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A Brief Review of Power Quality Issues Emerged due to Modernization of Power System Infrastructure

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Abstract: The architecture of power systems is evolving daily due to technological advancements aimed at reducing energy consumption and improving the environment. However, this improvement in the architecture of the network has affected the quality of the electricity and is producing several problems associated with the quality of power supplied. In a broad sense, the recent standard procedures for power generation, transmission and distribution are the root cause of the recently discovered problems with power quality. Investigating these problems is essential to accurately forecast the stochastic impacts on today network's functioning and locate the best remedy for these problems. This study includes a discussion on quality challenges that evolved due to modernization in the infrastructure of power network and an evaluation of the latest solutions presented in the literature to overcome those difficulties. This paper also makes recommendations for the future scope of research that should be done to address these new power quality problems.

Keywords: Voltage Fluctuations; Harmonics; Power Quality; Electric Vehicle; Solar.

1. Introduction

The main objective of power system is to supply high quality electricity, ensure that it is transmitted effectively, and provide it to customers at prices that are affordable. During the time of the conventional power networks, neither the accessibility of energy supplies nor the state of the environment was in danger. During that time period, electricity was created only via the use of energy systems derived from fossil sources by means of synchronous generators.

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These generators supplied good sinusoidal signal voltages in accordance with quality requirements and power was transferred to the consumers either by a single or a three phase overhead transmission network. The majority of the drives consisted of motors that were controlled directly, and there was no power electronics interface between the supply and that. Additionally, there was little concern for flexible control or energy conservation. Due to the absence of energy conservation techniques, the majority of the lighting loads were linear and totally resistive as well. There was no application of any power electronics circuits whatsoever. Therefore, it is possible to say that the most of the loads in ancient power networks were linear, and as a result, they were supplied by totally fundamental supply voltage. Utility grids are tasked with the duty of ensuring that all of their customers get electricity that is consistent with the specified magnitude, frequency, and voltage [1]. In addition, it is necessary for all of the consumers to get pure sinusoidal signals while maintaining unity power factor.

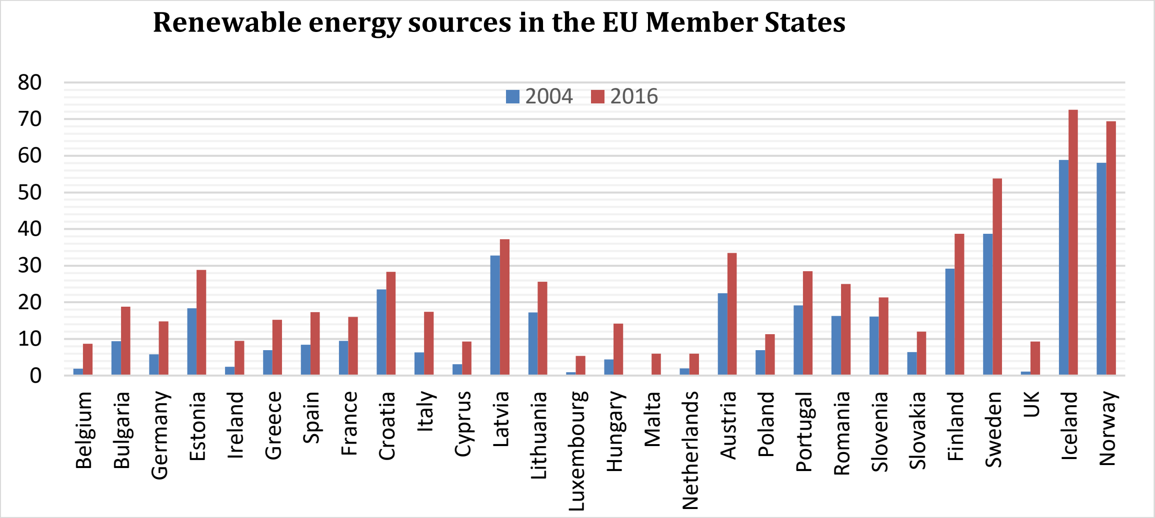

Fig. 1: Share of energy from renewables between 2004 and 2016 in % of gross final utilization [4]

The primary objective of today's contemporary power system architecture [2] is to reduce the amount of generation that is reliant on the utilization of fossil sources energy resources as much as possible in order to address the myriad of problems that are linked to this objective. Because of the positive effects that this behavior has on the surrounding environment, the generation of power via the use of renewable sources is favored. In addition, distributed generation (DG) that makes use of renewable energy resources has its own set of benefits, including a reduction in transmission losses and a lower impact on the environment [3]. As a consequence of this, the current situation of smart grids is seeing an improves in the percentage of generation that is derived from renewable resources all over the globe. Countries such as Sweden, Iceland and Norway are among those that meet higher than fifty percent of their entire energy demand via the production of electricity from renewable resources. Figure 1 depicts the total percentage of energy derived from renewables that was used in the production of gross total energy utilization in the states of the European Union (EU) between the years 2004 and 2016 [4]. Solar power (photovoltaic (PV), thermal and concentrated), tidal power, wind power, biofuels, geothermal energy and hydro power are all examples of renewable energy sources. Although the interconnection of power generating systems based on renewable energy resources (RES) into the current transmission grid presents a number of power quality difficulties [5-7], the potential future advantages of using RES as a source of electricity generation are promising. Owing to the fact that the quality of the electricity produced by RES such as PV or wind power is influenced by the unpredictability of the surrounding environment [8]. As a result, the utilization of renewable generating systems such as PV and wind power, as well as these systems frequent integration with the grid, has resulted in major power quality challenges in the networks that are now in place. Therefore, the generating methods of advanced power system networks have led to in the emergence of more power quality challenges.

The transformation in the manner in which contemporary power systems' infrastructures use energy has also resulted in concerns with the power supply's overall quality. Harmonic signals and reactive power have been introduced into power systems as a direct result of the excessive utilization of power electronic equipment [9]. The demand of supple control of industrialized and energy effective domestic consumer load gear has dominated the utilization of power electronic elements to a large degree. This is particularly accurate in the case of residential consumer load equipment. The number of electric cars on the road is rapidly growing in response to rising worries about the environment. Due to the rectifier circuit, the charging system of an electric car operates as a non-linear system, and it has dominated harmonics current in power systems [10]. Harmonics and reactive current have become more prevalent in power systems because of the extensive use of completely converter controlled motor drives as an alternative to conventional direct driven motors. Additional shifts in the sorts of household appliances that are used on a daily basis have also contributed significantly to the growth of harmonic current in power networks [11]. Therefore, the shift in consumption patterns within the current power system architecture has also resulted in the emergence of new power quality issues.

In addition, the shifts in procedures that have been employed for the transmission of electricity have also contributed to difficulties with the power's quality. Concerns near power quality have arisen as a consequence of the widespread usage of cables for transmission purposes in today's contemporary power system since high-voltage direct current transmission is also employed for shorter distances.

According to the researchers understanding, there is not a single publication that provides a full analysis of current power quality concerns and systematically categorizes all of the problems based on the degree to which the power network has been modernized. This paper includes a comprehensive discussion on power quality challenges, which have become more prevalent as a result of modernization in power networks, as well as a review of the most recent and cutting-edge recommendations that have been suggested in the literature to report these concerns. It has been extensively explored how the incorporation of power production that is based on renewable resources into the grid might lead to problems with the electricity's overall quality. There has been discussion on the impact that switching to electric car technology will have on the power quality of the grid. It has been extensively debated how contemporary lighting systems, rechargeable household items, and industrial motor drives all have a consequence on the grid power quality.

In this paper, an extensive review study has been carried out on the quality challenges that have surfaced as a direct significance of the transformation of the infrastructure of the power networks. Additionally, day-by-day recommended state-of-the-art solutions to those challenges have also been inspected and dissected in seriousness at this point in time. The major purpose of this paper is to speak about new power quality challenges that have been brought up by the current power system and to provide the solution that is both the most suitable and effective one. The stochastic consequences of those newly emerging PQ concerns on the system are not within the purview of this work's investigation and so will not be discussed. In part II, power quality problems and the IEEE standards that are related with them are categorized, and the root causes of these problems are examined. A comprehensive discussion on the process of assessing a problem with the power quality is carried out. This section also addresses the manner in which each problem is characterized as well as the degree of severity of the problem. In Section III, the newly arising problems with electricity quality as a result of shifting generating techniques are discussed. This section includes a short discussion of the current situation for generation based on renewable energy sources and the topologies that are most typically utilized for this purpose. Problems with power quality have risen as a consequence of the integration of renewable production, and the most recent and effective solutions to these problems are explored in section III in great detail. Additional quality problems that have originated because of shifts in the methods of transmission and utilization are examined in sections IV and V, respectively, and so are the solutions that have been developed to solve these problems, which are also thoroughly explored in the same sections. In the last section, judgments are taken, and suggestions are made on the area of future study effort.

