Using Fast Fourier Extraction Method Power Quality Improvement by Dvr for Unbalanced Voltage Sag-Swell Control

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ABSTRACT:
Voltage sag and swell is big problem in power system. Sensitive load has a severe impact on itself due to voltage sag and swell. Dynamic Voltage Restorer (DVR) is a power customed device used in power distribution network. Matlab is an advanced simulation software used for effective modelling and simulation of DVR. Compensation for the control of voltage in DVR based on dq0 algorithm has been discussed here. To appropriately control the control targets for compensation voltage control, firstly the power circuit of a DVR systrm is analysed. The design is simple. The Simulation results are carried out by Matlab/Simulunk to verify the performance of the proposed method.

Keywords: *Power Quality, DVR, voltage sags/swells, VSI, Fast Fourier Extraction.*

I. INTRODUCTION

Power distribution systems, ideally, should provide their customers with an uninterrupted flow of energy at smooth sinusoidal voltage at the contracted magnitude level and frequency [1] however, in practice, power systems, especially the distribution systems, have numerous nonlinear loads, which significantly affect the quality of power supplies. As a result of the nonlinear loads, the purity of the waveform of supplies is lost. This ends up producing many power quality problems. Apart from nonlinear loads, some system events, both usual (e.g. capacitor switching, motor starting) and unusual (e.g. faults) could also inflict power quality problems[2].Power quality phenomenon or power quality disturbance can be defined as the deviation of the voltage and the current from its ideal waveform. Faults at either the transmission or distribution level may cause voltage sag or swell in the entire system or a large part of it. Also, under heavy load conditions, a significant voltage drop may occur in the system.Voltagesag and swell can cause sensitive equipment to fail, shutdown and create a large current unbalance. These effects can incur a lot of expensive from the customer and cause equipment damage [1]. The voltage dip magnitude is ranged from 10% to 90% of nominal voltage and with duration from half a cycle to 1 min and *swell* is defined as an increase in rms voltage or current at the power frequency for durations from 0.5 cycles to 1 min. Typical magnitudes are between 1.1 and 1.8 p.u[2].

There are many different methods to mitigate voltage sags and swells, but the use of a custom power device is considered to be the most efficient method, e.g. FACTS for transmission systems which improve the power transfer capabilities and stability margins. The term custom power pertains to the use of power electronics controller in a distribution system [10], especially, to deal with various power quality problems. Custom power assures customers to get pre-specified quality and reliability of supply. This pre-specified quality may contain a combination of specifications of the following: low phase unbalance, no power interruptions, low flicker at the load voltage, and low harmonic distortion in load voltage, magnitude and duration of over voltages and under voltages within specified limits, acceptance of fluctuations, and poor factor loads without significant effect on the terminal voltage.

There are different types of Custom Power devices used in electrical network to improve power quality problems. Each of the devices has its own benefits and limitations. A few of these reasons are as follows. The SVC pre-dates the DVR,butthe DVR is still preferred because the SVC has no ability to control active power flow [3]. Another reason include that the DVR has a higher energy capacity compared to the SMES and UPS devices. Furthermore, the DVR is smaller in size and cost is less compared to the DSTATCOM and other custom power devices. Based on these reasons, it is no surprise that the DVR is widely considered as an effective custom power device in mitigating voltage sags. In addition to voltage sags and swells compensation, DVR can also add other features such as harmonics and Power Factor correction. Compared to the other devices, the DVR is clearly considered to be one of the best economic solutions for its size and capabilities [4].

The voltage injection schemes and design of the DVR and the different control strategies for the controllers of the DVR have been discussed in [14-15]. E.g., the instantaneous reactive power theory (IRPT) [15], adaline based fundamental extraction have been implemented in [14]. Instantaneous symmetrical component theory, space vector modulation, synchronous reference frame theory (SRFT) based control techniques for a DVR are reported in this literature. The SRFT based algorithm reported in [15] involves conversion of three phase voltages from the stationary frame to rotating frame and vice versa. The IRPT algorithm has been used in [16] based on unit templates and instantaneous symmetrical component theory. In this paper, a new control algorithm is suggested based on SRF theory which includes P-I Controller for the generation of reference Vd and Vq. Reference load signal generation involves the conversion from three-phase to two-phase and vice versa. Moreover low pass filters are essential part of this algorithm which has slow dynamic response of the compensator.

