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Implementation of Single Phase SRF based Dynamic Voltage Restorer in Distribution System for Power Quality Improvement.

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Abstract—: Power Quality (PQ) is becoming an important issue as the increase in electricity use continues. Reduction in the quality of electrical power is due to various kinds of voltage related problems such as voltage sag, voltage swell, short-lived interruptions, harmonic distortions, notches, flickers, spikes and transients. The major power quality problems in single phase system are voltage sag and harmonics. The Mitigation of voltage sag and harmonics in single phase system under the distorted power supply situations was effectively eliminated with Dynamic Voltage Restorer (DVR). The single-phase SRFT (Synchronous Reference Frame Theory) was implemented in the controller design for DVR. DVR will produce required amount of instantaneous voltage to be injected. Designed controller technique will utilize the function of Moving Average Filter (MAF) for getting the fundamental quantity of positive sequence component from the disturbed supply voltage. Experimental results of DVR prove its effectiveness to mitigate voltage sag and harmonics during disturbed power supply condition.

Key Words- DVR, Voltage Sag, Voltage swell, Power Quality, Total harmonic distortion, Single Phase Synchronous Reference Frame Theory, MAF (Moving Average Filter).

I. INTRODUCTION

The advancements in industries and commercial sectors are depending on the power electronics based process control techniques and high sensitive electronic equipment, will further depends on their amenability to power quality problems [3]. If an industrial load is increased it leads to the more harmonic distortion in the supply voltage because of drop in line voltage especially when reactance of line is high1].The well discerned power quality problem in single phase system are harmonics and voltage sag. During the unbalanced voltage sag, supply voltage consist of zero and negative sequence components along with positive sequence component, which leads in non-dc (sinusoidal) *d-q* components. In such situations, the conventional proportional-integral (PI) controller is unable to get the reference signal perfectly [4]. DVR (Dynamic Voltage Restorer) is one of the more prominent component because of its flexibility, accuracy and effective restoration capabilities of Dynamic Voltage Restorer (DVR) for power quality (PQ) improvement which works on the full bridge inverter with sinusoidal pulse width modulation (SPWM) and which is having the closed loop feedback signals.

PWM inverters control the voltage to reduce the harmonic contents in the output voltage. The DVR is more dynamic and efficient contemporary power device which is used in the distribution networks for the improvement of power quality [5]. DVR is a power converting device, which

convert the power from DC form to AC form by proper control of switches (IGBT's or MOSFET's) which are used in the inverter. DVR inject the magnitude of voltage and frequency into the system to restore the terminal voltage to its desired value. When the voltage sag occurs in the system, DVR will inject the missing voltage cycles in to the system through series connected voltage injecting transformer. DVR consists of energy storage devices; these storage devices will store the energy in the DC form. Batteries, Super Capacitors and Fly Wheels will be used as energy storage devices [6]. DVR corrects the load voltage by supplying reactive power generated internally on the occasion of small faults. The DVR is commonly connected in between the load terminal and supply in the distribution system[7]. The main advantage of this methodology is capacity to compensate the long duration voltage sag and harmonics. This paper discusses the method of extraction of positive sequence component with the singe phase SRF (Synchronous Reference Frame) Control method for DVR [9]. This control strategy is used for fast and accurate extraction of fundamental component and positive sequence component of supply voltage which further used to restore the load voltage to its required value during sag and unbalanced power supply conditions. Single phase to *α-β* conversion is done by delaying the actual supply voltage by quarter cycle and then PLL (Phase Locked Loop) is applied for SRF d-q transformation [8]. The decoupled *d-q* components will be used for the generation of reference injected voltage with the DVR for the load

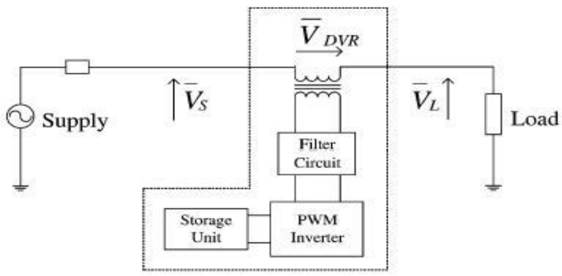

Fig.1.Schematic Diagram of DVR

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In-Phase Compensation Technique.

