Results in Engineering 23 (2024) 102449

Contents lists available at ScienceDirect

Results in Engineering

journal homepage: www.sciencedirect.com/journal/results-in-engineering

Reactive power compensation during the convergence of grid system with FACTS devices

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ARTICLE INFO

Keywords:
Reactive power
Renewable energy
FACTS devices
D-STATCOM
Series phase compensator

ABSTRACT

From the last few years power demanding is increasing as per load requirement. The condition of power demand is not accompanied by only generation and transmission of electricity. Many industrial power plants are running on higher capacity to fulfill load requirement. There are many issues such as voltage instability and power quality which led to many power plants. In distributed generation generators are distributed asynchronous type and mostly affected by the reactive power. They basically cannot generate reactive power but draws away from the power system. It causes the voltage drop to the consumer side which may be not acceptable. Then reactive power management is essential for reducing those problems and provides continuity of electricity to the consumers. Distributed generation systems and FACTS devices are converting conventional power grid into smart grid. Reactive power compensation is now challenging issue to preserve adequate power quality and improve the performance of distribution system. There are many FACTS devices such as we can control power factor of the circuit and reactive power compensation. Many researchers have focused on behavior of FACTS device in an unbalanced condition and majority work is done only with DSTATCOM. This paper deals with different FACTS devices in grid systems with analysis and overview of D-FACTS devices. Hence in this paper, applications of various D-FACTS devices have been described to find location of compensation devices for reliable operation.

1. Introduction

Globally distributed energy production in conventional power network sector has been seen a significant growth by the adoption of renewable energy sources for attaining clean and reliable energy. Renewable energy is now commonly integrated with utility grid often alongside with energy storage system. As such there are various renewable energy sources like wind, solar, geothermal etc. Available but as per availability of energy source, a considerable amount of energy can be produced. The authors and researchers have done extremely discussion on such energy sources with the integration of DER along with electric grid. In conventional times fixed capacitors have utilized for reactive power compensation. Some recent literature survey has represented with emerging trends like voltage source converter (VSC) along with power electronic devices for smooth regulation of electricity. As by using these power electronic devices there may be chances of production of distortions which may affect on the performance of power system. Further some additional devices like static synchronous compensator (STATCOM), static VAR compensator (SVC) etc. can be used for achieving stable electricity (see Tables 1–5).

Through the functioning of such things, electric power network faces some challenges because of some complex designing and their functioning. Considering all such aspects the major issue is reactive power planning etc. which may evolve some difficulties in modern energy

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https://doi.org/10.1016/j.rineng.2024.102449
Received 19 March 2024; Received in revised form 12 June 2024; Accepted 18 June 2024
Available online 19 June 2024

Table 1
Comparison among various FACTS devices for reactive power compensation.

S. No.	Year	FACTS Device	Objective	Conclusion
1	2021 [1]	TCSC, TSSC, DSSC	Determination of series compensation techniques	DSSC provides more efficient operation and improved control.
2	2020 [2]	STATCOM, UPFC, SSSC, TCSC	Comparison among various FACTS devices for reliable power flow control	Enhanced power quality, flexible power flow control
3	2021 [3]	STATCOM, UPFC	Determination of power system stability	Provides voltage stability with emerged technology
4	2022 [4]	SVC	Designing and simulation in MATLAB interface	Discussed voltage and reactive power management
5	2024 [5]	FACTS devices	Analysis of smart grid operation emerging with FACTS	Role of FACTS is crucial for smart grid operation.
6	2023 [6]	UPFC	Comparison of FACTS devices along with discussion of voltage stability approaches	Ability of power control using UPFC FACTS device.

Table 2
Comparison among various optimization approaches for study of FACTS devices.

S. No.	Year	FACTS	Optimization Technique	Findings
1	2016 [7]	SVC	Artificial Bee Colony	Able to minimize power loss and improve voltage profile
2	2018 [8]	SVC, STATCOM, TCSC	Genetic algorithm	STSACOM surpasses SVC and able to identify ideal location
3	2019 [9]	D-STATCOM	Artificial fish swarm optimization	Ability to improve voltage profile and reduce losses
4	2020 [10]	SVC, TCSC	Whale optimization	Reduce transmission line losses
5	2020 [11]	SVC, UPFC, TCSC	Cuckoo search and particle swarm optimization	Cuckoo search algorithm performs better than PSO
6	2021 [12]	SSSC	Salp swarm optimization	Its modified version improves overall system performance
7	2021 [13]	SVC, UPFC, TCSC	Differential evolution algorithm	Able to identify proper location and reduce electrical power losses
8	2022 [14]	TCSC, SVC	TLBO, HBO, PSO, GSA	HBO and TLBO improves performance and provide optimal location.

Table 3
DSTATCOM parameters.

S. No.	Parameter	Values
1.	Breaker resistance	0.001 Ω
2.	Active power	5 kW
3.	Reactive power	3kVAR
4.	Input voltage	400v (rms)

DSTATCOM model has been designed that line parameters are taken as resistance of 0.002 Ω and inductance of 0.5 mH. This compensating device has been installed based on voltage source inverter and we are voltage measurement on load side is phase to ground.

Table 4
Parameters of single-phase series compensator.

S. No.	Parameters	Values
1.	Nominal voltage	220
2.	Nominal frequency	50Hz
3.	Active power	0.1 kW
4.	Reactive power	5kVAR
5.	FET resistance	0.1 Ω

In a single-phase series compensator, there are two stages of power conversion. Firstly, it comprises of DC-DC boost converter then the output stage is DC-AC tie converter which is installed between DC link and power grid. The role of voltage compensator is to reduce the ripples which are present in output of boost converter.

Table 5
Characteristics of D-FACTS devices.

S. No.	D-FACTS Devices	Characteristics
1.	D-STATCOM [Distributed Static Compensator]	Controlling of reactive power Uninterrupted power supply during the use of energy device Voltage regulation of power system
2.	D-SSC [Distributed Static Series Compensator]	Controlling of active power Smaller in size Less expansive
3.	D-SFC [Distributed Switched Filter Compensator]	Improvement of power factor Reduction of Total harmonic Distortion
4.	D-GPFSC [Distributed Green Plug SFC]	Less power losses DC bus voltage stabilization
5.	D-TCSC [Distributed Thyristor Controlled Series Compensator]	System Voltage Controlling System security by cyber control method

system management. The objective of reactive power planning is to reduce active power losses and voltage profile issues. Hence in this case an objective is to assess active and reactive power have become for all researchers and authors. So, researchers have suggested solution for attaining optimal balance between accessibility of power and cost reduction by implementing of some optimization techniques. Additionally, to minimize equipment cost associated with energy transmission, the distributed generation system has incorporated near the load or consumer center. Hence for achieving sustainable and exquisite distribution network, a systematic approach has been employed with DG unit and optimized controller. Distributed energy resources such as wind, solar, bio-gas are becoming popular in each energy sector as it is demanding and leveraging natural or alternate energy sources. By the adoption of renewable energy sources, there is start of declining of conventional energy sources to confront the limitation of fossil fuels. There are various limitations to the usage of fossil fuels as production of carbon gas emission, low efficiency and high maintenance cost. Hence by considering all aspects authors and researchers have move towards distributed energy sources. Apart from using renewable energy sources, there are also limitation towards using natural energy to convert into electricity. Some environmental challenges may occur and can affect on the performance of production of electricity. All such variables must be maintained at specific values to ensure proper and reliable plant operations. So by the adoption of distributed energy sources integrated with conventional energy system may reduce generation cost.

