Research Article

Recent Trends in Power Quality Improvement Using Custom Power Devices and Its Performance Analysis

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Article History: Received: 11 January 2021; Revised: 12 February 2021; Accepted: 27 March 2021; Published online: 16 April 2021

Abstract : Power quality is the measure of any deviation from the standard voltage level and nominal frequency values. A power quality problem seen from the customer's point of view is defined as any power problem expressed in voltage, current or frequency deviations that result from a power failure or equipment customer misoperation. This paper presents the working, configurations, and important functions of each custom power device. Because many of these devices can reduce power quality problems, researchers are focusing on new technologies using power electronics-based concepts. The power electronics application to the power distribution system for the benefit of a customer or a customer group is called custom power. The custom power devices like Distribution Static compensator (DSTATCOM), the Dynamic voltage restorer (DVR) and the Unified Power Quality Conditioner (UPQC) are discussed for this work. Detailed results are provided to evaluate the working of each device as a potential custom power solution using MATLAB simulink.

Keywords: Distribution Static compensator, Dynamic voltage restorer, Unified power quality conditioner, voltage magnitude, Power Quality

1. Introduction

Due to increased power quality problems on nonlinear loads and induction motors in domestic and industries, power quality (PQ) problems such as harmonics, flicker, and imbalance have become serious concerns. Also, lightning strikes on transmission lines, switching capacitor banks, and various network faults can cause PQ problems, such as transients, voltage sag/swell, and interruption. On the other hand, increased load involving sensitive digital electronics and complex process controllers requires a pure sinusoidal supply voltage for proper load operation. Some sort of compensation is needed for meeting power quality [1-3] standard limits.

Using passive filters like capacitor banks in the conventional systems is to reduce the distribution system's power quality problems. Now, this research takes much attention to reduce power quality issues [4] with power control devices. The power conditioning devices are Distribution Static Compensator (DSTATCOM), Unified Power-Quality Conditioner (UPQC) and Dynamic Voltage Restorer (DVR) [5-7]. The performance of a custom power device depends on the way the reference compensation signal is approximated. Instantaneous reactive power (IRP) theory [8], synchronous frame (SRF) theory [9] and modified P-Q theory [10] are well-known methods of generating current reference and also maintaining dc-link voltage.

The methods stated above are very attractive for their simplicity and ease of implementation. Nevertheless, they have been unable to provide a reasonable solution in the presence of more harmonics, reactive power and their combination with a limited power rating of voltage source inverter (VSI) used as active power filter [11, 12]. Neural network-based Soft computing techniques have been discussed in [13] - [14]. So it can be seen that artificial intelligence has been used many times as a controller in shunt active filters. A model reference adaptive mode control (MRASMC) using the sliding radial basis function (RBF) [15-18] (APF) has been used as a controller in single-phase active power filters.

2. Proposed Compensating Power Devices

Compensation custom power devices are used for active filtering, load balancing, power factor improvement and voltage regulation (sag/swell). There are three main types of these devices: static shunt compensation, series and hybrid compensator. These are called DSTATCOM, DVR and UPQC, respectively.

2.1 Distribution Statcom

The goal of DSTATCOM is to eliminate load current harmonics. Couplings from DSTATCOM are three-phase, parallel to the source. The Distribution of the Statcom structure is shown in Figure 1. It acts as a current source, connected in parallel with a nonlinear load, resulting in a current alignment load requiring well Balance and providing reactive power. DSTATCOM injects current to the common coupling point to compensate for the current load's undesirable components. This principle applies to any kind of load being considered harmonious.

The advantage of this is that it can carry only a small amount of the active current supplied to compensate for losses in the system in addition to the compensation current. Examples of shunt active power filter in current control mode are called DSTATCOM

