VSC BASED SERIES RESISTANCE AND REACTANCE EMULATION AS DISTRIBUTION SYSTEM FAULT CURRENT LIMITER

Shravya J[1]

[1]*Assistant Professor, Department of Electrical and Electronics Engineering, GSSSIETW, Karnataka, India*

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Abstract - *Power system should supply power to various load centres as per the demand. The power flow is controlled in AC transmission to improve power transfer capacity, to reduce fault current caused by major disturbances. Increase in line current may be caused due to increase in the loading of the transmission line and/or shortage of reactive power. The problem of fault current can be overcome by connecting series Flexible AC Transmission System(FACTS) device with the transmission line. This project work mainly focuses on studying the effectiveness of resistance emulation in association with reactance emulation as a fault current limiter.*

The VSC based series voltage compensator can inject a voltage in series with the distribution line. The injected series voltage which is in phase with line current emulates a series resistance. The component of injected voltage which is in quadrature with line reactance emulates a reactance. For fault current limiting the emulated reactance should be inductive that is the injected voltage should lead the line current by 90°.

In this present work is aimed at analyzing the present effectiveness of resistance emulation to supplement the inductive reactance emulation in limiting the fault current. When positive resistance is emulated it causes absorption of active power. This absorbed active power can be stored in a battery which is connected to the dc bus of Voltage Source Converter.

Key Words: VSC, SSSC, PLL, reactance compensation, resistive compensation.

1. INTRODUCTION

Power system engineers are effectively addressing the power system problems from several decades. Modern power systems, are distinguished by wide area interconnections and long distance bulk power transmissions. The existing transmission lines should be used more effectively or new lines should be connected to the system, to supply the load demand in a complex interlinked power system.

Due to short circuit level, the interconnected power systems are subjected to over rating of substation equipment and circuit breakers of the related substation. Power system controllers have very brilliantly introduced advancement of power electronic technologies and presented a new degree of freedom for power system operation. This concept is referred to as Flexible AC Transmission Systems(FACTS). There are two major compensation in implementing FACTS i.e., shunt compensation and series compensation. Static Series Synchronous Compensator(SSSC) is one of the initiative work in the development of FACTS. It is a solid state voltage source converter which is connected in series to the transmission line. In this project, a concept of fault current limiting by SSSC has been proposed.

2. STUDIED SYSTEM AND SIMULATION

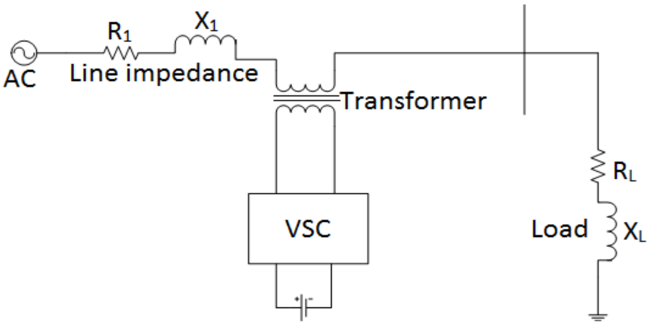

Fig -1: Representation of studied system

Fig -1 represents the studied system, in which SSSC is connected in series with the transmission line. The parameters considered in this system are
AC voltage source = 230V
Line resistance R_1 = 1 for 10km
Line reactance X_1 = 3.83 for 10km
Load resistance R_L= 59.75Ω
Load reactance X_L = 5.47Ω

VSC:
Frequency of repeating sequence = 20kHz
DC voltage = 200V

Filter:
Inductor=1mH
Capacitor= 2.6mF
Resistor= 0.1Ω

2.1 SIMULATION IN MATLAB/SIMULINK

The modeling of different blocks of SSSC connected to the transmission line. The SSSC is modeled as sub-blocks in Simscape and are connected as shown in Fig - 2.

