International Journal of Electrical and Power Engineering 4 (3): 164-168, 2010
ISSN: 1990-7958

Modeling and Simulation of PWM Switched Autotransformer for Voltage Sag Mitigation Using MATLAB

[1]T. Devaraju, [2]V.C. Veera Reddy and [1]M. Vijaya Kumar
[1]JNTU College of Engineering, Anantapur, A.P., India
[2]Department of EEE, SVUCE, Tirupati, A.P., India

Abstract: This study addresses the modeling and simulation of a new voltage sag mitigation technique is presented besides custom power devices like dynamic voltage restorer and STATCOM are normally employed as a solution for mitigation of voltage sag and swell. In this study, modeling and analysis of PWM switched autotransformer that can compensate during voltage sag and swell condition is discussed. The proposed system has less number of switching devices and has good compensating capability in comparison to commonly used compensators. Simulation analysis of three-phase compensator is performed in MATLAB/SIMULINK and performance analysis of the system is presented for various levels of sag and swell. Also, the compensator can maintain the load powers both real and reactive powers constant. Simulation results are presented for various conditions of sag and swell disturbances in the supply voltage to show the performance of the new mitigation technique.

Key words: DVR, voltage sag, voltage swell, sag mitigation, switched autotransformer, PWM

INTRODUCTION

Power Quality (PQ) problems have become an increasing concern with an increased usage of critical and sensitive loads in industrial processes. Disturbances such as voltage sags and swells, short duration interruptions, harmonics and transients may disrupt the processes and lead to considerable economic loss. Power Quality (PQ) problems are classified as per the international standards and methods of classifying primary and secondary distribution problems by duration, type and severity (Ghosh and Ledwich, 2002). Among the disturbances, voltage sags are considered to be the most significant and critical.

Voltage sag is a momentary decrease of the voltage RMS value with the duration of half a cycle up to many cycles. Voltage sag can cause serious problem to sensitive loads that use voltage sensitive components such as adjustable speed drives, process control equipment and computers and voltage sags last until network faults are cleared. In order to increase the reliability of a power distribution system, many methods of solving power quality problems have been suggested (Arnold, 2001). Various voltage sag mitigation schemes are based on inverter systems consisting of energy storage and switches.

The D-STATCOM has emerged as a promising device to provide not only for voltage sag mitigation but a host of other power quality solutions such as voltage stabilization, flicker suppression, power factor correction and harmonic control (Hingorani and Gyugyi, 2000). The D-STATCOM has additional capability that provides voltage support and regulation of VAr flow. Because the device generates a synchronous wave form, it is capable of generating variable reactive or capacitive shunt compensation at a level up to the maximum MVA rating of the D-STATCOM inverter.

A dynamic voltage restorer is one device having capability of protecting sensitive loads from all supply side disturbances. The Dynamic Voltage Restorer (DVR) employs series voltage boost technology using solid state switches to correct the load voltage amplitude as needed (Cao *et al*., 2001).

The basic concept is that during sag period, the DVR operates in boost mode and injects voltage of sufficient magnitude to maintain constant voltage throughout the sag period. This developed controllable voltage is added to the supply voltage through the use of a series transformer to get the required load voltage.

A new mitigation device for voltage sag is proposed by Lee *et al*. (2007) using PWM-switched autotransformer. The performance of the compensator for various sag conditions is presented. This study presents mitigating device for voltage sag disturbances using PWM-switched autotransformer. Here, the control circuit based on RMS voltage is used to identify the sag

Corresponding Author: T. Devaraju, JNTU College of Engineering, Anantapur, A.P., India

and swell disturbances. This compensator has less switching devices and hence reduced gate drive circuit size but has the capability to supply the required undistorted load voltage and currents. It has only one switching device per phase and no energy storage device. Simulation of the compensator is performed using MATLAB/SIMULINK and performance results are presented.

