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Power QualityAnalysis by Calculating Total Harmonic Distortion at Different Sag Values Using Dynamic Voltage Restorer

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Abstract

Power Quality is the most important issue in distribution network due to frequency variation, voltage dip, voltage swell and Harmonic Distortion.The Paper deals with the compensation of voltage dip using a series connected device Known as Dynamic voltage Restorer, which is relatively less expensive, small in size, higher energy storage and power efficient device as compared to other custom power devices.In this paper,two level Pulse Width Modulation system is utilized to adjust the voltage plunge at various sag esteems. The Total Harmonic Distortion esteems are likewise determined utilizing Fast Fourier Transform investigation and compared with and without filter section utilized in the DVR unit and the rate enhancement in the Total harmonic Distortion by utilizing channel unit is likewise assessed.

Keywords: *Dynamic Voltage Restorer, Voltage Sag, Two Level Pulse Width Modulation (PWM), THD Calculations, Park's Transformations.*

INTRODUCTION

Power quality includes every promising conditions in which the waveform of the source voltage (voltage quality) or current taken by the load (current quality) diverge from their ideal behavior for all phases at nominal frequency with magnitude equivalent to the rated Root Mean Square (RMS) value [7]. A disturbance in the quality of power includes sudden, short duration variations viz. impulsive and oscillatory transients, voltage sags, interruptions i.e.temporary interruption (0.5 cycle and up to 3 second), temporary interruption(3 second to 1 minute) and long interruption (more than 1 minute), as well as steady state variations [8,9,14]. The basis how to differentiate is related to the origin, intermediate problems associated with the quality of the source voltage and the dependent current quality which is taken by the load.

Power quality as "the conception of powering and grounding sensitive electronic equipment in a manner suitable for the equipment." Power Quality can also be defined in different aspects as:

The Power Quality is characterized as how much the power supply approaches the perfect instance of steady, continuous, zero mutilation and unsettling influence free supply.

a. The Power Quality is defined as the degree to which the power supply approaches the ideal case of stable, uninterrupted, zero distortion and disturbance free supply.

b. Power quality might be characterized as "How much both the use and conveyance of electric power influences the execution of electrical equipment"[10].

c. Power Quality is a Combination of Voltage profile, Frequency profile,

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Harmonics substance and dependability of intensity supply [2].

Voltage dip is known asthe most rigorous cause,as temporary change in voltage causes variations in sensitive load. Voltage sag is produced by a magnitude change with or without a phase shift of the input voltage. The potential temporarily drops to a lower value and comes back again after a certain period of time. Short circuit faults, motor starting and transformer energizing will cause short duration increase in current, and this will cause voltage sags on the line. Despite their short duration, such events can cause serious problems for a wide range of equipment [3].Voltage swells are not frequent as voltage sags, as they are less common in distribution systems. The main reason that causes swell is turning off the highly inductive load or initialisation of the capacitor bank of high capacity [1].

There are many available solutions to mitigate voltage sags and improve power quality using available custom power devices but one of the highly efficient and cost effective approaches is by using the DVR. Dynamic Voltage Restorer is a device in which converter is connected in series between the distribution system and the load [16, 12], also the DVR has recently been introduced to protect sensitive loads from voltage dip and other voltage disturbance. In addition to this, DVR has a capability to mitigate harmonics distortion.

OPERATIONOF DVR

Dynamic Voltage restorer is a solid state series connected power electronic device, which is connected between the supply system and the load end of a distribution system to maintain constant load voltage [13]. It is best amongst the several devices, which mitigate the issues related to power quality and specially designed for voltage sag mitigation.

Configuration of DVR

The block diagram of DVR is shown in Fig.1 consists of

1. An injection *transformer* - It is basically a step up transformer which is used step up the injected voltage into load end. This transformer is generally connected to isolate the low voltage circuit i.e. DVR circuit to high voltage distribution network.
2. A harmonic filter- It is used to remove the higher order harmonic by inserting the filter unit converter side. It can either be placed at inverter side or the load side to remove harmonics from the system.
3. A Voltage Source Converter (VSC)- Generally Pulse-Width Modulated Voltage Source Inverter (PWMVSI) is used whose function is to transform DCpower into AC power.
4. An Energy storage- An Energy storage- It is used to provide the required energy during abnormal conditions. In online monitoring and conditioning systems, the required energy for compensation is drawn from supply line feeder through a rectifier and capacitor. Lead-acid battery, flywheel, Super-conducting magnetic energy storage (SMES) etc. are utilized for energy storing purpose.
5. A control system-It is provided to generate the required pulse needed to trigger the VSI.

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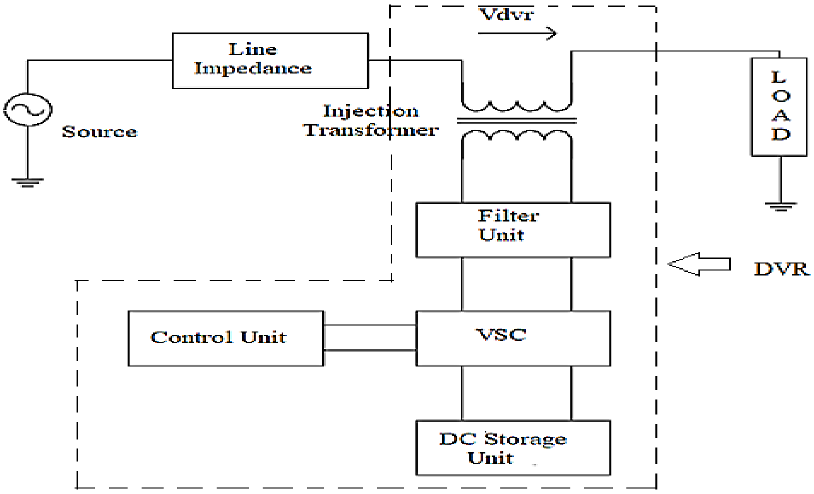

