Advanced Research in Electrical and Electronic Engineering
p-ISSN: 2349-5804; e-ISSN: 2349-5812 Volume 2, Issue 14 October-December, 2015, pp. 27-31

http://www.krishisanskriti.org/Publication.html

Various Techniques of Power Quality Improvement using Custom Power Devices

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Abstract—*The use of non-linear loads are increasing in both commercial as well as industrial sector over the last few decades and is expected to increase dramatically in the years ahead. Thus, it has become essential to set up criteria for limiting problems associated with these type of loads from system voltage degradation. Their power control is best possible by using various semiconductor devices based upon power electronics technology. When the power control is being done in large industrial applications employing these type of loads, it will result into production of harmonics in the supply network and hence the power quality of the system gets deteriorated. Thus, to increase the reliability of the distribution supply system and to face the power disturbance problems, advanced power electronics controller devices have launched over the last years. The evolution of power electronics controller devices has given to the birth of custom power devices. There are many factors on which the selection of any particular custom power device has to be done. In this paper, a comparison of various such devices has been done for the improvement of power quality in distribution system as per IEEE standards.*

1. INTRODUCTION

The concept of power quality has been introduced to ensure the continuity of supply in transmission and distribution networks and should aim to compensate customers for long term supply interruptions and create incentives to reduce the total time duration of these interruptions. The power quality concept is especially superior to many industrial and commercial areas of power system. The non-linear loads are increasing day by day especially in case of electronic devices for the power system control [1]. For giving the solution of power quality to users, various power filtering technologies such as passive filters, active filters and hybrid filters have been used from time to time, but they couldn't fully satisfy them. After that various techniques of improving power quality like STATCOM (Static Synchronous Compensator), SVC (Static VAR Compensator), DVR (Dynamic Voltage Restorer) etc. had been introduced from time to time. Then a device UPQC (Unified Power Quality Compensator) had been introduced which consists of both series and shunt controllers.

2. DIFFERENT TYPES OF CUSTOM POWER DEVICES

In general, it has been figured out that the most advanced transmission and distribution systems are not able to provide power with the desired level of reliability for the proper functioning of their respective loads [2]. It has been found out that if a facility has more than 15% non-linear load, then a harmonic study should be implemented before applying the power quality solutions. Custom power is intended principally to convene the requirement of industrial and commercial consumers. The concept of the custom power is to use power electronics controller devices into power distribution system to supply quality of power, demanded by the sensitive users. These power electronics controller devices were named as custom power devices because these are used to supply valuable power to the customers. Most of these are available as commercial products and they have good performance at medium distribution levels. The custom power devices are divided into two categories: network reconfiguring type and compensating type. Here is a brief description about some custom power devices starting with Voltage Source Converter which in itself is not a custom power device but forms a major component in many custom power devices like DVR and DSTATCOM.

2.1 Voltage Source Converter

In many of the custom power devices, there is a Voltage Source converter (VSC) used in their circuits which consists of six-pulse converters consisting of six power semiconductor switching devices and anti-parallel diodes as shown in fig. 1. From a direct current (DC) voltage source, the VSC generates a set of controllable three-phase output voltages at the frequency of the system voltage. Pulse width modulation is used to control the firing of the semiconductor switching devices, generating an average sine wave. By adding two pulses in each line cycle when the fundamental voltage crosses zero, the total harmonic distortion (THD) of output current can be reduced significantly [3].

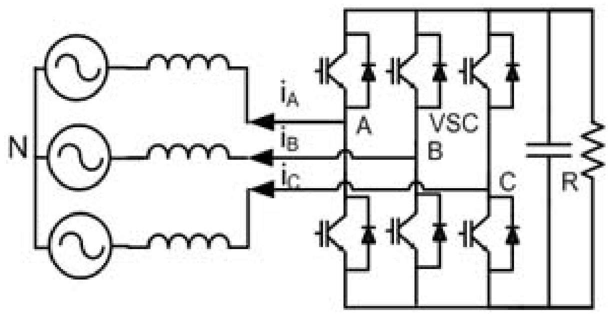

Fig. 1: Voltage Source Converter

2.2 Static VAR Compensator

It consists of passive elements that are used for AC voltage control by generation and absorption of reactive power. As shown in fig. 2, it is normally constituted by one Thyristor controllable reactor (TCR) and a number of Thyristor switched capacitor (TSC) branches. The ability to absorb changes in reactive power makes to some extent the SVC suitable for flicker reduction. However, the ability of the SVC to mitigate flicker is limited by its low speed of response. The unique selling point of SVC is their simple mechanically-switched compensation schemes and it's economically reasonable as compared to another compensators. Main uses of SVC are:

1) Regulating voltage
2) Regulating power factor
3) Harmonics and stabilizing the system

