Simulation of Dynamic Voltage Restorer Using Matlab to Enhance Power Quality in Distribution System

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ABSTRACT

Power quality is one of major concerns in the present era. It has become important, with the introduction of sophisticated devices, whose performance is very sensitive to the quality of power supply that results in a failure of end user equipment's. One of the major problems dealt here is the voltage sag. To solve this problem, custom power devices are used. 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. Its appeal includes lower cost, smaller size, and its fast dynamic response to the disturbance. It can provide the most commercial solution to mitigation voltage sag by injecting voltage as well as power into the system. This paper presents modeling, analysis and simulation of a Dynamic Voltage Restorer (DVR) using MATLAB. The efficiency of the DVR depends on the performance of the efficiency control technique involved in switching the inverters. In this model a PI controller and Discrete PWM pulse generator is used.

I. INTRODUCTION

Power quality is the delivery of sufficiently high grade electrical services to the customer. A power quality problem is an occurrence manifested as a non-standard voltage, current or frequency that results in failure or mis-operation of end user equipment's. Power distribution systems, ideally should provide customer with an uninterrupted flow of energy at smooth sinusoidal voltage at the contracted magnitude level and frequency [1], but in practice distribution systems, have nonlinear loads, which affects the purity of waveform of supply. A momentary disturbance for sensitive electronic devices causes voltage reduction at load end leading to frequency deviations which results in interrupted power flow, scrambled data, unexpected plant shutdowns and equipment failure. Some events both usual (e.g. Capacitor switching, motor starting) and unusual (E.g. Faults) could also inflict power quality problems [5]. Under heavy load conditions, a significant voltage drop may occur in the system. A dip is usually taken as an event lasting less than one minute when voltage decreases to between 0.1 and 0.9 p.u. (dip greater than 0.1 p.u. is usually treated as an interruption) or a Voltage sag can occur at any instant of time, with amplitudes ranging from 10-90 % and a duration lasting for half cycle to one minute [2].

Power quality in the distribution system can be improved by using DVR, as assures pre-specified quality and reliability of supply. This pre-specified quality may contain a combination of specification of following: low phase unbalance, low harmonic distortion in load voltage, no power interruptions, acceptance of fluctuations, and poor power factor loads without significant effect on the terminal voltage, low flicker at the load voltage, magnitude and duration of overvoltage and under-voltage within specified limits [6].

DYNAMIC VOLTAGE RESTORER (DVR)

DVR is a series connected solid state device that is used for mitigating voltage disturbances in the distribution system by injecting voltage into the system in order to regulate the load side voltage [9]. DVR maintains the load voltage at a nominal magnitude and phase by compensating the voltage sag/swell, voltage unbalance and voltage harmonics presented at the point of common coupling [10, 11, 12]. The DVR is a series conditioner based on a pulse width modulated voltage source inverter, which is generating or absorbing real or reactive power independently.

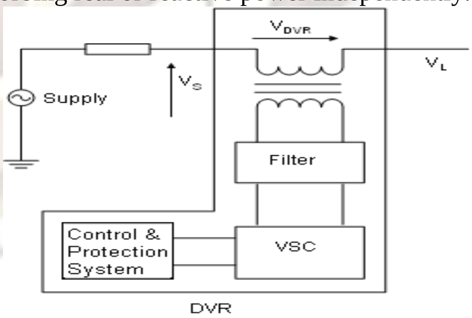

Fig.1.conventional circuit configuration of the DVR [14].

It is normally installed in a distribution system between supply and critical load feeder [4]. These systems are able to compensate voltage sags by increasing the appropriate voltages in series with the supply voltage, and therefore avoid a loss of power. Voltage sags caused by unsymmetrical line-to line, line to ground, double-line-to-ground and symmetrical three phase faults is affected to sensitive loads, the DVR injects the independent voltages to restore and maintained sensitive to its nominal value. Its primary function is to rapidly boost up the load side voltage in the event of a disturbance in order to avoid any power disruption to load [3, 7].

The basic components of a DVR:

DVR can be applied for medium voltage [13, 14] and in low voltage application [15]. The DVR components have been discussed in [16, 17]. Figure 1 shows conventional circuit configuration of the DVR. DVR basically consists of [21, 18, 19, 22, and 20] following parts:

- **Series Voltage Injection/booster Transformers**: The injection/booster transformer limits coupling of noise and transient energy from primary to secondary side [23]. Generally High voltage side of the injection transformer is connected in series to the distribution system and the power circuit of the DVR can be connected at the low voltage side. Its main function are: connects DVR to the distribution system through HV-winding and transforms and couples the injected compensating voltages generated by VSC to incoming supply voltage, to increase the voltage supplied by the filtered VSI output to the desired level while isolating the load from the system (VSC and control mechanism).The transformer winding ratio is pre-determined according to the voltage required at the secondary side of the transformer basically it is kept equal to supply voltage to allow DVR to compensate for full voltage sag. A higher transformer winding ratio will increase the primary side current, which will adversely affect the performance of the power electronic devices connected in the VSI [24].