Distribution networks perform at low voltage level and transmit energy to the consumer side. But due to availability of large interconnection, expansion of network and shortage of infrastructure cause poor quality power of system and high-power losses in the network. Employing DG sources and FACTS devices reactive power compensation has become main objective. To achieve this many researchers have done work. Some of the techniques have been used as micro genetic algorithm [15]. The power system performs on ac supply system and many of the loads require reactive power energy. Hence sometimes VAR compensation device has to be characterized for enhancing the operation of power system [16]. The performance of entire power system depends upon utilization of load with and without grid. For both the conditions Vf control and PQ control is to adopted [17]. But during islanding operation of network management of power becomes difficult because loads are connected in uncertain conditions [18]. Renewable energy sources play a vital role in achieving the best operation with DG system for example solar PV cell with MPPT controller and its conversion process is low efficient and reliable [19]. In some conditions there is a problem of generating and transmitting energy to the consumers due to low capacity of large transmission lines. The solution of these issues can be solved with DG systems, employment of FACTS devices, configuration of lines, optimal sitting and location of automatic voltage regulators etc.

Block diagram of reactive power compensation is shown in Fig. 1 load compensation comprises adjusting of real power delivering from supply and improvement in voltage regulation. Series and shunt compensation both can be used. To improve transmission loss and power transfer capability power electronics-based devices have been developed.

Hence these FACTS devices like STATCOM, SVC, SSSC etc. have been used to compensate reactive power in electric distribution network. Basically, these devices have been used for the study of stability analysis for voltage and angle. With the proper management of reactive power, this has become an important aspect of distribution power network.

There are various equipment's which provide reactive power in the system and perform under various conditions. These equipments are basically placed in generators, static compensators and synchronous condensers etc. to provide better reactive power control. These equipments also help in controlling losses in the systems and improving the performance of system.

1) Shunt capacitor: In some power plants capacitor banks are placed in parallel in order to generate reactive power. Along this it also increases the power factor and then active power quantity of transformers.
2) Series capacitor: At the network the series capacitors are used to overcome the impedance of transmission lines which boost the power transmitting ability. Sometime series capacitors are also used to compensate the series inductive effect of transmission lines by introducing negative reactance.
3) Synchronous condenser: Synchronous condenser is basically preferred as synchronous motor which runs at no load and can be functioned as motor or generator. There are basically three modes of operation like under excited, normal excited and over excited which are all dependent upon power factor.
4) Reactor: These are the reactive power consumers which installed at substations and at transmission line end in parallel configuration. So, reactor are performed as when load is minimum reactor is turned on and when load is maximum reactor is turned off.

The major problem is power quality in micro grid operation and it is mitigated by applying harmonic, voltage sag and voltage swells. Due to this sudden disturbance occurs near at the customer side. Different research work has given suggestion reactive power compensation devices for better power quality operation. For reactive power management it is necessary to understand the management of active power. Reactive power takes place in order to generate electric and magnetic field. Hence reactive power consumption introduces reduced power factor and less reliable operation of the entire system. The contribution of this paper deals with introduction to FACTS device and its switching operation on applying unsymmetrical faults. At the end best FACTS device is to be identified for better reactive power compensation.

Organization: In this paper section no.2 elaborates literature review of FACTS devices along with comparison of various optimization techniques. Section no. 3 highlights the description of reactive power compensation devices for efficient operation of power system. Section no.4 demonstrates the modeling and simulation results of FACTS devices on different switching operation. Section no. 5 elaborates about conclusion of FACTS devices for reactive power compensation and section no. 6 highlights future work of FACTS devices.

2. Literature review

The concept of FACTS device was introduced by N. G. Hingorani for controlling operation of active and reactive power [21]. There are various FACTS devices such as SVC, STATCOM, single phase series compensator are used for ensure continuous power supply. Regulation of reactive power compensation is important in any unbalance load or power supply condition. The transient voltage response is most important parameter of power system assuming fast dynamic behavior of load. For stabilizing voltage profile dynamic compensation is needed to stabilize the operation of power system. In all FACTS devices STATCOM has been used most widely for operation with robust control [22]. In addition to reactive power compensation many optimization techniques have been preferred such as genetic algorithm, artificial neural network for stabilizing voltage profile. N. K. Saxena et al. [23] has been proposed different optimization techniques for reactive power compensation devices. Rudresh B. Magadum et al. [24] has been proposed integration of multiple DGs with STATCOM and analysis is carried out under MiPower software environment. Shazly Abdo Mohamed et al. [25] have proposed static compensator for reactive power compensation on transmission system and it is found more flexible and having fast response time.

Holtsmark et al. have proposed AC-DC FACTS device and use

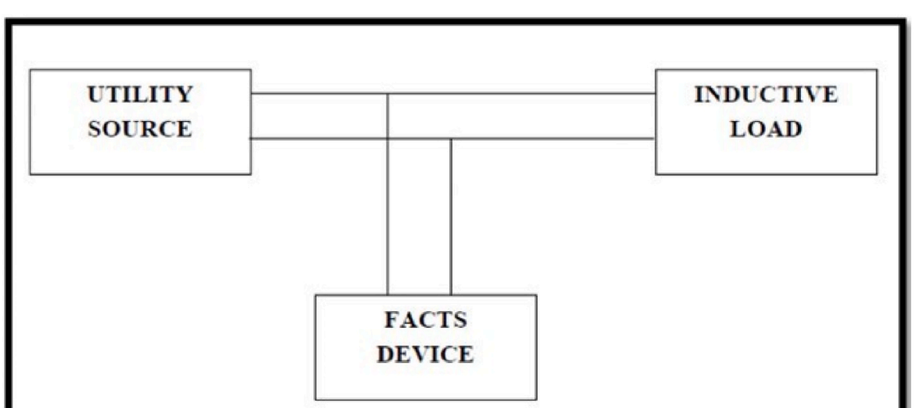

Fig. 1. Block diagram of reactive power compensation [20].

