Harmonics Reduction and Balanced Transition in Hybrid Renewable Energy Sources

G. Balram(✉) and P. Satish Kumar

Department of Electrical Engineering, University College of Engineering, Osmania University, Hyderabad, Telangana 500007, India
gyadaribalram@gmail.com, satish_8020@osmania.ac.in

Abstract. Renewable energy sources (RES) are becoming more popular because the entire globe wants to use clean energy and it is easy to get to them. Renewable energy methods are now easy to add to power systems, so they can be used in both small distribution systems and large power grids. This integration of RES is bad for the quality of the power, the stability of the system, and the security of the network. Harmonics are made by devices that aren't linear and are linked to the power grid. Harmonics in a power source are multiples of the fundamental frequency, and these harmonic frequencies can cause voltages and currents to be messed up. Changes in volts and currents can hurt the power system and cause problems with the power quality. So, estimating harmonics is a very important part of making sure the power system network works well. Harmonic loss evaluation is becoming a bigger problem for the renewable power system business because it affects the cost of running the system and how long its parts last. In remote places, there is a lot of interest in hybrid applications that use more than one renewable energy source, such as solar and wind energy. In the study, a model of a micro-grid that uses renewable energy sources is made. The goal is to create a model of a hybrid wind/solar micro-grid by using an asymmetrical multilevel inverter, which is a new way of doing things. The goal is to design a solar-PV, wind, and battery source with a boost converter using the maximum power point tracking technique (MPPT) to get the most energy out of the renewable energy sources and test the performance of the system in terms of harmonics. A method called "nearest level control" is used, and the results are compared to the reviews that have already been done to improve the reduction of harmonics. This article lays out the challenges presented by various storage methods for usage in micro-grids. The ideas presented in this paper significantly contribute to the growing movement toward developing a low-cost, high-efficiency, and long-lived energy storage technology model suitable for usage in micro-grids.

Keywords: Hybrid Micro-Grids (HMG) · Distributed Energy Resources (DERs) · Bidirectional AC-DC Converter (BAC) · Renewable Energy Sources (RES) · Harmonics Analysis

B. Raj et al. (Eds.): ICETE 2023, AER 223, pp. 697–708, 2023.
https://doi.org/10.2991/978-94-6463-252-1_70

1 Introduction

Many issues plague today's power grid, such as the inefficiency, environmental damage, and financial strain caused by the reliance on polluting, expensive, and finite fossil fuels for heat generation [1]. The existing electrical power system is in danger because more people want electricity, conventional resources are running out, and transmission and distribution networks are getting old. RES can help solve the energy crisis, problems, and limitations. Even though instability has always been a problem with the transmission system, RES have made it so that it is far more common in the distribution system [2]. Also, the intermittent nature of RES makes it harder for the distribution grid to deal with unstable conditions.

There must be a regulatory framework for constant monitoring and coordination of the distribution system to ensure that it is secure, reliable, and efficient even while it undergoes constant transformation. This will make the whole system more efficient. Also, power electronic devices make it easier to control and change the power that comes from renewable energy sources [3]. This method also makes the power better for the people who use it. Distributed generation of renewable energy has a big effect on hybrid research. A hybrid system is a group of different types of RES that work together. The load needs are met by connecting these hybrid sources to the grid that is already in place [4].

There are a variety of renewable power generation systems now in use, but the most cutting-edge and frequently implemented ones are solar and wind energy conversion systems (WECS). Because solar and wind energy systems work over and over again, there will be problems when they are hooked up to the grid. In particular, the system will have problems with sag, swell, and harmonics, which are all types of power quality. Because of these issues, there is a chance that the grid's voltage levels will fluctuate suddenly, triggering a trip. This happens so often that it can seriously affect how reliable the grid is. Putting in place grid standards and keeping the grid firm can stop people from tripping.

