Mitigation of Power Quality Problems using SRF For Controlling DVR

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Abstract-This project enhances the protection of the sensitive nonlinear loads from Power Quality problems like sag, swell, harmonics etc. A Dynamic voltage restorer (DVR) is one of the custom power devices which are connected in series between the supply and critical loads. Different control techniques are used for the generation of compensating voltages for controlling the dynamic voltage restorer (DVR). In this paper, a Synchronous Reference Frame Theory (SRF) based self-supported DVR has been proposed. It maintains the balanced sinusoidal load voltage with desired magnitude against any power quality problems like voltage sag, swell harmonics etc. Simulation are analyzed for different operating conditions and carried out through MATLAB\SIMULINK environment.

Keywords: Dynamic voltage restorer(DVR), hysteresis band controller, nonlinear loads, voltage source converter(VSC).

I. INTRODUCTION

The recent growth in the use of power electronics has caused a greater awareness on power quality. It is an occurrence of voltage, current and frequency deviations resulting in equipment overheating, damage devices and EMI related problems. Most of the PQ issues are closely related with power electronics in almost every aspect of commercial, domestic, and industrial application. Equipment using power electronic devices are residential appliances like TVs, PCs etc., business and office equipment like copiers, printers etc. industrial equipment like programmable logic controllers (PLCs), adjustable speed drives (ASDs), rectifiers, inverters, CNC tools and so on. All kinds of power quality variations can cause problems with sensitive loads. Categories for these variations can be designed in a consistent manner and thereby information can be shared between different groups performing measurements and evaluations. Power quality variations fall into two basic categories.

Disturbances: Disturbances are measured by triggering on an abnormality in the voltage or the current. Transient voltages may be detected when the peak magnitude exceeds a specified threshold value. RMS voltage variations (e.g. sags or interruptions) may be detected when the RMS variation exceeds a specified level.

Steady state variations: These include normal RMS voltage variations and harmonic distortion. These variations must be measured by sampling the voltage and/or current over time. The information is presented as a trend of the quantity (e.g. voltage distortion) over time and then analyzed using statistical methods.

Non-linear loads: The current of the AC loads is not proportional to the voltage are considered as nonlinear Loads. The Nonlinear loads generate harmonics in the current waveform that leads to distortion of the voltage waveform; under these conditions the voltage is no longer proportional to the current. From the domestic installations to the largest industries, electricity supplies with the pure sine waves are almost a thing of the past. The continued proliferation of non-linear devices, from PC's and rectifier, induction motors are found be the major contribution of non-linear loads in the power network. The proportion of non-linear loads are the biggest contributor of non-linearity in the power converter fed loads *via* variable-speed AC drives, chopper fed drives, etc. Therefore, it is essential to look into the problems that are created by these non-linear loads.

Problems due to non-linear loads: The first and fore most consequence of any non-linear load is *harmonics.* "Harmonics" means a component with a frequency that is an integer multiple (where n is the order of harmonic) of the fundamental frequency; the first harmonic is the fundamental frequency (50 or 60 Hz). The second harmonic is the component with frequency two times the fundamental (100 or 120 Hz) and so on. In this chapter more emphasis is given for the study about harmonics and its problems, that too particularly due to the power converters. Since, power converters take responsibility for forming the majority of the nonlinear loads connected to the power network. There are mainly two ways for controlling the harmonic levels in the power system. They are

a. End users must limit the harmonic currents injected onto the power system.

b. The power supplier will control the harmonic voltage distortion by making sure system resonant conditions do not cause excessive magnification of the harmonic levels.