2. Broad classification of power quality issues and associated standards

The phrase "power quality problem" refers to any instance in which the signal of the current or voltage deviates from the standard sinusoidal, either in terms of the rated magnitude or the frequency [13]. In layman's terms, a power quality issue is any fault connected to the supply current or voltage that outcomes in the miscarriage of receiver load equipment's. The distribution of electricity to customers is the fundamental objective of the utility. If the power quality of the utility is inadequate, it will have an adverse economic impact on the load of consumers who are linked to the system as well as on the utility. There are a variety of potential reasons for the various power quality issues, and each one has the potential to have a negative impact on the sensitive equipment used by customers in a specific manner. The stages required in analyzing a power quality concern are shown in figure 2, which may be found here. It is abundantly evident that determining the category of the issue is the first stage in this process.

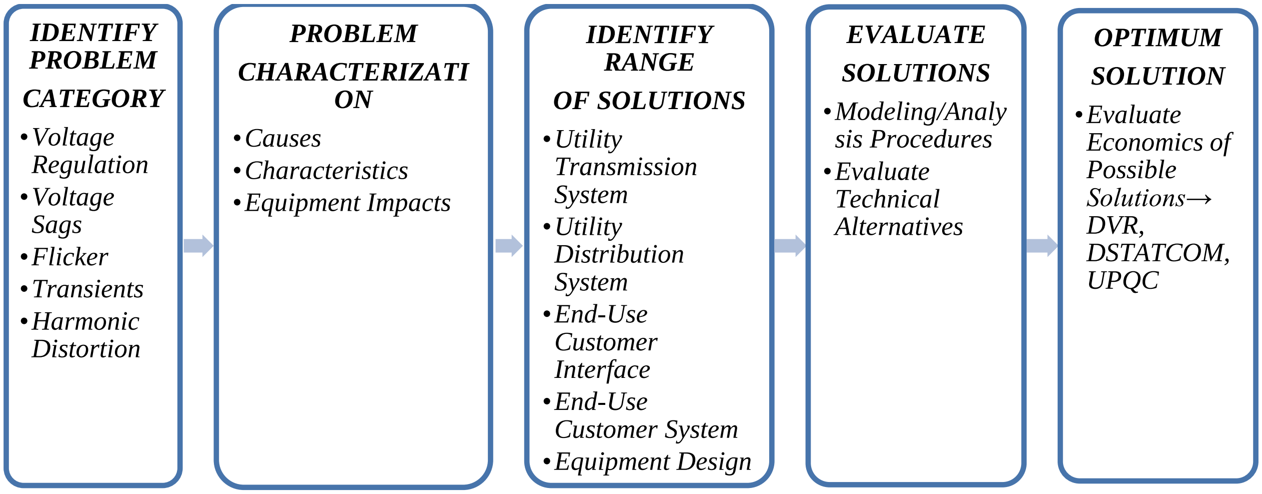

Fig. 2: Procedure of evaluating a power quality problem [14]

There are five distinct types of issues that might potentially be present, and they are voltage regulation or imbalance, voltage sags or interruptions, flicker, transients, and harmonic distortion, in that order. The following phase, which comes after the category of the issue has been recognized, is to identify that problem by certain metrics, such as the causes, features, and effect it has on a certain type of sensitive equipment. The subsequent processes include of identifying the feasible range of solutions, doing assessments of the solutions, and ultimately locating the solution that is the most optimal given the choices that are accessible [14]. Table I provides a broad categorization of power quality issues, along with their respective descriptions and hypothesized causes [15]. When conducting an examination of power quality, governing criteria for each different kind of power quality problem play a very crucial role. Table.II has a list of these standards, including some of them.

Table. I: Power quality issues and their causes [15]

Broad Categories	Particular Categories	General Causes	Basis of Characterization	Severity
Transients	Impulsive	Lightning strike, transformer energization, capacitor switching	Peak magnitude, rise time and duration	Very High
	Oscillatory	Line or capacitor or load switching	Peak magnitude, frequency components	
Short duration voltage variation	Sag	Single line-to-ground faults	Magnitude, duration	Moderate
	Swell	Single line-to-ground faults	Magnitude, duration	
	Interruption	Temporary faults	Duration	
Long duration voltage variation	Under voltage	Switching on loads	Magnitude, duration	Moderate
	Overvoltage	Capacitor energization	Magnitude, duration	
	Sustained interruptions	Faults	Duration	
Voltage imbalance		Single-phase loads, single-phasing condition		High
Waveform distortion	Harmonics	Adjustable speed drives and other nonlinear loads	THD, Harmonic spectrum	Moderate
	Notching	Power electronic converters	THD, Harmonic spectrum	
	DC offset	Geo-magnetic disturbance, half-wave rectification	Volts, Amps	
Voltage flicker		Arc furnace, arc lamps		Moderate

Table II: Power quality issues and associated standards

Issue	Standards
Classification of power quality	IEC 61000-2-5 (2017) [16]; IEC 61000-2-1 (1990) [17]; IEEE 1159 (2009) [18]
Transients	IEC 61000-2-1 (1990) [17]; IEEE c62.41(1991) [19] IEEE 1159 (2009) [18]; IEC 816 (1984) [20]
Voltage sag/swell and Interruption	IEC 61009-2-1 (1990) [17]; IEEE 1159 (2009) [18]
Harmonics	IEC 61000-2-1 (1990) [17]; IEEE 519 (2014) [21] IEC 61000-4-7 (2002) [22]
Voltage flicker	IEC 61000-4-15 (2015) [23]

3. Power Quality Issues Caused by Changes in Methods of Generation

The idea of transforming the existing grid into a contemporary one, or, to put it another way, updating the infrastructure of the power network, has an effect on the quality of the electricity. New technological obstacles have surfaced along with the social and environmental advantages that have resulted from the progress of electricity systems. The use of fossil fuels to generate electricity and other human activities have contributed to the pollution of the atmosphere with carbon dioxide and emissions that contribute to global warming; as a result, the creation of electricity from renewable resources has arisen as a green energy source [24]. A study conducted in the United States found that the generation of energy is accountable for around 29 % of the country total greenhouse gas productions [25]. Because of this, renewable energy systems such as solar and wind produce green energy, and their penetration throughout the whole globe is expanding day by day. According to the yearly report provided by GWEC and IEA, 2016 [26-27], Figure 3 illustrates the percentages of the world's total wind and solar energy production that each contributes. The production of energy through the use of renewable resources looks to have a promising future owing to the benefits it offers over generation via the use of fossil fuels. In order to make use of renewable energy sources like solar and wind power, power plants need to be connected to the grid that is already in place [28]. The overall structure of the system that converts wind energy into electrical energy is shown in Figure 4(a). [29] The architecture of a big wind power facility that is linked to the grid is shown in further detail in Figure 4(b). The topology of a grid-connected solar power plant is quite similar to that of a wind power plant, with the exception of the early step of conversion. A full structure of a solar power plant that is linked to the grid is shown in Figure 5 [30].

3.1 Power quality issues and solutions

The grid interconnection of RES presents various hurdles for the power system network [31]. The use of RES in independent operation does not provide several technological obstacles as the interconnection of RES with the utility does. The operators of the utility grid are able to centrally manage the quality of the power that is provided without resorting to the use of power electronics systems. However, the quality of electricity generated by photovoltaic and wind systems is dependent on environmental elements and the control provided by power electronics. Because the integration close to such green energy based generating systems is substantially expanding, the possible danger to power quality caused by such grid incorporation would likewise go up significantly [32]. Regulation of harmonics, frequency, and voltage in output current are the criteria that are recommended to check the quality of power generated by PV systems in accordance with IEEE standards 929-2000.

A. Voltage and frequency fluctuations

Because of the unpredictability of the weather, the production of renewable energy is very intermittent. For example, the output voltage and power of a photovoltaic module alter in response to shifts in solar irradiation and temperature, while the output voltage of a wind energy system responds to shifts in wind speed [33, 34].

