IJCTA
Vol.8, No.1, Jan-June 2015, Pp.345-355

Control of Reduced-Rating DVR with a Lithium-Ion Battery Energy Storage System

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ABSTRACT

Now a days Voltage disturbances places a major role in power quality problems. In this paper voltage injection schemes for dynamic voltage restorers (DVRs) are analyzed with particular focus on Lithium-ion battery energy storage which is used to minimize the rating of the DVR. A novel control technique i.e SRF theory is proposed to control the DVR. The Lithium-ion battery energy storage system of VSC is demonstrated with a reduced-rating DVR. Both DVR with LI-BESS and with LI-BESS systems has been simulated and found that DVR with LI-BESS system gives the better results.

Keywords— DVR; LI-BESS; SRF; VSC;

1. INTRODUCTION

The solicitation of voltage-sensitive equipment, such as automatic production lines, computer centers, hospital equipment, programmable logic controllers (PLC), and adjustable speed drives (ASD), and air-conditioning controllers [1] has been increasing. Voltage sag is defined as the decrease in voltage RMS between 0.1 and 0.9 PU within 0.5 cycles to a few seconds. Swell is defined as an increase in nominal voltage between 1.1 and 1.8 PU during 0.5 cycles to 1 minute. Faults or large induction motors starting in the power system may cause voltage sags or swell. Consequently, other equipment may shut down. A solution for power quality improvement is to use custom power devices like a dynamic voltage restorer (DVR). External energy storage is necessary to provide the requirement for real power. Thus, the maximum amount of real power that can be provided to the load during voltage sag mitigation is a deciding factor of the capability of a DVR. However, the energy requirement cannot be met by the application of such phase advance technology alone to compensate the deep sag of long duration [2]. Custom power devices are mainly of three categories such as series-connected compensators known as dynamic voltage restorers (DVRs), shunt-connected compensators such as distribution static compensators, and a combination of series- and shunt-connected compensators known as unified power quality conditioner [2]–[6]. The DVR can regulate the load

Voltage from the problems such as sag, swell, and harmonics in the supply voltages. Hence, it can protect the critical consumer loads from tripping and consequent losses [2]. The custom power devices are developed and installed at consumer point to meet the power quality standards such as IEEE-519 [7].

Voltage sags in an electrical grid are not always possible to avoid because of the finite clearing time of the faults that cause the voltage sags and the propagation of sags from the

Transmission and distribution systems to the low-voltage loads. Voltage sags are the common reasons for interruption in production plants and for end-user equipment malfunctions in general. In particular, tripping of equipment in a production line can cause production interruption and significant costs due to loss of production. One solution to this problem is to make the equipment itself more tolerant to sags, either by intelligent control or by storing "ride-through" energy in the equipment. An alternative solution, instead of modifying each component in a plant to be tolerant against voltage sags, is to install a plant wide uninterruptible power supply system for longer power interruptions or a DVR on the incoming supply to mitigate voltage sags for shorter periods [8]–[23]. DVRs can eliminate most of the sags and minimize the risk of load tripping for very deep sags, but their main drawbacks are their standby losses, the equipment cost, and also the protection scheme required for downstream short circuits.

Many solutions and their problems using DVRs are reported, such as the voltages in a three-phase system are balanced [8] and an energy-optimized control of DVR is discussed in [10]. Industrial examples of DVRs are given in [11], and different control methods are analyzed for different types of voltage sags in [12]–[18]. A comparison of different topologies and control methods is presented for a DVR in [19]. The design of a capacitor-supported DVR that protects sag, swell, distortion, or unbalance in the supply voltages is discussed in [17]. The performance of a DVR with the high-frequency-link transformer is discussed in [24]. In this paper, the control and performance of a DVR are demonstrated with a reduced-rating voltage source converter (VSC). The synchronous reference frame (SRF) theory is used for the control of the DVR.

2. LITHIUM ION BATTERY

A lithium-ion battery is a rechargeable battery in which lithium ions move from the negative electrode to the positive electrode during discharge, and back when charging. Li-ion batteries use an intercalated lithium compound as the electrode material, compared to the metallic lithium used in the non-rechargeable lithium batteries.

