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Dynamic Voltage restorer Application for Power Quality improvement in nonlinear load

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Abstract: *Voltage disturbances, particularly the voltage sag and swell are the most common power quality problems due to increased use of a large number of sophisticated and sensitive electronic equipment in industrial systems. To overcome this problem, custom power devices are used, it is a series connected power electronic based device such as Dynamic Voltage Restorer (DVR. This paper presents modeling, analysis and simulation of DVR in MATLAB SIMULINK with Feed forward and Feedback voltage controller. In this method DVR protects a sensitive load, to counter voltage sag under unbalanced loading conditions.*

Keywords: Dynamic Voltage Restorer (DVR), feed forward controller, Power Quality Pulse Width Modulation (PWM), Voltage Sag and swell.

Introduction

Uninterruptible Power Supplies (UPS), Dynamic Voltage Restorers (DVR) and Active Power Filters (APF) are examples of commonly used custom power devices [1-2]. Among those APF is used to mitigate harmonic problems occurring due to non-linear loading conditions, whereas DVR are used to compensate for voltage sag and surge conditions [3-5]. Voltage sag may occur from single phase to three phases [6-8].

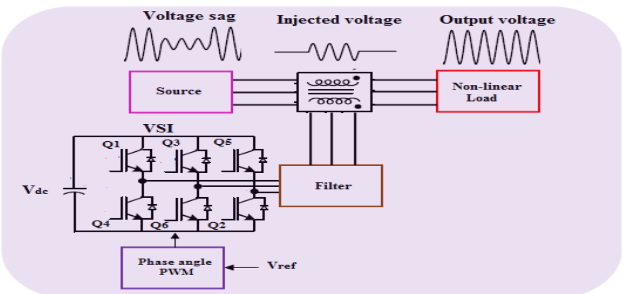

Figure 1Block diagram of the DVR

A DVR is connected between the supply and the load as shown in the Figure 1. Besides voltage sag compensation DVR also carry out other Functions. Such as line voltage harmonic compensation, reduction of transients in voltage and fault current limitation [9]. DVR is a solid state power electronic switching device which is associated in series to the power system. It comprises of the following components: Energy storage device, Voltage source Inverter, Injection transformer, and Control unit [10-11]. Thus, the industries that use single and three phase supply will undergo several interruptions during their production process and they are forced to use some form of voltage compensation equipment [12]. If active voltage is less prominent in DVR then it can be delivered to the load for maintaining stability[13-16].

1. DVR control

The section includes an analysis of the load voltage controllers, DC-link controllers and the synchronization and detection of voltage dips. Voltage control requires measurements and controllers to secure acceptable load voltages. The control must be robust to different disturbances from both the supply side and the load side. The disturbances could for example be non-symmetrical loads or non-symmetrical supply voltages. Various DVR voltage controllers have been tested and described in literature and. The two main voltage controllers, which have been proposed, are:

- Feed forward voltage controller
- Feedback voltage controller

Feed forward control is used in several papers, for instance in and. The principles of feed forward operation are illustrated in Figure. 2. The line above the variables indicates a three phase value represented as a space vector. From measurements of the supply voltages and the wanted load voltages the required injected DVR voltages can be calculated.

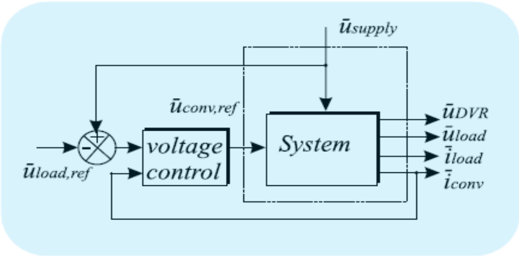

Figure 2Feed forward controller

2. DVR control

In the feedback control, either the load voltages or the DVR voltages are measured and used in a feedback loop. The method has the potential of a fast and more correct response, but the tuning of the voltage controllers is complex and depends on the connected load. Figure. 3 illustrate the principles in the feedback control with the load voltages used as feedback signals.