Fig: 1. *Block Diagram of DVR [11]*

Operating Principle of DVR

Dynamic Voltage restorer is the series device which maintains a desired voltage across the sensitive load. Whenever there is voltage sag or swell in distribution system which occurs due non-linear load, switching operations, reactive load, atmospheric conditions, unstable load, arcing loads, neighboring unbalanced load or any another disturbances in distribution system, Controlling unit is used to detects the difference in voltage between reference voltage and sagged voltage and the difference voltage (also known as correcting voltage) is given to voltage source inverter which act as the pulse generator for inverter to generate the required voltage with the help of energy storage device(i.e. DC storage unit). The correcting voltage after passing through filter unit is given to injection transformer and the injected voltage from voltage source inverter is added with the sag distribution voltage to maintain the required voltage at load side for proper operation.

MATHEMATICALASPECTS OF DVR

Level of fault at load voltage side decides the system impedance (Z_{TH}). The load voltage (V_L) can be kept maintain by injection of required voltage (V_{DVR}) from the injection transformer, when the system voltage (V_{TH}) drops.

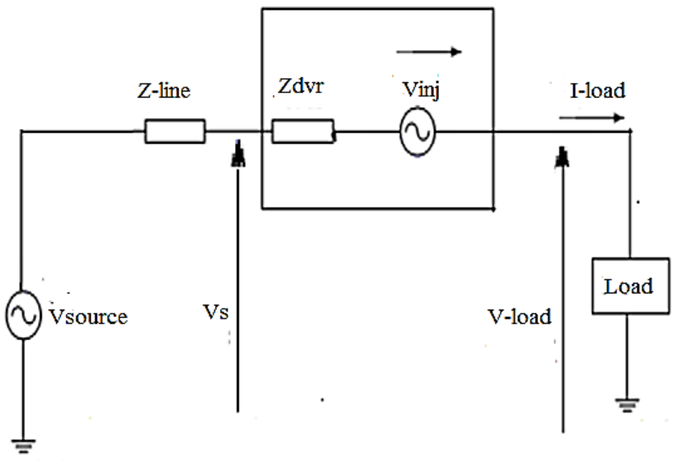

Fig: 2. *Equivalent Circuit of DVR [11]*

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Journal of Power Electronics and Devices
Volume 4 Issue 3

From the equivalent circuit, following equations can be given as [11]:
V_{DVR}=V_L+$Z_{TH}$$I_L$-$V_{TH}$(1)

Where
V_L= The Desired Load Voltage
Z_{TH}= The load impedance
V_{TH}= Systemvoltage when fault occur
I_L= Current taken by load

The load current is given by
$I_L = \frac{[P_L + jQ_L]}{V_L}$(2)
Further the equation can be given as, after consideration ofV_L as reference

$V_{DVR}\angle\alpha = V_L\angle 0 + Z_{TH}\angle(\beta-\theta) - V_{TH}\angle\delta$(3)

α,β,δ are the corresponding angles of V_{DVR},Z_{TH},V_{TH} andθ is called as angle of load power.

The DVRpower can be given as,
S_{DVR}=V_{DVR}.I_L*(4)

Insertion of reactive power is required and generation of reactive power is done by the DVR itself.

OPERATING MODES OF DVR

DVR is designed to maintain the constant voltage at the load end, which is injected by the force commutated Voltage Source Inverter (VSI) when there is reduction in load voltage from their required voltage values. The voltage injected into the system is in series with source voltage by means of injection transformer. This momentary three phase voltage is injected into the system so that it does not disturb the load voltage profile and maintain the reliable operation [18]. Operating modes of DVR are

Protection Mode–In this mode of operation, the DVR unit detached itself from the system (by opening switch S2 and S3) if the current at the load end go beyond a tolerable limit, which happens due to short circuit condition or due to flow of large amount of current and the Switch S1 is closed to provide another path to for current.

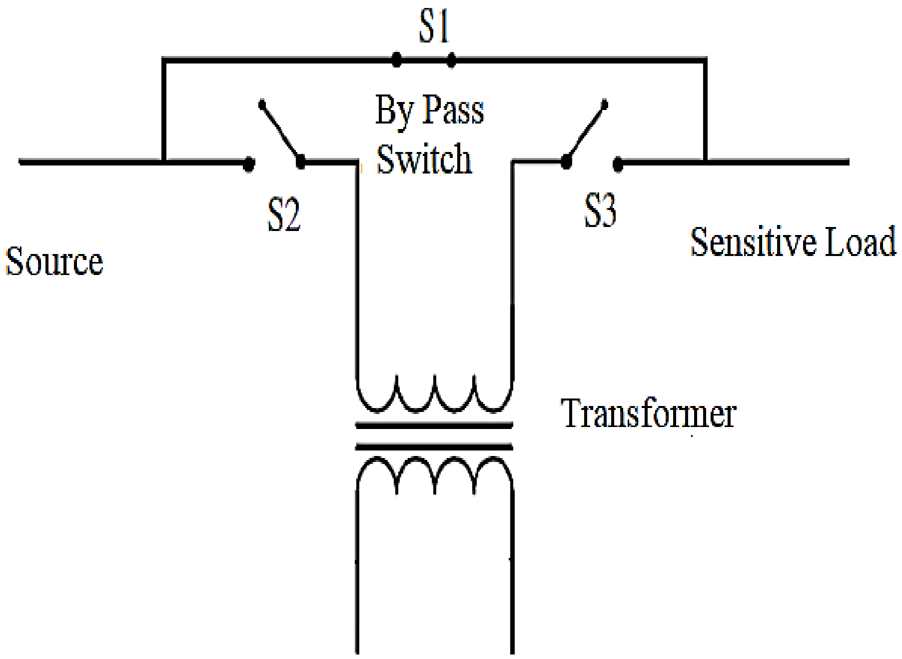

***Fig: 3.**1 Protection Mode [18]*

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Stand-by Mode: - In the standby mode, DVR does not inject any voltage into the system (V_{DVR} = 0) i.e. it can have two operations, one it can be short circuit and other, it can provide small injecting voltage for compensation of voltage difference due to reactance of transformer and their losses

