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# Analysis and Implementation of Power Quality Enhancement Techniques Using Custom Power Devices

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## ABSTRACT

Traditional power production has become challenging for utilities due to the depletion of fossil fuels, coal, and oil. This must be done in a less expensive and more efficient manner. To meet the consumer's power needs, a new source is needed. The alternative source should be sustainable and capable of fulfilling the needs of the customer. The incorporation of renewable energy into the grid is a helpful method of meeting demand. The integration of renewable energy has three main challenges: frequency fluctuation, power quality issues, and power system instability. The following issues were critical in nature. An expert system based on an analytic hierarchy method is used to detect and classify power quality issues. Previously, it could detect sag, swell, transients, harmonics, interruptions, and flickers. A method for categorizing events that is error-free has been proposed. The streamlined process provides for more accurate identification and classification of power quality issues. an examination of power quality issues and their mitigation via the use of unified power quality conditioners (UPQC) To reduce different power quality problems, an Adaptive Neuro Fuzzy Inference System (ANFIS) is employed. Using renewable energy sources effectively reduces environmental impact. The proposed technique corrects voltage imbalances and reduces overall harmonic distortion at the point of common connection (PCC). The installation of an ANFIS-controlled DVR is utilized to minimize voltage fluctuations induced by the integration of renewable energy sources and transmission line failures. With the aim of using renewable energy, a fake fault was introduced to power quality events. The ANFIS-controlled DVR plan is in place to mitigate the negative impacts of power quality events. ANFIS-controlled DVR is compared to a conventional surveillance method. Nonlinear loads generate voltage flickers and total harmonic distortion, therefore a distributed static compensator (D-STATCOM) is employed to avoid these. It is recommended that D-STATCOM use three control methods: instantaneous power theory, synchronous vector PI control, and harmonic elimination. The D-efficacy of STATCOMs is tested under severe load conditions. Various control methods will be used to evaluate and debate the proposed expert system and customized power devices.

***KEYWORDS:*** *Power Quality Improvement; Renewable Energy; Custom Power Device's FACT's; UPQC; PCC; DVR; STATCOM; Neuro Fuzzy (ANFIS); PI Controller*

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## 1. INTRODUCTION

Electric power distribution networks are vast and play an important role in the infrastructure that supports commercial, residential, and industrial establishments. These networks are constantly changing because to the requirement for age-related renewal, the use of clean and renewable energy sources, power sector deregulation, and increasing or reduced demand [1]. These problems have resulted in the proposal of new structures, devices, control systems, management techniques, and even power distribution system restructuring, where new network architecture has been suggested or new devices have been deployed. Furthermore, the installation of photovoltaic cells (PVs) has grown considerably in recent years, having a major effect on radial distribution networks. As a result, it is essential to consider renewable integration problems for efficient and safe power system operation and maintenance, while also keeping track of modernization.

### 1.1. DISTRIBUTED ENERGY RESOURCES

The phrase "distributed energy resource" (DER) refers to a broad category of energy resources that includes renewable energy producers, batteries, and electric cars (EVs). These resources are supplied through low voltage feeders at client locations. While the term distributed generator (DG) refers to an electric power source that is directly linked to the distribution network or is located on the customer side of the meter. It is becoming more popular as a result of its low cost and global environmental consciousness. As a consequence, the operational structure of low voltage distribution networks is undergoing change. Despite the fact that current data show that DG connections range between 0.45 and 10.86 percent of average load, DG penetration in LV networks may reach 100 percent of average load in the next decades [2]. Photovoltaic (PV) cells are expected to overtake reciprocating engines and wind turbines as the primary method of distributed generation between 2010 and 2020 [2]. In addition to this, other types of distributed generators such as microturbines, biogas engines, and fuel cells will be widely accessible [2]. The installation of these will fundamentally transform the character of the LV networks, since each LV section will resemble a small power system. Furthermore, these networks will no longer be radial, necessitating significant changes in their security hardware and tactics.

Despite the availability of a substantial mix of nuclear, hydro, and wind energy, traditional fossil fuel-based power production (e.g., coal, natural gas) remains the primary source of power generation. Coal and gas plants produce greenhouse gases, whereas nuclear facilities are deemed hazardous. Furthermore, hydro plants are heavily reliant on geographical topography. Electric power production based on renewable sources, on the other hand, is often referred to as ecologically beneficial green electricity. Figures 1.1 and 1.2 depict the diagrams of energy production using conventional and green power, respectively. Table 1.1 lists the power generating capabilities.

DG units are used in a variety of applications in electrical systems, depending on the system's structure, such as:

