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Voltage Sag Compensation Using PWM-Switched Autotransformer

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ABSTRACT: This paper presents a novel voltage control scheme that compensates voltage sag in three phase power system. The custom power devices like dynamic voltage restorer and STATCOM are normally employed as a solution for mitigation of voltage sag and swell. Fault occurring in power distribution systems or facilities in plant cause voltage sag or swell. If a fault occurs, it can damage the power system or users facility. For sensitive loads, even voltage sag of short duration can cause serious problem in the entire system. Normally, a voltage interruption triggers a protective device, which causes shut down of the entire system. This paper presents modelling and analysis of PWM switched auto-transformer that can compensate during voltage sag conditions. The proposed scheme is able to quickly recognize the voltage sag condition and it can correct the voltage by either boosting the input voltage sag events or reducing the input voltage during voltage swell events. This system has less number of switching devices and has good compensating capability in comparison to commonly used compensator. The simulation analysis of three phase compensator is performed in MATLAB/SIMULINK and performance analysis presented for various levels of sag and swell. Simulation results are presented for various condition of voltage sag and swell disturbances in the supply voltage to show the performance of the new mitigation technique.

KEYWORDS: DVR, PWM, sag mitigation, switched auto-transformer, voltage sag.

I. INTRODUCTION

Now a day's power quality issues have become an increasing concern because of the increase in use of the sensitive loads. The production process is interrupted because poor distribution of power quality results in power disruption for the user and huge economical losses. Disturbances in power quality such as voltage sags and swells, short duration interruptions, harmonics and transients. Voltage sag and swell are the most significant and critical disturbances present in industrial power system facing industrial customers [1], [2].

According to IEEE standard 1159-1995, voltage sag is defined as an RMS variation with a magnitude between 10% to 90% of nominal voltage and duration between 0.5 cycles and one minute. Voltage sag can cause serious problem to sensitive load that use voltage sensitive components such as adjustable speed drives, process control equipment and computers and voltage sags last until network fault are cleared. In order to increase the reliability of a power distribution system, many method of solving power quality problems, have been suggested [2], [7]. Various voltage sag mitigation schemes are based on inverter systems, consisting of energy storage and power switches.

The flexible ac transmission systems (FACTS) devices such as a dynamic voltage restorer (DVR) and a distribution static synchronous compensator (D-STATCOM) that use the inverter technology to regulate power flow in the transmission system. The D-STATCOM has not only for voltage sag compensator but also to solve the power quality problem such as voltage stabilization, flicker suppression, power factor correction and harmonic control. It has additional capability that provides voltage support and regulation of VAR flow. Because the synchronous wave form generated by this device and it is capable of generating variable reactive or capacitive shunt compensation at a level up to maximum MVA rating of the D-STATCOM inverter [3], [4], [5]. A dynamic voltage restorer is a device having capability of protecting sensitive loads from all supply side disturbances. The dynamic voltage restorer employs series voltage boost technology using solid state switches to correct the load voltage amplitude as needed. The basic concept

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is that during sag period DVR operates in boost mode and inject voltage of sufficient magnitude to maintain constant voltage throughout 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 PWM-switched autotransformer is a new mitigation device for voltage sag is proposed. This paper presents compensation device for voltage sag disturbances using PWM-switched autotransformer [6]. The control circuit is based on the RMS voltage is used to identify the sag 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. In this paper, simulation of the compensator is performed using MATLAB and performance results are presented.

II. BASIC CONFIGURATION OF PROPOSED SYSTEM

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

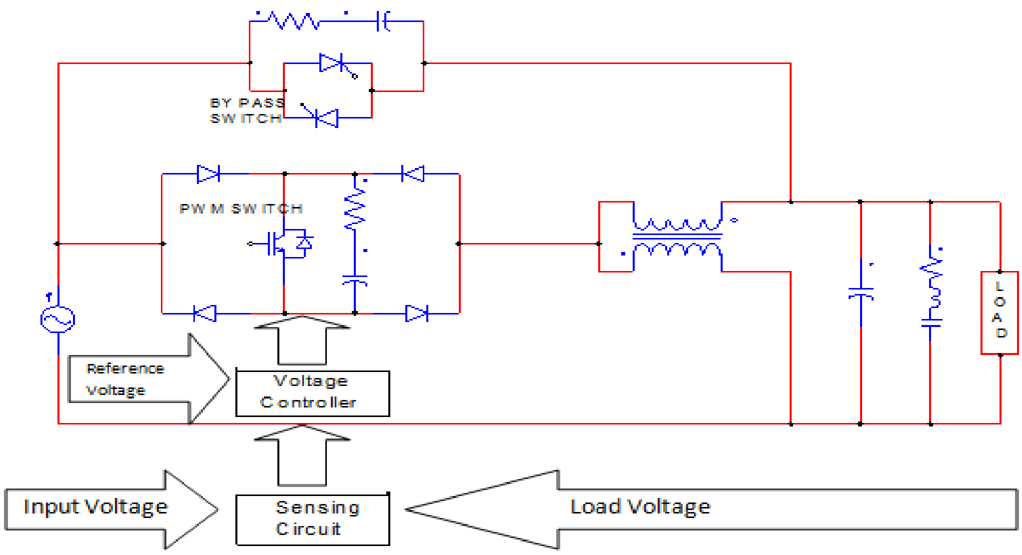

Fig. 1 Basic configuration of the proposed voltage compensation scheme

III. WORKING PRINCIPLE

An IGBT is used as a power electronic device to inject the error voltage into the line so as to maintain load voltage constant. Four power diodes (D1 to D4) connected to IGBT switch control the direction of power flow and connected in ac voltage controller configuration as shown in fig.1. This combination 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} .

