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Application of DVR to alleviate voltage sag and swell

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ABSTRACT : *This paper deals with modelling and simulation technique of a Dynamic Voltage Restorer (DVR) to alleviate the problem of voltage sags and swells and its severe impact on non linear loads or sensitive loads. Dynamic Voltage Restorer (DVR) is one of the most reliable and efficient custom power devices used in power distribution network. This paper describes space vector PWM technique used for VSI. There are two important parts in the DVR one is to detect the voltage disturbance and the other is to compensate it as fast as possible. The proposed control scheme is simple to design and has excellent voltage compensation capabilities. Effectiveness and fast response of proposed technique is investigated through computer simulation by using MATLAB/SIMULNK software. The simulation results have shown validation of the control system*
Keywords - *Dynamic Voltage Restorer (DVR), power quality, SVPWM, voltage sags, voltage swells.*

I. INTRODUCTION

Most of the world's electric power supply systems are widely interconnected. This is done for economic reasons, to reduce the cost of electricity and to improve reliability of power supply. Transmission interconnections enable taking advantage of diversity of loads, availability of sources, and fuel price in order to supply electricity to the loads at minimum cost with a required reliability. As power transfers grow, the power system becomes increasingly more complex to operate and the system can become less secure for riding through the major outages. It may lead to large power flows with inadequate control, excessive reactive power in various parts of the system, large dynamic swings between different parts of the system and bottlenecks, and thus the full potential of transmission interconnections cannot be utilized. There is a widespread use of microelectronics, computers and high-speed communications for control and protection of present transmission systems, however, when operating signals are sent to the power circuits, where the final power control action is taken, the switching devices are mechanical and there is little high-speed control. Another problem with mechanical devices is that control cannot be initiated frequently, because these mechanical devices tend to wear out very quickly. Both, dynamic and steady-state operation of the system is really uncontrolled.

In recent years, development in FACTS technology has proved it as a effective tool to alleviate some of these difficulties by enabling utilities to get the most service from their transmission facilities and enhance grid reliability.

Some of the most common occurring problems in transmission system are Voltage sag (or dip), Very short Interruptions, Long interruptions, Voltage spike, Voltage swell, Harmonic distortion, Voltage fluctuation, Noise, Voltage Unbalance etc., From above stated problem, voltage sag and swell collectively is a major factor in deteriorating power quality.

Voltage sag is a decrease of the normal voltage level between 10 and 90% of the nominal rms voltage at the power frequency, for durations of 0. 5 cycle to 1 minute. Faults on the transmission or distribution network, faults in consumer's installation, connection of heavy loads and start-up of large motors are some of the causes. That led to malfunction of information technology equipment, namely microprocessor-based control systems (PCs, PLCs, ASDs, etc) that may lead to a stoppage of process, tripping of contactors and electromechanical relays, disconnection and loss of efficiency in electric rotating machines. And voltage swell is the momentary increase of the voltage, at the power frequency, outside the normal tolerances, with duration of more than one cycle and typically less than a few seconds. Start/stop of heavy loads, badly dimensioned power sources, badly regulated transformers are the major causes. That led to problems such as data loss, flickering of lighting and screens, stoppage or damage of sensitive equipment, if the voltage values are too high. 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.

II. DYNAMIC VOLTAGE RESTORER

A Dynamic Voltage Restorer (DVR) is a series connected solid state device that injects voltage into the system in order to regulate the Source side voltage. It can be used to prevent non-linear loads from polluting the rest of the distribution system. The rapid response of the DVR makes it possible to provide continuous and dynamic control of the power supply including voltage and reactive power compensation, harmonic mitigation and elimination of voltage sags and swells.