In this method, only the magnitude is restored. voltage is to be injected in phase with the supply voltage.

Whenever the supply voltage is reduces because of sag in the network, the injected voltage is generated by the Voltage Source Inverter and VSI will inject the appropriate voltage according to the dropped voltage due to voltage Sag [9].

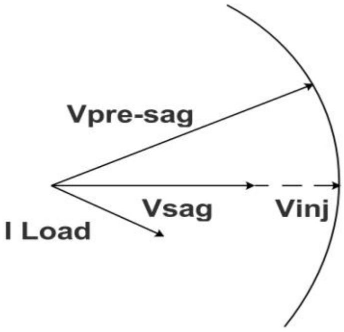


Fig.2.Vector Diagram of in-phase compensation.

II. DVR CONTROL STRATEGY

A Single Phase DVR consists of H-Bridge Voltage Source Inverter (VSI), in series with voltage injecting transformer and also self-supporting DC link. The working strategy of Dynamic Voltage Restorer (DVR) is to inject the voltage (V_{inj}) is in phase with load current to sustain the load voltage (V_{Load}) to its reference value. In this proposed control technique of DVR, the load current (i_L) will be considered as same as source current (i_s). During normal operation, if the source voltage (V_s) is pure sinusoidal, then the DVR does not inject any reactive component of power in to the line[9].Whenever the unbalanced condition due to faults or unbalanced loads, reactive component of power is compulsory injected by the DVR leads to maintain the pure sinusoidal voltage at load terminals. This recovery of voltage could be done by operating electronic switches of VSI with the voltage (V_{dc}) of DC- Link Capacitor (C_{dc}). L_1 ,L_2 and C represents passive π filter .

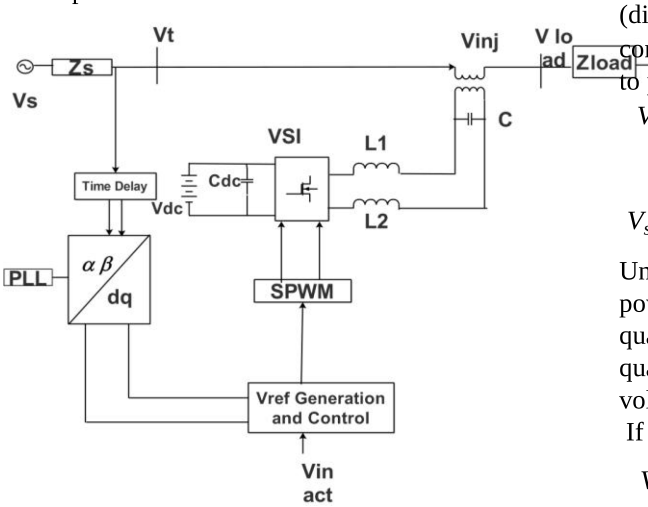


Fig 3.Control Diagram of DVR with SRF Controller.

A. Single Phase SRF Control methodology to extract d-q components from source voltage.

The available supply signal V_s will be considered as $V_{s\alpha}$ as $V_m \sin(wt)$ along with fictitious signal $V_{s\beta}$ as $V_m \cos(wt)$ are orthogonal with each other could be treated as equivalent representation of a single phase system in orthogonal $\alpha - \beta$ frame. The fictitious phase $V_{s\beta}$ is created by delaying the input signal by quarter cycle of supply voltage and it could be treated as β phase with the available α phase.

This $\alpha - \beta$ both the phases will rotate at fundamental frequency of system with the utilisation of rotation matrix as it is indicated in equation (1) to get the SRF $d - q$ transformation. This transformation is called as a Park Transformation.

$$\begin{bmatrix} V_{sd} \\ V_{sq} \end{bmatrix} = \begin{bmatrix} \sin\theta & -\cos\theta \\ \cos\theta & \sin\theta \end{bmatrix} \begin{bmatrix} V_{s\alpha} \\ V_{s\beta} \end{bmatrix} \qquad (1)$$

III. OPERATION STRATEGY OF DVR

A.Operation strategy of DVR for linear load under sinusoidal supply condition.