A. Construction:

The three primary functional components of a lithium-ion battery are the negative electrode, positive electrode, and the electrolyte. The negative electrode of a conventional lithium-ion cell is made from carbon. The positive electrode is a metal oxide, and the electrolyte is a lithium salt in an organic solvent. The electrochemical roles of the electrodes change between anode and cathode, depending on the direction of current flow through the cell.

The most popularly used negative electrode material is graphite. The positive electrode is generally one of three materials: a layered oxide (such as lithium cobalt oxide), a polyion (such as lithium iron phosphate), or a spinel (such as lithium manganese oxide).

The electrolyte is typically a mixture of organic carbonates such as ethylene carbonate or diethyl carbonate containing complexes of lithium ions. These non-aqueous electrolytes generally use non-coordinating anion salts such as lithium hexafluorophosphate (LiPF6), lithium hexafluoroarsenate monohydrate (LiAsF6), lithium perchlorate (LiClO4), lithium tetrafluoroborate (LiBF4), and lithium triflate (LiCF3SO3).

Depending on materials choices, the voltage capacity, life, and safety of a lithium-ion battery can change dramatically. Pure lithium is very reactive. It reacts vigorously with water to form lithium hydroxide and hydrogen gas. Thus, a non-aqueous electrolyte is typically used, and a sealed container rigidly excludes water from the battery pack [4].

B. Characteristics

High Output performance with standard discharge of 2C to 5C and continuous discharge high current capacity of up to 10C and the instantaneous discharge pulse up to 20C. Good performance is observed at high temperatures from 65 to 95 degree centigrade keeping the battery in good safe condition.

It shows excellent life cycles as after 500 cycles also it shows discharge capacity to be above 95%. Even though during excessive discharge to zero volts there is no damage caused.

It gets quickly charged with very less time as compared to other batteries. Cost is not very high and hence can be used for variety of applications. It's also environmental friendly battery which does not produce any waste.

3. WORKING OF DVR

The schematic of a DVR-Connected system is shown in Fig. 1. The voltage V_{inj} is inserted such that the load voltage V_{load} is constant in magnitude and is undistorted, although the supply voltage Vs is not constant in magnitude or is distorted.

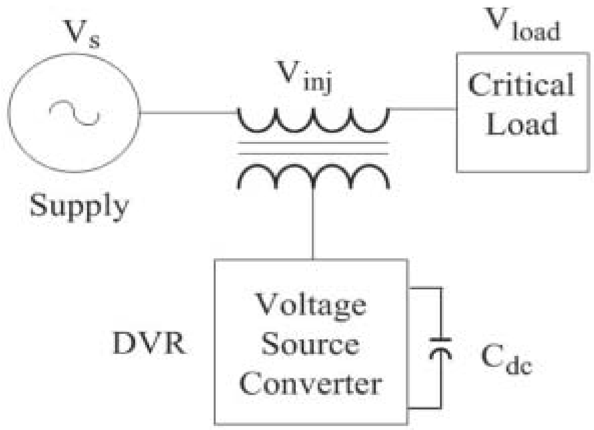

Fig. 1. Basic circuit of DVR.

Injection schemes of the DVR. V_L (pre−sag) is a voltage across the critical load prior to the voltage sag condition. During the Voltage sag, the voltage is reduced to Vs with a phase lag angle of θ. Now, the DVR injects a voltage such that the load voltage magnitude is maintained at the pre-sag condition.

The DVR is operated in this scheme with a Lithium-Ion battery energy storage system (LI-BESS). Fig. 2 shows a schematic of a three-phase DVR connected to restore the voltage of a three-phase critical load. A three-phase supply is connected to a critical and sensitive load through a three-phase series injection transformer. The equivalent voltage of the supply of phase a V_{Ma} is connected to the point of common coupling (PCC) V_{Sa} through short-circuit impedance Z_{sa}. The voltage injected by the DVR in phase a V_{Ca} is such that the load voltage V_{La} is of rated magnitude and undistorted. The three-phase DVR is connected to the line to inject a voltage in series using three single-phase transformers Tr. L_r and C_r represent the filter components used to filter the ripples in the injected voltage. A three-leg VSC with Insulated-Gate Bipolar Transistors (IGBTs) is used as a DVR, and a LI-BESS is connected to its DC bus.