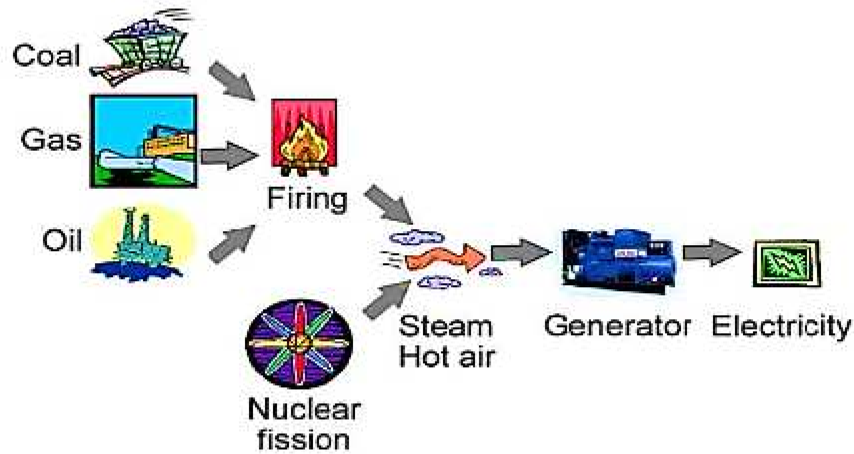



**Fig 1.1: Power Generation through convention energy sources**

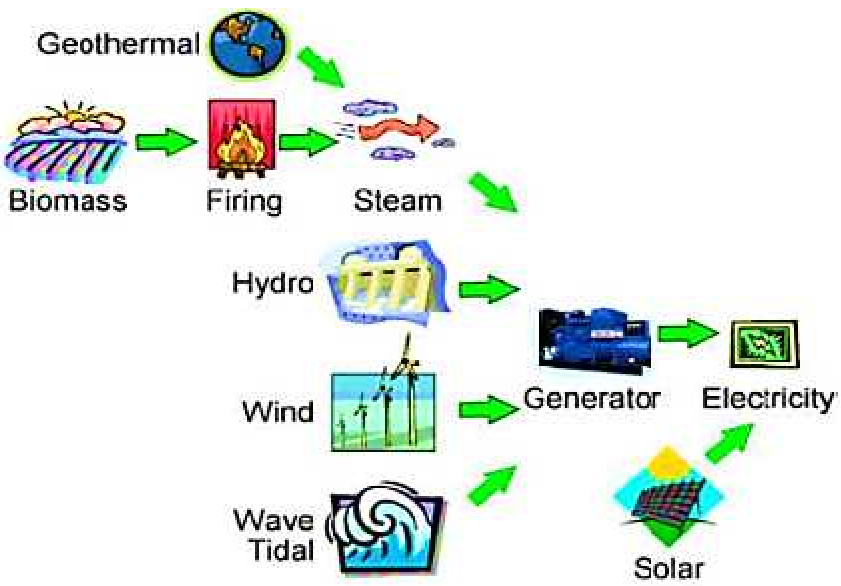



**Fig 1.2: Power Generation through Renewable energy sources**

## 1.2. POWER QUALITY PROBLEMS

The Institute of Electrical and Electronic Engineers Standard (IEEE Std 1100) defines power quality as "the idea of powering and grounding sensitive electronic equipment in a way appropriate for the equipment" [9]. "Power Quality is a set of electrical limits that enables a piece of equipment to operate in its intended way without substantial loss of performance or life expectancy," according to a more succinct definition [10]. Primarily, power quality at the transmission and distribution levels relates to voltage remaining between +/- 5% [11]. It is suggested that the voltage violation be corrected within 2 seconds of its occurrence [12]. Poor power quality has an impact on an electrical device's performance and life expectancy. They are both inextricably linked to the voltage, current, and frequency delivered to the electrical equipment [10]. An ideal distribution system is intended to have pure sinusoidal voltage and current waveforms of fundamental frequency, with the amplitude of the voltage remaining within certain predefined limits. The majority of power quality issues arise in the distribution system network, particularly when the majority of the system is comprised of overhead wires rather than subterranean cables. There may be many natural causes for the disruption, such as contact of the lines with each other, particularly on windy days, or due to birds or contact of tree branches with wires, cutting of the lines owing to falling trees or branches, lightings, and so on. All of these contribute to power quality problems in the network. Switching on and off huge loads, particularly massive electrical motors in industry, and power electronic devices utilized in Electronic devices, capacitor or inductive bank operation and switching, transformers, and so on [10, 13]. This thesis considers the following power quality events:

- Voltage Fluctuation: Voltage variation (such as sag, swell, or interruption) with a length less than one minute is classified as short time voltage variation, whereas voltage variation with a period more than one minute is classified as long time voltage variation [10, 13]. Voltage fluctuations may cause damage to consumer appliances as well as other power quality issues as a byproduct.
- Electricity Factor and Reactive Power: According to the IEEE Recommended Practice for Photovoltaic (PV) System Utility Interface, all PVs must inject power at unity power factor [14]. This PV injection raises the voltage at the connecting point and introduces nonlinearity into the system. However, by controlling the PVs' reactive power, the voltage at the connection point may be adjusted. Ideally, reactive power should be produced near to the demand to compensate for it, freeing up greater capacity on the network's conductors and transformers [10].Despite the fact that certain power quality issues are caused by power electronic loads, the usage of power electronics as a remedy to these issues is also extremely popular [10]. The aforementioned issues will be addressed in this research, and mitigating strategies will be suggested. All of the devices utilized in mitigation will be VSC-based. It should be mentioned that PV is the most common kind of small size DG unit at the moment. As a result, the words DER, DG, and PV are used interchangeably throughout this thesis.

## 1.3. SOLAR ENERGY AND LOAD MANAGEMENT

Solar energy is utilized in two ways –solar photovoltaic (PV) or solar thermal. PV is the most prominent renewable energy sources used in low voltage feeders. A PVs cell work on the I-V characteristics of the elements used in their production The I-V characteristic PV system can be expressed as [16]:

$$I(V) = \alpha I_{\max}\left(1 - e^{\beta}\right)$$

$$\beta = \frac{V}{b(\alpha\gamma + 1 - \gamma)V_{\max}} - \frac{1}{b}$$

where, V and I(V) are the output voltage and current of the photovoltaic array; Vmax is the rated open circuit voltage of PV array when the light amount is the highest, Imax is the maximum current; b is the index constants; α is the light intensity percentage of photovoltaic cells; γ is a linear factor dependent on Vmax. PV can be off grid, grid connected or grid-connected centralized. Regardless of the connection strategy they follow, power electronic interface is needed for PVs for network connection. Usually both dc-dc and dc-ac converters are used. Among the inverters used, the popular types are "central inverters", "Module integrated or module oriented inverters", "String inverters" and "Multi string inverters" [17].From the I-V characteristic relation, it can be seen that the output power of PV is not controlled. Rather it is dependent on instantaneous power from the sun. Though advantageous, integration of PV creates several technical problems to the existing network such as harmonics, voltage profile and power loss. Some of these are investigated in [18-20]. Several studies on the voltage violation due to PV integration have been conducted [21-24]. The studies have been carried out at different countries on different geographic location. From all these studies it is found that distributed networks with PVs faces two types of voltage problems. In the evening when network is in peak hour, the residential load increases while the power output of PVs diminishes. As a result, voltage drop occurs throughout the network. On the other hand, at noon, the PVs are at the peak of their power generation, while the residential loads are at their minimum level. This may lead to an increase in voltage. In [25], it has been found that if the PV rating does not exceed 2.5 kW, the voltage in the network is not adversely affected even with the worst case scenario. But it is not practical to restrict the PV rating because PV rating will be bigger with the advancement of technology and the increased market availability. A comprehensive study on Australian network is reported in [26] and the results show that there is significant voltage rise, feeder loss, voltage unbalance and reverse power flow during midday. A mitigation strategy for neutral current is proposed in [27] using energy storage to balance the power injections into the grid and the power imports from the grid in the three phases. Along with changing the voltage level ofthe network, high (20% or higher) penetration of PV increases voltage imbalance. In[28–30], different VU measurement and calculation methods based on line or phase voltages in three phase and three- and four-wire systems were investigated. From[31], the voltage unbalance can be calculated as

$$\%\text{Unbalnce} = \left|\frac{V_2}{V_1}\right| \times 100$$

where V1 and V2 are the positive and negative sequence voltages, respectively. Minor voltage imbalance may be ignored if the system contains mainly single-phase loads. It may, however, create severe problems for three-phase loads (motors for pumps, elevator etc). Voltage imbalance was investigated in [32] using PV placed on a single feeder. The results indicate that the PV installation has only a small impact on the voltage imbalance at the start of an LV feeder. However, it rises to more than 2% at the feeder's end, which is unacceptable by most standards. Some research suggested remedies to this imbalance issue. In [33], an energy storage-based control method is used to reduce voltage imbalance in a distribution network. [34] proposes a technique for evaluating voltage variation sensitivity owing to PV power fluctuations in an unbalanced network, as well as a solution based on the unbalanced line characteristics and realizing the network's potential. It should be emphasized that voltage/current imbalance is determined by the voltage quantity, which is linked to the bus voltages where the PVs are connected indirectly. As a result, the main emphasis of this thesis has been voltage quality control. The voltages are maintained below the permissible limits of 0.05 per unit by using different mitigating techniques (pu). Rooftop PVs are placed for a typical home distribution network. haphazardly across distribution systems [35] does a stochastic study of two actual LV networks in the North West of England for various PV penetration levels. It has been shown that voltage issues in long lines with heavy load may begin as early as 40% PV penetration. This image may vary based on the area's geographic location and demographics. Several techniques for reducing voltage increase due to PV penetration have previously been proposed and researched.

### 1.4. CUSTOM POWER DEVICES (CPDs)

There are two basic models of CPDs – one is connected in shunt and the other one connected in series [10]. The device which is connected in shunt is named as a distribution static compensator (DSTATCOM) and the series connected device is named a dynamic voltage restorer (DVR). Voltage source converter (VSC) is the basic building block of both these devices. The dc bus of the DSTATCOM VSC is equipped with a dc storage capacitor, while the dc bus of the DVR can have a storage capacitor. In this study, it is assumed that CPDs can supply some amount of power to the system. So instead of a capacitor, a battery has been used. It serves two purposes – its more easy control and can supply/absorb real power. The batteries can be kept fully charged by drawing a predefined amount of power from the grid.

