A Review on Power Quality Compensation Devices

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***Abstract*: In recent trend, the usage of various electronics devices in industrial and residential application creates certain power quality issues. Hence smart grid associated with such power quality problems may affect the different types of loads like non-linear, linear & sensitive type loads. Various Power filters can mitigate such power quality issues. Different techniques for the compensation are introduced which can operate with transformer or without transformer such as Dynamic Voltage Restorer (DVR), Distribution Static Compensator (DSTATCOM), Series active filter with SIT, Unified Power Quality Conditioner (UPQC), Conventional hybrid series active filter, Transformer less hybrid series active filter (THSeAF), etc. In this paper, the characteristics and performance these different techniques are analyzed with various power quality issues such as harmonics, voltage sag and swell. Various power filters are overviewed. Control strategies used by power quality conditioning devices has been discussed in this paper. From overall analysis transformer less topology has comparatively better performance than that of the other devices.**

***Keywords*: Voltage sag, voltage swell, harmonics, Transformer less hybrid series active filter (THSeAF), Dynamic Voltage Restorer(DVR), Distribution Static Compensator(DSTATCOM), Unified Power Quality Conditioner(UPQC).**

1. INTRODUCTION

Now a day's modern society is abundantly dependent on the Electric Power and our traditional power system includes three parts i.e. generation, transmission and distribution of electrical power in the form of AC. This electric power should have good quality so that it can supply all equipment or appliances equally and satisfactorily. Because of the heavy loads or any abnormal conditions or faults in the system the quality of the power is reduced and becomes less suitable for further applications. Also, due to increasing the usage of electronic devices may degrade the power quality. Different types of loads like non-linear and sensitive type load may generate the harmonics and disturb the waveform of voltage and current [13].

Voltage magnitude is also one of the major factors that determine the quality of electrical power. It is essential to enhance the quality of power before it is used for any application. Power quality directly affects the end users or customers as utilization of power is directly associated to distribution system. So, Different techniques are proposed and now implemented in day-today applications to work out on the harmonics, voltage sag and voltage swell problem [8].

In last decades, lossless passive filters are selected to mitigate harmonics and for compensation of reactive power at nonlinear loads. But, passive filters have some drawbacks. It provides fixed compensation and it has large size and resonance with the supply system. So, Active filers have been preferred in shunt and series configurations to compensate different types of nonlinear loads. Many analysts have classified different types of nonlinear loads and have advised different filter options for their compensation. In response to these factors, a series of hybrid filters has been evolved and widely used in practice as a cost-effective solution for the compensation of nonlinear loads [1], [5].

Power conditioning devices may be used to solve PQ problems. Using proper interface devices, isolation of the loads from disturbances deriving from the grid can be possible. Different devices for the compensation are introduced which can operate with transformer or without transformer such as Dynamic Voltage Restorer (DVR), Distribution Static Compensator (DSTATCOM), Series active filter with SIT, Unified Power Quality Conditioner (UPQC), Conventional hybrid series active filter, Transformer less hybrid series active filter (THSeAF), etc. This paper reviewed the power quality issues, effect of power quality issues and different devices and methods for its correction. Control strategies preferred for such devices are overviewed.

2. POWER FILTERS

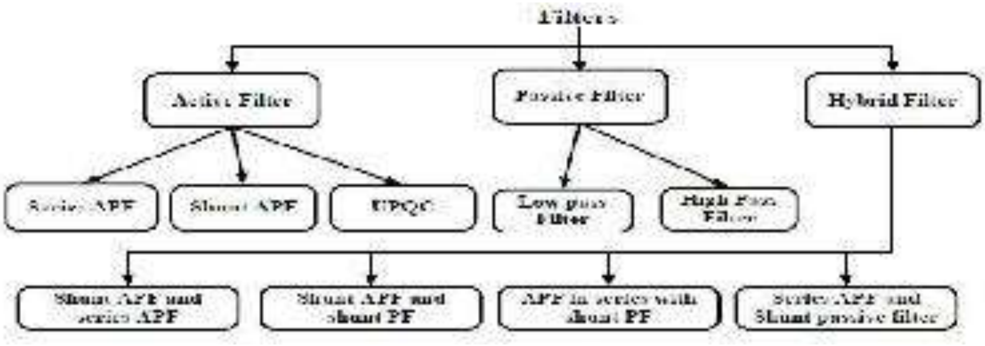

Fig 2. Types of filters

The different filters present in the literature are classified into three basic types. They are Active Filters, Passive Filters and Hybrid filter [1], [5], [13]. Each type has its own sub classification. Fig. 2 shows the detailed classification of the filters. The active power filters are better solution for power quality improvement but they require high converter ratings. So the hybrid power filters are designed. The hybrid power filters are the combination of both active and passive power filters. They have the advantage of both active and passive filters. There are different hybrid filters based on the circuit combination and arrangement [14].

