Power Quality Improvement Using DSTATCOM: A Review

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Abstract— **Power electronic devices are an essential component of the majority of today's commercial and domestic applications. Despite this, the power quality of these devices is quite poor for a variety of reasons, some of which include voltage fluctuations and flicker, harmonics, transients, voltage imbalance, and many more. Voltage fluctuations like this cause the greatest number of problems in electrical distribution networks. In this review article, a variety of strategies, such as network reconfiguration and devices of the compensatory type, are reviewed in order to improve the power quality in the distribution systems. There are several power quality challenges that have been portrayed along with their features. Filters, unified power quality conditioners (UPQC), dynamic voltage restorers (DVR), and distribution static synchronous compensators (D-STATCOM) are only some of the methods that have been considered for improving the power quality in distribution systems. Additionally covered are the design parameters, as well as the application of these strategies in electrical machines..**

Index Term— CPD; D-STATCOM; DVR; UPQC; APFC Filters; Power Quality Improvement

I. INTRODUCTION

Power quality problems are currently the world's most pressing electricity-related challenge. The decline in the reliability of the electricity supply has raised consumer consciousness. There are three primary components to every power grid: the producing station, the transmission system, and the distribution network [1]. In order to meet customer demand for a stable power supply, the producing unit must produce far more energy than is strictly necessary. Transmission systems are also needed to send the bulk electricity that may otherwise overwhelm or disrupt the system while sending signals across great distances. In addition, the distribution system must draw electrical power from the bulk power networks and deliver it to each customer's premises [2]. The varied demographics of electricity consumers have bolstered support for deregulating power quality [3]. There have been several efforts to find a flexible and dynamic answer to the power quality issues. Passive filters frequently employ L-C-adjusted frequency to needed frequency elements that are intended to have attenuation in order to reduce or eliminate oscillating frequency components. When compared to active filters, passive ones are more effective and cheaper [4]. However, these passive filters have a number of drawbacks, such as the unity impedance problem, fixed compensation, and reduced stability and issues with supply and load resonance. To overcome these limitations, active power filters are employed. There are several types of active power filters (APF), including shunt, series, and hybrid designs. The Hybrid APF combines the best features of the other two types of APF, the series APF and the shunt APF. Shunt APF is used to balance current-based distortions, whereas series APF is used to balance voltage-based distortions. The use of a hybrid APF allows for complete filtration of the higher order harmonics. Occasionally, issues arise in prototypical performances because the ratings are indistinguishable from the load (almost 80%) [5, 6]. Because of this, customers may get dissatisfied with the service. Power electronics controller devices, such as bespoke power devices, have therefore made it possible to provide the least deformation in power supply through the use of advanced power electronics devices. In order to provide sufficient power as required by the picky consumers [7, 8], it is common practise to deploy custom power devices in operation in addition to the power distribution system. The distribution unit makes use of the voltage source inverter custom power devices because of the unit's big dc capacitor and ability to maintain its own dc bus voltage. Custom power devices may be divided into two broad groups: those that configure networks and those that correct for power fluctuations. Electrical machinery applications need specialised power devices. Modulating the power flow is one application for FACTS devices, which are also utilised at gearbox levels. FACTS regulates the high-voltage side of a network to improve power flow through power electronics. In the same way as FACTS devices account for the use of a lower power electronic controller at the supply end, a CPD accounts for the use of a higher power electronic controller at the distribution level in industrial, commercial, Custom power devices (CPD) are the FACTS controllers used in the distribution system to boost power quality.Applications for custom power devices in distribution networks permit attention to power flow quality and network dependability. CPD's convenience is well-coordinated with the low-voltage, single-use application (UPS) for which it was developed. Devices designed specifically for the user's power needs demonstrate how adding sophistication to standard power makes it practical for end users. The end of the power grid that is connected directly to the customer side is known as the distribution system [9]. This is why reliable electricity at the distribution end of the grid is so important. FACTS devices, such as static synchronous series compensators (SSSC), static synchronous compensators (STATCOM), unified power flow controllers (UPFC), and interline power flow controllers (IPFC), etc., are first introduced to improve the power quality of the system [10]. Custom power devices assist fix a number of power quality problems, making the system more stable. Different bespoke power devices can be broken down into one of three basic types according to their architecture: the Dynamic Voltage Restorer (DVR), the Distribution STATCOM (D-STATC0M), or the Unified Power Quality Compensator (UPQC). The many bespoke power device kinds and classifications are shown in Fig. 1.

