**Indonesian Journal of Electrical Engineering and Computer Science**
Vol. 22, No. 3, June 2021, pp. 1223~1235
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v22.i3.pp1223-1235

# Mitigating power quality disturbances in smart grid using FACTS

**Yahia M. Esmail[1], Ali H. Kasem Alaboudy[2], M. S. Hassan[3], Gamal M. Dousoky[4]**
[1]Ministry of Power and Electricity, Cairo, Egypt
[1,3,4]Department of Electrical Engineering, Faculty of Engineering, Minia University, Minia, Egypt
[2]Department of Electrical, Faculty of Technology and Education, Suez University, Suez, Egypt
[3,4]Department of Electrical and Electronic Engineering, Kyushu University, Fukuoka, Japan
[4]Department of Communications and Computer Engineering, Nahda University, Beni Suef, Egypt

**Article Info**

***Article history:***

Received Sep 9, 2020
Revised Mar 22, 2021
Accepted Apr 1, 2021

***Keywords:***

FACTS
Power quality
Smart grid
STATCOM
UPQC

## ABSTRACT

Power quality (PQ) assurance is a vital part of electrical distribution networks. There are many advantages and benefits of improving PQ, especially in the modern/smart grid. Smart grid (SG) has a lot of complicated and sensitive electrical components (non-linear loads) in addition to renewable energy systems (wind-solar) that may also be a source of PQ disturbances. PQ problems harm personal life and national production. Static synchronous compensator (STATCOM) and unified power quality conditioner (UPQC) are among the fastest response flexible alternating current transmission systems (FACTS) installed in smart grids to mitigate power quality disturbances such as voltage fluctuations, sag, swell, and harmonics. In this research, STATCOM and UPQC are designed and simulated in MATLAB/Simulink to overcome PQ-related disruptions in smart grids. Accordingly, the differences between the proposed two solutions are highlighted across this research and renewable energy sources' reliability during faults. Therefore, the reader will be able to choose the appropriate FACTS devices. This study emphasizes the extent of the smart grid need for the FACTS. As per the given results of this study, STATCOM and UPQC have shown exemplary performance in the PQ improvement investigations conducted in the context of smart/modern grids.

***Corresponding Author:***

Yahia M. Esmail
Department of Electrical Engineering, Faculty of Engineering
Minia University
61517, Minia, Egypt
Email: eng_muslim100@yahoo.com

## 1. INTRODUCTION

Power quality (PQ) becomes concerns intensely with both electric utilities and customers. Globally, while nations are striving to develop industry and production, they should be eager to enable/promote PQ improvement continually. Moreover, the authors in [1], [2] defined the PQ as “any power problem detected in voltage, current, or frequency deviations that fail customer equipment”. PQ problems cost Europeans more than 200 billion dollars a year, while 30 billion dollars per year were spent in the United States of America (USA) to tackle such issues [3], [4].

Power quality disturbances include voltage flicker, sag, swell, transients, harmonics, interruption, unbalance, frequency deviations, and over/under voltages [5]. With the rapid spread of non-linear loads, they have become the primary reason for harmonic distortion in-branch currents, which, in due course, leads to harmonic voltage distortion at distribution system nodes/buses. Voltage sag, a severe PQ degradation, is an immediate or drastic drop in the root-mean-square (RMS) voltage value spanning from 0.1 to 0.9 per-unit and sustains within this abnormal drop from 0.5 cycles to a couple of seconds [6]. Voltage sags that last less than a 0.5 cycle duration are considered transients. On the other side, a rapid RMS voltage change (surge) ranging from 1.1 to 1.9 per-unit of the steady-state value and persists for 0.5 cycles for a few seconds is defined as voltage swell. Swells that continue for less than 0.5 cycles are classified as transients, also [7]. Voltage fluctuation, as described by IEEE-1453 [8], is "a sudden and noticeable change in RMS voltage level, usually caused by changing system loads" [9]. Table 1 displays power quality standards, according to International Electrotechnical Commission (IEC) and Institute of Electrical and Electronics Engineers (IEEE) standards.

Table 1. Power quality standards [10]

| Category | Typical Duration | Typical Amplitude |
|---|---|---|
| Harmonics | Steady-state | 0–20% |
| Voltage sag | 0.5 to 30 cycles | 0.1–0.9 |
| Voltage swell | 0.5 to 30 cycles | 1.1–1.9 |
| Voltage fluctuations | Intermittent | 0.1–9% |
| Interruption | 0.5 cycles to 30 s | > 0.1 pu |
| Undervoltage | > 1 min | 0.8–0.9 |
| Overvoltage | > 1 min | 1.1–1.2 |
| DC Offset | Steady-state | 0–0.1% |
| Noise | Steady-state | 0–1% |

Nowadays, power systems are undergoing an era of smart grids. A smart grid (SG) is defined as two-way communication and electric power network that improves the reliability, security, and efficiency of the power systems for distribution, transmission, generation, and storage [11], [12]. Three concerns of the utmost importance for consumers in the SG are electricity cost (Tariff), efficiency, and higher power quality [13]. Utilities with smart power grids spend a lot to satisfy customers and give pure trouble-free electricity without any PQ disturbances [14]. Smart grids are characterized by being efficient, accommodating, intelligent, motivating, opportunistic, resilient, and quality-focused. The SG structure and operation bring extra challenges to PQ assurance as it contains many complex and sensitive electrical components that may also be a source of PQ disturbances [15]. Examples of these components are intermittent wind and solar power generation, inverters and rectifiers, battery chargers, fuel cell interfacing, uninterruptible power supply (UPS), industrial drives, non-linear loads, capacitor switching, and power-electronics gadgets [16].

PQ has significant impacts on the smart grid, such as flicker affects the human brain reacts and corrupts vision, increasing losses, reducing production, reducing the performance of computers and sensitive devices, security system failure, and unwanted triggering UPS relays, significantly impacts on the transfer of data via smart meters, and induction motor breakdown. Given the above challenges, SG operators are still mandated to enforce PQ standardized levels to reduce energy waste, minimize the generation cost, avoid penalties, increase power system reliability, increase the equipment lifetime, and reduce the equipment outage times [17].

The first actual appearance of the flexible alternating current transmission systems (FACTS) was in the 1980s. For years, interest in FACTS has increased significantly, as it maintains the electrical network's PQ and stability. FACTS are counted among the best solutions for improving the power quality, reliability, and efficiency of an SG. Static synchronous compensator (STATCOM) and unified power quality conditioner (UPQC) are fast response power-electronics-based FACTS installed in the SG to mitigate the unfavourable PQ disturbances such as voltage fluctuations, sag, swell, and harmonics. Authors in [4], [6], [18]-[20] did not discuss the comparison of FACTS such as STATCOM and UPQC with each other, especially in SGs. They did not give a detailed study or solutions to all the problems facing smart grids combined with renewable energy sources.