The United States Department of Energy (DOE) describes a microgrid as an electrical system that may function autonomously and independently from the distribution grid, comprised of a collection of loads, micro-sources, and distributed energy resources with clearly defined electrical limits. This is done so that the dependability and consistency of the power supply can be ensured. Another concept for a microgrid is a collection of controllable electrical and thermal demands and distributed energy resources, as proposed by the Consortium for Electrical Reliability Technology Solutions (CERTS). Loads such as solar panels, wind turbines, fuel cells, diesel generators, and ESS-equipped microturbines are connected to the upstream grid in Fig. 1 so that they can receive power from these renewable energy sources.

2 Literature Review

Existing power systems have moved into DG because the need for and use of energy is growing. In recent years, more wind and solar power have been made. Also, hybrid systems can give consumers more reliable and high-quality power (Li et al., 2018).

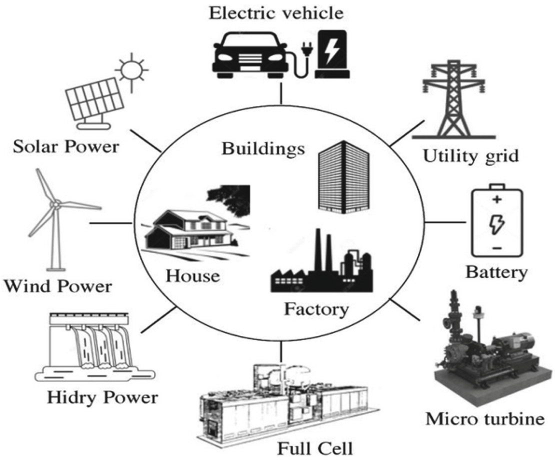


Fig. 1. MG typical structure

The DG facilitates long-distance transmission of electrical power. Micro-grids are a recently popular form of small, independent power grid node (Kanase-Patil et al., 2020). That's what the research shows (Ramu et al. Small, modular resources like wind, solar, batteries, fuel cells, and diesel generators can be linked together to form micro-grids.

Independent systems benefit more from micro-grids (Saravanan et al., 2021). This was found by Maza-Ortega et al. (2017). This was found by Maza-Ortega et al. (2017). The microgrids might take care of the power without or with the help of the utility grid if the correct control mechanisms were used. Use of renewable energy sources can be maximised by HMG integration of solar PV, wind power, energy efficiency measures, and local load. Standard HMG components include the BAC, DC, and AC subgrids. However, the HMG is also capable of operating on nonstandard forms of power. Nonlinear loads still have high reactive power, which significantly degrades the efficiency of the power supply. Protection and efficient operation of microgrids are directly related to power quality (PQ) (Kumar et al., 2021).

Gao et al. (2019) developed a method for finding harmonics using the Fourier transform. This technique can detect all harmonics with a high degree of accuracy. Real-time performance degrades as a result, particularly because of the numerous calculations and lengthy delay.

The authors created a flexible detection technique (Li et al., 2021a) by factoring in detection performance and verifying reaction time. However, the detecting performance has caused a change in the magnitude of the grid voltage. It functions well in real-time and requires no intricate matrix changes; furthermore, the effect on identification is rather constant.

Power exchange between AC and DC submicrogrids necessitates a control method based on harmonic identification analysis (Toghani Holari et al., 2021).

Droop control (DRC) can calculate the power relationship between AC and DC submicrogrids by modelling the frequency shift characteristics of the generators. According to the referenced research (Li et al., 2021b), a more efficient DRC technique is provided,

Table 1. The primary norms for regulating and measuring power quality and harmonics

Subject	Standard
Recommended Practices for power quality control.	IEEE 1159
Standard definitions for experimental use for the measurement of electrical energy.	IEEE 1459
Recommended practices and requirements for harmonic control.	IEEE 519
Characteristics of the voltage supplied by public distribution networks.	CENELEC EN 50160
General.	IEC 61000-1-4
Emission Environment (description and classification).	IEC 61000-2-1, 61000-2-2, 61000-2-3, 61000-2-4, 61000-2-6, 61000-2-12
Limits (emission and immunity limits).	IEC 61000-3-2, 61000-3-4, 61000-3-9, 61000-3-6, 61000-3-10, 61000-3-12,
Tests and Measurements.	IEC 61000-4-7, 61000-4-13, 61000-4-30, 61000-4-31

which leads to a BAC shutdown mode and disables the power electronic device. To counteract BAC frequency hopping, a layered DRC strategy has been proposed (Wang et al., 2020). The above-described methods for DRC are idealised examples. A grid doesn't account for loads that don't move in a straight line. Added power outages and complications for linked devices are brought on by non-linear loads altering the current flow. When this happens, microgrid voltages become unstable (Baharizadeh et al., 2021).