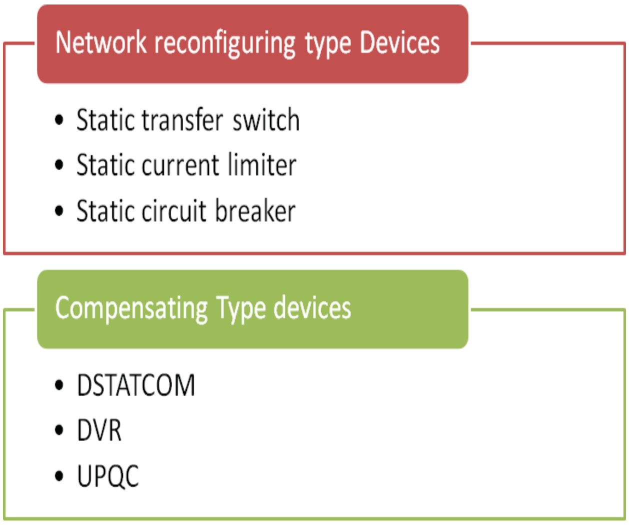

Fig.1 Classification of Custom Power Devices

The voltage source converter or inverter is the foundation for these [11]. The acronym UPQC refers to the combination of D-STATCOM and DVR in one system. Through the elimination of harmonics in the supply, the D-STATCOM is utilized to improve the power factor. The assumption for reactive power correction is that the reference current will remain steady. Active filters and power conditioners are two names for specialized types of custom-made power devices. STATCOM is positioned in such a way that it is able to keep reactive current at low voltages, and it is a shunt concatenated device. Shunt connected static compensator is the name given to the innovative static VAR compensator that was recently developed. In place of thyristors, GTO and IGBT are often utilized in the VSC in order to accomplish the task of regulating the flow of electric current by self-commutation. Formerly known as static condenser, STATCOM is an abbreviation for "static condenser" [12]. Harmonics may be traced back to the systems that make up power electronics. When there is a distortion, it is important for the consumer's needs to be met appropriately. The problem of poor power quality has a significant impact on the loads of industry, commerce, and residential buildings [13].The presence of electromagnetic interferences in power transmission and distribution networks can lead to a variety of problems with the quality of the electricity [14]. Electromagnetic disturbances can be divided into the following six categories:

• Phenomena involving low and high frequencies that are conducted

• Phenomena involving low and high frequencies that are radiated

• Phenomena involving electrostatic discharge

• Phenomena involving nuclear electromagnetic pulses there are transient phenomena, phenomena that occur during steady states, variations in voltage and flicker, and variations in power frequency.

These phenomena are categorized differently according on the PQ application. There are three categories of temporary phenomena: transients, lengthy, and duration voltage fluctuations, interruptions that last for an extended period of time, and changes in voltage with a short duration. [15-17] The steady state phenomena is referred to as voltage imbalance (unbalance), and waveform distortion.

II. TYPES OF POWER QUALITY ISSUES

The following is a list of numerous issues that might arise in electrical machinery as a result of various power quality problems:

• Transients

• Power Frequency Variations • Voltage Fluctuation and Flicker • Voltage Imbalance • Waveform Distortion • Short-Duration Voltage Variations • Long-Duration Voltage Variations • Voltage Imbalance • Voltage Fluctuation and Flicker • Voltage Imbalance • Waveform Distortion • Voltage Fluctuation

