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Basic Review on Custom Power Devices for Power Quality Improvement

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ABSTRACT

Power quality is a focus area that is widely deliberated and looks after the usage of electricity customers at parallel levels of usage. Its enhancement is valuable to both distribution utility as well as customer contentment. We all know that sensitive power electronics devices and nonlinear loads are far and wide used and thus they are principal reasons of distortion in voltage and current waveforms. Utility distribution networks, profound industrial loads and indispensable commercial operations suffer from various types of outages and service disruptions which can cause malfunctioning of numerous components as well as cost substantial financial losses. So it is highly recommended to have a check on power quality enhancement. Introduction of Custom Power have made quality of power and reliability an area of concern in electrical power system.

Custom Power Devices (CPD) like - Dynamic Voltage Restorer (DVR), Distribution Static Compensator (D-STATCOM), and Unified Power Quality Compensator (UPQC) - are used for removing power quality problems. They also are used to alleviate all types of faults. The present work is to review the measures that can enhance the quality of the power.

Keywords: Power Quality, Custom Power Devices, DVR, D-STATCOM, UPQC

I. INTRODUCTION

Power quality problem in the power system has acquired significant status since the late 1980s. Power Quality (PQ) is relevant to all three parties concerned with the power i.e. utility companies, equipment manufacturers and electric power consumers [6-16]. Electrical energy is the most efficient and widespread form of energy and the modern society is heavily reliant on the electric supply. The life cannot be imagined without the supply of electricity. At the same time the quality and continuity of the electric power supplied is also vital for the efficient functioning of the end user equipment. Most of the commercial and industrial loads demand high quality uninterrupted power. Thus maintaining the qualitative power is of utmost important.

There are two terms known in power systems about the quality of power: Good power quality and poor power quality. Good power quality can be used to describe a power supply that is always available, always within the voltage and frequency tolerances and has a pure noise-free sinusoidal wave shape to all equipment, because most equipment was intended on that basis [2]. Unfortunately, most of the equipment

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that is manufactured too distorts the voltage on the distribution system, leading to what is recognized as poor power quality. And thus upsetting other equipment that was designed with the prospect of consistent undistorted voltage, and consequently they become sensitive to power disturbances resulting in reduced performance and miss operation or premature failure [3]. Results of these problems can be very high cost add to the cost of downtimes, loss of customer confidence and, in some cases, equipment damage.

In this paper, Custom Power Devices which helps to improve power quality are described. This paper is divided into five sections. Section 1 covers the introduction. Section 2 defines the power quality and its problems. Section 3 describes the custom power devices. Section 4 share out description of D-STATCOM, DVR, UPQC. Section 5 deals with the conclusions and references.

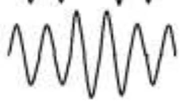
II. POWER QUALITY AND ITS PROBLEMS

The quality of electric power delivered is characterized by two factors namely- “continuity” of supply and the “quality” of voltage. POWER QUALITY is defined as

“the ability of a system or an equipment to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment”.

There are many reasons by which the power quality is affected. The occurrence of such problems in the power system network is almost indispensable. Thus, here is a table which shows problems generally seen as a result of poor quality of power.

Table1: Power Quality categories [5]

CATEGORIES	TYPICAL SPECTRAL CONTENT	TYPICAL DURATION	TYPICAL VOLTAGE MAGNITUDE	DISTURBANCE
1.0 Transients 1.1 Impulsive 1.1.1 Nanosecond 1.1.2 Microsecond 1.1.3 Millisecond 1.2 Oscillatory 1.2.1 Low frequency 1.2.2 Medium frequency 1.2.3 High frequency	 5-ns rise 1-_s rise 0.1-ms rise <5 kHz 5–500 kHz 0.5-5 MHz	 <50 ns 50 ns–1 ms >1 ms 0.3–50 ms 20 µs 5 µs	 0–4 pu 0-8 pu 0-4 pu	
2.0 Short-duration variations 2.1 Instantaneous 2.1.1 Interruption 2.1.2 Sag (dip) 2.1.3 Swell 2.2 Momentary 2.2.1 Interruption 2.2.2 Sag (dip) 2.2.3 Swell 2.3 Temporary 2.3.1 Interruption		 0.5–30 cycles 0.5–30 cycles 0.5–30 cycles 30 cycles-3 s 30 cycles-3 s 30 cycles-3 s 3s-1 min	 <0.1 pu 0.1–0.9 pu 1.1-1.8 pu <0.1 pu 0.1-0.9 pu 1.1-1.4 pu <0.1 pu	  