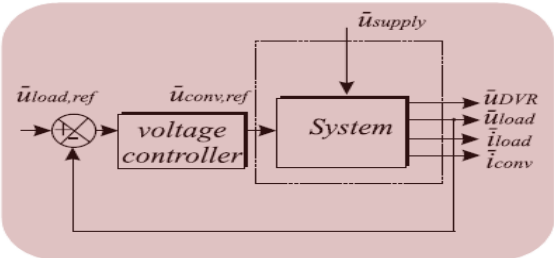

Figure 3Feedback control of the load voltage in a DVR

2.1 Feed forward controllers

In feed forward control the reference parameter is the wanted load voltages, $U_{LOAD\ \ REF}$and the error, $U_{SUPPLY,ERROR}$between actual supply voltage and reference load voltage must be injected by the DVR equation 1:

$$U_{LOAD} = U_{SUPPLY} - U_{DVR} \qquad (1)$$

A voltage drop in the line-filter and the injection transformer can be expected and this voltage drop, *drop* can also to some extend be compensated with a feed forward control before the DVR voltage is injected by equation 2:

$$U_{CONV,RE} = U_{SUPPLY\ ERROR} - U_{DROP} \qquad (2)$$

Only the stationary 50 Hz voltage drop is expected to be compensated. Feed forward control has been tested DVR without compensation of the line-filter voltage drop.

2.2 Feedback controllers

One method in the feedback control is to set a reference for the load voltage, $U_{REF}$and correct the error with a voltage controller flowing equation 3 and 4:

$$U_{LOAD\ ERROR} = U_{LOAD\ REF} - U_{DLOAD} \qquad (3)$$

$$U_{CONV\ REF} = -U_{LOADERROR\ CONV} \qquad (4)$$

With an infinite fast control and an infinite DVR rating the load voltage would be an ideal voltage and non-ideal supply voltages would be out compensated. With the load voltage used as reference to the controller tries to control the load voltage to a symmetrical and ideal voltage. An alternative method sets the load voltage as reference $U_{LOAD,\ REF}$calculates the wanted DVR voltage on the basis of the actual supply voltage and any deviation is going to be injected by the DVR, U_{DVR}

3 DC-link voltage controllers

So far the control of the AC voltages across the DVR has been analyzed. In this section different methods to control the DC-link voltage are further described. The DC-link voltage can to some degree is controlled by the series DVR converter. In the DVR converter is used to charge the DC-link and the attached batteries, but often the DC voltage is controlled by an externally DC-link charger. The load voltage is a summation of the supply and the DVR voltage equation 5:

$$U_{LOAD} = U_{SUPPY} \text{-} U_{DVR} \qquad (5)$$

The DVR voltage is equal to the generated converter voltage (U_{CONV}) subtractedLine-filter voltage drop equation 6

$$U_{LDV} = U_{SUCONV} - U_{LINE\ FILTER} \qquad (6)$$

To be able to charge the DC-link the injected converter voltage must include a charging voltage drop, which corresponds to a resistive voltage drop across the DVR. In order to control the load voltages to rated values the DVR can circulate reactive power. The ability to take active power from the grid and still maintain a rated load voltage depends on the grid strength, the supply voltage level, resistive and inductive voltage drop caused by the line-filter and finally the equation 7 apparent power absorbed by the load is:

$$U_{LLOAD} = U_{SUPY} + U_{CONV} - (Z_{LINE\ FI})\sqrt{3}I_{LC} \qquad (7)$$

A current has to flow to the load in order to be able to charge the DC-link and the charging voltage is always in-phase with the load current. During low load currents the charging voltage has to be increased to ensure a fast charging. In this condition the voltage drop across the line-filter, supply line etc. is also low and a higher charging voltage can be accepted.