2.1. Basic Configuration of DVR:

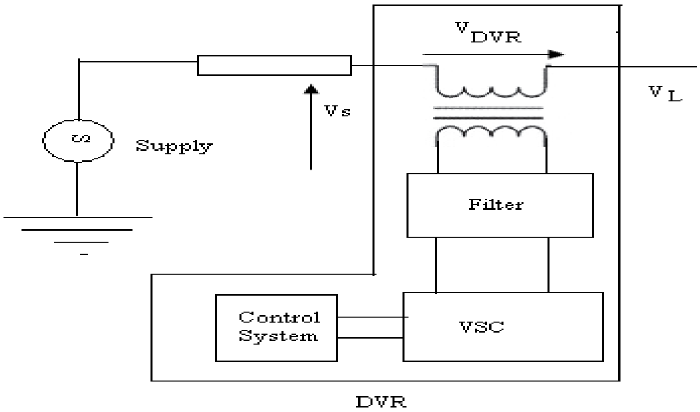


Fig.1 General Block Diagram of DVR.

2.1.1. Injection/Booster Transformer
2.1.2. Voltage Source Inverter
2.1.3. Harmonic Filter
2.1.4. Energy Storage Device
2.2. Working Principle of Dynamic Voltage Restorer
2.3. Equations Related To DVR

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.

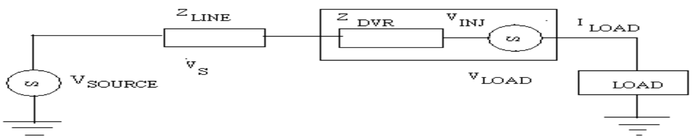


Fig.2. Equivalent Circuit Diagram of DVR

The series injected voltage of the DVR can be written as $V_{DVR} = V_L + Z_{TH} - V_{TH}$ (1)

Where **V_{DVR}**: The desired load voltage magnitude

Z_{TH}: The load impedance.

I_L: The load current.

V_{TH}: The system voltage during fault condition.

The load current I_L is given by, $I_L = \frac{[P_L + jQ_L]}{V}$ (2)

When V_L is considered as a reference equation can be rewritten as,

$$V_{DVR}\angle 0 = V_L\angle 0 + Z_{TH}\angle(\beta - \theta) - V_{TH}\angle\delta$$ (3)

α, β, δ are angles of V_{DVR}, Z_{TH}, V_{TH} respectively and θ is Load power angle

$$\theta = \tan^{-1}\left(\frac{\theta_L}{P_L}\right) \quad (4)$$

The complex power injection of the DVR can be written as,

$$S_{DVR} = V_{DVR} I_L^{\,*} \quad (5)$$

III. SPACE VECTOR PWM TECHNIQUE

The space vector modulation is a highly efficient way to generate the three PWM pulses necessary at the power stage for three-level inverter. S1 to S6 are the six power switches that shape the output, which are controlled by the switching variables a, a′, b, b′, c and c′. When an upper transistor is switched on, i.e., when a, b or c is 1, the corresponding lower transistor is switched off, i.e., the corresponding a′, b′ or c′ is 0. Therefore, the on and off states of the upper transistors S1, S3 and S5 can be used to determine the output voltage.

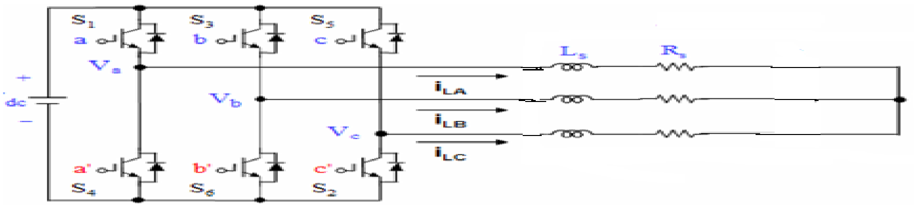


Fig.3. Three-Phase Voltage Source PWM Inverter

3.1. Relation between Switching Variable Vector and Line-Line and Phase-Phase Voltages
3.2. Switching vectors, Line to Neutral voltages and Line to Line voltages
3.3. ABC-DQ Reference Frame Transformation
3.4. Switching time at each sector

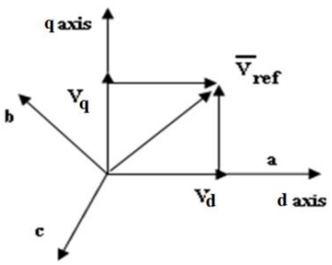


Fig.4. Relation between ABC reference frame and αβ reference frame

The relation between abc and dq reference frame is given as

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (6)$$

3.5. Basic Switching Vectors and Sectors
3.6. Determination of V_d, V_q, V_{ref}, And Angle (α)
3.7. Determination of Time Durations T_1, T_2, T_0