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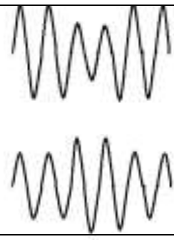
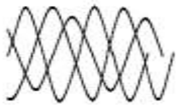
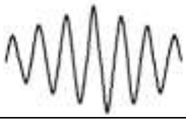
2.3.2 Sag (dip) 2.3.3 Swell		3s-1 min 3s-1 min	0.1-0.9 pu 1.1-1.2 pu	
3.0 Long-duration variations 3.1 Interruption, sustained 3.2 Under voltages 3.3 Overvoltage		 >1 min >1 min >1 min	 0.0 pu 0.8-0.9 pu 1.1-1.2 pu	
4.0 Voltage unbalance		Steady State	0.5-2%	
5.0 Waveform distortion 5.1 DC offset 5.2 Harmonics 5.3 Interharmonics 5.4 Notching 5.5 Noise	 0- 100thharmonic 0-6 kHz Broadband	 Steady State Steady State Steady State Steady State Steady State	 0-0.1% 0-20% 0-2% 0-1%	
6.0 Voltage fluctuations	<25 Hz	Intermittent	0.1-7% 0.2-2 Pst	
7.0 Power frequency variations		<10s		

NOTE: s-second, ns-nanosecond, µs-microsecond, ms-millisecond, kHz-kilohertz, MHz-megahertz, min-minute, pu-per unit.

Major aim for the increased concern:

1. Newer-generation load equipment, with microprocessor-based controls and power electronic devices, is more sensitive to power quality variations than was equipment used earlier.

2. The increasing emphasis on overall power system efficiency has resulted in continued growth in use of devices such as adjustable-speed motor drives and shunt capacitors which in turn has resulted in increased harmonic levels on power systems.

3. End users have an increased awareness of power quality issues.

4. Many things are now interconnected in a network. Integrated processes mean that the failure of any component has much more important consequences.

III. CUSTOM POWER DEVICES

Now and then different works are being conducted to provide an active and flexible solution to mitigate power quality disturbances. Before the advent of active filters, passive filters based on inductors and capacitors [17-19] were used and still used in many power transmission and distribution applications, but it has numerous disadvantages such as instability, fixed compensation, resonance with supply along with loads and utility.

To overcome these drawbacks active power filters (APFs) have been used [20-24]. However, they are costly options for power quality enhancement because their ratings are sometimes very close to full load (up to 80%) in typical applications.

To face the power quality problems and increase the reliability, an advanced power electronic based devices have launched over last decades. These power electronic based devices are called Custom power devices (CPDs) [25-30]. N.G.Hingorani [12] introduced the concept of custom power. Custom power solution can be network reconfiguration type or compensation type as shown in Figure1. Power electronic controller devices which satisfy the requirement of industrial and commercial consumers by improving quality of power are called custom power devices. Their performance is good at medium distribution levels and mostly available as commercial products. For the generation of custom power devices Voltage Source Inverter (VSI) is generally used, due to self-supporting of dc bus voltage with a large dc capacitor. In this paper, a comprehensive review of compensating type is presented [14]. The compensating custom power devices are used for active filtering, load balancing, voltage regulating (sag/swell), harmonic elimination and power factor correction. These devices are either connected in shunt or in series or a combination of both and also called D-STATCOM, DVR and UPQC.