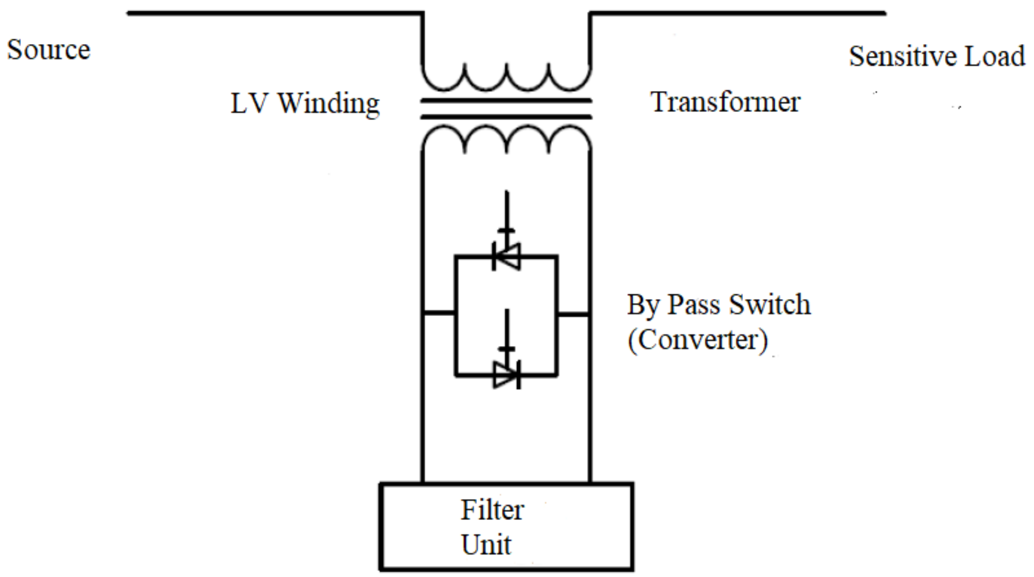

Fig: 3.2.*Standby Mode [18]*

Injection/Boost Mode: (V_{DVR} >0) –The compensating voltage is given into system when there is difference between supply and load side. The magnitude of injection voltage is decided by type of sag or loading conditions.

COMPENSATIONTECHNIQUES

The compensation method of DVR is a process of tracking the error or correcting voltage between the input side and the load side. Compensation techniques in DVR is required due to decrement in the magnitude of load voltage (i.e. sag), phase shift or distortion in wave shape of waveform [16]. The compensation depends upon rating of DVR, different loading conditions and magnitude of sag etc.

Pre-Sag Compensation–It is generally used for non-linear loads such as thyristorcontrolled drives. Voltage restores to its initial value by compensating the voltage error between the sagged and initialvalues well as the phase angle needs to be compensated. This technique needs a largefacilitypower device and voltage injection transformer [4]. It is shown in Fig. 4.1

In-phase Compensation - The load voltage and the compensated voltage having same phase in this technique. So only voltage magnitude compensation is required and there is no need of phase compensation [7]. It is shown in Fig.4.2

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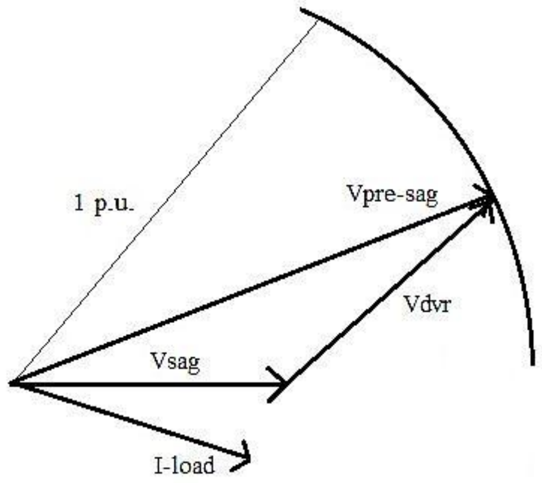

Fig: 4.1. *Pre Sag compensation [4]*

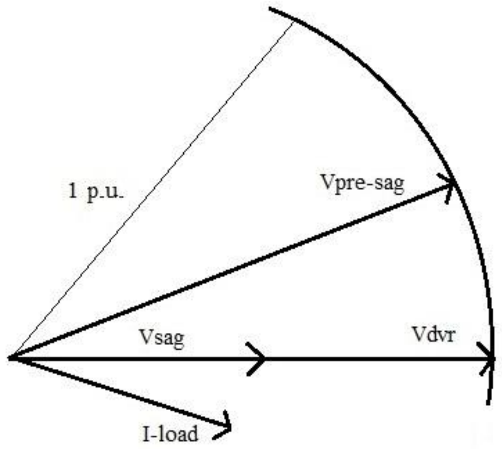

Fig.4.2. *In phase compensation[7]*

CONTROLOF DVR

Control scheme in the DVR system detects the sag events. Whenever sag occurs in the distribution system it detects the event and according to depth of sag value (i.e. 10%-90% of reference value) it generates the corresponding trigger pulse for the two level sinusoidal pulse width modulated based DC-AC converter. DVR terminates the switching pulse when the incident has finished and then the inverter generates the corresponding voltage magnitude in phase with the distribution system with the help of DC storage system used in the DVR unit.The output of voltage source inverter after passing through the filter section is given to injection/series transformer, which adds with the source voltage to maintain constant load voltage.