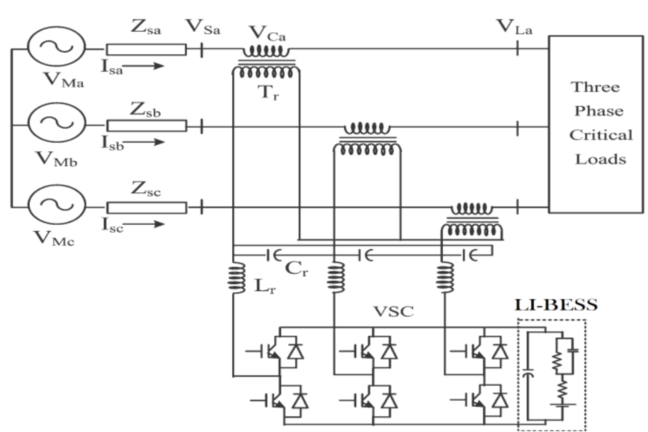

Fig.2. Schematic of the DVR-connected system

The compensation for voltage sags using a DVR can be performed by injecting or absorbing the reactive power or the real power [17]. When the injected voltage is in quadrature with the current at the fundamental frequency, the compensation is made by injecting reactive power and the DVR is with a self-supported dc bus. However, if the injected voltage is in- phase with the current, DVR injects real power, and hence, a Lithium-ion battery is required at the dc bus of the VSC. The control technique adopted should consider the limitations such as the voltage injection capability (converter and transformer rating) and optimization of the size of energy storage.

Fig. 3 shows a control block of the DVR in which the SRF theory is used for reference signal estimation. The voltages at the PCC V_S and at the load terminal V_{La} are sensed for deriving the IGBTs' gate signals. The reference load voltage V^* is extracted using the derived unit vector [23]. Load volt- ages (V_{La} , V_{Lb} , V_{Lc}) are converted to the rotating reference frame using abc−dqo conversion using Park's transformation with unit vectors (sin, θ, cos, θ) derived using a phase-locked loops.

