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Closed Loop Reactive Power Compensation on a Single-Phase Transmission Line

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Abstract: ***Nowadays the power consumption is increasing significantly. Due to this, the transmission lines are heavily loaded and in turn results in instability of the line. So orderly transmission of power is essential. For the proper operation of the load the voltage has to be maintained within the acceptable limit. Due to the changes in load, the voltage level of the line also changes. The voltage levels can be improved by using the reactive power compensator like capacitor banks, series compensator, STAT COM and svc. Here, we considered the SVC as reactive power compensator. This paper presents the reactive power compensation for a 230v transmission line model with variable inductive load using SVC and designed in Simulink. Here we considered the SVC model which contains of anti-thyristors in series to the inductor and a shunt capacitor. The required reactance is fed from the inductor to the transmission line by changing the gate triggering pulse to the thyristor pair. So, the main disadvantage of the open loop var compensation using svc is the triggering to the thyristor pair has to be changed every time depending on the load. This can overcome by implementing it using the feedback loop. Here for the feedback, we used the PI controller. under The PI controller gives the required gating pulse to the thyristor pair. The performance of this model is studied variable load conditions.***
Keywords: Voltage control, SVC, Reactive power compensation, PI controller, PLL

I. INTRODUCTION

A power system network should always be able to meet the continuous changes in the active and reactive power. Unlike the other form of energies, electrical energy is something which can't be stored in sufficient quantities. The problem of maintaining voltage within the prescribed level is complicated because the power system network supplies power to vast number of loads and is fed from the various generating stations.

As the load changes, the reactive power required by the transmission line also changes. The objective of reactive power compensation is to maintain stable, acceptable voltages not only under normal operating conditions but also after disturbances. when there are disturbances, increase in load demand, or changes in system conditions then there will be a drop in voltage and also the voltage becomes unstable [1]. The most obvious solution is to expand the size and quantity of generating units. However, this is inefficient, uneconomical and introduces significant flaws.

To avoid these issues, power systems can be scaled based on the maximum demand for real power, with compensators managing reactive power [2]. Compensating devices are essential for maintaining voltages within safe ranges. Some of the compensators are Capacitive banks, Shunt compensator, Series compensators, Reactors, Synchronous Condensers, SVC, STATCOM, and more [3]. In this paper SVC is used forvar compensation.

There are various types of SVC. Appropriate combination of SVC is usually chosen based on various parameters like operating efficiency, economy and more.

The different types of svc are Thyristor Controlled Reactor (TCR) Shunt connected controlled inductor whose productive reaction is continuously regulated, Thyristor Switched Reactor (TSR) which is a series connection of thyristor pair and inductor, Thyristor Switched Capacitor (TSC) which is similar to TSR where inductor is replaced with capacitor and the reactive power modified in steps depends on quantity of banks of capacitor.

PI controller and PLL are used for the feedback loop. The PI controller reduces the steady state error and also maintains the stability of the system. PI controller is similar to lag compensator where in the response becomes slow. The PI controller is most widely used controller. PLL is used to produce a reference signal that follows the synchronization with the given input signal. PLL being a dynamic element causes the changes in the stability of the system and also the dynamic response. The gains of the PI controller help in increasing the system stability and also reduces the steady state error. Thus, the closed loop implementation for VAR compensation helps in increasing the voltage levels irrespective of the load reactive power.

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II. THEORETICAL BACKGROUND

In this section the relationship between the reactive power and voltage change is observed by considering the single-phase transmission line.

A. Power Flow in Transmission Line

Let's consider a power system network which consists of two buses having voltages V_s and V_r respectively.

Fig. 1. Two bus transmission line

The transmission line can be represented in terms of ABCD parameters [4].

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_r \\ I_r \end{bmatrix}$$

Here, V_s is the sending end voltage

V_r is the receiving end voltage

δ is the torque angle

I_s is the sending end current

I_r is the receiving end current

$A = D = \cosh(\gamma l)$

$B = Z_C \sinh(\gamma l)$

$D = \frac{1}{Z_C} \sinh(\gamma l)$

Z_C is the characteristic impedance of the line

γ is the Propagation constant

l is the length of transmission line

let's say,

$A = |A|\angle\alpha$

$B = |B|\angle\beta$

$D = |D|\angle\Delta$

Real and reactive power flow expressions are as follows

$$P_r = \frac{|V_S|\,|V_r|}{|B|}\cos(\beta - \delta) - \left|\frac{A}{B}\right|\,|V_r|^2\cos(\beta - \alpha) \quad (1)$$

$$Q_r = \frac{|V_S|\,|V_r|}{|B|}\sin(\beta - \delta) - \left|\frac{A}{B}\right|\,|V_r|^2\sin(\beta - \alpha) \quad (2)$$