4 SIMULATION RESULTS

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The performance analysis of the DVR system simulation model is carried out on non-linear load conditionsthe simulation model shown in Figure 4 and 5. The performance analysis presented in three cases. In case one, the supply voltage is undergoing voltage sag 0.05 seconds to 0.1 and swell during 0.15 to 0.2 with feed forward controller. In case two and three, it is discussed about DVR with and without harmonic diction sag and swell same duration of case one, it is discussed about DVR; in order to maintain a constant load voltage to a nominal THD value.

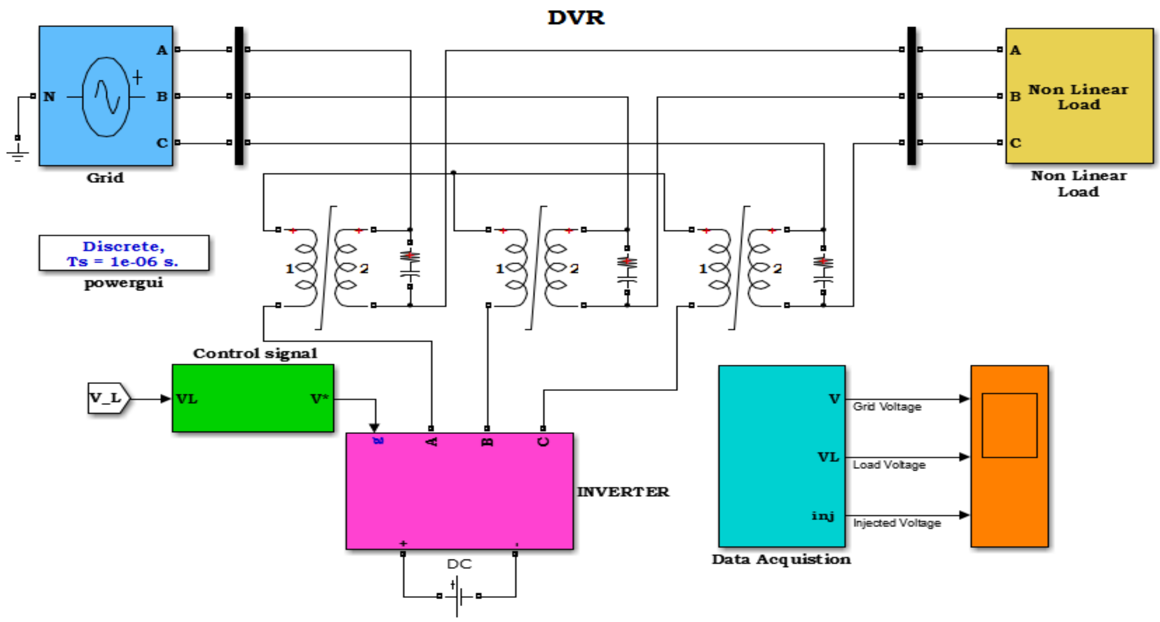


Figure 4Simulink Model of DVR

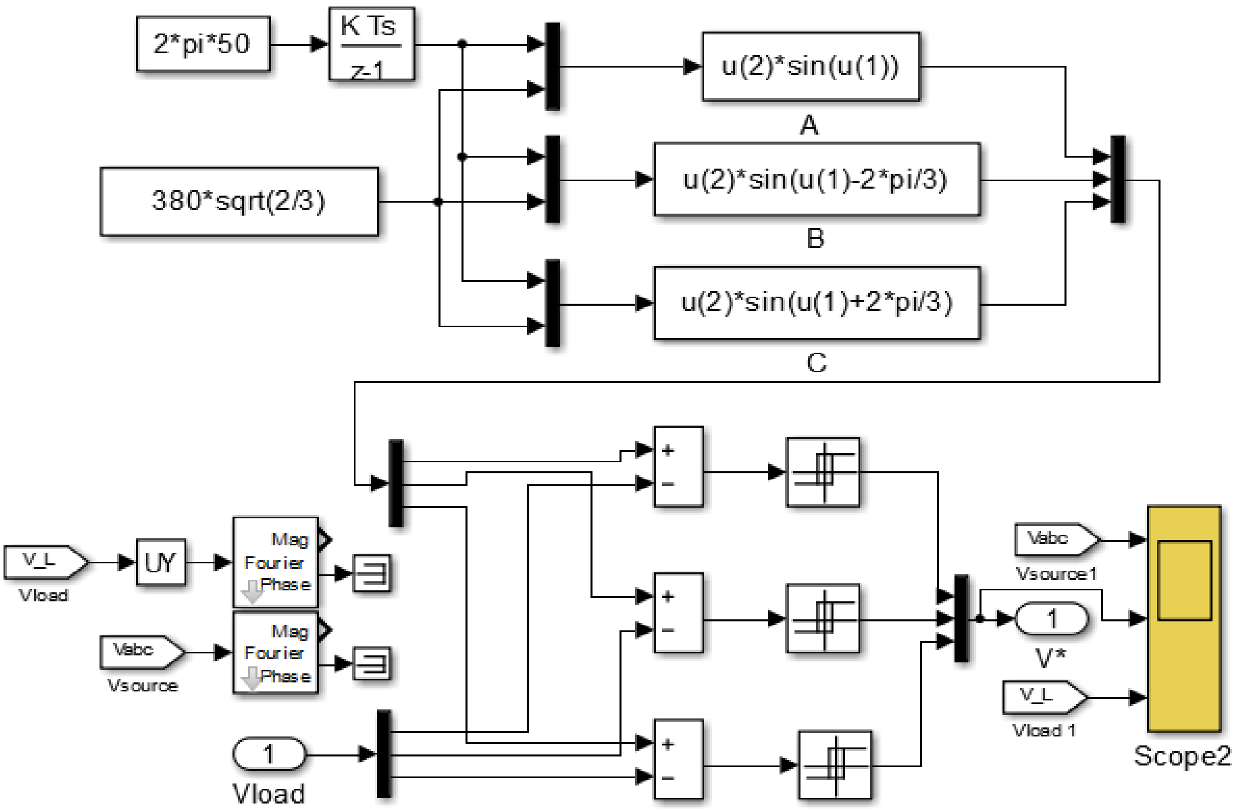


Figure 5Control Strategy Controllers

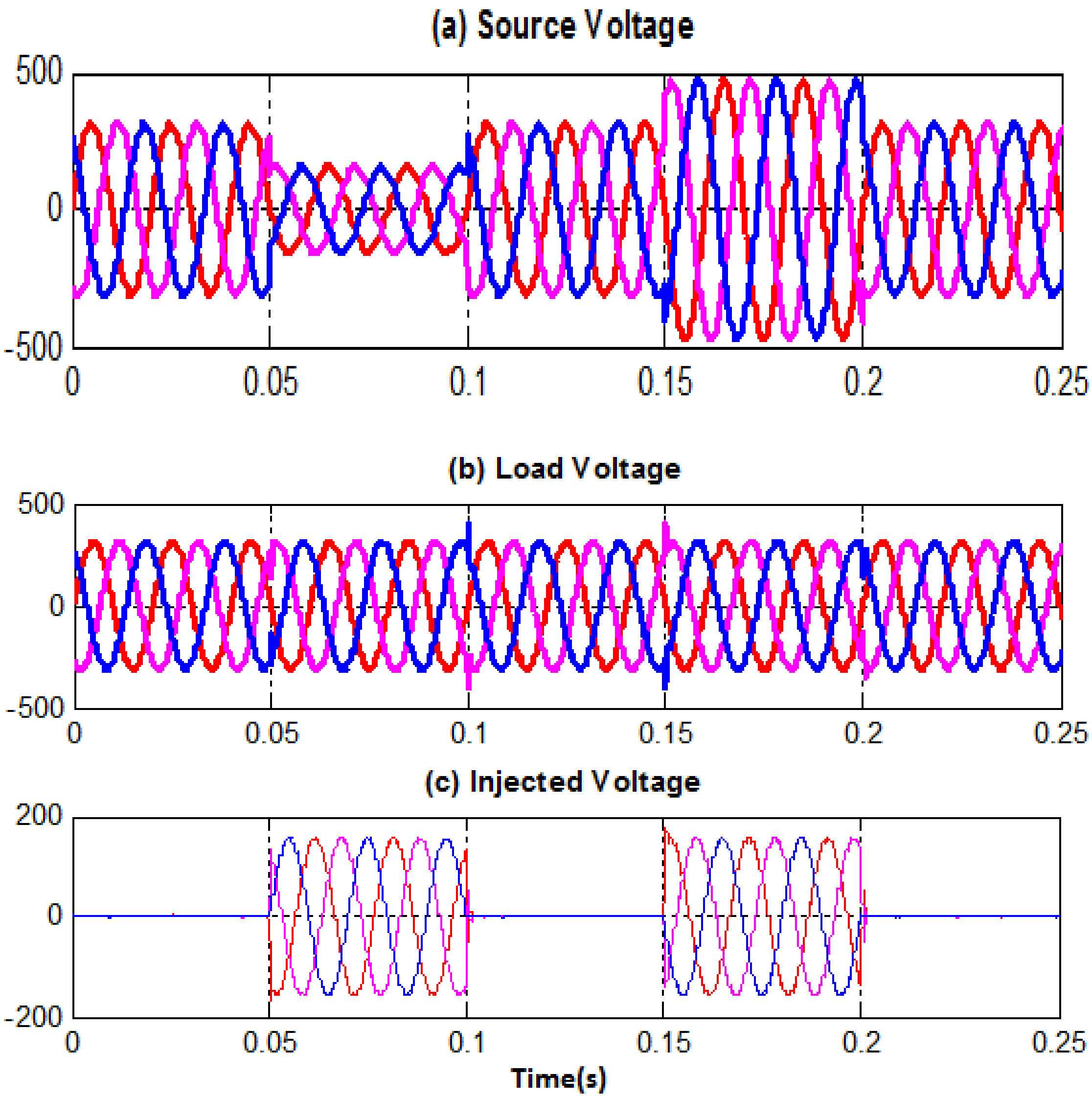


Figure 6 (a) Non-linear load with controlled DVR (b) source voltage,(b) Load voltage, (c) Injected voltage