Controlling of DVR is done by the Park's transformation method which is also known as d-q-0 or direct-quadrature-zero transformation [6, 11].

$$\begin{bmatrix} V_d \\ V_q \\ V_o \end{bmatrix} = \begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & 1 \\ -\sin\theta & -\sin\left(\theta - \frac{2\pi}{3}\right) & 1 \\ 1/2 & 1/2 & 1 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} (5)$$

Equation (5) gives park's Transformation i.e. conversion from a-b-c system to d-q-0system. Inverse of equation is done to recover the actual voltages in three phases i.e. from d-q-0 frame to a-b-c reference frame.

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First of all convert the Supply voltage and reference voltage from a-b-c configuration to d-q-0 configuration by applying Park Transformation after which both are compared and again converted from d-q-0system to a-b-c system on applying Inverse park transformation and PLL is connected between supply voltage and converted a-b-c signal. It maintains a constant phase between both the signals and now this signal is used as triggering pulse for PWM inverter. Zero phase sequence from d-q-0 reference are ignored for simplicity.Flow chart of feed forward control technique for DVR based on d-q-0transformation is shown in the Fig.5

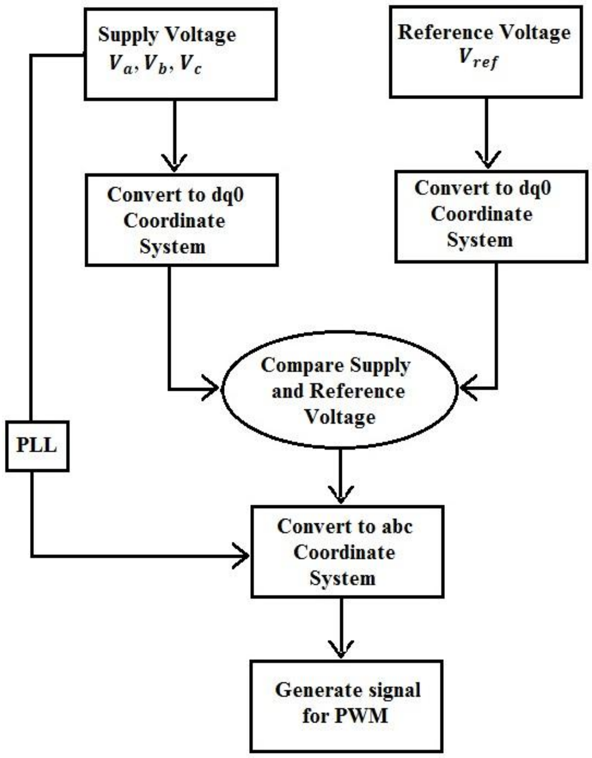

Fig: 5. *Flow chart of control scheme of DVR [11]*

SIMULATIONPARAMETERS AND RESULTS

This model is desinged for mitigation of voltage dip problems and their performance evalution is done by using THD of the load voltage, which is calculated using the Fast Fourier Transform analysis.Analysis of Voltage at load end after getting compensated at 1 p.u by using DVR is done in two ways. Firstly, DVR with filter section and Secondly DVR without filter section. THD of the load voltage for the above two is calculated after load voltage becomes constant at 1 p.u. value and percentage improvement in the THD value is also shown by using filter section. Analysis of the system performance at different sag values is performed to achieve the rated conditions forspecified load.

Table:1. *Simulation Parameters*

Parameters	**Values**
Input Voltage per phase	220 volts
Line Parameter	Ls =1mH Rs = **0.1 Ω**
Series transformer turns ratio	1:1