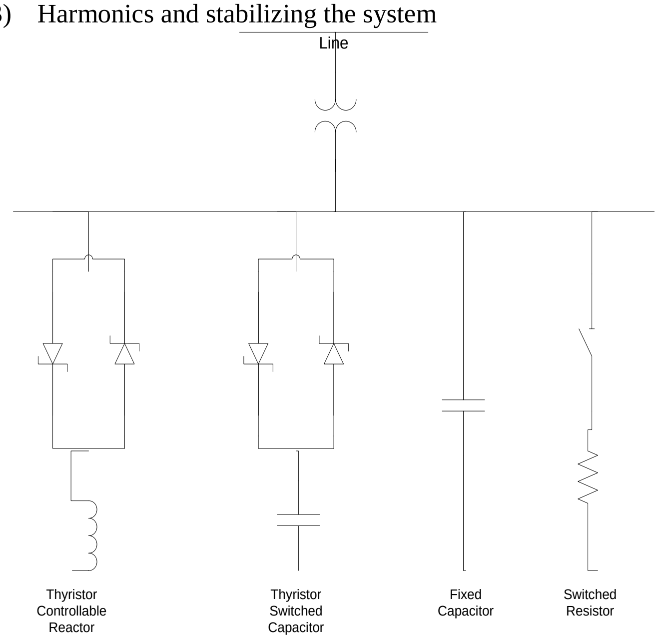

Fig. 2: SVC

The SVC is mainly used to improve the power factor of a system using impedance matching. i.e. it can operate in both lagging as well as in leading loads. A leading and lagging power can be compensated using a reactor and capacitor bank.

2.3 D-STATCOM

A distribution system suffers from current as well as voltage-related power-quality (PQ) problems, which include poor power factor, distorted source current, and voltage disturbances [4][5]. D-STATCOM injects a current into the system to correct the different voltage variations as discussed before. It provides quite good voltage regulation.

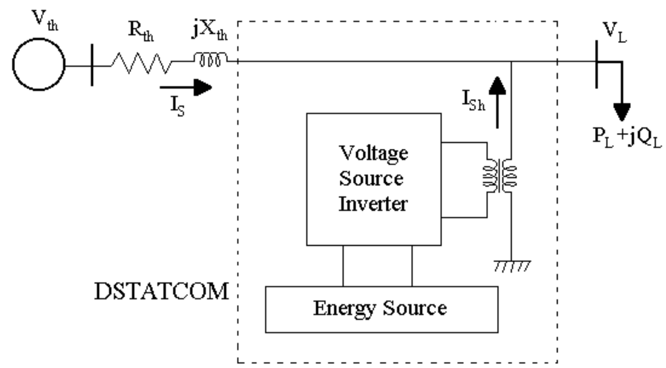

Fig. 3: D-STATCOM

The Pulse Width Modulation (PWM) based control only measures the r.m.s voltage at the load point and no reactive power measurements are being made. A simple configuration of DSTATCOM is shown in fig. 3.

2.4 Dynamic Voltage Restorer

Dynamic Voltage Restorer (DVR) is the most efficient and effective modern custom power device used in power distribution networks. The DVR is essentially a voltage-source converter connected in series with the ac network via an interfacing transformer, which was originally conceived to a ameliorate voltage sags [6]. DVR is a recently proposed series connected solid state device that injects voltage into the system in order to regulate the load side voltage. It is normally installed in a distribution system between the supply and the critical load feeder at the point of common coupling (PCC). The location of a DVR showing its position in power system network is shown in fig. 4.

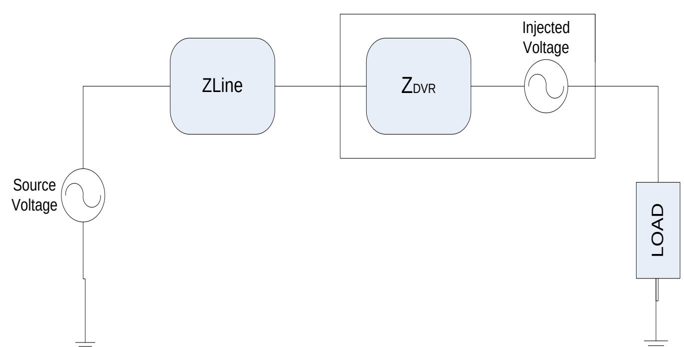

Fig. 4: Location of DVR

Other than voltage sags and swells compensation, DVR can be also are added to other features like: line voltage harmonics compensation, reduction of transients in voltage and fault current limitations. On event of fault which results in voltage sag, the magnitude reduction is accompanied by phase angle shift and the remaining voltage magnitude with respective phase angle shift is provided by the DVR. Employing minimum active voltage injection mode in the DVR with some phase angle shift in the post fault voltage can result in miraculous use of DVR. If active voltage is less prominent in DVR then it can be delivered to the load for maintaining stability. The main components of DVR are energy storage unit, voltage source inverter circuit, and filter unit and series injection transformers as shown in fig. 5. DVR can operate in three modes naming Protection mode, Standby mode or Injection mode. This means that any differential voltages caused by transient disturbances in the AC feeder will be compensated by an equivalent voltage generated by the converter and injected on the medium voltage level through the booster transformer.

