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Single Phase Dynamic Voltage Restorer for Abnormal Conditions

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***Abstract*— Power quality is one of the major concerns in the era of power system. Power quality problem occurred due to non- standard voltage, current or frequency, that result in a failure of end user equipment. To overcome this problem, Dynamic Voltage Restorer (DVR) is used, which eliminate voltage sag and swell in the distribution line, it is efficient and effective power electronic device. The size of DVR is small, cost is low and fast dynamic response to the disturbance. By injecting an appropriate voltage, the DVR restores a voltage waveform and ensures constant load voltage. The compensating signals are determined dynamically based on the difference between desired and measured values. The DVR is consisting of VSC, Booster transformer, Filter and Energy storage devices.**

***Index Terms*— Power quality, Dynamic Voltage Restorer (DVR), Voltage Source Converter (VSC).**

I. INTRODUCTION

The electric power system is considered to be composed of three functional blocks generation, transmission and distribution. For a reliable power system, the generation unit must produce adequate power to meet customer's demand, transmission systems must transport bulk power over long distances without overloading system stability and distribution systems must deliver electric power to each customer's premises from bulk power systems. Distribution system locates the end of power system and is connected to the customer directly, so the power quality mainly depends on distribution system. The reason behind this is that the electrical distribution network failures account for about 90% of the average customer interruptions. In the earlier days, the major focus for power system reliability was on generation and transmission only as these more capital cost is involved in these. In addition their insufficiency can cause widespread consequences for both society and its environment. But now a day's distribution systems have begun to receive more attention for reliability assessment.

Initially for the improvement of power quality or reliability of the system FACTS devices like static synchronous compensator (STATCOM), static synchronous series compensator (SSSC), interline power flow controller (IPFC), and unified power flow controller (UPFC) etc are introduced. These FACTS devices are designed for the transmission system. But now a days more attention is on the distribution system for the improvement of power quality, these devices are modified and known as custom power devices. The main custom power devices which are used in distribution system for power quality improvement are distribution static synchronous compensator (DSTATCOM), dynamic voltage Restorer (DVR), active filter (AF), unified power quality conditioner (UPQC) etc.

In this paper work from the above custom power devices, DVR is used with PI controller for the power quality improvement in the distribution system. Different fault conditions are considered with load to analyze the operation of DVR to improve the power quality in distribution system.

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II. DYNAMIC VOLTAGE RESTORER (DVR)

The Dynamic Voltage Restorer (DVR), is also referred to as Series Voltage Booster (SVB) or the Static Series Compensator (SSC), is a device utilized solid state power electronic components, and it is connected in series with distribution circuit. The DVR consist of an Injection/Booster transformer, a Harmonic Filter, a Voltage Source Converter (Power converter), DC charging circuit and Control as shown in the block diagram of DVR in fig.1.

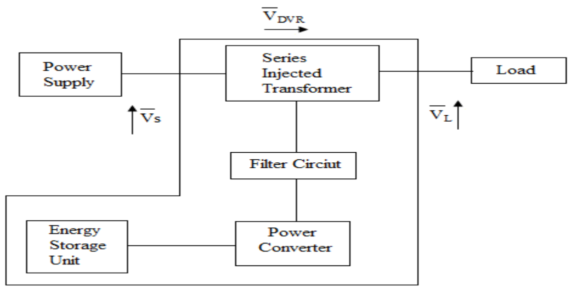

Fig. 1. Block Diagram of DVR Circuit

A. DC energy Storage device

It is used to supply the real power requirement for the compensation during voltage sag. Lead-acid batteries, Super Conducting Magnetic Energy Storage (SMES), Flywheels and Super capacitors can be used as the storage devices. For DC drives such as capacitors, batteries and SMES, DC to AC conversion (inverters) are needed to deliver power, whereas for flywheel, AC to AC conversion is required [4,5,8].

The maximum compensation ability of DVR particular for voltage sag is dependent on the active power supplied by the energy storage devices.

B. Voltage Source Inverter (VSI)

The basic function VSI is to convert DC voltage supplied by the energy storage device to an AC voltage. This is coupled to an injection transformer to the main system. Thus a VSI with low voltage rating is sufficient [4,8].