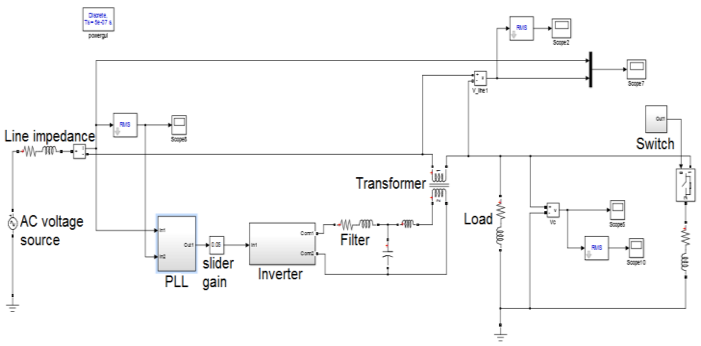

Fig -2: Simulink model of SSSC connected to the system

2.2 PHASE LOCKED LOOP(PLL)

2.2.1 REACTIVE COMPENSATION

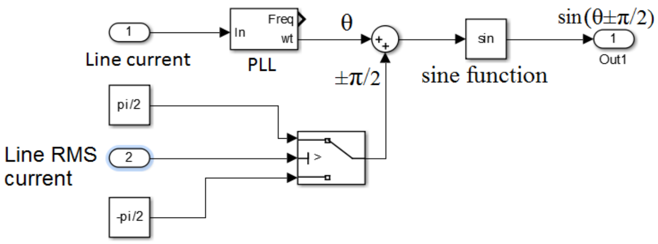

Fig -3: Simulink model to generate reference signal for SPWM for inductive and capacitive reactive compensation

Fig -3 shows the simulink model to generate reference signal for Sinusoidal Pulse Width Modulation(SPWM) for inductive reactive compensation. The phase of the line current is tracked by PLL which uses a feedback control. The firing pulses for the MOSFEts switches have to be synchronized to the line current so that, in steady state, the fundamental component of the injected voltage from SSSC should be ±90° with respect to the line current. This synchronization is accomplished by PLL. For reactive compensation in inductive mode, the injected voltage should lead the line current by 90°. This emulates inductive reactance in the transmission line. For capacitive reactive compensation, the injected voltage should lag the line current by 90°.

2.2.2 Resistive compensation

POSITIVE RESISTIVE EMULATION

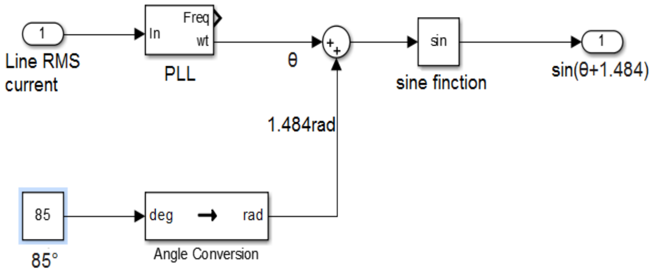

Fig -4: Simulink model to generate reference signal for SPWM for positive resistive emulation

Fig -4 shows the simulink model to generate reference signal for SPWM for positive resistive emulation. The PLL tracks the line current angle, the 85° is converted into radian and then summed up with the tracked line current and fed to sine function.

NEGATIVE RESISTIVE EMULATION

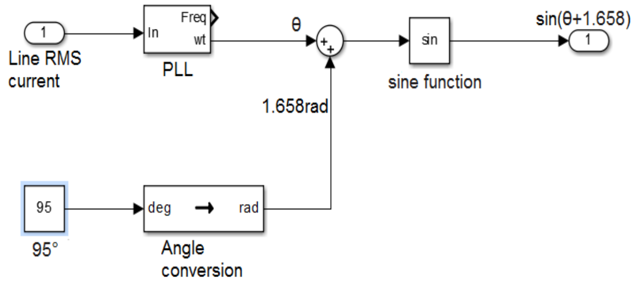

Fig -5: Simulink model to generate reference signal for SPWM for negative resistive emulation

Fig -5 Simulink model to generate reference signal for SPWM for negative resistive emulation. Here the PLL tracked line current angle is summed up with the 95° and fed to the sine function.

2.3 VOLTAGE SOURCE CONVERTER

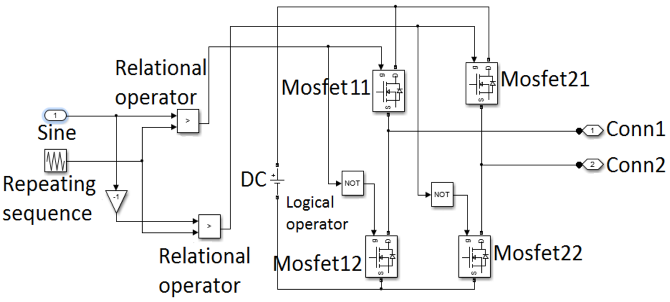

Fig -10: Simulink model of voltage source converter

A voltage-source H-bridge inverter as shown in Fig -10 is based on Sinusoidal PWM. SPWM technique is generally used to control turn-on/turn-off of the inverter switches. MOSFET11 and MOSFET22 are turned on simultaneously after turning off MOSFET21 and MOSFET12. A small dead time is needed in practical condition between turning off of one set and turning on of the other to prevent the formation of a direct path between the DC supply and ground. Based on the switching behaviour of H-bridge inverter, a Simulink model has been used for the simulation as shown in Fig -10