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

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When a disturbance occurs, an error voltage which is the difference between the reference rms voltage and the load rms voltage is generated. Voltage error applied to the PI controller gives the phase angle δ . The control voltage given in equation (1) is constructed at power frequency $f = 50Hz$.

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

Where m_a is the modulation index.

The phase angle δ is dependent on the percentage of disturbance and hence the magnitude of $V_{control}$. This control voltage is then compared with the triangular voltage V_{tri} to generate the PWM pulses during 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 circuit connected across the IGBT and thyristor.

IV.VOLTAGE SAG COMPENSATION

The ac converter topology is employed for realizing the voltage sag compensator. This paper considers the voltage mitigation scheme that use only one shunt type PWM switch for output voltage control as shown in fig. 2. The autotransformer shown in fig.2 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.

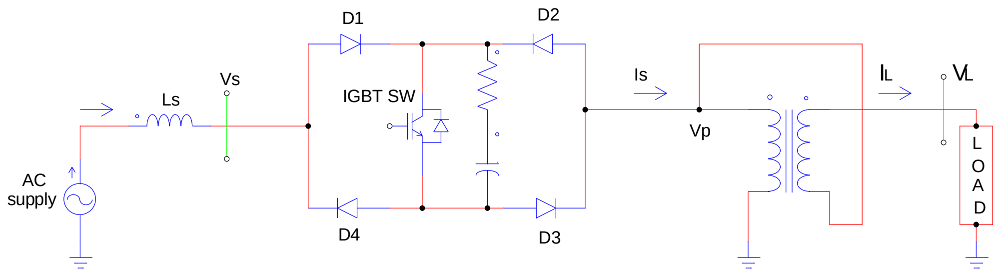

Fig. 2 Voltage sag/swell mitigating device

The voltage and current distribution in the autotransformer is shown in fig. 3. 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 equation (2),

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

Where
α is the turns ratio;
V_P is the primary voltage;
V_L is the secondary voltage = Load voltage;
I_1, I_2 are the primary and secondary currents, respectively;
I_S is the source current;
I_L is the load current

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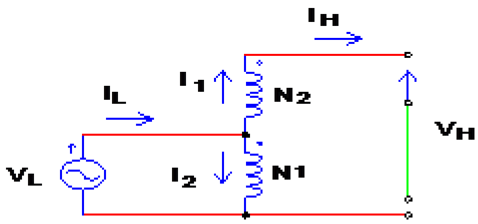

Fig. 3 An autotransformer

The autotransformer in fig. 3 does not offer electrical isolation between primary side and secondary side but has the advantages of high efficiency with small volume. A transformer with $N_1 : N_2 = 1:1$ ratio is used as an autotransformer to boost the voltage on the load side when sag is detected. With this, the device can mitigate voltage sag up to 50% during the sag period. 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 equation (2), it is clear that $V_L = 2V_P$ and $I_S = 2I_L$. The switch is located on the autotransformer's primary side and the magnitude of the switch current equals the load current. The voltage across the switch in the off-state is equal to the magnitude of the input voltage. When sag is detected by the voltage controller, IGBT is 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.

V. 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 notch filter to remove the harmonics and a low pass filter for the fundamental component are used as shown in Fig.1. 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 equation (3).

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

Where R, L_r, 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 into C_{total}.

VI. SIMULATION ANALYSIS AND RESULTS

Simulation analysis is performed on a three-phase system to study the performance of the PWM switched autotransformer in mitigating the voltage sag and swell disturbances. The MATLAB/SIMULINK model of the system used for analysis is shown in fig. 4. An RL load is considered as a sensitive load, which is to be supplied at constant voltage.