Voltage Source Inverter (VSI): A VSC is power electronic system consists of a storage device and switching devices. It generates a sinusoidal voltage at any required frequency, magnitude, and phase angle. The function of an inverter system in DVR is used to convert the DC voltage supplied by the energy storage device into an AC voltage [29] and to temporarily replace the supply voltage or to generate part of supply voltage which is missing [26].

- **Passive Filters:** In DVR, filters convert the inverted PWM waveform into a sinusoidal waveform, by eliminating the unwanted harmonic components generated by the VSI action [25].
- **DC charging circuit:** The dc charging circuit has two main functions: The first is to charge the energy source after a sag compensation event and second is to maintain dc link voltage at the nominal dc link voltage. To charge the dc-link various topologies are used such as an external power supply or by connecting the dc side of the DVR to the controlled or uncontrolled rectifier to maintain the dc voltage. The other side of the rectifier can be from a main power line or from an auxiliary feeder
- **Control and Protection:** The control process generally consists of hardware with programmable logic. In past it consists of Digital Signal Processing boards which provide controls like detection and correction. Filters can also be used. There are different types of filter algorithm: Fourier Transform (FT), Phase-Locked Loop (PLL), and Wavelet Transform (WT), out of which Fourier Transform is the most common type. Direct feed forward type control architecture maximizes dynamic performance of DVR and compensation of voltage sags can be achieved in a fast response time (approximately 1ms) [27,28].

II. OPERATING PRINCIPLE OF DVR

The basic function of the DVR is to inject a dynamically controlled voltage VDVR generated by a forced commutated converter in series to the bus voltage by means of a booster transformer. The momentary amplitudes of the three injected phase voltages are controlled such As to eliminate any effects of a bus fault to the load voltage.

The DVR has three modes of operation which are: protection mode, standby mode, injection/boost mode.

- **Protection Mode :**If the over current on the load side exceeds a permissible limit due to short circuit on the load or large inrush current, the DVR will be isolated from the systems by using the bypass switches (S2 and S3 will open) and supplying another path for current (S1 will be closed).

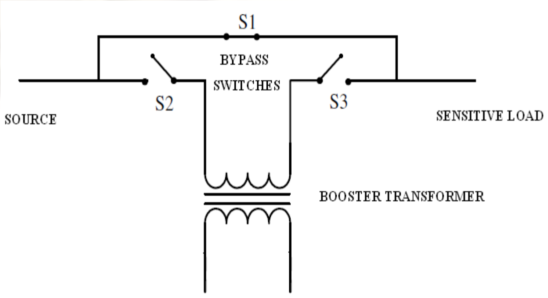

Fig 2: Protection mode

- **Standby mode: (V_{DVR}= 0)**

In the standby mode the booster transformer's low voltage winding is shorted through the converter.

No switching of semiconductors occurs in this mode of operation and the full load current will pass through the primary

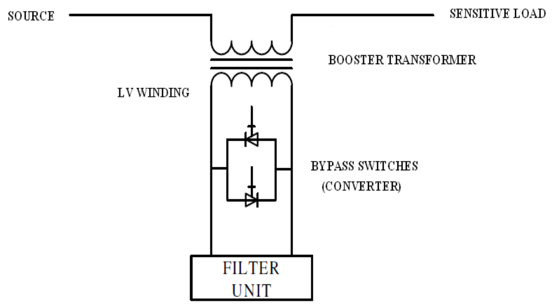

Fig 3 Standby mode

- **Injection/Boost Mode: (V_{DVR}>0)**

In the Injection/Boost mode the DVR is injecting a compensating voltage through the booster transformer due to the detection of a disturbance in the supply voltage.

COMPENSATION TECHNIQUES IN DVR:

Concept of compensation techniques which are applied in DVR can be divided into categories as follows;

(a).Pre-Sag Compensation:

In this method it is important for both magnitude and the phase angle to be compensated. The difference during sag and pre-sag voltage are detected by DVR and it injects the detected voltage, hence phase and amplitude of the voltage before the sag has to be exactly restored [16, 18]. Figure.6 shows the pre-sag compensation technique before and after the voltage sags. [30, 32].