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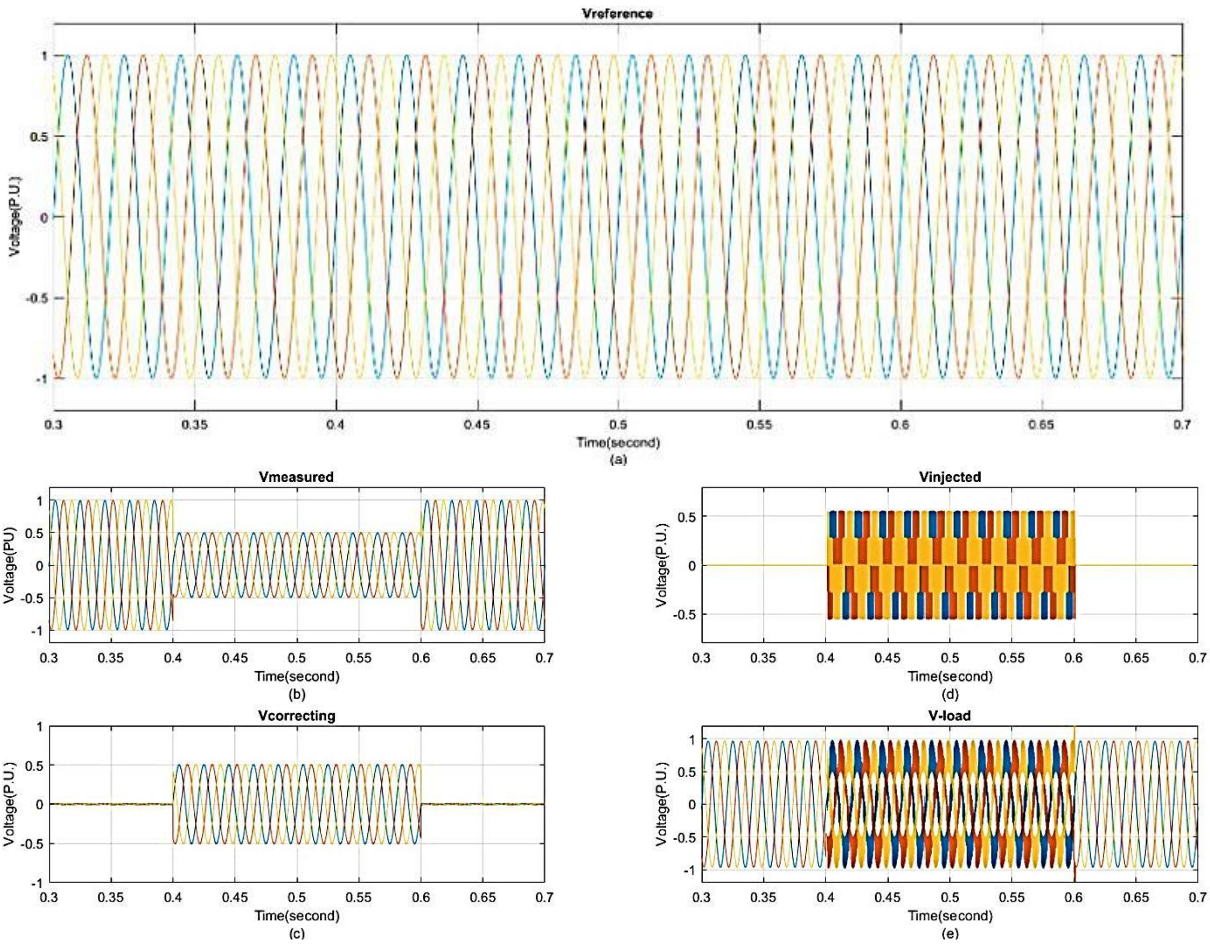
Parameters	Values
Converterparameters	Three arm IGBT based 6 pulse, Sample time-50 µs, carrier frequency-1000Hz
Filter Inductance	50 µH
Filter capacitance	1 µF
Load resistance	40 Ω
Load inductance	60mH
Frequency of Line	50Hz

Various cases of different sag values are considered to study the impact of DC storage on sag compensation.

Case.1: AMagnitude of 0.5 p.u. sag is generated and DVR model is simulated for 1 second. The changeover instance of sag is intended for 0.4 second to 0.6 second. Fig.6 shows the simulated results of DVR compensating technique.



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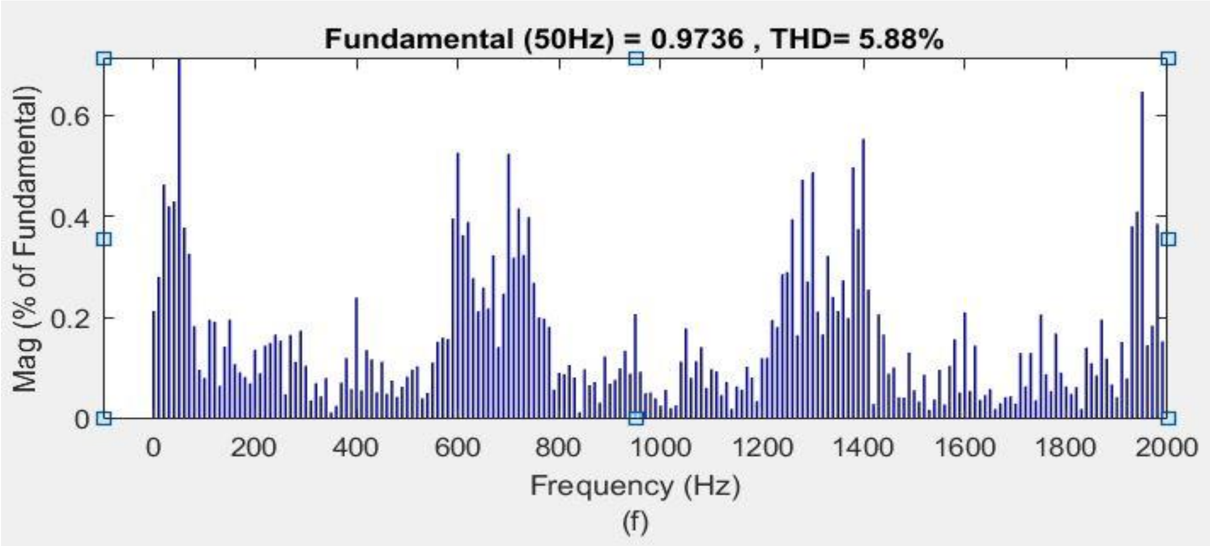