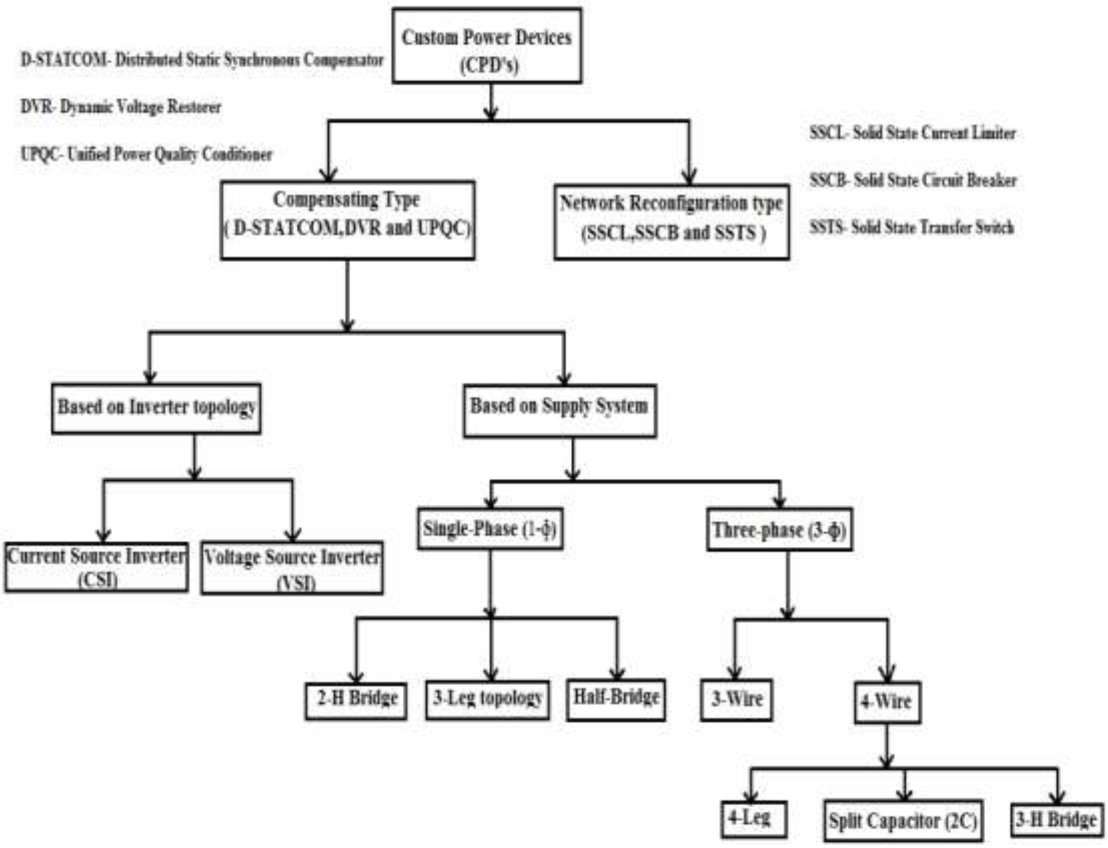


Figure 1. Classifications of CPDs [5]

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IV. D-STATCOM, DVR and UPQC

1. D-STATCOM

A Distribution Static Compensator is in short known as D-STATCOM. It is a power electronic converter based device used to protect the distribution bus from voltage unbalances. D-STATCOM is a shunt connected device designed to regulate the voltage either by generating or absorbing the reactive power. D-STATCOM is capable of compensating either bus voltage or line current. The basic operating principle of a D-STATCOM in voltage sag mitigation is to regulate the bus voltage by generating or absorbing the reactive power. Therefore, the D-STATCOM operates either as an inductor or as a capacitor based on the magnitude of the bus voltage.