A. Transients

Transients in the power system are abrupt occurrences that last for just a brief period of time. A change in a variable that vanishes in operational condition while transitioning from another steady state is referred to as a transient. Transients are identical to surge. The component properties of a transient, such as its amplitude, rise time length, frequency of occurrence, and so on, can be used to classify the transient. There are two different kinds of transients:

a) Oscillatory

Because it is of a bidirectional nature, an oscillatory transient may be computed for both voltage and current in both positive and negative polarities [18]. It also indicates a sudden frequency under situations when the system is in a stable state. This takes place as a result of the switching of a variety of appliances, as well as fast-acting overcurrent protection devices and capacitor bank switching. Depending on the frequency range, high frequency transients are caused by the response of the network; medium frequency transients are caused by the energization of back-to-back capacitors; low frequency transients are caused by the energization of capacitor banks; zero resonance and transformer energization occur with principal frequencies that are below 300 Hz; and low frequency transients are caused by capacitor bank energization. Oscillatory transients are seen in figure 2, which may be found here.

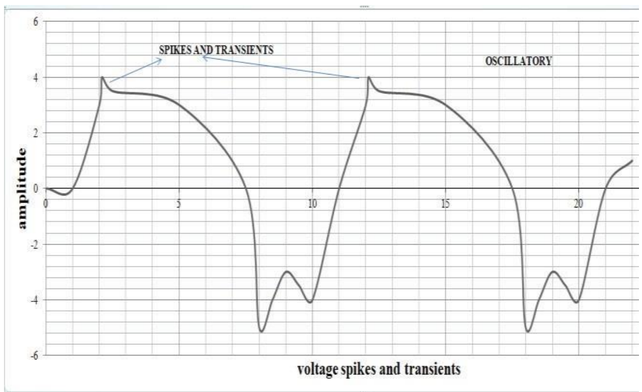

Fig.2 oscillatory transients

a) Impulsive

An impulsive transient is used to detect a sudden frequency change in the steady-state condition for both voltage and current but it is unidirectional nature in polarity. Lightning current surge is one of the most common causes of this impulsive transient. It excites natural frequency of system.It is characterized by peak value, rise time and decay time. In Fig. 3 impulsive transients are shown.

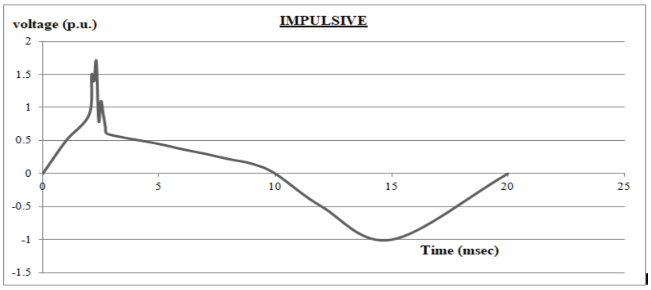

Fig.3 Impulsive transients are shown in the above figure

A. *Short-Duration Voltage Variations*

This short duration variations in voltage detect the voltage dips and shorter interruptions. There are basically 3 types of short duration occurrence that comprehensively includes instantaneous, momentary and temporary events. Further, each of these events is sub-divided into sag, swell and interruption. Fault conditions, loosen connections and sometimes large load energization are a cause for these conditions. Fig. 4 depicts variation voltage changes occurring in a sinusoidal voltage signal.

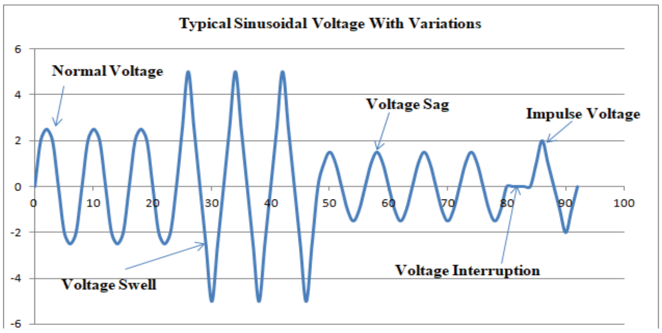

Fig. 4 Voltage swag and swell, interruption and impulse occurring in a typical sinusoidal voltage signal

These short duration voltage variations are characterized as:

a) Interruption

Whenever there is a decline in the supply voltage or load current that lowers to less than 0.1 p.u. for a length of less than 1 minute, then interruption occurs. This is the case whether the drop in voltage or current lasts for less than 1 minute. Equipment failures, blown fuses or breaker openings, and control malfunctions are some of the factors that might contribute to this issue. One of the most significant distinctions between a sustained interruption and a protracted interruption is that the former lasts for a longer period of time.