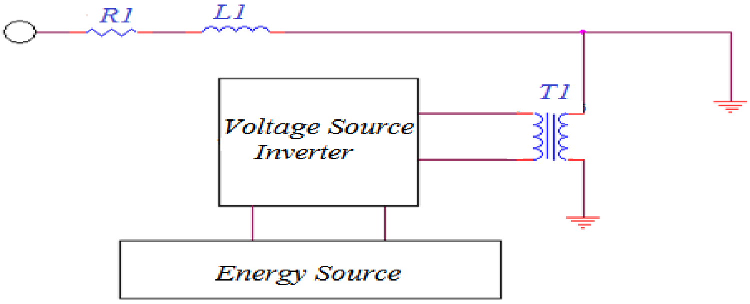

Figure 1. Structure of DSTATCOM

2.1.1 Control Scheme of DSTATCOM: In the configuration of the SRF technique, as shown in the Figure. 2. Conventional SRF methods can be used to extract harmonics present at source or current voltages. At present, the distortion is first transferred to the two-phase DC components for compensation in line with the current. After that, the number of stationary frames transferred to the rotating frame corresponds to the cosine and sine function using Phase-Locked Loop (PLL). The sine and cosine functions help to maintain synchronization with the source voltage and current. The conventional SRF algorithm is also known as the d-q method and is based on the abc to d-q-0 transformation. In this work, a proportional-integral controller is used to eliminate the DC component's steady-state error and maintain the constant dc-side voltage. The dc capacitor voltage is sensed and compared with the reference voltage to calculate the fault voltage. Following the PI controller, the output is dripped from the direct axis (d axis) of the tuned component to remove the steady-state error.
PWM based hysteresis controller is currently employed through fast reference current, and current sensed sources. If it comes to $i_{sa} < (i_{sar}\text{-}h_b)$, the top switch is turned 'OFF,' and the bottom switch is turned 'ON.' If it comes $i_{sa} > (i_{sar}\text{+hb})$, the top switch is turned 'ON' and the bottom switch is turned 'OFF.' In this way, the switching logic for the other two phases is taken, and the control can be arranged right now in the band around the desired reference value.

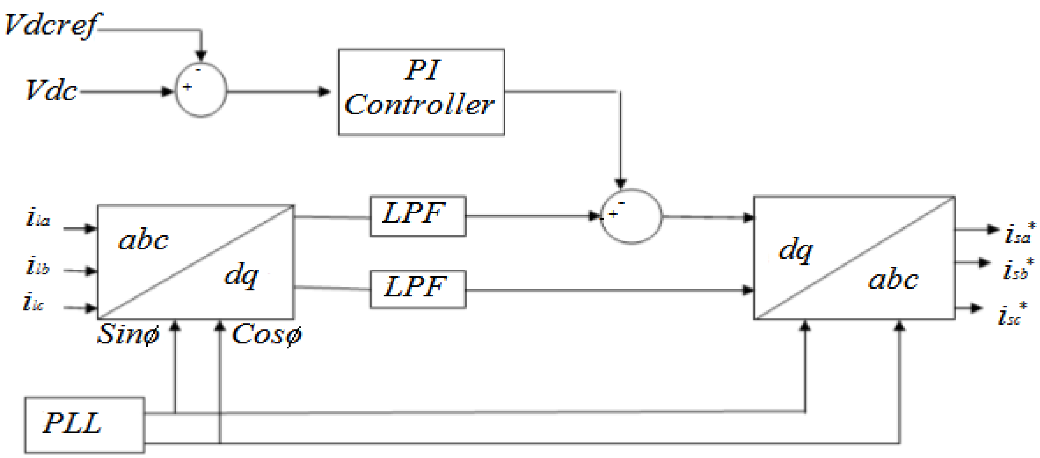

Figure 2. SRF Control Technique – DSTATCOM

2.2 Dynamic Voltage Restorer

Dynamic Voltage Restorer (DVR) infuses a voltage segment in series with the supply voltage as demonstrated in Figure-3, subsequently recompensing voltage sags and swells on the load side. Control reaction takes a time period of 3msec, guaranteeing a protected voltage supply under transient organization conditions. Voltage infusion of the subjective stage concerning the load current infers active power transition to the load. The DC link transfers the active power which is supplied a energy storage connected with the PWM inverter. It isolates the harmonics from the source voltage and the load also provides voltage balance and voltage regulation. The DVR comprises of Voltage Source Inverter, Injection Transformers, Passive Filters and Energy Storage.

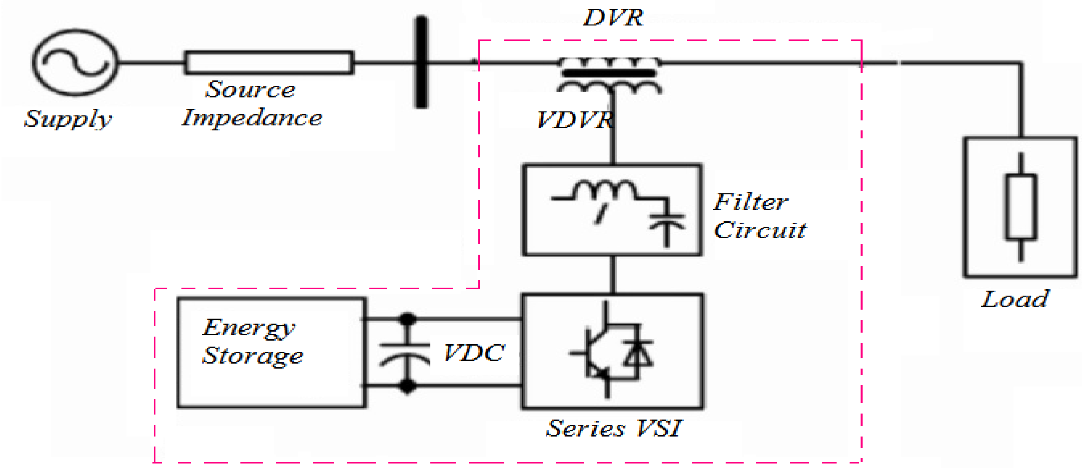

Figure 3. Structure of DVR

Figure 4 shows the control block diagram of DVR, which consists of hysteresis voltage control and synchronous reference frame theory.