3 Methodology

3.1 Standards that Regulate the Limits and Measurement of Harmonics

American IEEE (Institute of Electrical and Electronics Engineers) and European IEC (International Electro technical Commission) standards are the most well-known in proposing the requirements for the supply signal, the constraints, and the techniques for detecting current and voltage harmonics. To provide a point of comparison, CENELEC (Comité Européen de Normalisation Electro technique) is the body responsible for implementing IEC standards across European Union member states. As shown in Table 1, these groups have developed a number of important standards for quantifying power quality, including those that set bounds on harmonic measurement and describe how it is to be performed.

3.2 Grid-Connected Distributed Generation System Integrating a Hybrid Wind-PV Farm Using UPQC

The usage of RESs to produce electricity has increased dramatically in recent years (A. Al-Quraan and Al-Qaisi, 2021), in response to both rising electricity demand and international efforts to lessen the environmental damage caused by traditional fossil fuels. In an effort to keep the average global temperature rise this century due to the greenhouse effect and global warming to well below 2 degrees Celsius, many countries committed to boost cross-border cooperation at the 2015 Climate change conference in Paris, France. Governments throughout the world are aiming to increase their usage of renewable energy in order to reach a high degree of integration of 20% by 2020 (Y. Zhou et al., 2022). Renewable energy is a clean, practical, and economical energy source.

An innovative new strategy for improving power grids has been presented, and it is based on distributed generation (DG) systems fueled by renewable energy sources (RES). Reducing carbon dioxide emissions and distribution losses are two additional benefits of implementing DG (S. Samal et al., 2020).

The fundamental job of DGs is to contribute actual electricity to the grid; however, its multifunctionality can be broadened to include the active power line conditioning goals (S. Kumar and B. Singh, 2018).

Here, an integrated DGs can do more than just generate energy; they can also immediately execute active power line correction, which helps boost PQ metrics (X. Zhang et al., 2021).

Potential sources of DGs in this scenario include photovoltaic and wind power, which just need access to sunlight and wind to generate electricity in places where these resources are abundant, relatively clean, and free (J. Zhao et al., 2021). There is a cascade of current and voltage harmonics created when many solar cells, wind turbines, and power inverters are utilised to generate electricity. This trend not only worsens the quality of the network but also increases the nonlinear demands already being placed on it.

UPQC has been proposed as a solution to power quality problems caused by nonlinear loads and the integration of renewable energy sources like photovoltaic and wind turbines into the utility system. Flicker, sag, and swell in the supply voltage can all be corrected by UPQC, as can harmonics, unbalances, reactive currents, and neutral currents in the load. In contrast to steady-state (voltage imbalances and voltage harmonics), transient (voltage sag and swell) line voltage PQ occurrences can be resolved or at least mitigated by using series active power filters, also known as dynamics voltage restorers (Y. Zhou, 2020).

However, parallel active power filters are widely utilised to resolve PQ difficulties induced by load arrangement or even nonlinear characteristics of load currents. But the UPQC can also be set up in either a single-phase or three-phase configuration to cut down on PQ events coming from the mains and the load.

4 Results and Discussion

At the 0.05 s mark, HMG. The current system's HMG does not account for the DRC, and the frequency variation occurs 0.05 s later.

As can be shown in Fig. 2(b), the suggested system load current is superior to the current method in terms of maintaining synchronisation both before and after the introduction of the HMG.

