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# Investigation on Performance Efficacies of Custom Power Devices for Power Quality Improvement

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**ABSTRACT:-**This paper presents investigation on Performance Efficacies of three Custom Power Devices (CPDs) viz. Dynamic Voltage Restorer (DVR), Distribution Static Synchronous Compensator (DSTATCOM) and Unified Power Quality Conditioner (UPQC) for power quality improvement. The CPDs are simulated on the modified IEEE 16-Bus radial distribution system using MATLAB/SIMULINK under various power quality (PQ) disturbances viz. voltage sags, voltage interruption, and harmonic distortions. The simulation results reveal that the effectiveness of each device to compensate the power quality disturbances depends on the performance efficacies during PQ disturbances.

**KEYWORDS:-** Power Quality; Power Quality Disturbance; CPD; DVR; DSTATCOM; UPQC.

## I. INTRODUCTION

Power Quality phenomenon includes all possible situations in which the waveform of the supply voltage (voltage quality) or load current (current quality) deviate from the sinusoidal waveform for all three phases of a three-phase structure at rated frequency with amplitude corresponding to the rated Root Mean Square (RMS) value. With the advance use of power distribution systems, power quality problems with different levels of severity may cause and this causes a huge financial drawback to the application use [1]. To protect the sensitive loads, Custom Power Devices (CPDs) can be applied in the system as an advanced power electronic-based solution. In addition, the integration of multiple CPDs within a specific part of the system can form a Premium Power Park to meet customer's requirements and offer a high-quality power for end-users [2, 3]. Depending on the device topology and applied control strategy, CPDs can protect system components against various types of PQ disturbances, such as voltage sag and voltage and current harmonic distortions [4, 5]. In addition, depending on the structure and capacity limitation of the DC-link storage element, the performance and operation longevity of the CPDs under different PQ disturbances may vary. Therefore, a careful analysis is required to understand the dynamic behaviour of CPDs in different situations for choosing an appropriate device based on technical and economy justifications at the time of system planning [6, 7]. This paper presents a study on the performance of the CPDs viz. Dynamic Voltage Restorer (DVR), Distribution Static Synchronous Compensator (DSTATCOM) and Unified Power Quality Conditioner (UPQC) under different PQ disturbances. Each device is modelled on the modified IEEE 16-Bus Radial Distribution System using MATLAB/SIMULINK software. Several PQ disturbances viz. voltage sag, momentary voltage interruption, and voltage and current harmonic distortions are simulated to investigate the Performance Efficacies of CPDs.

## II. POWER QUALITY PROBLEMS

Electrical supply is designed to operate under constant magnitude and frequency of sinusoidal voltage waveform. Any deviation from these predesigned magnitude and frequency can be interpreted as PQ problem [8]. Power quality problems are usually due to inappropriate interactions between the utility grids and the customer equipment, and these disturbances can result in serious technical and financial problems for the system components. For example, voltage sags down to 80% of nominal voltage with a few tens of millisecond duration can cause interruption in processing plants, resulting in hours of downtime and more turnover losses [3, 9]. The most regular and important PQ issues that require practical solutions are as follows:

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*A. Voltage Sag*

The IEEE definition of voltage sag is short-term reductions in the rms voltage to a value between 10% and 90% for a duration of 1 min (0.5 cycle). Voltage sags are characterized by magnitude and duration. These voltage reductions are caused by motor starting, transformer energizing, or faults. Analysing voltage sags is a complicated task which requires considering a large variety of random factors, such as type of short circuits, location of faults, and protective system performance. Voltage sags can be harmful to equipment with insufficient internal energy storage for riding through sags or sensitive semiconductor-based devices that may cause shut down, lock up, or garble data [10].

*B. Voltage Interruption*

The IEEE definition of Voltage Interruption can be defined as the complete loss of a supply voltage for a specific time, which can be categorized into Momentary Interruption (duration between 0.5 cycles and 3 s), Temporary Interruption (lasting between 3 s to 1 min), and Long Voltage or Sustained Interruption (duration, more than 1 min). These disturbances occur due to the normal or false operation of protection system and isolation of the power source from the loads which may cause severe financial losses due to the decrease in the operational life of the equipment such as transformers or equipment downtime in processing plants [11].