C. Passive Filter

It is used to convert PWM pulse waveform in to sinusoidal waveform. It consists of an inductor and a capacitor. It can be placed either high voltage side or low voltage side of the injection transformer. By placing it inverter side higher order harmonics are prevented from passing through the voltage transformer. And it will reduce stress on the injection transformer. When the filter is placed on the high voltage side, the higher order harmonic current do penetrate to the secondary side of the transformer, a higher rating of the transformer is required [4,8].

D. Voltage Injection Transformer

The basic function is to increase the voltage supplied by the filtered VSI output to the desired level. The high voltage side of the injection transformer is connected in series to the distribution line and low voltage side is connected to the power circuit of the DVR. In this study single phase injection transformer is used. For three has DVR, three single phase transformer can be connected either in delta/open or star/open configuration.

E. By-pass Switch

The DVR is series connected device, if fault current that occur due to fault in the downstream will flow through the inverter circuit [10]. The power electronic component are rated to the load current hence to protect the inverter from higher current, a by-pass switch is used and it is located between the inverter and the isolating transformer.

III. System Model And Control Aspects

A single line schematic diagram of DVR for simulation is shown in Fig.2. The set up consists of a source feeding R-load, a series active filter connected in series with the source and the load, through series injection transformer running on common dc link. The voltage rating is the maximum voltage that the series active filter can inject into the line. Therefore, the rating (per phase) of the series active filter is the product of the maximum injecting voltage times the primary current. The switching ripple in the pulse width modulated ac output voltage is filtered using a LC filter.

A. Conventional Voltage Injection Methods In DVR

The possibility of compensating voltage sag can be limited by a number of factors including finite DVR power rating, different load conditions and different types of voltage sag. Some loads are very sensitive to phase angle jump and others are tolerant to it. Therefore, the control strategy depends on the type of load characteristics. There are three distinguishing methods to inject DVR compensating voltage.

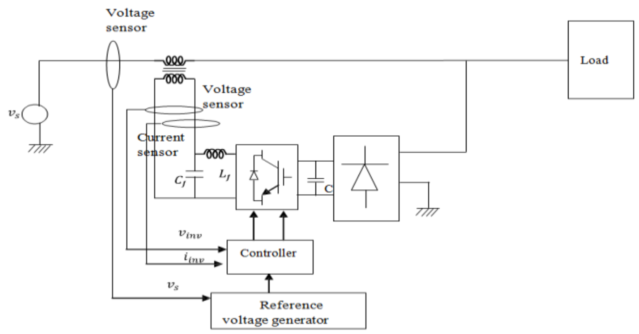

Fig. 2. Schematic diagram of DVR

B. Pre-Dip Compensation

The PDC method tracks supply voltage continuously and compensates load voltage during fault to pre-fault condition. In this method, the load voltage can be restored ideally, but the injected active power cannot be controlled and it is determined by external conditions such as the type of faults and load conditions. The lack of the negative sequence detection in this method leads to the phase oscillation in the case of single-line faults. Fig.3 shows the single-phase vector diagram of this method.

According to Fig.3, the apparent power of DVR is:

$S_{1DVR} = I_L V_{1DVR}$

(1)

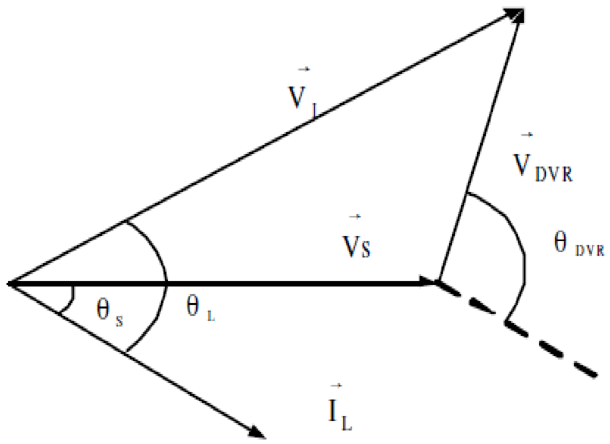

Fig. 3. Single-phase vector diagram of the PDC method

And the active power of DVR is

$P_{1DVR} = I_L(V_L \cos\theta_L - \cos\theta_S)$

(2)