The objective of the DVR control system is to provide sinusoidal positive sequence component at the load terminals. To provide load voltage (V_{Load}) only at positive sequence component, V_{inj} should cancel out the zero sequence, negative sequence, and harmonic components present in V_s.

$$V_s + V_{inj} = V_{Load.} \qquad (2)$$

DVR is effectively compensating reactive power demand but the active power is to be supplied by the energy storage devices (ESD) like Battery. Under dynamic operation of system, the DVR has to provide both reactive and active power by injecting voltage V_{inj} at an angle α which restores the load voltage to its pre-sag voltage. So iinjected voltage V_{inj} should have both components i.e. V_{injd} (direct axis component) and V_{injq} (quadrature axis component) in SRF are necessary to restore its load voltage to pre specified value.

$$V_{sd} + jV_{sq} + V_{injd} + jV_{injq} = V_{Load\,d}^{\ ref} + jV_{Load\,q}^{\ ref} \qquad (3)$$

$$V_{sd} + V_{injd} = V_{Load\,d}^{\ ref} \qquad (4)$$

$$V_{sq} + V_{injq} = jV_{Load\,q}^{\ ref} \qquad (5)$$

Under steady state operation, DVR do not inject any active power into the system for that Vinj should be 90 in phase quadrature to line current I. This signifies that only Vinjq, quadrature component of the Vinjq will bring back the load voltage.

If Vinjd= 0. Equation . (3) will be

$$V_{sd} + jV_{sq} + jV_{injq} = V_{Load\,d}^{\ ref} + jV_{Load\,q}^{\ ref} \qquad (6)$$

$$V_{Load\,d}^{\ ref} = V_{sd} \text{ and } V_{Load\,q}^{\ ref} = jV_{sq} + jV_{injq} \qquad (7)$$

Hence the supply voltage is pure sinusoidal , V_{sd} had present with dc component, hence from Eq (6) $V_{Load\ d}{}^{ref}$ = V_{sd} and to regulate the peak of the load voltage to $V_{Load\ d}{}^{ref}\_peak$,

$V_{Load\ q}{}^{ref}$ can be directly obtained by

$$V_{Load\ q}{}^{ref} = \sqrt{V_{load\ peak}{}^2 - V_{load\ ref}{}^2} \quad (8)$$

$$V_{Load\ q}{}^{ref} = \sqrt{V_{load\ peak}{}^2 - V_{sd}{}^2} \quad (9)$$

B. Operation strategy of DVR during distorted supply condition.

When the supply is distorted, it contains the lower order harmonics which leads to generation of oscillation and error in the assessment of phase angle phase angle the regular techniques[8]. Subsequently Phase Locked Loop (PLL) will not give satisfactory results [10]. Under this condition, distorted supply terminal voltage will be segregated as,

$$V_s = V_{sF\_1} + V_{sH} \quad (10)$$

where V_{sF_1} represents the positive sequence component of V_s and Vs_H represents the harmonic component of V_s . By applying the single - phase SRF $d - q$ theory on V_s , the instantaneous active component voltage V_{sd} , will present with the both , dc component and the harmonic components. So it could be denoted as

$$V_{sd} = V_{sF\_1} + V_{sH} \quad (11)$$

The recommended control logic to perform satisfactorily during distorted situation, the samples of V_{sd} must be filtered to get only the only the positive sequence component of supply voltage V_s at the source terminal.

Usually with the application of SRF d - q transformation, low pass filter (LPF) with lower cut-off frequency will be carrying out to segregate negative and positive can be obtained by the combination of MAF and SRF theory .MAF provides the pure constant dc sequence symmetrical components. The harmonic components present in d - q values are eliminated by using Moving Average Filter (MAF). Fundamental component extraction value by doing the average of samples of the d - q components. Reference voltage of DVR can be obtained by applying the Inverse Park Transformation [10].

$$\begin{bmatrix} V_{s\alpha} \\ V_{s\beta} \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} V_{sd} \\ V_{sq} \end{bmatrix} \quad (12)$$

C. Control Design of DVR with Fundamental Component Extraction.

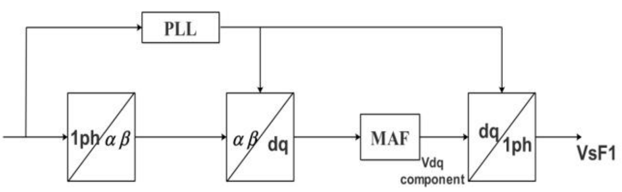


Fig.4. Fundamental component Extraction using MAF.

