Multilevel Inverter Based Dynamic Voltage Restorer with Hysteresis Voltage Control for Power Quality Improvement

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***Abstract* - Dynamic Voltage Restorer (DVR) is a power electronic converter based custom power device used to compensate for voltage variations. The inverter used in the DVR structure can have different topologies. The cascaded multilevel inverter with separate DC source is the most feasible topology for medium high power applications due to their modularization and extensibility. In this paper, cascaded H-bridge multilevel inverter based DVR is used to regulate the load terminal voltage during sag and swell in the supply voltage. Hysteresis controller is used to trigger the switches of an inverter and provides good dynamic performance. Simulation results carried out by MATLAB with its simulink and simpower system toolboxes is used to verify the performance of the system. Also a comparative study of THD is done for different levels of cascaded multilevel inverter.**

***Keywords* - Dynamic Voltage Restorer (DVR); cascaded H- bridge multilevel inverter; hysteresis controller.**

I. INTRODUCTION

Voltage sag and swell are two most important term in power quality problems that produced almost 80% of the distribution system power quality problem. According to the IEEE standard, voltage sag is decrease of 0.1 to 0.9 p.u in the rms voltage level at the system frequency and with duration of half cycle to 1 min. Short circuits, starting large motors, sudden changes of load, and energization of transformer are the main cause of voltage sag. Considering the use of sensitive device in modern industries. Different methods of compensation of voltage sags have been used. One of those method is using a dynamic voltage restorer (DVR) with energy storage can be used to control power quality problems. Many variant DVR circuit topologies are available. The VSI as the main part of the DVR can have different circuit topologies. A cascaded H-bridge (CHB) multilevel inverter-based voltage sag compensator has been presented in [2] which is controlled by using the fundamental frequency control method. The cascaded multilevel inverter topology is used and makes it possible to implement cost-effective series sag compensation by eliminating the injection transformer and output filter components. Therefore as the output voltage is a stepped voltage, the output voltage quality is not acceptable for some operating points. Apart from the CHB topologies, other multilevel inverters such as the neutral point clamped (NPC) multilevel inverter [7-8] is also used. Especially, in medium-voltage grids the demand for securing larger loads has increased significantly. Installing higher power levels leads to the consideration of multi-level converters with an increased number of levels. Therefore, the 5-level NPC could be an interesting solution. The drawback of this topology is that its voltage levels are not stable for active power transmission. The flying capacitor multilevel inverter [9] has also been used in the DVR structure. The major advantages of the flying capacitor inverters are; (a) large amount of storage capacitors can provide capabilities during power outages. (b) These inverters provide switch combination redundancy for balancing different voltage levels. Considering the literature review presented above, different types of multilevel inverters have been used in the DVR structure to generate the required compensating voltage. However, the main issue considering the multilevel inverter based DVR is the fact that the output voltage of the multilevel inverter varies depending on the voltage sag depth. Clearly, for deep voltage sags the output voltage magnitude should be high and inversely for shallow voltage sags it is low. This implies that if the dc-link voltage is considered to be constant then the number of output voltage levels depends on the voltage sag depth. For shallow voltage sags, the number of voltage levels must be reduced. In this paper a new scheme is proposed for multilevel inverter-based DVR for better utilization of the multilevel inverter. The dc-dc converter is used to adjust the dc-link voltage considering the depth of voltage sag. Using this method, the maximum possible number of output voltage levels is generated for a wide variation of voltage sag depths. In this way, the quality of the output voltage is improved by reducing the filtering requirements.

II. DYNAMIC VOLTAGE RESTORER

Among the power quality problems voltage sags, swells and supply voltage unbalances are the most severe disturbances. DVR is one of those device used in recent times which is the most efficient and effective modern custom power device used in power distribution networks as shown in Fig.2. It is normally installed in a distribution system between the supply and the critical load feeder at the point of common coupling (PCC).

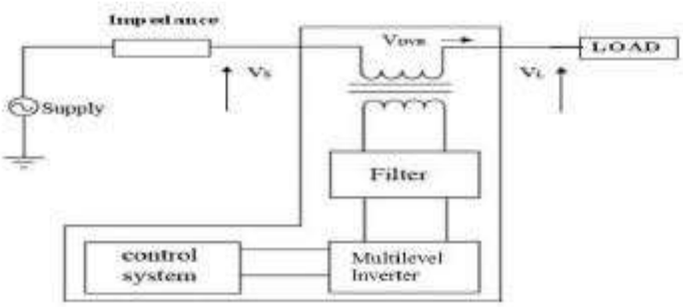

Fig.2 Schematic diagram of DVR

A. Basic Configuration of DVR

The general configuration of the DVR consists of:

1. An Injection transformer
2. A Harmonic filter
3. Storage Devices
4. A Voltage Source Converter (VSC)
5. DC charging circuit
6. A Control and Protection system

- An Injection transformer/ Booster transformer

Its main tasks are:

1. It connects the DVR to the distribution network.
2. In addition, the Injection / Booster transformer serves the purpose of isolating the load from the system (VSC and control mechanism).