MATERIALS AND METHODS

Proposed system configuration: The proposed device for mitigating voltage sag and swell in the system consists of a PWM switched power electronic device connected to an autotransformer in series with the load. Figure 1 shows the single phase circuit configuration of the mitigating device and the control circuit logic used in the system. It consists of a single PWM Insulated Gate Bipolar Transistor (IGBT) switch in a bridge configuration, a thyristor bypass switch, an autotransformer and voltage controller.

Principle of operation: To maintain the load voltage constant an IGBT is used as power electronic device to inject the error voltage into the line. Four power diodes (D1-D4) connected to IGBT Switch (SW) controls the direction of power flow and connected in ac voltage controller configuration with a suitable control circuit maintains constant RMS load voltage. In this scheme, sinusoidal PWM pulse technique is used. RMS value of the load voltage V_L is calculated and compared with the reference RMS voltage V_{ref}.

During normal condition the power flow is through the anti parallel thyristors. Output filters containing a main capacitor filter and a notch filter are used at the output side to filter out the switching noise and reduce harmonics. During this normal condition, $V_L = V_{ref}$ and the error voltage V_{err} is zero. The gate pulses are blocked to IGBT.

Due to sudden increase or decrease in the load or due to faults voltage sag or swell occurs. The supply voltage V_S and hence V_L decreases. When the sensing circuit detects an error voltage V_{err} >10% of the normal voltage the voltage controller acts immediately to switch off the thyristors. Voltage V_{err} applied to the pi controller gives the phase angle δ. The control voltage given in Eq. 1 is constructed at power frequency f = 50 Hz:

$$V_{control} = m_a * \sin(\omega t + \delta) \quad (1)$$

Where m_a is the modulation index. The phase angle a is dependent on the percentage of disturbance and hence controls the magnitude of $V_{control}$.

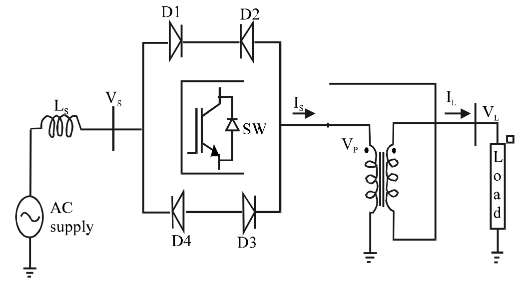

Fig. 1: Voltage sag/swell mitigating device

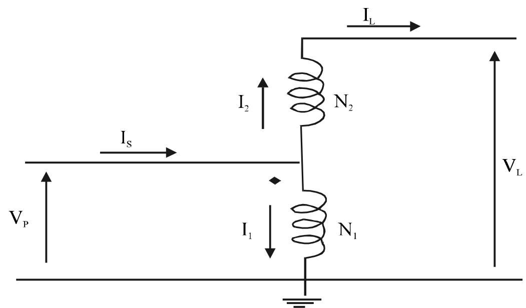

Fig. 2: Voltage and current relations in an autotransformer

This control voltage is then compared with the triangular voltage V_{tri} to generate the PWM pulses VG which are applied to the IGBT to regulate the output voltage. Hence, the IGBT switch operates only during voltage sag or swells condition and regulates the output voltage according to the PWM duty-cycle. To suppress the over voltage when the switches are turned off, RC snubber circuits are connected across the IGBT and thyristor.

Voltage sag compensation: The ac converter topology is employed for realizing the voltage sag compensator. This study considers the voltage mitigation scheme that use only one shunt type PWM switch (Fitzer *et al*., 2004) for output voltage control as shown in Fig. 2. The autotransformer shown in Fig. 1 is used in the proposed system to boost the input voltage instead of a two winding transformer. Switch IGBT is on the primary side of the autotransformer. The voltage and current distribution in the autotransformer is shown in Fig. 2. It does not provide electrical isolation between primary side and secondary side but has advantages of high efficiency with small volume. The compensator considered is a shunt type as the control voltage developed is injected in shunt. The relationships of the autotransformer voltage and current are expressed in Eq. 2:

$$\frac{V_L}{V_P} = a = \frac{I_S}{I_L} = \frac{N_1 + N_2}{N_1} \quad (2)$$

Where:

a = The turns ratio
V_p = Primary voltage
V_L = Secondary voltage = Load voltage
I_1, I_2 = Primary and secondary currents, respectively
I_S = Source current
I_L = Load current