In this study, STATCOM and UPQC are designed and simulated in MATLAB/Simulink to improve PQ disturbances since they are fully compatible with compensating for the adverse impacts of sensitive and non-linear loads. Furthermore, the differences between the two presented solutions are highlighted under three case studies non-linear load, wind turbine, transient fault and then the reader would choose the appropriate FACTS. In this paper, we will connect the smart grid to the wind turbine, non-linear load, transient fault, and see its impacts and how both STATCOM and UPQC overcame these problems, as well as evaluate the reliability of the smart grid and wind turbines with different FACTS during various faults. Here the problem values that appear will be compared to standard values. This research is considered as a comprehensive guide to maintaining the power quality and stability in the smart distribution grid by using the most recent FACTS. The results obtained from this study are very motivating and can be used in many projects in the smart grid.

This manuscript is organized as follows. Section 2 explores the description and modus operandi of both FACTS device STATCOM and UPQC. Section 3 explains the use and design of STATCOM in improving the smart grid's power quality and describes UPQC and its ability to overcome PQ disturbances in details. Furthermore, the discussion is addressed in Section 4. A comparison is also carried out between the two systems (STATCOM and UPQC), clarifying each of its capabilities, advantages, and disadvantages. Finally, Section 5 addresses the main conclusions and future work in Section 6.

## 2. FACTS IN THE RESEARCH

### 2.1. Static synchronous compensator (STATCOM)

STATCOM is a fast response power-electronic device installed in the SG for reactive power compensation, improving voltage quality, and mitigating other power quality disturbances [21]. STATCOMs have been in service since the 1980s. Figure 1 shows an illustrative diagram of the STATCOM. STATCOM is a controlled reactive power source, where a set of a voltage source converter (VSC) and dc capacitors is shunt connected to medium voltage transmission lines, close to central loads [22]. The function is to provide a swift reactive power compensation that inherently supports the terminal voltage and mitigates PQ disturbances such as voltage fluctuation, sag, swell, and harmonics. The VSC is a power electronic device, which converts either from alternating current (AC) to direct current (DC) (rectification) or from DC to AC (inversion). pulse-width modulation (PWM) technique is used as a switches driver to develop a switched sinusoidal voltage waveform from a dc voltage. Integrated gate bipolar transistors (IGBTs) are typically used as switching elements since they have small and lower switching losses [22]. Figure 1 shows an illustrative diagram of the STATCOM. A coupling transformer represents a predefined inductive link between the PWM-inverter and the power system. The transformer inductance, along with the capacitive shunt element, acts as an LC filter to mitigate the unwanted high-frequency switching harmonics.

The operation of the STATCOM is as follows. The VSC voltage is matched with the AC bus voltage. When the AC bus's voltage is higher than the VSC voltage, STATCOM works as an inductance connected to the AC bus to attenuate the bus voltage increase. On the other hand, if the AC bus voltage becomes lower than the VSC voltage, then STATCOM works as a capacitance connected to the AC bus and injects an amount of reactive power as desired. If the AC bus and the VSC voltages have the same value, the selected reactive power exchange is zero [23].

STATCOM controls the amount of reactive power exchanged between the VSC and the AC bus. Here, the firing pulses driving the PWM-VSC are directed. The actual bus voltage is compared with the reference value, and the error is passed to a PI controller. The controller generates signals that drive the PWM-VSC. In this way, the STATCOM is operated, and accordingly, the voltage fluctuation is mitigated.

### 2.2. Unified power quality conditioner (UPQC)

UPQC is a compound of the two FACTS devices: dynamic voltage restorer (DVR) and STATCOM [24]. Thus, it combines the advantages of both STATCOM and DVR systems simultaneously. UPQC is a combined shunt and series active power filter (APFs) called (universal active filter) as shown in Figure 2. UPQC system is fully compatible with electrical distribution networks and smart grids, especially with sensitive loads connected at the point of common coupling (PCC) of the sensitive loads. The active shunt filter mitigates current disruptions such as current harmonics and controls dc-Bus to secure the system's ability to compensate, while the active series filter mitigates voltage quality disturbances such as harmonics, voltage swell, and sag [25].

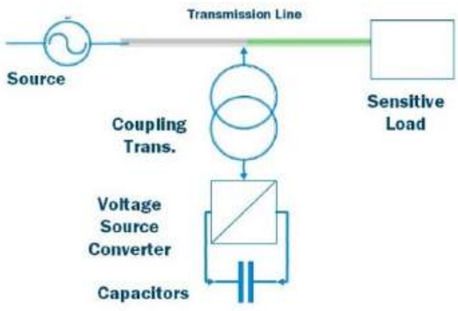


Figure 1. Structure of STATCOM

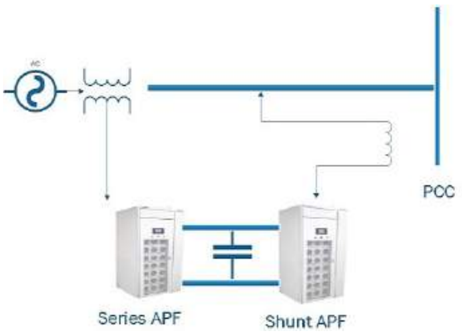


Figure 2. UPQC structure

UPQC comprises active shunt and series filters to mitigate the distorted voltage on both the supply and the load sides and ensure that the load voltage and the supply currents have a perfectly smoothed sinusoidal wave than any distortions. However, UPQC efficiency in power quality improvement remains constrained in its implementation. In this research, UPQC is employed for mitigating current and voltage harmonics in a power distribution network as a fundamental active power conditioning tool [25]. The findings of UPQC depend almost entirely on the rapid and precise compensation of the generated signals. UPQC has been configured to compensate both active and reactive power components based on a fuzzy logic control (FLC) strategy. The FLC is used to achieve reliable management of the existing nonlinearity [24].

FLC employs the fuzzy logic concept of the switching between membership and the non-membership functions resulting in unpredictable and unclear circumstances. The fluffy logical theory can be considered a subjective mathematical multi-valued logic that includes artificial intelligence and numerical methods. It imitates the human brain and uses interpretation in the connection and decision-making of various data sets. Figure 3 shows the three fundamental elements of the fuzzy logic system of control: fuzzification, decision making, and de-fuzzification. The control strategies of UPQC could be categorized into three systems [26]:

- Shunt control strategy: A shunt active power filter is provided when the system requires compensation for the current distorted signal or reactive power. This functions as a regulated current generator, which compensates the load current to make the source currents drawn from the network sinusoidal and synchronized.
- Series control strategy: The active series filter mitigates voltage quality. The compensation voltage, which was synthesized and placed in series with power supply voltage by the PWM converter, is generated to make the voltage sinusoidal at the point of standard coupling (PCC).
- The DC voltage regulator: The voltage value at the DC side of the control system varies while the compensation process takes place as UPQC improves the power factor by compensating the reactive power and the distortion concerning voltage and current. In case the value of DC voltage does not coincide with that of the rated value of voltage, the series active filter output voltage will not equate to the desired rate of compensation accordingly. The DC voltage control system is employed to produce a control signal that sustains the voltage at a steady value. In the case of an active shunt filter to derive an extra current from the system. To ensure maximum filtering characterization at minimum expenses, the proportional integration (PI) regulator is an adequate compromise.