3. POWER QUALITY CONDITIONING DEVICES

These devices are used to solve PQ problems. Using proper interface devices, one can isolate the loads from disturbances deriving from the grid.

3.1 Dynamic Voltage Restorer (DVR)

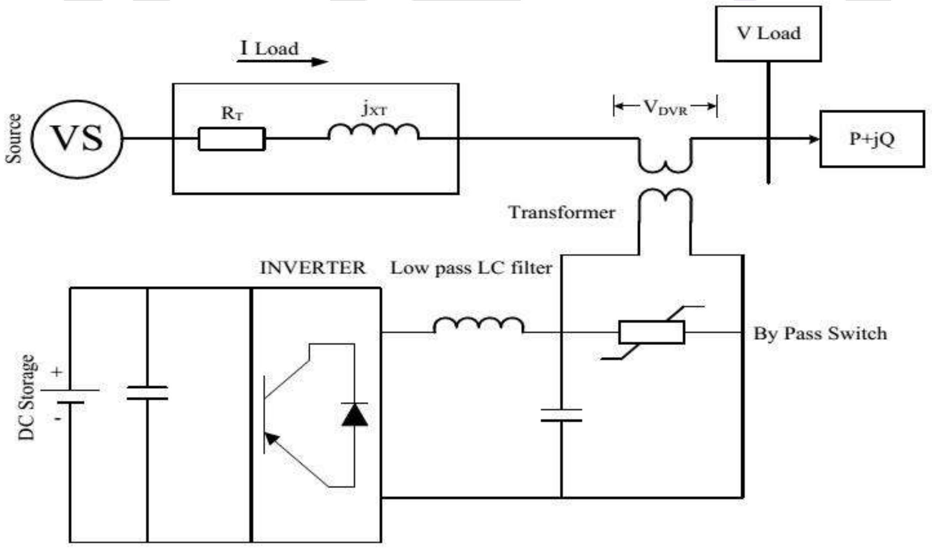

Fig 3.1 Dynamic Voltage Restorer (DVR)

Dynamic Voltage Restorer (DVR) is a series compensating device. It can protect a sensitive load from the distortions. The basic principle of Dynamic Voltage Restorer (DVR) involves the injection of the voltage of required magnitude and frequency which restores the load side voltage to the desired magnitude. The Dynamic Voltage Restorer (DVR) employs GTO thyristors power electronic switches with pulse width modulated (PWM) inverter structure. The Dynamic Voltage Restorer (DVR) injects a set of three phase output voltages in series with the distribution feeder, which is made of a solid-state converter. At the load side the DVR can generate or absorb the real and reactive power independently. The magnitude and the phase angle of the voltages injected by DVR can be variable which allows the reciprocation of the real and reactive power between the Dynamic Voltage Restorer (DVR) and the distribution feeder system [8]. The dc input terminal of a dynamic voltage restorer is connected to an energy source or an energy storage device of proper capacity. The transfer of reactive power between the DVR and the distribution feeder generated internally by the DVR without any AC passive reactive components. An external energy source or an energy storage system is used for the real power exchange at the DVR output ac terminals. The DVR structure comprises of rectifier, inverter, filter and coupling transformer. PWM technique is used to control variable voltage. Filter is used for eliminating harmonics generated from high switching frequency in PWM technique. DVR system is connected in series with the distribution feeder in the power system that supplies a sensitive load shown in Fig 3.1. In order to maintain the load voltage, reactive power must be injected by DVR system. Upon the occurrence of the fault which may be a short circuit current flow, a line-line-ground fault which leads to reduction in the voltage magnitude at the Point of Common Coupling (PCC) [8].