- Harmonic Filter:

The harmonic filter keeps the harmonic voltage content generated by the VSC to the permissible level.

- Storage Devices:

The purpose of storage devices is to supply the necessary energy to the VSC via a dc link for the generation of injected voltages. The different kinds of energy storage devices are Superconductive magnetic energy storage (SMES), batteries and capacitance.

- Voltage Source Converter:

In DVR, the VSC is used to temporarily replace the supply voltage or to generate the part of the supply voltage which is missing. The main switching devices are MOSFET, GTO, IGBT, and IGCT. The IGCT has enhanced performance and reliability that allows building VSC with very large power ratings.

- DC Charging Circuit:

The DC Charging Circuit has two main tasks.

1. To charge the energy source after a sag compensation event.
2. To maintain dc link voltage at the nominal dc link voltage.

The system impedance Z_{TH} depends on the fault level of the load bus. When the system voltage (V_{TH}) drops, the DVR injects a series voltage V_{DVR} through the injection transformer so that the desired load voltage magnitude V_L can be maintained. The series injected voltage of the DVR can be written as

$$V_{DVR} = V_L + Z_{TH} I_L - V_{TH} \qquad (1)$$

Where

V_L: The desired load voltage magnitude

Z_{TH}: The load impedance

I_L: The load current

V_{TH}: The system voltage during fault condition

III. MULTIBAND HYSTERESIS MODULATION

Cascaded multilevel configuration of inverter has the advantage of its simplicity and modularity over the configurations of diode-clamped and flying capacitor multilevel inverters. Hysteresis Band Voltage control is used to control load voltage and determine switching signals for inverter switches. A hysteresis voltage control technique is implemented with a closed loop system where an error signal, e(t), is used to determine the switching states and to control the load voltage . The graphical representations of the cascaded multilevel inverter with the generalized multiband hysteresis modulation is shown in Fig.3 The basic building block of the H bridges required for an n-level inverter is N = (n-1)/2. For higher voltage/power-rating applications, the switching frequency and device ratings are limited. Therefore, it is desirable to distribute the voltage and power stress among the number of devices. For an n-level inverter, the voltage stress on the semiconductor switches and the dc-link capacitor is 1/N times the net dc-link voltage Vdc required. The voltage output of the n-level inverter is denoted by Vc = nVdc. With this modulation scheme, the frequency spectrum of the output voltage can be appropriately shifted to the high-frequency region and that the magnitude of the switching harmonics in the output voltage will also be reduced significantly. The number of hysteresis loops in each odd quadrant, as shown in Fig.3, is N, which is the same as the number of H-bridges in the cascaded multilevel inverter. Parameter h is the net hysteresis band, and ∂ is a small dead zone introduced to avoid any overlapping between adjoining loops.

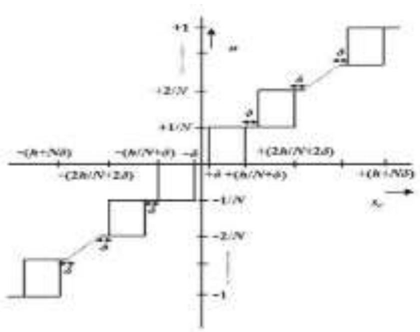

Fig.3 Multiband hysteresis modulation

IV. SIMULATION RESULTS

Cascaded H-bridge inverter based DVR is modeled and simulated using the MATLAB and its Simulink and Sim-Power System toolboxes. The MATLAB model of the DVR connected system is shown in Fig.4 below. A three-phase programmable voltage source is connected to the three phase non-linear load through the DVR in order to generate sag,swell and harmonics in supply side. The cascaded H bridge inverter of the DVR is connected to the system using an injection transformer with a transformation turns ratio equal to 1:1.