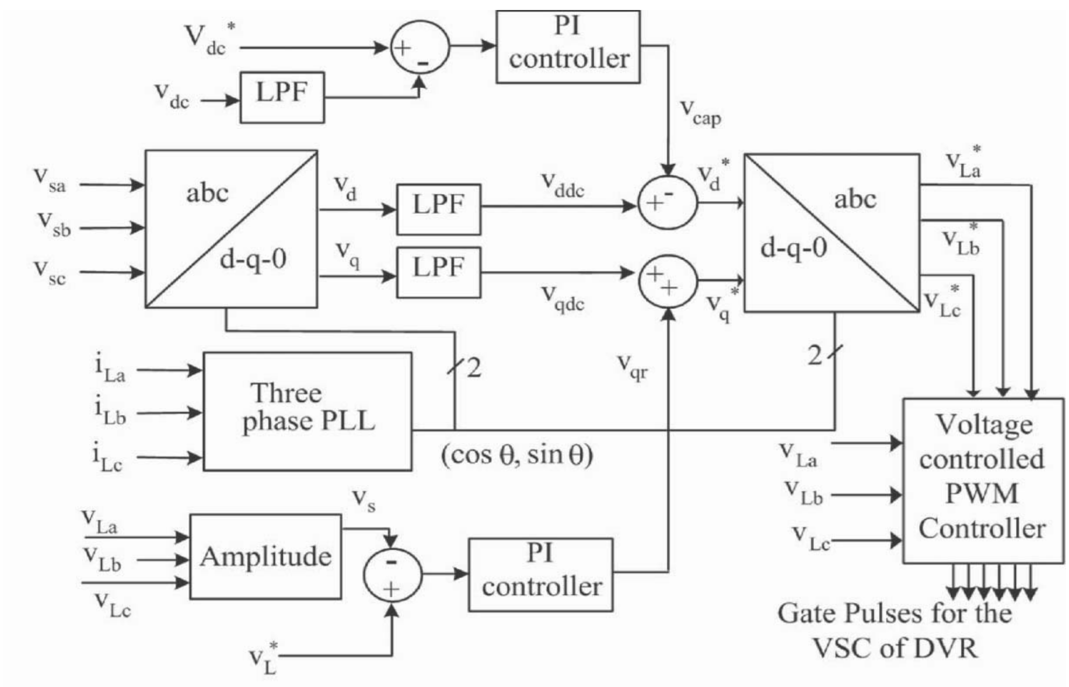

Fig. 3. Control block of the DVR that uses the SRF method of control

4. SIMULATION AND MODELING

A. Modeling of LI-BESS:

The Li-ion batteries are getting enormous attention as power sources and energy storage devices in Renewable energy system. The LI-BESS will naturally maintain dc capacitor voltage constant and is best suitedVSC since it rapidly injects or absorbed reactive power to stabilize the grid system. It also controls the distribution and transmission system in a very fast rate. When power fluctuation occurs in the system, the LI-BESS can be used to level the power fluctuation by charging and discharging operation. The battery is connected in parallel to the dc capacitor.

The equivalent circuit model of the Li-ion battery is shown in Fig: 4

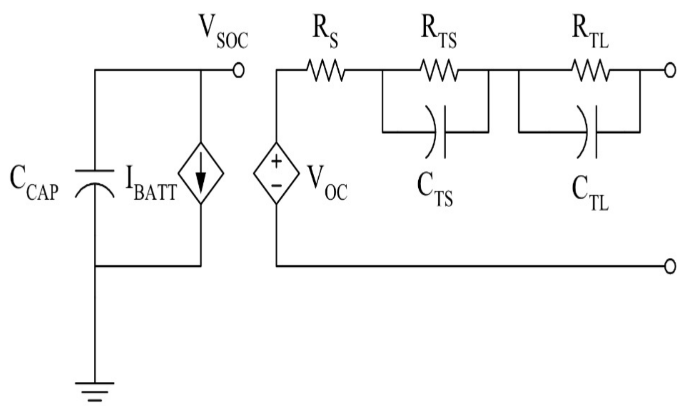

Fig: 4 Model of LI-BESS

The ordinary differential equation for the Li-ion battery is shown as

(1)

(2)

The equation describes the circuit diagram above, where

1. R_{TS} and C_{TS} are the resistance and capacitance in the shorter time constant RC circuit,
2. R_{TL} and C_{TL} are the resistance and capacitance in the longer time constant RC circuit,
3. C_{CAP} represents the overall capacitance of the battery,
4. RS is the series resistance, and
5. $g(\mathbf{x})$ is the non-linear function which maps V_{SOC} to V_{OC}.
6. The state vector **x** represents the voltages across C_{CAP}, C_{TS}, and C_{TL}.
7. The input **u** is the current entering the battery, and
8. The output **y** is the voltage across the battery terminals

These R_{TS} , C_{TS} , R_{TL} and C_{TL} are calculated for the Nano Scaled Battery

B. Simulink of LI-BESS based DVR:

The LI-BESS based DVR connected system consisting of a three-phase supply, three-phase critical loads, and the series injection transformers shown in Fig. 5 is simulated as follows.