In order to get the maximum real power, differentiate P_r w.r.t to δ. By solving we get, $\delta = \beta$. Thus, the maximum real power equation is shown below.

$$P_{rmax} = \frac{|V_S|\,|V_r|}{|B|} - \left|\frac{A}{B}\right|\,|V_r|^2\cos(\beta - \alpha) \quad (3)$$

The reactive power equation

$$Q_r = \left|\frac{A}{B}\right| |V_r|^2 \cos(\beta - \alpha) \quad (4)$$

For the short transmission line, |A| =1, α =0, |B| = |Z|, β = θ.

$$P_r = \frac{|V_S|\,|V_r|}{|Z|}\cos(\theta - \delta) - \frac{1}{|Z|}|V_r|^2 \cos(\theta) \quad (5)$$

$$Q_r = \frac{|V_S|\,|V_r|}{|Z|}\sin(\theta - \delta) - \frac{1}{|Z|}|V_r|^2 \sin(\theta) \quad (6)$$

P_{max} occurs for $\delta = \theta$.

$$P_{max} = \frac{|V_S|\,|V_r|}{|Z|} - \frac{1}{|Z|}|V_r|^2 \cos(\theta) \quad (7)$$

Reactive power during P_{max} is,

$$Q_r = \frac{|V_S|\,|V_r|}{X}\cos(\delta) - \frac{1}{X}|V_r|^2 \quad (8)$$

If δ is very small, then $cos\delta$ can be approximated to 1.

$$Q_r = \frac{|V_S|}{X}(|V_s| - |V_r|) \quad (9)$$

For R appropriately equal to 0 and δ is very small then,

$$P_r \propto \sin(\delta) \propto \delta \quad (10)$$

$$Q_r \propto |\Delta V| \quad (11)$$

The real power transfer depends on power angle and the reactive power depends on the difference of voltage between the sending end and receiving end. Hence from equation (9), it is confirmed that reactive power and voltage are related. Most of the machines, work efficiently at the rated voltage. If any apparatus experiences overvoltage or undervoltage then the machine gets damaged. So, the voltage must always be maintained at the rated voltage or nearly equal to rated. As the voltage level depends on the reactive power, in order to increase or decrease the voltage level the VAR should either be absorbed or received. Static VAR compensator is one of the
VAR compensating device.

B. Static VAR Compensator

Basically, SVC is a shunt VAR compensator which helps in improving the voltage levels by absorbing or adding the reactive power. The word static in SVC specifies that it doesn't have any moving parts which means it is a stationary device. SVC consists of a VAR generator or absorber and has a control device.

SVC is an electrical device which absorbs or delivers the reactive power. In this paper, the svc model consists of a bidirectional thyristor in series with a inductor and a fixed shunt capacitor [1]. Here, the bidirectional thyristors conduct on alternate cycles of the supply frequency. Depending on the triggering pulse given to the thyristor, the reactive power is compensated. At α= 90^0, there will be a complete conduction.

The firing angle can be any angle between 90^0 and 180^0[4]. The α< 90^0 adds the dc component into the current waveform making it asymmetrical. Thus, we can achieve the rated output voltage by varying the triggering angle to the thyristor. If the reactive is more than required then the inductor absorbs the reactive power. Similarly, if the reactive power is less then the capacitor supplies more KVAR to the transmission line.

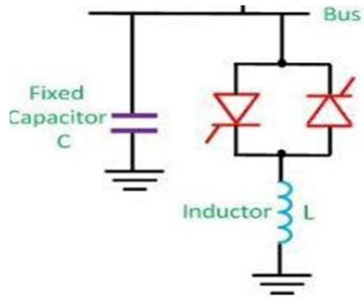

Fig. 2. Static VAR Compensator

III. DESIGN OF SVC

In this section, the design parameters of the svc are calculated for a single-phase transmission line with given RL load. Considering an RL load of 230V, 10A and 0.85lagging power factor, the active and reactive power are calculated as follows.