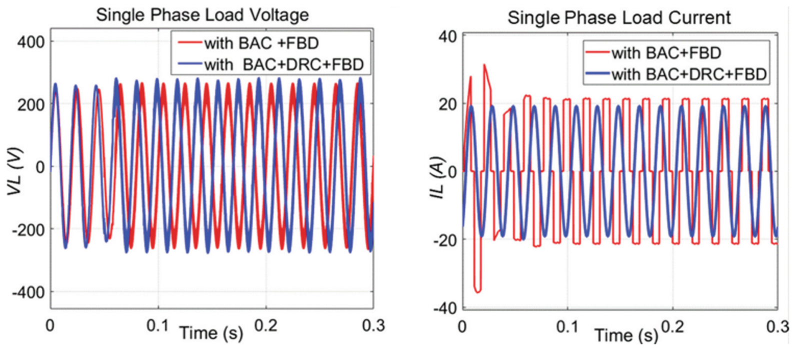


Fig. 2. Variables in both the proposed and current systems are compared with regard to (a) single-phase load voltage. (b) Current drawn by a single-phase load

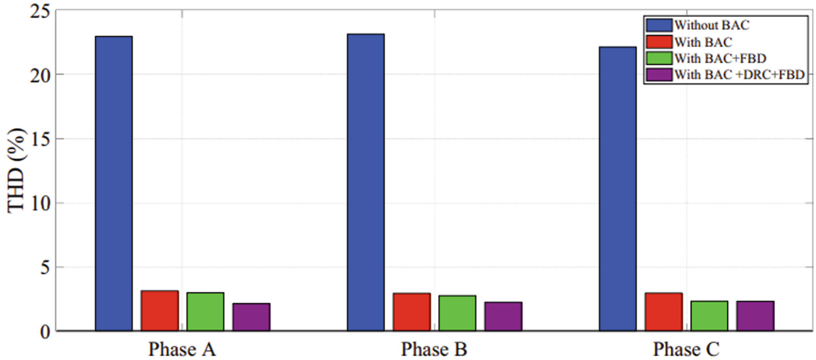


Fig. 3. THD comparison of the proposed system with the existing system

The THD representation of the proposed system is compared to that of the existing converter in Fig. 3, which displays the contrast. Through the use of BAC, DRC, and FBD theory, this suggested system investigates the suppression of harmonics. The grid side phase voltage harmonics are significantly lower when compared to those produced by traditional converters. It is difficult to determine which method of lowering harmonic current in HMG is the most successful due to the fact that there are numerous different methods. Table 2 displays data on multiple fronts, such as the proportion of renewable energy employed, the circuit's complexity, the mode of operation, the load, harmonic current suppression, power sharing, and the outcomes. The suggested system's viability is demonstrated by its ability to handle linear and non-linear loads, incorporate renewable energy sources like solar and wind, and minimise unwanted harmonics through the use of droop control and BAC, and allow for cooperative energy production and consumption. As far as performance goes, the proposed system is head and shoulders above the rest.

In order to simulate grid-side current demands of 3A, 6A, and 9A, a continuous-current load is applied through the DC bus during testing. Using a conventional PI controller, the present behaviour is shown in Fig. 4. Figure 4a shows the current waveform at 3A demand, which yields a THDi of 10.47%. Figure 4b displays the harmonic content

Table 2. Comparison of proposed works with existing works

REF	RE Integration			Operating mode		Control method		Outcomes
	Solar	Wind	Hydro	SS	ST	DRC	BAC	
Li et al. (2018)				√			√	HCS using BAC
Toghani Holari et al. (2021)				√				Sliding mode controller for HMG
Baharizadeh et al. (2021)				√				HCS using a current controlled method
Tian et al. (2018)				√				HCS using BAC
Liu and Li (2020)		√		√				Inductive filtering approach for PQ improvement
Campanhol et al. (2019)				√				HCS using DRC and BAC
Suresh and Ramesh (2019)	√			√				HCS using extended reference signal generation technique
PW	√	√	√	√	√			HCS and PS using DRC and BRC with solar, wind, hydro energy integration

of the converter currents at 3, 6, and 9A and demonstrates that total harmonic distortion (THDi) reduces with increasing load current. Exhibited in Fig. 5 is the current behaviour after the PI+ Resonant controller was implemented. As can be seen in Fig. 5a, the THDi value is 3.06% at the instant when a load of 3A is required. Figure 5b shows the harmonic content of the converter currents at 3A, 6A, and 9A.

