Four Leg Voltage Source Converter Based Dynamic Voltage Restorer

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***Abstract*— The demand for Power Quality is one of the major concerns in the present era. With the increasing need of power electronic devices and other sophisticated devices, makes the entire system sensitive to the quality of power supply. Power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that not only results in failure of end use equipment but also provides dissatisfaction on the customer front. One of the major problems dealt here is the voltage sag. To solve this problem, custom power devices are used. Dynamic Voltage Restorer (DVR) is a series connected VSC based FACTS Controller that is used to keep the load voltage constant during an imbalance in the system. DVR's appeal includes lower cost, smaller size, and its fast dynamic response to the disturbance. Analysis, Modelling and Control of Dynamic Voltage Restorer (DVR) are described. The Voltage Restorer is based on a four-leg Voltage Source Converter. The three- phase input variables are resolved into sequence components. A four-leg converter is used to eliminate the presence of zero sequence components in an unbalanced system. Fuzzy logic control techniques are used to test its performance. The response of both the controllers, the conventional PI controller and the novel Fuzzy Logic Controller, are compared and validated. MATLAB, Simulink Software is used to simulate the results.**

***Keywords*— Dynamiv Voltage restorer, FACTS, Four-Leg Voltage Source Converter, Fuzzy Logic Control, MATLAB, PI Control, Simulink**

I. INTRODUCTION

Flexible AC Transmission system (FACTS) and DC links are a proven solution to rapidly enhancing reliability and upgrading transmission capacity on a long-term and cost effective basis. It has been considered as an excellent controller in a power system network after considerable effort on the development of power electronics based power flow controllers. As power systems are encountering increasing power demand, it becomes difficult to build new transmission lines for power management. The concept of FACTS controller was timely and appropriate .Due to the advance in semiconductor industry; high power rating and high speed gate turn-off power electronic devices are introduced practically in power system applications.

These developments provide a new generation of FACTS controllers called VSC based FACTS controllers with promising features in flexible power flow control, transient stability and power system oscillation damping enhancement. The family of compensators and power flow controllers based on VSC are the Static Synchronous (shunt) Compensator (STATCOM), the Static Synchronous Series Compensator (SSSC) and the Unified Power Flow Controller (UPFC). The UPFC is used as a powerful tool for the cost effective utilization of individual transmission lines by facilitating the independent control on both the real and reactive power flow, while the Interline Power Flow controller (IPFC) concept provides a solution for the problem of compensating a number of transmission lines at a given substation. Dynamic Voltage Restorer (DVR) is a static or voltage source inverter that is used to inject controllable AC voltages at the point of common coupling or sensitive load bus.

II. DYNAMIC VOLTAGE RESTORER

Recently the demand for high power quality has increased significantly. The consequences of Industrial processes are classified into two, they are the presence of non-linear and unbalanced loads and high vulnerability to momentary deviations (voltage sags) in the distribution system's voltage. The well known custom power devices are D-STATCOM (Distribution side Static Synchronous Compensator), DVR (Dynamic Voltage Restorer) and UPQC (Unified Power Quality Conditioner). They are available for protection of a critical load from disturbances. Dynamic Voltage Restorer is thus a custom power device that is inserted between the power distribution system and the industrial load. Dynamic Voltage Restorer is a series connected device whose function is to generate three-phase voltages and to inject them in correct synchronism with the distribution system voltages to maintain the load voltages at their nominal values.

III. BASIC STRUCYURE OF DYNAMIC VOLTAGE RESTORER (DVR)

A Dynamic Voltage Restorer (DVR) is basically a controlled voltage source converter that is connected in series with the network. It injects a voltage on the system to compensate any disturbance affecting the load voltage. The compensation capacity depends on maximum voltage injection ability and real power supplied by the DVR. Energy storage devices like batteries and SMES are used to provide the real power to load when voltage sag occurs. If a fault occurs on any feeder, DVR inserts series voltage and compensates load voltage to pre-fault voltage.

A basic block diagram for open loop DVR is shown in Fig.1

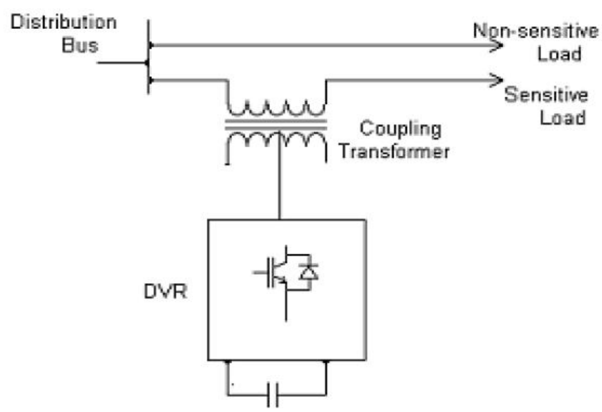

Fig.1 A Basic Block Diagram

IV. FOUR LEG VOLTAGE SOURCE CONVERTER

Voltage imbalances are normally brought about by unbalanced loads or unbalanced short-circuit faults, thus producing overheating in synchronous machines and, in some extreme cases, leading to load shutdowns and equipment failure. The DVR is essentially a voltage-source converter connected in series with the AC network via an interfacing transformer, which was originally conceived to ameliorate voltage sags. However, its range of applicability can be extended very considerably when provided with a suitable control scheme.