Active power, $P = V * I * \cos\emptyset$ (12)

$$P = 230 * 10 * 0.85 = 1.955KW \approx 2KW$$

Reactive power $Q = V * I * \sin\emptyset$ (13)

$$Q = 230 * 10 * 0.52 = 1.21KVAR \approx 1.5KVAR$$

Clearly the maximum active power demand is 2KW and maximum reactive power demand is 1.5KVAR. The design parameters of svc are inductance and capacitance and are calculated at 50Hz operating frequency. The calculations are shown below.

Inductance, $L = \frac{v2}{2\pi fQ}$ (14)

$$L = 112.3mH$$

Capacitance, $C = \frac{Q}{2\pi f V^2}$ (15)

$$C = 90\mu F$$

IV. SIMULATION

In this section, the simulation model of a single-phase transmission line with var compensator is presented. The various parameter values are listed in the table below.

Table I. Parameters used in simulation

Grid	Source Voltage = 230V
	Frequency = 50Hz
Transmission Line	Length = 150Km
	Inductance = 0.04mH/Km
	Capacitance = 0.16µF/Km
Load	Voltage = 230V
	Current = 10A

Whenever the load varies the voltage levels also varies depending on the reactive power of the load. Without compensation, for loads of 1.5KVAR, 1KVAR and 0.5KVAR connected the single-phase power network consisting of two bus bars and the load side voltages are 217.6V, 221.4V and 225.2 respectively. The compensating devices are always connected at the load side. The firing angles to the bidirectional thyristor is converted as time delay. By using the compensating device, the voltage levels for the given three loads are increased to 230 at a triggering angle of 180^0 for 1.5KVAR, 128^0 for 1KVAR and 112^0 for 0.5KVAR respectively.

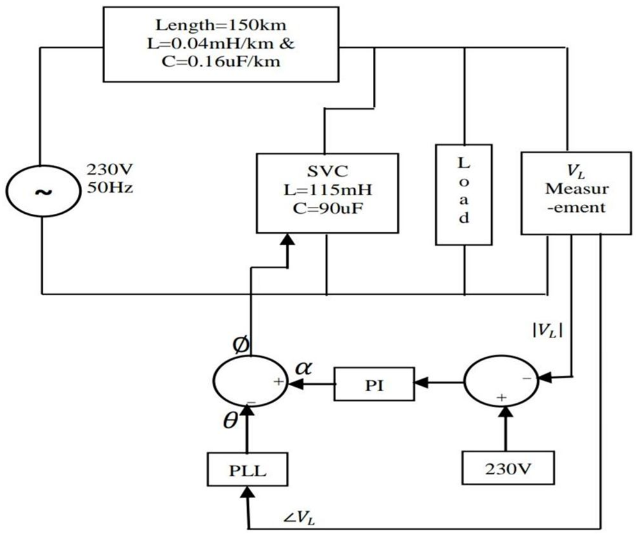

Fig. 3. Block diagram for Closed loop control

Fig 3 shows the block diagram for the closed loop reactive power control for the given single phase transmission line. The voltage across the load is measured using a voltage measurement block. The obtained load voltage along the supply voltage are the inputs to the PI controller. By trial-and-error method, the proportional and integral gains are obtained for PI controller. Thus, the k_p and k_i are 0.06 and 1.1. PI controller thus provides the error signal based on the given inputs. The phase of the load voltage is fed to the PLL. The output of PLL and PI controller are given to a delay block. This delay block produces two triggering pulses which are 180^0 out of phase.