In the former scenario, restoring the supply would require manual intervention, but in the later scenario, it would be done automatically. Interruption is primarily quantified by its duration, which is established by the amount of time protective devices are allowed to be in operation.

b) Sags (Dips)

In the time that elapses between the beginning of the problem and the action of the protective mechanism to clear he fault, the voltage drops. IEC (international electrical technical commission) describes voltage sag as drop in voltage. It is contingent on the distance of the fault from the bus at the location where the sag takes place. The majority of these are attributable to flaws in the system. The sag conditions are caused by any and all drops in the RMS voltage that are of shorter duration and fall between 0.1 and 0.9 p.u. In most cases, the cycle duration is 0.5 minutes, and the time period is 1 minute. When starting big induction motors, the major cause of voltage sags is the energising of huge loads. This is because starting these motors requires a lot of power. Another cause for the formation of sags or dips in voltage is ground faults that are associated to single lines, in addition to other reasons for moving the load between various sources of power.

c) Swells

The phenomenon known as swell occurs when the magnitude of the voltage increases in a range that falls somewhere between 1.1 and 1.8. On the other hand, these swellings do not occur as frequently as sagging. It is defined by the size of its r.m.s and the length of its duration. These are connected with faults in the system, such as the SLG fault that creates unfaulted phases. Generally, it results due to switching off a large load energizing a capacitor bank or sudden increase in voltage of various faulty phases occurring during a single line to the ground fault. In many contexts, the phenomenon known as swell is also referred to as a transient overvoltage.

B. Voltage Changes Over Prolonged Timescales

The RMS voltage, also known as the root mean square voltage, will exhibit long duration voltage changes whenever it deviates from its usual value over a length of time that is more than one minute. fluctuations in load and other switching processes carried out inside the systems are some of the primary factors that contribute to fluctuations of this kind in the voltage. In addition to this, it may be further classified into the following three primary groups: persistent interruption, undervoltage, and overvoltage.

a) Interruption That Lasts a While

The term power outage is interchangeable. When there is no change in the supply voltage over a length of time that is longer than one minute. The duration of a persistent interruption is typically three minutes. This type of power quality event is the most severe and has been around the longest. It occurs when the voltage dips to zero and does not restore automatically. The sustained length is larger than three minutes (or, according to IEEE standards, greater than one minute). The failure of a component or piece of equipment as a result of the incorrect intervention of a protective relay is one of the primary reasons for this interruption. It is also possible that this interruption was caused by any kind of scheduled interruption in a network that was operating at a lower voltage and had no redundancy. Figure 5 illustrates prolonged disruptions in communication.

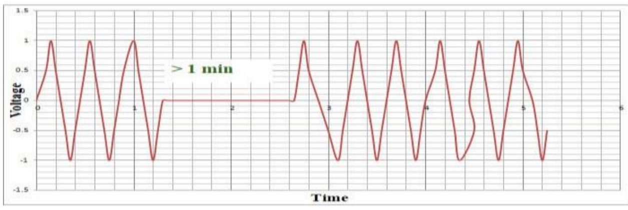

Fig.5 Sustained interruptions in long duration voltage variation

III. VARIOUS TECHNIQUES TO IMPROVE POWER QUALITY

Harmonic currents are produced when a variety of nonlinear loads interact with an electric circuit. These currents often travel to another area before finally returning to their source by travelling in the opposite direction. In addition, the propagation of these harmonic currents leads to the propagation of harmonic voltage inside the devices and equipments that make up the power system. It has been suggested to use a variety of different strategies in order to reduce the development of harmonic currents and voltages in power systems as well as their impacts. The following is a list of some of these different methods.

