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Voltage Sag Mitigation Using Pulse Width Modulation Switched Autotransformer through Matlab Simulation

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Abstract

In this paper, a new voltage sag compensator for critical loads in electrical distribution system discussed. The proposed scheme employs a Pulse width modulation ac-ac converter along with a auto transformer. During a disturbance such as voltage sag, the proposed scheme supplies the missing voltage and helps in maintaining the rated voltage at the terminals of the critical load. Under normal condition the approach work in bypass mode and delivering utility power directly to load. 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.

***Keywords**:- Power Quality, Voltage Sag, PWM Switched Autotransformer, IGBTs, Sag Mitigation.*

I. INTRODUCTION

Power Quality issues 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 [3,4]. A power distribution system is similar to a vast network of rivers. It is important to remove any system faults so that the rest of the power distribution service is not interrupted or damaged. When a fault occurs somewhere in a power distribution system, the voltage is effected throughout the power system. Among the various power quality problems, the majority of events are associated with either a voltage sag or a voltage swell, and the often cause serious power interruptions. A voltage sag condition implies that the voltage on one or more phases drops below the specified tolerance for a short period of time [2,5].

A new mitigation device for voltage sag is proposed in [1] using PWM-switched autotransformer. The performance of the compensator for various sag conditions is presented. This paper presents modeling and analysis of PWM switched autotransformer that can compensate during voltage sag and swell conditions. The proposed scheme has less number of switching devices and has good compensating capability in comparison to commonly used compensators. Simulation and analysis of 3-phasecompensator is performed in MATLAB/SIMULINK and performance of the new mitigation conditions of sag and swell.

II. 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.

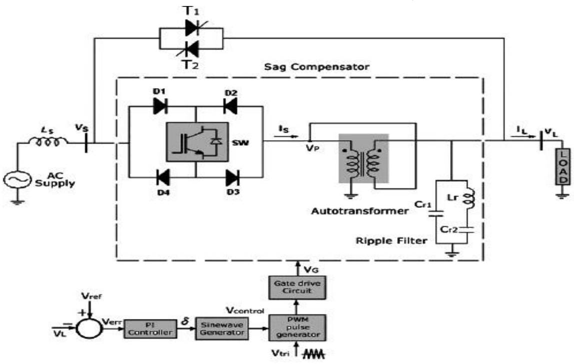


Fig.1. Voltage sag mitigating device with PWM switched autotransformer

Fig.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.

III. 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 to 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 voltage sag or swell occurs. The supply voltage VS and hence VL decreases. When the sensing circuit detects an error voltage Verr greater than 10% of the normal voltage the voltage controller acts immediately to switch off the thyristors. Voltage Verr applied to the pi controller gives the phase angle δ. The control voltage given in Eq. (1) is constructed at power frequency f = 50Hz.

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

Where m_a is the modulation index.

The phase angle δ is dependent on the percentage of disturbance and hence controls the magnitude of Vcontrol. This control voltage is then compared with the triangular voltage Vtri 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.

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[1] 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.

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 Eq. (2)

$$V_L/V_P = a = I_S/I_L = (N_1 + N_2)/N_1 \quad (2)$$

where a is the turns ratio; V_P=Primary voltage; V_L =Secondary voltage; I_1, I_2 =primary and secondary currents, respectively; I_S =Source current; I_L =Load current.

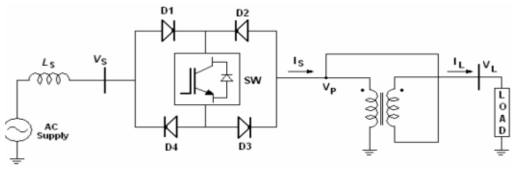


Fig2. Voltage sag/sell mitigating device

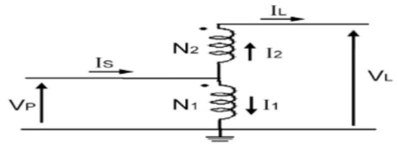


Fig3.Voltage and current relations in an autotransformer

The autotransformer in Fig.3 does not offer electrical isolation between primary side and secondary side but has advantages of high efficiency with small volume. An 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 during the sag period. As the of that VL = 2VP and IS=2IL.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 VP is such that the load voltage on the secondary of autotransformer is the desired rms voltage.