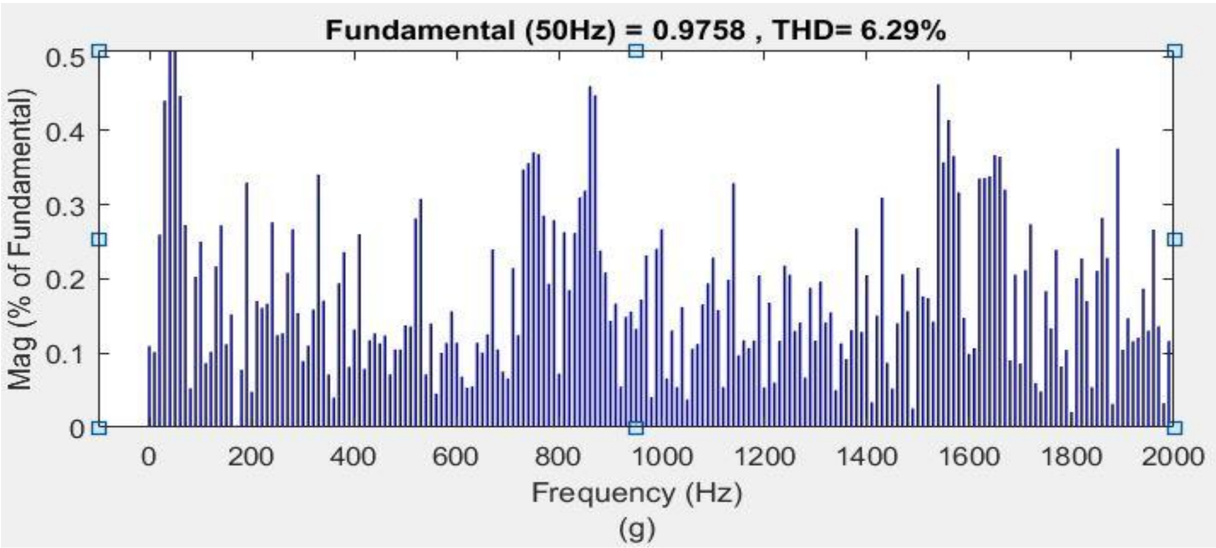

Fig: 6.*(a) The Reference Voltage, (b) Load voltage before compensation, (c) correcting voltage, (d) Injected voltage by DVR and (e) the load voltage after compensation (e). FFT analysis is done to calculate the Total Harmonic Distortion (THD) on Load side. Percentages of THD (f) with DVR with filter and(g) with DVR without Filter.*

Hence, the DVR has compensated 100V (actual value of voltage) and the Load voltage after compensation of 0.5p.u. or 50% comes out to be almost constant to its nominal value.

Case.2: A Magnitude of 0.4p.u. sag is generated and DVR model is simulated for 1 second. The changeover instance of sag is intended for 0.4 second to 0.6 second. Fig.7 shows the simulated results of DVR compensating technique.

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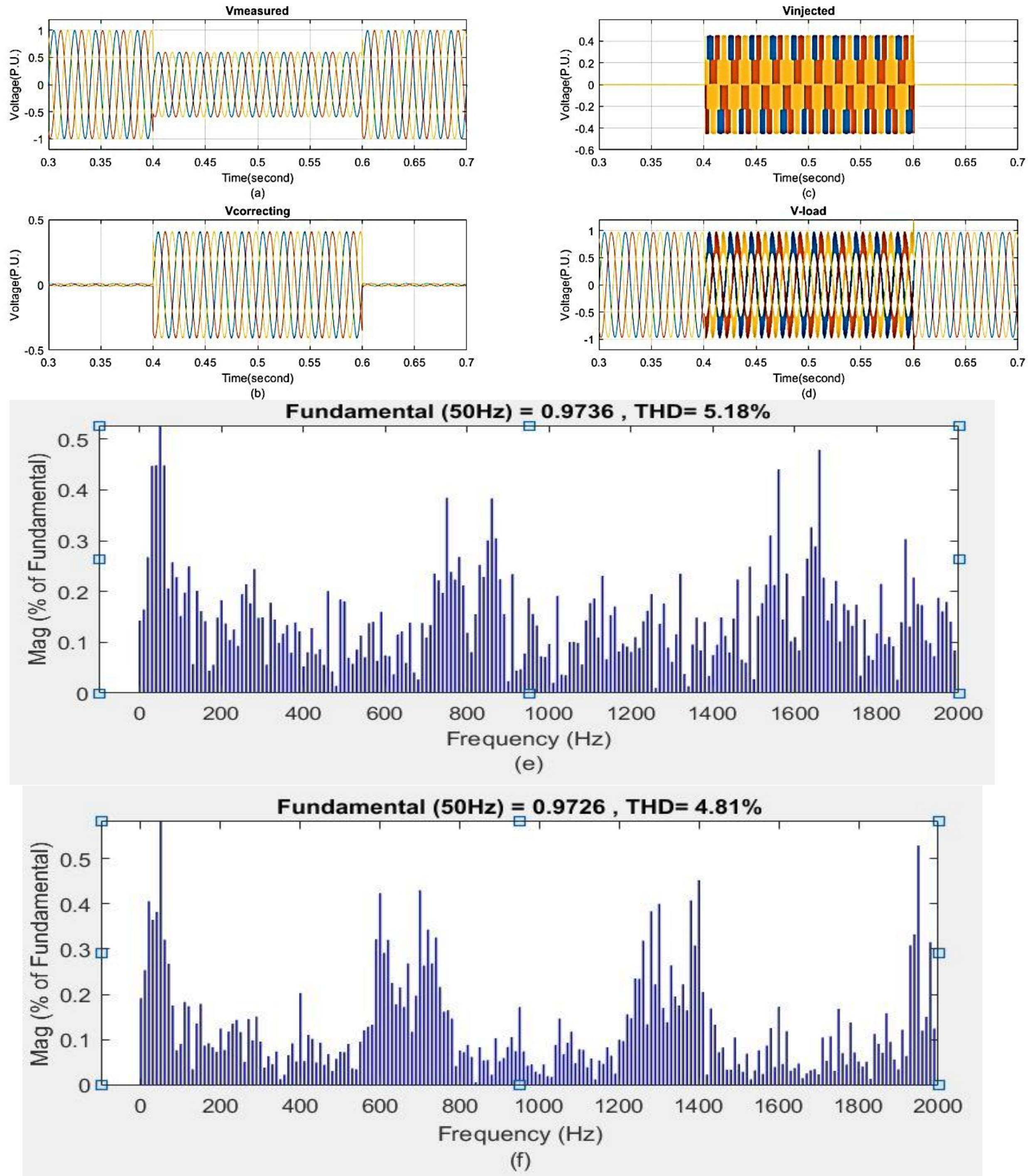