Harmonic cancellation, as well as the design of high power quality equipment

Dedicated line or transformer, derating of power system devices Optimal location and size of capacitor banks Dedicated line or transformer Derating of power system devices

• Custom power devices such as active power line conditioners (APLCs) and unified or universal power quality conditioners (UPQCs). • Harmonic filters (passive, active, and hybrid).

Filters, of both the active and passive and hybrid variety, are among the most common types of devices used in power quality enhancement strategies. Active filters, passive filters, and other hybrid filters are only some of the varieties of filters. Aside from filters, some of the bespoke power devices are the most recently employed ways for mitigating the power quality concerns in the power systems and equipments. These difficulties may be mitigated by reducing the amount of impurities in the power. These bespoke power devices are further broken down into two categories: devices of the network reconfiguring kind and devices of the compensating type. In the next paragraphs, each of these kinds of power quality enhancement strategies is broken down into depth.

A. Filters in Power System

In modern electrical power systems, harmonic filters and the process of implementing them are an essential component of every single system. The technology behind power electrical devices has recently been shown to be capable of a wide variety of important upgrades and developments. It is now absolutely necessary to install filters at various stages of power electronic equipment due to the requirements that must be met to provide a source of energy that is both dependable and of high quality. The problem with the filter installation is that it only takes into account the harmonic voltages and currents of the bus in which it is installed. It does not take into account the harmonics of any other buses, which means that the power quality of the buses that are not affected by the filter is reduced. The rise in the number of non-linear loads necessitates the installation of a considerable number of harmonics filters as well. Because of this, a new generation of active filters has emerged, which are known as unified power quality conditioners (UPQCs) and active power line conditioners (APLCs). All passive shunt filters work according to the same fundamental concept, which is to supply a shunt branch with lower impedance than is typically created by a nonlinear load. This is the case for all of these filters. In nonlinear loads, filters are also employed to correct for harmonics using current-based compensation, and this requires the utilisation of current.

a) Passive filters

In most cases, passive filters are utilised in order to stop a sizeable quantity of harmonic distortion that was created locally from being fed into the power supply of the gadget that was being manufactured. When a power system malfunction creates large harmonic distortion locally, passive filters prevent that distortion from being injected into the power system. These fault mitigation devices have a cheap cost and are utilised in the power system. They are typically situated in close proximity to the nonlinear loads in a power system that are responsible for the generation of harmonics. When tuning a passive filter, extreme precision is required such that the resulting attenuation is smaller than that of the harmonics being filtered out.

b) Filters that are active

Active filters are an additional viable alternative to the passive category of filters. Each and every location that calls for dynamic compensation must have an active filter. These are utilised in a wide variety of applications, particularly those in which either the design of the system is subject to change or the nonlinear load produces continually shifting harmonics inside the system. In situations such as this one, an active filter is often employed whenever there is a fluctuation in the order number of harmonics. These filters, for the most part, are reliant on the active power conditioning in order to adjust for a variety of currents and harmonics in the system that are not acceptable. In contrast to passive filters, active filters offer a superior response for load transforming and imbalance brought on by harmonics. This is one of active filters' key advantages. On the other hand, these active filters cover all the bases when it comes to the other necessities for compensating the reactive power and the harmonic components. Additionally, they are utilised in three-phase AC power circuits that have massive penetrating non-linear demands.