methods to increase capability of reactive power compensation with application of three vector scheme [26]. The power converters are also employed into the distributed generation system and utilizing of these converters provides fast operation and reliable function. Now generally in electric power distribution systems active power and reactive power management both take place. Damian O. Dike et al. has been proposed bus voltage stability based reactive power compensation scheme with incorporation with Newton Raphson's method [27]. Muhammad A. Sakib et al. has proposed the role of static synchronous compensator for achieving better power quality of wind integrated power system [28]. Reactive power compensation is a method to overcome the reduction of energy losses also with advantages of improving power factor correction, voltage stability and advancement of voltage profile. Ritesh Dash et al. have proposed dynamic active compensation system under IEEE standard 1547 and done comparison between conventional hysteresis controller and fuzzy system controller [29]. Reactive power is generated inherently by power stations, synchronous condensers and static compensators etc. The generation of reactive power has two major issues like generation capacity of reactive power is limited and second is extensive capacities of transformers and distribution lines with huge losses in system. Aishvarya Narain et al. [30] has described about different reactive power compensation techniques with their comparison and found UPFC is better for voltage control and load flow. D. A. Krishna et al. [31] has implemented STATCOM for reactive power compensation through transmission line under IEEE standard 5 bus system under MATLAB environment. The existence of reactive power sources introduces not only reduction of losses but also raises the capacity of transmission lines. Normally synchronous generator behaves as a diesel generator and induction generator performs in wind turbines for the achievement of better performance. An induction generator has enormous advantages than synchronous generators but in induction generators reactive power is major problem for its operation. After all synchronous generators contribute reactive energy to the induction generator but there is always deficit of reactive power in the system [32].

Sometimes in hybrid systems there may be need of more than one electric generator then an induction generator provides immense advantages over traditional synchronous generators as origin of confined power supply. The benefits of employing induction generators are reduction of unit cost, absence of carbon brushes and dc sources for production of current and short circuit but it necessitates reactive power reinforcement [33]. Kumar et al. [34] has presented pricing of reactive power compensation under steady-state and dynamic conditions using fixed capacitor and STATCOM. Nitin Saxena et al. [35] has proposed adaptive neuro fuzzy interference system for tuning the parameters of STATCOM of wind diesel-based hybrid model. Huang G et al. [36] have proposed transient voltage stabilizing controller for enhancing voltage stability with effect of steady state and small signal voltage stability.

In FACTS devices there are some switching operation which are conducted by electronic switches. By employing these ones, they try to enhance flexible operation and able to increase transmission capacity up to 50 % [37]. Authors have suggested both types like series and shunt FACTS devices which may allow to flow the current in the circuit. Mostly shunt type compensators are used for reactive power compensation while series FACTS devices depend upon some specific design for proper flow of electric current in network [38]. Based on SVC type FACTS devices, it is used for determining amount of reactive power by using some specific expression using variable susceptance B_{SVC} [39]. An author proposed STATCOM for keeping voltage stable at buses, it uses less amount of active power to regulate and monitor the flow of reactive power by managing voltage angle of output converter [40]. Then further in case of preferring thyristor switched series capacitor, author provided a low-cost FACT device for improving dynamic behavior of proposed system [41]. Authors reviewed about static synchronous series condenser type FACT device for providing constant voltage across the condenser. This enabled to provide efficient power flow control and power system oscillation handling capacity in both inductive and capacitive mode operation [42].

There are many studies carried out for optimal location and size of FACTS device for attaining efficient electricity. Authors and researchers have proposed various algorithms for achievement of proper location with tuning of their parameters [43]. There are different optimization approaches for attaining proper location and sizing of FACTS devices. The complexity of proposed power system designing has been reduced by advanced programming techniques for appropriate position of FACTS device. These computational techniques have been preferred to sometimes meta-heuristic or heuristic approach such as tabu search, ant colony optimization, particle swarm optimization, differential evolution, artificial bee colony optimization, dual programming etc. Some optimization techniques can be merged and they may be called as hybrid optimization techniques. These may be combination of analytical techniques, conventional techniques, analytical-conventional techniques. Hence in these days some modern meta-heuristic techniques have been preferred which may reduce their iteration time and production cost.

So, by using different optimization techniques on FACTS devices there has a discussion on such approaches below in tabular form in which we can see comparison among various types of FACTS devices operation.

3. .Study of reactive power compensation devices

Reactive power is basically used for non-real power from capacitive or inductive loads. Reactive power is usually measured in terms of VAR (volt-amperes reactive). In order to keep maintaining advantageous conditions for electric power system it is essential to apply reactive power compensation technology to enhance better operation. The basic definition of reactive power compensation is governing reactive power to alleviate the generation of alternating current in an electric network [44].

There are various reactive power compensation device technologies like as synchronous condenser, static synchronous compensators and static VAR compensators.

3.1. Synchronous condenser

Synchronous generators have played the wide role for more than many previous years in reactive power control. Basically, a synchronous generator behaves as synchronous machine associated with power system. Voltage regulator is used to produce or absorb reactive power for power system operation on a suitable power factor [45]. In a synchronous condenser an excitation system is used to produce direct current and it can be divided into as ac and dc excitation system [46]. When the entire unit is synchronized throughout its field current is regulated to either produce or absorb reactive power. With better association with automatic exciter circuit machine can provide reactive power control continuously. So synchronous condensers are employed at both means transmission and distribution voltage levels to revise voltage stability and maintain voltage at all required positions under different load varying conditions. Synchronous condensers also contribute into short circuit conditions and these are not accessible to compensate with rapid changes.

Most of the times super machines activate immediately in order to secure grid with problems like voltage sag, flickers and surges which further introduces lightning storm, short circuits etc. Hence dynamic

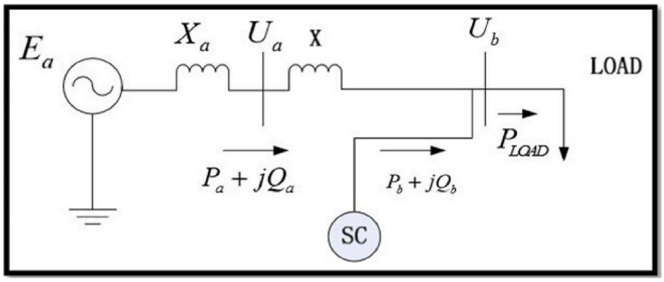

Fig. 2. Layout of synchronous condenser with grid connected [44].

VAR compensating devices overcome stabilizing problems and provide cost effective techniques for improving reliability and sustainability.

3.2. *Static* synchronous *compensator (STATCOM)*

Static synchronous compensator is another part of FACTs devices. It has primary objective to provide fast acting, rigorous and flexible quantity of reactive power to an AC power system network. For proper functioning of bridge inverter circuit DC still needs certain size of capacitor because it behaves as energy storage component [47].

As per different configuration of circuits static synchronous compensator is divided into two types as current-bridge and voltage-bridge. Generally, voltage-bridge has been utilized more because of higher rate than current-bridge circuits. In Fig. 2 Fig. 3, Fig. 4 layout of voltage-bridge based STATCOM has been shown comprising of capacitor at DC voltage side, voltage source inverter operated by using PWM technique in order to regulate power electronic switch. Coupling transformer removes harmonics or distortion of the output voltage of voltage source inverter. So this FACT device requires no more infrastructures due to absence of reactors and capacitors to produce reactive power. Hence it provides production and absorption of reactive power by means of voltage source converter [48] (see Fig. 4).