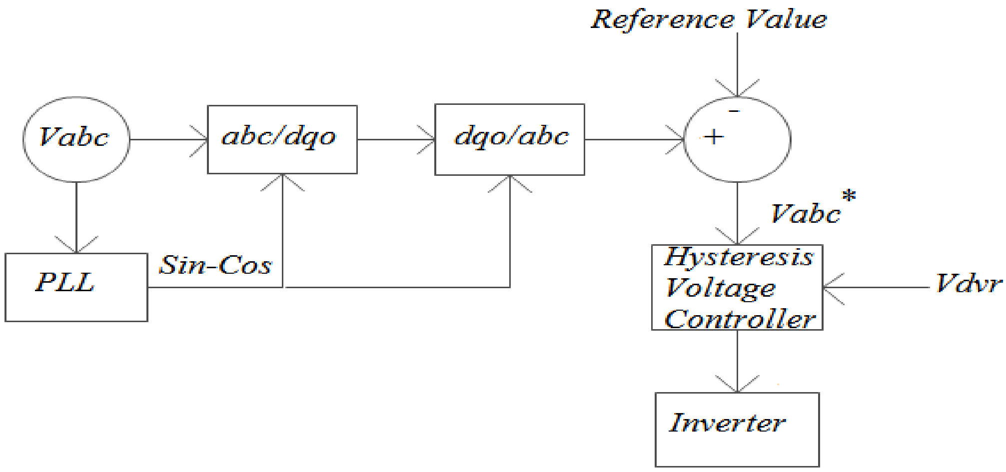

Figure 4. Control Block of DVR

The Source Voltage Vabc is detected and contributes to the transition block (abc/dq0), and a similar source voltage (Vabc) is given as a contribution to the PLL block. The PLL block generates sin_cos signals. This is given to the block (abc/dq0) and reverse change block (dq0/abc). At that point, the correlation of the reference and voltage generated by the reverse transformation block is executed. The outcome acquired from this is Vabc*, and a voltage signal generated by DVR (Vdvr) is given to the hysteresis voltage regulator to generate switching pulses for an inverter. Changes of abc/dq0 and dq0/abc voltages are:

$$\begin{bmatrix} Vd \\ Vq \\ Vo \end{bmatrix} = \frac{2}{\pi} \begin{bmatrix} Cos\theta & Cos(\theta - \frac{2\pi}{2}) & Cos(\theta + \frac{2\pi}{2}) \\ Sin\theta & Sin(\theta - \frac{2\pi}{2}) & Sin(\theta + \frac{2\pi}{2}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix}$$ …………………... Eq. 1

$$\begin{bmatrix} V_a^* \\ V_b^* \\ V_c^* \end{bmatrix} = \begin{bmatrix} Cos\theta & Sin\theta & 1 \\ Cos(\theta - \frac{2\pi}{2}) & Sin(\theta - \frac{2\pi}{2}) & 1 \\ Cos(\theta + \frac{2\pi}{2}) & Sin(\theta + \frac{2\pi}{2}) & 1 \end{bmatrix} \begin{bmatrix} Vd \\ Vq \\ Vo \end{bmatrix}$$ …………………………… Eq. 2

SRF theory identifies the voltage sag in supply voltage and generates reference voltage utilizing change in conditions and the yield voltage of DVR utilizing hysteresis voltage Controller. The distinction got from above should be in the middle of upper level (VH) and lower level (VL) of hysteresis band for switching less activity, and when it passed as far as possible and furthest cutoff, the distinction diminishes or increments.

2.3 Unified Power Quality Conditioner

The protection for sensitive loads from insufficient quality sources is shunt & series association, known as unified power quality conditioner (UPQC). Researchers have explored many ways to use a UPQC to tackle practically all power quality issues, such as voltage sag, voltage swell, voltage blackout and overcorrection of power factor unsuitable degrees of harmonics in the current and voltage. The essential arrangement of UPQC has appeared in Figure.5. The fundamental motivation behind a UPQC is to make up for supply voltage flicker/imbalance, reactive power, negative-succession current, and harmonics. All in all, the UPQC can improve power quality to establish power circulation frameworks or modern power frameworks. The UPQC, along these lines, is normal as perhaps the most powerful answers for huge limit sensitive loads to voltage flicker/imbalance.