c) Hybrid filtering systems

The high ratings of active filters, which serve as a key negative, are responsible for the introduction of about 80% of non-linear loads in a variety of applications. However, voltage and current-based disturbances in power quality cannot be corrected by a single active filter. This is because of the nature of the disturbances. The usage of active filters in a variety of applications has been restricted due to their more expensive price tag and their inability to withstand higher ratings. In this scenario, the hybrid filter has emerged as a solution that is both cost effective and efficient in terms of giving compensation to the non linear loads. The development of hybrid filters results in the creation of an effective and comprehensive capability to adjust a wide variety of nonlinear loads. These filters, in essence, combine the properties of active and passive filters and have a variety of structural topologies, including series topology, parallel topology, and a mix of both of these topologies. The passive filters are responsible for controlling the 5th and 7th harmonic frequencies, while the active filters are responsible for mitigating the higher harmonics. This contributes to the overall size reduction as well as the cost reduction of the active filtering process. The power rating, supply system, topology, number of active and passive components, speed of reaction, compensatory parameters, and control technique are some of the characteristics that may be used as a basis for classifying active and hybrid filters. Other factors that can be employed include the number of active and passive elements. A more efficient perspective is based on the combination of both series and shunt active filters, which helps in providing compensation for both the current and voltage power quality. This combination of filters helps ensure that the power is of high quality.

B. *Network reconfiguring type custom power devices*

There is a subcategory of bespoke power devices known as network reconfiguration type devices. These devices make use of GTO or thyristors to achieve current limiting with the least amount of latency and current breaking in various applications. These may be broken down into four categories:

• Static Transfer Switch • Static Breaker • Solid State Current Limiter • Uninterruptible Power Supply

a) Static Current Limiter (SCL), which is a solid-state device.

In order to bring the fault current down to a more manageable level, the static current limiting devices use a sequence of different inductances connected together. This fundamentally forms a connecting device that operates on a series basis. In order to do this, a GTO together with an inductor and a snubber circuit are required.

b) Static Transfer Switch (often abbreviated as STS)

Utilising a static transfer switch, also known as an STS, allows for protection against a wide variety of sagging and swelling in sensitive loads. In this particular circuit, there are two thyristors or GTO blocks that are connected in parallel. Each individual block corresponds to one of the three phases of the power system. Connecting an STS that has two parallel pairs of antiparallel thyristors requires the usage of a bus tie position. This makes it possible to quickly switch the power supply from the malfunctioning feeder device to an alternative feeder device within a time period that is measured in milliseconds. At the level of distribution, clients receive a supply of electricity that is uninterrupted at all times. The high conducting loss that happens in high power applications that follow in the range of 0.5 to 1 percent of the load power is nonetheless the primary feature of this switch. This loss occurs in the region of 0.5 to 1 percent of the load power.

c) Solid State Breaker (often abbreviated as SSB)

Solid state breakers are yet another type of high-speed switching device. These breakers provide protection against high currents and cut down on the number of electrical failures that occur in distribution systems. This apparatus use the thyristor or GTO-based technology as its foundation as well. This SSB can also be utilised as a static transfer switch, a single switch, a hybrid switch, or to lessen the faults interrupting at a lower level. These are all examples of possible applications. The operation of this SSB is accomplished by the usage of an auto reclosing mechanism. The number of switching devices, the cost of the device, and other losses of the breaker for various voltage and current ratings all play a role in determining whether or not an SSB should be used in a particular power system.

d) An uninterruptible power supply, sometimes known as a UPS

As an alternative to traditional power sources, an uninterruptible power supply, often known as a UPS, can be utilised to circumvent potential issues with the manufacturing process, such as interference or unexpected equipment failure. Conversions from alternating current to direct current and from direct current to alternating current are two of the many operations that are carried out by the UPS in order to transfer load power from the source. In the event that there is a disruption or a drop in voltage, the energy that is generated by the battery is used to ensure that the load voltage remains at a constant value. Because it must convert from AC to DC and then back to AC, the battery has a somewhat high maintenance cost, which renders it unsuitable for use with large power loads.

C. *Compensating Type Custom Power Devices*

There are several specialised power devices that can be utilised for active filtering, enhancement of power factor, balancing of load, and control of voltage. These devices are of the compensatory kind, and they are custom-made power devices. The static shunt compensator, the series compensator, and the hybrid compensator are the three primary types of compensating devices. These are then broken down even further into D-STATCOM, DVR, and UPQC categories, respectively. The next paragraphs will elaborate on these tools.

a) Unified power quality conditioners (often abbreviated as UPQC).