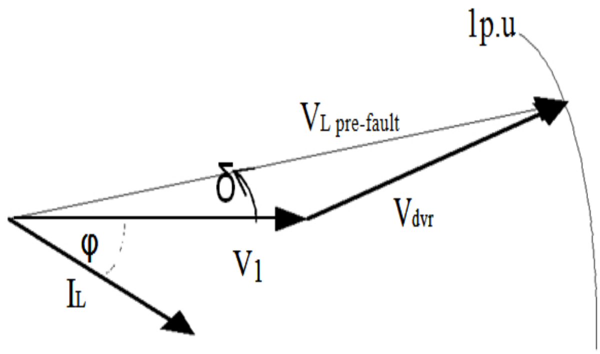

Fig.4. Pre-sag compensation

(b).In- Phase Compensation:

In this method, injection voltage is in phase with the source voltage [31]. When the source voltage is drop due to sag in the distribution network, then injection voltage produced by the Voltage Source Inverter (VSI) will inject the missing voltage according to voltage drop magnitude [18, 32]. This method can be shown in Figure.7 [30].

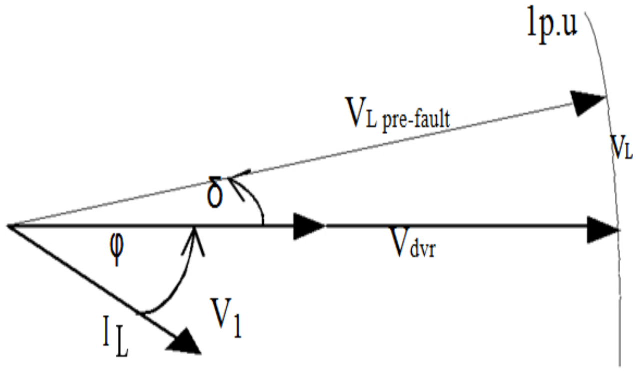

Fig.5. In–Phase compensation

(c).Phase Advanced or Minimum Energy Compensation:

This method reduces the energy storage size. Active power P_{DVR} depends on the angle α. During the sag, phase of load voltage jump's a certain step that causes difficulties for load [18, 32, and 33]. The magnitude of the restored load voltage that is maintained at pre-fault condition is shown in fig.8. [5].

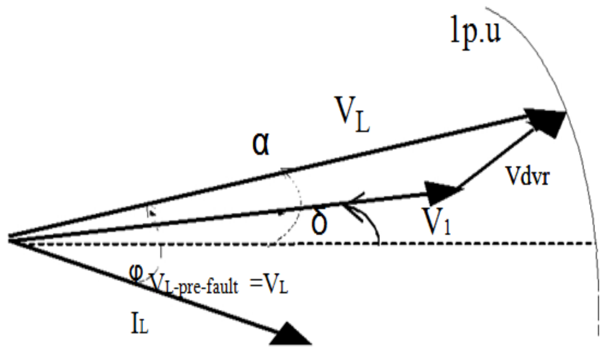

Fig.6. Phase advanced compensation

III. SIMULATIONS AND RESULTS

MATLAB Simulink /power system block set (PSB) will be used in this work to perform the simulation. One of the major problems dealt here is the power sag. A DVR is connected to the system through a series transformer with a capability to insert a maximum voltage of 50% of the phase to ground system voltage and a series filter is also used to remove any high frequency components. The role of DVR to compensate load voltage is investigated during the different fault conditions like voltage sag, single phase to ground, double phase to ground faults. The aim of the control scheme is to maintain a constant voltage magnitude at the sensitive load point, under the system disturbance. In order to mitigate the simulated voltage sags in the test system of each compensation control scheme is implemented.

The control system only measures the rms voltage at load point. Voltage sag is created at load terminals by a three-phase fault. Load voltage is sensed and passed through a sequence analyzer. The magnitude is compared with reference voltage (*Vref*). Pulse width modulated (PWM) control technique is applied for inverter switching so as to produce a three phase 50 Hz sinusoidal voltage at the load terminals. The IGBT inverter is controlled with PI controller. PI controller input is an actuating signal which is the difference between the *Vref* and *Vin.* PI controller based on the feed forward technique processes the error signal (difference between the reference voltage and actual measured voltage) and generates the angle δ to trigger the switches of an inverter using a Pulse Width Modulation (PWM) scheme to drive the error to zero. The proposed DVR utilizes energy drawn from the supply line source during normal operation and stored in capacitors and which is converted to an adjustable three phase ac voltage suitable for mitigation of voltage sags.

Output of the controller block is of the form of an angle δ, which introduces additional phase-lag/lead in the three-phase voltages. The output of error detector is *Vref - Vin*. An advantage of a proportional plus integral controller is that its integral term causes the steady-state error to be zero for a step input.