To extract the β component from the supply voltage, supply signal will be delayed by the quarter cycle. To regulate the injected voltage by the DVR, Pulse Width Modulation (PWM) control strategy will be applied. PWM controller only not sufficient to restore the load terminal voltage to pre–defined value because of different losses occurs in inverter, passive filter and injecting transformer. These losses can be eliminated by using additional PI controller which maintains the voltage in dc link capacitor [6] .To regulate the voltage error in dc link with respect to reference voltage value, small magnitude of voltage to be injected in series with the current using DVR. Errors in dc link voltage which denoted as V_{d_losses} can be reduced by Proportional and Integral (PI) Controller .

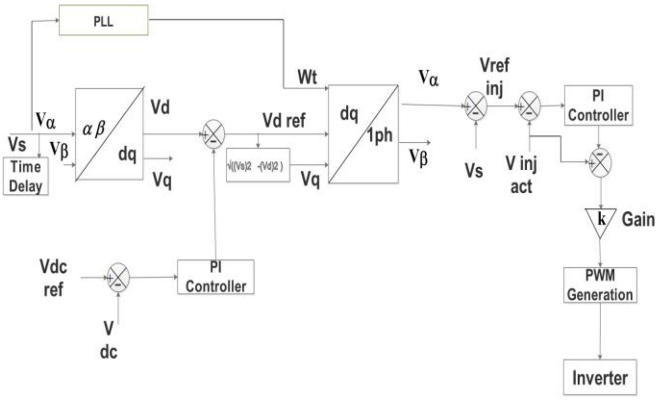
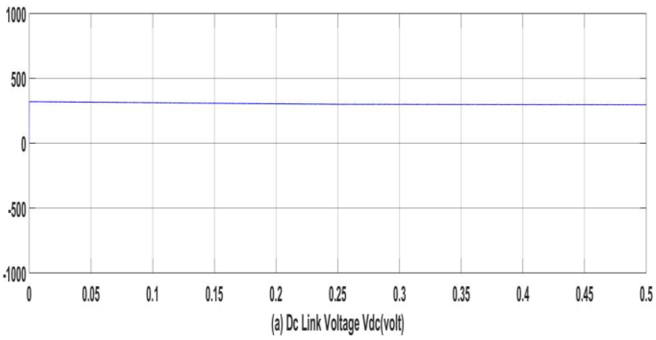


Fig.5.MATLAB based model of SRF (Synchronous Reference Frame) control method.

IV. SIMULATION RESULTS

The schematic diagram of control strategy represented in fig .5 is simulated for both un-balanced and balanced conditions, where the DVR is regulated the voltage sag and provide the smooth voltage at the load terminals. The sag voltage is created by line to ground fault with fault resistance 1.8 ohm at instant 0.05 s and ends at 0.2s because of this sensitive load suffers from 70% of voltage sag. Digital simulation was done using the blocks of MATLAB Simulink.



(a).DC Link Voltage Vdc (volt)