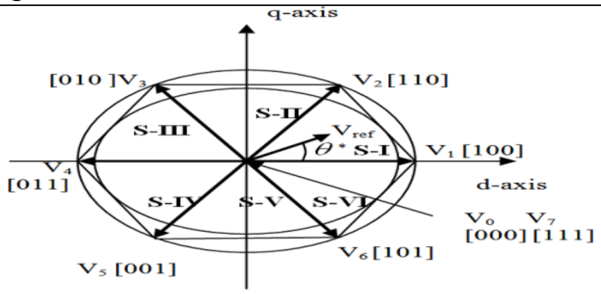
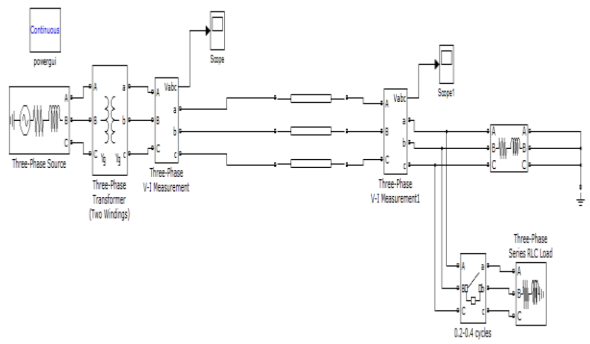


Fig.5. Vector Representations of the Switching Gates

3.8. Space Vector PWM based Control System

IV. SIMULATION RESULTS AND DISCUSSION



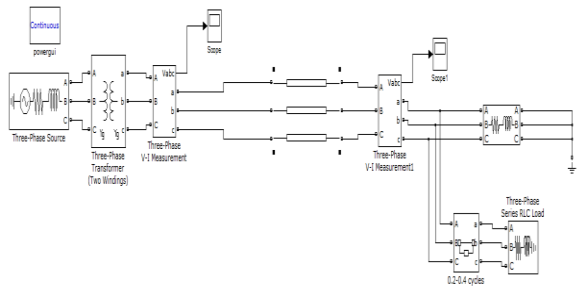


Fig.6. SIMULINK Block Diagram When Sag Occurs

Fig.7. SIMULINK Block Diagram When Swell Occurs

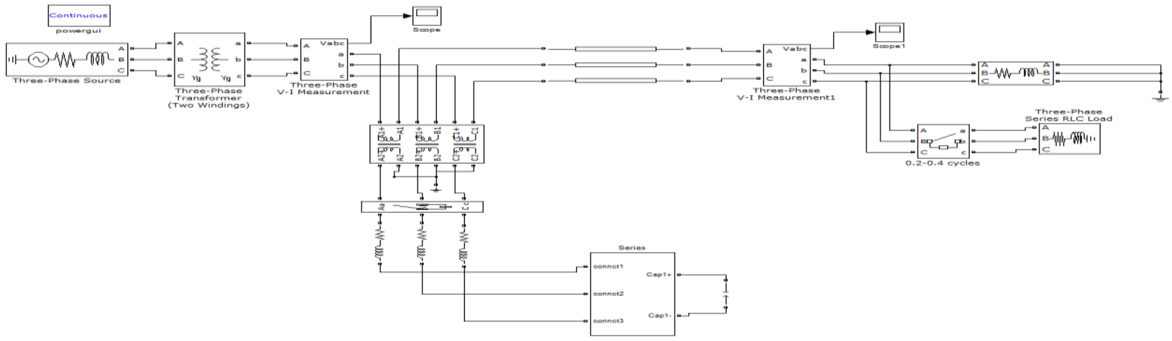


Fig.8. SIMULINK Block Diagram of Closed Loop System For Compensation Of Sag & Swell