*C. Harmonic Distortion*

Generally, voltage waveform generated in the AC generators under constant frequency is pure. However, when a nonlinear load is fed by a pure sinusoidal voltage, the resulting current is not completely sinusoidal. The current drawn by the nonlinear load produces voltage distortion at the load terminal under the effect of system impedance. The distorted voltage contains harmonic which is defined as a perfectly sinusoidal component of a periodic waveform that has a frequency equal to an integer multiple of the fundamental frequency [12]. Voltage and current harmonic distortions may increase losses in transformers and electro motors, overheating of equipment, and miss operation of protective devices.

## III. CUSTOM POWER DEVICES

*A. Dynamic Voltage Restorer (DVR)*

The DVR is an IGBT-based series CPD which is used to protect sensitive loads from the most common PQ disturbances in the utility grid [13]. DVR can effectively mitigate voltage sags up to 100% and also voltage imbalance for critical loads with a very fast response to meet most PQ standard requirements, such as IEEE Std 1100-1999 [14, 15]. Also it is able to inject a three-phase voltage with a controllable magnitude and phase to recover the load voltage at the point of common coupling (PCC) [16, 17].The presence of DC energy storage unit in DVR is to provide the required power for correcting voltage disturbances The DVR structure is based on a DC-Link in the sense a capacitor bank or an energy storage device to supply the required compensation power, a LC low-pass filter with damping resistor (R), an injection transformer, and a bypass switch as shown in Fig.1. From the figure, the terminal voltage of the converter, $v_C$(t), can be defined as [18].

$$v_C(t) = \frac{t.v_{PCC}(t)}{T_s} \quad (1)$$

where,

$$T_s = t_1 + t_2 \quad (2)$$

$t_1$ and $t_2$ are the sampling period time intervals between 0 to $T_s$, and $v_{PCC}(t)$ is the measured voltage at PCC.
To compensate voltage sags and swells, the nominal load voltage, $v_L(t)$ can be expressed as

$$v_L(t) = v_{PCC}(t) + v_{inj}(t) \quad (3)$$

where,

$$v_{inj} = \frac{v_C(t)}{N} \quad (4)$$

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*N* is the turn ratio of the injection transformer.

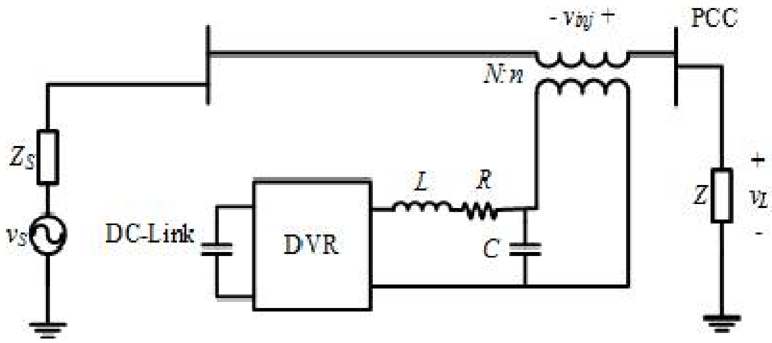


Fig.1. Single-Line Diagram of DVR

*B. Distribution Static Synchronous Compensator (DSTATCOM)*

The DSTATCOM is known as a parallel CPD with voltage source inverter topology which can be used in the utility's distribution systems to regulate voltage variations and mitigate PQ disturbances [19]. It is able to regulate voltage variation resulting from the motor starting condition or in-rush current and mitigate current harmonic distortions [20, 21]. The main components of DSTATCOM are a buffer capacitor and DC/AC power converter, where the capacitor unit provides the required DC compensation power for DSTATCOM and the DC/AC unit injects the required current to compensate PQ disturbances as shown in Fig. 2. The instantaneous load current, $i_{Load}(t)$, and the PCC voltage, $v_{PCC}$(t), shown in Fig. 2 can be defined as [18],

$$i_{Load}(\mathrm{t}) = I_1 \sin(\omega t + \varphi_1) + \sum_{h=2}^{n} I_h \sin(h\omega t + \varphi_h) \quad (5)$$

$$v_{PCC}(\mathrm{t}) = V_m \sin(\omega t) \quad (6)$$

where, $\omega$, $h$, and $\varphi$ are radial frequency, harmonic order, and phase angles of the load current and the PCC voltage, respectively.

The source current supplied by the PCC $i'_{pcc}(t)$, aftercompensation should be purely sinusoidal as

$$i'_{pcc}(\mathrm{t}) = p_f(\mathrm{t}) / v_{pcc}(\mathrm{t}) = I_1 \cos(\varphi_1) \sin \omega t \quad (7)$$

Where, $p_f(t)$ is the fundamental components of power.