3.2 D-STATCOM

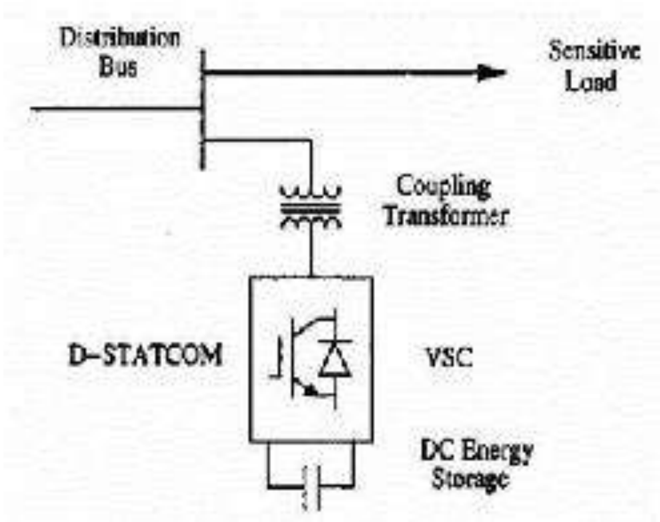

Fig 3.2 D-STATCOM

A voltage-sourced converter (VSC) with PWM provides a faster control that is required for flicker mitigation purpose. A PWM operated VSC utilizing IGBTs and connected in shunt is normally referred to as “STATCOM” or “DSTATCOM”. A shunt-connected synchronous machine has some similarities with the STATCOM, but does not contain power electronics. The capability of the synchronous machine to supply large reactive currents enables this system to lift the voltage by 60% for at least 6 s. D-STATCOM has the same structure as that of an STATCOM. It can potentially be used in the context of (EMI). The valves are cooled with circulating water and water to air heat exchangers. PWM switching frequencies for the VSC typically range between 1-2 kHz depending on the converter topology, system frequency and specific application. The Block diagram of the D-SATCOM shows that phase locked loop (PLL) technique is used for voltage sag detection and mitigation. However, this technique provides good results only if voltage sag is not coupled with phase angle jump. The reactive power control strategy for the D-STATCOM has been employed for load compensation. PI controller is used to control the flow of reactive power to and from the DC capacitor. Phase-locked loop (PLL) has been used to generate the switching signals for the VSC. The DSTATCOM has been developed using DSP controller to achieve excellent overall performance. D-STATCOM is capable of mitigating voltage sag caused by three phase balanced fault [4]. However, as PLL is used for detection and mitigation of sag in the control strategy, it provides good results only if sag is not accompanied by phase jumps.