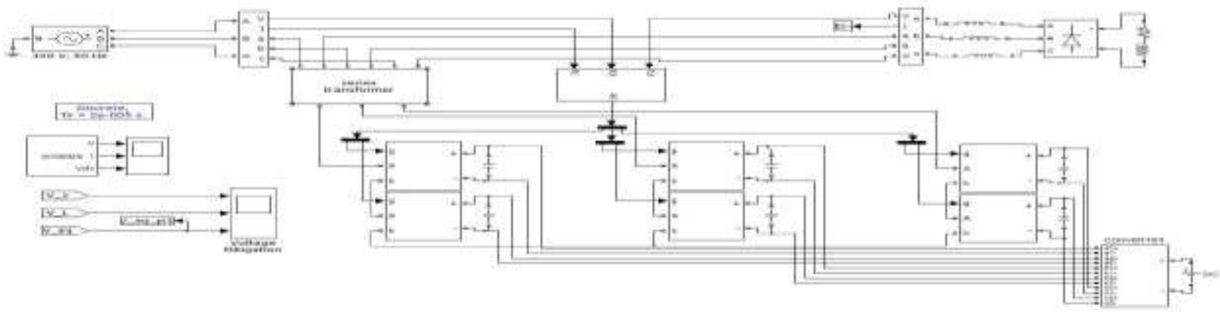

Fig.4 Simulation model of the system

V. PERFORMANCE OF THE SYSTEM

The performance of the DVR is demonstrated for different supply voltage disturbances such as sag and swells using a three phase programmable voltage source of 415V, 50Hz. A five level cascaded H-Bridge multilevel inverter has been used. A three-phase voltage sag of 60%(.4 p.u) initiated at 200 ms and it is kept until 400 ms, with total voltage sag duration of 200 ms. Fig.5 show the compensated load voltage and the voltage injected by the DVR, respectively. As a result of DVR, the load voltage is kept at 1 p.u. throughout the simulation, including the voltage sag period. It is observed that during normal operation, the DVR is not operational whereas it quickly injects necessary voltage components to smoothen the load voltage upon detecting voltage sag.

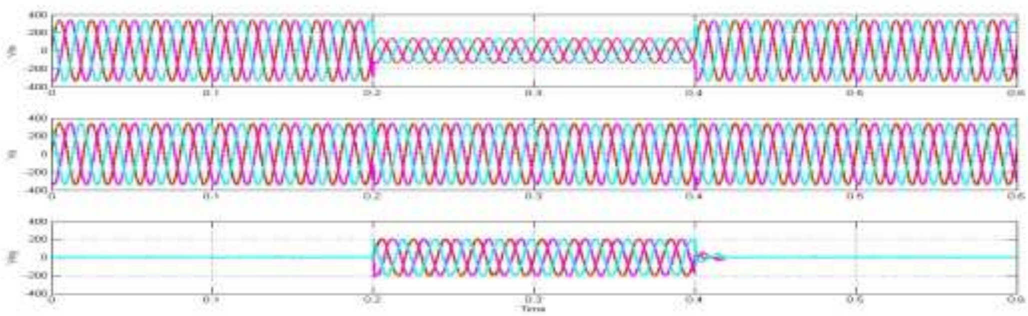

Fig.5 Source voltage, Compensated load voltage and DVR injected voltage for sag

Similarly a three-phase voltage swell of 25%(1.25 p.u) initiated at 700 ms and it is kept until 900 ms, with total voltage sag duration of 200 ms. Fig.6 shows the compensated load voltage and the voltage injected by the DVR, respectively. As a result of DVR, the load voltage is kept at 1 p.u. throughout the simulation, including the voltage swell period..

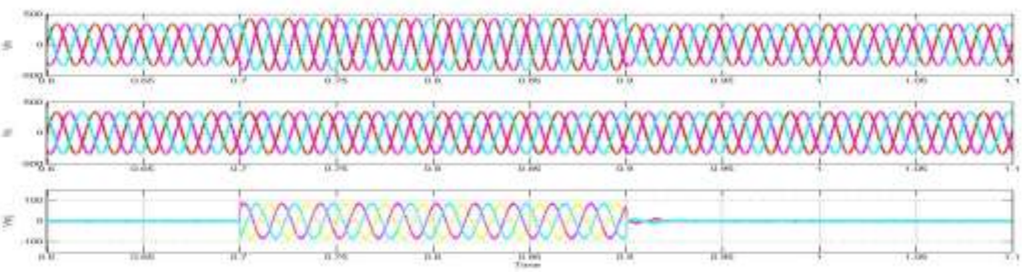

Fig.6 Source voltage, Compensated load voltage and DVR injected voltage for swell

A. Comparative study of harmonic analysis for cascaded H-bridge multilevel inverter

This paper has presented Total Harmonic Distortion (THD) analysis for Cascaded H- Bridge Multilevel Inverter. The simulation results for three-level, five-level, seven level and nine level cascaded inverters and their harmonic analysis are obtained. The THD of cascaded multilevel inverters have been calculated. The THD of three, five, seven and nine level multilevel inverters are 1.65%, 1.06%, 0.84% and 0.4% respectively. It can be observed that as the number of levels increases THD decreases without the use any filter circuit.