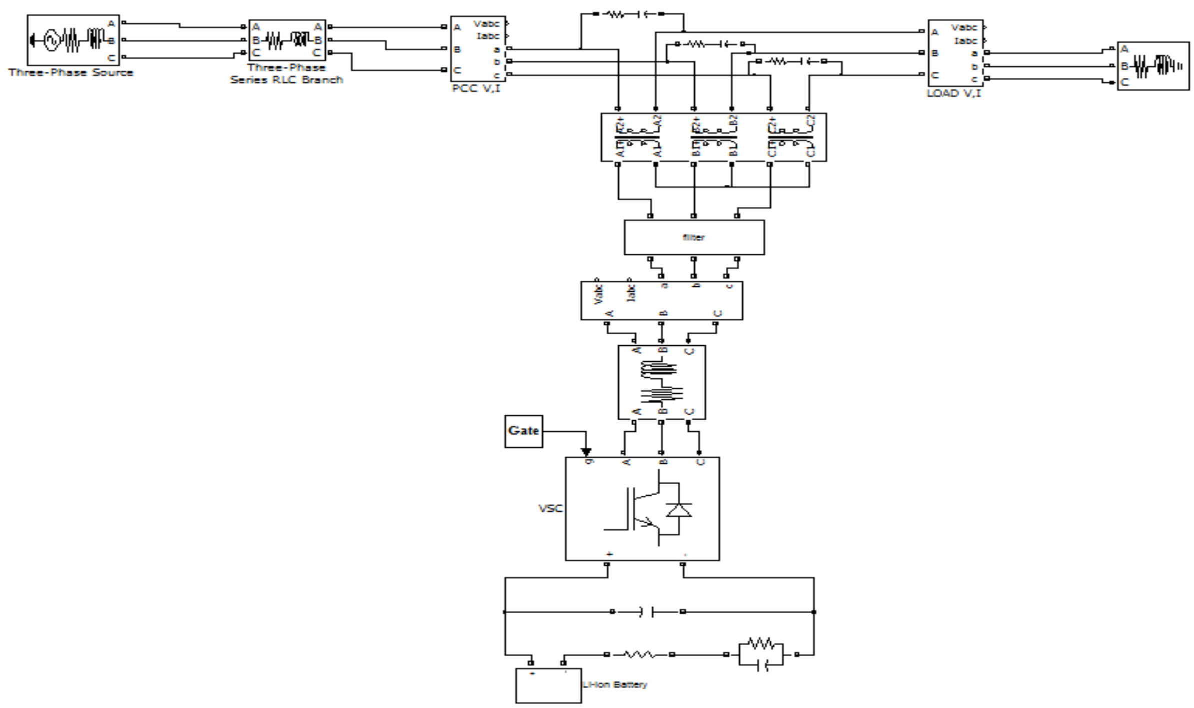

Fig. 5. MATLAB-based model of the LI-BESS based DVR-connected system

5. PERFORMANCE OF LI-BESS DVR

The performance of the LI-BESS based DVR is demonstrated for supply voltage disturbances i.e voltage sag. At 0.3 s, a sag in supply voltage is created, and at 0.6 s, it is removed. In this paper simulation results for both with and without LI-BESS based DVR has been presented

The magnitudes of voltage injected by DVR with LI-BESS and without LI-BESS has been noted. The performance of DVR has been observed.

Case:1 DVR with out LI-BESS system.

In this case performance of the DVR has been observed without LI-BESS, a voltage disturbance i.e voltage sag has been created at 0.3s and removed at 0.6s. Here the DVR injected voltage magnitude is 200V, at the same time load side harmonics also calculated using FFT analysis it is found that the THD % is 1.80.

The performances of DVR and FFT analysis has been shown in the Fig: 6, Fig: 7, respectively.