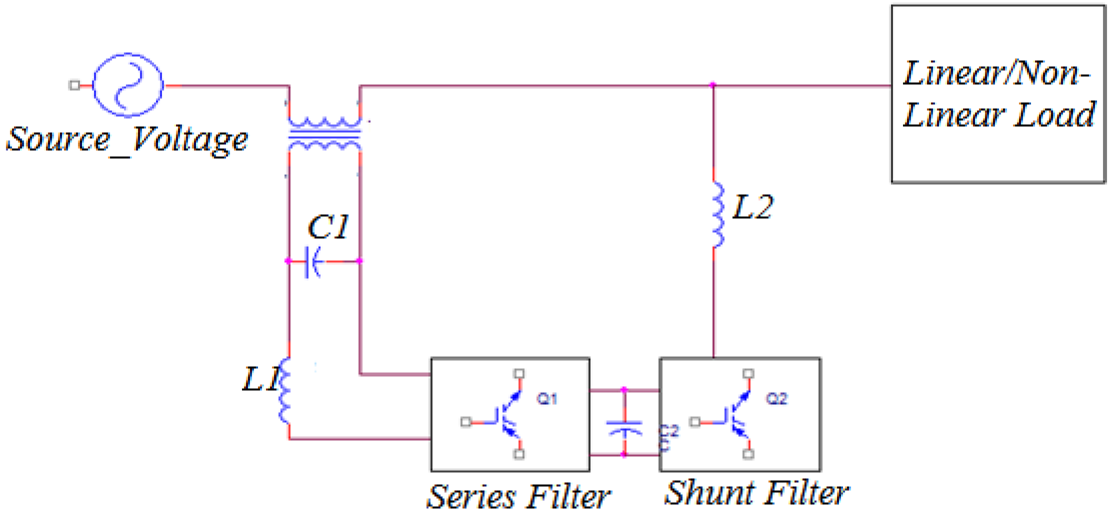

Figure5.Structure of UPQC

The UPQC consists of two three-phase inverters connected in a cascade. The inverter I is connected in series with the source voltage via a transformer, and inverter II is connected in parallel with the load. The shunt compensator's main purpose is to eliminate harmonics to compensate for reactive power as the load demands and regulate normal DC-link voltage. The PWM is operated in a voltage-controlled manner in a series compensator. This means that the supply voltage at the end of the load voltage is always maintained at the desired value, i.e., the voltage in advance of the quadrature in time. Two inverters operate in an organized manner. The principal elements of the custom power concept are:

i. The DVR delivers a series recompense by voltage injection to sag and swell

ii. Providing continuous variable shunt relief from current injections to eliminate voltage fluctuations in the Distributed Static Compensator (D-STATCOM) and obtain the correct power factor in a three-phase system. This is to prevent disturbing loads from defiling the rest of the ideal app distribution system.

iii. Unified Power Quality Conditioner (UPQC) provides both Shunt and series compensation, i.e., Inject voltage at sag and swell conditions and inject current to eliminate voltage fluctuations, correct power factor, and other pollution Avoidance of distribution system

Required custom power projects and precision system modeling, and the optimal selection of appropriate protection equipment will increase power quality

Table 1. Comparison of Various Custom Power Devices

S.no	Factors	DSTATCOM	DVR	UPQC
1	Rating	Used for Low Rating	Used for Medium rating	Can be utilized for higher ratings
2	Speed of Operation	Slow	Faster than DSTATCOM	Faster than both DSTATCOM and DVR

3	Compensation	Only Shunt	Only Series	Both Series and Shunt
4	Active/Reactive Power	Reactive	Active/Reactive	Both
5	Harmonics Reduction	Better	Good	Higher than DVR and STATCOM
6	Problem Addressed	Sag/Swell	Sag/Swell/Harmonics	Sag/Swell/Harmonics/Flicker/Transients/unbalance
7	Cost	Nominal	High	Higher

2.4 UPQC's advantages over other devices

Each of the custom power tools has its advantages and limitations. The UPQC is one of the most powerful solutions to loads that has large capacity of voltage and current imbalances. It is more flexible than a single inverter device. It can simultaneously correct unbalance and distortion at source voltage and load current, while other devices correct current or voltage distortion. Therefore the purpose of both devices has been served by UPQC only.

3. RESULTS AND DISCUSSION

This section discusses the simulation results and performance analysis of DVR, DSTATCOM and UPQC. The following figures discuss the Simulink model and THD analysis of DVR, DSTATCOM and UPQC.

