restorer and distribution static compensator," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 26, no. 1, pp. 160–171, 2022, doi: 10.11591/ijeecs.v26.i1.pp160-171.
[55] B. N. Harish and U. Surendra, "A review on power quality issues in electric vehicle interfaced distribution system and mitigation techniques," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 25, no. 2, pp. 656–665, 2022, doi: 10.11591/ijeecs.v25.i2.pp656-665.
[56] T. M. T. Thentral, K. Vijayakumar, and R. Jegatheesan, "Performance Comparison of Hybrid Active Power Filter for p-q Theory and SVPWM Technique," *Int. J. Electr. Comput. Eng.*, vol. 11, no. 1, pp. 84–93, 2021, doi: 10.11591/ijece.v11i1.pp84-93.
[57] M. T. Yaqoob, M. K. Rahmat, S. M. M. Maharum, and M. M. Su'ud, "A review on harmonics elimination in real time for cascaded h-bridge multilevel inverter using particle swarm optimization," *Int. J. Power Electron. Drive Syst.*, vol. 12, no. 1, pp. 228–240, 2021, doi: 10.11591/ijpeds.v12.i1.pp228-240.

BIOGRAPHIES OF AUTHORS

Mr. Vasupalli Manoj was born in 1988 in India. He received his B.Tech degree in Electrical & Electronics Engineering from JNTU, Kakinada, India in 2010 and his M.Tech degree from GITAM University in Power Systems & Automation, in 2012. Currently, he is pursuing his Ph.D in the Department of Electrical Engineering at Sri Satya Sai University of Technology & Medical Sciences, Bhopal. He has published or presented more than 20 papers in international and national journals and conferences of repute. His research interests include power quality improvement and power system operation and control. He can be contacted at email: manojv287@gmail.com.

Dr. Prabodh Khampariya is a Professor at the Department of EEE, Sri Satya Sai University of Technology & Medical Sciences, Bhopal, India, where he has been teaching for the past 14 years. He has published or presented 26 papers in international and national journals and conferences of repute. His areas of interest are power systems and power quality issues. He can be contacted at email: khampariya5@gmail.com.

Dr. Ramana Pilla has been teaching at the GMR Institute of Technology in Rajam, Andhra Pradesh, India, for the past 21 years. He received his B.Tech degree in EEE, M.Tech in Electrical Power Engineering, and PhD degree in EEE from JNTUH, Hyderabad. He has authored or co-authored 12 text books, out of which 6 text books from SChand Publications, 2 text books from Universities Press (India) Pvt. Ltd., 1 text book from Reem Publications Pvt. Ltd, and 3 textbooks from Shree Publishing House. He has published or presented 54 papers in international and national journals and conferences of repute. His research interests include state estimation and controller design for electrical drives; automatic generation control; and the application of soft computing techniques to electrical power systems. He was a life member of ISTE and IE (India) and a member of several academic bodies. He can be contacted at email: ramana.pilla@gmrit.edu.in.