The Forecasted PV active power generation is shown in Fig. 6. The waveforms in Fig. 7 are nearly pure sinusoidal, although current fluctuations still occur during a transient state because of the DC regulator's health. In addition, as shown in Fig. 8, Fast Fourier Transform analysis is used to calculate the amount of harmonic suppression afforded by the installation of the hybrid-power filter. Fast Fourier Transform analysis

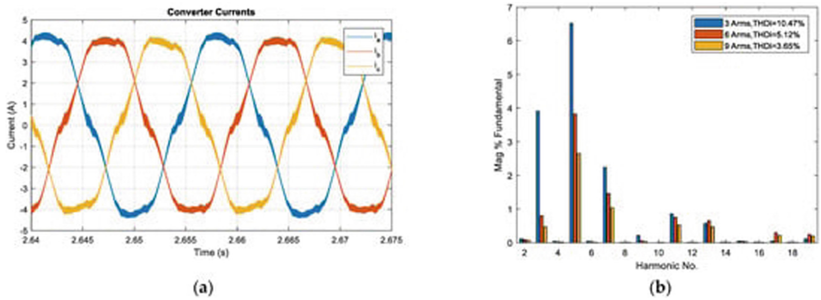


Fig. 4. The (a) grid waveform for a 9A current demand, and (b) simulated response of the grid currents when using a traditional PI controller. Harmonic content of grid currents at 3A, 6A, and 9A loads

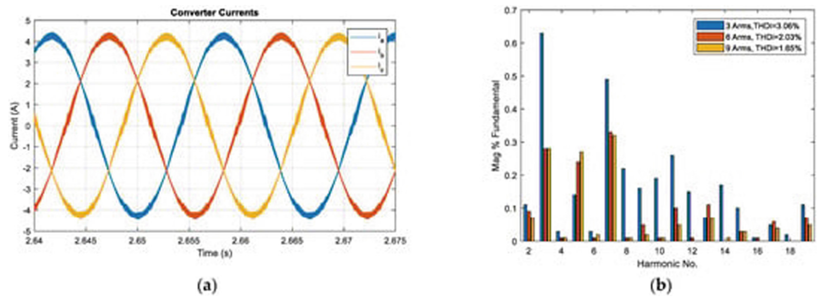


Fig. 5. Waveform of the grid at 9A current demand (a) and harmonic content of the grid currents (b) as simulated by the proposed PI+ Resonant controller for loads of 3A, 6A, and 9A

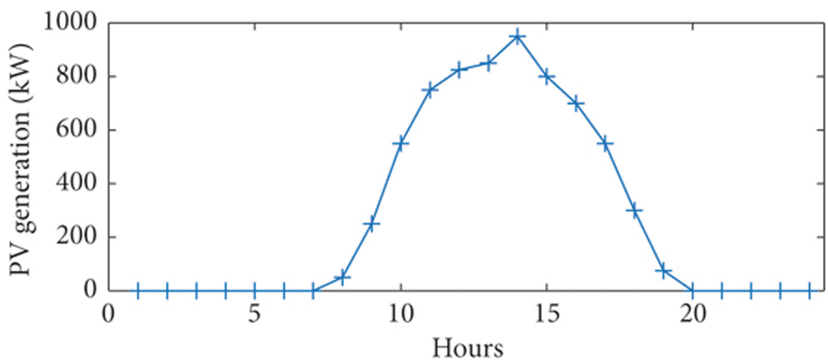
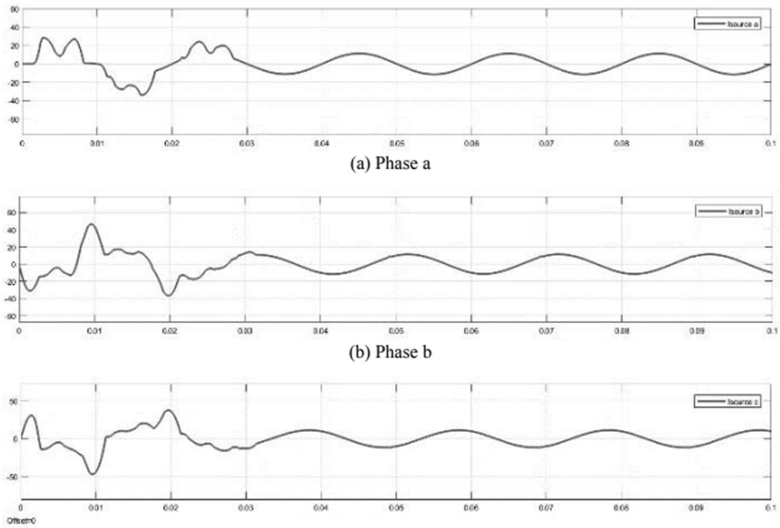