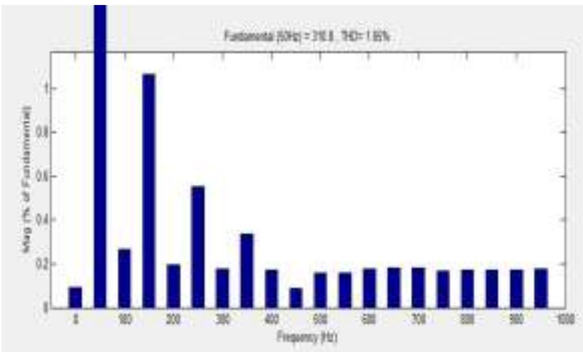

Fig.7 THD analysis of load voltage for 3-level cascaded inverter

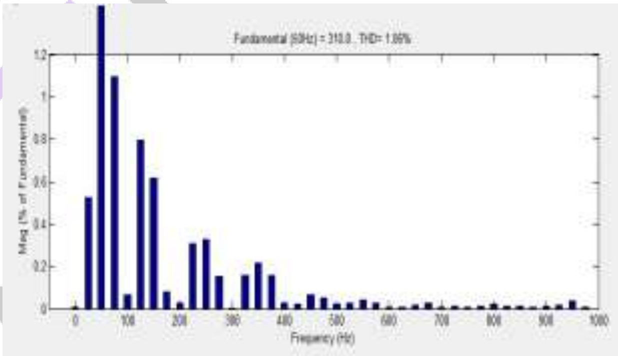

Fig.8 THD analysis of load voltage for 5-level cascaded inverter

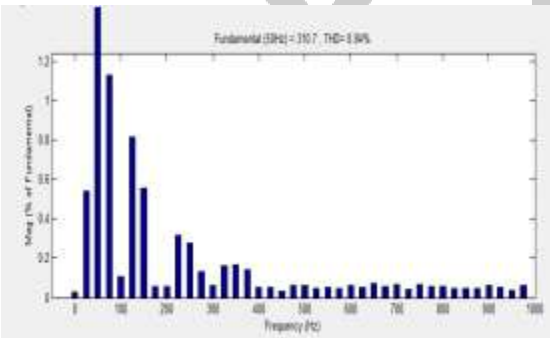

Fig.9 THD analysis of load voltage for 7-level cascaded inverter

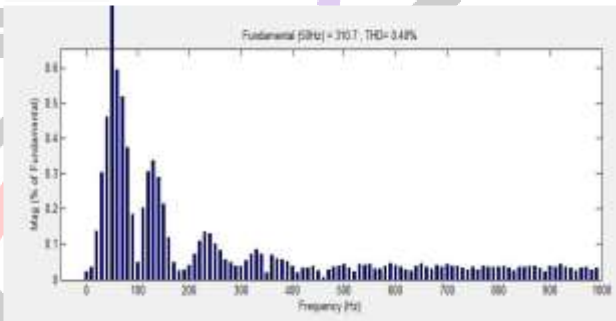

Fig.10 THD analysis of load voltage for 9-level cascaded inverter

CONCLUSION

The H-bridge inverter eliminates the excessively large number of bulky transformers required by conventional multilevel inverters, clamping diodes required by multilevel diode-clamped inverters, and flying capacitors required by multilevel flying-capacitor inverter. The simulation of a 415V, 50Hz, power distribution system is done using Matlab/ Simulink to study the effectiveness and response of suggested DVR control strategy. Hysteresis band voltage control is used to control load voltage and determine switching signals for inverter switches. The hysteresis voltage control has a very fast response, simple operation and variable switching frequency. In the case of voltage sag/swells, the DVR injects voltage in all three phases to compensate for the supply system. Simulation results show that, the DVR successfully protects the most critical load against voltage sags. From the comparative study of different levels of cascaded multilevel inverter it can be seen that as the number of levels increases THD decreases.

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