- Inductive Operation: If the bus voltage magnitude (VB) is more than the rated voltage then the D-STATCOM acts as an inductor absorbing the reactive power from the system.
- Capacitive Operation: If the bus voltage magnitude (VB) is less than the rated voltage then the D-STATCOM acts as a capacitor generating the reactive power to the system

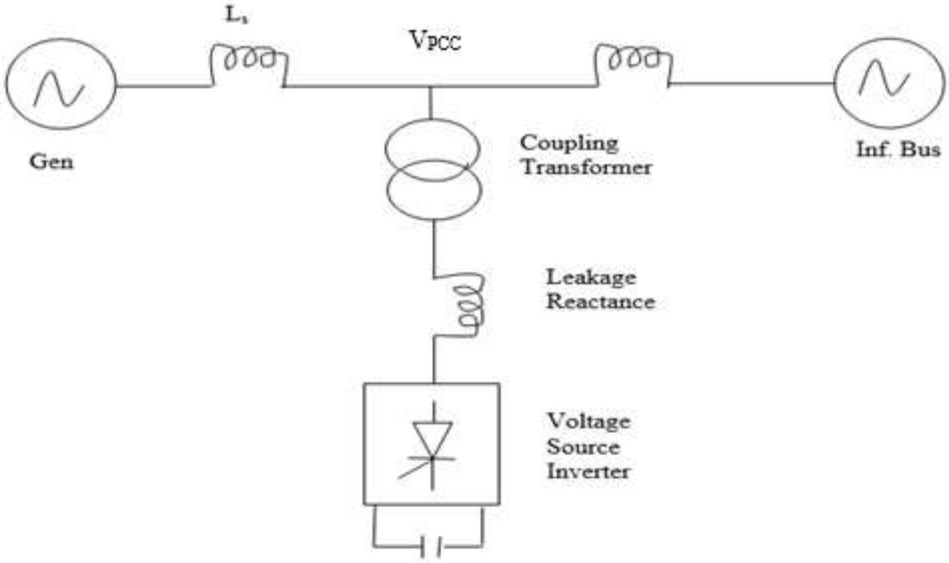

Figure 2: D-STATCOM

The main aim of the control strategy implemented to control a D-STATCOM used for voltage mitigation is to control the amount of reactive power exchanged between the STATCOM and the supply bus. To achieve the desired characteristics, the firing pulses to PWM VSI are controlled. The actual bus voltage is compared with the reference value and the error is passed through a PI controller. The controller generates a signal which is given as an input to the PWM generator. The generator finally generates triggering pulses such that the voltage imbalance is corrected. In [14], [32], a D-STATCOM model is used for feasibility and validating the design. K.R. Padiyar [15], H. Fugita et al. [33], Arya et al. [34] discussed D-STATCOM for voltage regulation in detail The block diagram of the control circuit is shown in Figure 3.

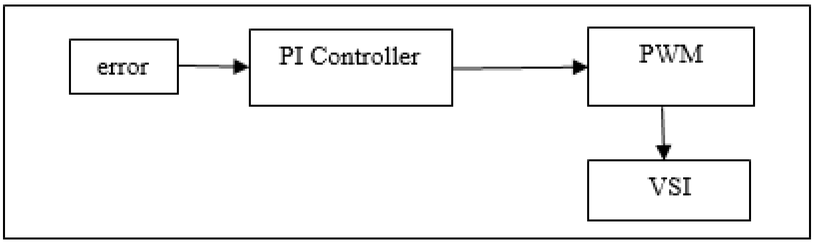

Figure 3: Control Circuit of D-STATCOM

2. **DVR**

A Dynamic Voltage Restorer (DVR) is a power electronic converter based gadget intended to ensure the discriminating burdens from all supply-side unsettling influences other than deficiencies [1]. The DVR is a series connected power electronic device used to inject voltage of required magnitude and frequency