Fig: 7.*(a) Load voltage before compensation, (b) correcting voltage, (c) Injected voltage by DVR, (d) the load voltage after compensation. FFT analysis is done to calculate the Total Harmonic Distortion (THD) on Load side. Percentages of THD (e) with DVR without filterand (f) with DVR with Filter.*

It is observed that the DVR has compensated 80V (actual value of voltage) and the Load voltage after compensation of 0.4p.u. or 40% comes out to be almost constant to its nominal value.

Case.3:A Magnitude of 0.3 p.u. sag is generated and DVR model is simulated for 1 second. The changeover instance of sag is intended for 0.4 second to 0.6 second. Fig.8 shows the simulated results of DVR compensating technique.

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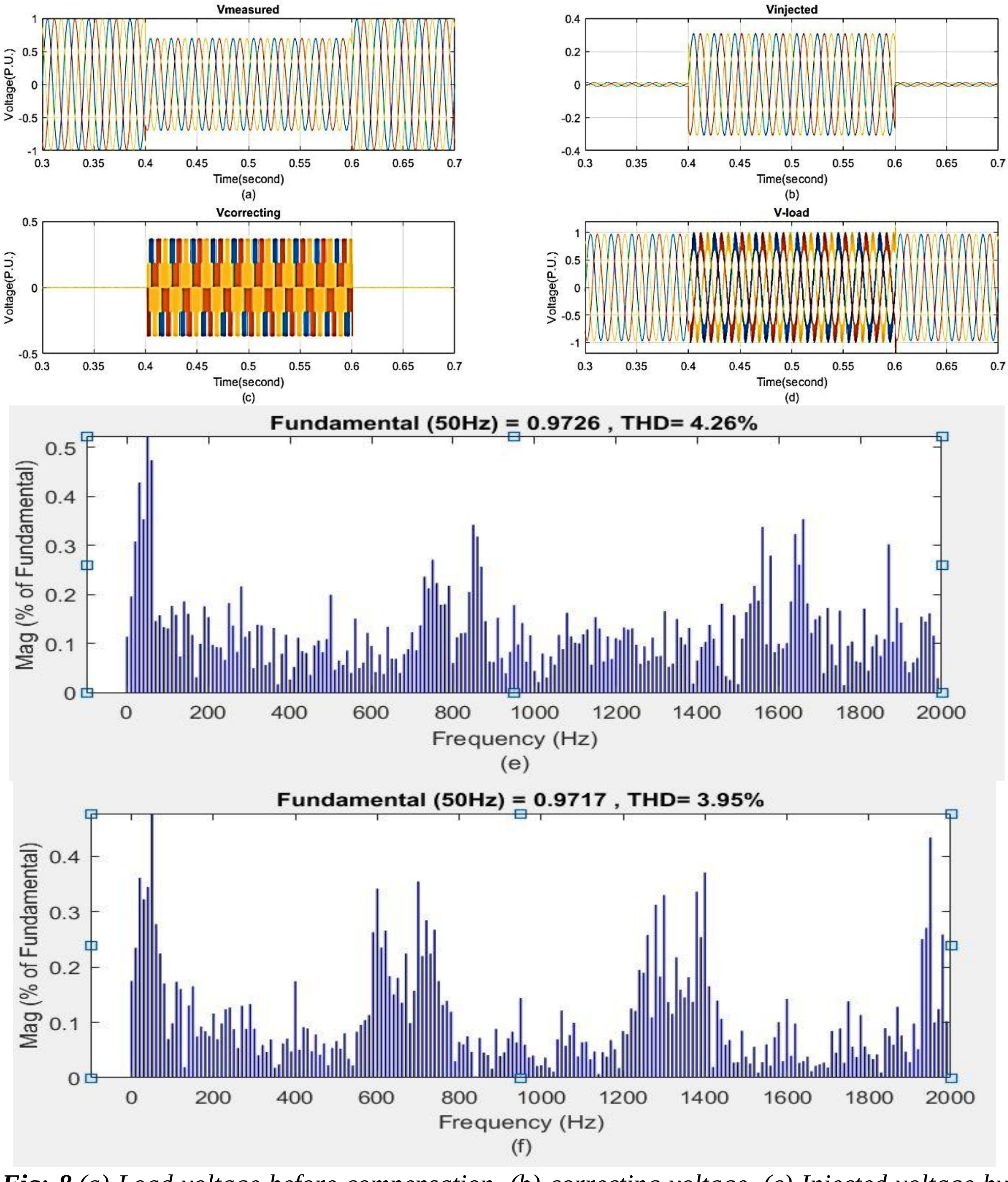

Fig: 8.*(a) Load voltage before compensation, (b) correcting voltage, (c) Injected voltage by DVR, (d) the load voltage after compensation. FFT analysis is done to calculate the Total Harmonic Distortion (THD) on Load side. Percentages of THD (e) with DVR without filter (f) with DVR with Filter.*

It can be seen that the DVR has compensated 60V (actual value of voltage) and the Load voltage after compensation of 0.3p.u. or 30% comes out to be almost constant to its nominal value.

Case.4: A Magnitude of 0.2 p.u. sag is generated and DVR model is simulated for 1 second. The changeoverinstanceof sag is intended for 0.4 second to 0.6 second. Fig.9 shows the simulated results of DVR compensating technique.