Solutions to the power quality problems: There are two approaches for the mitigation of power quality problems. The solution to the power quality problem can be done from the customer side or from the utility side first approach is called load conditioning, which ensures that the equipment is less sensitive to power disturbances, allowing the operation even under significant voltage distortion. The other solution is to install the line conditioning systems that suppress or counteracts the power system disturbances. Currently, they are based on PWM converters and connect to low and medium voltage distribution system in shunt or in series. The power quality problems (sags, swells, harmonics…) voltage sags are the most severe disturbances. In order to overcome these problems the concept of custom power devices is introduced recently. One of those devices is the Dynamic Voltage Restorer (DVR), which is the most efficient and effective modern custom power device used in power distribution networks. The function of the DVR will inject the missing voltage in order to regulate the load voltage from any disturbance due to immediate distort of source voltage. The synchronous reference frame theory based DVR inject compensating voltage.

II. DYNAMIC VOLTAGE RESTORER

Basic Functioning of DVR: The first DVR was installed in North America in 1996 - a 12.47 kV system located in Anderson, South Carolina. Since then, DVRs have been applied to protect critical loads in utilities, semiconductor and food processing. Today, the dynamic voltage restorer is one of the most effective PQ devices in solving voltage sag, swell, and harmonics problems. DVR (Dynamic Voltage Restorer) is a static var device that has seen applications in a variety of transmission and distribution systems. It is a series compensation device, which protects sensitive electric load from power quality problems such as voltage sags, swells, unbalance and distortion through power electronic controllers that use voltage source converters (VSC). Among the power quality problems (sags, swells, harmonics…) voltage sags are the most severe disturbances. In order to overcome these problems the concept of custom power devices is introduced recently. One of those devices is the Dynamic Voltage Restorer (DVR), which is the most efficient and effective modern custom power device used in power distribution networks. The function of the DVR will inject the missing voltage in order to regulate the load voltage from any disturbance due to immediate distort of source voltage. The schematic diagram of dynamic voltage restorer is shown below.

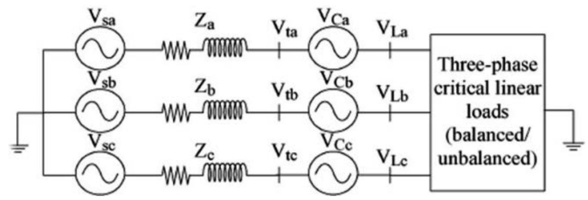

Fig1. Schematic diagram of DVR

A dynamic voltage restorer (DVR) is a solid state inverter based on injection of voltage in series with a power distribution system. The DC side of DVR is connected to an energy source or an energy storage device, while its ac side is connected to the distribution feeder by a three-phase inter facing injection transformer. A single line diagram of a DVR connected power distribution system is shown in the Fig.1.Since DVR is a series connected device, the source current, is same as load current. DVR injected voltage in series with line such that the load voltage is maintained at sinusoidal nominal value. It is normally installed in a distribution system between the supply and the critical load feeder at the point of common coupling (PCC).

The main aim of the DVR is to inject a required amount of compensating voltage in series with the supply to regulate the load terminal voltage. In this section, a proposed control algorithm is discussed with an ideal DVR model. A three-phase supply is represented by the star-connected three single-phase voltage sources (V_{sa}, V_{sb}, V_{sc}) along with their series source impedances (Z_a, Z_b, Z_c). To regulate the load voltages (V_{La}, V_{Lb}, V_{Lc}) to be balanced and sinusoidal against various PQ problems in the terminal voltages (V_{ta}, V_{tb}, V_{tc}), DVR injects the required compensating voltages (V_{Ca}, V_{Cb}, V_{Cc}) in each phase in order to give the required pulses to the inverter.

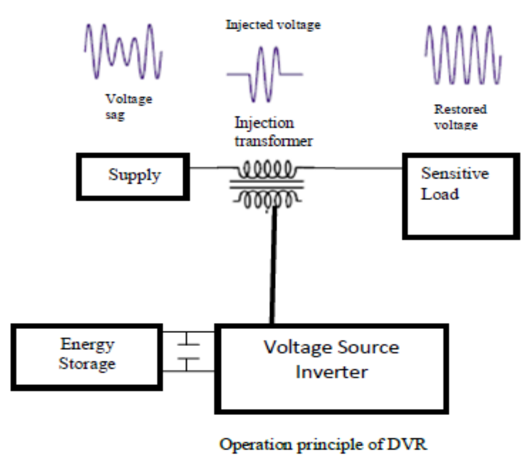

Fig.2 Dynamic voltage restorer (DVR)

The DVR should not supply any real power in steady state. This implies that, the phase difference between instantaneous DVR voltages and instantaneous line currents must be 90◦.