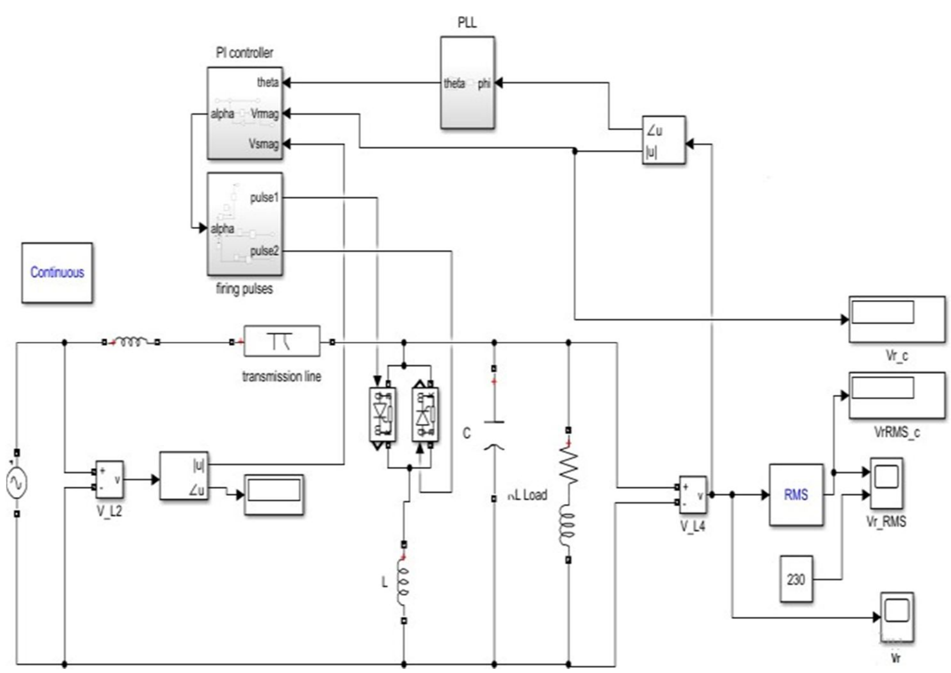

Fig. 4. Simulation model for Closed loop var compensation

V. RESULTS

In this section, the results obtained for the designed simulation model under various load conditions is shown.

Fig. 5 views the receiving end voltages for three load conditions of 1.5KVAR, !KVAR, 0.5KVAR after reaching the steady state value of rated voltage through closed loop implementation.

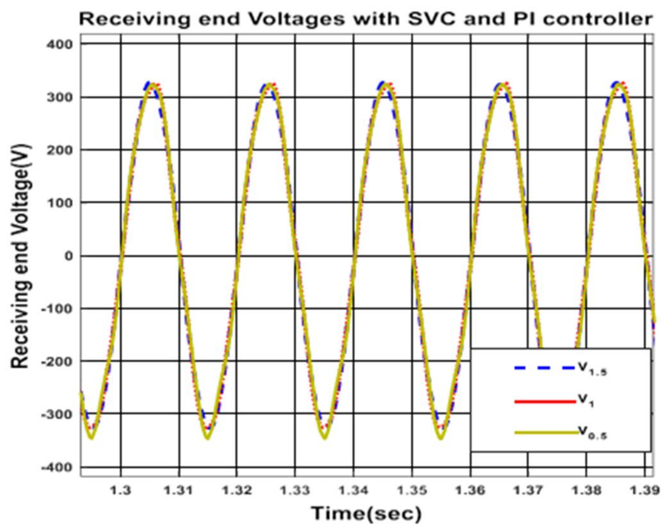

Fig. 5. Voltages at different loads with SVC and controller

From Fig. 6 it is observed that at different loads the feedback loop is acting to reduce the voltage sag and increase the receiving end voltage to approximately 230V and reduce the steady state error. Thus, closed loop control for reactive power compensation is achieved inorder to maintain the voltage at 230V.

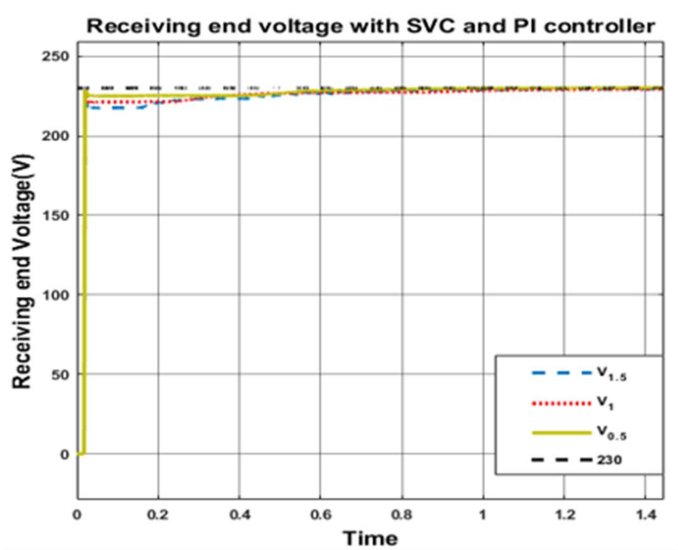

Fig. 6. RMS voltages at different loads with SVC and PI controller

VI. CONCLUSION

This paper presents the closed loop VAR compensation on a single-phase short transmission line. The results shows that the feedback loop is helping in the effective compensation. This model is designed in Simulink. Here we understood that as the reactive power increases, the voltage levels decrease. By varying the triggering pulse to the bidirectional thyristor, we get the rated voltage. The load type considered is RL having current of 10A, Voltage of 230V and 0.85 lagging power factor. This closed loop implementation helps in achieving the nearly rated voltage i.e., 230V irrespective of the load KVAR.

