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Mitigation of Voltage Sags and Swells using PWM Switched Autotransformer

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ABSTRACT

In the modern world use of electrical energy is going to increases day by day. Myriad scholars and scientists are working in field of generation and utilisation. This paper is towards that goal. We are trying to improve the power quality problem and issues. Efficiency is main aspect of good energy. This work presents [1] a novel distribution-level voltage control system design for compensation of voltage sag and voltage swell condition in 3- phase power system. In the normal operating conditions the approach work in bypass mode and delivering utility power directly to load. Complexity reduces because of using less number of switches and has great compensating capability in comparison to commonly use other compensators. Its effectiveness and capability in instantly detecting and compensating [4] voltage sags and swells is verified via MATLAB 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 means [2] a perfect power supply which has no variation from standard voltage or frequency and a noise free sinusoidal wave shape. According to IEEE Standard 1159-1995[1], voltage sag is defined as an RMS variation with a magnitude between 10% and 90% of nominal voltage and duration between 0.5cycles and one minute. Power Quality problems have become an increasing concern with an increase in the use of critical and sensitive loads. Disturbances such as voltage sags and swells, short duration interruptions, long interruption, spikes, harmonics and transients may disrupt the processes. These result in power disruption for the user and lead to considerable economic loss. A voltage sag condition implies [3] that the voltage on one or more phases drops below the specified tolerance for a short period of time. Voltage swells [2] are brief increases in rms voltage that sometimes accompany voltage sags. A new mitigation device for voltage sag is proposed using [5] PWM-switched autotransformer.

II. PROPOSED SYSTEM CONFIGURATION

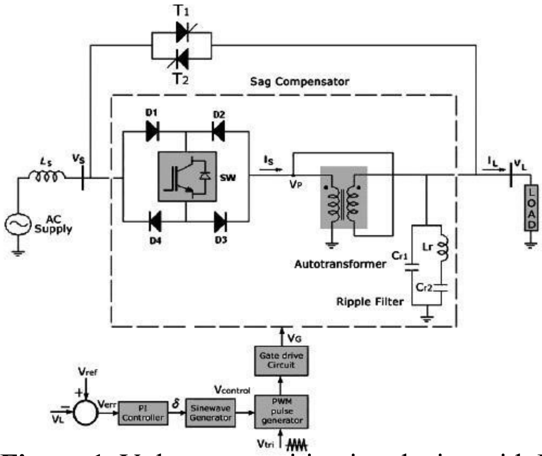

Figure 1. Voltage sag mitigating device with PWM switched auto-transformer

The proposed device for alleviation of voltage sag and swell in the system consists of a PWM switched power electronic [1] device connected to an autotransformer in series with the load. Fig.1 shows the single phase circuit composition 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 [5] in a bridge configuration, a thyristor bypass switch, an autotransformer, and voltage controller.

III. RIPPLE FILTER DESIGN

The output voltage V_P given by the IGBT [2] 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 [4] to eliminate 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 centre frequency [5] 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.(1)

$$Z=R+j(wL-1/wC)...............(1)$$

IV. PRINCIPLE OF OPERATION

In this scheme 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 which shows a suitable control circuit maintains constant rms load voltage. Here A PWM pulse technique is used. Calculated RMS value of load voltage is then compared with the reference rms voltage V_{ref}.

Under normal condition the power flow is through the anti parallel thyristors because there is no voltage disturbance. Output filters which containing a main capacitor filter and a notch filter are used at the output side. which is used 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 occurrence of voltage sag or swell in the system The supply voltage V_S and hence V_L decreases. When the sensing circuit detects an error in voltage Verr greater than ±10% of the normal voltage the voltage controller acts immediately to switch off the thyristors. This voltage V_{err} is then applied to the pi controller gives the phase angle δ. The control voltage given in Eq. (1) is constructed at power frequency f = 50Hz.

$$V_{control} = m_a \times \sin(\omega t + \delta)......(2)$$

Where m_a is the modulation index.

The generated phase angle δ is dependent on the percentage of disturbance and hence controls the magnitude of $V_{control}$. This control voltage is then compared with the triangular voltage V_{tri} to generate the PWM pulses V_G 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.

V. 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 relationships of the autotransformer voltage and current are expressed in Eq. (3)

$$V_L/V_H=aI_H/I_L=N_1/(N_1+N_2)..........(3)$$

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.