Fig. 6. Forecasted PV active power generation

for the phase a source current reveals a Total Harmonics Distortion of 0.58%, which is about a 25% reduction in comparison to the initial source current before the application of the Shunt Hybrid Active Power Filter. In addition, the hybrid-power filter's effect on the source voltage wave is depicted in Fig. 9. The predicted harmonic currents are



(a) Phase a

(b) Phase b

(c) Phase c

Fig. 7. Current waveform after applying shunt hybrid active filter.

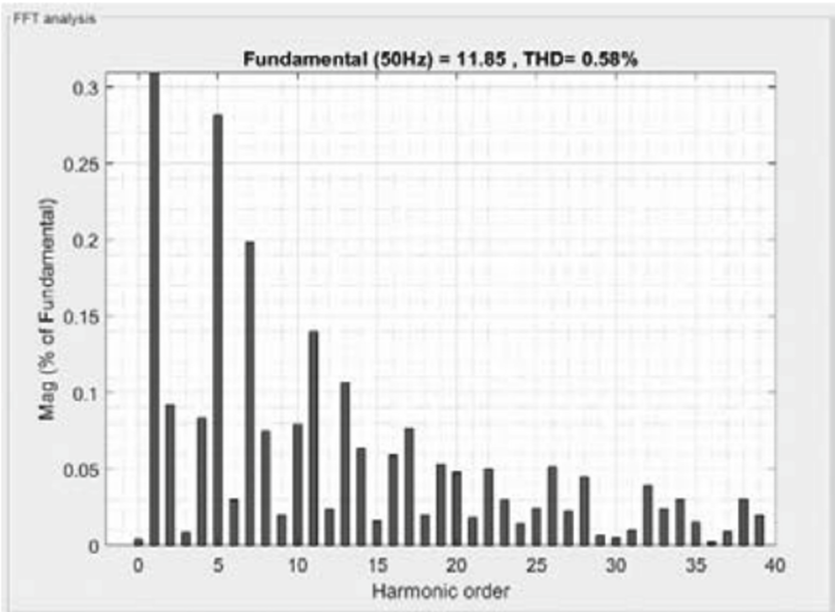


Fig. 8. Source current harmonic spectrum of phase-a after applying shunt hybrid active power filter

effectively lowered by the Shunt Hybrid Active Power Filter; for example, the fifth order is decreased from 21% to 0.275%, the seventh order is decreased from 12% to 0.2%,