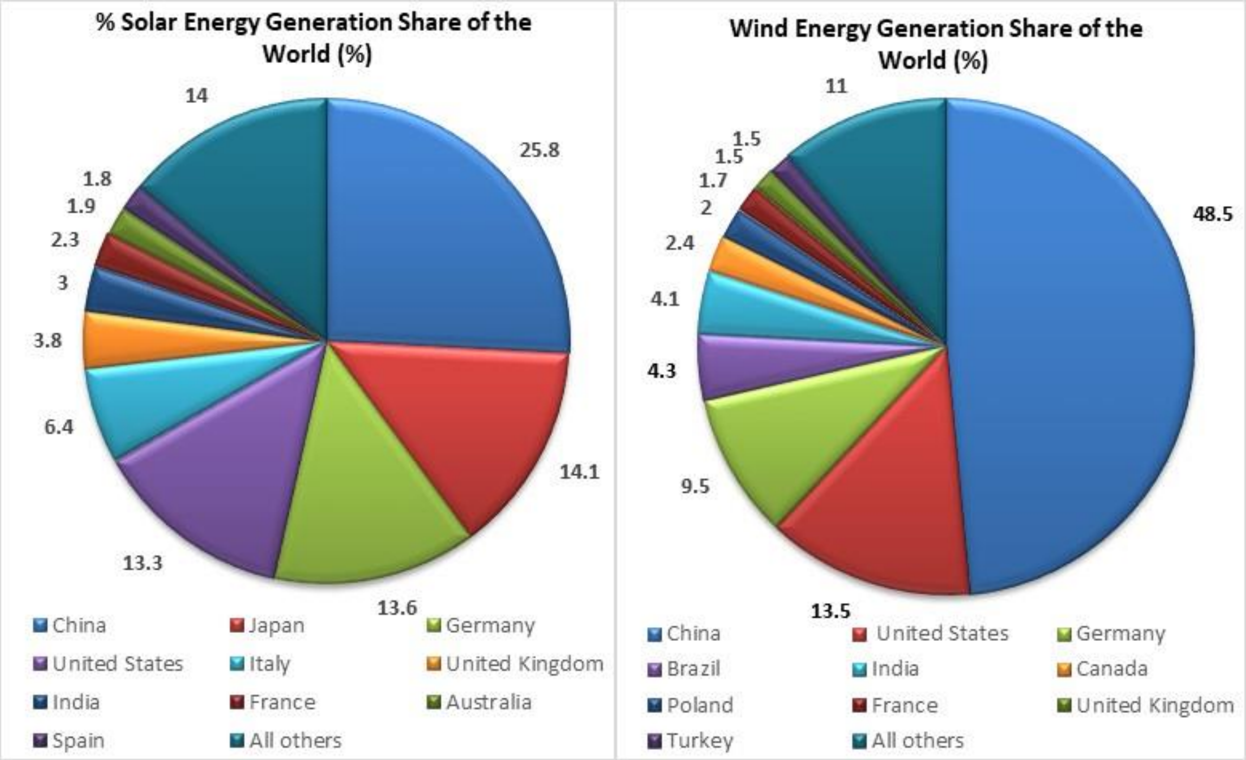

Fig. 3: Shares of total wind and solar energy generation around the world [26-27]

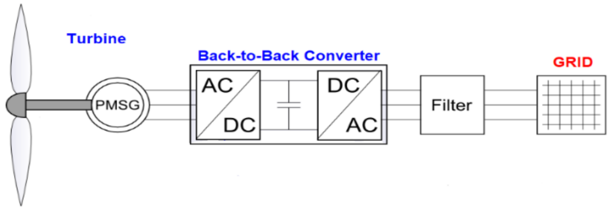

Fig. 4(a): General structure of wind energy generation system

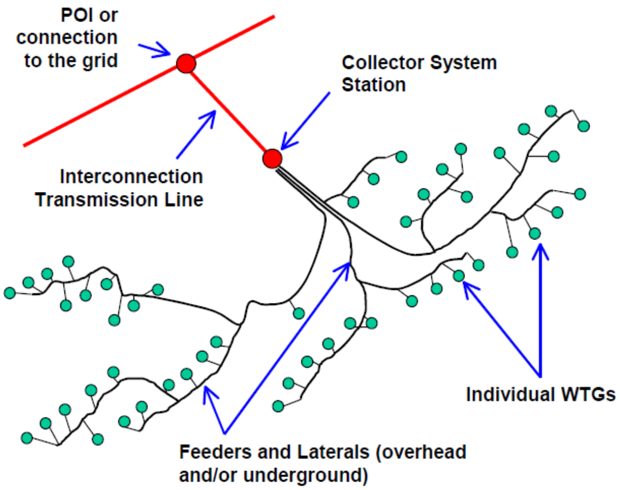

Fig. 4(b): Complete layout of grid integrated wind system network [30]

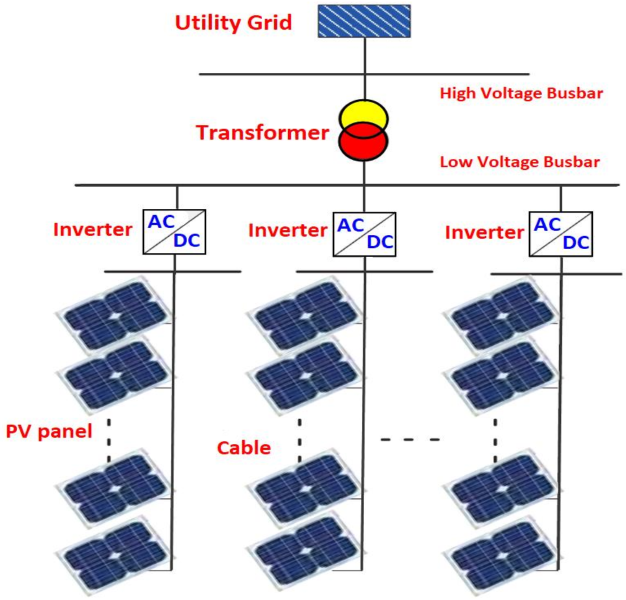

Fig. 5: Detailed model of grid integrated PV [30]

Therefore, variations in power acquired during the energy conversion process are caused by the unpredictable and intermittent nature of renewable resources. These fluctuations in power, in turn, generate changes in voltage and frequency when such systems are connected into the existing grid. Therefore, it is necessary to make weather forecasting technologies more advanced so that the controlling system of photovoltaic or wind generation plants can be designed in such a way that in the event of any change in environmental conditions, voltage sag or swell caused can be mitigated effectively either by spinning reserve (SR) or by sufficient energy storage systems. If nothing else, these voltage oscillations need to be stabilized by use of a specialized power supply. Therefore, it is necessary to develop a well-coordinated controlling system of systems based on renewable energy in order to make it possible for such systems to be linked with the grid in any location in a manner that is self-regulating. There are a variety of state-of-the-art solutions described in the available literature for addressing the problem of voltage and frequency shifts. In some strategies, the use of custom power devices (CPD) is suggested as a means of reducing voltage variations. A general categorization of the fundamental methods described in the literature is shown in Figure 6.

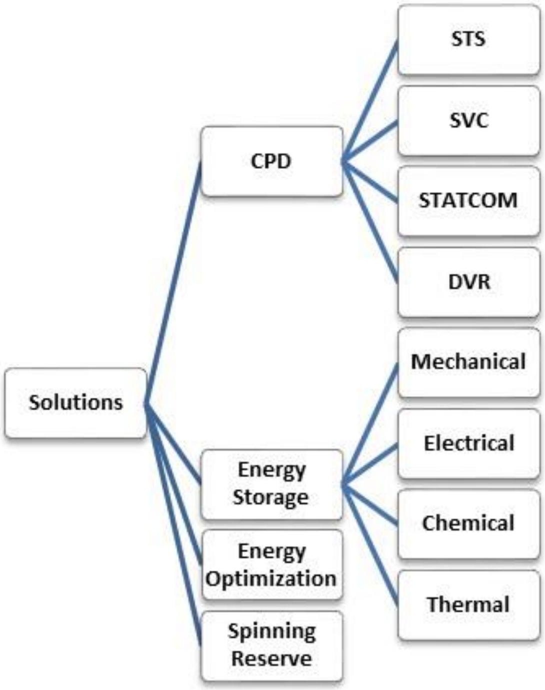

Fig. 6: Broad classification of solutions to voltage and frequency fluctuations

One of these solutions is called a Static Transfer Switch (STS), and it uses two static switches for each phase. Each static switch is, in essence, a collection of thyristors that are coupled in anti-parallel [35]. In the event that there is a drop in voltage or an interruption, it moves the sensitive load to the phase that is operating normally. In compared to the several alternative CPD solutions, STS offers the most cost-effective choice. The Static VAR Compensator is still another choice for CPD, and it is an example of a power electronically controlled passive device [35]. By adjusting the firing angle, it regulates the flow of reactive power between the PCC and passive parts like the capacitor and the reactor.

Controlling the flow of power into the grid in the event that the amount of renewable energy that is available varies is yet another potential method for addressing power quality issues brought on by the combination of renewable resources and grid integration. Kelvin Tan et al. [36] proposed a mechanical sensor less control of a PMSG based grid linked wind energy conversion system for maximum power tracking. The controller makes it possible for the PCC voltage to change to an operating point where it produces the most power based on the results of the power mapping loop and the PMSG frequency derivative loop. The use of a distributed generation (DG) system-based series compensator is one method that may be used to reduce the severity of further voltage variations. Transient response of DG series compensator has been compared with static transfer switch in one such research that has been carried out by the authors of reference [37]. According to the findings of the research, STS provides a solution to the issue of voltage quality that is both economical and effective. A study that can be found in reference [38] investigated the part that the power quality control center (PQCC) plays in reducing the negative effects that voltage has on sensitive loads. A unique strategy for the mitigation of voltage fluctuations has been described. This strategy makes use of the characteristics provided by the PQCC and is innovative in its own right. According to the findings of the analysis, the ride-through capacity of the system may be greatly increased to accommodate for downstream voltage sags. It is also possible to employ a technique that is based on a virtual synchronous machine (VSM) for the purpose of minimizing voltage and frequency fluctuations in grid-integrated renewable energy systems [39]. This approach represents the whole renewable energy system as a machine that uses alternating current and synchronous rotation.