#### 1.4.1. DISTRIBUTED STATCOM (DSTATCOM)

The schematic diagram of a DSTATCOM structure is shown in Fig. 1.3. This can perform, power factor correction, load compensation load balancing and harmonic filtering. The DSTATCOM can be operated in current control mode or voltage control mode. These are discussed briefly below:

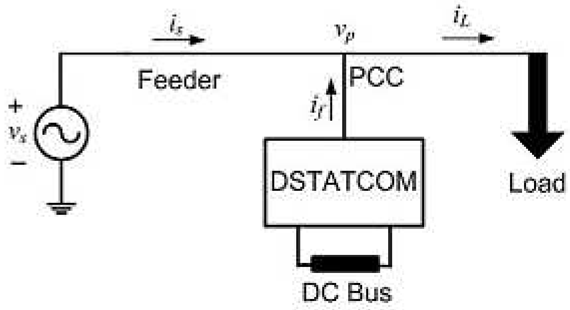



**Fig. 1.3: Schematic diagram of DSTATCOM.**

Current Control Mode: To remove imbalance or distortions in the source current, the DSTATCOM injects an unbalanced and harmonically distorted current in the current control mode [55]. In Fig. 1.3, is represents the source current, iL represents the load current, and if represents the current injected by the DSTATCOM. The voltage at the point of common coupling (PCC) is denoted by vp. If KCL at PCC is given, it is iL. (1.3) If iL is unbalanced and has harmonics, the source current will be imbalanced and have harmonics as well. However, if the DSTATCOM injects a current with the harmonic components of the load (if), the source current will be harmonics free and will only have a fundamental component. This is shown in Fig. 1.4. Furthermore, power factor adjustments and current balancing may be accomplished via the injection of it.

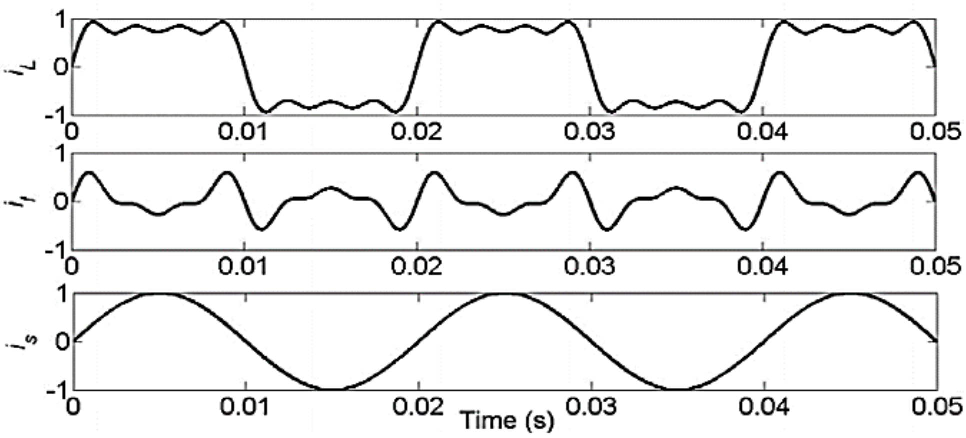



**Fig. 1.4: Current correction by DSTATCOM.**

Now if the source voltage (vs) is fundamental and the DSTATCOM makes is fundamental, the PCC voltage (vp) will be also fundamental and free of harmonics. If the load is connected through a feeder with source, the current and voltage at PCC will have harmonics due to DSTATCOM VSC switching. To avoid this, suitable passive filters need to be added and the control scheme need to be modified [56].Two different multi-level inverter structures are presented for high power DSTATCOM applications [57].Voltage Control Mode: In voltage control mode the PCC voltage (vp) is controlled and made balanced. As a result, the current in between the source and the PCC, is also becomes balanced [58]. It is shown in [59] that DSTATCOM can be flexibly operated in both voltage and current control mode. Necessary hardware topology and control algorithm is derived for that. The concept of custom power park where voltage is tightly regulated by a diesel-generator backed DSTATCOM is discussed in [60]. This also enables supplying sensitive load during outage and increase reliability. Both of these modes of operation are discussed in detailed in later chapters.

### 1.4.2. DYNAMIC VOLTAGE RESTORER (DVR)

A DVR is a series-connected device with the structure shown in Fig. 1.5. DVR is used to protect critical loads against sag/swell and supply-side disruptions. This is achieved via the use of instantaneous series voltage injection. The voltage at the load side may be precisely regulated by a DVR [61]. It may also function as an active filter in the medium voltage range [62]. If the supply side has an imbalanced sag/swell, the DVR may have to inject unbalanced voltages to maintain the voltage at the load. To offset voltage harmonics, it may also inject a distorted voltage. Figure 1.6 depicts typical voltage waveforms with DVR use. To eliminate any power supply or absorption by DVR, a DC capacitor may be used instead of a DC source to power the DVR [63]. [64] compares the performance of a VSC-based shunt with a series compensator. It was discovered that DVR has excellent bandwidth and attenuation characteristics, and that with a powerful stiff source, DSTATCOM cannot adjust the load bus voltage in this situation.

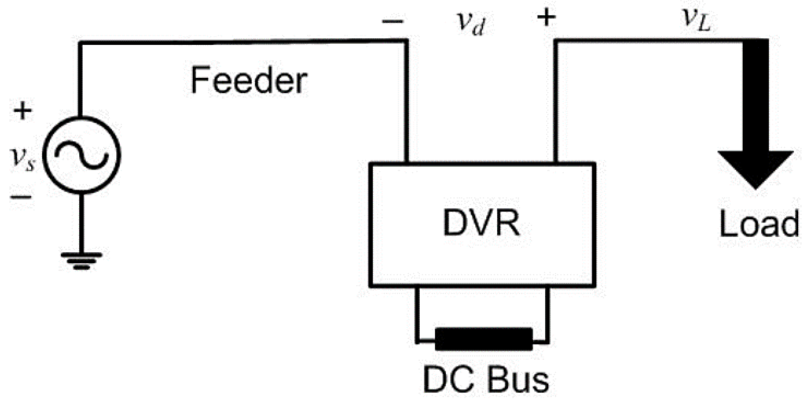



**Fig. 1.5: Schematic diagram of DVR.**

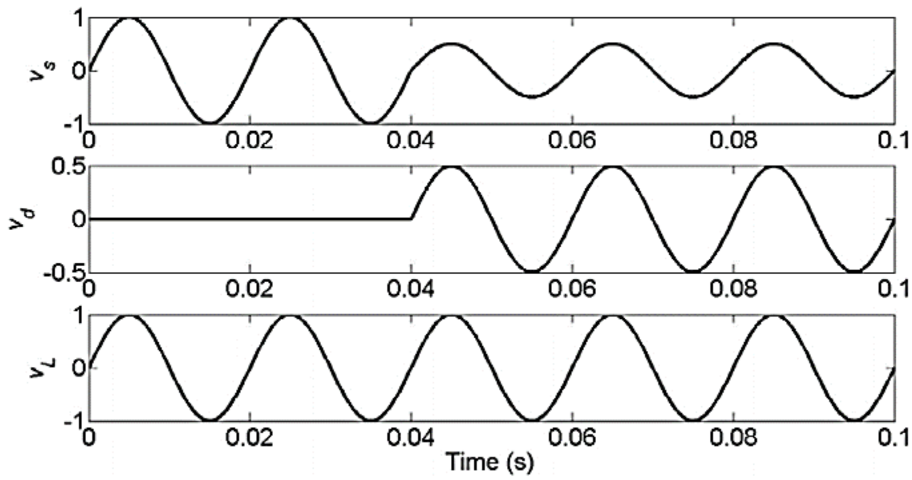



**Fig. 1.6: Voltage correction by DSTATCOM.**

### 1.4.3. UNIFIED POWER QUALITY CONDITIONER (UPQC)

Figure 1.7 depicts a schematic representation of a UPFC. This is a DSTATCOM and DVR combo linked to a shared DC bus. In a dual control mode, the UPQC is a highly flexible device that can inject current in shunt and voltage in series at the same time. As a result, it can adjust for the load while also controlling the voltage. The UPQC, like DSTATCOM or DVR, may inject unbalanced and distorted voltages and currents.