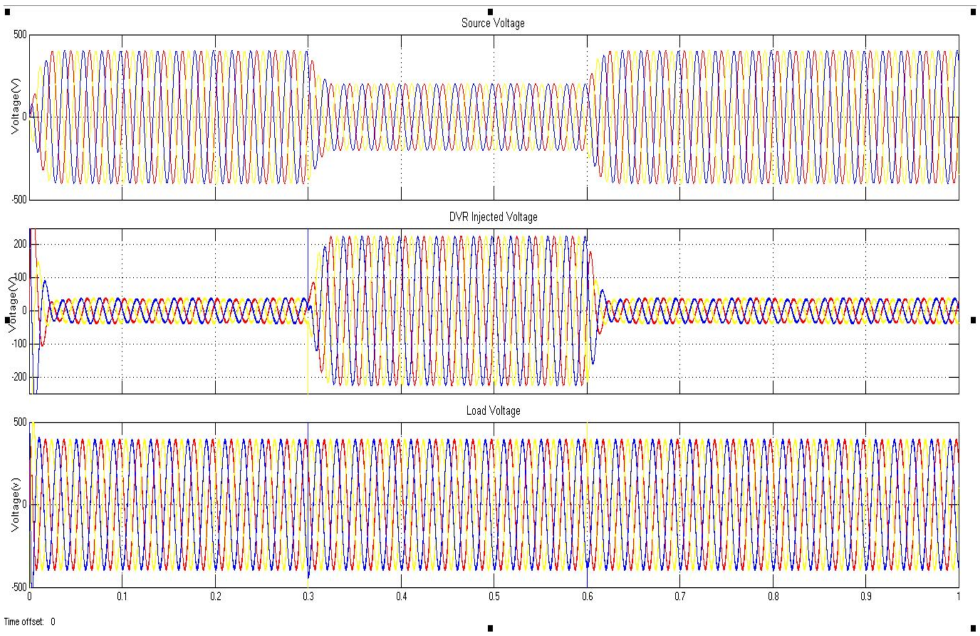

Fig. 6. Performance of the DVR without LI-BESS

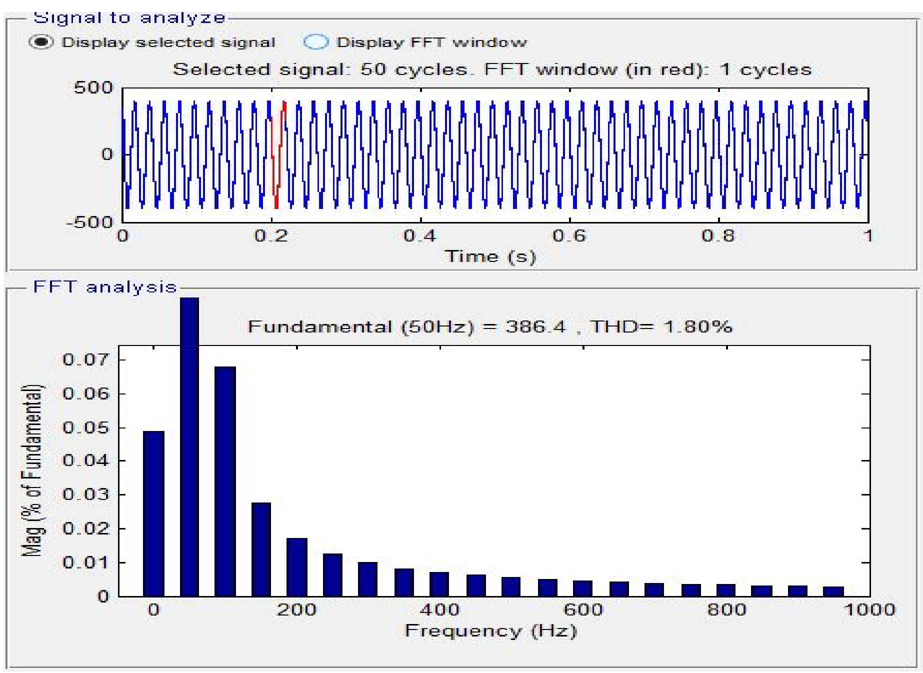

Fig. 7. THD analysis of DVR without LI-BESS

Case:2 DVR with LI-BESS system.

In this case performance of the DVR has been observed with LI-BESS, a voltage disturbance i.e voltage sag has been created at 0.3s and removed at 0.6s. Here the DVR injected voltage magnitude is 100V, at the same time load side harmonics also calculated using FFT analysis it is found that the THD % is 0.45.

The performances of DVR and FFT analysis has been shown in the Fig: 8, Fig: 9, respectively.