The organization of the paper is as follows. In section II, the constructional part of the DVR is briefly described, the operating principle and the voltage injection capabilities of the DVR is discussed in section III, proposed control algorithm enumerated in section IV and the detailed description of MATLAB Simulation model along with its performance in electrical network discussed in section V and section VI respectively.

II. DYNAMIC VOLTAGE RESTORER(DVR)

DVR is a Custom Power Device used to eliminate supply side voltage disturbances. DVR also known as Static Series Compensator maintains the load voltage at a desired magnitude and phase by compensating the voltage sags/swells and voltage unbalances presented at the point of common coupling.

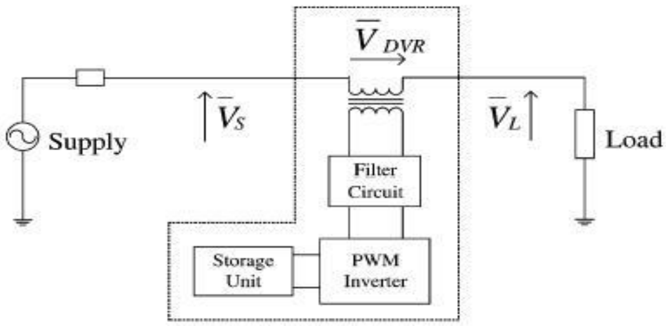


Figure-1: DVR series connected topology

The power circuit of the DVR is shown in Fig. 1.The DVR consists of 6 major parts:-

a) Voltage Source Inverter (VSI)

These inverters have low voltage ratings and high currentratings as step up transformers are used to boost up the injected voltage.

b) Injection Transformers

Three single phase injection transformers are connected indelta/open winding to the distribution line. These transformers can be also connected in star/open winding. The star/open winding allows injection of positive, negative and zero sequence voltages whereas delta/open winding only allows positive and negative sequence voltage injection.

c) Passive Filters

Passive filters are placed at the high voltage side of the DVR to filter the harmonics. These filters are placed at the high voltage side as placing the filters at the inverter side introduces phase angle shift which can disrupt the control algorithm.

d) Energy storage

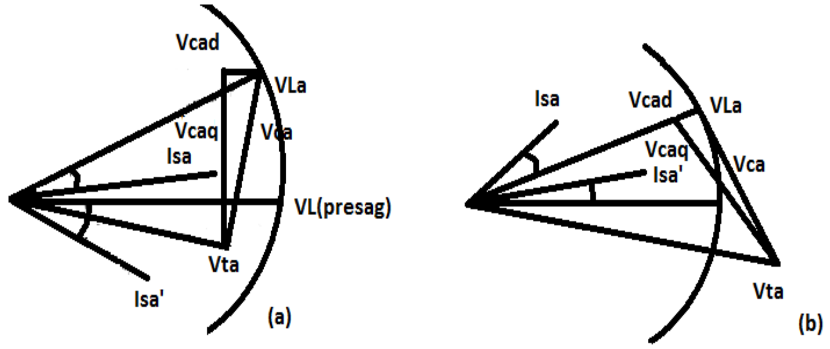
Batteries, flywheels or SMEs can be used to provide real power for compensation. Compensation using real power is essential when large voltage sag occurs.

e) Capacitor

DVR has alarge DC capacitor to ensure stiff DC voltage input to inverter.

f) By-Pass Switch

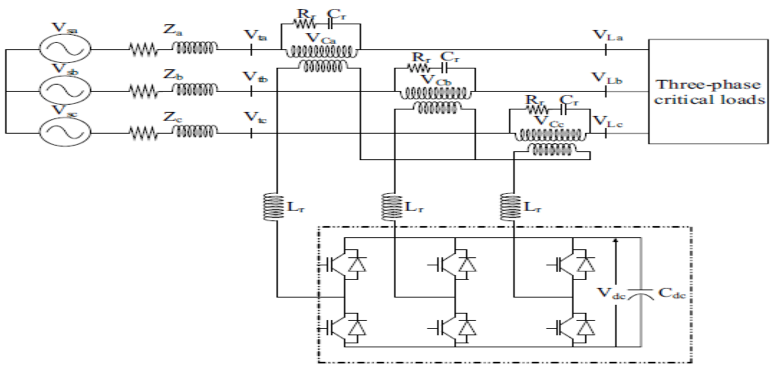
If the over current on the load side exceeds a permissible limit due to short circuit on the load or large inrush current, the DVR will be isolated from the system by using the bypass switches and supplying another path for current.