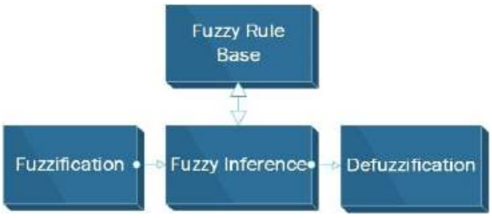


Figure 3. Basic diagram of the fuzzy logic controller of UPQC

## 3. RESEARCH METHOD AND RESULTS

In this section, the performance of both STATCOM and UPQC to overcome PQ disturbances in the smart distribution grid is demonstrated. STATCOM and UPQC are designed and simulated in MATLAB/Simulink to overcome PQ-related disruptions in smart grids. Three cases are selected to examine the performance of each type of considered FACTS. The first case is to connect the electric network with non-linear loads, which represent a significant portion of SG loads. The second test is to connect the electrical power system with a wind farm that is widely spread in SGs. The third case addresses the capability of FACT techniques to overcome transient grid faults and maintain the stability of SGs.

SG has many complex and sensitive electrical/electronic components (such as non-linear loads) in addition to renewable energy systems (wind & PV) that may represent a source of PQ disturbances. Most smart network loads have become non-linear due to power converters, rectifiers, battery chargers, UPS, variable frequency drives, and varying loads. Renewable energy sources, such as wind & solar, are now regarded as essential sustainable sources of electricity. Due to the inherent intermittent nature of the stochastic atmosphere conditions (i.e., variable air velocity), the power delivered by wind generators is highly variable. Accordingly, the voltage level generated by the wind generator continuously varies. According to the system's custom designs, wind farm instability is highly susceptible to grid faults due to the high reactive power consumption associated with large rotor slips of wind-power induction generators.

### 3.1. Performance of STATCOM in smart grid

A three-phase 22 kV power system connected to a non-linear load and a wind generator via a step-down transformer (22kV/380V) is shown in Figure 4. The base voltage at STATCOM and feeder bus: 22 kV. The feeder bus is connected to a step-down transformer (22 kV/380 V) to supply the non-linear load. The STATCOM system is connected in parallel to the electrical network immediately after the feeder bus, as shown in Figure 4. The wind turbine system uses a squirrel caged induction generator with a 500 kW rating, 380 V, with an average wind speed of 7 m/s. The most prominent PQ problems that arise from connecting the wind turbine to the smart grid are voltage fluctuations and harmonics, as will be verified later. Table 2 addresses the smart grid with STATCOM system MATLAB/Simulink parameters.

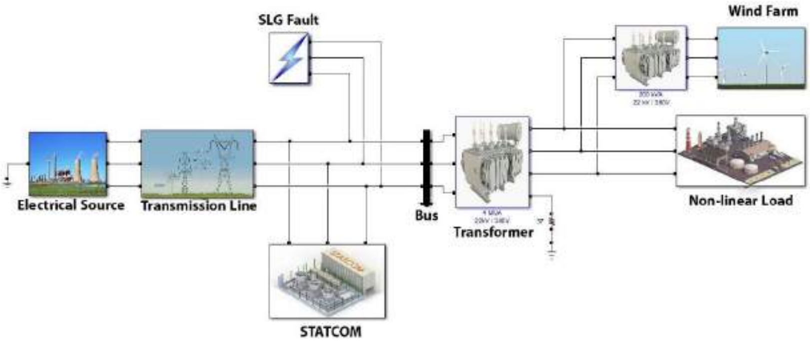


Figure 4. STATCOM with wind farm and non-linear load in SG model

Table 2. STATCOM system parameters

| System parameter | Value |
|---|---|
| Supply feeder voltage | 22 kV |
| Distribution Trans | 22000/380 V |
| STATCOM voltage | 22 kV |
| Frequency | 50 Hz |
| The load | 1 MVA |
| STATCOM rating | 500 KVAR |
| Wind turbine rating | 500 KW |
| Wind speed | 7 m/s |
| DC capacitor | 3 μF |
| Booster Tr. Turns ratio | 1:20 |
| Filter Inductance | 4 mH |
| Filter Capacitance | 10 μF |
| Controller type | PI Controller |
| Simulation time | 0.5 Second |

#### 3.1.1. Performance of STATCOM with non-linear load

In this section, the electric network (Figure 4) is connected to a non-linear load. The rating of the non-linear load is 1 MVA. Typically, non-linear loads result in voltage fluctuation, voltage, and current harmonics at the load bus, where this section explores how STATCOM soundly meet such challenges. Figure 5 and Figure 6 show the voltage waveforms at the feeder bus, which feed the non-linear load without and with STATCOM, respectively. Here it is clear that the voltage fluctuates between (1.09 and 0.99) pu. STATCOM mitigates voltage fluctuation, gives smoother voltage waveforms, and keeps the voltage nearly to 1 pu and within the permissible voltage limits. STATCOM efficiently improves the voltage quality in the high response (2 ms), as shown in Figure 6.

Figure 7 (a) shows the effect of employing the STATCOM on the feeder bus in the form of its voltage harmonic contents. This figure shows that the STATCOM reduces the voltage total harmonic distortion (THD) from 4.5% to 2.42%. Moreover, it has a significant effect on the load current harmonic content, in which its value reduced from a very high amount of 20.46% to an acceptable amount of 5.57%, as shown in Figure 7 (b).

#### 3.1.2. Performance of STATCOM with wind turbine

In this section, the electric network is connected to a wind turbine. This condition has resulted in voltage fluctuation, voltage harmonics, and current harmonics at the feeder bus. It will clear how STATCOM worthily overcomes all of these unfavourable disturbances. Figure 8 and Figure 9 show the STATCOM effect on improving voltage fluctuations caused by the wind turbine. Here it is clear that the voltage fluctuates between (1.02 and 0.94) pu. STATCOM regulates the voltage around one pu and keeps it between the prescribed limits.

By investigating the THD content for the feeder bus voltage, it has been observed that the grid-tied wind generator before connecting the STATCOM devices has a 4.18%. This relatively high value has been reduced to only 1.62% by adopting the STATCOM, as illustrated in Figure 10 (a). Similar to the performance of STATCOM exhibited with non-linear load, the STATCOM has a significant effect on the current harmonic contents, in which its value reduced from 16.25% to 5.47%, as depicted in Figure 10 (b).