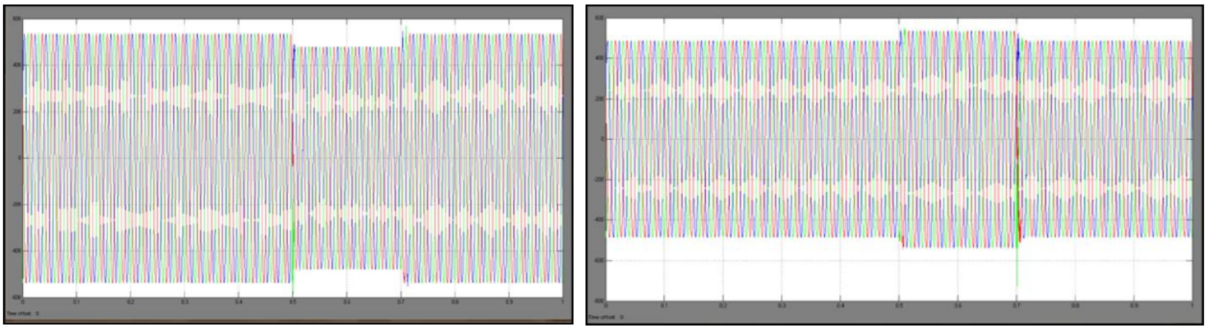


Fig.9. Source Side Voltage before Compensation When Sag & Swell Was Occurs

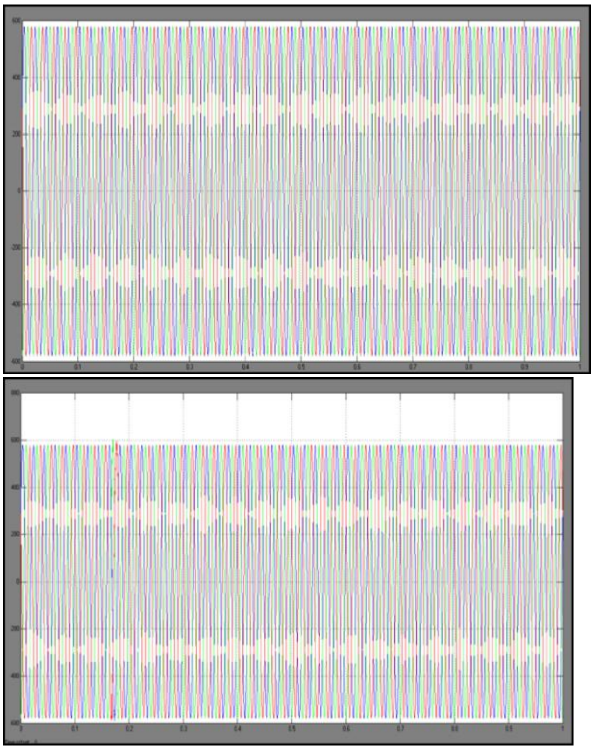


Fig.10. Source Side Voltage after Compensation When Sag & Swell Was Occurred

V. CONCLUSION

This paper presents the power quality problems such as voltage sag and swell, consequences and mitigation techniques of Dynamic Voltage Restorer (DVR). The performance of dynamic voltage restorer against voltage sags and voltage swells using Fundamental frequency method and SVPWM Technique is presented. The highly developed graphic facilities available in MATLAB/SIMULINK were used to conduct all aspects of model implementation and to carry our extensive simulation studies on test system.

A compensation strategy based on Phase Locked Loop (PLL) is also presented for DVR to compensate voltage sags with phase jump. The modeling and simulation of a DVR with PLL using MATLAB/SIMULINK is presented. The simulation shows that the DVR performance is satisfactory in mitigating voltage sag with phase jump.

The mitigation capability of DVR is mainly influenced by the maximum load and also limited by the energy storage capacity. Results show that for increasing load demand the DC energy storage capacity also increases. From the results it is observed that after a particular amount of load increases on 11KV feeders, the voltage levels at the load terminal decreases. Simulation results also show that the DVR compensates the sags quickly and provides excellent voltage regulation. The main advantage of this DVR is low cost and its control is simple. It can mitigate long duration voltage sags efficiently.

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