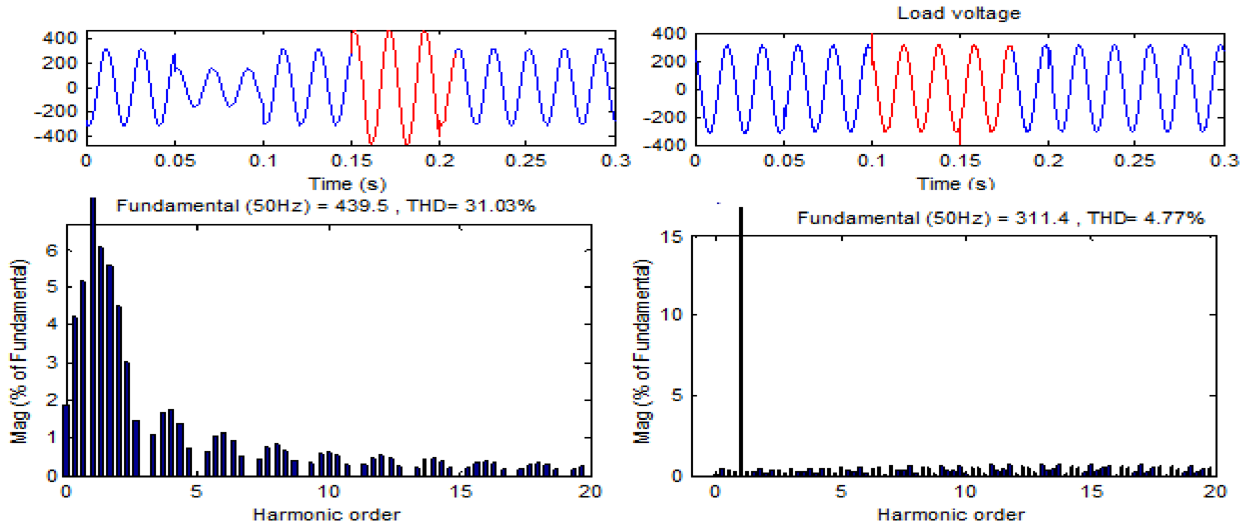
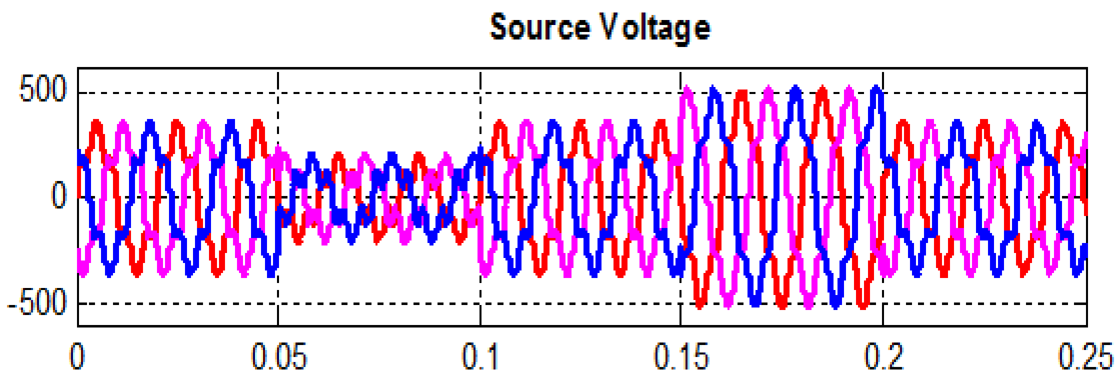