III. OPERAT ION OF DVR

The schematic diagram of a DVR is shown in Figure-2. Three phase source voltages (Vsa, Vsb, and Vsc) are connected to the 3-phase critical load through series impedance (Za, Zb, Zc) and an injection transformer in each phase. The terminal voltages (Vta, Vtb, Vtc) have power quality problems and the DVR injects compensating voltages (VCa, VCb, VCc) through an injection transformer to get undistorted and balanced load voltages (VLa, VLb, VLc). The DVR is implemented using a three leg voltage source inverter with IGBTs along with a dc capacitor (Cdc). A ripple filter (Lr, Cr) is used to filter the switching ripple in the injected voltage. The considered load, sensitive to power quality problems is a three-phase balanced lagging power factor load. A self-supported DVR does not need any active power during steady state because the voltage injected is in quadrature with the feeder current.

The DVR operation for the compensation of sag, swell in supply voltages is shown in Figure-3. Before sag the load voltages and currents are represented as VL (presag) and Isa' as shown in Figure-3(a). After the sag event, the terminal voltage (Vta) is gets lower in magnitude and lags the presag voltage by some angle. The DVR injects a compensating voltage (VCa) to maintain the load voltage (VL) at the rated magnitude. VCa has two components, VCad and VCaq. The voltage in-phase with the current (VCad) is required to regulate the dc bus voltage and also to meet the power loss in the VSI of DVR and an injection transformer [5]. The voltage in quadrature with the current (VCaq) is required to regulate the load voltage (VL) at constant magnitude. During swell event, the injected voltage (VCa) is such that the load voltage lies on the locus of the circle as shown in Figure-3(b).



IV. CONTROL OF DVR

The compensation for voltage sags using a DVR can be performed by injecting/absorbing reactive power or real power. When the injected voltage is in quadrature with the current at the fundamental frequency, compensation is achieved by injecting reactive power and the DVR is self-supported with dc bus. But, if the injected voltage is in phase with the current, DVR injects real power and hence a battery is required at the dc side of VSI. The control technique adopted should consider the limitations such as the voltage injection capability (inverter and transformer rating) and optimization of the size of energy storage.

Figure-4 shows the control block of the DVR in which the synchronous reference frame (SRF) theory is used for the control of self-supported DVR. The voltages at PCC (Vt) are converted to the rotating reference frame using the abc-dqo conversion. The harmonics and the oscillatory components of voltages are eliminated using low pass filters (LPF). The components of voltages in d-axis and q-axis are,

$$Vsd = Vsd\ dc + Vsd\ ac$$
$$Vsq = Vsq\ dc + Vsq\ ac$$

The compensating strategy for compensation of voltage quality problems considers that the load terminal voltage should be of rated magnitude and undistorted.

The dqo transformation or Park's transformation [6] is used to control of DVR. The dqo method gives the sag depth and phase shift information with start and end times. The quantities are expressed as the instantaneous space vectors. Firstly convert the voltage from a-b-c referenceframe to d-q-o reference. For simplicity zero phase sequence components is ignored.

Illustrates a flow chart of the feed forward dqo transformation for voltage sags/swells detection. The detection is carried out in each of the three phases. The control is based on the comparison of a voltage reference and the measured terminal voltage (Va, Vb, Vc).The voltage sags is detected when the supply drops below 90% of the reference value whereas voltage swells is detected when supply voltage increases up to 25% of the reference value. The error signal is used as a modulation signal that allows generating a commutation pattern for the power switches (IGBT's) constituting the voltage source converter. The commutation pattern is generated by means of the sinusoidal pulse width modulation technique (SPWM); voltages are controlled through the modulation.