Authors J. Zaragoza et al. present the control of a PMSG-based wind energy conversion system (WECS) using field oriented control (FOC) for the purpose of regulating speed regulation and producing current. For this objective, a PI controller is used, and the tuning parameters are obtained using a zero-pole cancellation (ZPC) technique [40]. This publication [41] reported research work on increasing integration of wind energy to the grid by better coordinating conventional resources of generating and energy storage systems. This may aid in optimizing wind energy generation, but it also enhances the predictability of wind farm output. The research was presented by the authors of the paper. In a similar manner, the authors Li Wang et. al. suggested a unique control strategy for the reduction of power fluctuations in grid integrated wind farms by the employment of variable frequency transformers [42]. The steady-state analysis of operating circumstances shows that the active power produced by a wind farm may be transmitted to the utility grid by precisely managing the torque output of the dc drive motor of the variable frequency transformer. This was discovered as a result of the findings of the study that was conducted. The authors [43] describe a novel method for managing the flow of electricity. By providing a service that reduces peak demand at the lowest possible cost, the goal is to facilitate the integration of a large amount of solar electricity into the grid. It is recommended that an optimum predictive power scheduling method should be used as the basis for the construction of a power supervisor. An enhanced design for grid interfacing is provided in reference [44] with the goal of enhancing the voltage quality that is achieved via the incorporation of wind energy into the grid. Several different series–parallel grid-interfacing system topologies have been suggested as possible solutions. They are well suited for DG applications, as well as for power transmission and the enhancement of voltage quality. The suggested systems have been compared with traditional series–parallel systems and shunt-connected systems, revealing that they have flexible application thanks to the reconfigurable capabilities.

The integration of wind farms into the current power system may present a number of challenges, some of which may be ameliorated by the use of energy storage and STATCOM. These findings are supported by the authors cited in reference [45]. Initially, the investigation will identify the power quality concerns that are present in the system operated by Southern California Edison, which has a significant amount of wind generating. In addition to this, it discovers the route limitation difficulties in one of the wind energy producing locations in that territory, which includes loads that are susceptible to disruptions in the power system. It has been shown via the use of computer models that the installation of a STATCOM and Energy Storage at certain sites within the region served by SCE may contribute to the reduction of voltage quality issues. [46] presents a novel control method that may be used in a grid-connected wind energy conversion system (WECS) that is based on a doubly fed induction generator (DFIG). The power shifts that occur on the grid as a result of the variable characteristics and unpredictability of wind may be mitigated with the use of a battery energy storage system (BESS), which is part of the proposed architecture. An investigation is carried out in terms of the active power sharing that occurs between the DFIG and the grid. This investigation takes into consideration the power that is either stored or discharged by the BESS depending on the amount of wind energy that is readily accessible. After that, the suggested approach is run via a simulation in Matlab-Simulink, and the constructed model is used to make predictions about the behavior. When compared to the previous research that has been done on the subject of the factors that regulate grid-fed DFIG-based WECS, this study makes an attempt to be as up-to-date and original as possible.

The information included in reference [47] provided a complete categorization of the many conceivable scenarios of voltage sag and swell. This classification was based on changes in irradiation, wind speed, and load. The performance of the inverter controller has been increased thanks to the extraction of features from the many conceivable instances.

Researchers [48] have suggested using VSM in conjunction with reactive power correction to create a combined operating mode. The STATCOM-based mitigation strategy is inferior to this methodology in terms of the synchronization it provides. There is a proposal for a new variable-speed WECS that makes use of a PMSG and a Z-source inverter [49]. The control of the permanent magnet synchronous generator is covered in this article. The goal of this control is to get the most amount of power possible from the wind that is blowing while maintaining the highest possible level of efficiency. Z-source inverter characteristics are used for optimum power tracking control while concurrently supplying power to the grid. This is done in tandem. [50] reveals a unique hybrid adaptive fuzzy control technique that was developed by the authors. This provides short-term frequency control assistance for DFIG-Based wind energy applications by using both the spinning mass of the DFIG and a super-capacitor bank as the virtual inertia sources. A super capacitor is linked to the DC link of the back-to-back converters in order to compensate for the intermittent nature of the wind, and an extra adaptive fuzzy controller is added to the super capacitor system controller in order to accomplish short-term frequency support. This is done in order to correct for the nature of the wind itself.

After the wind turbine is connected, the characteristics that are associated with the power quality issues are monitored and evaluated in accordance with the IEC Standard (IEC 61400-21). Concerning the quality of the power, there are seven parameters: the voltage unbalance, the harmonics, the inter-harmonics, the active power, the reactive power, the grid protection, and the reconnection time. Authors referred to in reference [51] shows how the wind mill is accountable for the following metrics after it has been researched and STATCOM has been added into the system by connecting it at PCC in order to provide the best solution to combat the power quality difficulties that were described.

An technique based on shunt compensators was presented in order to solve the issue of voltage fluctuation that arises with the integration of renewable energy into the grid. This strategy utilizes reactive power compensation as its foundation. This paper [52] presents a new control method to suppress the frequency fluctuations that occur due to a large amount of photovoltaic (PV) power generation and wind power generation. This control method is based on power flow control of high voltage direct current (HVDC) interconnection line and makes use of a dead band in its frequency control system. In addition, a variety of strategies for the regulation of power quality in grid-integrated renewable energy based systems may be found in the relevant body of published research [53–55].

B. *Current harmonics injection*

In order to integrate with the grid and facilitate the transfer of energy between the two, generating systems that are powered by renewable energy need inverter circuits that are powered by power electronics. Because of the high switching frequency at which these power electronics inverter circuits operate, they are responsible for the injection of high frequency harmonic current into the grid [34]. Interharmonic and supraharmonic emissions are produced by wind and solar energy generation systems that are grid integrated [56]. [57] The frequency range of supraharmonics ranges from two to one hundred and fifty kilohertz, and it is a novel sort of harmonic that has only lately attracted the attention of academics. It is necessary to conduct an in-depth analysis of the field data on harmonics emission caused by grid-connected renewable DG systems in order to guarantee improved power quality in the infrastructure of future power systems. Because of the tightly coupled nature of low voltage consumer loads, loads that are connected inside a solar or wind power plant are not as vulnerable as loads that are connected to dispersed generating. The use of a shunt active power filter is the typical method for mitigating the negative effects of harmonics. While there is room for study on how to regulate the inverter interface in such a way that the emission of harmonics is kept to a minimum, this research is not yet complete. For the purpose of making the provided current of DG systems fully active and closer to pure sinusoidal, several approaches have been offered in the relevant literature. A classification and analysis of these three approaches was provided in reference [58], which can be found in [59], [60], and [61] respectively. The current controlled mode, the voltage controlled mode, and the hybrid control mode. The ability of a grid-integrated DG system to limit harmonics emission, correct for harmonics, and improve voltage quality at the point of common coupling (PCC) is made possible by the operation of the controller in each of the modes. The table below provides a comparison of the three generalized compensation systems' respective degrees of flexibility [58]. Another innovative approach based on virtual impedance has also been documented in the published literature [62]. As illustrated in figure 7 [62], the virtual impedance method is versatile enough to be used to current as well as voltage source type converters, making it possible to achieve a number of different goals. When it comes to the successful completion of all of these goals with the integration of DG systems, the appropriate design of virtual impedance plays a very crucial role [63-66].