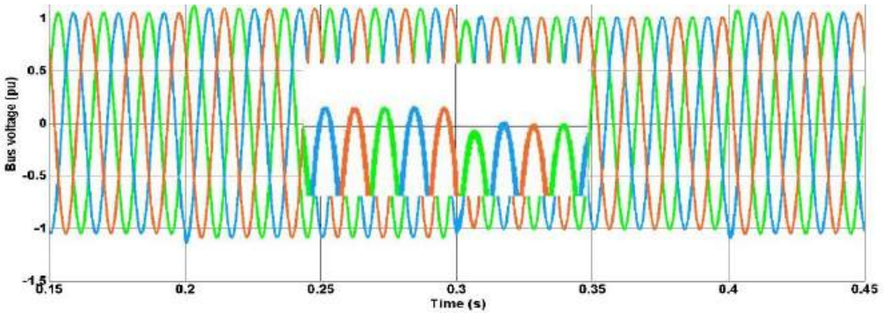


Figure 5. Voltage waveform at the feeder bus with the non-linear load without STATCOM

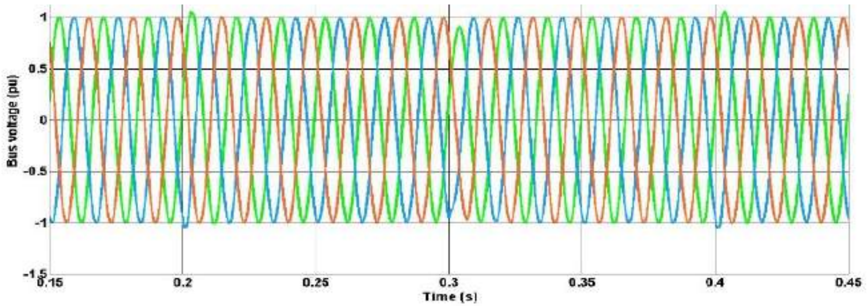
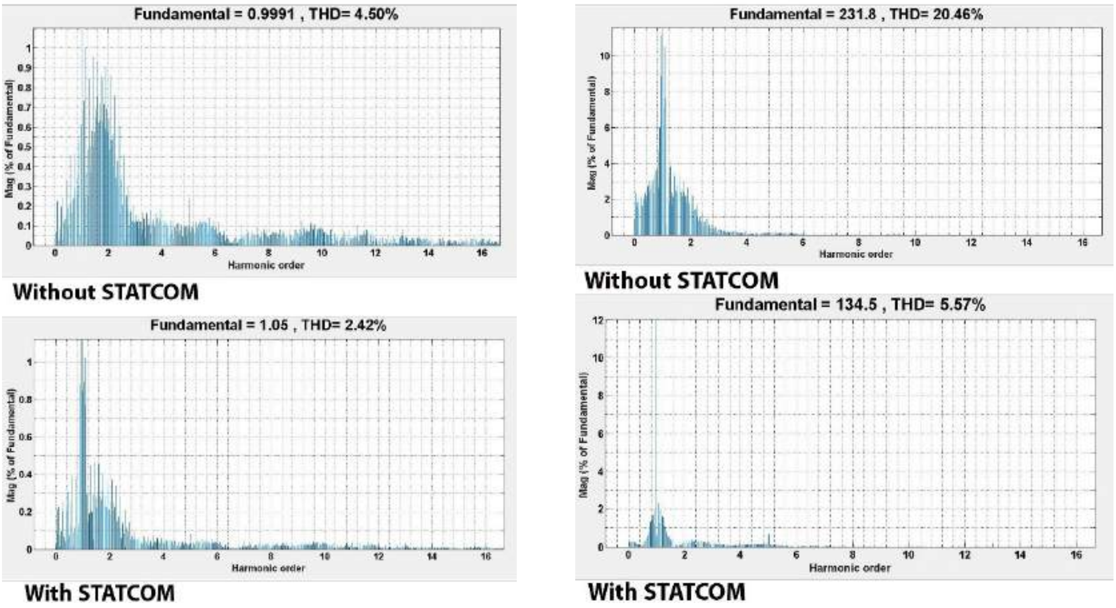


Figure 6. Voltage waveform at the feeder bus with non-linear load with STATCOM



(a) (b)

Figure 7. THD of the feeder bus with the non-linear load without and with STATCOM;
(a) THD of bus voltage, and (b) THD of bus current

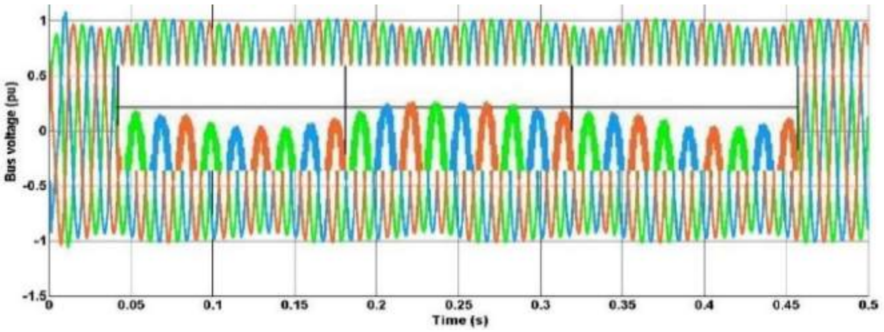


Figure 8. Voltage waveform at the feeder bus with wind turbine without STATCOM

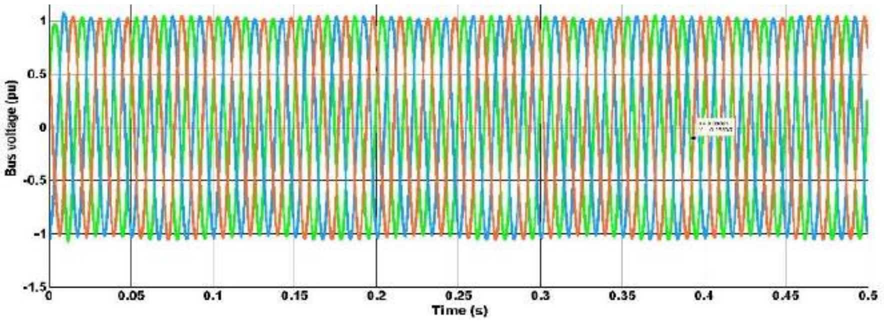
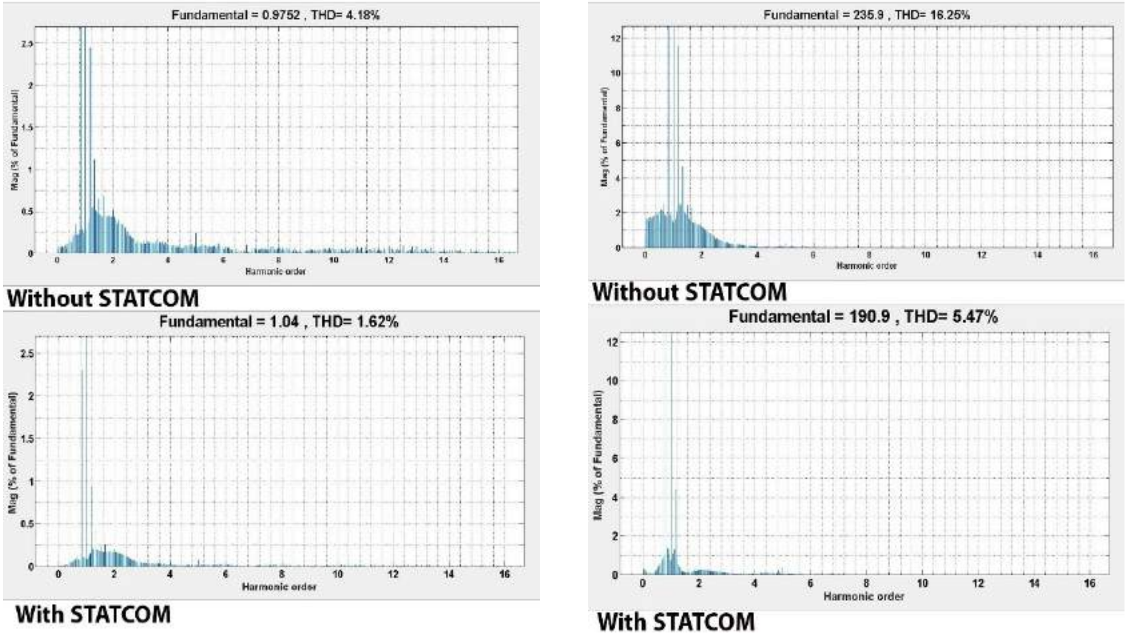


Figure 9. Voltage waveform at the feeder bus with wind turbine with STATCOM



(a) (b)

Figure 10. THD of the feeder bus with the wind turbine without and with STATCOM; (a) THD at bus voltage, and (b) THD at bus current

### 3.1.3. Performance of STATCOM with transient fault at grid side

Faults shall be included, which give rise to system failure, in which the results are analyzed in the MATLAB/Simulink environment. The transient three-phase to ground fault is applied in the period from 0.1-

0.12 s. It is worth to mention that system faults are one of the common issues that can contribute to system instability, which can be handled by STATCOM as studied in this section.