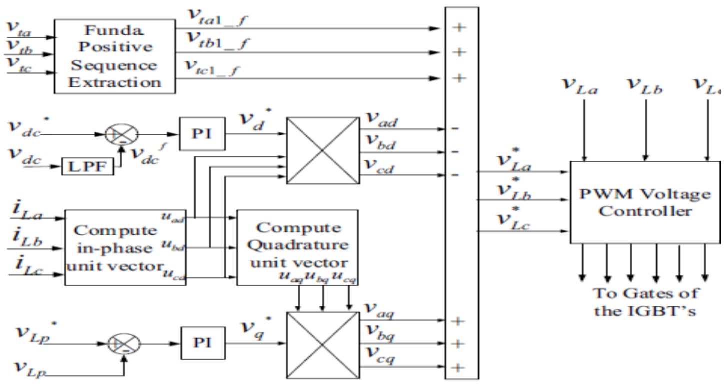


Figure-4: Proposed control strategy for the DVR

The speed of the response is determined by parameters K, Kp and Kv. Theseparameters control transient as well as steady state behaviour of the filter. There exists a compromise between speed and accuracy. For large K and KpKv , the convergence of the estimated values to actual values is faster but the steady state misadjustment is higher. This is an inherent characteristic of an adaptive algorithm. Parameters and ought to be selected appropriately according to the application. Increasing the value of K increases the speed. However, it creates oscillations in the peak detection response. There is a trade-off between speed and accuracy (or smoothness). Decreasing K and KpKv yields an estimation of the peak which is insensitive / robust to the undesirable variations and noise in the input signal. The presented PLL provides the following advantages online estimation of the amplitude, phase and their corresponding time derivatives of the pre-selected component of the input signal are provided.

V. MATLAB MODELLING AND SIMULATION

The DVR is modelled and simulated using the MATLAB and its Simulink and Sim Power System toolboxes. The MATLAB model of the DVR connected system is shown in fig. below. The three-phase programmable source is connected to thethree-phase load through the DVR in order to generate sag, swell and harmonics in supply side. The considered load is a lagging power factor load. The VSI of the DVR is connected to the system using an injection transformer. In addition, a ripple filter for filtering the switching ripple in the terminal voltage is connected across the terminals of the secondary of the transformer. The dc bus capacitor of DVR is selected based on the transient energy requirement and the dc bus voltage is selected based on the injection voltage level. The dc capacitor decides the ripple content in the dc voltage.The system data are given in Appendix.

The control algorithm for the DVR is simulated in MATLAB. The control algorithm shown in Fig.-4 is modelled for DVR control of Fig.-5. The reference load voltages are derived from the sensed terminal voltages, load supply voltages and the dc bus voltage of the DVR. A pulse width modulation (PWM) controller is used over the reference and sensed load voltages to generate gate signals for the IGBT's of the VSI.

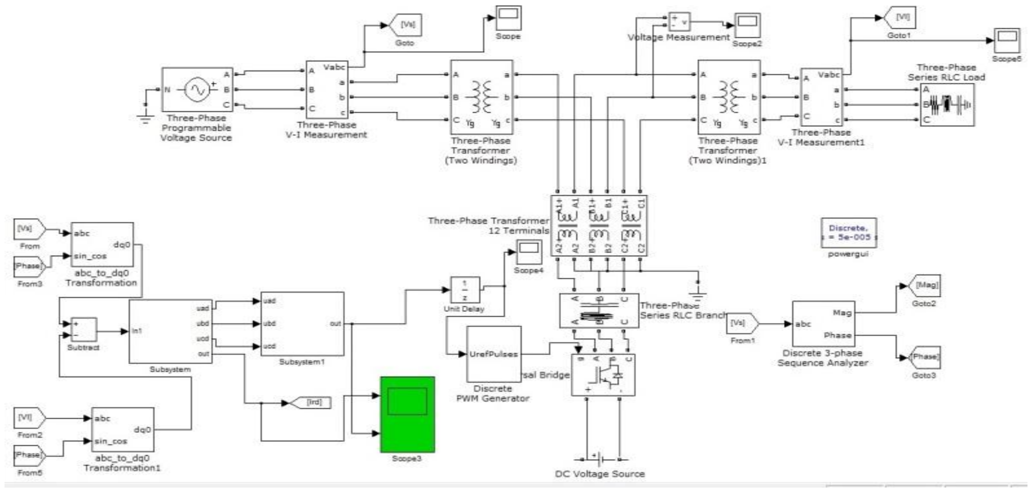


Figure 5.Matlab model of the DVR connected system

VI. PERFORMANCE OF THE DVR SYSTEM

The performance of the DVR is demonstrated for different supply voltage disturbances such as sag and swells in supply voltage [3].A case of Three-phase voltage sag is simulated and the results are shown in Figure-6. A case of Three-phase voltage swell is simulated and the results are shown in Figure-7(a),(b) and (c) show the voltage injected by the DVR and the compensated load voltage, respectively. As a result of DVR, the load voltage is kept at 1 p.u. throughout the simulation, including the voltagesag period. It is observed that during normal operation, the DVR is not operational. It quickly injects necessary voltage components to smoothen the load voltage upon detecting voltage sag.