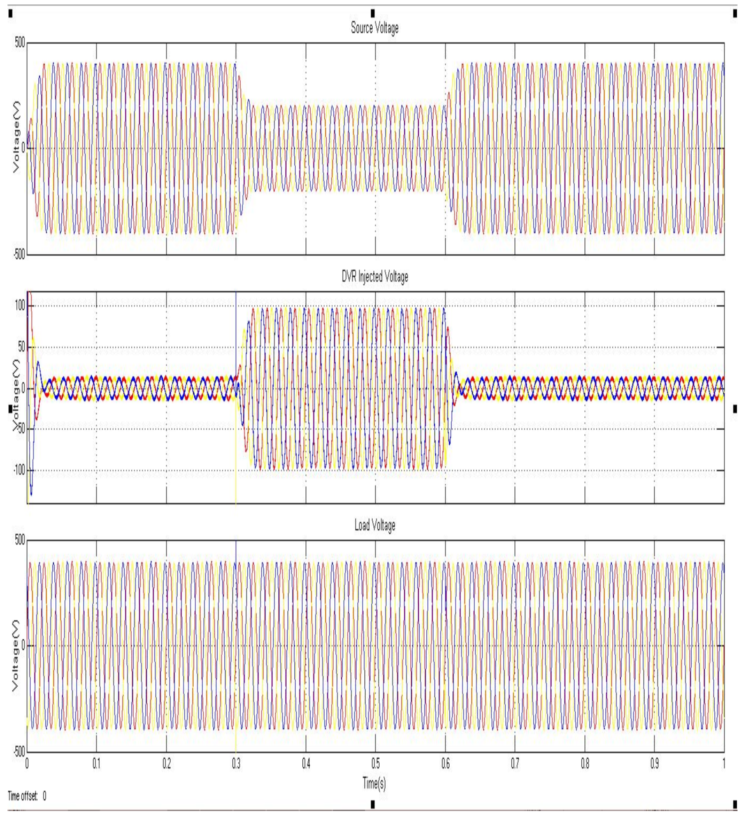

Fig. 8. Performance of the DVR with LI-BESS

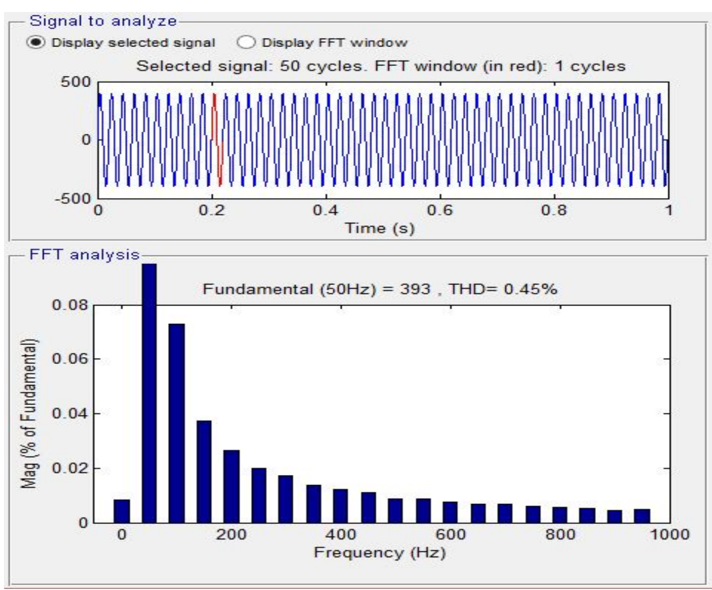

Fig. 9. THD analysis of DVR with LI-BESS

From the above analysis it is found that the DVR injected voltage has reduced form 200V to 100V.

6. CONCLUSION

In this paper DVR with LI-BESS and DVR without LI-BESS has been presented. The simulation results clearly shows that the DVR Voltage injected magnitude has been reduced from 200V to 100V hence the rating of the DVR has been reduced by LI-BESS system. Also power quality has been improved i.e THD reduced form 1.80% to 0.45%.

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