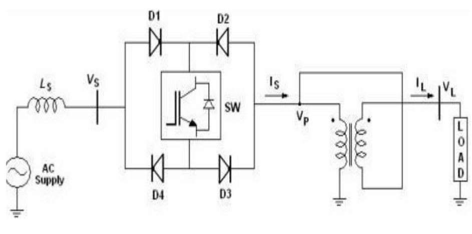

Figure 2. Voltage sag/sell mitigating device

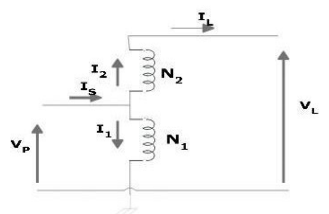

Figure3. Voltage and current relations in an autotransformer

V_P is such that the load voltage on the secondary of autotransformer is the desired rms voltage.

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 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 up to 50% voltage sag during the sag period. As the of that $V_L = 2V_P$ and I_S=$2I_L$. 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.

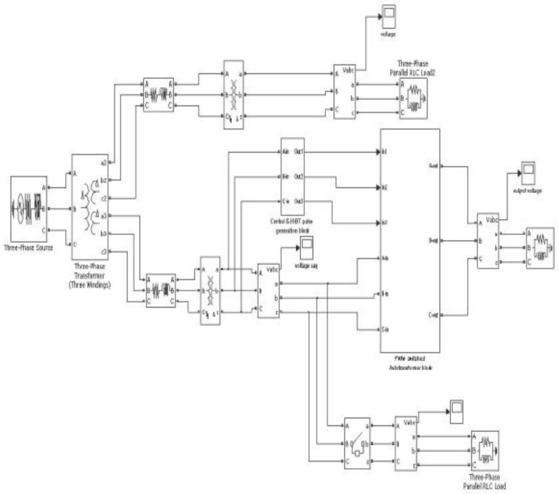

Figure4. MATLAB model of a 3-phase used for voltage sag studies

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.

S. No.	Parameters	Values
1	Supply	3-phase 100 MVA, 11 KV, 50hz
2	Autotransformer	Primary:6.35MVA,35MVA ,50 Hz, Secondary: 6.35 or 7MVA, 35MVA,50Hz
3	Ripple filter at output of transformer	Lr=300mH, Cr1=Cr2=5uF
4	Load1	P=10KW, Q=10Kvar
5	Load2(for sag generation)	P=10 MW, Q=5Mvar
6	Frequency	50Hz

Table 1. System parameters used for simulation

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

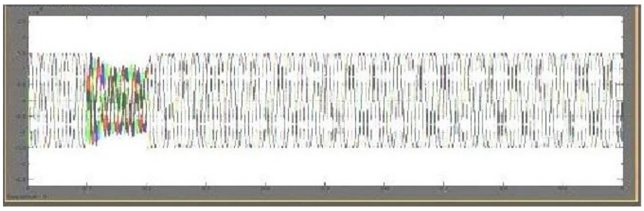

Figure 5. The simulation waveform of the load voltage for voltage sag of 27%

Figure 6. Simulation waveform for voltage sag formation during 0.1 second

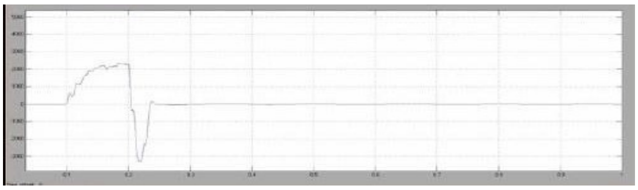

Figure 7. Simulation waveform for per phase error voltage1 in RMS value

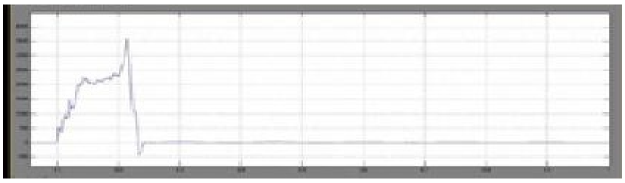

Figure 8. Simulation waveform for per phase error voltage 3 in RMS value

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%.

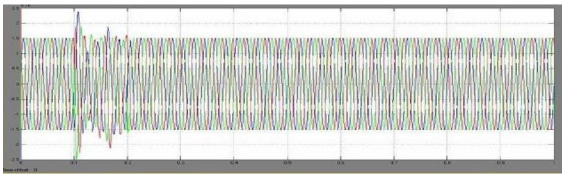

Figure 9. Simulation waveform for voltage sag mitigated using PWM switched autotransformer

VII. CONCLUSION

In field of power quality improvement, new voltage sag compensator based on PWM switched autotransformer has been presented in this paper. The proposed work could identify the disturbance and capable of mitigating [1] the disturbance by maintaining the load voltage at desired magnitude within limits. The paper technique is simple and for a single phase there is only one IGBT switch required. Hence the system is more simple and economical compared to commonly used DVR or STATCOM. Simulation analysis is done for 27% voltage sag for three phase system. Result of this paper verify that the proposed device is effective in compensating the voltage sag and swell disturbances.

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