Table III: Comparison of Different Harmonic Compensation Schemes [58]

CCM		VCM	HCM
Local load harmonics compensation	Yes	Yes (without good damping)	Yes
PCC harmonic voltage compensation	Yes	Yes	Yes
DG line current harmonic rejection	Yes	Yes (indirect current control)	Yes
Grid impedance variations	Insensitive	Sensitive	Insensitive
Stand-alone operation with voltage control	No	Yes	Yes
Harmonics Sharing	Yes	Yes (requires information of feeder impedance)	Yes

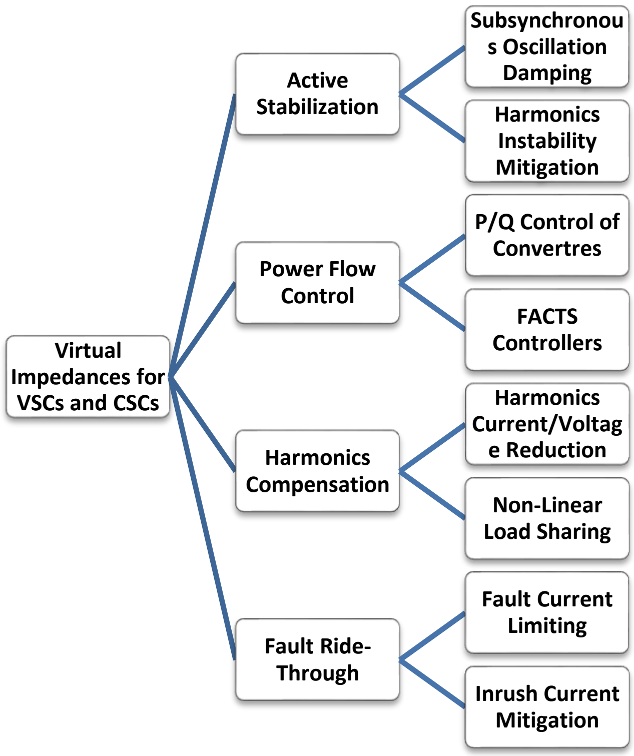

Fig. 7: Classification of virtual impedances [62]

Another alternate technique is to utilize a multi-functional grid connected inverter, which is an upgraded version of a traditional inverter and is able to efficiently conduct harmonics correction in addition to integrating DG systems into the grid [67]. This inverter is an enhanced version of the traditional inverter. Therefore, there is no longer a need for any other supplementary compensating mechanism for the point of common connection.

Control of a grid-interfaced solar photovoltaic (PV) power producing system was the topic of discussion for the authors M. Rezkallah et al. [68]. For the purpose of serving the tasks of active power injection to the grid, balanced grid currents at unity power factor, and load currents harmonics adjustment, a Lyapunov function based control strategy has been created and modeled for the dc–ac inverter. In addition to that, a method known as sliding mode control is used for the purpose of attaining maximum power tracking control of solar-PV arrays. A harmonic and interharmonic controller for grid-tie converters intended for use with renewable energy sources was presented in reference [69]. The measurement of the voltage at the point where the generating unit is connected is the sole factor considered in the control of the system. The authors also studied how the stiffness of the feeder affected the performance of the correction. The authors in [70] presents a proposal for a repeating controller that may mitigate voltage harmonics in voltage-source inverter (VSI)-based islanded micro grids. In this research, an explicit analysis of the phase lead filters and a unique design technique of the time advance unit in repetitive controllers are proposed in order to guarantee the stability of the system.

4. Power Quality Issues Caused by Changes in Methods of Transmission

Concerns about power quality have arisen as a result of the increased usage of cables for transmission purposes in contemporary power systems since high-voltage direct current transmission is being employed over shorter distances as well. The structure of the transmission system has been altered as a result of the implementation of devices based on communication technologies in the smart grid scenario. Because of recent advancements in the field of insulation and the optimization of cable size, cable transmission has become a solution that is both efficient and cost-effective. The majority of European nations have completely buried their power grids, both at low and medium voltage levels. There are two different reasons why an overhead transmission could be replaced with cable transmission on a regular basis. The first advantage is a decreased susceptibility to the effects of adverse weather, and the second advantage is a decreased likelihood of LG and LL faults occurring in distribution networks. As a direct consequence of this, the occurrences of voltage sags and surges are quite uncommon. In addition, the transmission of data via subterranean cables contributes to the protection of communities from the adverse effects of electromagnetic fields. However, as a result of this shift in the way electricity is transmitted, two significant problems have arisen with the power's quality. Figure 8 presents a categorization of the problems that have been encountered. Aside from that, the transmission of electricity through subterranean cables presents a number of challenges for the operators of utility transmission systems, including the prevention of corrosion and the control of stray currents.

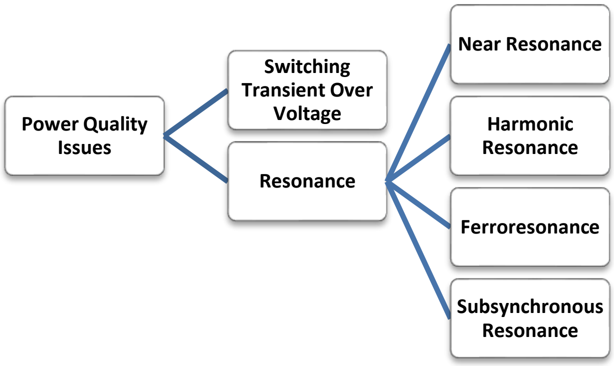

Fig. 8: Classification of PQ issues due to underground cable transmission

Switching transients are caused by various switching actions in the power network, such as the operation of circuit breakers, the energization of lines, transformers, and capacitor banks, and so on. As the name implies, switching transients are present in the power system. Switching transients are most important issues that pay to power quality issues that influence the power transmission system. Because subterranean cables have different properties than above lines, the problem of switching transients becomes more prevalent when the cables are used for transmission rather than the traditional overhead lines. The quantity of charging current rises as a result of the increasing capacitance of the cable, which is replacing the overhead line. When sent over longer distances via cable, the situation becomes much more severe. The most cost-effective method for addressing the high charging current flow in subterranean cable is known as shunt reactive compensation. In addition to this, it offers methods for correcting the extra reactive power that is caused by the capacitance of the cable. However, when shunt reactors are connected in a manner that is relatively near to one another, this enables the cable to participate in resonant situations [71-73]. As may be seen in figure 8, there are 4 different types of resonance difficulties that are nowadays recognized. Because of the increased capacitance of the cable, the resonance frequency drops, and the magnitude of the lower order voltage harmonic rises as a result of the lower resonant frequency. This change in resonance frequency may result in problems such as saturation on the core of the transformer or inappropriate performance of HVDC converters. There is no mistaking the fact that cable transmission has an influence on the frequency reaction of the power transmission system [74]. This highlights the need of transmission system operators carrying out the necessary technical analysis, particularly the computations in the time and frequency domains.

5. Power Quality Issues Caused by Changes in Methods of Consumption

There has been a significant shift in the ways in which the distribution network practices the use of electric power. The transformation in the manner in which contemporary power systems' infrastructures use energy has also given birth to significant problems with the power supply's quality. The parts that follow will go through these topics in further detail.

5.1 *Power Quality Issues due to Electric Vehicle*

As the effects of climate change become more severe, it is strongly advised that people purchase environmentally friendly automobiles, such as electric or hybrid electric systems. In the same time, the extensive implementation of electric vehicles (EV) poses a substantial hazard to the distribution network power quality if the number of EVs continues to increase. The feeding of these EVs from the grid in a manner that is both intelligent and flexible is an essential element of a smart grid. These battery-powered electric cars are connected to the power grid by means of a converter circuit so that their batteries may be charged. The power quality of the structure that distributes electric energy to these EVs is seriously compromised as a result of these electric car chargers [75]. As a consequence of its non-linear charging mechanism, an electric vehicle (EV) pulls harmonics current, which in turn leads other customers connected at PCC to have difficulties with low voltage quality, which in turn creates problems for equipment that is linked to voltage quality. There are 2 different types of charging elements that may be used for various purposes. One of them is an ordinary charger, while the additional one is a rapid charger [76].
The signal of the current strained by an EV is seen in Figure 9 both in the time domain and in the frequency domain [77]. Based on the results of the frequency study, it is abundantly obvious that EVs are a cause of harmonic emissions in the super harmonics band.

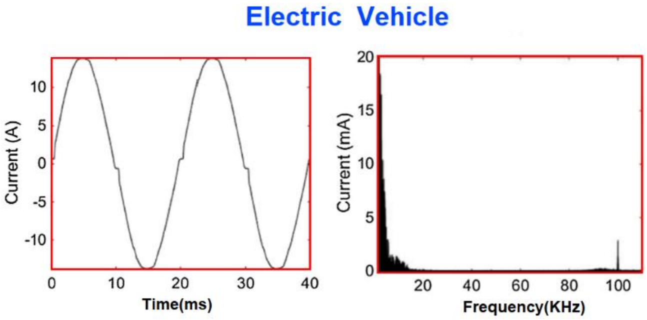

Fig. 9: Current drawn by EV in time and frequency domain [77]

There is a lot of room for study to be done in the field of potential solutions for increasing the power quality of electric cars, and while there is not a lot of published information on the subject, there are some strategies that have been recommended by researchers to help reduce the power quality issues that are brought on by charging systems for electric vehicles. The author of reference [78] suggested using a transformer-less hybrid series active filer for harmonics current correction, which guarantees a distortion-free voltage supply at PCC. This approach makes use of RES in order to enhance the power quality, and it also offers active power assistance to the grid. An other choice is to make use of a transformer-less hybrid single-phase shunt active filter. This kind of filter compensates for a broad range of harmonic current in an electrical vehicle that is linked to the grid and also offers reactive power assistance. In addition to that, this method provides an auxiliary service to the grid in the form of active power support [79]. Harmonics correction of the suggested SC with the DC capacitor voltage mechanism established the authors Fuka Ikeda et al. [80] studied technique for electric vehicles in single-phase three-wire distribution feeders under the circumstances of distorted source voltage and load currents. This unique and straightforward control technique was able to provide balanced source currents while maintaining a power factor of unity.