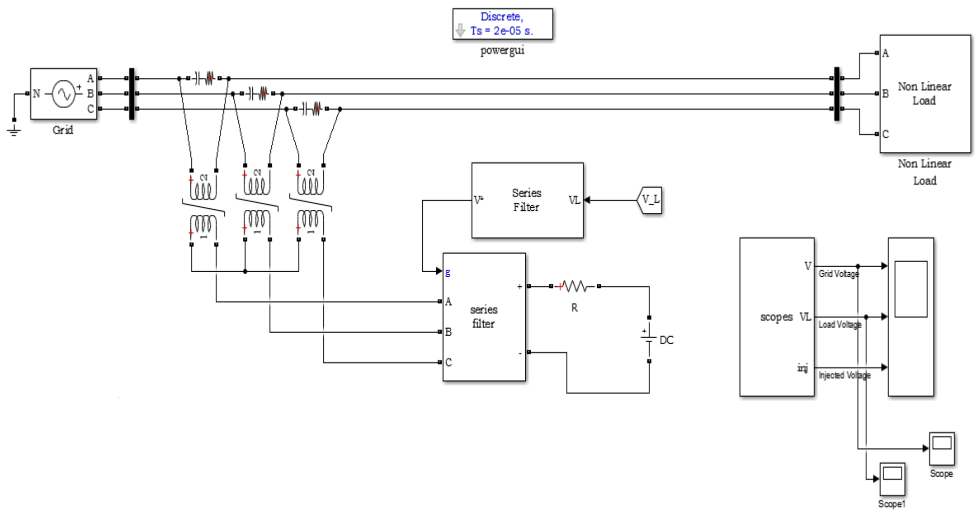

Figure 7. Simulink of Model of DVR

The Simulink model of Dynamic Voltage Restorer is shown in Figure 7. A non-linear load is connected with a source and the series filter which has the series inverters is connected with grid which compensates for the voltage related disturbances like sag and swell.

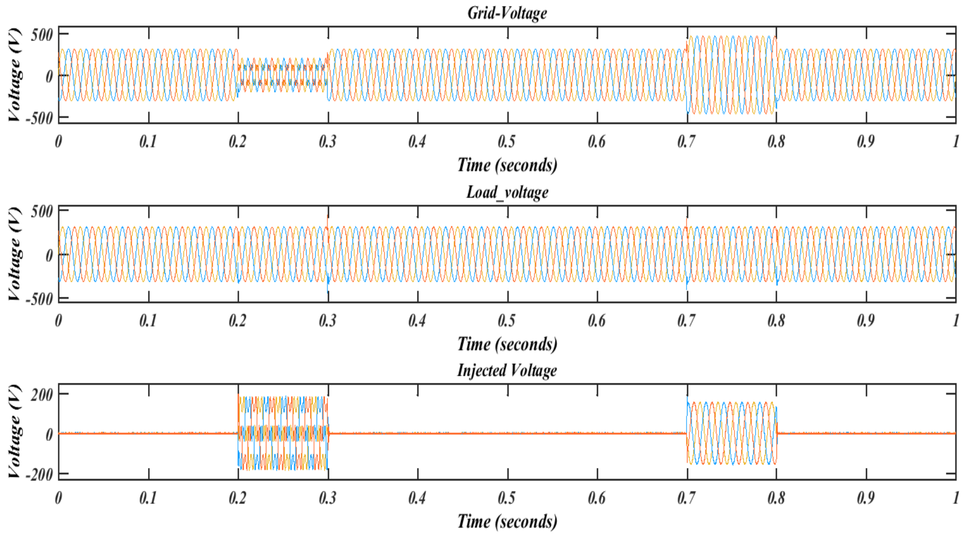

Figure 8. Simulation Result of DVR

The simulation result of DVR is shown in Figure 8. These results contain grid voltage, load voltage and injected voltage. The sag and swell are compensated by 0.2-0.3Sec and 0.7-0.8Secs.