The magnitude and the angle of the DVR voltage are

$V_{1DVR} = [V_L^2 + V_S^2 - 2V_L V_S \cos(\theta_L - \theta_S)]^{1/2}$

(3)

C. In-phase Compensation

This is the most used method in which the injected DVR voltage is in phase with the supply side voltage regardless of the load current and the pre-fault voltage as shown in Fig.4. The IPC method is suitable for minimum voltage or minimum energy operation strategies. In other word, this approach requires large amounts of real power to mitigate the voltage sag, which means a large energy storage device. The apparent and active powers of DVR are.

$S_{2DVR} = I_L V_{DVR} = I_L (V_L - V_S)$

(4)

$P_{2DVR} = I_L V_{DVR} \cos\theta_S = I_L(V_L - V_S)\cos\theta_S$ of DVR

(5)

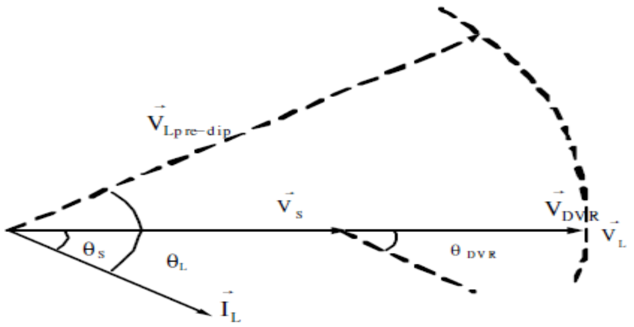

Fig.4. Single-phase vector diagram of the IPC method

The magnitude and the angle of the DVR voltage are

$V_{2DVR} = V_L - V_S$
(6)

$\theta_{LDVR} = \theta_S$ (7)

D. In phase Advance Compensation

Voltage disturbance. However, the amount of possible injection active power is confined to the stored energy in DC link, which is one of the most expensive components in DVR. Due to the limit of energy storage capacity of DC link, the DVR restoration time and performance are confined in these methods. Pre-Dip and in-phase compensation method must inject active power to loads to correct.

E. SPWM Technique

The basic principle of the PWM is to control the output voltage as well as optimize the harmonics by performing multiple switching within the inverter with constant DC input voltage. There are many possible PWM techniques are available, in this project analyzes the most widely used PWM scheme for IGBT inverter such as SPWM. The SPWM technique is very popular for industrial converters the basic principle to control the output voltage is explained in Fig.5. Where the isosceles triangle carrier wave of frequency f_C is compared with the fundamental frequency f. sinusoidal modulating wave and the points of intersection determines the switching points of power devices. The notch and the pulse widths of output voltage wave vary in a sinusoidal manner so that the average of fundamental component frequency is same as F and its amplitude is proportional to the command modulating voltage ($V_{control}$).

The modulation index is defined as

m = (peak amplitude of $v_{control}$) / (amplitude of $V_{triangle}$) (8)

Where $V_{control}$= peak value of the modulating wave and V_{tri}= peak value of triangular carrier wave. Ideally the m can be varied between 0 and 1 to give a linear relation between the modulating and output wave. The inverter basically acts as a linear amplifier and its gain is given by

$G = [(0.5mV_{dc})/V_{control}] = (0.5V_{dc}/V_{tri})$
(9)

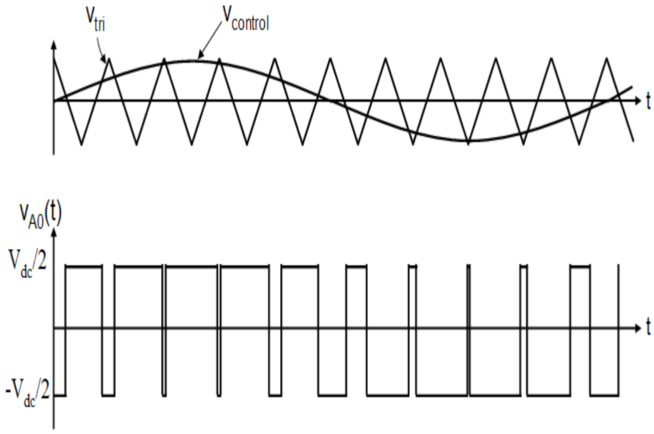

Fig. 5. Pulse width modulation.