Another type of advanced hybrid filter is known as UPQC, and it is a workable device that is put to use to ensure that the standards and requirements for the provided power are satisfied at the site of installation. The ideal uninterruptible power supply controller (UPQC) is a mix of all three devices—a common DC link, a current source converter, and a voltage source converter. The right shunt UPQC is the kind of conditioner in which the shunt compensator is positioned at the right end of the series compensator. On the other hand, the left shunt UPQC is the type of conditioner in which the shunt compensator is positioned at the left end of the series compensator device. The UPQC has two converters that are each coupled to a common DC connection that contains energy storage capacitor banks. DC capacitors, series and shunt power converters, low pass and high pass passive filters, DC transformers, and series and shunt power converters are some of the several components that make up the UPQC. These UPQC compensators are utilised for the correction of both forms of distortions, namely distortions happening due to three phase voltage systems as well as distortions occurring owing to unbalanced line current with frequency components of a higher order.

b) Distribution Static Compensator (often referred to as D-STATCOM)

A DSTACOM voltage source converter is an additional static compensator device that is frequently used to maintain the bus voltage sags. Its application is common in this context. It does this by either giving or receiving the reactive power that is needed in the distribution system. This keeps the sag at the proper levels. Diverse distribution feeders are linked to the transformers in shunt where this DSTATCOM is attached, and these transformers are connected to the DSTATCOM. A DSTATCOM will typically have a VSC, an AC filter, a DC energy storage device, and a coupling transformer as standard components. It is possible to store the active power of the system with the assistance of energy storage technologies. As the operational principle of the DSTATCOM circuit, this section involves continually monitoring the load voltages and currents in order to correct for any disruptions that may occur inside the system. The difference in the magnitudes of the voltages is used to continually manage the angle that exists between the voltage of the VSC and the voltage of the AC power system in order to control both the active power flow and the reactive power flow.

c). A dynamic voltage restorer, often known as a DVR

The term "Dynamic Voltage Restorer," or DVR for short, is commonly used to refer to a static series compensator. A DVR is a controlling device that has a very rapid switching speed and is employed in the field of power electronics. A DVR is also often referred to by the moniker series voltage booster. A connection in series is always taken into consideration by the DVR. Along with a coupling transformer, this voltage is injected into the distribution line, where it is then dynamically regulated by the DVR in terms of both its magnitude and its phase. This is done in order to either improve the load voltage or make adjustments to it. The amplitude, frequency, and phase angle of the voltage produced by this device, which functions as an external voltage source, may be adjusted. A digital variable regulator (DVR) is designed to keep a fixed load voltage constant by preserving the amplitude and phase angle of that voltage. A DVR typically has the following components: an energy storage device, a DC to DC boost converter, an AC filter, a voltage source inverter, and a coupling transformer. When voltage deregulation occurs, the DVR produces a reference voltage, which is then compared with the voltage coming from the source. The result of this comparison is used to determine the amount of synchronised voltage that must be injected into the system in order to keep the load voltage at a constant value.

D. CONCLUSION

There are many different kinds of errors that may happen in the power distribution system, and their implications on the quality of the electricity have been explored. In this research, various tools that may be utilised for the purpose of mitigating the effects of these issues have also been discussed. It is possible to pick the suitable device, taking into account the various uses and impacts that these devices have on the power quality. This allows for the elimination of particular errors that may arise in power distribution systems. In the case of networks with a single bus, filters are used because they are the most effective way to get rid of voltage fluctuations and harmonic currents. On the other hand, the majority of the different types of filters are deemed inadequate for multi-bus and complicated network arrangements, and instead, bespoke power devices are required. A variety of network reconfiguration type devices have been discovered as a solution to the issues of sags and swells in all of a network's buses, as well as the management of enormous quantities of currents and distortions inside the network. In addition to this, load balancing and voltage regulation may be achieved with greater efficiency with the assistance of compensatory type bespoke power devices such as DSTATCOM and DVR.

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