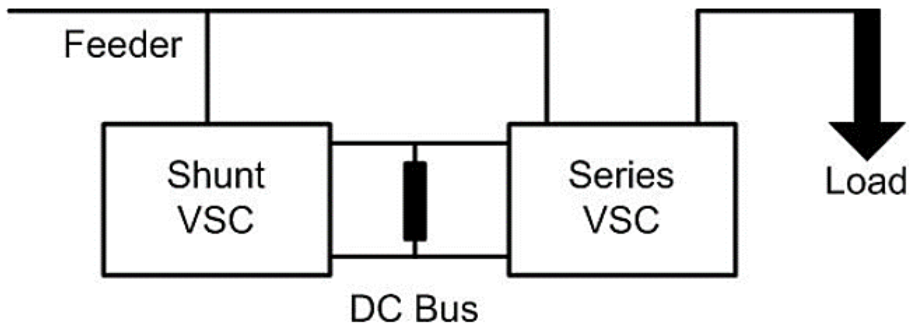



**Fig.1.7 Schematic diagram of UPQC**

## 2. LITERATURE REVIEW:

**"Xin Chen; Emiliano Dall'Anese; Changhong Zhao; Na Li** Distribution systems are anticipated to be capable of providing capacity support for the transmission grid as a result of large-scale integration of distributed energy resources (DERs). This article investigates distribution-level power aggregation methods for transmission-distribution interaction in order to efficiently harness the collective flexibility from large DER devices. This article, in particular, provides a technique for modeling and quantifying aggregate power flexibility in imbalanced distribution systems over time, i.e., the net power injection possible at the substation. The suggested approach provides an effective approximate feasible area of net power injection by using network restrictions and multi-phase unbalanced modeling. It is shown that a viable disaggregation solution exists for any aggregate power trajectory inside this area. Furthermore, a distributed model predictive control (MPC) framework is created for the actual implementation of the transmission-distribution relationship. Finally, we show the suggested method's performance using numerical testing on a real-world distribution feeder with 126 multi-phase nodes. Due to its non-dispatch ability, a distribution grid is traditionally regarded as an equal passive load in transmission system operation [1]. In the last decade, there has been a fast growth of distributed energy resources (DERs) in distribution networks, particularly photovoltaic (PV) production, energy storage (ES), and demand response. As the penetration of dispatch able DERs grows, considerable flexibility is being introduced into energy distribution, transforming the distribution networks from passive to active [2]. The power flexibility of distribution systems, like that of transmission systems, refers to the additional power capacity that may be dispatched to ensure safe and efficient system operation, particularly in the event of a crisis. Distribution flexibility is supplied by a large number of diverse DERs, as opposed to large-scale spinning and non-spinning reserves in transmission networks. Although each DER typically has a modest capacity, the coordinated dispatch of ubiquitous DERs is capable of providing substantial flexibility assistance, allowing distribution systems to actively participate in transmission system operation. Power networks may fully utilize potential flexibility and achieve better efficiency and resilience by using coordinated transmission-distribution dispatch.

**Smit Solanki; Mihir Trivedi; Poornesh Rawal; Siddharthsingh K. Chauhan; P. N. Tekwani** Because of the recent increase in power consumption, an intensively integrated penetration of distributed generation (DG) has become a need. Because of its excellent controllability, grid-connected inverter-based DG is gaining popularity. Voltage imbalance is sometimes seen at the Point of Common Coupling (PCC) owing to changing needs of active-reactive power injection by the DG into the Grid. This article describes the implementation of two alternative grid-tied inverter topologies: traditional two-level three-phase four-wire and three-level T-type Neutral Point Clamped (T-NPC) based DG, both controlled by a three-phase damping control method. The simulation experiments provided show that both of these inverter topologies provide excellent operational management for DG under a variety of operating circumstances. The main purpose of DG is examined, which is to inject electricity into the grid and reduce the load on the traditional generating system. This article describes the effective behavior of the proposed two-level and three-level DGs without causing voltage imbalance. The imbalance index and total harmonic distortion (THD) for PCC voltages and currents are examined in detail. In addition, the performance of both proposed DGs for meeting load requirements while operating in islanding mode is given. The reported findings for single-phase asymmetric faults and three-phase symmetric faults show that DGs have adequate voltage compensation capabilities. The primary characteristics of the proposed DG systems are low voltage ride through capability, reduced imbalance index, and THD within standard norms. Distributed power production encompasses a broad range of methods for producing electricity at a localized level using renewable or non-renewable energy resources in an ecologically acceptable manner. Distributed Generation (DG) effectively delivers dependable, low-cost, high-quality electricity while increasing flexibility. Because of its closeness to the end user, it offers a low-cost transmission option with minimal line losses. The DG is often implemented utilizing renewable energy sources because to the growing demand, simple availability, and eco-friendly nature of renewable electricity. This has enabled renewable energy-based DG to function as a possible backup supply for the localized micro-grid in the event of a main grid breakdown [1], [2]. Grid-connected inverters aid in the implementation of DG systems based on renewable energy sources. Photovoltaic-based DG are increasingly widely used owing to their simplicity of installation and operation. In the case of photovoltaic-based DG, the primary purpose of the grid-tied inverter is to produce output voltage that is of the right magnitude and phase with the grid. A wind turbine-based grid-tied system, on the other hand, offers isolation between two distinct frequencies, namely the changing mechanical frequency of the wind turbine and the relatively constant electrical (power) frequency [3].

## 3. PRINCIPLE OF DSTATCOM:

There are two basic models of CPDs – one is connected in shunt and the other one connected in series [10]. The device which is connected in shunt is named as a distribution static compensator (DSTATCOM) and the series connected device is named a dynamic voltage restorer (DVR). Voltage source converter (VSC) is the basic building block of both these devices.

The dc bus of the DSTATCOM VSC is equipped with a dc storage capacitor, while the dc bus of the DVR can have a storage capacitor. In this study, it is assumed that CPDs can supply some amount of power to the system. So instead of a capacitor, a battery has been used. It serves two purposes – its easier control and can supply/absorb real power. The batteries can be kept fully charged by drawing a predefined amount of power from the grid.[6]

### 3.1. Introduction

As electric power is need of every industry. These industries have different types of loads. Some of the loads are very sensitive and need pure power or good quality of power otherwise the loads are effective by power quality of power for example, the problem of voltage sags can affect sensitive loads. However, there are no specific standards for different categories of equipment, except in the case of data processing equipment. Only Computer Business Equipment Manufacturers Association (CBEMA) has developed the CBEMA curve which describes the tolerance of main frame computers to the magnitude and duration of voltage variations on the power systems. Most of the Computer companies have their different tolerance but the CBEMA curve has become a standard design target for sensitive equipment and also a common format for reporting power quality variations.[5]

### 3.2. CUSTOM POWER DEVICES

The introduction of power electronic loads has raised much concern about power quality problems caused by harmonics, distortions, interruptions, and surges. The use of electronic devices increases the power quality problem Equipment such as large industrial drives (e.g., cycloconverters) generate significantly high voltage and current (inter-, sub-) harmonics and create extensive voltage fluctuation. The addition of electronic devices is addition to power quality problem.