2.4 CONTROLLER

The MATLAB/SIMULINK model for current limiting in SSSC is shown in Fig -11. Only the reactive power is exchanged between the converter and the ac system, since the losses and DC bus dynamics are neglected. Hence the phase angle between the line current and the voltage injected by the SSSC is 90° (it depends on the sign of the error between the measured value of VC and the reference). Single phase PLL is used to find the phase angle of line current. A discrete PI controller output determines the magnitude of the modulation index(MI). PI controller output is limited within ±1 using scaling factor (K). The control signal is obtained by multiplying the magnitude of modulation index and the sinusoidal signal which is phase shifted.

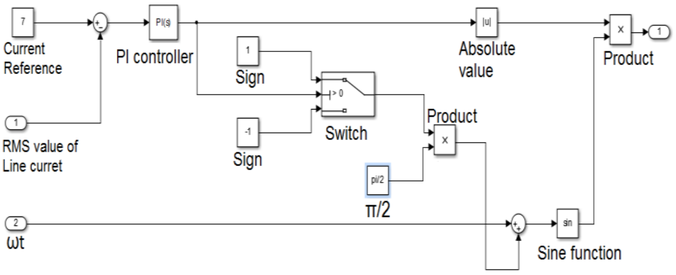

Fig -11: Simulink model of SSSC current limiting controller.

MATLAB is the tool used for simulation study. All the blocks were modeled using Simscape toolbox.

3. RESULTS AND DISCUSSIONS

The SSSC connected in series with the transmission line has been simulated with test signals for validity of the models. It has been found that simulation results were satisfactory.

The active power transfer between the SSSC and the grid is limited and can be controlled by varying the phase angle between grid voltage and inverter output voltage. For only reactive power interaction, the line current and inverter output voltage are kept ±90° and inverter voltage is varied in magnitude. Fig -12 shows the inverter output voltage. The output voltage of the Voltage Source Inverter(VSI) is not a pure sine wave.

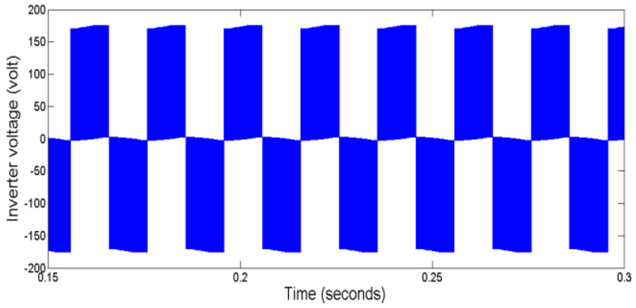

Fig -12: Inverter output voltage

Instead it contains voltage pulse train of 20 KHz frequency due to switching of inverter switches. This gives rise to higher order harmonics to exist in the output of VSI. Hence a low-pass filter composed of low-frequency inductor and capacitor is used. Fig -13 shows the filtered inverter output voltage.

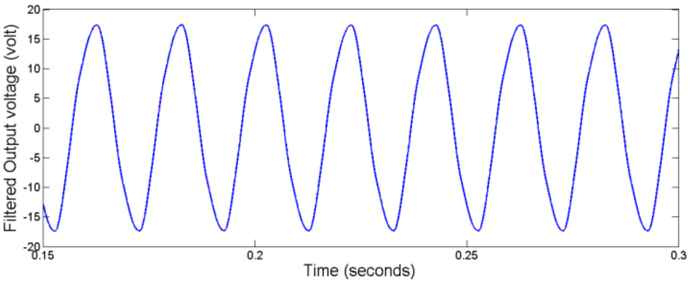

Fig -13: Filtered Inverter output voltage

The filtered output is injected to the transmission line through coupling transformer. This injected voltage may lead or lag the line current by 90°. If the Injected voltage leads the line current by 90° then it is called inductive mode of operation. If the injected voltage lags the line current by 90°, then it is capacitive mode of operation. Fig -14 shows capacitive and inductive mode of operation. The condition to switch from capacitive mode to inductive mode is given such that if the line current exceeds 4A it is switched to inductive mode. The line current is reduced by working in inductive mode.