The basic operating principle behind the DVR is the injection of an in phase series voltage with the incoming supply to the load, sufficient enough to re-establish the voltage to its pre-sag state. Its rate of success in combating voltage sags in actual installations is well documented, this being one of the reasons why it continues to attract a great deal of interest in industry and in academic circles. Research work has been reported on DVR two leg and three leg topologies as well as on control and operation. The DVR may be operated to inject the series voltage according to several criteria, such as minimum energy exchange with the grid.

The two most popular strategies to compensate voltage sags are: 1) pre-sag compensation. The injected DVR voltage is calculated to simply compensate the load voltage to its pre-sag condition; 2) in phase compensation. The DVR voltage is always in phase with the grid voltage. Although these are the best well-known control strategies, many efforts are being made to develop new ones to enable better DVR utilization.

The controller is normally designed with some specific aims firmly in mind, such as the kind of disturbances it should ameliorate, the velocity of time response, error in steady-state, etc. Here, DVR uses a simple proportional-integral (PI) control and Fuzzy Logic control law implemented in a frame of reference which rotates with the frequency of the grid voltage. This basic approach is sufficient to enable voltage sag compensation, to warrant zero tracking error for the fundamental component certain kinds of unbalanced conditions.

The main feature of a three phase inverter, with an additional neutral leg, is its ability to deal with load unbalance in a standalone power supply system. The goal of the three phase four leg inverter is to maintain the desired sinusoidal output voltage waveform over all loading conditions and transients. It is ideal for applications like data communication, industrial automation, military equipment, which require high performance uninterruptible power supply. Fig 4.1 shows the three phase four leg inverter used in Dynamic Voltage Restorer.

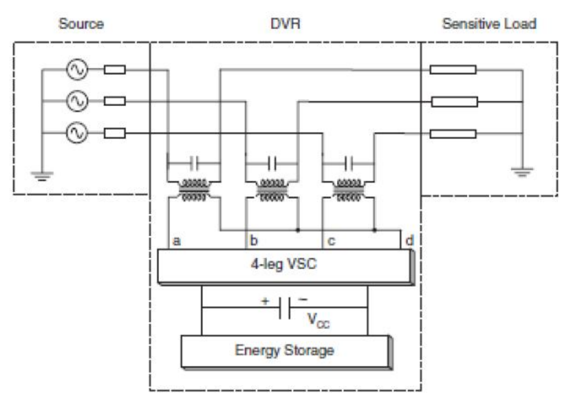

Fig 4.1 Four Leg VSC based DVR

The four leg inverter is connected to the secondary side of the transformer. The fourth leg generates the compensating signal to balance the system. The pulses to the four leg inverter is generated by Pulse Width Modulation technique and the switching pattern of the switches in the four leg inverter is shown as in Fig 4.2

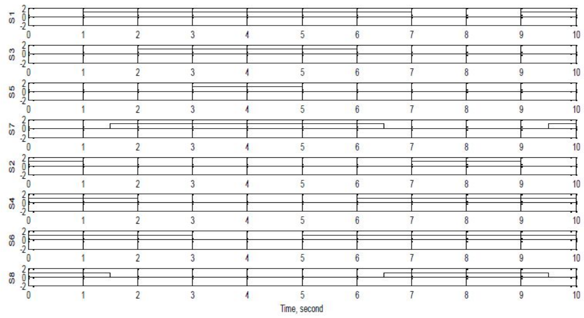

Fig 4.2 Switching Pulses to the Four Leg Inverter

V. PULSE WIDTH MODULATION

The Pulse-width modulation (PWM) is a commonly used technique for controlling power to an electrical device, made practical by modern electronic power switches. The average value of voltage (and current) fed to the load is controlled by turning the switch between supply and load on and off at a fast pace. The longer the switch is on compared to the off periods, the higher the power is supplied to the load.The PWM switching frequency has to be much faster than what would affect the load, which is to say the device that uses the power.

The main advantage of PWM is that power loss in the switching devices is very low. When a switch is off there is practically no current, and when it is on, there is almost no voltage drop across the switch. Power loss, being the product of voltage and current, is thus in both cases close to zero.

Here, the control signals are compared to a ramp signal. These signals are ANDed with the switching pulses and are given as input to gate of the switches.