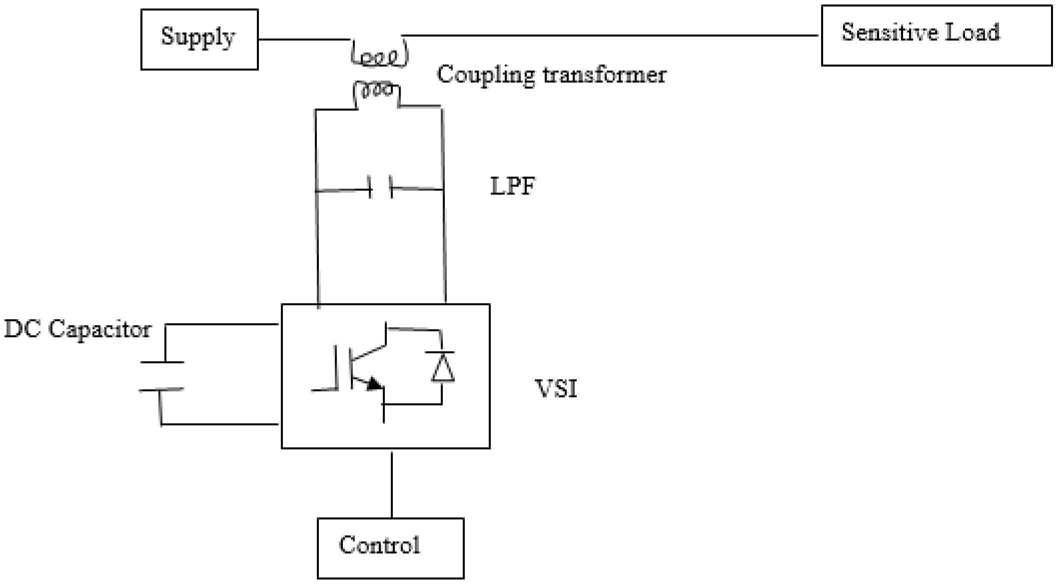

Figure 4: Basic Structure of DVR

The main operation of the DVR is to inject voltage of required magnitude and frequency when desired by the power system network. During the normal operation, the DVR will be in stand-by mode. During the disturbances in the system, the nominal or rated voltage is compared with the voltage variation and the DVR injects the difference voltage that is required by the load. The basic idea behind the control strategy is to find the amount by which the supply voltage is dropped. For this the three phase supply voltage is compared with the reference voltage V_{ref}. If there is voltage sag (or any other voltage imbalance) then an error occurs. This error voltage is then sent to the PWM generator, which generates the firing pulses to the switches of the VSI such that required voltage is generated. The whole control strategy can be implemented in 2-ϕ rotating (d-q) coordinate system. The flow chart of the control technique based on dq0 transformation is shown in Figure 5. The different aspects such as modeling, design and simulation for harmonic elimination, voltage flicker suspension [14], voltage sag and swell mitigation are reported in [35-38]. A.K.Jindal et al. [39] highlighted dynamic voltage restorer for voltage regulation function.