In this section, there is a transient three-phase to ground fault during the time 0.1-0.12 s, which is considered one of the most dangerous fault types. During the faults period, the bus voltage has been dropped to 0.73 pu of its original value, and network instability has been observed, as shown in Figure 11. The voltage limit has been improved to 0.95 pu, as shown in Figure 12.

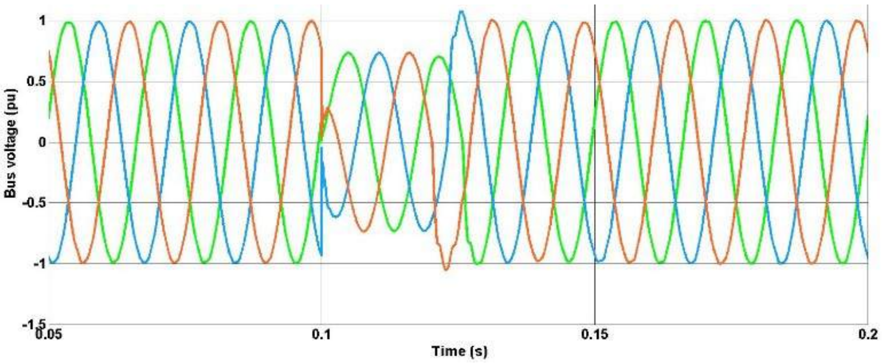


Figure 11. Voltage waveform at feeder bus with fault without STATCOM

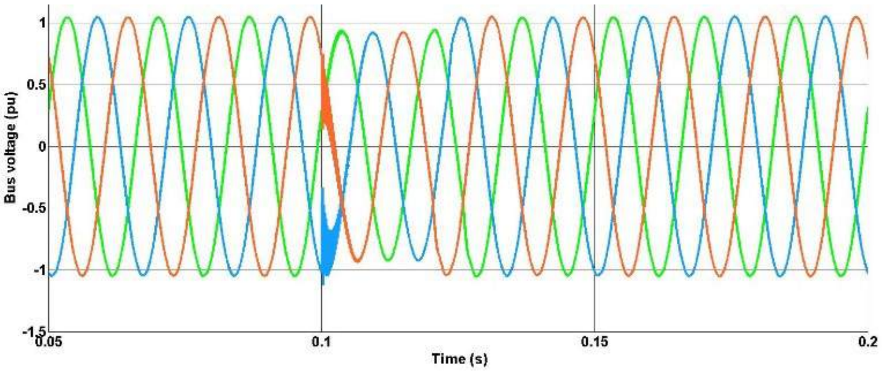


Figure 12. Voltage waveform at the feeder bus with a transient fault with STATCOM

### 3.2. Performance of UPQC in smart grid

UPQC is the most versatile but expensive FACTS device that can instantaneously regulate the flow of active power, reactive power, and voltage-independent. It has already been used in three-phase power systems around the globe. The network under study, shown in Figure 13, operates in the same operating conditions as the previous STATCOM network described earlier. The difference that the utilized FACTS here is the UPQC. The system in Figure 13 is meant to demonstrate how UPQC reacts with various PQ disturbances. Table 3 addresses the UPQC system MATLAB/Simulink parameters.

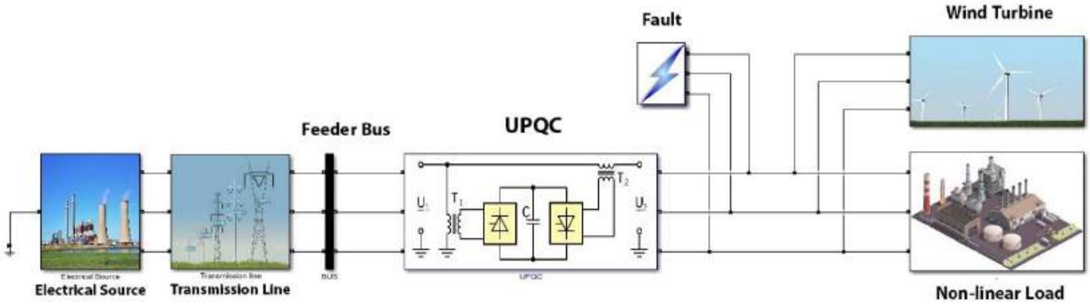


Figure 13. UPQC with wind turbine and non-linear load in SG

Table 3. UPQC system parameters

| System Parameter | Value |
|---|---|
| Supply feeder voltage | 22 kV |
| Distribution Trans | 22000/380 V |
| STATCOM voltage | 22 kV |
| Frequency | 50 Hz |
| The load | 1 MVA |
| UPQC rating | 500 KVAR |
| Wind turbine rating | 500 KW |
| Wind speed | 7 m/s |
| DC capacitor | 3 μF |
| Booster Tr. Turns ratio | 1:10 |
| Filter Inductance | 3 mH |
| Filter Capacitance | 10 μF |
| Controller type | Fuzzy Controller |
| Simulation time | 0.5 Second |

### 3.2.1. Performance of UPQC with non-linear loads

In this section, the electric network is connected with non-linear loads. The rating of the non-linear load is 1 MVA. Voltage distortion, voltage harmonics, and current harmonics at the feeder bus are highly expected. The UPQC overcomes voltage distortion caused by integrating non-linear loads from the time of 0.1-0.22 s. It keeps the voltage within limits the voltage becomes nearly one pu (pure sinusoidal wave), as shown in Figures 14 and 15. As is evident, UPQC instantaneously reacts with PQ disturbances, as shown in Figure 15. The UPQC worthily overcomes voltage harmonics due to non-linear load and minimizes THD values from 6.13% to 1.5%, as shown in Figure 16 (a). The UPQC efficiently overcomes current harmonics, which appears because of non-linear load, and reduces THD values from 12.14% to perfect discounts of 2.3%, as shown in Figure 16 (b).

### 3.2.2. Performance of UPQC with wind turbine

In this section, the electric network is connected to a wind turbine. This test results in voltage harmonics at the feeder bus. There is a THD 1.5% of feeder bus voltage due to combining with the wind turbine. UPQC overcame it and mitigated this value to 0.16%, as shown in Figure 17.