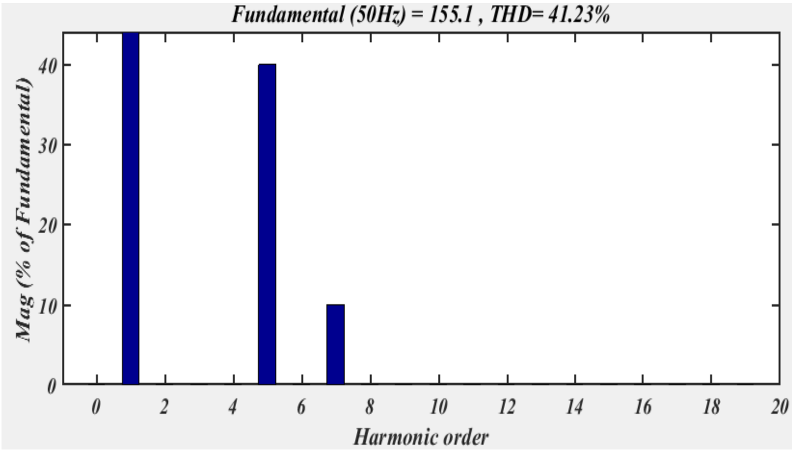

Figure 9. THD Result of Source Side –DVR

The Total Harmonics Distortion result of the source side of Dynamic Voltage Restorer is shown in Figure 9. The THD is 41.23% concerning 50Hz fundamental frequency.

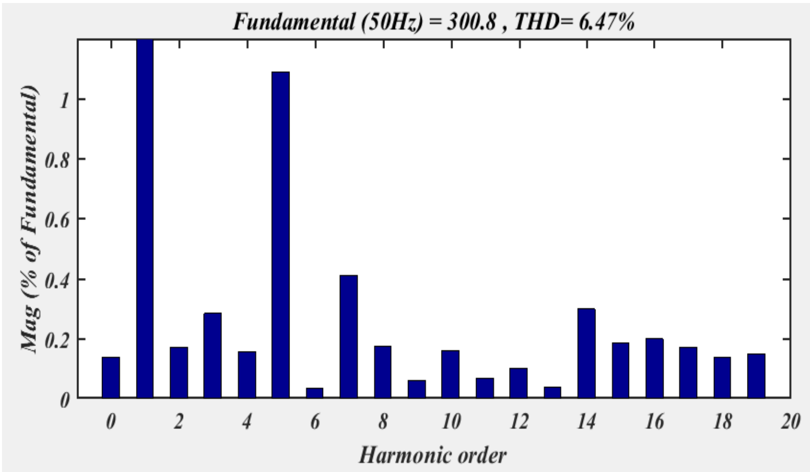

Figure 10. THD Result of Load Side -DVR

The Total Harmonics Distortion result of the load side of Dynamic Voltage Restorer is shown in Figure 10. As compared with grid side THD, the load side THD is significantly reduced. The THD is 6.47% concerning 50Hz fundamental frequency.

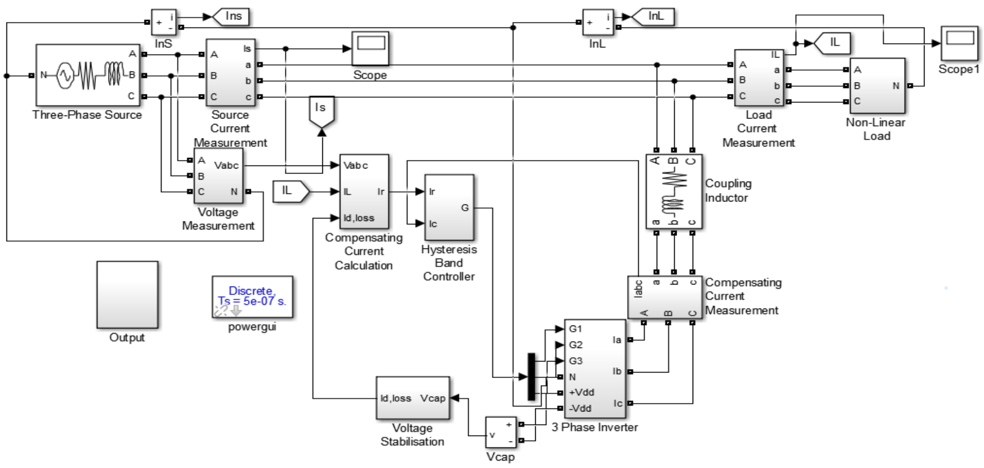

Figure 11. Simulink of Model of DSTATCOM

The Simulink model of DSTATCOM is shown in Figure 11. In this, DSTATCOM is used to reduce the Total harmonics distortion in currents.

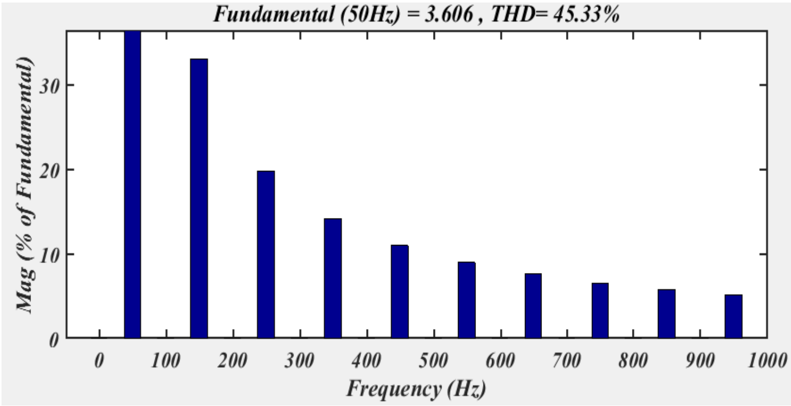

Figure 12. THD Result of Current – Without DSTATCOM

The Total Harmonics Distortion result of current without DSTATCOM is shown in Figure 12. The THD without DSTATCOM is 45.33%.