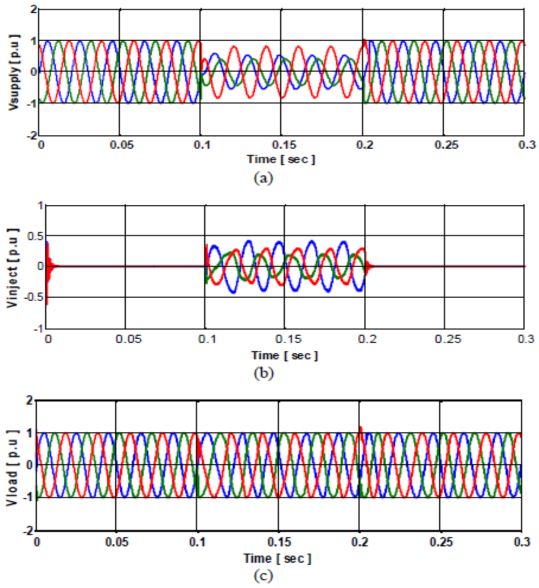


Fig.-Unbalanced voltage sag (a) Source voltage (b) Injected voltage (c) Load voltage

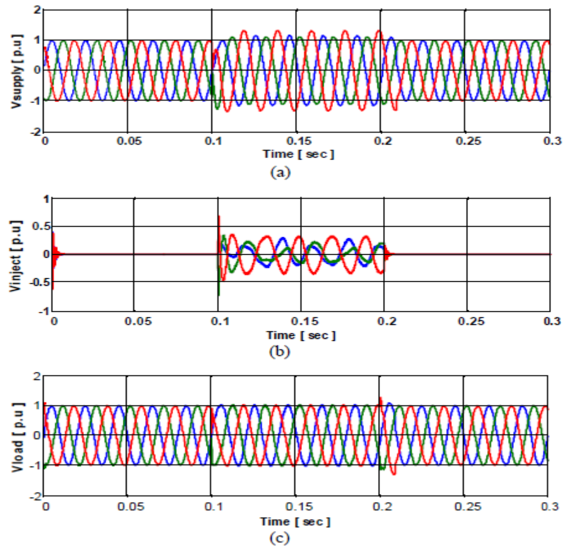
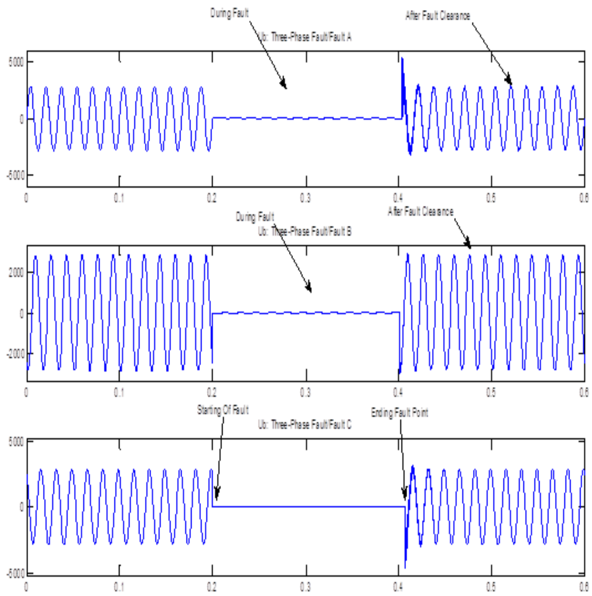


Fig.-Unbalanced voltage swell (a) Source voltage (b) Injected voltage (c) Load voltage

Figure-8(a) shows the first simulation was done with no DVR and a three phase fault is applied to the system at point with fault resistance of 0.66 U for a time duration of 200 ms. Figure-8(b) shows The second simulation is carried out at the same scenario as above but a DVR is now introduced at the load side to compensate the voltage sag occurred due to the three phase fault applied.