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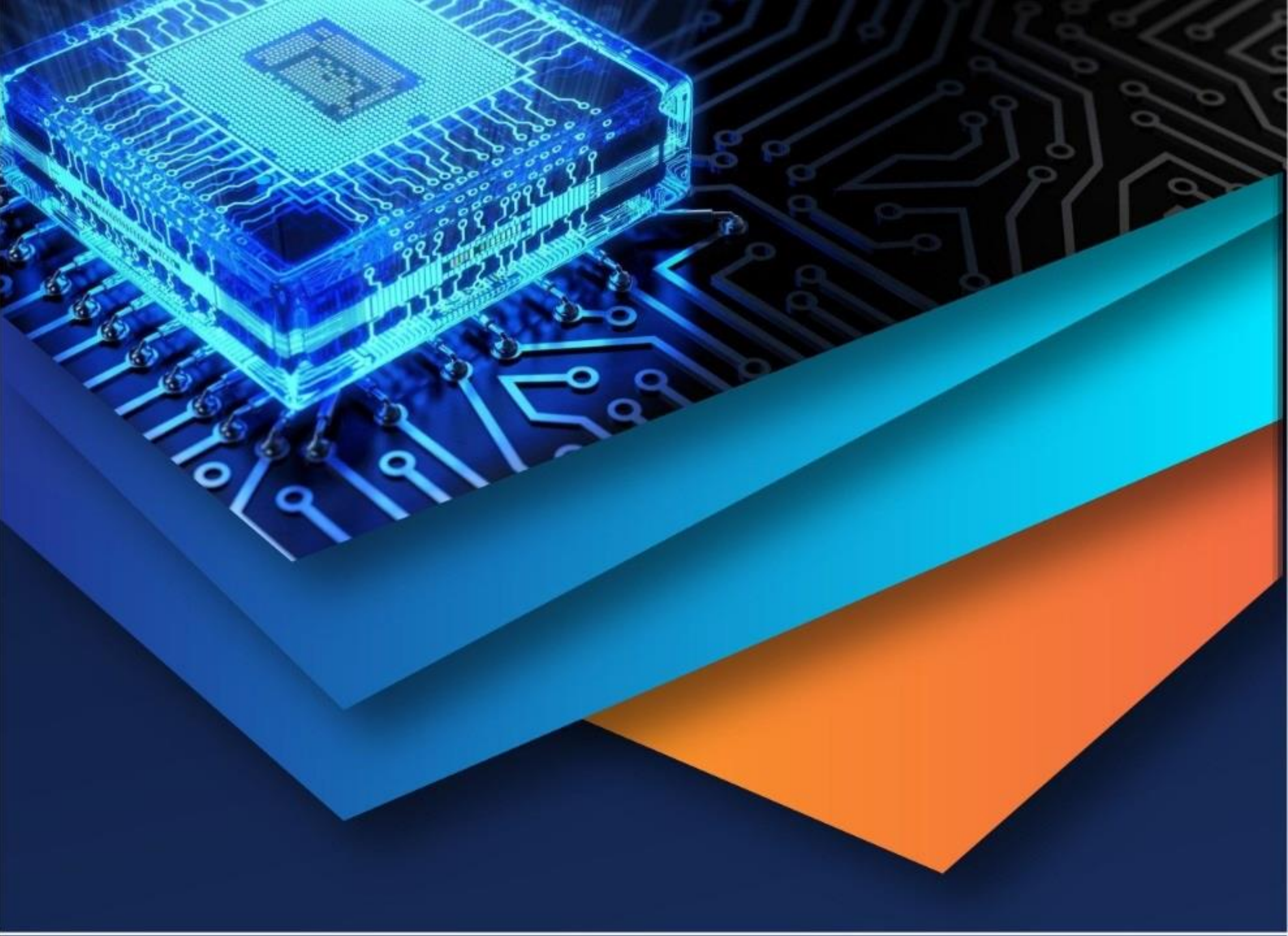

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