In this research work there are some mathematical relations among variables of DSTATCOM have been represented as shown below which are used for simulation purposes.

The three-phase instantaneous voltage at the point of common coupling can be written as:

$$V_A = \sqrt{(2/3)}\ Vs\ \sin\omega t \quad (1)$$

$$V_B = \sqrt{(2/3)}\ Vs\ \sin(\omega t\text{-}2\pi/3) \quad (2)$$

$$V_C = \sqrt{(2/3)}\ Vs\ \sin(\omega t+2\pi/3) \quad (3)$$

In matrix from we can expressed as:

$$\begin{bmatrix} VA \\ VB \\ VC \end{bmatrix} = \sqrt{(2\backslash\backslash\backslash/3)}\ Vs \begin{bmatrix} \sin\omega t \\ \sin(\omega t - 2\pi/3) \\ \sin(\omega t + 2\pi/3) \end{bmatrix} \quad (4)$$

The relationship between point of common coupling (PCC), inverter output voltage and current can be obtained by writing the KVL equations such as:

$$R_f I_A + L_f di_A/dt = V_A\text{-}V_{CA} \quad (5)$$

$$R_f I_B + L_f di_B/dt = V_B\text{-}V_{CB} \quad (6)$$

$$R_f I_C + L_f di_C/dt = V_A\text{-}V_{CC} \quad (7)$$

We can write equation from (5) to (7) in matrix form as shown below:

$$d\backslash/dt \begin{bmatrix} iA \\ iB \\ iC \end{bmatrix} = \begin{bmatrix} -Rf\backslash\backslash/Lf & 0 & 0 \\ 0 & -Rf/Lf & 0 \\ 0 & 0 & -Rf/Lf \end{bmatrix} \begin{bmatrix} iA \\ iB \\ iC \end{bmatrix} + 1/\mathrm{Lf} \begin{bmatrix} VA - VCA \\ VB - VCB \\ VC - VCC \end{bmatrix}$$

Basically equations from (5) to (7) describe differential equations. For controlling the current in voltage source inverter transformation of these equations we may prefer synchronous reference frame.

3.3. *Static VAR compensator*

Static VAR compensator or SVC is another type of FACT devices which is thyristor-controlled generator for producing reactive power. It depends upon lagging, leading or both conditions. It is termed as high voltage device which regulates throughout network voltages at its coupling points. It basically performs as keeping network voltage constant at reference nodes. It has inherently characteristics like reactive power control, voltage control and damping of oscillation. Hence it improves the flexibility and ability of transmission network. Static VAR compensator can be classified as thyristor-controlled reactor, thyristor switched reactor and thyristor switched capacitor [50].

For medium voltage applications static var compensators are used and it can be preferred in star connected mode with active power filter hybrid system. Distributed generation systems have been carried out for remote areas for developing better and sustainable energy and to provide the beneficiaries to the consumers. Various techniques with reactive power compensating devices have been developed to control and monitor the operation of DG system with integration of renewable energy sources. Many researchers and academicians are dealing with these areas to give a new and innovative algorithm for reducing the cost of fossil fuels and transportation issues for the fuels.

Similarly for static synchronous series compensator FACT device as used in this proposed research work has been represented in the form of mathematical expression as discussed below:

Considering the input voltage is V_G and input current I_G taken as grid input parameters.

So, we can write mathematically as:

$$V_G = V_M \sin\omega t \quad (1)$$

$$I_G = I_M \sin(\omega t + \varphi) \quad (2)$$

where V_M and I_M are magnitude of V_G and I_G respectively. ω is angular frequency, f is frequency and φ is the phase difference between V_G and I_G.

Now the instantaneous power will be

$$P_G = V_G.\ I_G \quad (3)$$

Putting the values of V_G and I_G in eq. (3).

$$P_G = V_M \sin_{\omega t}.\ I_M \sin(\omega t + \varphi) = 2\ P_G/\cos\varphi.\ \sin\omega t.\ \mathrm{Sin}(\omega t + \varphi) \quad (4)$$

Now when we apply KCL at node of DC link capacitor so it will show the relationship between inverter input current and output current of boost converter.

$$i_C = i_B\ \text{-}\ i_J. \quad (5)$$

where i_C is DC link capacitor current, i_B is output current of booster and i_J is Inverter input current.

3.4. *Case study*

Many researchers have done work on different IEEE bus by using FACTS devices and contribute their results. In case of IEEE 30 bus system there are two sections such area 1 and area 2. These two areas are connected to each other via eight interconnected transmission lines. For these transmission lines available transfer capability is to be measured. Depending upon the power transfer capability by each eight transmission lines existing transmission commitments have been derived which indicate total amount of power transferred by each transmission lines in IEEE 30 bus. ATC is varied in other cases as an amount with consisting of UPFC and SSSC and maximum power is delivered from area 1 to area 2. Hence by installing UPFC and SSSC the maximum transfer capability is increased for more efficient utilization of transmission

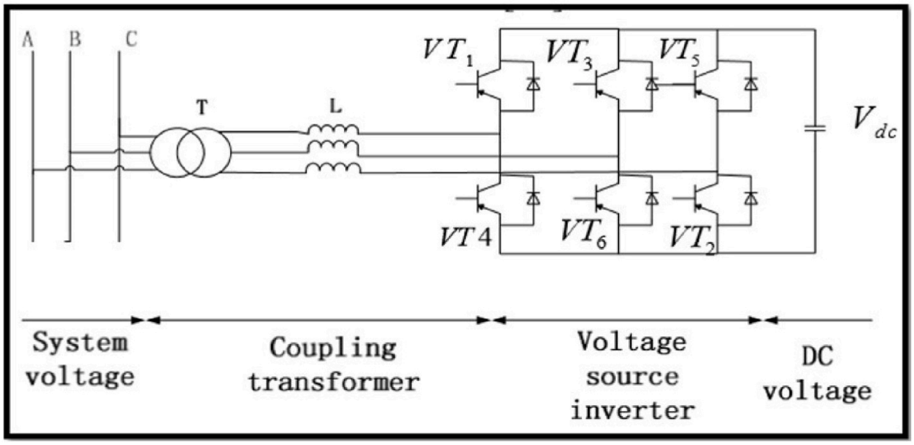

Fig. 3. Layout of static synchronous compensator (statcom) [44].