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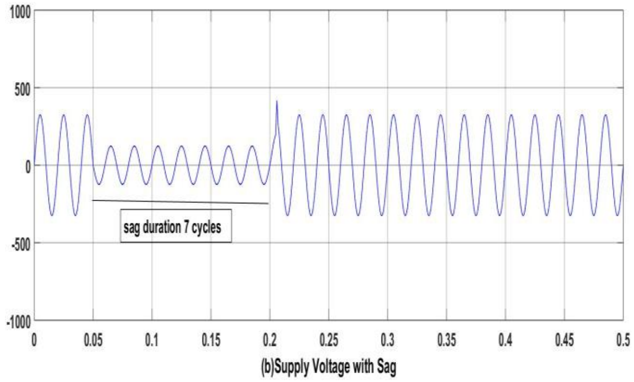
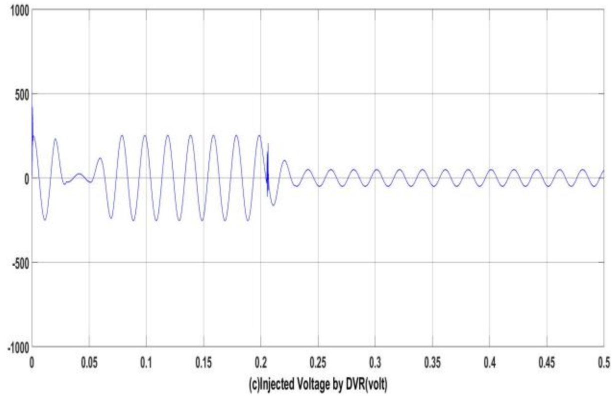
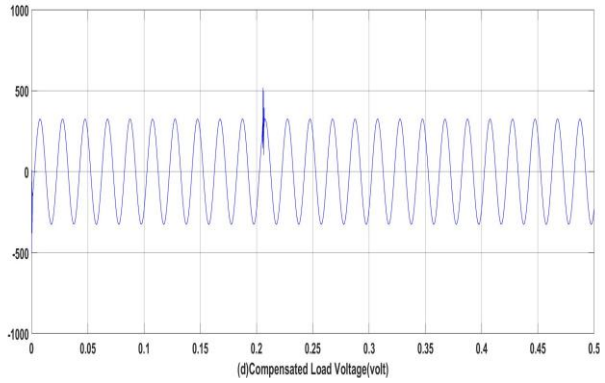


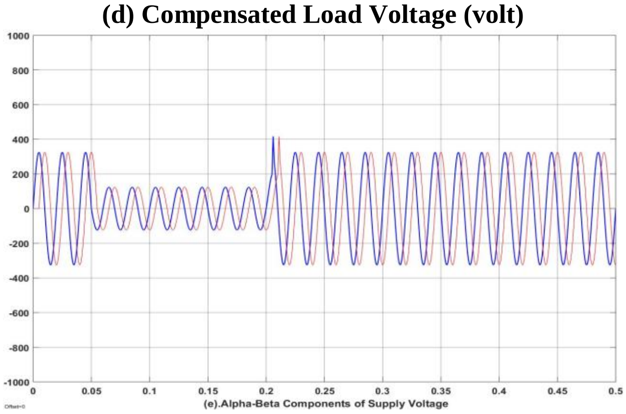
(b).Supply Voltage With Sag



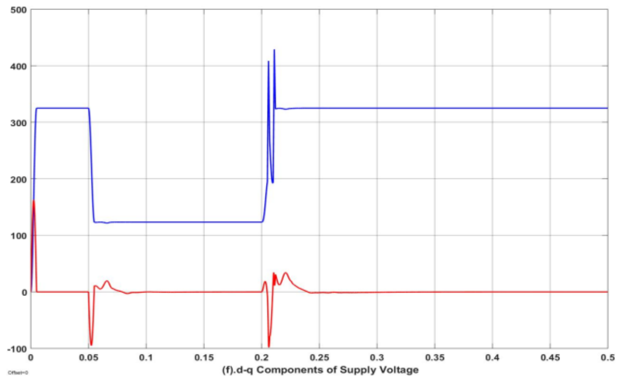
(c).Injected Voltage by DVR (volt)



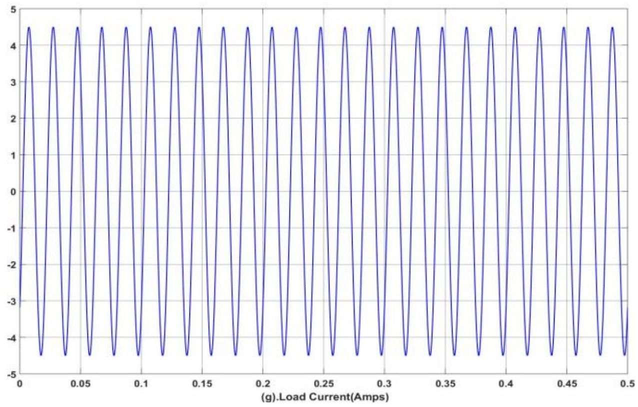
(d) Compensated Load Voltage (volt)