3.3 Single phase series active filter with series injection transformer and Switching ripple filter

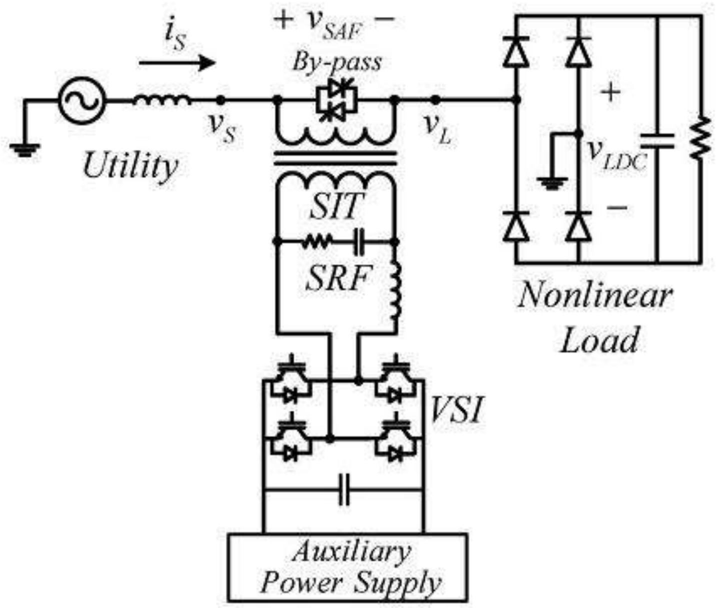

Fig. 3.3 Series active filter with SIT and SRF

The SAF power circuit is composed of a single-phase full-bridge voltage-source inverter (VSI), a SIT, and a switching ripple filter (SRF) as shown in fig 3.3 SAF is generally applied to voltage harmonic type (V-type) loads such as diode rectifiers with dc bus capacitors for the purpose of power quality improvement. A SAF injects a series harmonic compensation voltage between the line and the load such that it cancels the load harmonic voltage and eliminates the line harmonic current. Thus, the line current waveform becomes a clean sinusoid and the load voltage waveform becomes square under the ideal load harmonic isolation condition. The auxiliary power supply is required for load voltage regulation against line voltage variations [11]. In some cases, the dc buses of the SAF inverter and the load rectifier can be connected to each other (common dc bus configuration) instead of utilizing an auxiliary power supply. Furthermore, if the SAF does not require any electrical isolation and any voltage/current matching between the inverter and utility sides,[15] the series injection transformer (SIT) may be omitted. Compared to a single-phase parallel active filter (PAF), a SAF has the following several advantages. First, unlike a PAF, a SAF does not require a large smoothing inductance (~15%) in order to form a harmonic source type (I-type) load from a V-type load. Second, for the cases, where electrical isolation is required, a PAF utilizes a transformer with full-fundamental frequency voltage and flux ratings, and rated load harmonic current rating (~50% of rated load current), while a SAF requires approximately 50% voltage, 20% flux linkage, and full fundamental load current ratings. Considering that the transformer size is mainly determined by amount of winding material (driven by current rating) and amount of core material (driven by flux linkage rating), the SAF transformer size and volume is expected to be less than half of the PAF transformer, while both require the same apparent power (kVA) rating, which is 50% of the load rated power. Finally, a SAF, unlike a PAF can be utilized for the mitigation of line voltage variations and the load voltage can be well regulated. Also, the SAF harmonic isolation performance can be realized such that the line current distortion can be decreased down to 4% THD, which is the practically achievable value by a single-phase PAF. Thus, comparable harmonic distortion reduction performance to the PAF can be achieved. However, there are some difficulties involving the SAF performance. In the following, SAF harmonic isolation, its challenges, and the proposed approaches are discussed. The SAF requires the harmonic extraction of the line current and the load voltage for harmonic isolation. After the amount of injection voltage is determined by the SAF controllers, the inverter provides the injection voltage through a series transformer and the power quality is restored [2]. Thus, the signal decomposition (harmonic voltage/current extraction) algorithms play a major role in determining the SAF performance. For three-phase SAF systems, this problem could be successfully overcome by the waveform reconstruction method (WRM) and also line current sampling delay reduction method (SDRM).

3.4 Unified Power Quality Conditioner (UPQC)

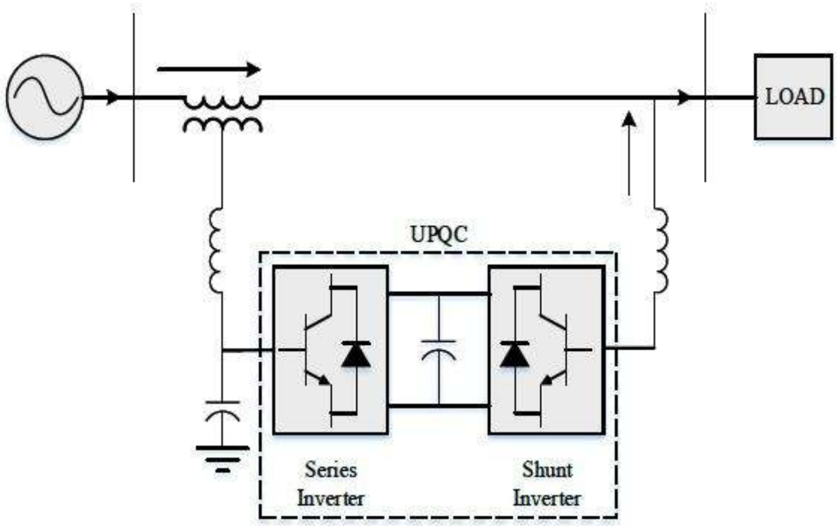

Fig.3.4 Unified Power Quality Conditioner

The active power filtering has appeared as one of the best solutions for mitigation of major power quality problems [5]. For a complete compensation of power quality issues, Unified power quality conditioner (UPQC) was introduced. This approach is recommended to take advantages of both mentioned active filters. The series connected filter compensates voltage harmonics and related issues, and the shunt filter connected across the load eliminates current distortions. The UPQC which is an integration of shunt and series APF is one of the most appropriate as well as effective device in this concern. The main motive of UPQC is to solve the problems coming from both source side and load side, such as voltage sag, voltage swell, harmonic reactive currents, distortion in the supply voltage, etc. Using a common dc bus capacitor, the components of UPQC series and shunt inverter connected back to back [10].