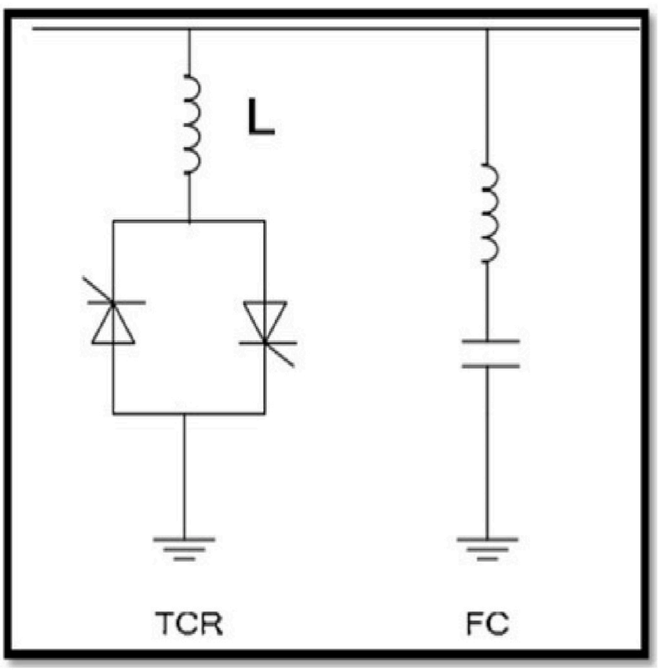

Fig. 4. Layout of static var compensator (SVC) [49].

lines.

The other combination has been preferred by using both UPFC and TCSC for monitoring voltage stability and power quality issues by using IEEE 14 bus system. This IEEE 14 bus consists of two generators such G1 and G2. Analysis of classical model of generators is taken for transient stability analysis. In addition, with this combination SVC and UPFC have taken on same bus IEEE 14 bus for power system stability under different fault conditions under EUROSTAG software.

3.5. Methodology

The system is analyzed by using different FACTS device. In this paper DSTATCOM, SSSC and DVR has been taken for observation of fault analysis. On giving unsymmetrical fault voltage and current is to be measured by using DSTATCOM. In DVR system switching operation is using with keeping total harmonic distortion level around 22.24 % and analyzes grid voltage, load voltage and injected voltage. Then SSSC device is being taken with considering voltage swell and observing total voltage, voltage across inductor and voltage across capacitor in both cases with and without fault. There are various power quality issues occur during the operation by using FACTS devices as structured below in Fig. 5. The novelty of such proposed work has been carried out by considering different power quality issues and shows the comparison (see Fig. 6).

4. Simulation results of various FACTS devices

In this section analysis of different FACTS devices has been done by applying faults and switching operation.

4.1. Simulation results using DSTATCOM FACTS device

Using DSTATCOM device with interconnected with solar PV cell we get voltage, current and power with limitations of distortions of entire FACTS device. DSTATCOM uses voltage-based source inverter connected in parallel with load. Modeling and simulation of DSTATCOM are performed under MATLAB environment.

Below table is showing parameters of DSTATCOM in which breaker resistance is 0.001 Ω, active power is 5 kW, reactive power is 3kVAR.

So according to power balance theory, the instantaneous power at AC terminals of inverter must be equal to the instantaneous power at the DC terminals of inverter. Hence the performance of DSTATCOM can be controlled by the active and reactive components of current.

Figs. 7–9 shows the operation of DSTATCOM under unity power factor condition in which the injection of reactive power through DSTATCOM eliminates reactive part of load current and input current is adjusted near to real component. Under unity power factor operation, DSTATCOM adjusts its output response which further helps to maintain the voltage at point of common coupling (PCC). Here all parameters like voltage and current are showing through proper tuning and provides reliable response. At unity power factor, DSTATCOM maintains voltage constant at PCC after the rapid response of fluctuations or distortions. Hence these currents are adjusted to maintain unity power factor throughout operation which in turns to reduce losses of voltage source inverter and feeder (see Fig. 10).

4.2. Simulation results using single phase series compensator

In single phase series compensator loads are considered as inductive and capacitive loads and performed under MATLAB Simulink

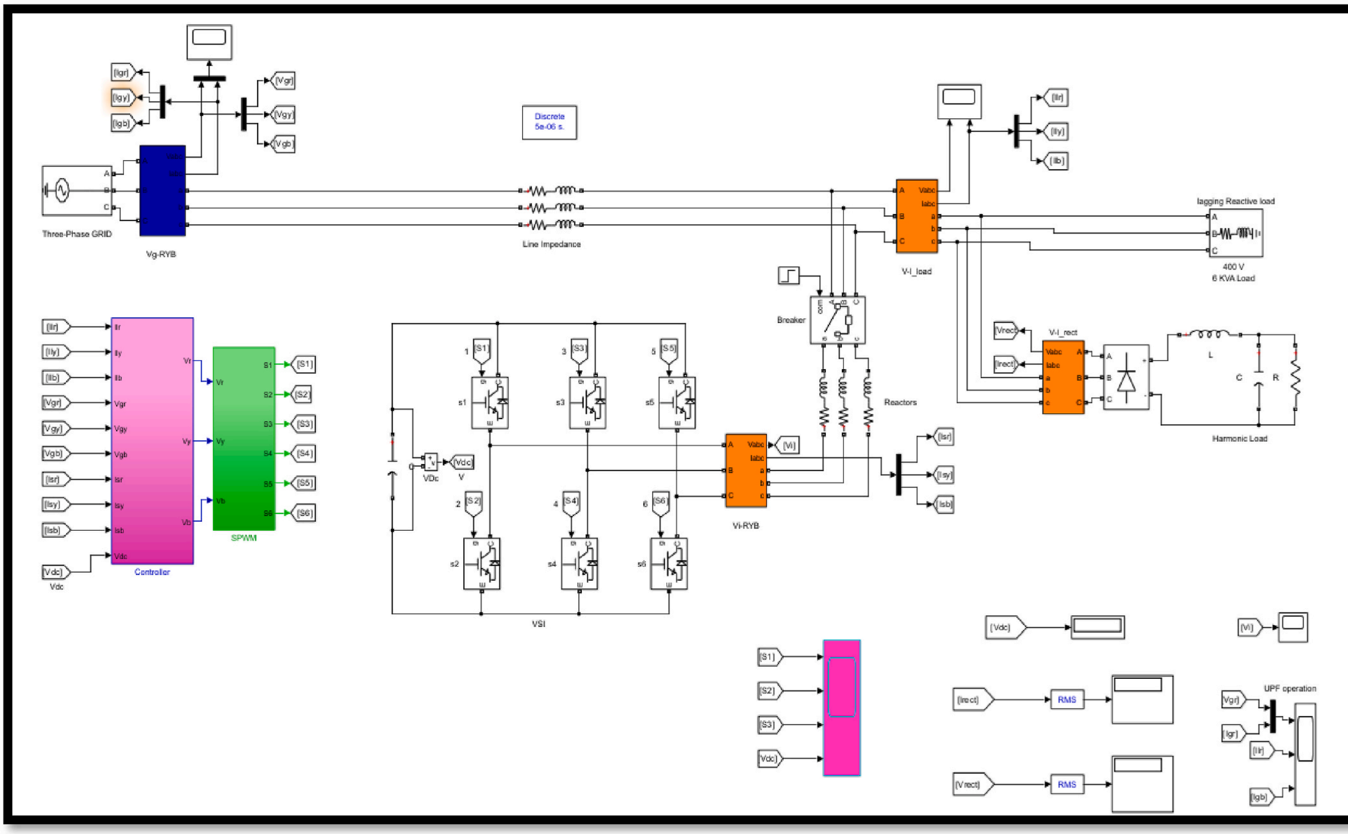

Fig. 5. Power quality issues.