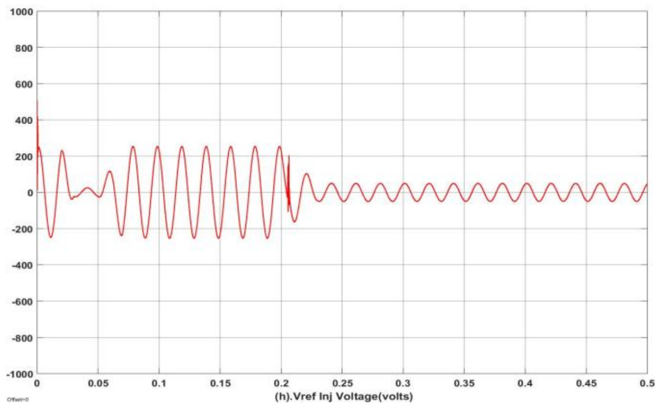
(e) Alpha-Beta Components of Supply Voltage.



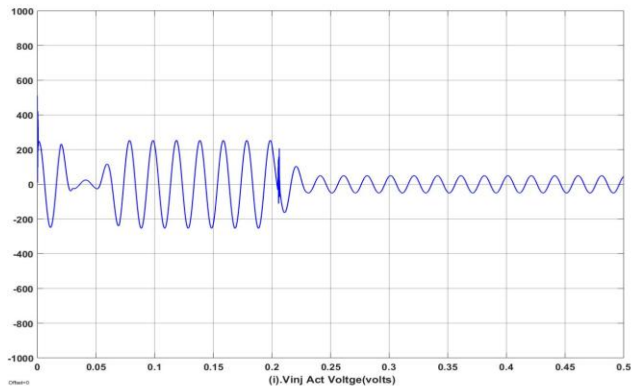
(f) d-q Components of Supply Voltage.



(g).Load current (Amps)

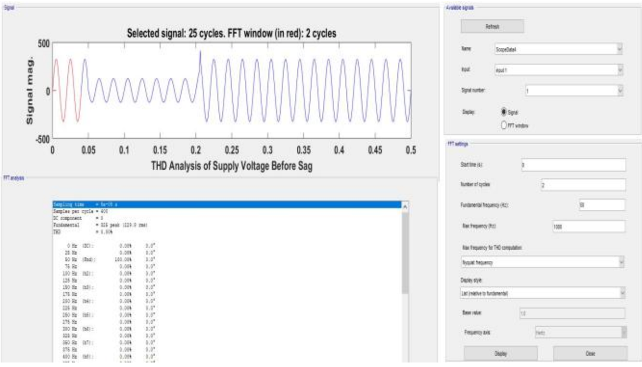


(h) Vref Inj Voltage (volt)

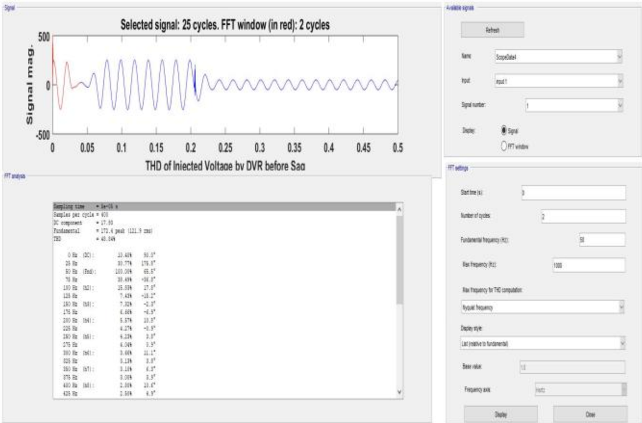


i) Vinj Act Voltage (volt)