At m=1 the maximum value of fundamental peak voltage is 0.5 V_{dc} which is 78.55 percent of the peak voltage of the square wave. One important term related to harmonics is carrier frequency to modulating frequency ratio P= ω_C/ω. If P is more than the line current harmonics can be well filtered by nominal leakage inductance .Here p should be an odd integer, if the P is not an integer there may exist sub harmonics at output voltage, if P is not odd, DC component may exist and even harmonics are present at output voltage. And it also should be multiples of three, and then in the output multiples of three and even harmonics are suppressed. The selection of carrier frequency is the tradeoff between the inverter switching loss and the machine harmonic loss.

IV. DVR CONTROLLER

A controller is required to control or to operate DVR during the fault conditions only. Load voltage is sensed and passed through a sequence analyzer. The magnitude of the actual voltage is compared with reference voltage (V_{ref}). Pulse width modulated (PWM) control system is applied for inverter switching so as to generate a single phase 50 Hz sinusoidal voltage at the load terminals. Chopping frequency is in the range of a few KHz. The IGBT inverter is controlled with PI controller in order to maintain 1p.u voltage at the load terminals. 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. Where V_{ref} equal to 1 p.u. voltage and V_{in} voltage in p.u. at the load terminals. The controller output when compared at PWM signal generator results in the desired firing sequence. The Duty cycle is defined as

Duty cycle

$$D = \frac{1}{V_{DC}}\left(V_{load} + \frac{L_f}{t_i}(I_{line\_ref} - I_{line})\right)$$

$$I_{line\_ref} = I_{load} + \frac{C_f}{t_v}(V_{load\_ref} - V_{load}) \quad (10)$$

(11)

A. Control Strategy of series Active Filter (DVR)

The series active filter is connected in series with the utility and the load through single phase injection transformers as shown in figure6. The control for the series active filter is derived to keep the phase voltage within the limits specified by the supplier. To derive the control law, the parasitic resistance of inductor and the capacitor (C_f) is neglected. Then the dynamic equation relating converter voltage V_{inv}, converter current I_{inv} and LC filter voltage (V_o) is

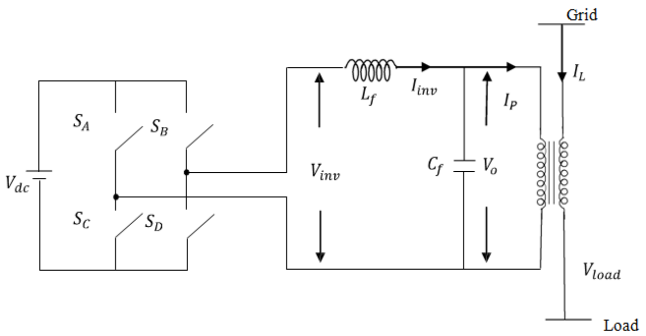

Fig.6. Schematic diagram of series active filter

$$V_{inv} = L_f(dI_{inv}/dt) + V_o \tag{12}$$

Among the dynamic variables I_{inv} and V_o I_{inv} is the fastest changing variable. The control strategy is therefore to regulate I_{inv} in the inner most loops. Let the desired response of desired I_{inv} the first order with a time constant of T_i the desired response may be written as

$$T_i\,(dI_{inv}/dt) + I_{inv} = I_{invref} \tag{13}$$

$$I_{inv} = C_f/T_v\,(V_{oref} - V_o) + I_p \tag{14}$$

The I_{inv} is nothing but I_{invref} which is the input for the inner control loop. Therefore the equation can be written as

$$I_{invref} = C_f/T_v\,(V_{oref} - V_o) + I_p \tag{15}$$

III. Simulation Results and Discussion

The output filter of series active filter consists of a low pass filter with L_f = 3.2 mH and C_f = 50µF. A Resistive load has been used as a local load. AC source voltage is of 230V and 50 Hz frequency.