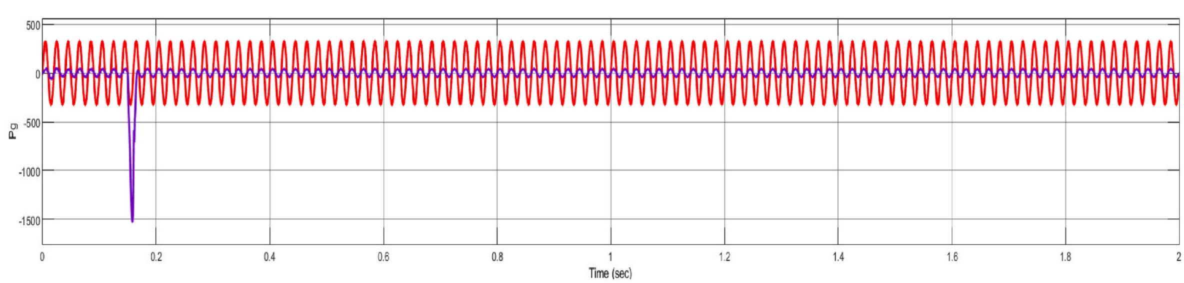

Fig. 6. Matlab model of Dstatcom

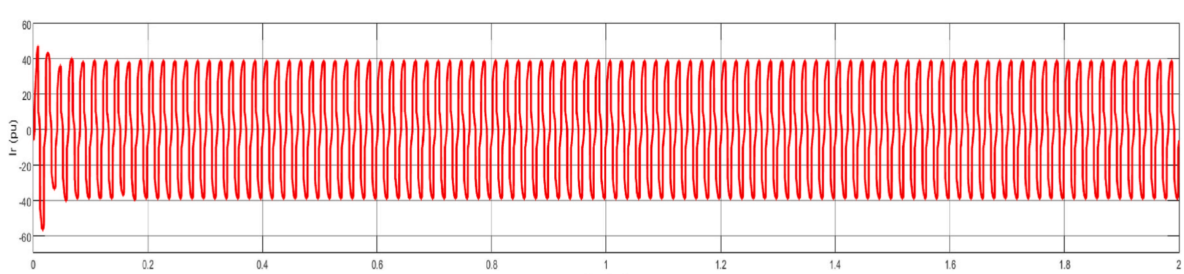

Fig. 7. Total power of DSTATCOM under UPF Operation.

environment. Under giving supply we get output voltage, voltage across capacitance and voltage across inductance.

At the load side we are considering active power is 100 kW and reactive power is 5kVAR. We have output voltages at inductor and capacitor which will be analyzed with the help of MATLAB environment.

As from Figs. 11–13, on applying fault at time 0.07 s voltage V_C distorts between 0.1 s and 0.38 s and voltage across inductance maintains to be keep continuous.

By preferring single phase series compensator, it is able to provide fast acting voltage help during the period of oscillations as showing in Figs. 14–16. It maintains stable voltage across inductance and

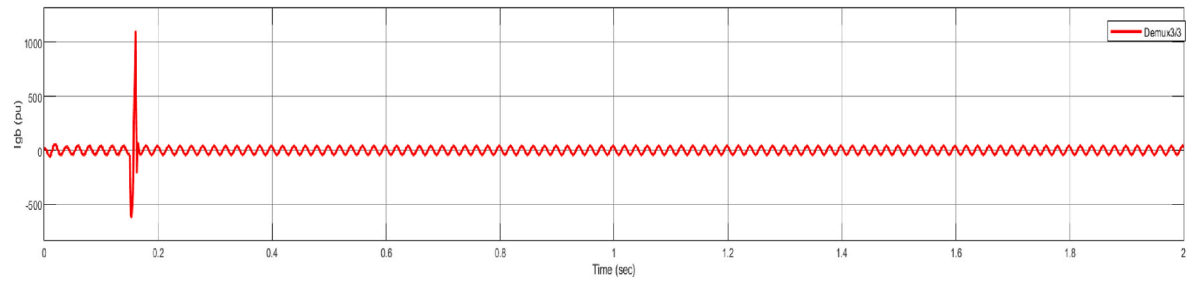

Fig. 8. Ir current of DSTATCOM under UPF Operation.

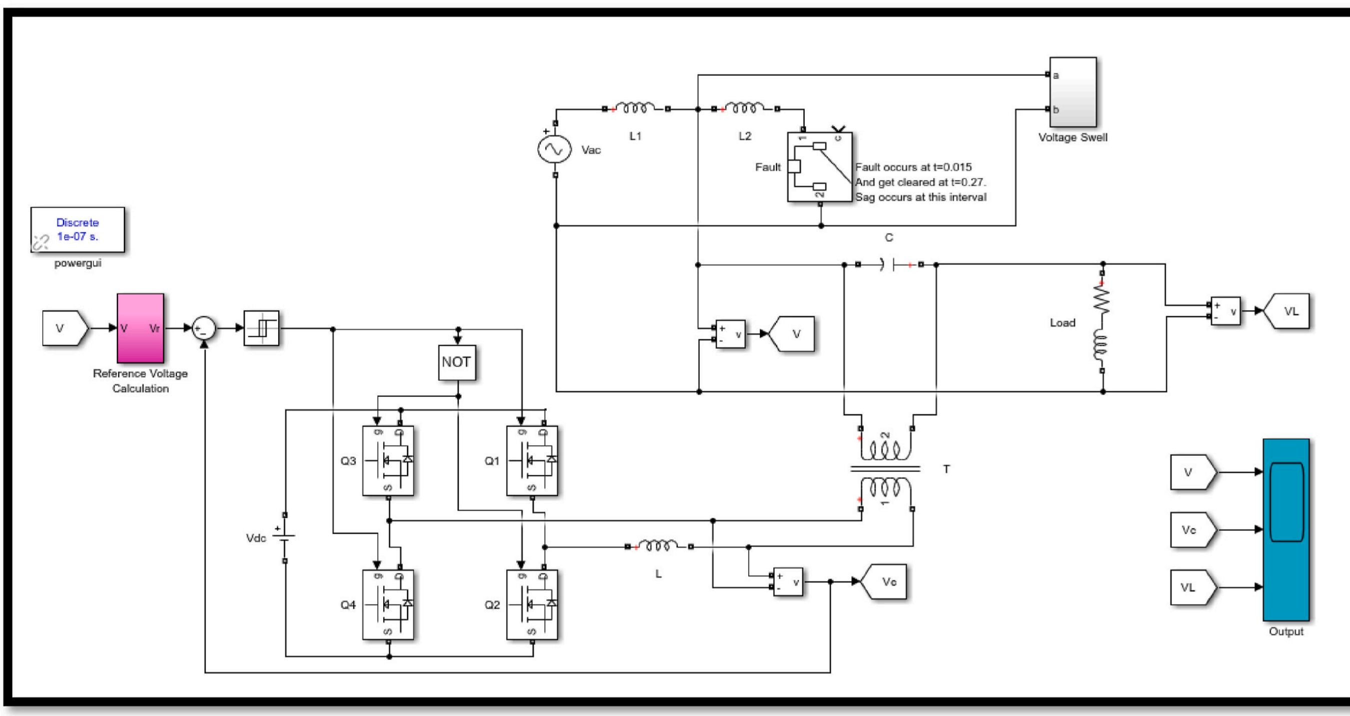

Fig. 9. Igb current of DSTATCOM under UPF Operation.