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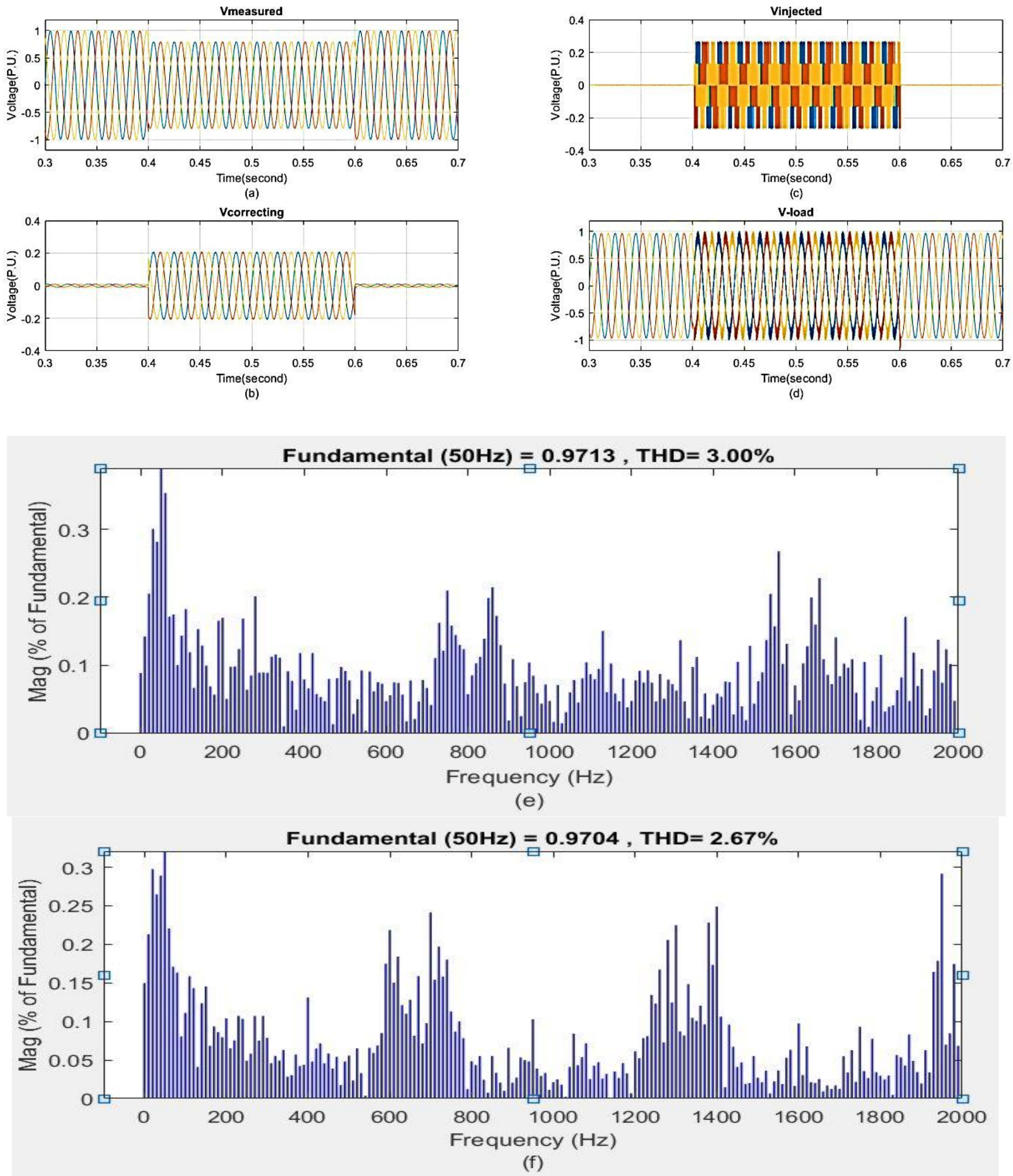

***Fig: 9.**(a) Load voltage before compensation, (b) correcting voltage, (c) Injected voltage by DVR, (d) the load voltage after compensation. FFT analysis is done to calculate the Total Harmonic Distortion (THD) on Load side. Percentages of THD (e) with DVR without filter (f) with DVR and with Filter.*

In this case, the DVR has compensated 20V (actual value of voltage) and the Load voltage after compensation of 0.2p.u. or 20% comes out to be almost constant to its nominal value.The DVR system is simulated at different sagged value and the results of simulation after compensation of the load parameters is shown. The load voltage after compensation comes out to be almost constant at their rated value. The THD analysis of the load voltage is shown in TABLE:II

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Table: 2. *Thd Anaylsis Of Load Voltage*

S. no.	Sag Value(p.u.)	THD of DVR system (in percent)		Improvementin THD using Filter(in percent)
		Without Filter	With Filter	
1.	0.5	6.29	5.88	06.21
2.	0.4	5.18	4.81	07.14
3.	0.3	4.26	3.95	07.27
4	0.2	3.00	2.67	11.00

From the above table, it can be stated that THD of the DVR system that is performed at load voltage, which is calculated using FFT analysis improves with filter arrangement. Hence, it can be concluded that on decreasing the sag percentage the THD of the system improves.

CONCLUSION

The DVR model is simulatedin MATLAB SIMULINK 2017(a) successfully. The load voltage of the distribution system after introducing sag from the source side gets compensated using DVR system and the load voltage becomes constant at their rated value i.e. 1p.u. according the system configuration. THD analysis of load voltage is done using FFT analysis in two ways i.e. with filter and without filter unit and percentage improvement in THD using filter unit is also shown.

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