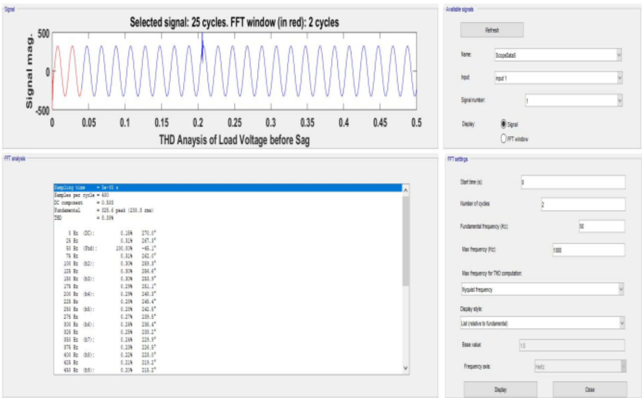
V. THD (Total Harmonic Distortion) Analysis of Supply Voltage Injected Voltage and Load Voltage.



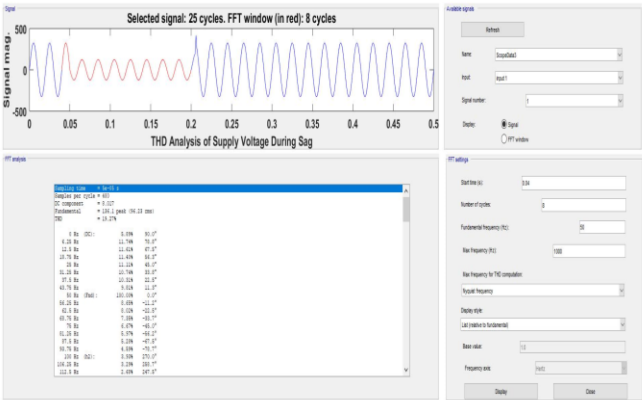
(a).THD Analysis of Supply Voltage Before Sag



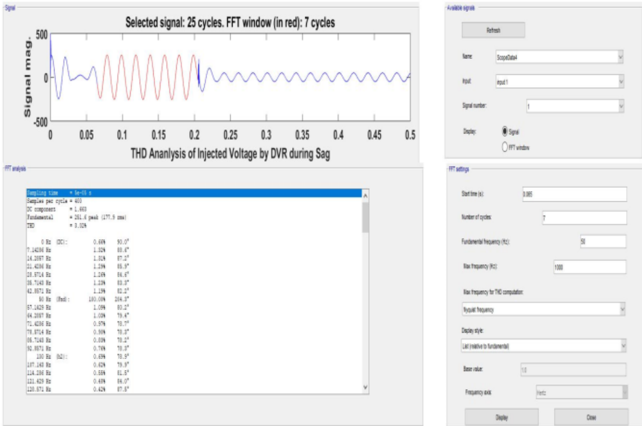
(b).THD Analysis of Injected Voltage by DVR Before Sag



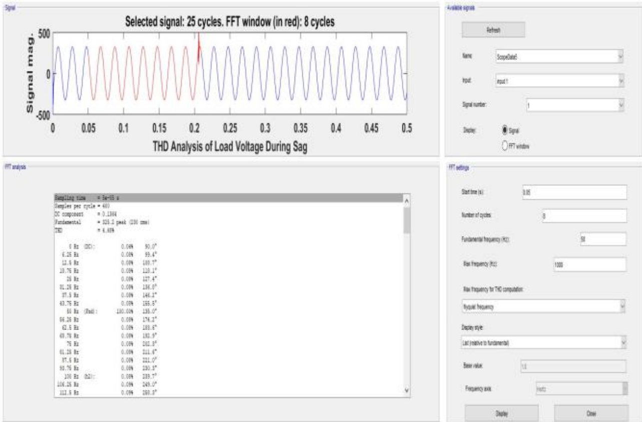
(C).THD Analysis of Load Voltage Before Sag.