A transformer with N1:N2 = 1:1 ratio is used as an autotransformer to boost the voltage on the load side when sag is detected. With this the device can mitigate up to 50% voltage sag. As the turns ratio equals 1:2 in autotransformer mode, the magnitude of the load current I_L (high voltage side) is the same as that of the primary current I_1 (low voltage side). From Eq. 2, it is clear that $V_L = 2V_P$ and $I_S = 2I_L$. The switch is located in the autotransformer's primary side and the magnitude of the switch current equals the load current.

The voltage cross the switch in the off-state is equal to the magnitude of the input voltage. When sag is detected by the voltage controller, IGBT switched ON and is regulated by the PWM pulses. The primary voltage V_P is such that the load voltage on the secondary of autotransformer is the desired RMS voltage.

Ripple filter design: The output voltage V_P given by the IGBT is the pulse containing fundamental component of 50 Hz and harmonics at switching frequency. Hence, there is a necessity to design a suitable ripple filter at the output of the IGBT to obtain the load voltage THD within the limits. A combination of notch filter to remove the harmonics and a low pass filter for the fundamental component is used. Capacitor C_{r1} in combination with source inductance and leakage inductance form the low pass filter.

The notch filter is designed with a center frequency of PWM switching frequency by using a series LC filter. A resistor may be added to limit the current. The impedance of the filter is given by Eq. 3:

$$|Z| = \sqrt{R^2 + \left(\omega L_r - \frac{1}{\omega C_{r2}}\right)^2} \tag{3}$$

Where, R, L_r and C_{r2} are the notch filter resistance, inductance and capacitances, respectively. The resonant frequency of the notch filter is tuned to the PWM switching frequency. The capacitor is designed by considering its kVA to be 25% of the system kVA. Capacitor value (C_{total}) thus obtained is divided into C_{r1} and C_{r2} equally. The notch filter designed for switching frequency resonance condition is capacitive in nature for frequencies less than its resonance frequency. Hence, at fundamental frequency, it is capacitive of value C_{r2} and is in parallel with C_{r1} resulting to C_{total}.

RESULTS AND DISCUSSION

Simulation analysis is performed on a three-phase, 115/11 kV, 100 MVA, 50 Hz system to study the performance of the PWM switched autotransformer in mitigating the voltage sag. The SIMULINK model of the system used for analysis is shown in Fig. 3. An RL load is considered as a sensitive load which is to be supplied at