The application of harmonic filters and SVCs to radial transmission systems can offer partial solution to high THD levels and voltage fluctuations. Yet, the lack of dynamic capabilities of these devices limits them to bulk correction. In addition, they might be effective in one application but fail to correct other power quality issues.

#### 3.2.1. Distributed STATCOM (DSTATCOM)

The distribution STATCOM is similar to a transmission STATCOM in that it uses a VSC of the required rating. However, the VSC used in a DSTATCOM is a Type 1 converter with PWM control over the magnitude of the injected AC voltage while maintaining a constant DC voltage across the capacitor. Faster power semiconductor devices such as IGBT or IGCT are used instead of GTO. The rapid switching capability provided by IGBT (or IGCT) switches enable the use of more sophisticated control schemes to provide functions of balancing (by injecting negative sequence current), active filtering (by injecting harmonic currents) and flicker mitigation. A DSTATCOM can be viewed as a variable current source determined by the control functions. To increase the dynamic rating in the capacitive range, a fixed capacitor/filter can be used in parallel with DSTATCOM. The schematic diagram of a DSTATCOM structure is shown in Fig. 1.3. This can perform, power factor correction, load compensation load balancing and harmonic filtering. The DSTATCOM can be operated in current control mode or voltage control mode. These are discussed briefly below:

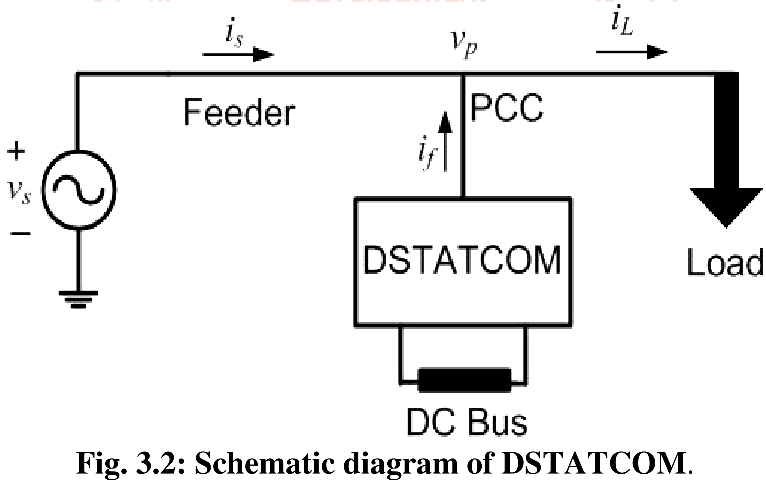



**Fig. 3.2: Schematic diagram of DSTATCOM**.

**Current Control Mode:**

In the current control mode, the DSTATCOM injects an unbalanced and harmonically distorted current to eliminate unbalance or distortions in the source current [55]. In Fig. 1.3, *is* is the source current, *iL*is the load current and *if* is the current injected by the DSTATCOM. If there is unbalance and harmonics in *iL*, the source current *is* will be also unbalanced and have harmonics. However, if a current with the harmonic components of the load is injected by the DSTATCOM (*if*), the source current will be harmonics free and will have only fundamental component. This is shown in Fig. 1.4. In addition, through injection of *if*, the power factor corrections and current balancing can also be achieved.

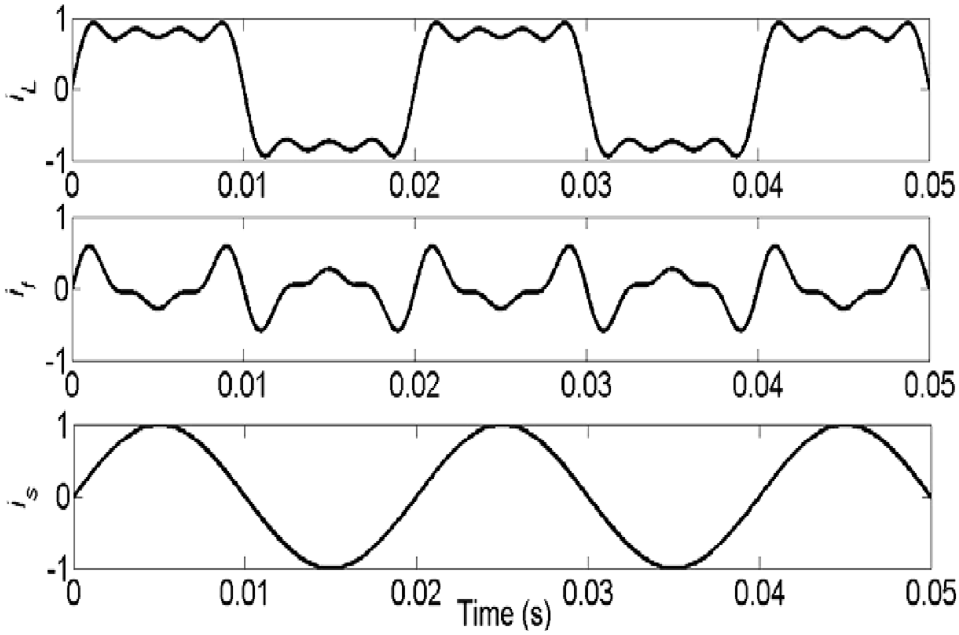



**Fig.3.3 Current correction by DSTATCOM**

Now if the source voltage (*vs*) is fundamental and the DSTATCOM makes *is* fundamental, the PCC voltage (*vp*) will be also fundamental and free of harmonics. If the load is connected through a feeder with source, the current and voltage at PCC will have harmonics due to DSTATCOM VSC switching.

To avoid this, suitable passive filters need to be added and the control scheme need to be modified [16]. Two different multi-level inverter structures are presented for high power DSTATCOM applications [17].

**Voltage Control Mode:**

In voltage control mode the PCC voltage (*vp*) is controlled and made balanced. As a result, the current in between the source and the PCC, *is* also becomes balanced [8]. It is shown in that DSTATCOM can be flexibly operated in both voltage and current control mode. Necessary hardware topology and control algorithm is derived for that. The concept of custom power park where voltage is tightly regulated by a diesel-generator backed DSTATCOM is discussed in [60]. This also enables supplying sensitive load during outage and increase reliability.

## 4. SYSTEM DESIGN IMPLEMENTATION:

The non-linear loads connected to power system produces harmonic current, Voltages. The introduced harmonics into the system will be in the form of currents whose frequencies are the integral multiples of the fundamental system frequency. The harmonic currents interact with the supply system impedance causing distortions in supply output voltage and current, which has worse effects on all other loads connected to the system. It also creates other effects such as overheating, increasing powers losses in the system, and malfunction of protection devices connected to the system. The non-linear loads were found in heavy industrial applications such as arc furnaces, large Variable Frequency Drives (VFD), heavy rectifiers for electrolytic refining, Switch Mode Power Supply (SMPS).