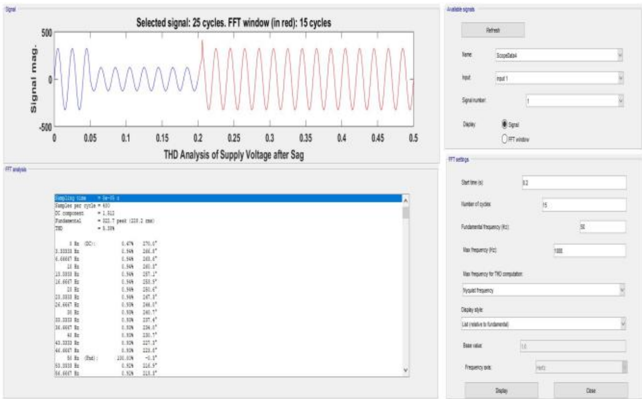
(d).THD Analysis of Supply Voltage During Sag



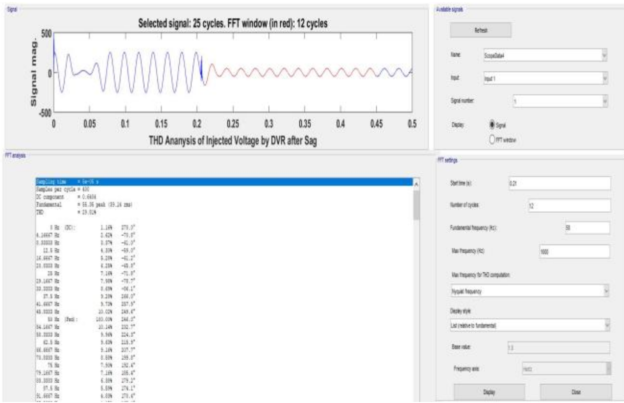
(e).THD Analysis of Injected Voltage by DVR During Sag



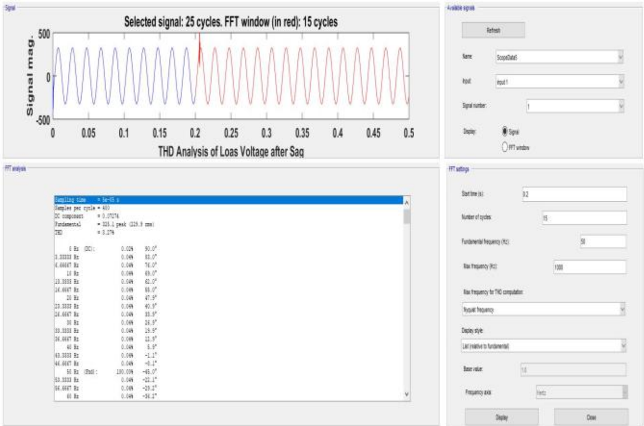
(f).THD Analysis of Load Voltage During Sag



(g).THD Analysis of Supply Voltage After Sag



(h).THD Analysis of Injected Voltage by DVR After Sag



(i).THD Analysis of Load Voltage After Sag.

Voltage	THD of Voltages		
	Before Sag	During Sag	After Sag
Source Voltage	0.00	19.27	5.38
Injected Voltage	48.84	3.02	19.81
Load Voltage	8.3	4.48	3.27

Table 1: THD of Voltages Before, During and After Sag.

VI. CONCLUSION

The effects of voltage sag and harmonics in a single phase system were reduced. It can be observed that the load voltage is regulated to constant value under sag condition by the DVR. The very close observation of experimental results it was shown that the modified Single –Phase SRF (Synchronous Reference Frame) $d - q$ theory with the Moving Average Filter (MAF) filter has been used for obtaining the fundamental positive sequence component of disturbed supply voltage.

The control technique was used in this paper is a unique method that can regulate the voltage sag in a fraction of cycles of sinusoidal waveform through observing the direct axis voltage of the synchronously rotating frame. And also minimization of harmonics in Load Voltage. The simulation results are plotted for the Voltage before, during and after sag conditions. And THD (Total Harmonic Distortion) Analysis was done for Supply Voltage, Injected voltage of DVR and Load Voltage before, during and after sag.

It can be observed from the simulation results, the dynamic performance of DVR to restore the load voltage to a pre-defined value and mitigation of harmonics in the output voltage .So that the DVR is the one of the most alternative device to improve the Power Quality.

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