VI. FOUR LEG VOLTAGE SOURCE CONTROLLER BASED DVR USING PI CONTROLLER

A PI (Proportional Integral) controller is used. It forms a feedback control as it compares the desired output with the actual output. After the comparison is made, an error is generated and this error signal is given to the Pulse Width Modulation to control the switching pattern. A three phase four leg Dynamic Voltage Restorer is simulated under (i) three phase fault condition, and (ii) unbalanced input voltage condition. Due to the presence of the Dynamic Voltage Restorer, the system restores immediately even during the presence of a three phase fault applied for duration of 0.2 to 0.4 second. The output voltage shows the absence of any unbalances. This is shown in Fig 8.1.

VII. FOUR LEG VOLTAGE SOURCE CONTROLLER BASED DVR USING FUZZY LOGIC CONTROLLER

Fuzzy Logic provides a simple way to arrive at a definite conclusion based upon vague, ambiguous, imprecise, noisy, or missing input information. Fuzzy Logic's approach to control problems mimics how a person would make decisions, only much faster. It is very robust and forgiving of operator and data input and often works when first implemented with little or no tuning. . A three phase four leg Dynamic Voltage Restorer is simulated under (i) three phase fault condition, and (ii) unbalanced input voltage condition. Due to the presence of the Dynamic Voltage Restorer, the system restores immediately even during the presence of a three phase fault applied for duration of 0.2 to 0.3 second. The output voltage shows the absence of any unbalances due to the presence of Fuzzy Logic Controller. Fig 8.3 shows the output voltage when subjected to both the disturbances. The response of Fuzzy Logic Controller is compared with PI controller and the results are tabulated. Both the responses of PI controller and Fuzzy Logic Controller are shown in Fig. 8.3 and Fig. 8.4 respectively.

VIII. FIGURES

The figures shown below show the output voltage with respect to the input voltage for a four leg voltage source converter based DVR using:

(i) PI control technique

(ii) Fuzzy Logic control technique.

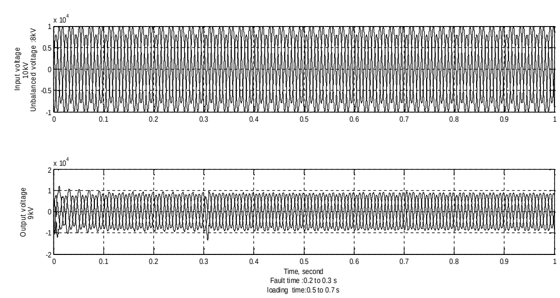

Fig. 8.1 Input and Output voltage of A Four Leg Voltage Source Converter Based DVR Using PI control

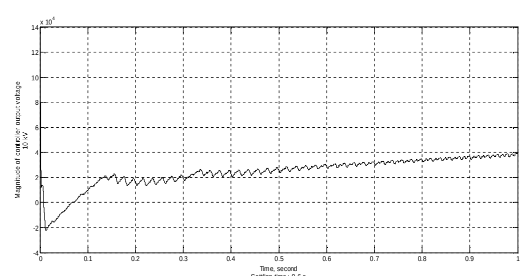

Fig. 8.2 PI Controller's response

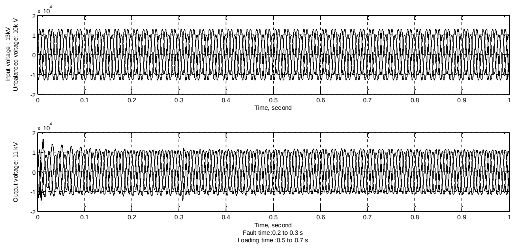

Fig. 8.3 Input and Output voltage of A Four Leg Voltage Source Converter Based DVR Using Fuzzy Logic Control

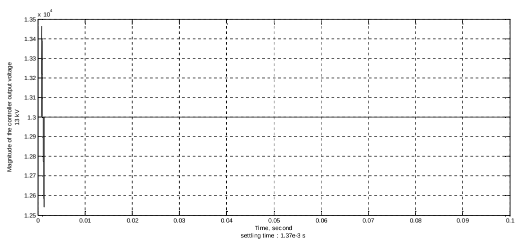

Fig. 8.4 Fuzzy Logic Controller's response

IX. TABLES

The response of Fuzzy Logic Controller is compared with PI controller and the results are tabulated and shown in Table.9.

Settling time for PI controller's response. (in seconds)	0.6 second
Settling time for Fuzzy Logic controller's response. (in seconds)	1.37e-3 second

Table.9 Response time of the controllers

X. CONCLUSION

Dynamic Voltage Restorer compensates both the steady state and the dynamic voltage quality problems. DVR is capable of absorbing real and reactive power at its AC terminals. The closed-loop control of the three phase, four leg VSC based Dynamic Voltage Restorer using PI and Fuzzy Logic Control is simulated and the objective of DVR is therefore verified.

The four leg Voltage Source Converter based DVR is able to protect the load from voltage sags due to various types of faults and unbalances. Fuzzy logic controller has an advantage over PI Controller, as the problems of fine-tuning are avoided. A comparison study of responses between PI Control and Fuzzy Logic Control is tabulated and the latter is proved fast and efficient compared to the conventional PI controller.

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