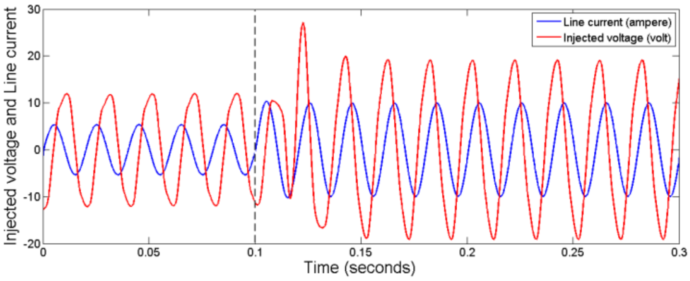

Fig -14: Capacitive and inductive mode of operation

In the Fig -15 it is shown that, from 0 to 0.1sec the SSSC works in capacitive mode of operation and at 0.1sec the load is connected in parallel hence the line current increases. When the line current increases more than 4A the SSSC switches to inductive mode of operation. At 0.2 sec, the modulation index is increased so that the injected voltage is increased and hence the current is limited to 4A.

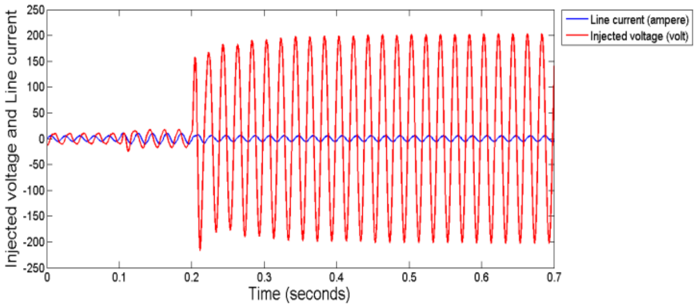

Fig -15: Waveform of injected voltage and line current when modulation index is varied

In Fig -16 it is shown that, from 0 to 0.1sec the SSSC acts in capacitive mode and line current is 3.775A. At 0.1 sec another load is connected in parallel and the line is increased to 7.06A, SSSC switches to inductive mode as explained earlier. From 0.2 sec modulation index is varied and the line current is brought back to 4A and the current is limited.

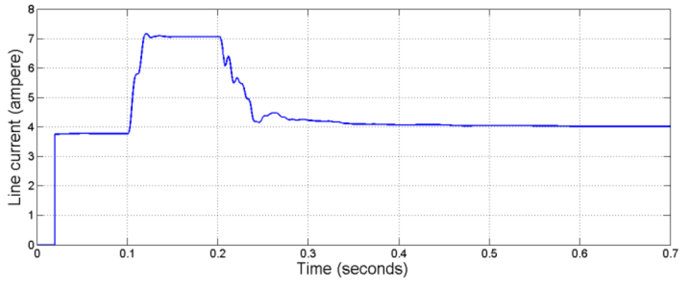

Fig -16: Line current

In Fig -17 it is shown that the SSSC is switched from capacitive mode to inductive mode of operation with the help of controller. Here the reference current is given as 7A. If the line current increases more than 7A the SSSC switches to inductive mode and the fault current is limited. Fig -18 is the magnified waveform of injected voltage and line current where the switching from capacitive mode to inductive mode can be clearly seen. The limitation of fault current is shown in Fig -19.

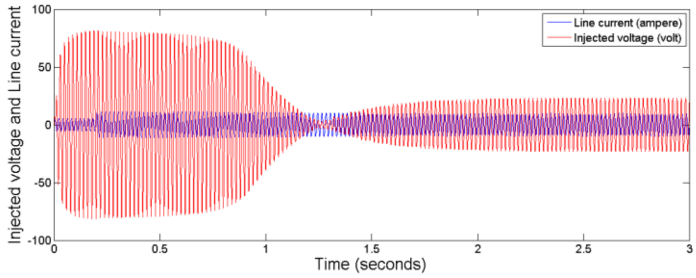

Fig -17: Waveform of Injected voltage and line current with controller

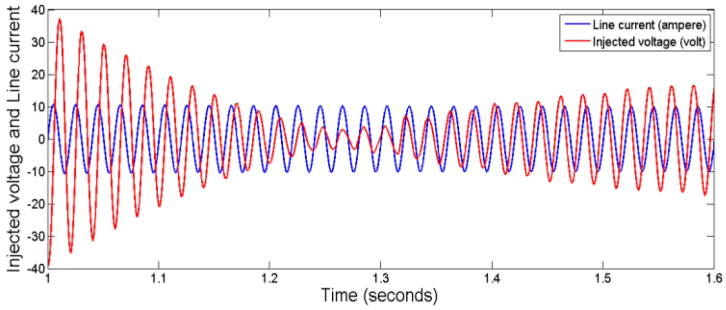

Fig -18: Waveform showing switching of SSSC from capacitive mode to inductive mode with controller