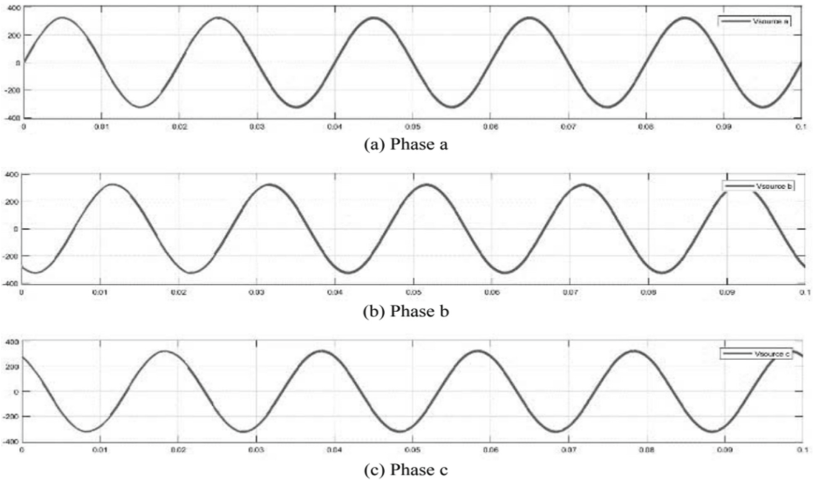


Fig. 9. Output voltage waveform after applying the hybrid filter

the eleventh order is decreased from 7.5% to 0.14%, and other odd harmonic orders are reduced to <0.12%. Total Harmonics Distortion analysis of sinusoidal output voltage waveforms under a non-linear load reveals a value of 1.9%. Total Harmonics Distortion is still below the acceptable range, demonstrating the effectiveness of the Shunt Hybrid Active Filter in lowering voltage harmonics.

5 Conclusions

Harmonic distortion rate is a metric that can be used to objectively and consistently evaluate the performance of various electrical infrastructures. As a result, they contribute to the improvement of system quality and the reduction of distortion levels. Not only must the harmonic and inter-harmonic content of the network itself be measured, but it must also be measured at the output of the various modern pieces of electronic equipment that have been connected to the electrical network. This is because these electronic converters are used in a variety of more recent pieces of equipment.

More reliable conclusions can be drawn from measurements if they are standardised to ensure that all measurements are taken in the same way using the same units of measure. Interestingly, a portion of the high-frequency range is also covered by these standards, even though they are primarily designed to meet the measurement needs of the low-frequency range. This is due to their limited scope of analysis, which is limited to electrical network signals. Many of these prices are predicated on the increased requirement to measure distortion introduced by the increasing number of grid-connected devices, including solar and wind generators, electric vehicle battery chargers, and other cutting-edge electronic equipment. This is to say that several rates appropriate for each measurement type are proposed in the literature. You can get these prices from many different sources.

The THD% of the classical practices is also calculated. While the overall harmonics of the connected framework are increased by a significant amount out of sight of the

Transient current limiter (TCL) circuit to the associated PV framework, the analysis reveals that power quality has essentially improved by reducing symphonic twisting. The proposed method is useful for advanced settings that need few toggles. Switching losses are decreased from 100% to 50%, making this method more efficient than others. The proposed topology improves efficiency over the status quo of network architectures. The aforementioned architecture is validated via laboratory experiments and simulations for further study.

References

Al Hosani Khalifa et al. An improved control strategy of 3P4W DVR systems under unbalanced and distorted voltage conditions Int. J. Electr. Power Energy Syst. (2018)

Al-Quraan and M. Al-Qaisi, “Modelling, design and control of a standalone hybrid PV-wind micro-grid system,” Energies, vol. 14, no. 16, pp. 4849–16, (2021).

Baharizadeh, M., H. R. Karshenas, and M. S. Golsorkhi Esfahani. Control method for improvement of power quality in single interlinking converter hybrid AC-DC microgrids. IET Smart Grid 4 (4):414–28. doi: https://doi.org/10.1049/stg2.12014 (2021)

Çelik Doğan et al. Current control based power management strategy for distributed power generation system Control Eng. Pract. (2019)

Dasgupta Souvik Single-phase inverter-control techniques for interfacing renewable energy sources with microgrid—Part II: Series-connected inverter topology to mitigate voltage-related problems along with active power flow control IEEE Trans. Power Electron. (2010)

Gao, Z., C. Li, W. Teng, C. Tian, and Y. Rao.. Hybrid microgrid load distribution and DC voltage control. 2019 IEEE 3rd Conference on Energy Internet and Energy System Integration (EI2), Changsha, China (2019).

J. Zhao, F. Li, Z. Wang, P. Dong, G. Xia, and K. Wang, “Flexible PVDF nanogenerator-driven motion sensors for human body motion energy tracking and monitoring,” Journal of Materials Science: Materials in Electronics, vol. 32, no. 11, pp. 14715–14727, 2021.