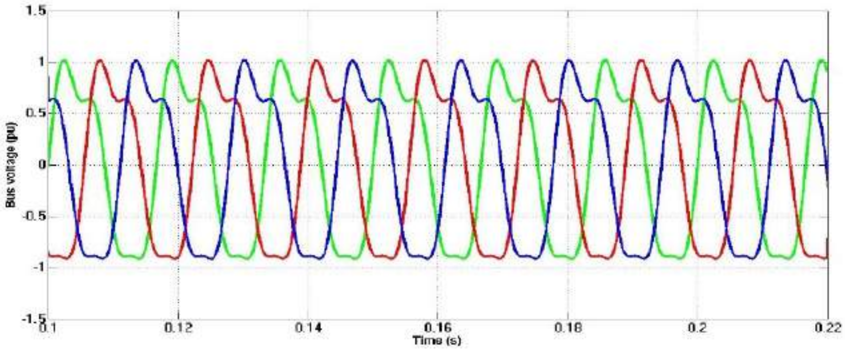


Figure 14. Voltage waveform at the feeder bus with the non-linear load without UPQC

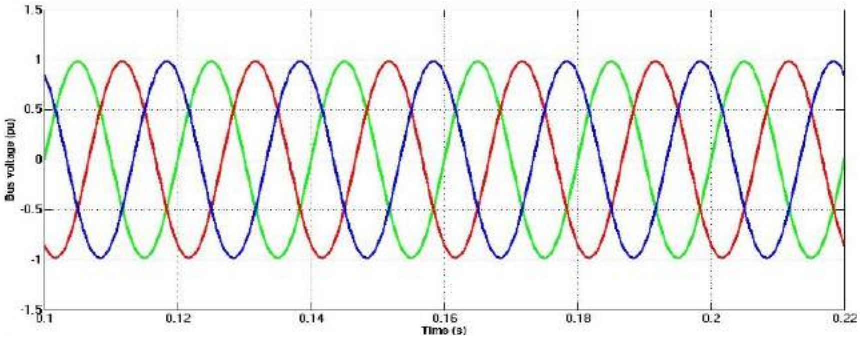
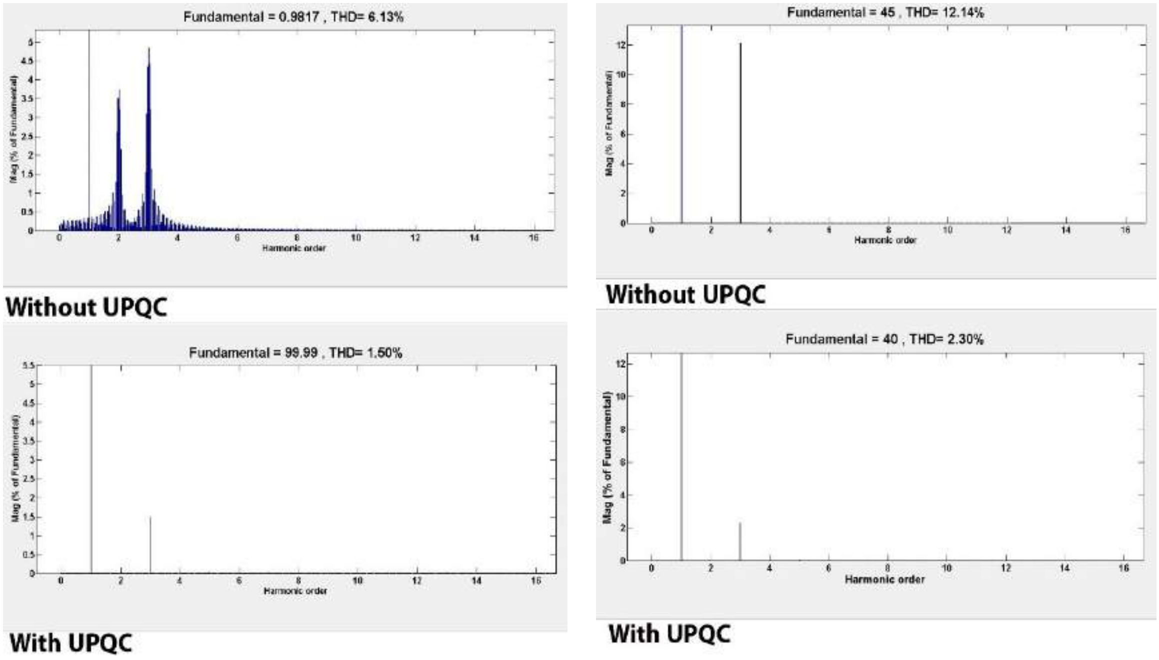
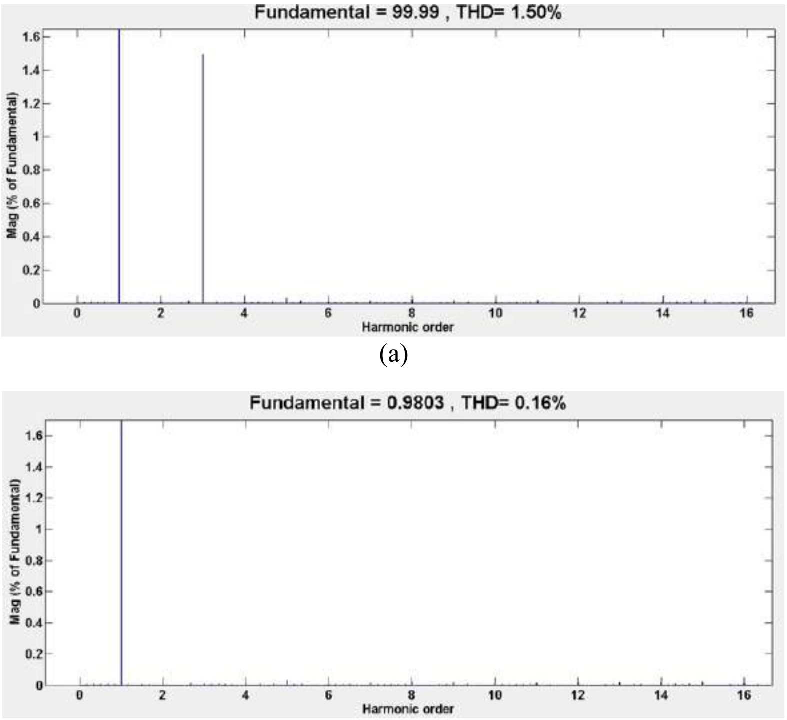


Figure 15. Voltage waveform at the feeder bus with non-linear load with UPQC



(a) (b)

Figure 16. THD of the feeder bus with the non-linear load without and with UPQC; (a) THD at bus voltage, and (b) THD at bus current



(a)

(b)

Figure 17. THD of the feeder bus voltage with the wind turbine load; (a) without UPQC and (b) with UPQC

### 3.2.3. Performance of UPQC with wind turbine

In this section, there is an occurrence of transient three-phase to ground fault during the time 0.1s - 0.12s, which causes system instability and is considered one of the most dangerous fault types. This fault results in the voltage drop (0.71 pu) and network instability shown in Figure 18. Figure 19 indicates that the UPQC overcomes this fault and limits voltage to nearly one pu (pure sinusoidal wave), and maintaining the network's stability. Thus, it can overcome any fault type with excellent efficiency.