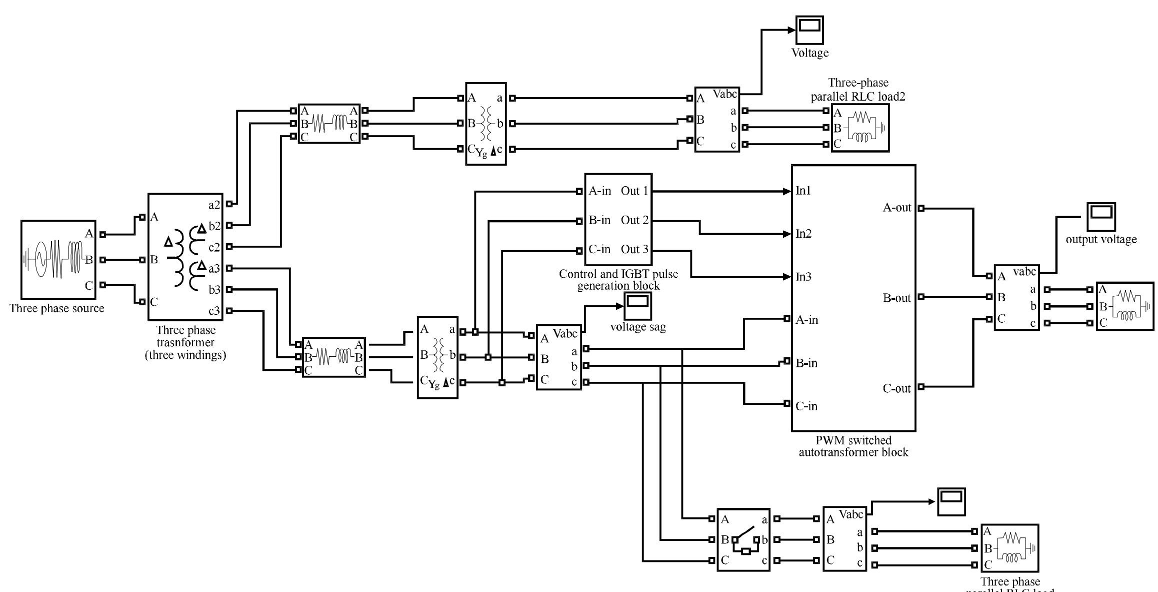

Fig. 3: MATLAB/SIMULINK model of a 3-phase system used for voltage sag studies

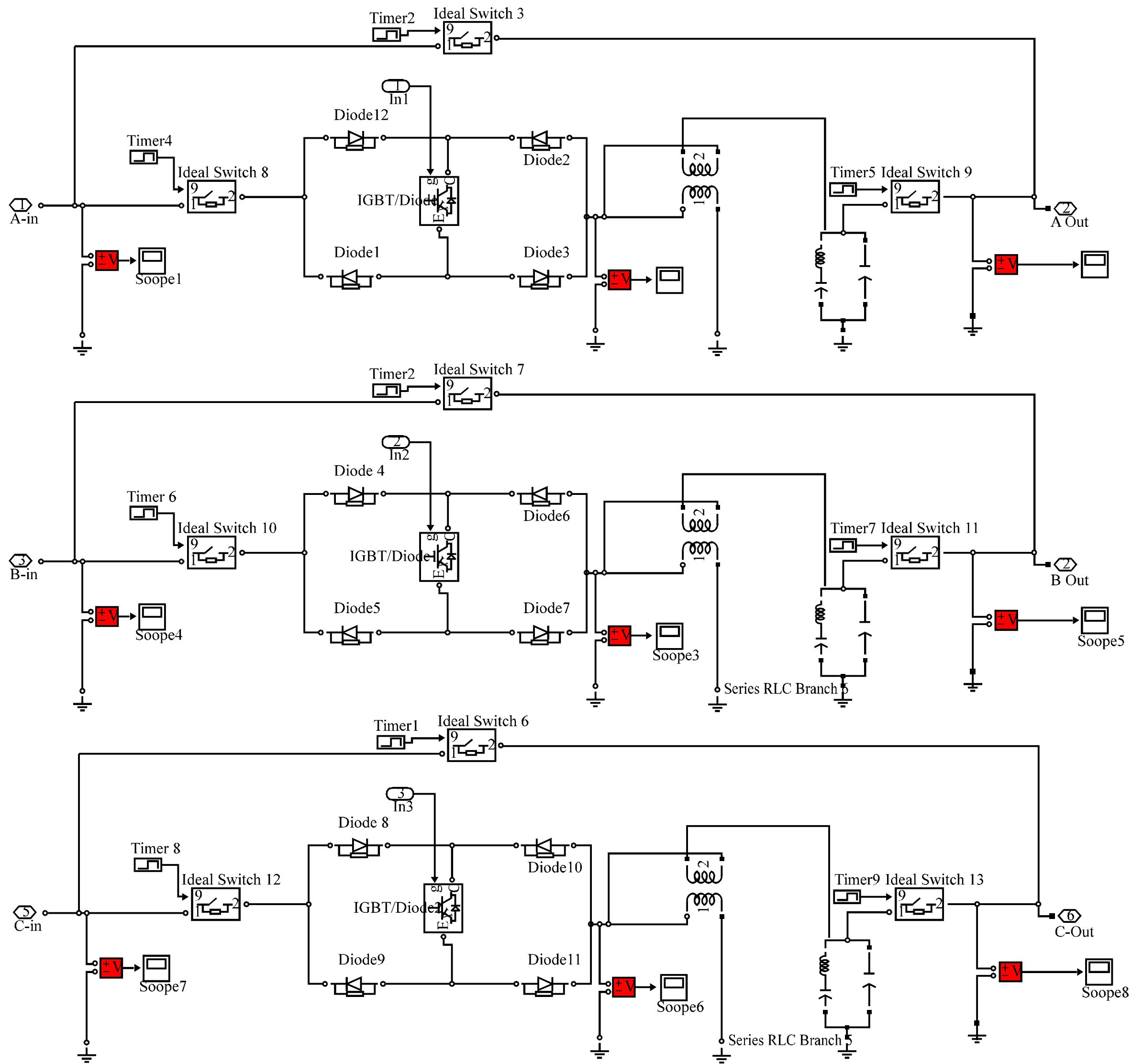

Fig. 4: Model of 3-phase PWM switched autotransformer

Table 1: System parameter use for simulation

Parameters	Values
Supply	3-Phase100 MVA, 11 kV, 50 Hz
Autotransformer	
Primary	6.35 kV, 35MVA, 50 Hz
Secondary	6.35 or 7 kV, 35 MVA, 50 Hz
Ripple filter at output of autotransformer	L_r = 300 mH C_{r1} = C_{r2} = 53 µF
Load 1	P = 10 KW , Q = 10 Kvar
Load 2 (for sag generation)	P = 10 MW , Q = 5Mvar

constant voltage. Table 1 shows the system parameter specifications used for simulation. Under normal condition, the power flow is through the antiparallel SCRs and the gate pulses are inhibited to IGBT. The load voltage and current are same as supply voltage and current. When a disturbance occurs, an error voltage which is the difference between the reference RMS

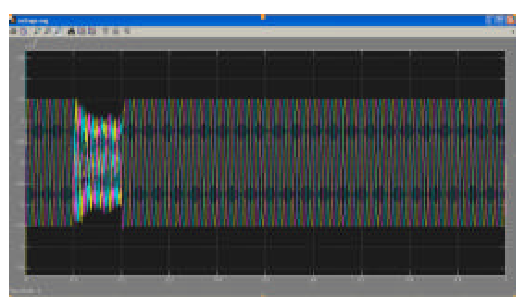

Fig. 5: The simulation waveforms of the load voltage for voltage sag of 27% at 0.1 sec

voltage and the load RMS voltage is generated. The PI controller thus gives the angle δ. Control voltage at