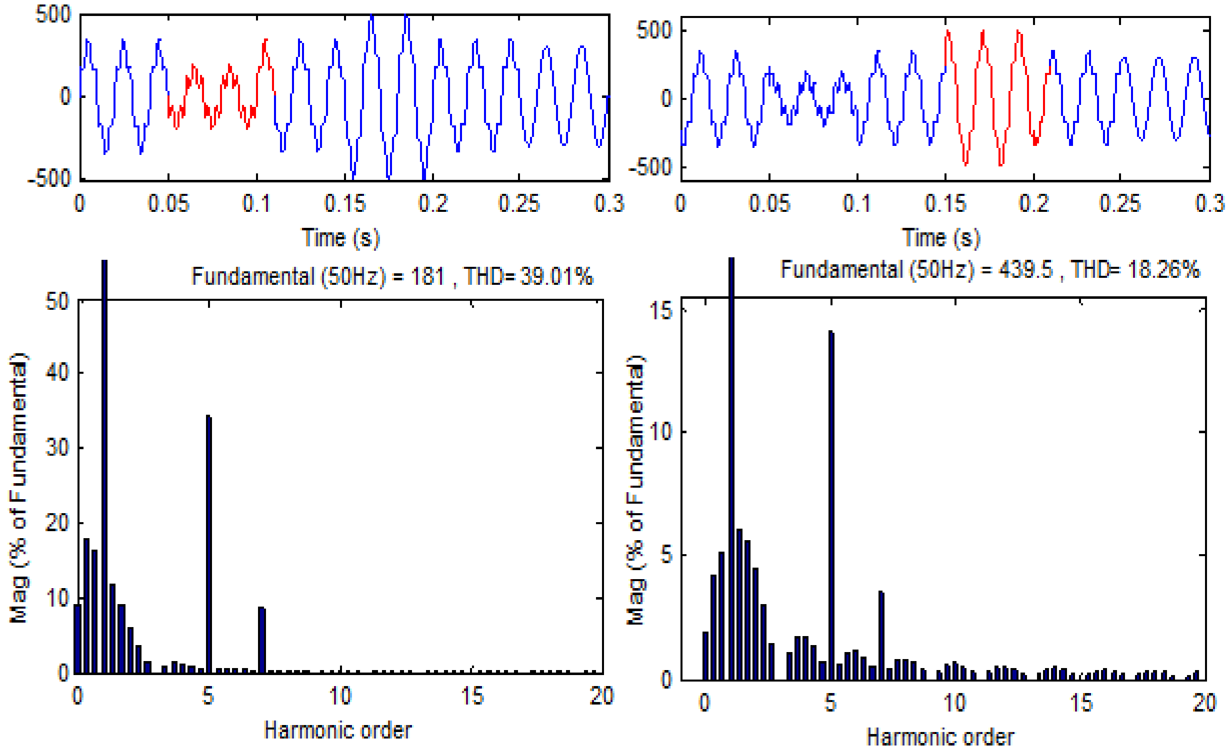