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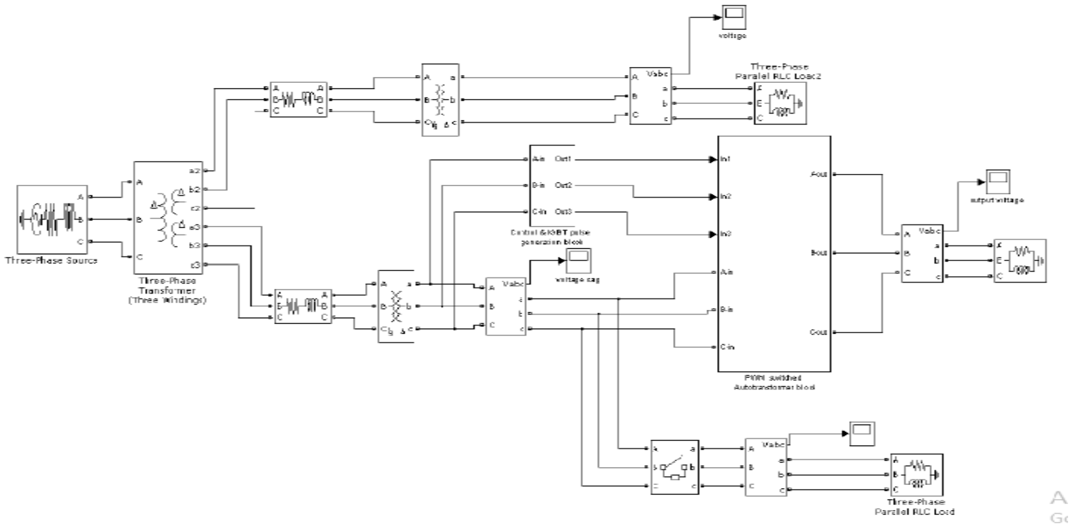

Fig. 4 MATLAB/SIMULINK model of the system.

Under normal condition, the power flow is through the anti parallel 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 voltage and the load rms voltage is generated. The PI controller thus gives the angle δ . Control voltage at fundamental frequency (50 Hz) is generated and compared with the triangular wave of carrier frequency 1.5 kHz. The PWM pulses now drive the IGBT switch. The simulation model of PWM switched autotransformer is used as a mitigating device.

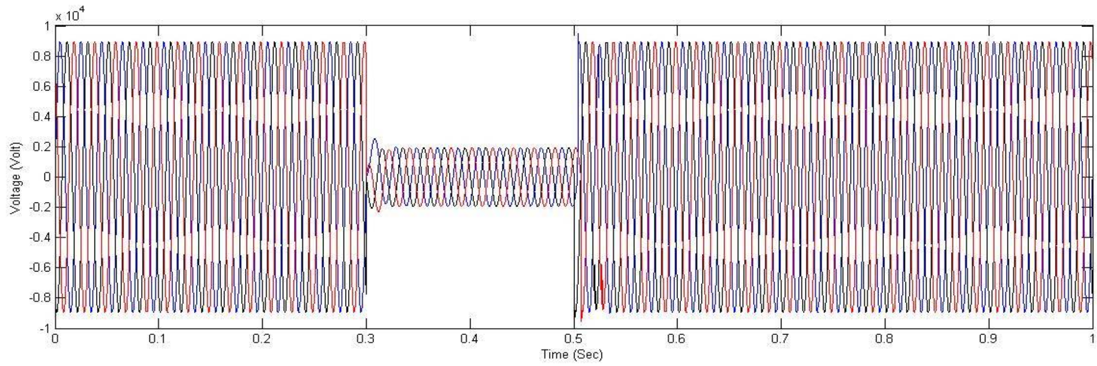

Fig. 5 Simulation waveform of the load voltage for voltage sag

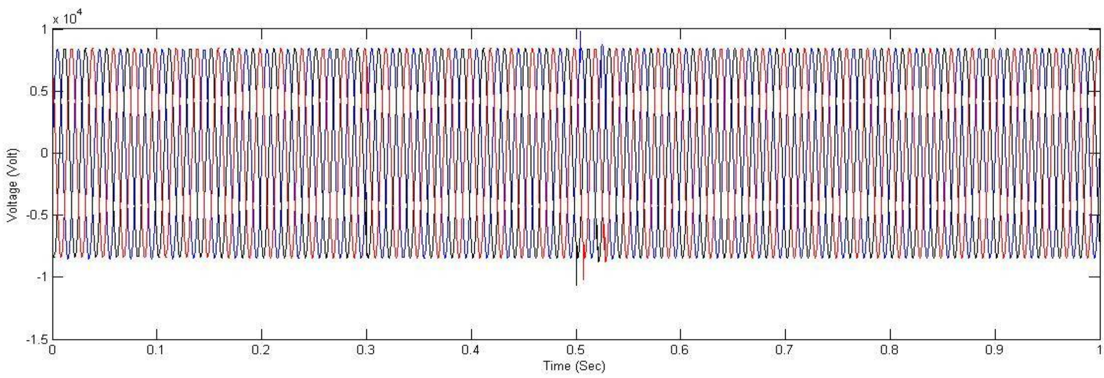

Fig. 6 Simulation waveform for voltage sag compensated using PWM switched autotransformer

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The autotransformer turns ratio is 1:1. The effective voltage available at the primary of autotransformer is such that the load voltage is maintained at desired rms value (1 pu). Voltage sag is created during the simulation by sudden application of heavy load for a period of 0.2sec from t_1 = 0.3sec to t_2 = 0.5 sec. Fig. 5 shows the simulation waveforms of the load voltage for voltage sag.

VII. CONCLUSION

This voltage sag mitigation method is simple, fast and economical solution because it uses the only one IGBT switch per phase. This technique is capable of mitigating the disturbance by maintaining the load voltage magnitude at desired limits. Proposed system was able to mitigate voltage sag with a fast dynamic response.

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