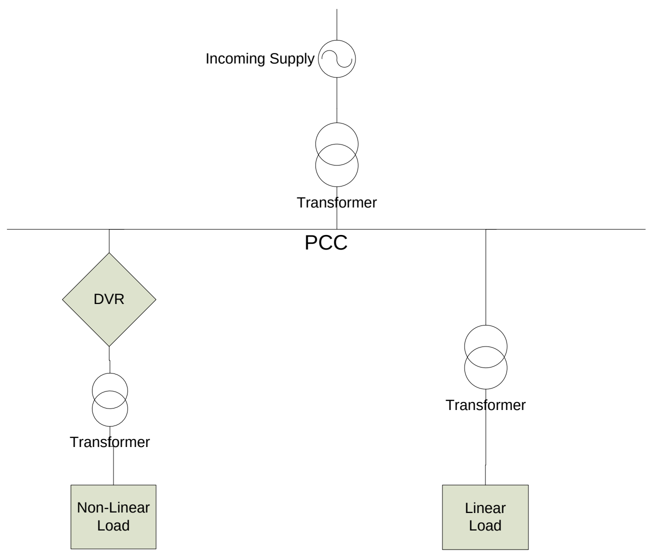

Fig. 5: Dynamic Voltage Restorer

The system impedance Z_{th} depends on the fault level of the load bus. When the system voltage (V_{th}) drops, the DVR injects a series voltage V_D through the injection transformer so that the desired load voltage magnitude V_L can be maintained. The series injected voltage of the DVR can be written as:

$$V_D = V_L + Z_{th}.I_L - V_{th}$$

Where:

V_L: The desired load voltage magnitude

Z_{th}: The load impedance.

I_L: The load current

V_{th}: The system voltage during fault condition.

The load current I_L is given by

$$\mathbf{I_l = (P_l + jQ_l) / V_L}$$

When V_L is considered as a reference equation

$$\mathbf{Ø = tan^{-1} (\theta_l / P_l)}$$

The complex power injection of the DVR can be written as

$$\mathbf{S_d = V_{dvr}\, I_L^{*}}$$

It requires the injection of only reactive power and the DVR itself is capable of generating the reactive power. Voltage injection or compensation methods by means of a DVR depend upon the limiting factors such as; DVR power ratings, various conditions of load, and different types of voltage sags. Some loads are sensitive towards phase angel jump and some are sensitive towards change in magnitude and others are tolerant to these. Therefore the control strategies depend upon the type of load characteristics.

2.5 Unified Power Quality Compensator

For a better supply system, both supply voltage and current drawn in a system needs utmost importance. UPQC consists of DC capacitors, low-pass and high-pass passive filters, series and shunt transformers and two IGBT based Voltage source converters (VSC), one shunt and one series cascaded by a common DC bus. To supply harmonic currents and provides VAR support to the load, the shunt converter is connected in parallel to the load. The series converter is connected in series to the load provides voltage compensation as shown in fig. 6. As the active filters configuration is of mainly two types; one is series based & other is shunt based. The former configuration is used to handle voltage based problems and the latter is used to handle current based. However, installing these two separate devices independently to compensate voltage and current related power quality problems may not be a cost effective solution. The shunt inverter in UPQC is controlled in current control mode such that it delivers a current which is equal to the set value of the reference current as governed by the UPQC control algorithm. Additionally, the shunt inverter plays an important role in achieving required performance from a UPQC system by maintaining the dc bus voltage at a set reference value. UPQC is mainly used to compensate for various power quality issues like voltage sags, swells, unbalance, flicker, harmonics, and for load current power quality problems[7] [8].

The construction of UPQC is quite similar to a unified power flow controller (UPFC). Both these devices use two voltage source inverters (VSIs) that are connected to a common dc energy storage element. The main difference lies in their field of application as UPQC is used in distribution network and UPFC is used in transmission network to perform the series and shunt compensation concurrently. However, a UPFC only needs to provide balance shunt and/or series compensation, since a power transmission system generally operates under a balanced and distortion free environment. On the other hand, a power distribution system may contain dc components, distortion, and unbalance both in voltages and currents. Therefore, a UPQC should operate under this environment while performing shunt and/or series compensation.