In this simulation the In-Phase Compensation (IPC) method is used. As it can be seen from the results, the DVR is able to produce the required voltage components for different phases rapidly and help to maintain a balanced and constant load voltage at the nominal value (400 V).

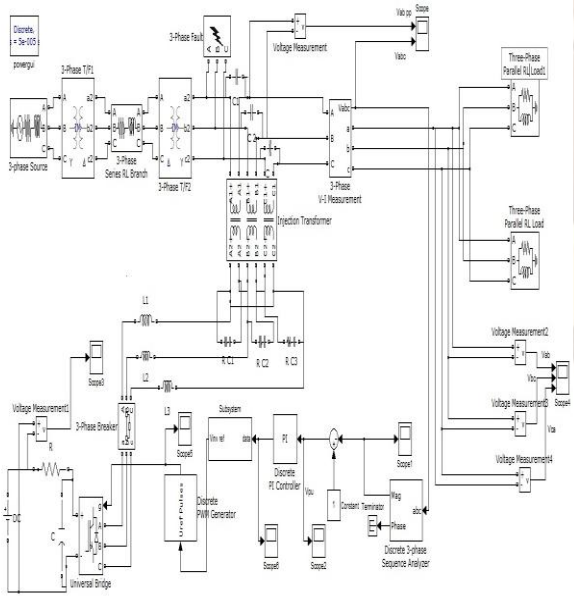

Fig.7.System with DVR and fault

A simulation model has been developed in MATLAB/SIMULINK as shown in fig.7 . The simulation parameters are: main supply voltage per phase-240 V, line impedance Ls-0.005 H,Rs-0.001 ohm, series transformer turns ratio- 1:1, DC bus voltage-640V, filter inductance- 1 mH, filter capacitance- 1 microfarad, load resistance-47 ohm, load inductance- 60mH, line frequency-50 Hz, isolation transformer 5 KVA and its line to line voltage-V_{L-L}-415 Vrms. In this model a Delta-Wye step-down transformer with neutral grounded is used therefore zero sequence current will not propgate through transformer when fault occur on high voltage side, and third harmonic voltages are eliminated by circulation of harmonic current trapped in the primary delta winding.

In the fig.8 red wave shows load voltage, black shows supply voltage, while blue shows injection voltage.

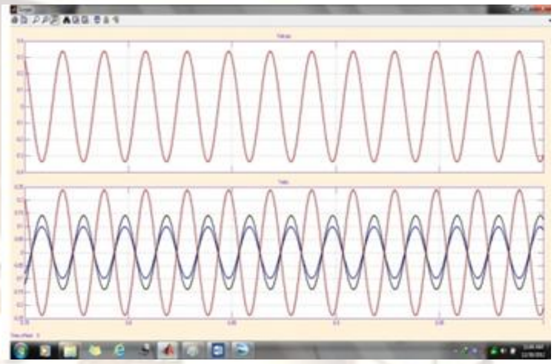

Fig.8.Simulation result supply voltage, injection voltage and load voltage

in the fig.9. voltage sag after fault is removed using DVR

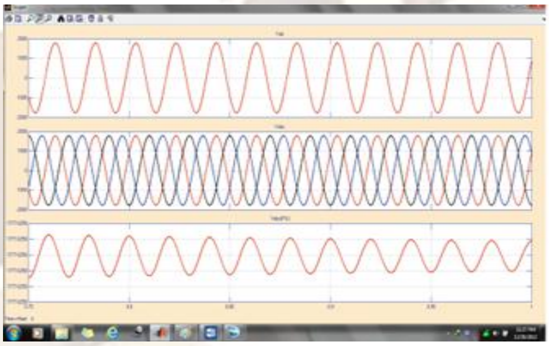

Fig.9.phase –phase, three-phase Va,Vb,Vc and p.u. voltages at load

IV. CONCLUSION

This paper represents simulation of DVR in MATLAB. In order to show the performance of DVR in mitigation of voltage sags, s simple distribution network is simulated using MATLAB. A DVR is connected to a system through a series transformer with a capability to insert a maximum voltage of 50% of phase to ground system voltage. In-phase compensation method is used. DVR injects the appropriate voltage component to correct rapidly any deviation in the supply voltage to keep the load voltage constant at the nominal value and handles both balanced and unbalanced situations without any difficulties. The main advantages of the proposed DVR are simple control, fast response and low cost. The proposed PWM control scheme using PI controller is efficient in providing the voltage sag compensation. As opposed to fundamental frequency switching schemes already available in the MATLAB/SIMULINK, this PWM control scheme only requires voltage measurements. This characteristic makes it ideally suitable for low-voltage custom power applications. The main shortcoming of the DVR, being a series device, is its inability to mitigate complete interruptions.

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