If the DSTATCOM compensates the total reactive and harmonic power, then the PCC current, $i'_{pcc}(t)$, can be in phase with the PCC voltage. Therefore, the injected compensation current, $i_{comp}(t)$, can be expressed as,

$$i_{comp}(\mathrm{t}) = i_{Load}(\mathrm{t}) - i'_{pcc}(\mathrm{t}) \quad (8)$$

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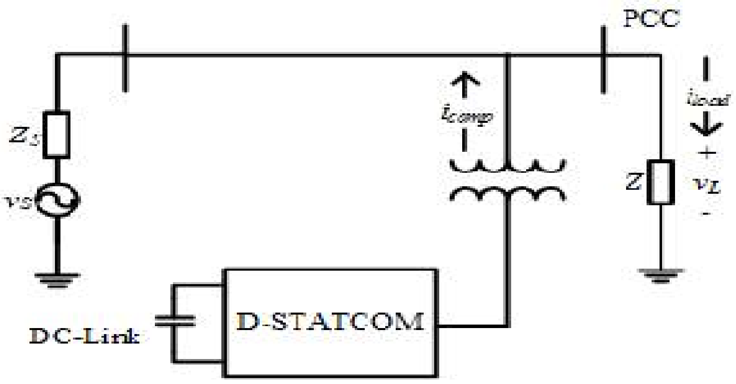



Fig.2. Single-Line Diagram of DSTATCOM

*C. Unified Power Quality Conditioner (UPQC)*

The topology of UPQC is two back-to-back connected DC/AC fully controlled converters functions as series and shunt filters shown in Fig.3 to compensate simultaneously load current harmonics and supply voltage fluctuations.

An active shunt filter is a suitable device for current-based compensation. It can compensate current harmonics and reactive power. The active series filter is normally used for voltage harmonics and voltage sag compensation. The UPQC, which has two inverters that share one DC link capacitor, can compensate the voltage sag, the harmonic current and voltage and control the power flow and voltage stability.

The compensated voltage and current equations for UPQC are same as former devices of DVR and DSTATCOM for series and shunt compensation respectively.

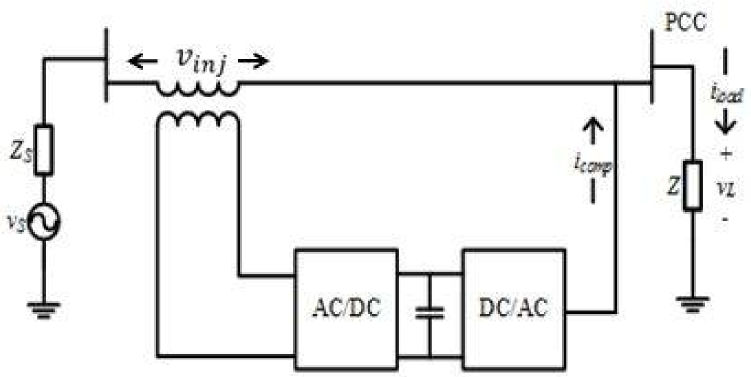



Fig.3. Single-Line Diagram of UPQC

The proposed model of modified IEEE 16-bus system is considered as shown in below.