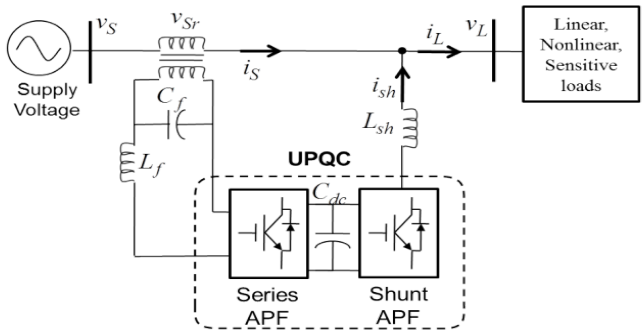

Fig. 6: UPQC

3. CHARACTERISTIC COMPARISON OF CUSTOM POWER DEVICES

There may be variety of power quality problems and to each problem, there is a solution. The overall comparison of all the four devices is shown in Table 1. It has been shown that DVR is superior to SVC and DSTATCOM. However if there is no cost consideration, then UPQC is the better choice for improvement of power quality.

Table 1: Comparison of Various Custom Power Devices

S. No	Factors	SVC	DSTATCOM	DVR	UPQC
1	Rating	low	low	high	higher
2	Speed of operation	low	More than SVC	Fast	Faster
3	Compensation Method	Shunt Compensation	Shunt Compensation	Series Compensation	Both series & shunt
4	Active /reactive Power	Reactive	Reactive	Active/Reactive	Both
5	Harmonics	high	Less than SVC	Very less	Lesser
6	Problems addressed	Transient	Sag/Swell	Sag/Swell/Harmonics	Sag/ Swell/ Harmonics/ Flicker/ Transients
7	Cost	Nominal	Nominal	High	Higher

4. IEEE STANDARDS FOR VOLTAGE & CURRENT HARMONICS LIMITS

In order to monitor power quality, it is essential to measure voltage, current, frequency, harmonic distortion and waveform. But power quality problems are not restricted to harmonic distortion. The standard IEEE 1159 classified various electromagnetic phenomena in power system voltage (which are related to power quality problems), namely: impulses, oscillations, sags, swell, interruptions, under-voltages, over-voltages, harmonics, noise, flicker and frequency variation etc [9] [10]. As per various standards of IEEE for non-linear loads, both voltage and current harmonics limits have been described [11]. These standards define the voltage & current distortion limits. As shown in the following tables, the voltage distortion limits are meant for less than 69 kV as shown in Table 2 and current distortion limit in Table 3.

Table 2: Effect of THD on Voltage Distortion Limit

Bus Voltage at Power Control Centre	Individual Voltage distortion (%)	THD (%)
Less than 69 kV	3	5
69-161 kV	1.5	2.5
More than 161 kV	1	1.5

The current distortion limits are for odd harmonics. Even harmonics are limited to 25% of the odd harmonic limits [12]. For all power generation equipment, distortion limits are those with I_{SC}/I_L<20; where I_{SC} is the maximum short circuit current at the point of common coupling (PCC) & I_L is the maximum fundamental frequency of load current at PCC.

Table 3: Current Harmonic Limits

I_{SC}/I_L	h<11	11≤h<17	17≤h<23	23≤h<25	THD (%)
<20	4.0	2.0	1.5	0.6	5
20-50	7.0	3.5	2.5	1.0	8
50-100	10	4.5	4.0	1.5	12
100-1000	12	5.5	5.0	2.0	15

Harmonic standards development by the IEEE has shifted to modifying Standard 519-1992. Discussion at the IEEE winter power meeting focused on appropriate limits for harmonic levels inside customer facilities. IEEE Standard 519-1992 provides recommended limits for harmonic levels at the PCC between the customer and the power system (i.e. the location where other customers could be supplied). The recommended voltage distortion limit for the PCC is 5% for the total harmonic distortion and 3% for individual harmonics. The revision to Standard 519 is considering higher limits for inside the facility and making these limits frequency-dependent. The limits specified in International Electro-technical Commission (IEC) for low-voltage systems allow THD of 8% and include limits for individual harmonic components, which decrease with frequency.

5. CONCLUSION

In this paper, various custom power devices for improvement of power quality have been discussed. The choice of a particular type of device depends upon the characteristics of system. As per the comparison of various devices, it has been found that DVR has superior properties than STATCOM & SVC. It has lower cost, smaller size, and it has fast dynamic response to the disturbances. DVR also has ability to control active power flow. But, if there is no cost consideration, UPQC may have preference over the other devices if we need improvement in both series and shunt based configurations simultaneously. However, the choice of the most suitable solution depends ultimately on the characteristics of the supply at the point of connection, the requirements of the load and economics.

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