Operating Principle of DVR: The schematic diagram of a self-supported DVR is shown in Fig.2 Three phase source voltages (V_{sa}, V_{sb}, and V_{sc}) 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 (V_{ca}, V_{cb}, V_{cc} 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.

III. FUNDAMENTAL POSITIVE-SEQUENCE EXTRACTOR

The line voltages are the difference of different phase voltages (*va−vb*, *vb−vc*, and *vc−va*), the summation of three line voltages is always zero irrespective of whether three phase voltages are balanced and sinusoidal or unbalanced. Therefore, by sensing only two line voltages V_{ab} and V_{bc} the third line voltage V_{ca} can be calculated as

$$V_{ca} = -(V_{ab} + V_{bc}) \qquad \text{(i)}$$

If Park's transformation is applied to three balanced sinusoidal line voltages, V_{ab}, V_{bc}, V_{ca} using a PLL over the same line voltages, then it gives constant direct-axis component V_d equal to the amplitude of line voltage, quadrature-axis component V_q equal to zero, and zero-sequence component V_0 equal to zero because line voltages are a positive sequence only without any harmonics.

When line voltages are unbalanced and/or distorted, then, V_d is composed of two parts: a constant component equal to the amplitude of positive-sequence line voltage and a varying component influenced by negative-sequence line voltage and harmonics.

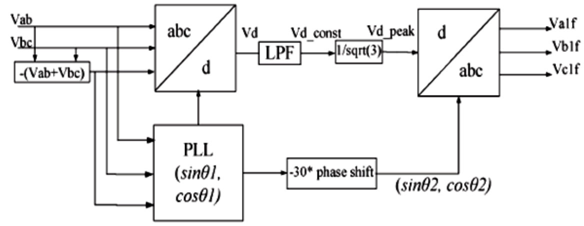

Fig.3 Block diagram of fundamental positive-sequence extractor.

IV. SRF BASED CONTROL ALGORITHM

The basic functions of a controller in a DVR are the detection of voltage sag/swell events in the system; computation of the correcting voltage, generation of trigger pulses to the PWM based DC-AC inverter, correction of any abnormalities in the series voltage injection and termination of the trigger pulses when the event has passed.

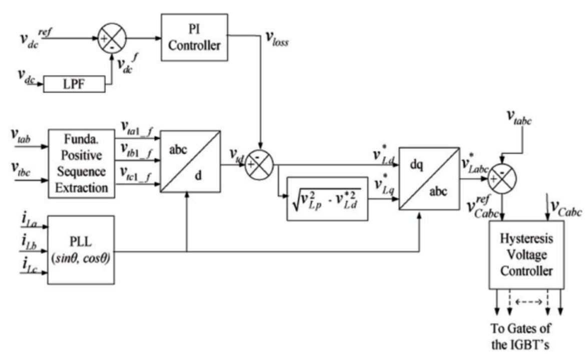

Fig.4 Control Block of DVR using SRF method of Control

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.

V. SIMULATION RESULTS AND DISCUSSION

The performance of the DVR is demonstrated for different supply voltage disturbances such as sag and swells at terminal voltages. The DVR is modeled and simulated using the MATLAB and its Simulink and Sim Power System toolboxes. The MAT-LAB model of the DVR connected system is shown in fig.5.

The Specification and parameters of the system were listed in the below.