5.2 *Power Quality Issues Caused by Domestic and Industrial Consumers*

The way in which domestic and commercial clients of contemporary power systems utilize energy has resulted in the emergence of new categories of power quality issues in the infrastructure of modern power systems. Directly driven drives have been substituted by totally power electronics converter based machines in the scenario of enhancing the energy efficiency and flexible controlling. This has resulted in improved energy efficiency. Electric heating has completely supplanted the more traditional use of gas for heating. LED lights, which use far less energy, have gradually phased out incandescent lighting [77]. According to the study published by the Department of BEIS in the UK in July 2017 [81], Table IV demonstrates how the typical amount of domestic applications in the UK has changed over time. Light bulbs and LEDs are both examples of lighting applications. Energy efficient light bulbs are another kind of light bulb. Electronics for consumers include TVs, DVD/VCR players, set-top boxes and so on. Home computing appliances include monitors, laptops, desktop computers, printers and multifunction devices. Examples include desktop and laptop computers, monitors, and printers. All of these household equipment involve power electronics, which results in the production of harmonics. The battery charger is the central element of a significant variety of power electronics-based devices that are now capable of communicating with the grid. Because of this, there has been a rise in the amount of voltage and current distortion since the introduction of such a huge number of power-electronics based consumer goods for the household and industrial markets. Some tests have shown that extremely high efficiency LED lights may potentially be a source of supraharmonics [82, 83]. Even while the magnitude is usually rather modest, the rapid rise in the use of LED lights is a cause for worry over the quality of the electricity. The computer and the television are both examples of household gadgets that contribute to the production of harmonics in the supraharmonic range. Both the frequency and time domains are shown in Figure 10 for the waveforms of the current drawn by LED and TV respectively [77]. Based on the results of the frequency analysis, it is abundantly evident that the two are the source of harmonic emission in the supraharmonics region.

Table IV: Change in average number of appliances per household [81]

Year	Lighting	Cold Appliances	Wet Appliances	Consumer Electronics	Home Computing	Cooking
1970	16	1	1	2	0	1
1980	20	1	1	2	0	2
1990	22	1	1	4	1	2
2000	24	1	2	8	1	3
2010	26	2	2	13	3	3
2015	27	2	2	13	3	3
2016	27	2	2	13	3	3

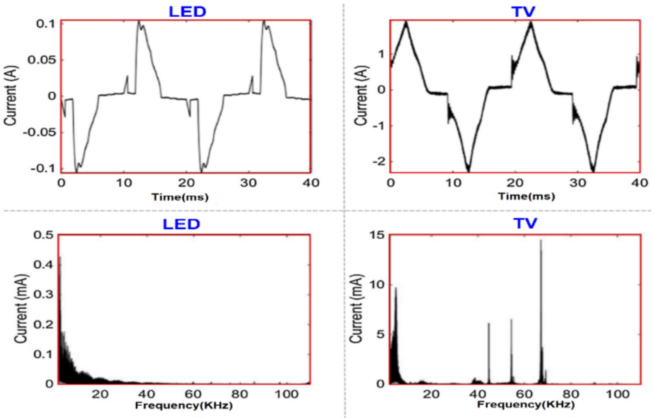

Fig. 10: Waveforms of current drawn by TV and LED [77]

The aforementioned household user equipment was the subject of a full investigation that was provided by the author [84-85]. In a similar vein, automation has led to increased levels of harmonic emission in industrial settings, which has contributed to a significant decline in the quality of both voltage and current.

6. Conclusion

A complete assessment of growing power quality issues brought on by the modernization of the power system has been carried out in this article of writing. It has been noticed that new quality difficulties have surfaced as a consequence of variations in the methodologies that are used to generate energy, changes in the methods that are used to transmit energy, and current activities that are used to consume energy. The most cutting-edge approaches to resolving these problems have also been covered, in a sequential order. It's possible that more traditional approaches to addressing power quality problems aren't as effective as they may be. As a result, there is a need for an in-depth examination of the most recent field data, which must be gathered while taking into account contemporary forms of power equipment.

The following are some proposals for the breadth of study that should be conducted in the future.

- The necessity for thorough monitoring of power quality is necessitated by the ongoing and present changes in the power system. In order for the current standards to be raised to a higher level, it is vitally important to do more research on the resistance of power system components to the newly discovered types of disruptions.
- There is a pressing need to place a greater emphasis on the analysis of data gathered from in-field quantities about the harmonic

spectrum of grid integrated RES and new type of consumer loads.

- It is necessary to develop an innovative control method for grid-interfacing inverters that is capable of concurrently mitigating voltage and frequency fluctuations brought on by variations in renewable energy sources and disruptions on the grid side.
- It is advised to do an analysis of the harmonics level in the grid, particularly when dealing with lengthy lengths of transmission wire. Harmonics level is an important topic that has to be researched in more depth, taking into account changes in line resistance with frequency as well as zero-sequence networks.
- A smooth change of the micro grid from an autonomous operation to a grid integrated operation and then back to an isolated mode is also highly important, and the monitoring and mitigation of quality issues that are created during that transition may also be an active field of learning.

Conflict of Interest

The authors declare, “No conflict of interest”

References

[1] IEEE Recommended Practice for Powering and Grounding Electronic Equipment - Redline," in *IEEE Std 1100-2005 (Revision of IEEE Std 1100-1999) - Redline*, vol., no., pp.1-703, May 24 2006.

[2] M. A. Mendes, P. R. Muniz, J. C. Marques, C. B. Donadel and J. F. Fardin, "Analysis of financial impacts caused by pollution from thermal power plants in Brazilian public health system," *2016 12th IEEE International Conference on Industry Applications*, Curitiba, 2016, pp. 1-6.

[3] H. Kuang, S. Li and Z. Wu, "Discussion on advantages and disadvantages of distributed generation connected to the grid," *2011 International Conference on Electrical and Control Engineering*, Yichang, 2011, pp. 170-173.

[4] EUROSTAT: *”Shedding light on energy in the EU – A guided tour of energy statistics”* Technical Report. Available: http://ec.europa.eu/eurostat/cache/infographs/energy-2016/images/eurostat/pdf-eurostat-print.pdf

[5] C. Roselund, and J. Bernhardt, "Lessons Learned Along Europe's Road to Renewables*”, IEEE Spectrum,* May 4, 2015.

[6] A. Zahedi, "A review of drivers, benefits, and challenges in integrating renewable energy sources into electricity grid," *Renewable and Sustainable Energy Reviews*, Vol. 15, pp. 4775-4779, 2011.

[7] A. H. Escribano, T. G. Sánchez, E. G. Lázaro, E. Muljadi, and A. M. Garcia, "Power quality surveys of photovoltaic power plants: characterisation and analysis of grid-code requirements," *IET Renewable Power Generation*, Vol. 9, pp. 466-473, 2015.

[8] G. Weng, S. Zhu, Y. Gong, T. Ma, F. Xie, "Research on power quality prediction for DG integrated smart grid based on neural network," *2017 IEEE Conference on Energy Internet and Energy System Integration*, pp. 1-6, 2017.

[9] E. Ebrahimzadeh, F. Blaabjerg, X. Wang and C. L. Bak, "Bus Participation Factor Analysis for Harmonic Instability in Power Electronics Based Power Systems," in *IEEE Transactions on Power Electronics,* Vol. 33, No. 12, pp. 10341-10351, 2018.

[10] A. Z. Khan, A. K. Janjua, S. T. Jan and Z. N. Ahmed "A comprehensive overview on the impact of widespread deployment of electric vehicles on power grid," *2017 IEEE International Conference on Smart Grid and Smart Cities*, Singapore, pp. 195-199, 2017.

[11] M. J. H. Rawa, D. W. P. Thomas and M. Sumner, "Experimental Measurements and Computer Simulations of Home Appliances Loads for Harmonic Studies," *2014 UKSim-AMSS 16th International Conference on Computer Modelling and Simulation*, Cambridge, pp. 340-344, 2014.

[12] H. J. Kim, J. W. Shim, K. Sim and K. Hur, "Assessment of Improved Power Quality Due to Fault Current Limiting HTS Cable," *IEEE Transactions on Applied Superconductivity*, Vol. 23, No. 3, pp. 5602104-5602104, June 2013.

[13] Von Meier, Alexandra, "Electric power systems: a conceptual introduction" *John Wiley & Sons*. p. 1., 2006.