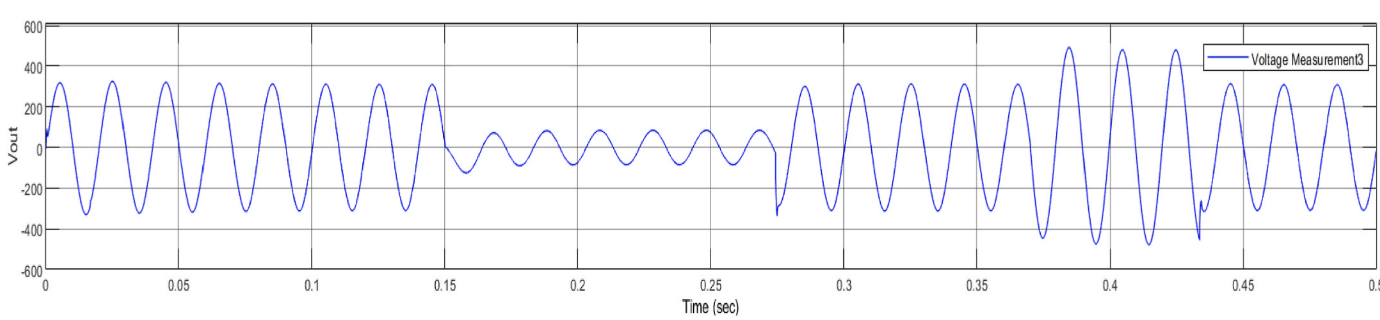

Fig. 10. Matlab model of single phase series compensator.

capacitance for certain period of time. Inductive and capacitive components experience voltage variation by the flow of reactive power. Such compensator device is able to damp oscillations and keeps ensure steady voltage across inductance and capacitance.

Advancement in FACTS Devices: For achieving better and reliable results there are some techniques which have been used to make FACTS devices more intelligent and provides excellent results. For this Distributed FACTS device have been introduced because sometimes due to the use of renewable energy sources there may be some harmonics problems due to changing weather conditions which results into cost effective operation.

In current times D-FACTS devices have been used for power controlling operations. These are less expansive and smaller in size rather than actual FACTS devices. So we can also used in micro grid operating system. Hence various power networks and industries are using D-FACTS devices for enhancing reliability, controllability and improved

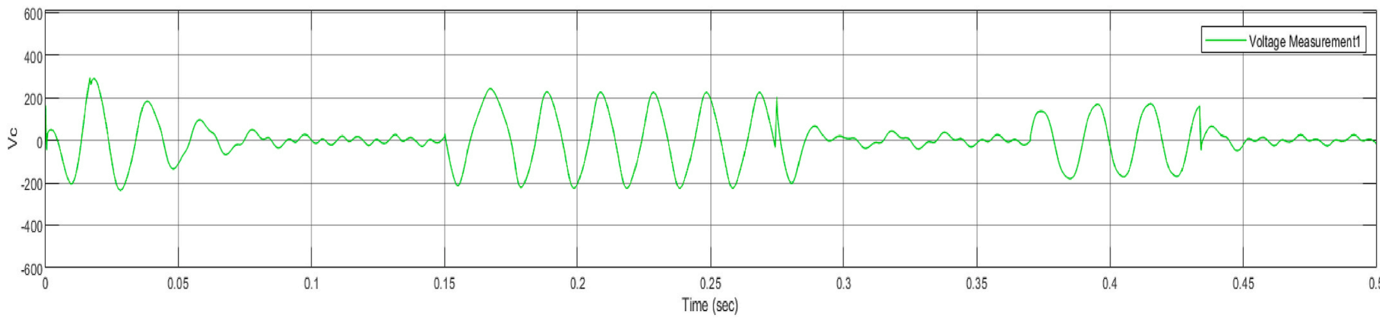

Fig. 11. Output voltage.

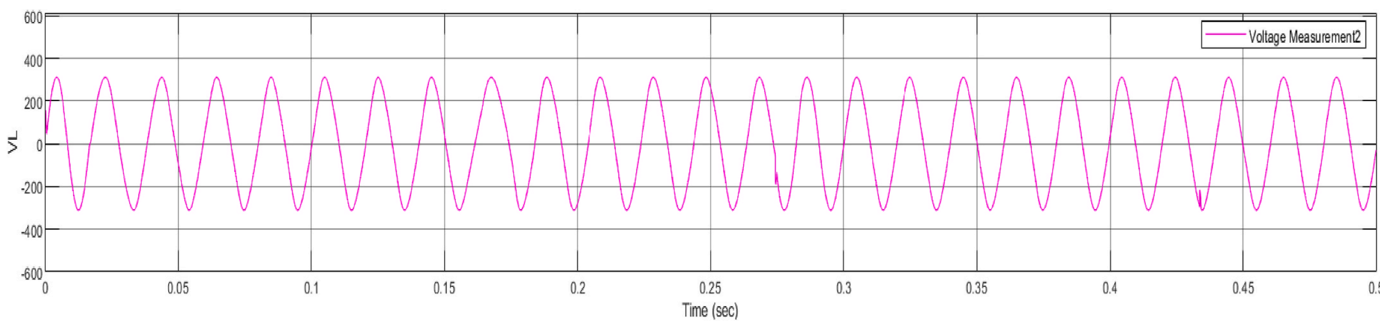

Fig. 12. Voltage across capacitance.

power quality. Further for overcome the problems of voltage sag, voltage flicker, and voltage swell, harmonics and voltage fluctuation in small and micro grid system. There are some characteristics of D-FACTS as listed below.

5. Conclusion

In this paper analysis of different FACTS devices has been carried and presented overview of advanced FACTS devices. Out of these FACTS devices, D-FACTS devices have been observed as more efficient for proper compensation of reactive power with convergence of distributed generation system rather for attaining reliability and security of utility grid.