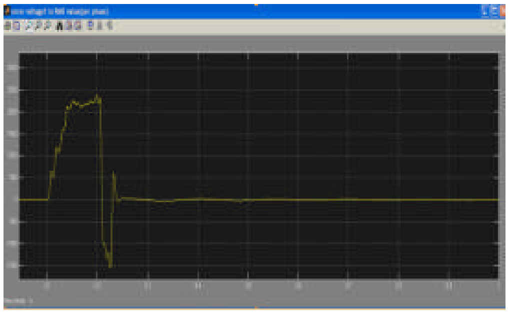

Fig. 6 : Simulation waveform for per phase error voltage 1 in RMS value

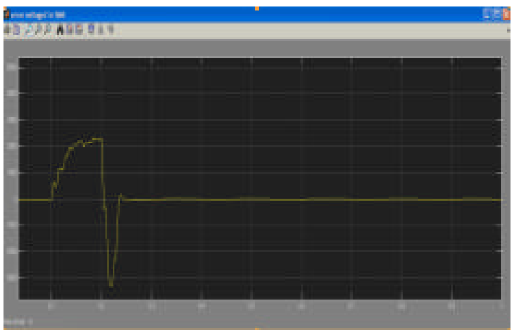

Fig. 7: Simulation waveform for per phase error voltage 2 in RMS value

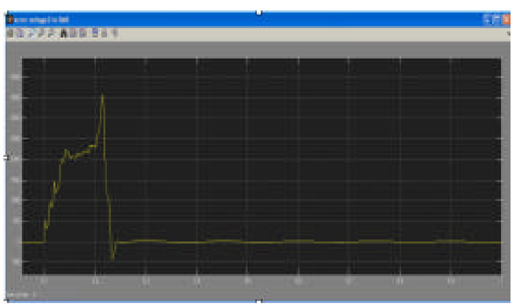

Fig. 8: Simulation waveform for per phase error voltage 3 in RMS value

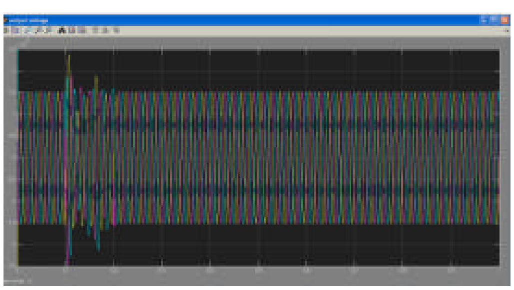

Fig. 9: Simulation waveform for voltage sag mitigated using pwm switched autotransformer

fundamental frequency (50 Hz) is generated and compared with the carrier frequency triangular wave of carrier frequency 1.5 kHz. The PWM pulses now drive the IGBT switch. The simulation modeling of PWM switched autotransformer used as mitigating device along with its control circuit is shown in Fig. 4.

The autotransformer rating in each phase is 6.35/6.35 kV (as line voltage is 11 kV) with 1:1 turns ratio. The effective voltage available at the primary of autotransformer is such that the load voltage is maintained at desired RMS value (6.35 kV or 1 pu). Voltage sag is created during the simulation by sudden application of heavy load of P = 10 MW and Q = 50 Mvar for a period of 0.1 sec (5 cycles) from t_1 = 0.1 sec to t_2 = 0.2 sec, Fig. 6-9 shows the simulation waveforms of the load voltage for voltage sag of 27%.

CONCLUSION

A new voltage sag compensator based on PWM switched autotransformer has been presented in this study. Control circuit based on RMS voltage reference is discussed. The proposed technique could identify the disturbance and capable of mitigating the disturbance by maintaining the load voltage at desired magnitude within limits. The proposed technique is simple and only one IGBT switch per phase is required. Hence, the system is more simple and economical compared to commonly used DVR or STATCOM. Simulation analysis is performed for 27% voltage sag for three phase system and simulation results verify that the proposed device is effective in compensating the voltage sag disturbances.

REFERENCES

Arnold, R., 2001. Solutions to the power quality problem. Power Eng. J., 15: 65-73.

Cao, R., J. Zhao, W. Shi, P. Ziang and G. Tang, 2001. Series Power Quality Compensator for Voltage Sags, Swells, Harmonics and Unbalance. Proc. IEEE/PES Trans. Distribution Conf. Exposition, 1: 543-547.

Fitzer, C., M. Barnes and P. Green, 2004. Voltage sag detection technique for a dynamic voltage restorer. IEEE Trans. Indus. Appl., 40: 203-212.

Ghosh, A. and G. Ledwich, 2002. Power Quality Enhancement Using Custom Power Devices. Kluwer Academic Publishers, Boston, USA., pp: 1-54.

Hingorani, N.G. and L. Gyugyi, 2000. Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems. IEEE Press, New York, pp: 432.

Lee, D.M., T.G. Habetler, R.G. Harley, T.L. Keister and J.R. Rostran, 2007. A voltage sag supporter utilizing a PWM-switched autotransformer. IEEE Trans. Power Electronics, 22: 626-635.