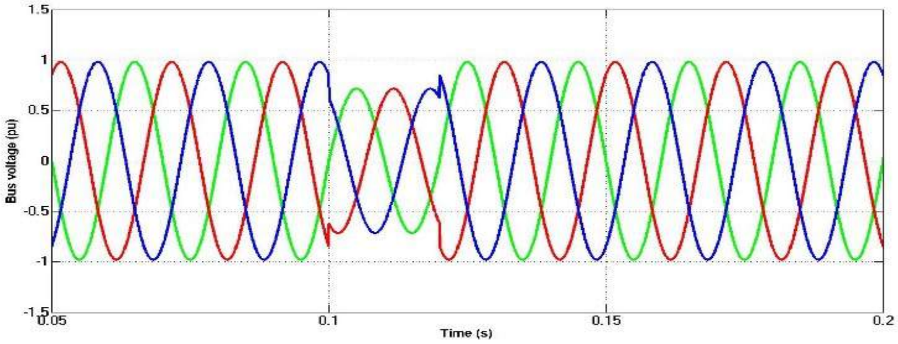


Figure 18. Voltage waveform at the feeder bus with transient fault without UPQC

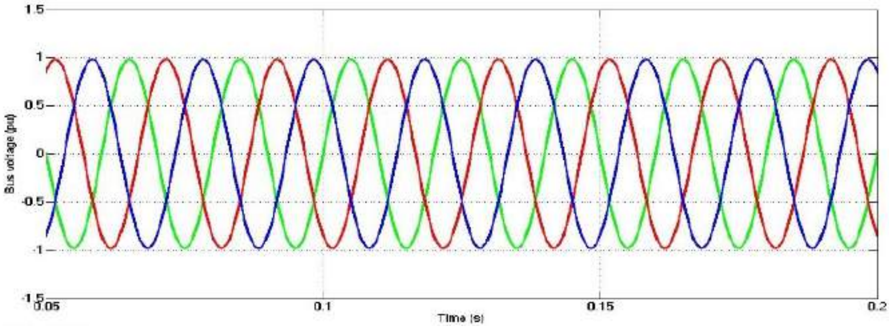


Figure 19. Voltage waveform at the feeder bus with a 3Ph.-G fault with UPQC

## 4. DISCUSSION

Although STATCOM and UPQC look similar for nonprofessionals, the circuitry structure, control scheme, purpose, and performance are distinctive for both STATCOM and UPQC. Based on the above-mentioned technical descriptions and simulation results, Table 4 compares the two FACTS devices according to this study. Based on this study, both systems STATCOM and UPQC are based on the gate-turn-off (GTO) thyristor switches and are considered fast; UPQC is superior as it responds instantaneously. While STATCOM must be connected in-shunt only, its response is within the limits of (2~4) ms. UPQC can be flexibly connected in shunt or series with specific conditions. It is worth to mention that UPQC is more expensive than STATCOM for the same kVAR ratings. Utility operators are advised to use STATCOM for PQ disturbances that are related to voltage variations and fluctuations. However, in the case of high sensitivity loads, the best option is UPQC adoption.

Table 4. Comparison between STATCOM and UPQC

| Type of FACTS | STATCOM | UPQC |
|---|---|---|
| Response Time | Fast (2 ms) | Very fast (instantaneous) |
| Control Type | PI Controller | Fuzzy Controller |
| Cost (USD) | 50-70 $/KVAR | 80-100 $/KVAR |
| Connection | Shunt | Shunt and Series |
| Purpose | Voltage control | Power flow control |
| Harmonics | Efficient | Excellent |
| Stability | Efficient | Excellent |
| Accuracy | High | Very High |

In this study and according to Table 5, one can notice that STATCOM has efficiency in overcoming harmonics troubles in SG, but UPQC is exceptional in overcoming such issues. The STATCOM system has overcome the voltage fluctuation by a percentage of 98%. In contrast, the UPQC system has overwhelmed the voltage distortion by a rate close to 100%. Moreover, STATCOM has regulated the fault voltage by a

95% percentage, while the UPQC system is close to 100%. Table 5 illustrates the THD values at feeder bus without and with STATCOM and UPQC in various cases where the table showed a remarkable ability of UPQC system to overcome the harmonics compared to the STATCOM system and in both of them are excellent. Consequently, both have maintained the PQ and stability of the considered electrical smart grid.

Table 5. THD values at feeder bus without and with STATCOM and UPQC

| Case | STATCOM | | UPQC | |
|---|---|---|---|---|
| | Without | With | Without | with |
| THD of voltage with non-liner load | 4.5% | 2.42% | 6.13% | 1.5% |
| THD of current with non-liner load | 20.46% | 5.57% | 12.14% | 2.3% |
| THD of voltage with wind turbine | 4.18% | 1.62% | 1.5% | 0.16% |

B. Li and Y. Ge [4], the author used the smart load to present and review only the PQ problems, and he did not give a sufficient study in this regard and therefore did not address the solution of the PQ problems. O. Ceaki *et al.* [5], the author only reviewed the problem resulting from connecting the smart grid to solar cells (Harmonics) and did not provide any solutions to the PQ problems. T. S. Saggu, *et al.* [18], the author just dealt with solving the harmonics using the UPQC system and did not give a detailed design or study in this regard. In review papers [6], [17], [20] The author has only reviewed some PQ problems.

Our paper gives a complete and detailed analysis study to solve the expected problems in smart distribution grids. This research is considered as a comprehensive guide to maintaining the power quality and stability in the smart distribution grid by using the most recent FACTS (STATCOM and UPQC) under different operating conditions from non-linear loads, during faults, and with renewable energy sources.

## 5. CONCLUSION

In this paper, the integration of STATCOM and UPQC into the smart grid is designed and simulated to mitigate power quality disturbances and stability using MATLAB/Simulink. This article constitutes guidelines for utility operators and consumers to select suitable FACTS devices based on their case constraints. UPQC instantaneously and exceptionally reacts with PQ disturbances by a percentage close to 100%, while STATCOM takes about two milliseconds to respond to grid disturbances and efficiently overcome PQ disturbances by a (95% to 98%) percentage. Therefore, UPQC seems to be the best FACTS system to improve PQ in the SG at high performance, especially in increased sensitivity loads. The results obtained from this study are very stimulating and can be used in many projects in SG. STATCOM and UPQC are practical solutions to improve most of the emerged PQ disturbances in smart power grids, and based on this detailed study, and the user would select a suitable FACTS based on the economic and technical constraints of each case. And we conclude that smart grids with their components are at their best conditions when FACTS are integrated into them. This study emphasizes the extent of the smart grid need for the FACTS. This research is considered a comprehensive guide to maintaining the power quality and stability in the smart distribution grid by using the most recent FACTS.

## 6. FUTURE WORK

A future application of this research is the development and use of FACTS in both the smart home, AC-DC hybrid smart grid, optimal use of vehicles to home (V2H), and vehicles to grid (V2G), fuel cell (FC), and super-capacitor systems. Consequently, it is necessary to develop and adopt the latest approaches and perspectives to protect smart grids from dire PQ danger. Also, more comparisons between FACTS are required to obtain the most efficient, cheapest and most suitable techniques.