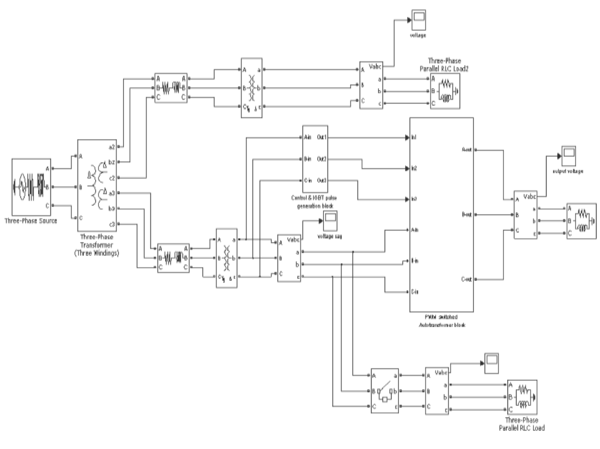


Fig 4. MATLAB/SIMULINK model of a 3-phase used for voltage sag studies

V. RIPPLE FILTER DESIGN

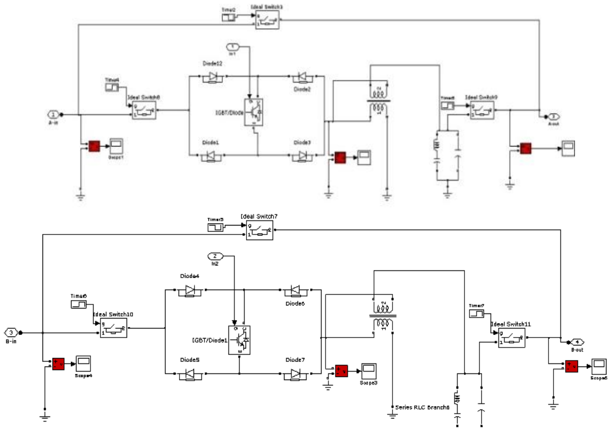
The output voltage VP given by the IGBT is the pulse containing fundamental component of 50 Hz and harmonics at switching frequency. Hence there is a necessity to design a suitable ripple filter at the output of the IGBT to obtain the load voltage THD within the limits. A notch filter to remove the harmonics 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 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)

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

where R, Lr and Cr2 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}.

VI. SIMULATION ANALYSIS AND RESULTS

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 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. Tab.1 shows the system parameter specifications used for simulation.



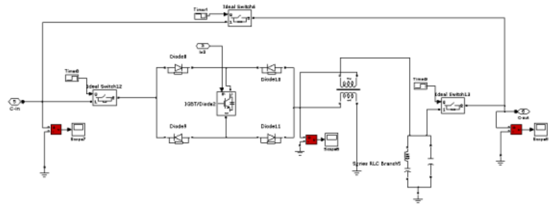


Fig.5.Model of 3-□ PWM switched autotransformer

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 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

Table 1. System parameters used for simulation

Supply	3-Phase100 MVA, 11kV, 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 $C_{r1} = C_{r2} = 53\mu$F
Load1	P = 10KW , Q = 10Kvar
Load2(for sag generation)	P = 10MW , Q = 5Mvar

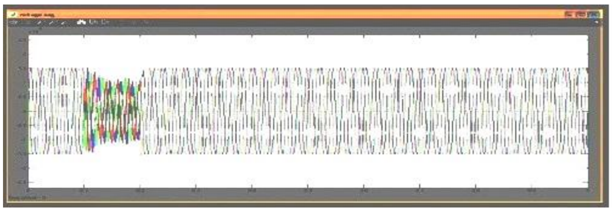


Fig 6.The simulation waveforms of the load voltage for voltage sag of 27%

Fig 7.Simulation waveform for voltage sag formation during 0.1 second

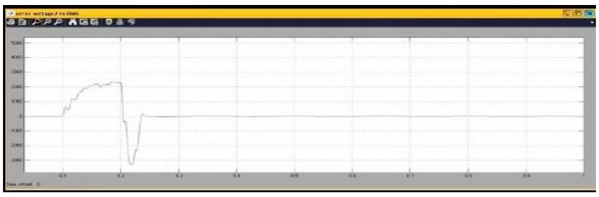


Fig 8.Simulation waveform for per phase error voltage1 in RMS value

Fig 9.Simulationwaveform for per phase error voltage 3 in RMS value

with its control circuit is shown in Fig. 5. 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=10MW and Q=50Mvar for a period of 0.1 sec(5cycles) from t1 = 0.1 sec to t2 = 0.2 sec Figs.(6 to 10) shows the simulation waveforms of the load voltage for voltage sag of 27%.

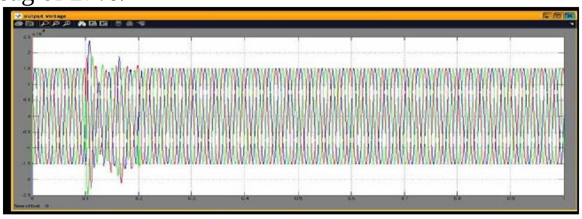


Fig 10.Simulation waveform for voltage sag mitigated using PWM switched autotransformer

VII. CONCLUSION

A new voltage sag compensator based on PWM switched autotransformer has been presented in this paper. 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.

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