Kanase-Patil, A. B., A. P. Kaldate, S. D. Lokhande, H. Panchal, M. Suresh, and V. Priya.. A review of artificial intelligence-based optimization techniques for the sizing of integrated renewable energy systems in smart cities. Environmental Technology Reviews 9 (1):111–36. doi: https://doi.org/10.1080/21622515.2020.1836035 (2020).

Kumar, R. S., I. G. Christopher Raj, S. Saravanan, P. Leninpugalhanthi, and P. Pandiyan.. Impact of power quality issues in residential systems. Power Quality in Modern Power Systems 163–91 (2021).

Li, P., T. Guo, Y. Li, X. Han, P. Wang, X. Li, and Z. Wang.. An adaptive coordinated optimal control method for parallel bidirectional power converters in AC/DC hybrid microgrid. International Journal of Electrical Power & Energy Systems 126:106596 (2021a). doi: https://doi.org/10.1016/j.ijepes.2020.106596

Li, S., J. Wang, T. Wang, H. Du, Y. Duan, H. Gao, R. Meng, L. Wang, X. Han, M. Wei, et al. 2018. The bidirectional AC/ DC power converter with capability of suppressing the harmonic current in hybrid micro grid.” Asian Conference on Energy, Power and Transportation Electrification (ACCEPT), Marina Bay Sands, Singapore (2018)

Li, X., C. Dong, W. Jiang, and X. Wu. An improved coordination control for a novel hybrid AC/DC microgrid architecture with Combined Energy Storage System. Applied Energy 292:116824. doi: https://doi.org/10.1016/j.apenergy.2021.116824 (2021b)

Maza-Ortega, J. M., E. Acha, S. García, and A. Gómez-Expósito.. Overview of power electronics technology and applications in power generation transmission and distribution. Journal of Modern Power Systems and Clean Energy 5 (4):499–514. doi: https://doi.org/10.1007/s40565-017-0308-x (2017)

Priyavarthini S. An improved control for simultaneous sag/swell mitigation and reactive power support in a grid-connected wind farm with DVR Int. J. Electr. Power Energy Syst. (2018)
Ramu, S. K., S. Paramasivam, S. Muthusamy, H. Panchal, K. K. Sadasivuni, and Y. Noorollahi.. A novel design of switched boost action based multiport converter using dsPIC controller for renewable energy applications. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects 1–16. doi: https://doi.org/10.1080/15567036.2021.1967522 (2021)
S. Kumar and B. Singh, "A multipurpose PV system integrated to a three-phase distribution system using an LWDF-based approach," IEEE Transactions on Power Electronics, vol. 33, no. 1, pp. 739–748, (2018).
S. Samal, P. K. Hota, and P. K. Barik, "Performance improvement of a distributed generation system using unified power quality conditioner," Technology and Economics of Smart Grids and Sustainable Energy, vol. 5, no. 1, (2020).
Saravanan, S., P. Pandiyan, T. Chinnadurai, T. Ramji, N. Prabaharan, R. Senthil Kumar, and P. Lenin Pugalhanthi.. Reconfigurable battery management system for microgrid application. Microgrid Technologies 145–76 (2021).
ToghaniHolari, Y., S. A. Taher, and M. Mehrasa.. Power management using robust control strategy in hybrid microgrid for both grid-connected and Islanding modes. Journal of Energy Storage 39:102600. doi: https://doi.org/10.1016/j.est.2021.102600 (2021).
Wang, Q., Y. Li and Q. Zhang.. The coordinated control technology of the AC/DC hybrid microgrid in the integrated energy station. The 16th IET International Conference on AC and DC Power Transmission (ACDC 2020), Xi'an, China (2021).
X. Zhang, Y. Zhao, H. Lin, S. Riaz, and H. Elahi, "Real-time fault diagnosis and fault-tolerant control strategy for Hall sensors in permanent magnet brushless DC motor drives," Electronics, vol. 10, no. 11, p. 1268, (2021).
Y. Zhou, M. Zhang, G. Kou, and Y. Li, "Travel preference of bicycle-sharing users: A multi-granularity sequential pattern mining approach," International Journal of Computers, Communications & Control, vol. 17, no. 1, (2022).