3.5 Conventional hybrid series active filter

This is also hybrid topology. The topology uses series active filter combined with shunt passive filter. Traditionally, a passive LC power filter is used to eliminate current harmonics when it is connected in parallel with the load. This compensation equipment has some drawbacks mainly related to the appearance of series or parallel resonances because of which the passive filter cannot provide a complete solution.

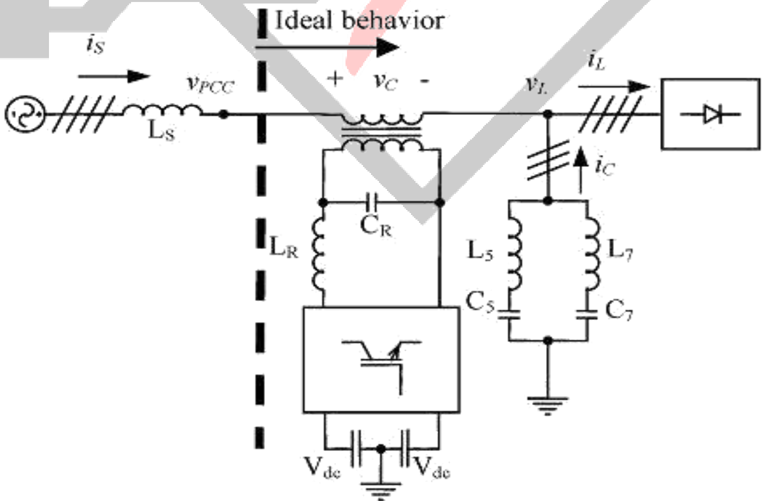

Fig 3.5 Conventional hybrid series active filter

The hybrid topologies aim is to enhance the passive filter performance and power-rating reduction of the active filter. Two configurations have been mainly proposed: active filter connected in series with a shunt passive filter and series active filter combined with shunt passive filter. Both topologies are useful to compensate harmonic current source load type. However, when the load also generates voltage harmonics, the second topology is the most appropriate. It also avoids the danger that the passive filter behaves as a harmonic drain of close loads, and likewise, the risk of possible series and/or parallel resonances with the rest of the system. In addition, the compensation is also possible with variable loads, not affecting the possible the passive filter detuning [3]. This strategy achieves unity power factor when the supply voltage is balanced sinusoidal. The system compensation can be applied to nonlinear load, both harmonic current source loads and harmonic voltage source loads. This approach represents an attractive alternative to shunt active filters, since no energy storage is required and the overall rating is reduced. The transformer issued to generate the compensating voltage and creating an electrical isolation between the converter, and the power system is bulky and could be replaced. This injection transformer is responsible for the extra cost of series active filters [7]. It increases the complexity and losses in the system. However, for a current compensating purpose, the rate of the transformer increases considerably. Different approaches were proposed to replace the series transformer.

3.6 Transformer less Hybrid Series Active Filter with H-Bridge

The setup is able to perform the task of compensation requirement by the system. Transformer less hybrid series active filter (THSeAF) consists of H bridge inverter in series connection with source and load as shown in Fig.1. Passive capacitance is connected in shunt for providing the path of low impedance to current harmonics. During voltage sags to inject power dc auxiliary source is required. A variable supply is connected to a nonlinear load and a linear load. The compensating voltage is injected by connecting THSeAF in series.