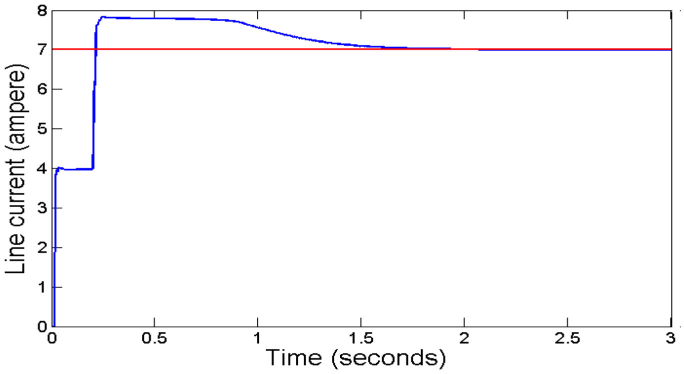

Fig -19: Line current limiting using controller

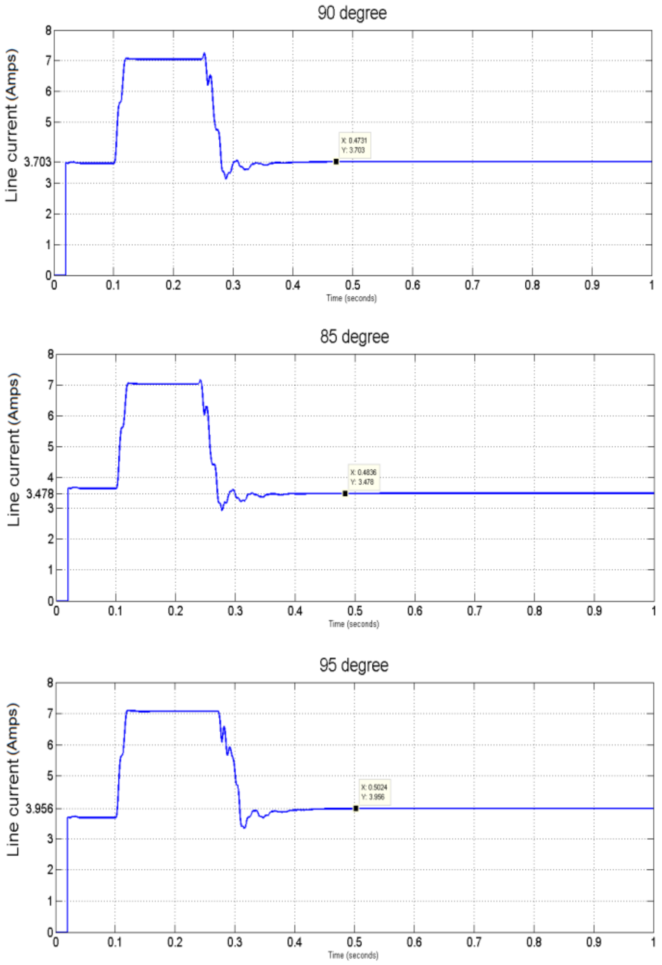

Fig -20: Line current for different phase angle between injected voltage and line current

From Fig -20, when the phase difference between injected voltage and line current is +90° it emulates inductive reactance and the line current is limited to 3.703A. This is termed as inductive reactance emulation. When the phase angle difference is 85°, it emulates positive resistance which adds up to the line and the line current settles down at 3.478A, it is found that the current is less than that of reactance emulation. This is called as positive resistance emulation.

When the phase difference between injected voltage and line current is set to 95°, it emulates negative resistance. The emulated resistance gets subtracted from the line reactance and the line current settles down at 3.956A, which is more than that of reactance emulation. This is called as negative resistance emulation.

In SSSC active power can be injected by controlling the angle between the injected voltage and the line current other than ±90°, this is one of the advantage of SSSC.

Fig -20 shows the line current for different phase angle between the injected voltage and the line current.

4. CONCLUSION

The SSSC connected in series to the transmission system has been simulated. In this work, a Simulink model of SSSC connected in series to the transmission line has been developed. The details of studied system are given. The model has been simulated for reactance emulation and resistive emulation and it is observed that the model performs satisfactorily. Unipolar SPWM technique is implemented and low-pass LC filter effectively produces near to pure sine wave output voltage. Active and reactive power control is achieved.

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BIOGRAPHY

Shravya J received B.E from Electrical and Electronics Engineering and M.Tech in Power Electronics from Visvesvaraya Technological University.