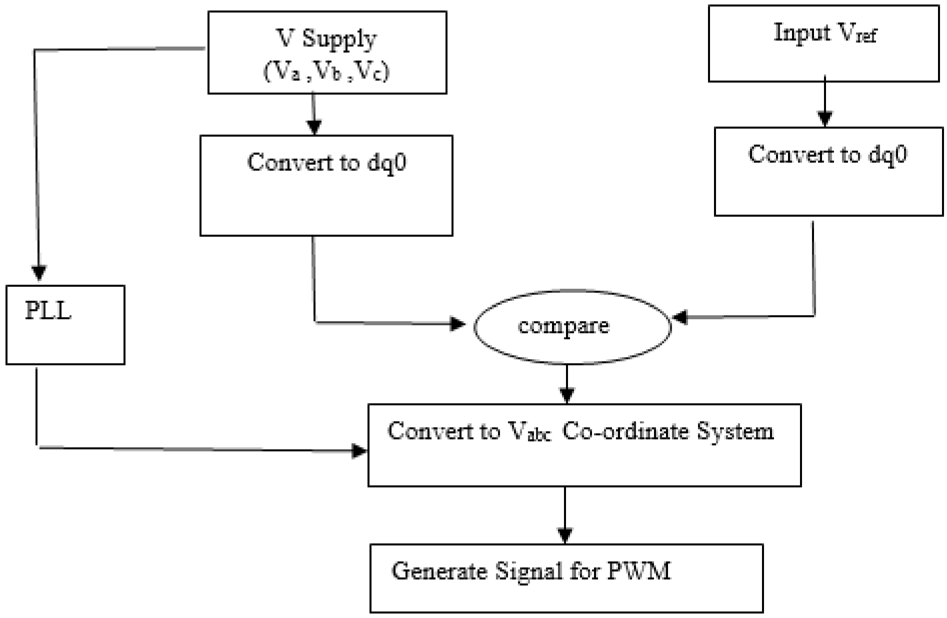

Figure 5: Flowchart of control algorithm of DVR

3. **UPQC**

For enhancing power quality in the system and protecting sensitive loads a universal solution can use by an integration of the series-parallel active power filters called unified power quality compensator UPQC as depicted in Figure 6 [5]. UPQC is a flexible device that can compensate almost all types of PQ disturbances related to voltage and current simultaneously. Shunt active power filter is the most promising to tackle the current-related problems such as current harmonics, current unbalance, reactive current whereas, the series APF is the most suitable to overcome the voltage-related problems such as voltage harmonics, voltage unbalance, voltage flicker, voltage sag and swell. In operating principal, UPQC is a union of shunt and series APFs with two VSI-based common self-supporting DC bus. The shunt APF is controlled in a current controlled mode such that it produces a current that is equal to the set of the reference current as produced by the control algorithm of UPQC.

- A UPQC that combines the operations of a Distribution Static Compensator (D-STATCOM) and Dynamic Voltage Regulator (DVR) together
- In short, Shunt active filters eliminate the harmonics, whereas, Series active filters allow the passage of only the fundamental wave.

$$i_{sh}(wt) = i^*_s(wt) - i_L(wt) \quad (1)$$

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where $i_{sh}(wt)$, $i^*_s(wt)$, $i_L(wt)$ represents the shunt APF current, reference source current and load current. Shunt active power filter should inject a current to eliminate the harmonics produced by a nonlinear load.

The series active power filter is controlled in voltage control mode such that it generates a voltage and injects in series with line to achieve a sinusoidal and distortion free voltage at the load terminal. In the case of voltage sag (VS) condition, series APF should inject a voltage to maintain the load voltage.

$$V_{SC}(wt)=V^*_L(wt)-V_s(wt) \quad (2)$$

where, $V_{SC}(wt)$, $V^*_L(wt)$,$V_s(wt)$ represents the series APF voltage, reference load voltage and source voltage. The system modeling aspects of the UPQC are reported in [40-47]. In [48], a mathematical modeling and design of a versatile UPQC are discussed clearly. A.Ghosh et al. [49] discussed the application of UPQC for voltage regulation in critical loads.

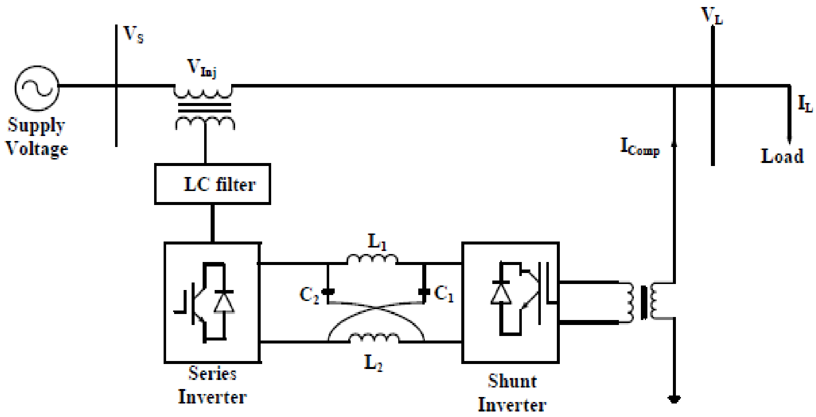

Figure 6: UPQC

V. CONCLUSIONS

Power quality maintenance is an important aspect in the economic operation of a system. Various PQ problems may lead to another undesirable problem. The mitigation of all the power quality related issues leads to the economic operation of the power system & long life of equipment's, and thus system efficiency improves. Overall the problem of power pollution is eliminated.

Thus this paper provides a brief review of custom power devices (compensating type) which are installed in power distribution system to eliminate various power quality disturbances; voltage sag/swells, flicker, dip, current harmonics, power factor reduction, etc. The D-STATCOM, which is connected in shunt can provide good power quality in both transmission and distribution level. UPQC is the key of custom power devices, can compensate both voltage and current related problems at the same time. These devices effectively provide solutions to power quality issues.

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