Parameters of the System Specifications –1.1Table

System Parameter	Values
Ac Source Voltage	415V,50Hz
Base Voltage Ac	415V
Base Voltage Dc	300V
Base KVA	10KVA
Line Impedence	X_{LS}=0.3, Rs=0.05pu
Shunt capacitor filter	X_{cf}=3pu
Ripple factor	L_r+$L_{transformer}$=4Mh, Cr=60, R_r=2

Table1.1 Parameters of the System Specifications

Mitigation of linear voltage sags:

In the simulation model, the voltage sags are generated by switching on impedance to the

Ground at the Point of Common Coupling (PCC), upstream the DVR. This situation is equivalent to a remote short-circuit fault which results in voltage dips with a phase angle jump. The result for situation is equivalent to a remote short-circuit fault which results in voltage dips with a phase angle jump. The result for simulation of voltage is shown in Fig.7. The 50% of Voltage sag is initiated for 2 cycles at the PCC.

Mitigation of non-linear voltage sags:

Unbalance sag is programmed to generate the grid voltage at the PCC as shown. One phase stays at 1 p.u. during the dip the other phases drop to 0.75 p.u. The injected voltage by the DVR and restored load voltage as shown in fig 7 and 8.. When positive sequence of the grid voltage drops <90%, the sag detected and DVR starts compensation. It is noted that from Fig. 7 that the compensated load voltage is balanced and the maximum error is < 2% which indicates the capacity of the DVR to cope with unbalanced sags.

Mitigation of linear and nonlinear voltage swells:

From the control point of view, the DVR should handle voltage swells in the same way it handles voltage sags. In either case, the reference of the injected voltage the stepped and actual voltage has to track its reference. But it is a different perspective from the energy handle capability.

In the case of voltage sags, the DVR delivers an active power to the load but in the case of voltages wells, the DVR may absorb the power from the grid. The voltage swell characteristics and the loading conditions are the main issues that determine the energy transfer of status from the grid to the DVR.