Figure 7 Feed forward controlled sag and swell harmonic spectrum





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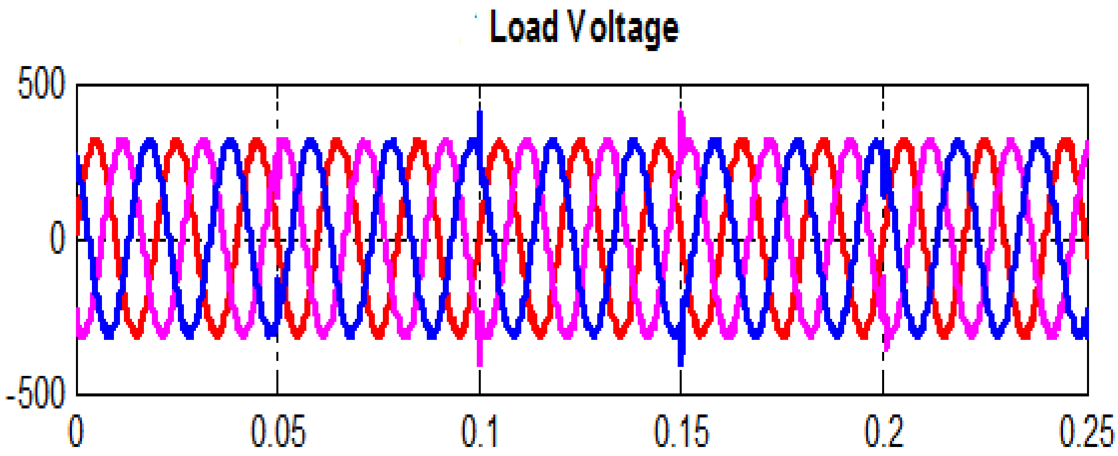