## REFERENCES

[1] D. Saxena, K. S. Verma, and S. N. Singh, "Power quality event classification: An overview and key issues," *International Journal of Engineering, Science and Technology*, vol. 2, no. 3, pp. 186-199, 2010, doi: 10.4314/ijest.v2i3.59190.

[2] J. Stones and A. Collinson, "Power quality," *Power Engineering Journal*, vol. 15, no. 2, pp. 58-64, 2001, doi: 10.1049/pe:20010201.

[3] S. Fielding and J. Collier, "Part IV," in *The Cry: A New Dramatic Fable*, Lexington, Kentucky, USA: University Press of Kentucky, 2017, pp. 217-288, doi: 10.2307/j.ctt1w8h3pz.9.

[4] B. Li and Y. Ge, "Improving power quality by smart load," *Energy Procedia*, vol. 17, pp. 813-817, 2012, doi: 10.1016/j.egypro.2012.02.174.

[5] O. Ceaki, G. Seritan, R. Vatu and M. Mancasi, "Analysis of power quality improvement in smart grids,"*2017 10th International Symposium on Advanced Topics in Electrical Engineering (ATEE)*, 2017, pp. 797-801, doi: 10.1109/ATEE.2017.7905104.

[6] S. P. Jolhe, M. D. Karalkar and G. A. Dhomane, "Smart grid and power quality (PQ) issues," *2016 Online International Conference on Green Engineering and Technologies (IC-GET)*, 2016, pp. 1-3, doi: 10.1109/GET.2016.7916614.

[7] S. A. Rahman and E. Dagnew, "Voltage sag compensation using direct converter based DVR by modulating the error signal," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 19, no. 2, pp. 608-616, 2020, doi: 10.11591/ijeecs.v19.i2.pp608-616.

[8] *IEEE Recommended Practice for the Analysis of Fluctuating Installations on Power Systems - Redline*, IEEE Std 1453-2015 (Revision of IEEE Std 1453-2011) - Redline, vol., no., pp.1-174, 30 Oct. 2015.

[9] R. C. Dugan, M. F. McGranaghan, S. Santoso, and H. W. Beaty, *Electrical Power Systems Quality*. New York, USA: McGraw-Hill Education, 2002.

[10] I. Monedero, C. León, J. Ropero, J. L. De La Vega, J. C. Montaño, and J. M. Elena, "A system for the generation and detection of electrical disturbances," *Proceedings of the Fourth IASTED International Conference Power and Energy Systems*, 2004, pp. 180-185.

[11] D. K. Tanti, M. K. Verma, B. Singh, and O. N. Mehrotra, "Optimal placement of custom power devices in power system network to mitigate voltage sag under faults," *International Journal of Power Electronics and Drive Systems*, vol. 2, no. 3, pp. 267-276, 2012, doi: 10.11591/ijpeds.v2i3.370.

[12] J. Li, T. Li, and L. Han, "Research on the evaluation model of a smart grid development level based on differentiation of development demand," *Sustainability*, vol. 10, no. 11, 2018, doi: 10.3390/su10114047.

[13] R. Cheggou, E. H. Khoumeri, and K. Ferhah, "Energy-saving through smart home concept," *International Conference in Artificial Intelligence in Renewable Energetic Systems*, vol. 35, pp. 50-58, 2018, doi: 10.1007/978-3-319-73192-6_6.

[14] K. S. Mani, D. Padmavathi, and R. S. Rao, "Power quality improvement in wind smart grid using FACTS SSFC," *IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)*, vol. 11, no. 3, pp. 57-66, 2016, doi: 10.9790/1676-1103035766.

[15] G. Lobaccaro, S. Carlucci, and E. Löfström, "A review of systems and technologies for smart homes and smart grids," *Energies*, vol. 9, no. 5, 2016, doi: 10.3390/en9050348.

[16] R. Habachi, A. Touil, A. Boulal, A. Charkaoui, and A. Echchatbi, "Solving economic dispatch and unit commitment problem in smart grid system using eagle strategy based crow search algorithm," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 14, no. 3, pp. 1087-1096, 2019, doi: 10.11591/ijeecs.v14.i3.pp1087-1096.

[17] A. H. Bagdadee and L. Zhang, "Power quality improvement provide digital economy by the smart grid," *IOP Conference Series: Materials Science and Engineering*, vol. 561, no. 1, 2019, doi: 10.1088/1757-899X/561/1/012097.

[18] T. S. Saggu, L. Singh and B. Gill, "Application of UPQC for power quality improvement in induction furnace," *2018 IEEE/IAS 54th Industrial and Commercial Power Systems Technical Conference (I&CPS)*, 2018, pp. 1-6, doi: 10.1109/ICPS.2018.8369987.

[19] N. G. Jayanti, M. Basu, M. F. Conlon and K. Gaughan, "STATCOM and UPQC: Options to enhance fault-ride-through capability of a fixed speed wind generator," *6th IET International Conference on Power Electronics, Machines and Drives (PEMD 2012)*, 2012, pp. 1-6, doi: 10.1049/cp.2012.0191.

[20] S. S. Bhosale, Y. N. Bhosale, U. M. Chavan and S. A. Malvekar, "Power quality improvement by using UPQC: A review," *2018 International Conference on Control, Power, Communication and Computing Technologies (ICCPCCT)*, 2018, pp. 375-380, doi: 10.1109/ICCPCCT.2018.8574264.

[21] Y. M. Esmail, S. K. Elsayed, and M. A. Mehanna, "Mitigation of voltage fluctuation in power distribution system using D-STATCOM," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 2, no. 3, pp. 530-536, 2016, doi: 10.11591/ijeecs.v2.i3.pp530-536.

[22] T. M. Shehata, M. S. Abdul moteleb, and E. M. A. El-Zahab, "STATCOM controllers based on fuzzy PI approach," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 18, no. 3, pp. 1138-1147, 2020, doi: 10.11591/ijeecs.v18.i3.pp1138-1147.

[23] Y. M. Esmail, "Voltage flicker reduction in comparison with using DSTATCOM and OLTC transformer," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 4, no. 2, pp. 263-270, 2016, doi: 10.11591/ijeecs.v4.i2.pp263-270.

[24] S. Balaslubramaniyan and T. S. Sivakumaran, "Fuzzy logic controller implementation of power quality improvement using UPQC," *Circuits and Systems*, vol. 8, no. 8, pp. 202-226, 2017, doi: 10.4236/cs.2017.88014.

[25] V. M. Moreno, A. Pigazo, M. Liserre, and A. Dell'aquila, "Unified power quality conditioner (UPQC) with voltage dips and over-voltages compensation capability," *Renewable Energy and Power Quality Journal*, vol. 1, no. 6, pp. 294-299, 2008, doi: 10.24084/repqj06.285.

[26] P. A. Kumar and K. K. Kuthadi, "Power quality improvement for microgrid based UPQC system with fuzzy controller," *International Journal of Advance Research in Science and Engineering*, vol. 4, no. 2, pp. 111-120, 2015.