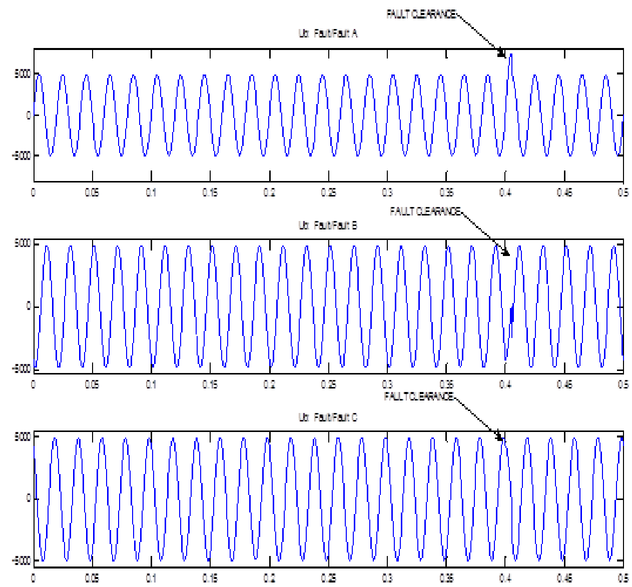


Fig.-8(a) Three phase fault without DVR

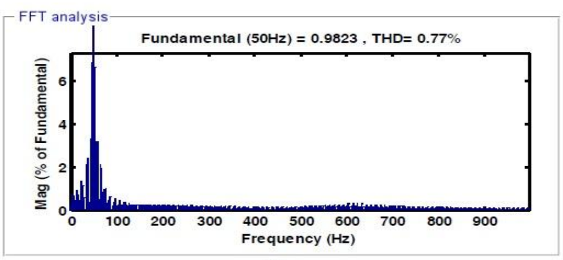
Fig.-8 Three phase fault with DVR voltage compensation

The harmonic compensation in load voltage achieved and depicted in Figure-9(a) and (b). The terminal voltage is distorted by adding 5th harmonic inversely proportional to their harmonic number. The load voltage is sinusoidal and constant in magnitude due to the injection of opposite harmonic voltage by DVR.

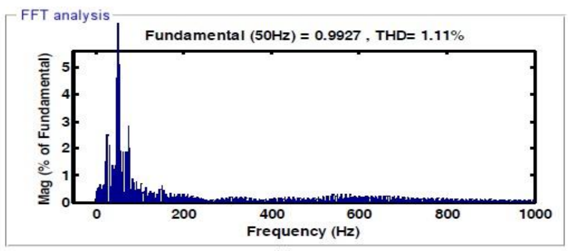
VII. CONCLUSION

The DVR modeling and simulation has been shown bythe aid of Matlab/Simulink. The control system is based on dq0 technique which is a scaled error, between source side of the DVR and its reference for compensating sags and swells. The simulation shows that the DVR performance is efficient in mitigation of voltage sags and swells.

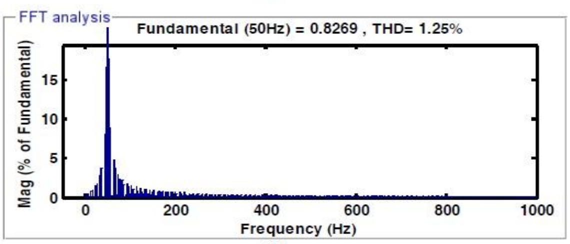
According to the simulation results, the DVR is able to compensate the sags and swells during single line to ground (SLG) fault and three-phase fault. As result of the FFT analysis, the compensated load voltage by the DVR has appropriate *THD*. The DVR handles both balanced and unbalanced situations without any difficulties. It injects an appropriate voltage component to correct any anomaly rapidly in the supply voltage; in addition, it keeps the load voltage balanced and constant at the nominal value.



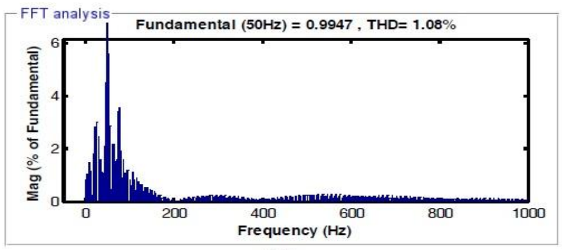
(a)



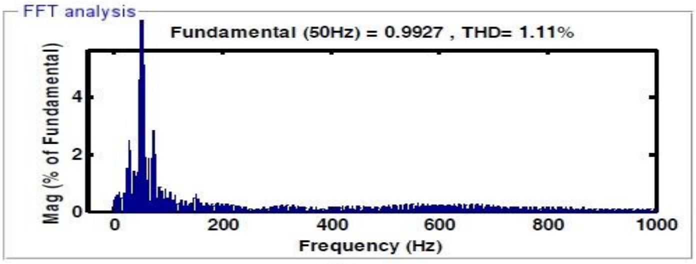
(c)



(b)



(d)



(e)

THD of compensated load voltage (a), three-voltage sag (b), Single-phase voltage sag (c), unbalanced voltage sag (d), three-phase Voltage swell (e) unbalanced voltage swell

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