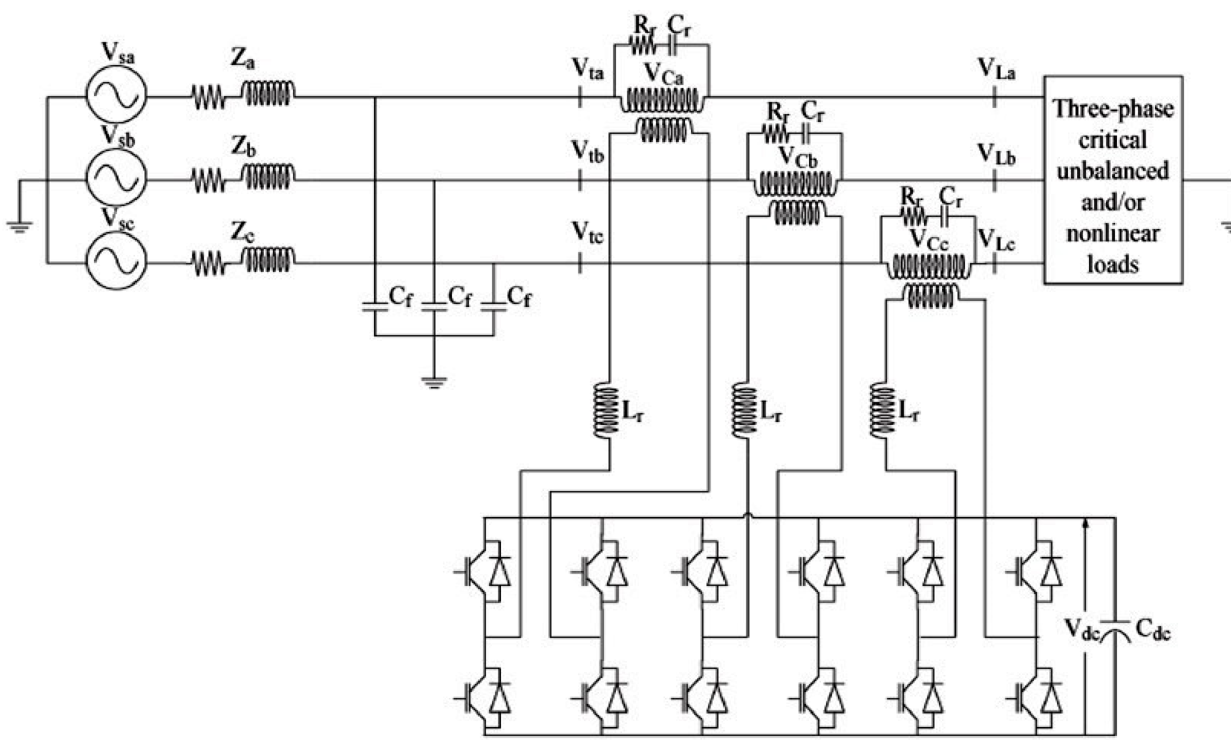

Fig.5 DVR Power Circuit

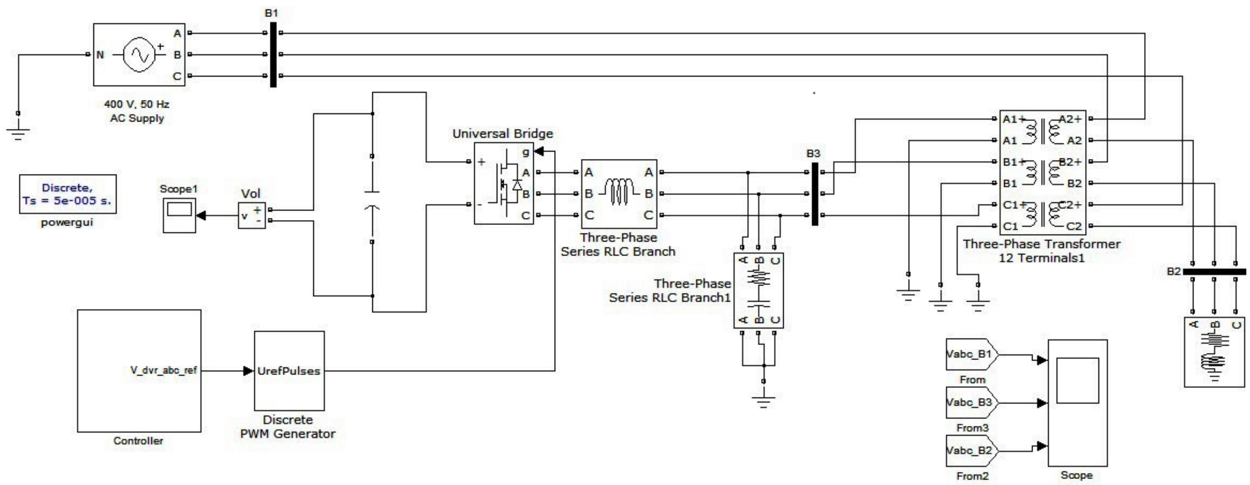

Fig.6 Matlab Simulink model SRF controlled DVR power circuit

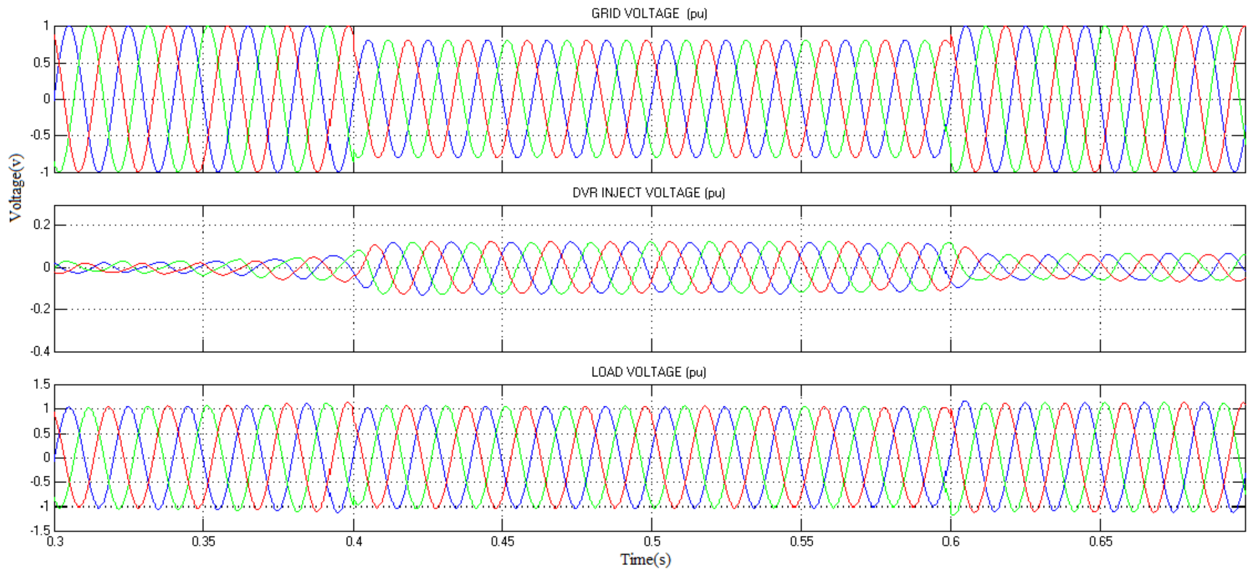

Fig.7 Sag Input voltage and Eliminated output voltage

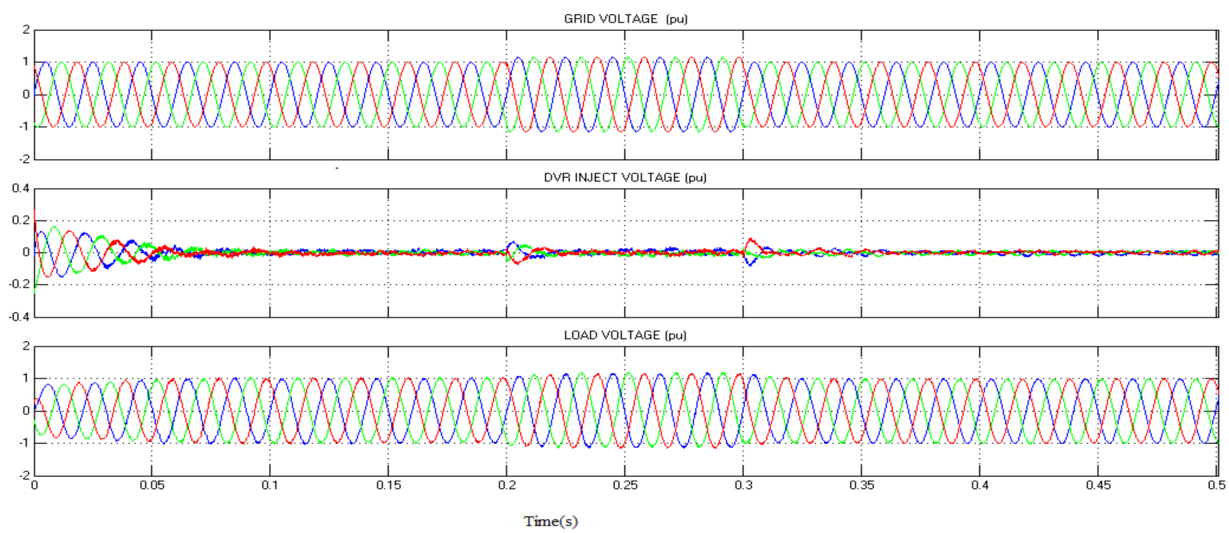

Fig.8 Swell Input voltage and Eliminated output voltage

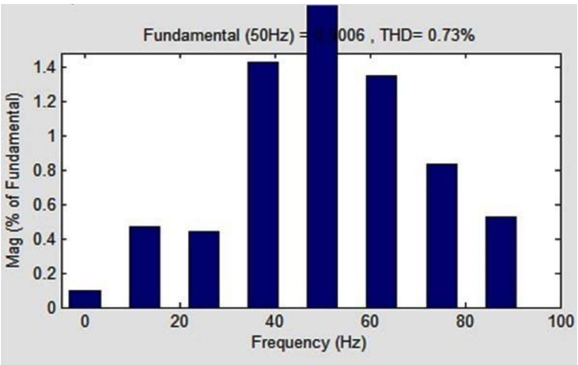

Fig.9 Total harmonic distortion

VI. Hardware Implementation of Single Phase Equivalent Circuit