D-STATCOM is installed to support electrical network from the impacts of the nonlinear load. A D-STATCOM is a Voltage Source Converter (VSC) based device. A suitable control system needs to be offered in order to control the IGBT switches in the voltage source converter, thereby enhancing the performance of D-STATCOM. This chapter highlights the proposed control concept for D-STATCOM.

### 4.1. IMPORTANCE OFD-STATCOM

A D-STATCOM can improve power-system Performance like:

- Dynamic voltage control in transmission and distribution systems,
- Reactive power control
- Voltage flicker control
- Reduction of Total Harmonic Distortions

The Simulation diagram of D-STATCOM is presented below in Figure.6.1

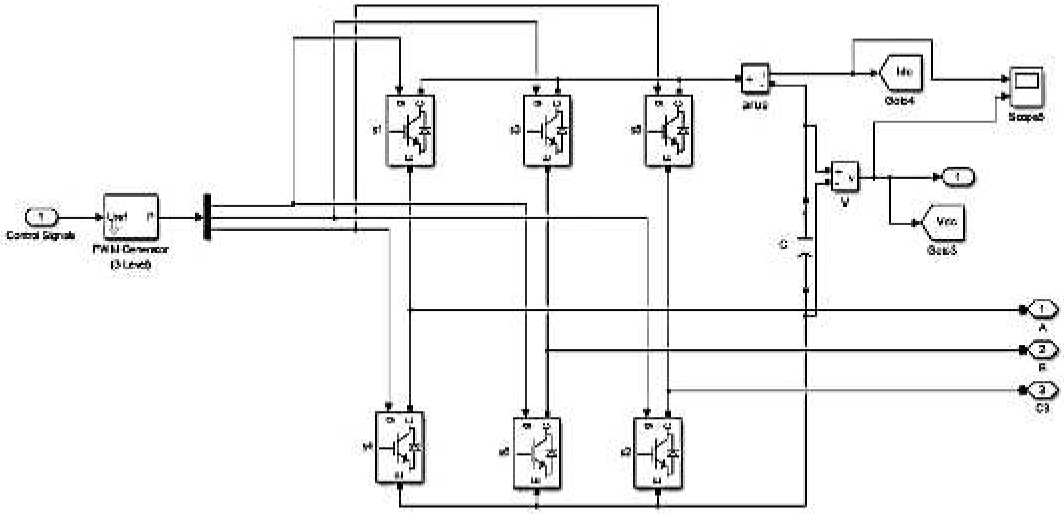


**Fig 4.1 MATLAB/Simulink diagram of a D-STATCOM**

## 5. RESULTS:

### 5.1. SIMULATION RESULTS AND DISCUSSION

The simulation analysis has been performed using MATLAB/Simulink environment. The simulation diagram is as shown in Figure 5.1. The valid points as per the proposed are presented below.

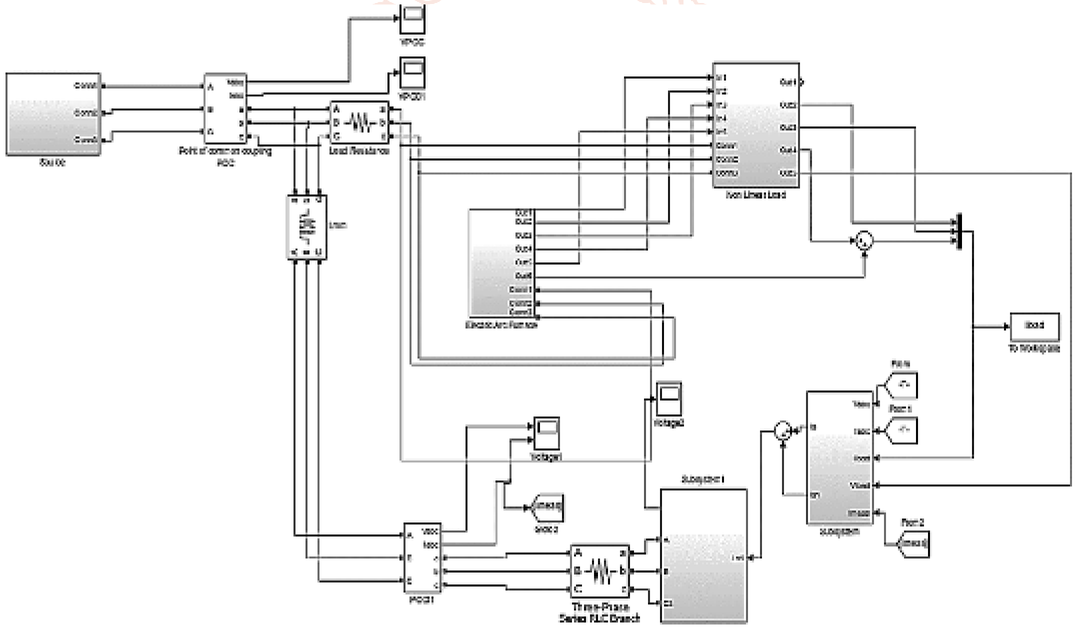
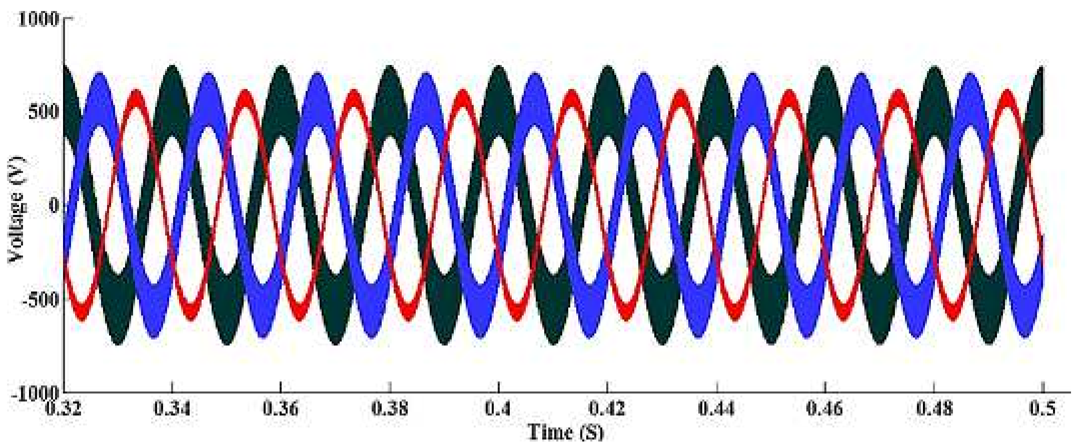
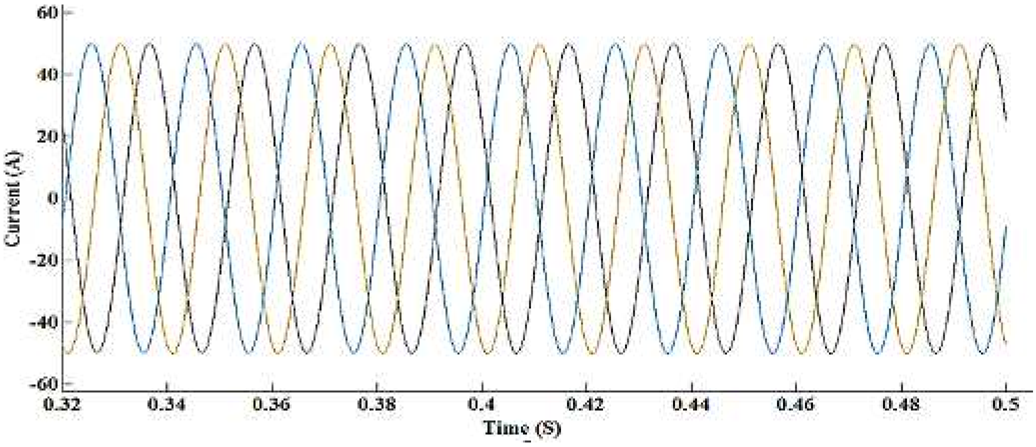