[14] Dugan, Roger C., Mark McGranaghan, Surya Santoso, H. Wayne Beaty, "Electrical Power

Systems Quality" *McGraw-Hill Companies, Inc.*, 2006. ISBN 0-07-138622-X.

[15] Ghosh, Arindam, "Power quality enhancement using custom power devices" *Kluwer international series in engineering and computer science;* SECS 701. ISBN 1-4020-7180-9.

[16] IEC 61000-2-5: 2017 Electromagnetic compatibility (EMC) - Part 2-5: Environment - Description and classification of electromagnetic environments.

[17] IEC 61000-2-1: 1990, Electromagnetic Compatibility (EMC), Part 2, Environment, Section I: Description of Environment - Electromagnetic Environment for Low Frequency Conducted Disturbances and Signaling in Public Power Supply Systems. First Edition, 1990-05.

[18] "IEEE Recommended Practice for Monitoring Electric Power Quality," in IEEE Std. 1159-2009 (Revision of IEEE Std. 1159-1995), vol., no., pp.c1-81, 26 June 2009.

[19] IEEE c62.41: 1991, IEEE Recommended Practices on Surge Voltages in Low-Voltage AC Power Circuits.

[20] IEC 816: 1984, Guide on Methods of Measurement of Short Duration Transients on Low Voltage Power and Signal Lines.

[21] "IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems," in IEEE Std. 519-2014 (Revision of IEEE Std. 519-1992), vol., no., pp.1-29, 11 June 2014.

[22] Standard, I. E. C. "61000-4-7." General guide on harmonics and interharmonics measurements for power supply systems and equipment connected thereto (2002).

[23] Standard, I. E. C. "61000-4-15; Electromagnetic Compatibility (EMC)." Part4: Testing and Measurement Techniques. Section 15.

[24] Environmental Protection Agency. 2017. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015.

[25] Energy Information Agency (EIA). 2017. How much of the U.S. carbon dioxide emissions are associated with electricity generation?

[26] "Global Wind Report 2016 - Annual Market Update" Report, *GWEC*. 22 April 2016. Available: https://www.gwec.net/wp-content/uploads/vip/GWEC_PRstats2016_EN_WEB.pdf

[27] "2016 Snapshot of Global Photovoltaic Markets" International Energy Agency, 2017. Available: http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/IEA-PVPS_-_A_Snapshot_of_Global_PV_-_1992-2016__1_.pdf

[28] M. K. Hossain and M. H. Ali, "Statistical analysis of ramp rates of solar photovoltaic system connected to grid," *IEEE Energy Conversion Congress and Exposition (ECCE)*, Pittsburgh, PA, 2014, pp. 2524-2531, 2014.

[29] WECC WGMG, Wind Power Plant Power Flow Representation, May 2010. Available: http://renew-ne.org/wp-content/uploads/2012/05/WECCWindPlantPowerFlowModelingGuide.pdf

[30] "Grid integration of large-capacity Renewable Energy sources and use of large-capacity Electrical Energy Storage" *International Electrotechnical Commission (IEC) White papers*. Available: http://www.iec.ch/whitepaper/pdf/iecWP-gridintegrationlargecapacity-LR-en.pdf

[31] X. Liang, "Emerging Power Quality Challenges Due to Integration of Renewable Energy Sources," *IEEE Transactions on Industry Applications*, vol. 53, no. 2, pp. 855-866, March-April 2017.

[32] Fanxin Kong, Chuansheng Dong, Xue Liu, and Haibo Zeng, "Quantity Versus Quality: Optimal Harvesting Wind Power for the Smart Grid", *Proceedings of the IEEE*, Col. 102, No. II, pp. 1762-1776, November 2014.

[33] International Electrotechnical Commission (IEC) White Paper, "Grid Integration of Large-Capacity Renewable Energy Sources and Use of Large-Capacity Electrical Energy Storage", Geneva, Switzerland 2012.

[34] WECC Renewable Energy Modeling Task Force, Western Electricity Coordinating Council Modeling and Validation Work Group, "WECC PV Power Plant Dynamic Modeling Guide", April 2014.

[35] A. Sannino, J. Svensson, and T. Larsson, "Power-electronic solutions to power quality problems," *Electric Power Systems Research*, vol. 66, pp. 71-82, 2003.

[36] K. Tan and S. Islam, "Optimum control strategies in energy conversion of PMSG wind turbine system without mechanical sensors," *IEEE Transactions on Energy Conversion*, vol. 19, no. 2, pp. 392-399, June 2004.

[37] K. J. P. Macken, M. H. J. Bollen and R. J. M. Belmans, "Mitigation of voltage dips through distributed generation systems," *IEEE Transactions on Industry Applications*, vol. 40, no. 6, pp. 1686-1693, Nov.-Dec. 2004.

[38] Y. Q. Zhan, S. S. Choi and D. M. Vilathgamuwa, "A voltage-sag compensation scheme based on the concept of power quality control center," *IEEE Transactions on Power Delivery*, vol. 21, no. 1, pp. 296-304, Jan. 2006.

[39] Hans-Peter Beck, and Ralf Hesse, "Virtual Synchronous Machine", 9th *International Conference on Electrical Power Quality and Utilisation (EPQU 2007)*, pp. 1-6, 2007.

[40] J. Zaragoza, C. Spiteri Staines, A. Arias, J. Pou, E. Robles and S. Ceballos, "Comparison of speed control strategies for maximum power tracking in a wind energy conversion system," *Melecon 2010 - 2010 15th IEEE Mediterranean Electrotechnical Conference*, Valletta, 2010, pp. 961-966.

[41] H. Han, T. K. A. Brekken, A. von Jouanne, A. Bistrika and A. Yokochi, "In-lab research grid for optimization and control of wind and energy storage systems," *49th IEEE Conference on Decision and Control (CDC)*, Atlanta, GA, 2010, pp. 200-205.

[42] L. Wang and L. Y. Chen, "Reduction of Power Fluctuations of a Large-Scale Grid-Connected Offshore Wind Farm Using a Variable Frequency Transformer," *IEEE Transactions on Sustainable Energy*, vol. 2, no. 3, pp. 226-234, July 2011.

[43] Y. Riffonneau, S. Bacha, F. Barruel and S. Ploix, "Optimal Power Flow Management for Grid Connected PV Systems with Batteries," *IEEE Transactions on Sustainable Energy*, vol. 2, no. 3, pp. 309-320, July 2011.

[44] F. Wang, J. L. Duarte and M. A. M. Hendrix, "Grid-Interfacing Converter Systems with Enhanced Voltage Quality for Microgrid Application—Concept and Implementation," *IEEE Transactions on Power Electronics*, vol. 26, no. 12, pp. 3501-3513, Dec. 2011.

[45] B. Gudimetla, S. Teleke and J. Castaneda, "Application of Energy Storage and STATCOM for grid quality issues," *2011 IEEE Power and Energy Society General Meeting*, San Diego, CA, 2011, pp. 1-8.

[46] V. C. Ganti, B. Singh, S. K. Aggarwal and T. C. Kandpal, "DFIG-Based Wind Power Conversion with Grid Power Leveling for Reduced Gusts," *IEEE Transactions on Sustainable Energy*, vol. 3, no. 1, pp. 12-20, Jan. 2012.

[47] P. K. Ray, S. R. Mohanty and N. Kishor, "Classification of Power Quality Disturbances Due to Environmental Characteristics in Distributed Generation System," *IEEE Transactions on Sustainable Energy*, vol. 4, no. 2, pp. 302-313, April 2013.

[48] C. Li, R. Burgos, I. Cvetkovic, D. Boroyevich, L. Mili and P. Rodriguez, "Evaluation and control design of virtual-synchronous-machine-based STATCOM for grids with high penetration of renewable energy," *IEEE Energy Conversion Congress and Exposition (ECCE)*, Pittsburgh, PA, 2014, pp. 5652-5658, 2014.

[49] R. Jegatheeswaran, "Variable speed wind energy conversion system using PMSG & Z-Source inverter," *2015 International Conference on Innovations in Information, Embedded and Communication Systems (ICIIECS)*, Coimbatore, 2015, pp. 1-7.

[50] X. Hao, T. Zhou, J. Wang and X. Yang, "A hybrid adaptive fuzzy control strategy for DFIG-based wind turbines with super-capacitor energy storage to realize short-term grid frequency support," *2015 IEEE Energy Conversion Congress and Exposition (ECCE)*, Montreal, QC, 2015, pp. 1914-1918.

[51] S. T. Chavhan, C. L. Bhattar, P. V. Koli and V. S. Rathod, "Application of STATCOM for power quality improvement of grid integrated wind mill," *2015 IEEE 9th International Conference on Intelligent Systems and Control (ISCO)*, Coimbatore, 2015, pp. 1-7.