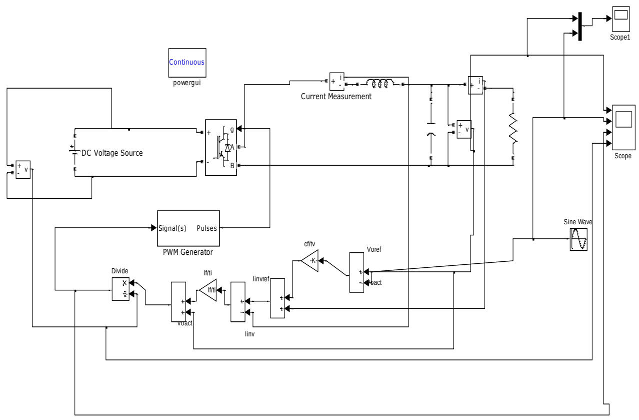

Fig.7. Simulink Test Model.

A systematic presentation of the simulation results for the developed Dynamic Voltage Restorer system connected is presented for several different conditions' i.e. voltage rise, voltage dip. Simulation result is presented to validate the developed models and control for the proposed DVR system.

A. *Simulink Results of Proposed System During Voltage Sag*

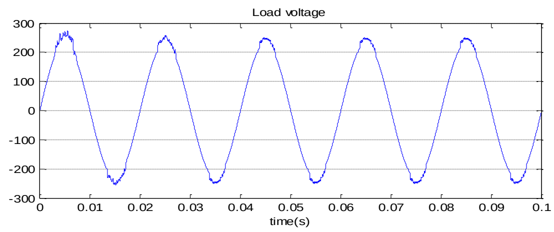

Fig. 8. Load voltage during sag.

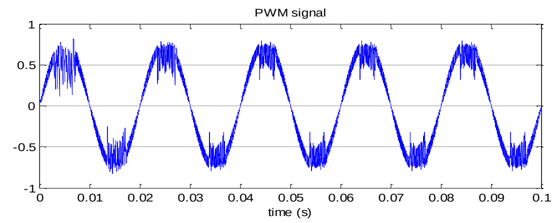

Fig. 9. PWM signal during sag.

B. *Simulink Results of Proposed System During Voltage Swell*

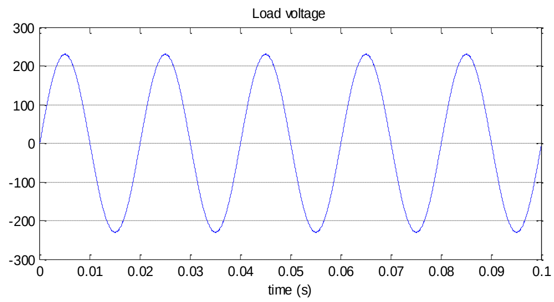

Fig. 10. Load voltage during swell.

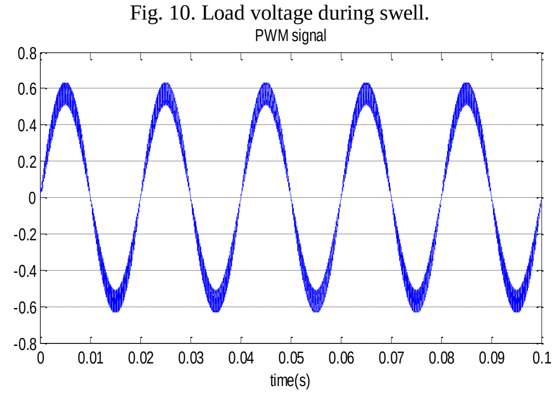

Fig. 11. PWM signal during swell.

VI. Conclusion

In this paper, the simulation of a DVR is done using MATLAB/SIMULINK software. Thus it became easier to construct the large distribution network and analyze the various results for two different types of faults. The controlling of DVR is done with the help of PI controller. The simulation results clearly showed the performance of the DVR in mitigating the voltage sag due to different fault conditions in distribution systems. DVR is one of the fast and effective custom power devices. DVR has shown the efficiency and effectiveness on voltage sag compensation hence it makes DVR to be an interesting power quality improvement Device.

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