**Fig 5.1 MATLAB/Simulink diagram of the system considered for study with D-STATCOM**

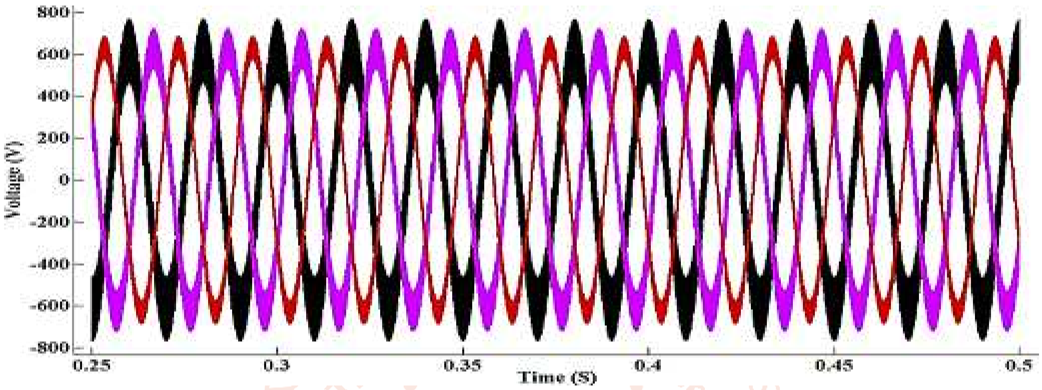
At the PCC, Voltage and current measurement and voltage across the nonlinear load were measured before inserting D-STATCOM at PCC. The following Figure 5.2 (a-c) shows the measurement of before inserting D-STATCOM.




**(a)**



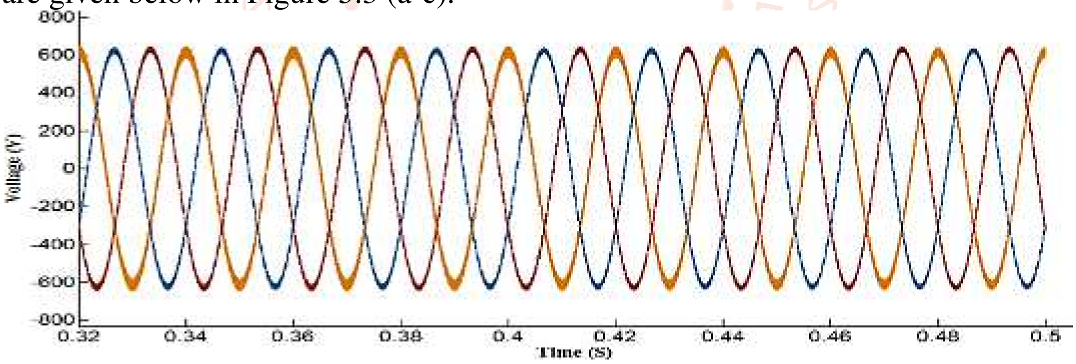

**(b)**



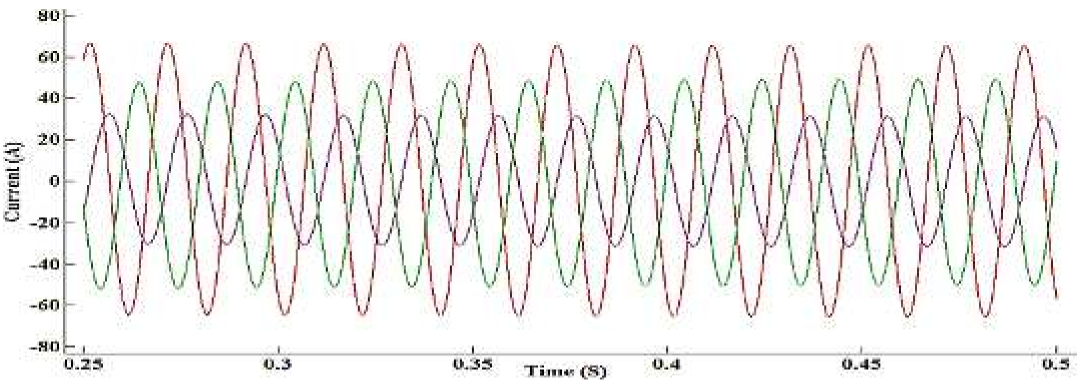

**(c)**

**Fig 5.2 (a) Voltage at PCC without D-STATCOM, (b) Current at PCC without D-STATCOM and (c) Voltage across nonlinear Load without D-STATCOM**

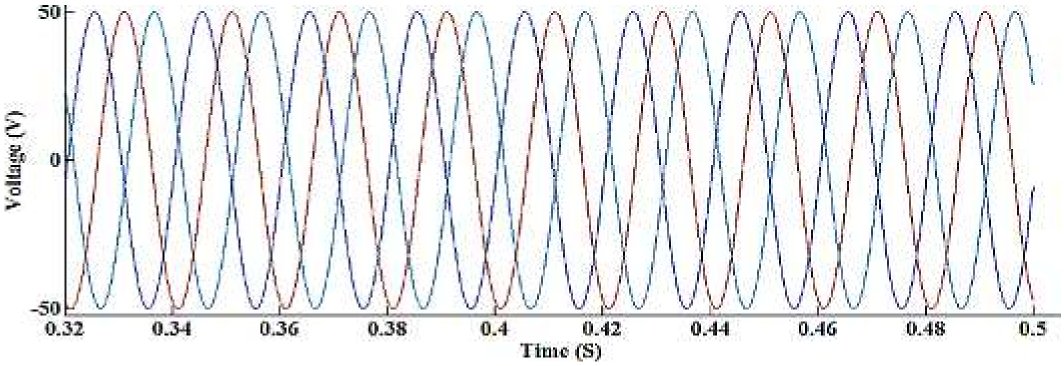
The D-STATCOM is introduced in the system at 0.3 Seconds. The corresponding waveforms after inserting D-STATCOM are given below in Figure 5.3 (a-c).