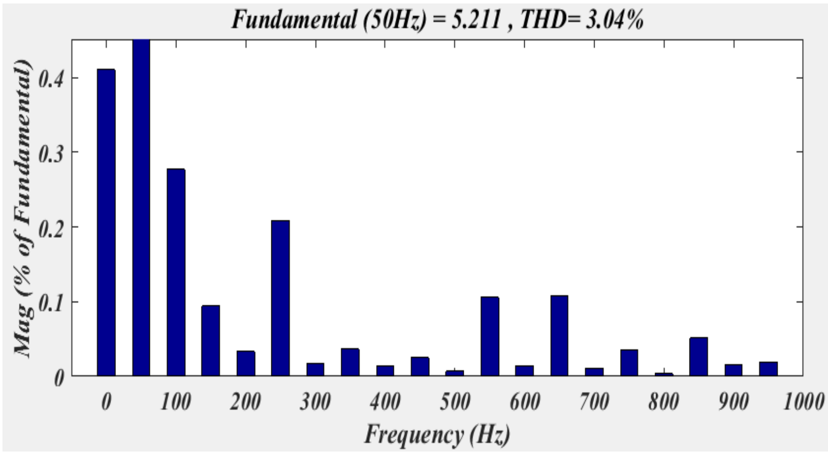

Figure 13. THD Result- with DSTATCOM

The Total Harmonics Distortion using DSTATCOM is shown in Figure 13. As compared to DSTATCOM, by using DSTATCOM, the THD is reduced. By using DSTATCOM, the THD is 3.04% concerning 50Hz fundamental frequency.

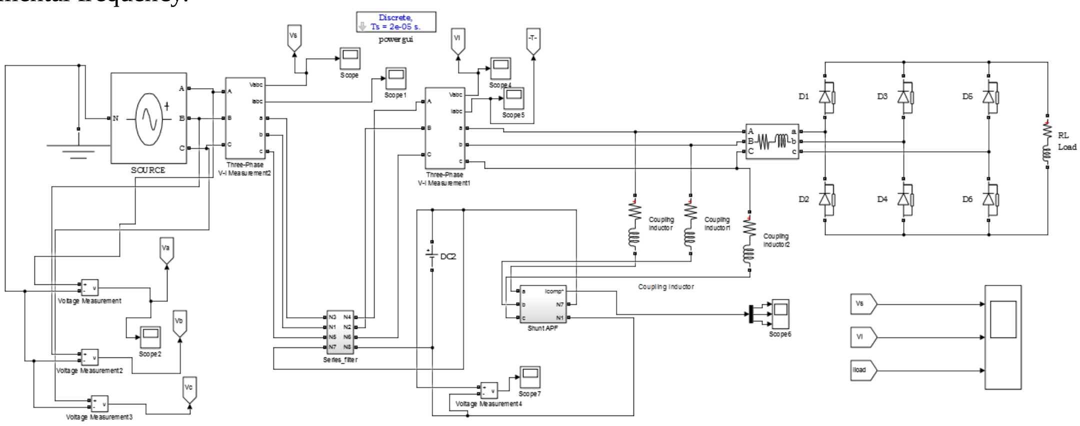

Figure 14. Simulink Model – UPQC

The Simulink model of UPQC is shown in Figure 14. By using UPQC, all the voltage and current related problems are solved.