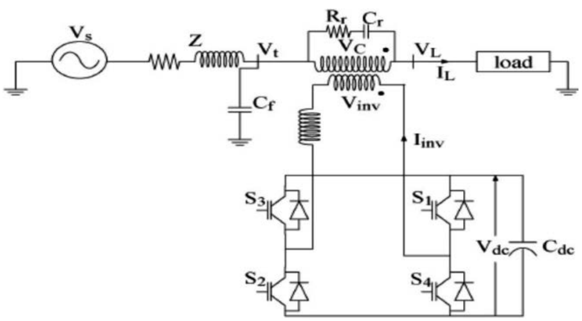

Fig.10 Single phase equivalent circuit of DVR connected circuit

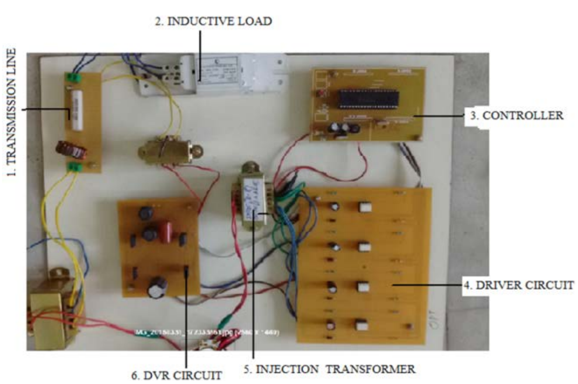

Fig.11 Single phase prototype DVR connected circuit

Switching Logic:

IF	S1	S2	S3	S4
$V_c<V_{cref}$	ON	ON	OFF	OFF
$V_c>V_{cref}$	OFF	OFF	ON	ON

Table 1.2 switching Logic

Where

Vc – Compensating voltage

Vcref – Reference voltage

S1,S2,S3,S4 – DVR switches in the circuit

Hardware Circuit Specifications:

CONTROLLER CIRCUIT	DRIVER CIRCUIT
PIC16F877A	IC-TLP250
Crystal oscillator	Capacitor-470uf
Capacitor & resistor	Resister-100Ω, 1k, 470k
Regulator(7805)	Diode IN4001
Rectifier	Power supply (12v)
Power LED	
DVR CIRCUIT	**SPECIFICATION**
IRF840	Grid i/p voltage:50V
Inductor	Load:60W RL load
Capacitor	Fund. Freq: 50Hz
Diode IN4001	
Input/output Connector	
PCB Board	

Table.1.3 Hardware Circuit Specifications

Input and Output Voltages for Elimination of swell:

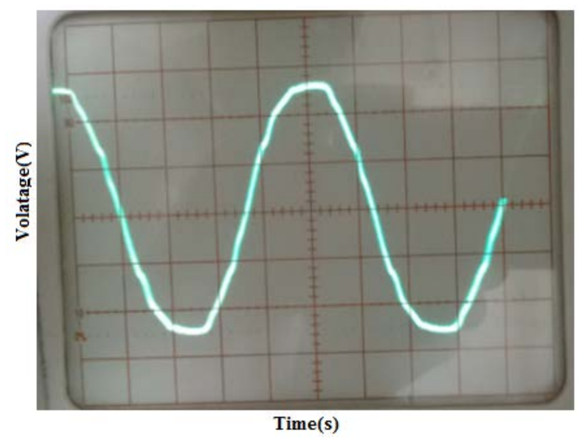

Fig.12 (a) Input Voltage=50

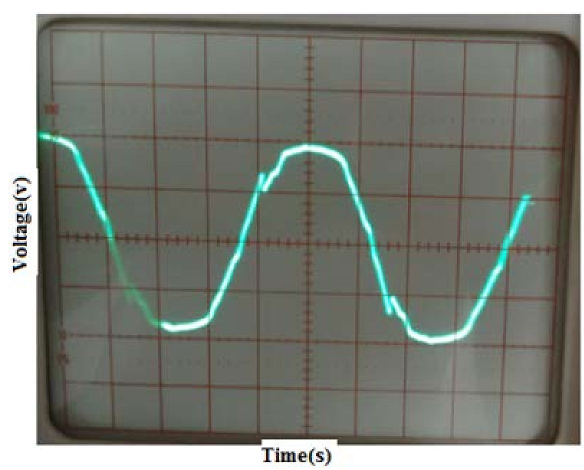

Fig.12 (b) Output voltage=40

Input and Output Voltages for Elimination of sag:

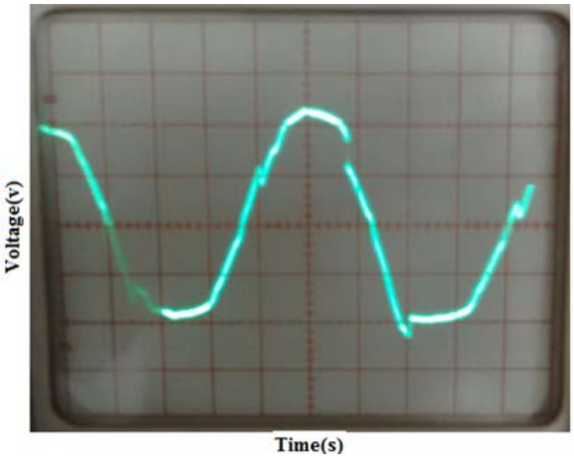

Fig.12 (c) Input voltage=40

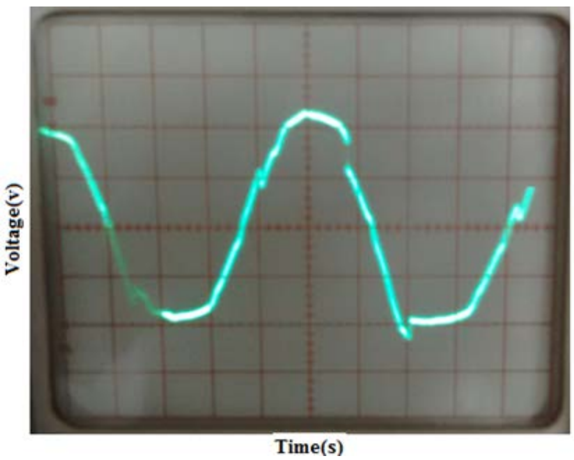

Fig.12 (d) Output voltage=47

VII. CONCLUSION AND FUTURE ENHANCEMENT

Conclusion: The Dynamic Voltage Restorer for mitigation of linear and nonlinear voltage sag, swell is studied in detail. DVR is used for the power quality control for the system. DVR for the micro grid is modelled in MATLAB Simulink. DVR is one of the series compensator and custom power devices are used to compensate the power quality problems (sag, swell, and harmonics….etc.). in this thesis, designed a DVR based on Synchronous Reference Frame Theory for the generation of instantaneous reference compensating voltages.

Future Scope: PI controllers are used in the simulation study to control the PCC voltage. A major limitation of PI controller is that, it does not guarantee the system stability under varying load conditions. Therefore, it may be desirable to employ advanced control techniques based on Fuzzy, Neural logic.

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