**(a)**




**(b)**



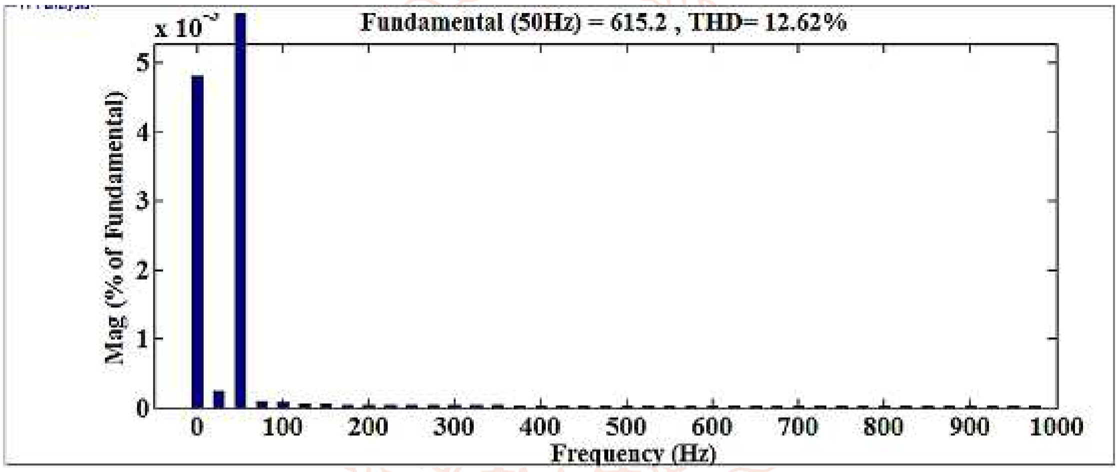

**(c)**

**Fig 5.3 (a) Voltage at PCC with proposed control concept of D-STATCOM, (b) Current at PCC with proposed control concept of D-STATCOM and (c) Voltage at nonlinear load with proposed control concept of D-STATCOM**

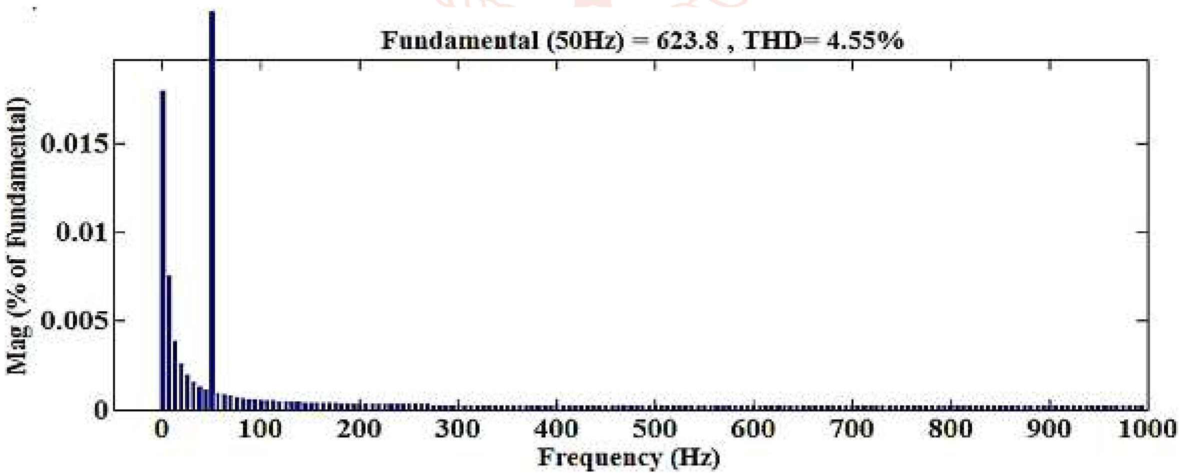
The voltage distortions at PCC are reduced to a minimum level after the introduction of the proposed control on D-STATCOM.

### 5.2. Total Harmonic Distortions

The Total harmonic distortions is measured at PCC using FFT tool. It is found that the proposed control on D-STATCOM suits for the reduction of Voltage distortions at PCC. The FFT representation for Phase A is as shown in Figure 5.4 (a&b).




**(a)**




**(b)**

**Figure 5.4 (a) THD at PCC without D-STATCOM and (b) THD at PCC with proposed control on D-STATCOM**

The Total harmonic distortions is evaluated for the other phases are presented below in Table 5.1.

**Table 5.1 Assessment of Total Harmonic Distortions (THD) at PCC**

| Phases | Total Harmonic Distortion (%) | |
|---|---|---|
| | System without D-STATCOM | System with proposed control concept of D-STATCOM |
| A | 12.62 | 4.5 |
| B | 8.24 | 4.4 |
| C | 7.65 | 4.1 |

The flicker measurement was made at PCC using flicker meter, for 1 Second duration. It is identified that there are considerable changes in the flicker levels when a D-STATCOM is introduced in the system. The short-term flicker events were measured at PCC which is as shown in Figure 5.5.

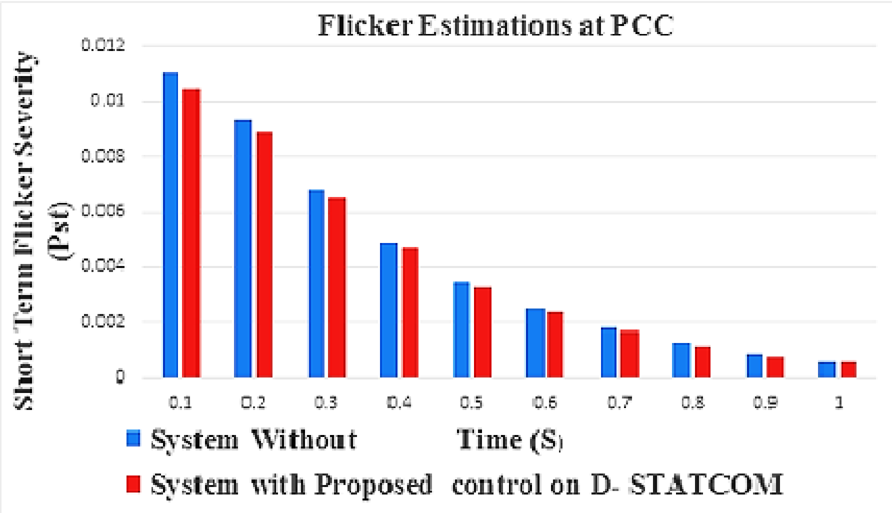



**Fig 5.5: Flicker Estimations at PCC**

The power quality issues were observed based on the impact of loads it is identified that the introduction of nonlinear loads will keep on rises the waveform distortions. Since the loads were volatile it is mandatory to have a control system. It is found that the combination of instantaneous power theory, synchronous vector PI controller and harmonic elimination method introduced to control D-STATCOM offers a better solution to control the voltage flickers and waveform distortions.

## 6. CONCLUSIONS AND FUTURE WORK

The main focus of this research is to provide a method for detection, classification of power quality events. It also offers a controller that suits to mitigate the power quality events that may rise due to the introduction of the renewable energy source and the nonlinear loads.

The important contributions of this research work are briefed as follows.

- The Proposed expert system offers a better classification in the power quality issues. Hence it is concluded that the expert system has a minimum training and testing error in detecting the power quality events to validate the effectiveness.
- The ANFIS controlled UPQC offers a solution to power quality problems like voltage imbalances and total harmonic distortion at the point of common coupling. It helps to integrate the renewable energy sources effectively with a minimum power quality impact.
- The Proposed ANFIS controlled DVR is used to mitigate power quality events that may occur during the introduction of fault. Simulation results prove that ANFIS controlled DVR mitigates the power quality disturbances like Sag. And total harmonic distortions.
- A D STATCOM offers a solution for the waveform distortions and voltage flickers. In order to validate the performance of the proposed D-STATCOM is introduced with severe load conditions.

## FUTURESCOPE

Research is a constant process and opens other venue to continue the work. The Further research work may be continued in the following areas.

- The other transformation methods like linear, Walsh and coordinate methods can be implemented for pre-processing stage in expert system. It can be applied for any industries that require power quality monitoring system.
- Various evolutionary algorithm can be implemented for the tuning process of the

controller implemented in the custom power devices.

- At micro grids, the Power quality issues can be assessed and mitigated using various energy storage systems.
- Energy storage system like super capacitors, fly wheel storage systems can be implemented in custom power devices to have a better performance.

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