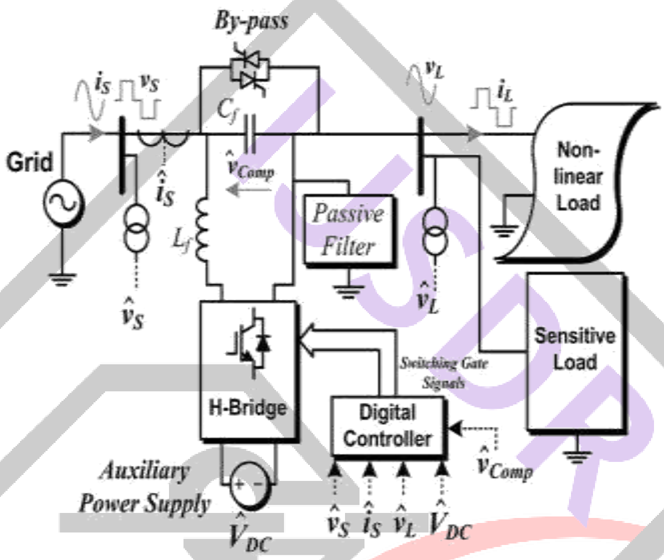

Fig 3.6 Electrical connection of THSeAF with single phase Utility

Fig 3.6 shows the diagram of 1single-phase smart load with the compensation device and Auxiliary DC source. Hybrid series active filter are preferring for the compensation of distortions in non-linear load. At normal operation of the system Current harmonics can results the distortion of voltage up to 3%. The proposed design is connected to the grid without costly and bulky transformer. So this topology becomes capable to compensate the voltage problems and currents harmonics at point of common coupling. For more number of switches, the configuration without transformer is more economical than other type of series compensators, which requires the transformer for injecting the voltage into the grid [7], [2]. The highpass, 5^{th} and 7^{th} filters are included in optimized passive filter. By the comparison between different schemes the advantages and limitations of the proposed system over the conventional system are acknowledged [3]. It has been cleared that total 45% of cost reduction for component and assembly is possible with proposed configuration. In this method, the THSeAF acts as high-impedance open circuit for current harmonics, while the shunt high-pass filter creates a low-impedance path for all harmonics and open circuit for the fundamental; also, corrects the PF. An adequate supply on the load terminals is maintained by dc auxiliary source. Power should be absorbed or injected to keep the voltage magnitude at the load terminals within a particular margin during the sag or swell situation. However, if the sags and swells compensation is having less importance, a capacitor could be used [7].

4. CONTROL STRATEGIES

Control strategy plays a crucial role in overall execution of compensating devices. In three stages, the control of a compensating device can be perceived. Hall-effect sensors, potential transformer, current transformer, isolation amplifier senses the necessary voltage and current during the first stage. By using various control methods, compensating commands in term of voltage and current are procured, in the second step. Lastly, gate pulses are developed for the solid-state devices. The control can either be open loop or closed loop. Pulse Width Modulation(PWM) and Sine Pulse Width Modulation (SPWM) are the most accepted schemes for open loop. Whereas for closed loop, for lower order system, hysteresis control technique is used. Conventional methods like pole shift control, linear quadratic regulator(LQR), sliding mode control, dead beat control is used for second and higher order system. Recently, complex algorithm like neural network, fuzzy logic, genetic have emerged due to development in microcontroller, microprocessor and digital signal processor[3].

4.1 Compensation in Frequency Domain

Fourier analysis, wavelet transform and infinite impulse response are the technique involved in frequency domain. Distorted signal is separated from the harmonic component with the aid of Fourier transform or wavelet transform for computing results on account of its slow response time. Hence, real time application of it is complex.

4.2 Compensation in Time Domain

It consists of p-q theory, extended ‘p-q’ theory, ‘p-q-r’ theory. Other acceptable control schemes to obtain reference signals in time domain are unit vector control, symmetrical component transformation and synchronous reference frame theory.

4.3 Generation of Gating Signal

Last step in control strategy is providing gating signal to compensating device. The gating signal is generated in terms of voltage and current for the compensating device.

5. CONCLUSION

Due to continually increasing nonlinear loads and higher demand of the consumer, the reliable supply of power need to maintain. So, for future smart grids concrete actions should be taken into consideration in order to smoothly integrate sensitive load and other type of loads into the grid. In this various power quality compensation devices are compared such as Dynamic Voltage Restorer (DVR), Distribution Static Compensator (DSTATCOM), Series active filter with SIT, Unified Power Quality Conditioner (UPQC), Conventional hybrid series active filter, Transformer less hybrid series active filter (THSeAF) etc. The paper highlighted that the THSeAF with H-Bridge configuration helps to improve the power quality of the system in a more acknowledged way by compensating a wide range of harmonics current than other devices. THSeAF regulates and improves the PCC voltage better than any other compensating device which uses the bulky transformers. From literature, analysis of consistent supply for critical loads can be ensured with this topology by compensating the THD and Voltage sag or Swell.

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