[52] K. Tada *et al.*, "Frequency control of power system with solar and wind power stations installed by flow control of HVDC interconnection line," *2017 20th International*

Conference on Electrical Machines and Systems (ICEMS), Sydney, NSW, 2017, pp. 1-5.

[53] J. C. Gonzales Arispe and A. B. Ponce Vasquez, "Wind and PV Farms Integration within Power Systems Using Static and Dynamic Simulations," *IEEE Latin America Transactions*, vol. 16, no. 1, pp. 148-154, Jan. 2018.

[54] B. Yang, T. Yu, X. Zhang, L. Huang, H. Shu and L. Jiang, "Interactive teaching–learning optimizer for parameter tuning of VSC-HVDC systems with offshore wind farm integration," *IET Generation, Transmission & Distribution*, vol. 12, no. 3, pp. 678-687, 2 13 2018.

[55] T. Mahmoud, Z. Y. Dong and J. Ma, "Integrated optimal active and reactive power control scheme for grid connected permanent magnet synchronous generator wind turbines," *IET Electric Power Applications*, vol. 12, no. 4, pp. 474-485, 4 2018.

[56] Yang, K., Bollen, M.H.J., Larsson, E.O.A., Wahlberg, M., "Measurements of harmonic emission versus active power from wind turbines" *Electric Power System Research*, 304–314, 2014.

[57] S. Rönnberg, "Emission and Interaction from Domestic Installations in the Low Voltage Electricity Network, up to 150 kHz" *PhD thesis,* Luleå University of Technology, 2013.

[58] Y. W. Li and J. He, "Distribution System Harmonic Compensation Methods: An Overview of DG-Interfacing Inverters," *IEEE Industrial Electronics Magazine*, vol. 8, no. 4, pp. 18-31, Dec. 2014.

[59] Y. W. Li, "Control and resonance damping of voltage source and current source converters with LC filters," *IEEE Trans. Ind. Electron.,* vol. 56, no. 5, pp. 1511–1521, May 2009.

[60] J. He, Y. W. Li, and S. Munir, "A flexible harmonic control approach through voltage controlled DG-grid interfacing converters," *IEEE Trans. Ind. Electron*., vol. 59, no. 1, pp. 444–455, Jan. 2012.

[61] J. He and Y. W. Li, "Hybrid voltage and current control approach for DG-grid interfacing converters with LCL filters," *IEEE Trans. Ind. Electron*., vol. 60, no. 5, pp. 1797–1809, May 2013.

[62] Xiongfei Wang, YunWei Li, Frede Blaabjerg, and Poh Chiang Loh, "Virtual-Impedance-Based Control for Voltage-Source and Current Source Converters", *IEEE Transactions on Power Electronics*, Vol. 30, No. 12, pp. 7019-7037, December 2015.

[63] T. Messo, J. Jokipii, J. Puukko, and T. Suntio, "Determining the value of dc-link capacitance to ensure stable operation of a three-phase photovoltaic inverter," *IEEE Trans. Power Electron*., vol. 29, no. 2, pp. 665–673, Feb. 2014.

[64] K. M. Alawasa, Y. A.-R. I. Mohamed, and W. Xu, "Active mitigation of subsynchronous interactions between PWM voltage-source converters and power networks," *IEEE Trans. Power Electron*., vol. 29, no. 1, pp. 121–134, Jan., 2014.

[65] Y. Zhang and Y. W. Li, "Investigation and suppression of harmonics interaction in high-power PWM current-source motor drives," *IEEE Trans. Power Electron*., vol. 30, no. 2, pp. 668–679, Feb. 2015.

[66] X. Wang, F. Blaabjerg, and Z. Chen, "Autonomous control of inverter interfaced distributed generation units for harmonic current filtering and resonance damping in an islanded microgrid," *IEEE Trans. Ind. Appl*., vol. 50, no. 1, pp. 452–461, Jan./Feb. 2014.

[67] Zheng Zeng, Huan Yang, Shengqing Tang, and Rongxiang Zhao, "Objective-Oriented Power Quality Compensation of Multifunctional Grid-Tied Inverters and Its Application in Microgrids", *IEEE Transactions on Power Electronics*, Vol. 30, No. 3, pp. 1255-1265, March 2015.

[68] M. Rezkallah, S. K. Sharma, A. Chandra, B. Singh, and D. R. Rousse, "Lyapunov function and sliding mode control approach for solar-PV grid interface system," *IEEE Trans. Ind. Electron*., vol. 64, no. 1, pp. 785–795, Jan. 2017.

[69] S. D'Arco, M. Ochoa-Gimenez, L. Piegari, and P. Tricoli, "Harmonics and interharmonics compensation with active front-end converters based only on local voltage measurements," *IEEE Trans. Ind. Electron*., vol. 64, no. 1, pp. 796–805, Jan. 2017.

[70] S. Yang, P. Wang, Y. Tang, and L. Zhang, "Explicit phase lead filter design in repetitive control for voltage harmonic mitigation of VSI-based islanded microgrids," *IEEE Trans. Ind. Electron*., vol. 64, no. 1, pp. 817–826, Jan. 2017.

[71] Wiechowski, W., Eriksen, P.B., "Selected studies on offshore wind farm cable connections-challenges and experience of the Danish TSO" *IEEE Power and Energy Society General Meeting*, July 2008.

[72] Bollen, M.H.J., Mousavi-Gargari, S., Bahramirad, S., "Harmonic resonances due to transmission-system cables" *Renewable Energies Power Q. J. (REPQJ)*, 2014.

[73] Bollen, M., Ackeby, S., Jansson, H., Jonsson, M., "Using transfer impedances to study harmonic resonances due to AC cables in a transmission system" *CIGRE Symposium*, Sweden, May, 2015.

[74] "Resonance and Ferroresonance in Power Networks" CIGRE WG C4.307, ISBN: 978-2-85873-264-7, 2014.

[75] Y. J. Liu, T. P. Chang, H. W. Chen, T. K. Chang and P. H. Lan, "Power quality measurements of low-voltage distribution system with smart electric vehicle charging infrastructures," 2014 *16th International Conference on Harmonics and Quality of Power (ICHQP)*, Bucharest, 2014, pp. 631-635.

[76] A. Supponen, A. Rautiainen, J. Markkula, A. Mäkinen, P. Järventausta and S. Repo, "Power quality in distribution networks with electric vehicle charging - a research methodology based on field tests and real data," *2016 Eleventh International Conference on Ecological Vehicles and Renewable Energies (EVER)*, Monte Carlo, 2016, pp. 1-11.

[77] Sarah Rönnberg, Math Bollen, "Power quality issues in the electric power system of the future" *The Electricity Journal*, Volume 29, Issue 10, 2016, Pages 49-61.

[78] A. Javadi, A. Ndtoungou, H. F. Blanchette and K. Al-Haddad, "Power Quality Device for Future Household Systems with Fast Electric Vehicle Charging Station," *2015 IEEE Vehicle Power and Propulsion Conference (VPPC)*, Montreal, QC, 2015, pp. 1-6.

[79] A. Javadi and K. Al-Haddad, "A Single-Phase Active Device for Power Quality Improvement of Electrified Transportation," in *IEEE Transactions on Industrial Electronics*, vol. 62, no. 5, pp. 3033-3041, May 2015.

[80] K. Nishikawa, F. Ikeda, H. Yamada, T. Tanaka and M. Okamoto, "Improvement of harmonics compensation performance of smart charger with constant DC-capacitor voltage control for electric vehicles in single-phase three-wire distribution feeders," *2016 IEEE 2nd Annual Southern Power Electronics Conference (SPEC)*, Auckland, 2016, pp. 1-6.

[81] "ENERGY CONSUMPTION IN THE UK" Report of Department of BEIS, July 2017. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/633503/ECUK_2017.pdf

[82] Blanco, A.M., Stiegler, R., Meyer, J. "Power quality disturbances caused by modern lighting equipment (CFL and LED)" *IEEE Power Tech (POWERTECH) Grenoble*, pp. 1–6, 2013.

[83] Martínez, D.A., Pavas, A., "Current supraharmonics identification in commonly used low voltage devices" *Power Electronics and Power Quality Applications (PEPQA)*, IEEE Workshop pp: 1–5.

[84] A. Gil-de-Castro, S. Rönnberg, M. H. J. Bollen, A. Moreno-Muñoz and V. Pallares-Lopez, "Harmonics from a domestic customer with different lamp technologies," 2012 IEEE *15th International Conference on Harmonics and Quality of Power, Hong Kong*, 2012, pp. 585-590.

[85] P. Gharde, N. Pande and P. D. Debre, "Load compensation of a stiff system using ISCT based D-STATCOM under unbalanced and non-linear load condition," 2017 *International Conference on Innovations in Information, Embedded and Communication Systems (ICIIECS)*, Coimbatore, pp. 1-4, 2017.

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