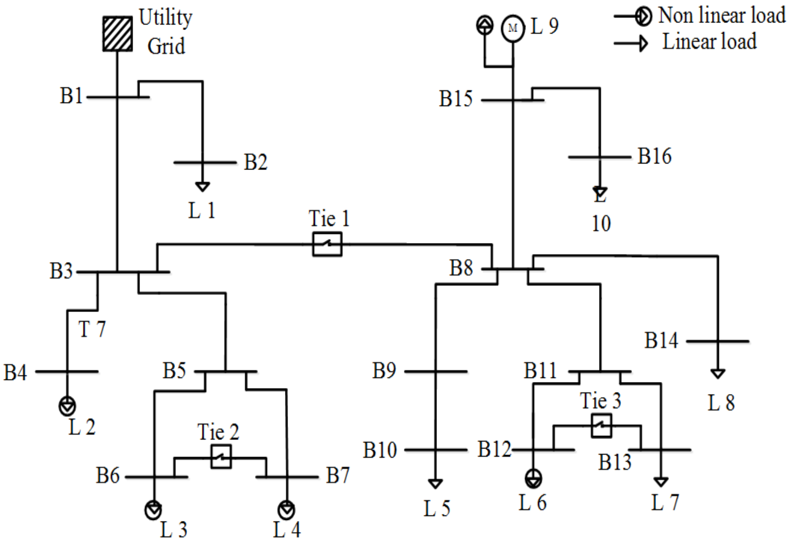


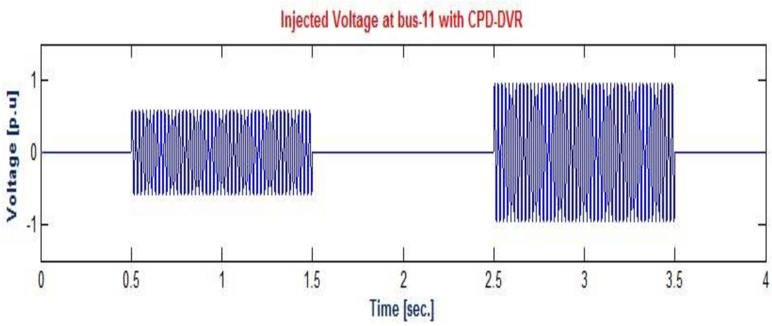

Fig.4. Single-Line Diagram of the 16-bus test system

## IV. SIMULATION RESULTS

To investigate the Performance Efficacies of the three CPDs (DVR, DSTATCOM and UPQC) on distribution systems for different Power Quality disturbances, a modified 16-Bus test system is considered as shown in Fig.4 [22,23]. Each CPD is individually placed at bus 11 to compensate PQ problems seen by loads L6 and L7.

To create a voltage sag and voltage interruption caused by motor starting current, a heavy induction is placed at bus 15, where other nonlinear loads contribute in harmonic distortion.

And to investigate the Performance Efficacies of CPDs, voltage sag with depth of 0.6 p.u. followed by a voltage interruption is created between the time 0.5 s to 1.5 s and 2.5 s to 3.5 s respectively. To illustrate the limitations of the devices better, the injected voltages and currents are shown in Figs. 5, 6 and 7.



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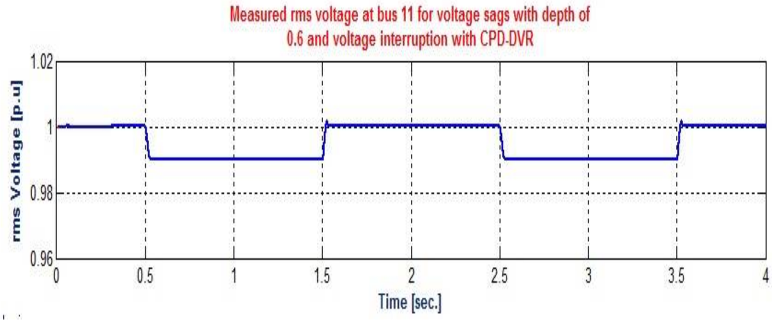



Fig.5. Injected Voltage during a 0.6 Voltage Sag and Voltage Interruption by UPQC and rms Voltage in p.u after mitigation.

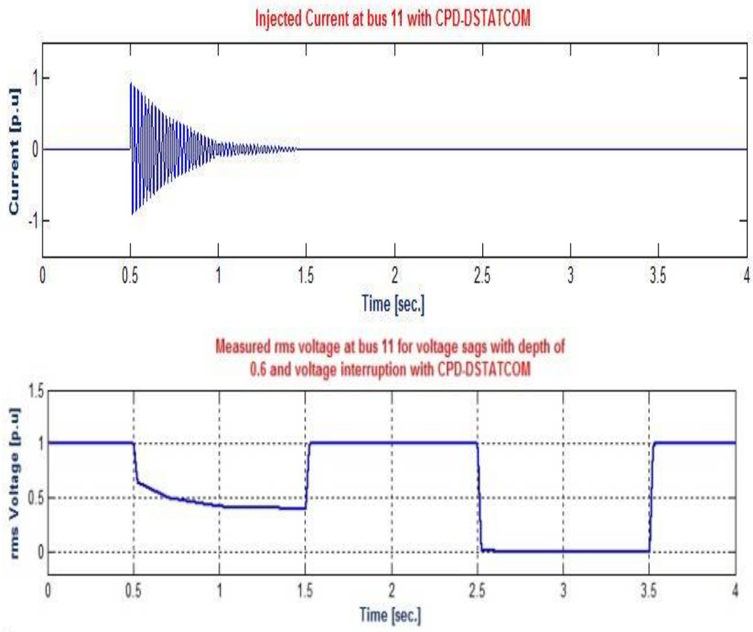
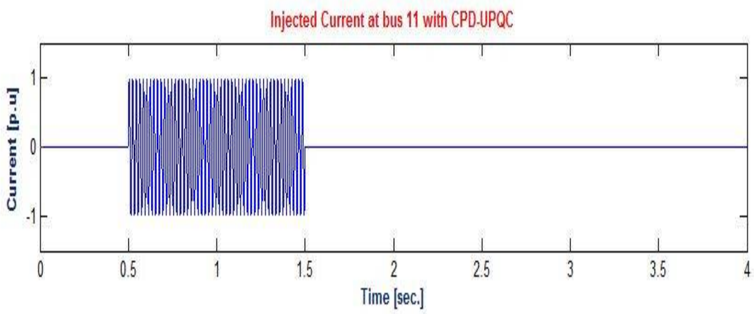