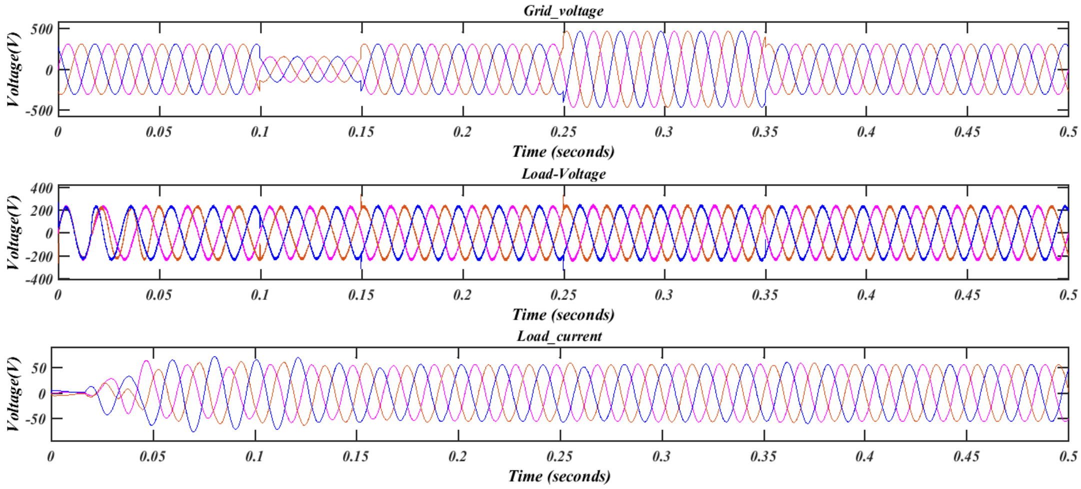

Figure 15. Simulation Result of UPQC

The simulation result of UPQC is shown in Figure 15. These results contain grid voltage, load voltage and load current. 0.1-0.15Sec and 0.25-0.35Secs compensate for the sag and swell. By using UPQC, both voltage and current related problems are compensated.

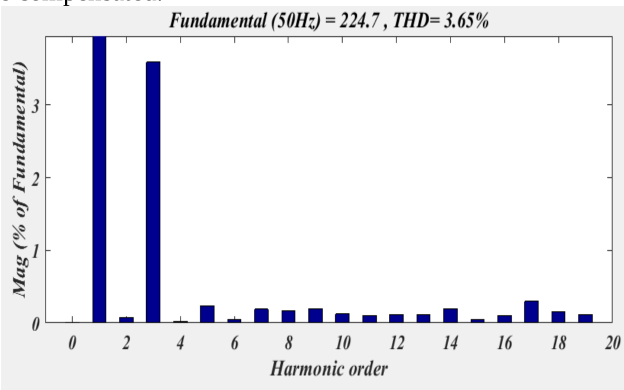

Figure 16. THD Result of Load Voltage – UPQC

The Total Harmonics Distortion result of the load side of UPQC is shown in Figure 16. As compared with grid side THD, the load side THD is significantly reduced. The THD is 3.65 % concerning 50Hz fundamental frequency.

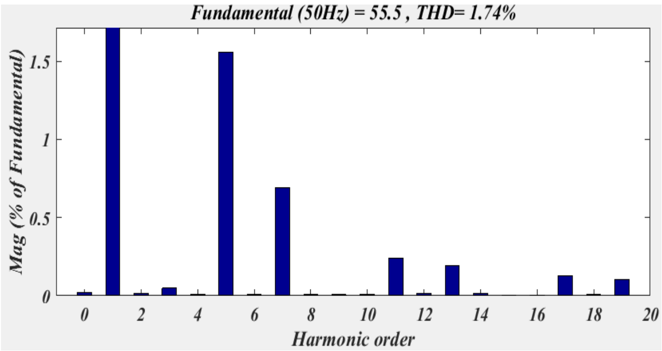

Figure 17. THD Result of Load Current – UPQC

The Total Harmonics Distortion for the load current using UPQC is shown in Figure 17. By using UPQC, the load current THD is 1.74% concerning 50Hz fundamental frequency. This is lesser than the other two compensating devices which makes the UPQC to be better than the DVR and STATCOM

4. CONCLUSION

This work has been done to compare series, shunt, and hybrid (shunt and series) compensators. The performance analysis is done by comparing the power quality of each compensator. The DVR has proven to compensate for the voltage level in a failed situation. Voltage harmonics are greatly reduced. Harmonics generated on the supply side had a THD of 41.23%, which has compensated for 6.47% in the last load. Even sag voltage during a fault can also compensate for the desired level. DSTATCOM has proven to compensate for the current level in a failed situation. The harmonics are now greatly reduced. The current harmonics without DSTATCOM is

45.33% and using DSTATCOM, and the current THD harmonics is 3.04%. Even the current level increased during the fault may have compensated for the desired level. UPQC has proven to compensate for current levels and voltages in distorted supply situations. The harmonics on both voltage and current is very much reduced. Harmonics present on the current at load side have compensated for 1.74% in PCC. The harmonic voltage created on the load side, which has been compensated for being 3.65%. Eveen during the unbalances and the distortions the current and volage is maintained to the desired level, so compared to DVR and DSTATCOM, and the UPQC gives good power quality results. This study gives a valuable comparison between the three major compensating devices at the distribution side of the grid providing better quality power to the customers.

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