Future work

Different FACTS devices can be modeled by using numerous renewable energy sources in addition with optimized by analytic approaches, Meta heuristic techniques and hybrid methods. By using analytic methods with Meta heuristic methods reduce space search of

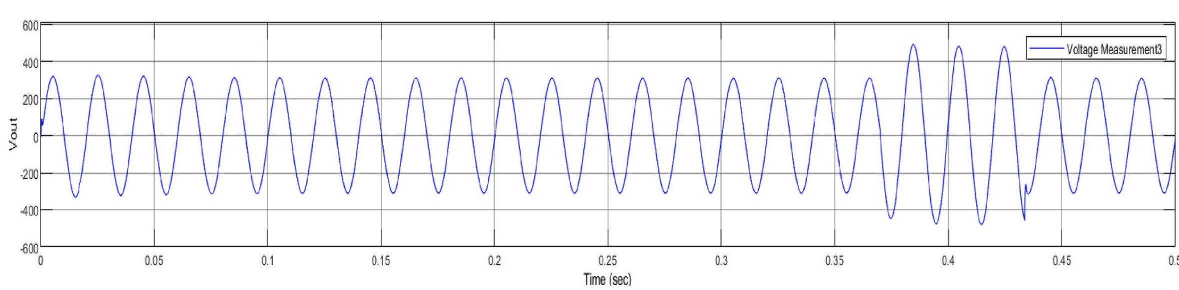

Fig. 13. Voltage across inductance.

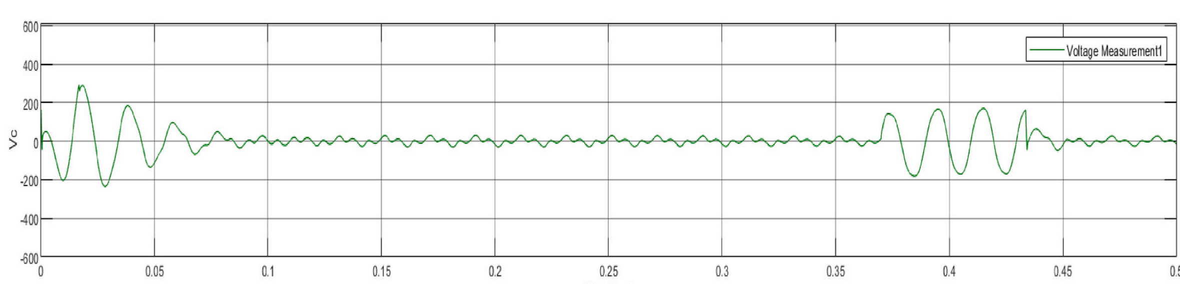

Fig. 14. Output voltage.

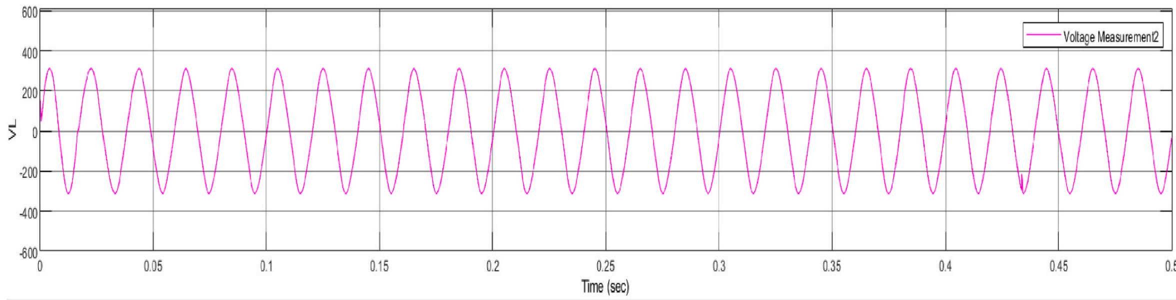

Fig. 15. Voltage across capacitance.

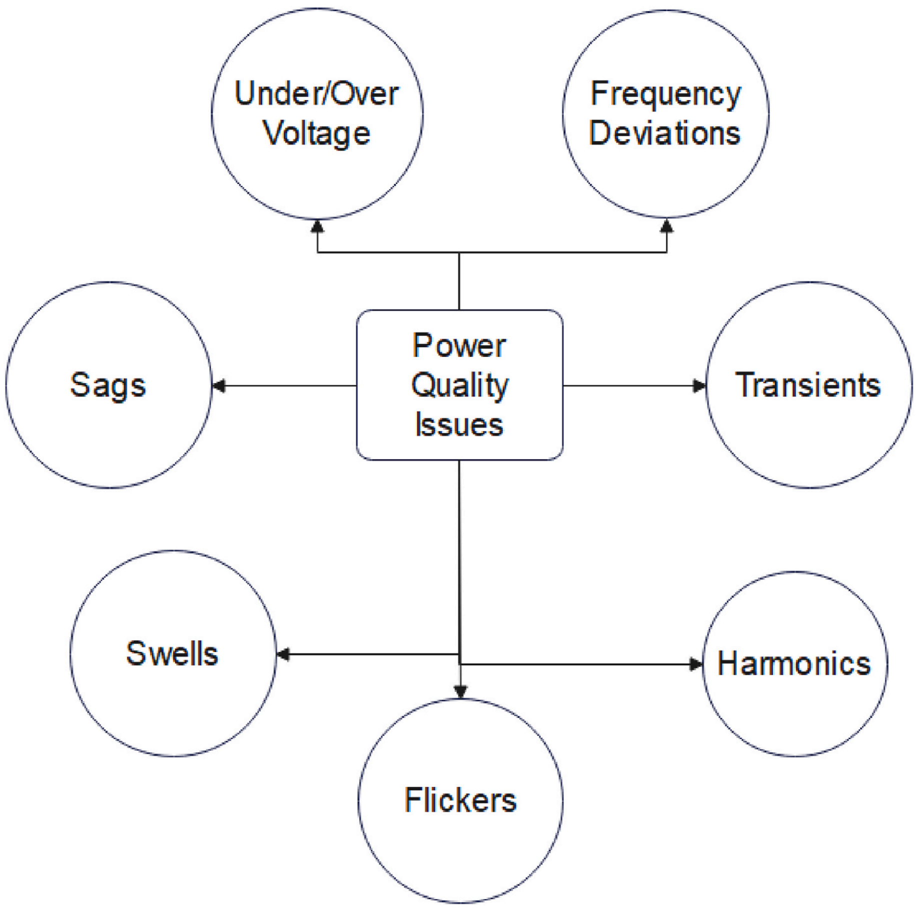

Fig. 16. Voltage across inductance.

proposed technique. One of the most important issues is power quality which can be resolved by reducing total harmonic distortion with optimal use of D-FACTS devices. The optimal sizing and location of D-FACTS devices, optimization problem can be sorted for unbalanced transmission network and predictability of power system.

CRediT authorship contribution statement

Akhil Nigam: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Conceptualization. **Kamal Kant Sharma:** Writing – review & editing, Writing – original draft, Visualization, Software, Methodology. **Muhammad Bilal Riaz:** Writing – review & editing, Resources, Investigation, Conceptualization, Funding acquisition, Formal analysis, Validation, Project administration. **Moh Yaseen:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis. **Anum Shafiq:** Writing – review & editing, Visualization, Supervision, Investigation, Formal analysis, Project administration. **Tabassum Naz Sindhu:** Writing – review & editing, Visualization, Investigation, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Acknowledgments

This article has been produced with the financial support of the European Union under the REFRESH – Research Excellence For Region Sustainability and High-tech Industries project number CZ.10.03.01/00/22_003/0000048 via the Operational Programme Just Transition.

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