Fig.6. Injected Current during a 0.6 Voltage Sag and Voltage Interruption by DSTATCOM and rms Voltage in p.u after mitigation.



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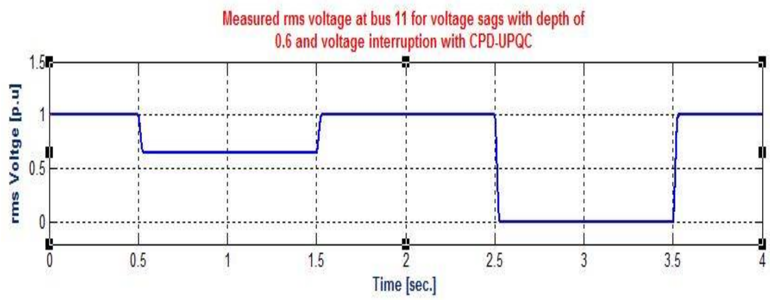


Fig.7. Injected Current during a 0.6 Voltage Sag and Voltage Interruption by UPQC and rms Voltage in p.u after mitigation.

Fig.5 shows that DVR has the superior performance for recovering deep voltage sags and voltage interruption due to the DC-link storage element. However, given the capacity limitation of the DC source, DVR may be limited during long voltage interruption.

Fig.6 shows that DSTATCOM is suitable for compensating slight voltage sag with short duration (depending on the DC source capacity). And this parallel device cannot accurately mitigate voltage sag when the depth of sag increases. This restriction occurs given the limitation of the DC-link storage in D-STATCOM (capacitor rapid discharges).

UPQC has good THD index of both voltage and current than DVR and DSTATCOM. But Fig.7 shows that the it cannot compensate the voltage interruption due to lack of energy source in its DC link.

To investigate the performance of CPDs in mitigating voltage and current distortion, the voltage and current total harmonic distortion (THD) at bus 11 is measured and shown in Table 1. The table clearly shows that all CPDs can significantly mitigate both voltage and harmonic distortions but the performance of parallel devices is much superior especially in current harmonic distortion. In addition, the ability of parallel CPDs in injecting compensation current to both upstream and downstream loads can improve the voltage and current THD index of the entire system.

Table.1. Measured Voltage and Current at Bus 11

| *CPD* | *THDV (%)* | *THDI (%)* |
|---|---|---|
| **No CPD** | 15.79 | 26.04 |
| **DVR** | 4.07 | 4.66 |
| **DSTATCOM** | 4.03 | 2.53 |
| **UPQC** | 3.88 | 2.58 |

## V. CONCLUSION

This paper presents an investigative study on the Performance Efficacies of three CPDs under different types of PQ problems. The CPDs viz. DVR, DSTATCOM and UPQC are modelled on a 16-Bus test system with a heavy induction motor and nonlinear loads using MATLAB/SIMULINK software, and a voltage interruption and voltage sag with a depth of 0.6 p.u are created to test the performance of each device. The simulation results showed that DVR has the superior performance for recovering deep voltage sags and voltage interruption, DSTATCOM is suitable for

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compensating slight voltage sag with short duration and UPQC supports for Voltage Sag. DSTATCOM and UPQC has good THD index over DVR and this performance and effectiveness of each device depends on the device's structure and characteristic during the duration of PQ disturbances.

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