Figure 8 source voltage and sag and swell harmonic spectrum

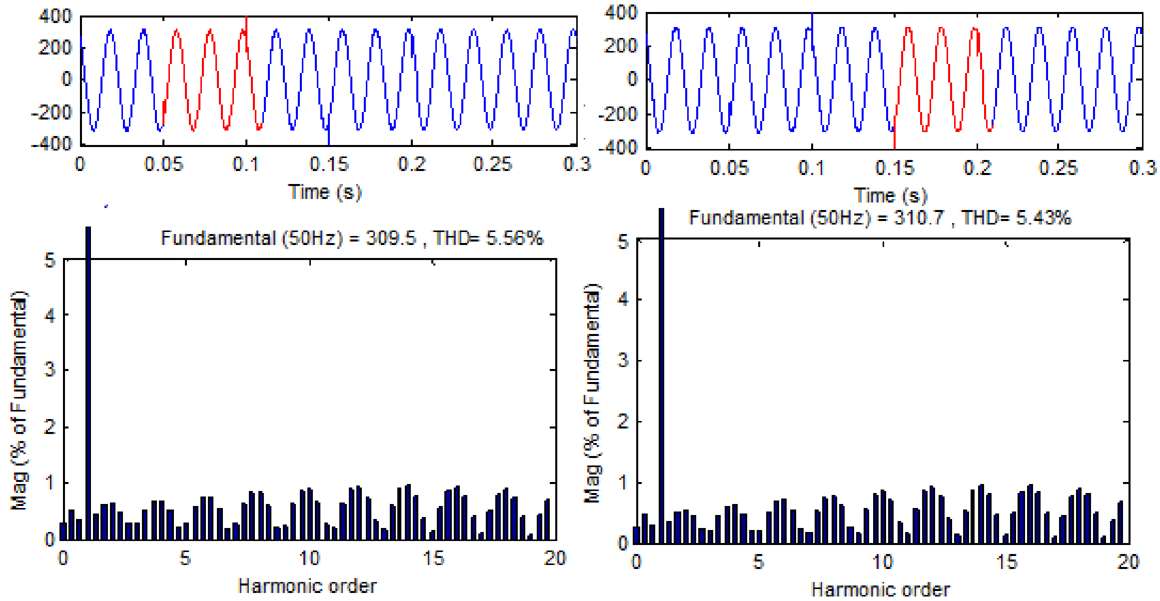

Figure 9load voltage, (a) sag (b) swell harmonic spectrum

Case 1: Feed forward controller

The electrical system performance analysis of non-linear load condition with feed forward compensation is shown in Figure 6 (a) to (c) source voltage, load voltage and injected voltage profile respectively. The THD value had shown in Figure 7 the source voltage and load voltage. The value of THD is 12.06% and 4.77% respectively.

Case 2: Feed backward controller with harmonic

The source voltage forthe three phases and its sag and swell harmonic spectrum shown in Figure 8.When the source voltage has voltage sag 0.05 seconds to 0.01 seconds and swell 0.15 second to 0.2 seconds. The sag and swell was occurred by introducing a heavy load into the system all of the sudden and since there is no DVR present in the system the sag is not compensated. Due to the non-linear load, the harmonics of the waveform is also high as 39.01% and swells 18.16% correspondingly.

The output voltage performance analysis of non-linear load condition with feedback controller for DVR is shown in the Figure.9. The load voltage for the three phases and its shows that the load voltage is maintained constant and the load voltage THD value of the sag and swell are 5.56% and 5.43% respectively shown in the harmonic spectrum analysis. At the load condition with the feedback controller for the DVR, The DVR can compensate the load voltage is kept at a constant value, regardless of voltage sag and swell in the source voltage magnitude. It is observed from the waveform, the harmonic Voltage is compensated and the source voltage is made sinusoidal.

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Table 1 Performance analysis

Description	Case 1THD%		Case THD%	
	Sag	Swell	Sag	Swell
Source Voltage	31.03	31.03	39.01	18.26
Load Voltage	4.77	4.77	5.56	5.46

The voltage waveforms are displayed with their respective THD spectrum. It is found that the both case voltage profile is improved results are tabled in Table 1. It is observed from the results, modified feedback controller gives better compared improved performance to feed forward controller.

5. CONCLUSION

The feed forward controller system shows a better efficiency both with harmonic and with harmonic distortion cases. Different control strategies have been treated, such as voltage quality optimized control, voltage amplitude optimized control and energy optimized control. The control methods have been discussed with respect to voltage quality, voltage injection, power drain of the energy storage and how it may the influence the connected load. The acceptable results for the proposed, system, summarized as follows. The proposed control system can compensate voltage sag and swell conditions. It is seen from the simulation result that the feed forward DVR conditioner has the better dynamic response and THD is less compared to conventional controller. Simulation results show the significant reduction of load voltage distortions, achieved by proposed controller.

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