

# Power Factor Improvement Using Static VAR Compensator

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**Abstract** — Power factor improvement can be achieved through several means. The SVC is one of such methods which behaves like a shunt connected reactance, either generating or absorbing reactive power, thus controlling the power factor. This project aims at improving the power factor of the load with Static VAR Compensator (SVC) using AVR microcontroller. The delay angle, generated from code is given through the microcontroller via an integrator and comparator circuit which triggers the SCR and controls the power factor. The circuits are prior simulated in Saber RD software and then implemented with a working prototype.

**Index Terms** — Power factor; Power factor correction; Static VAR Compensator (SVC); Saber RD; Fast Fourier Transform (FFT) Analysis; SCR; firing angle

## I. INTRODUCTION

Power factor is the ratio of true power (in watts) to apparent power (in volt amperes). It is also defined as the cosine of the phase angle between the voltage and current. The power factor is 1.0 only when the current and voltage are in phase with each other.

Low power factor is usually associated with motors and transformers. With low power factor loads, the current flowing through electrical system components is higher than necessary to do the required work. This results in excess heating, which can damage or shorten the life of the equipment. A low power factor can also cause low voltage conditions, resulting in dimming of lights and sluggish motor operation. Low power factor usually becomes a problem in industries, where multiple large motors are used. Hence there is a need to correct the power factor in industries in order to obtain higher efficiency.

Power factor correction is applied to adjust the power factor of an AC load or an AC power transmission system to unity. This can be implemented through various methods. Simple methods include switching of capacitor or inductor banks to cancel the respective capacitive or inductive effects of the load. But non-linear loads create harmonic currents in addition to the original AC current. The use of these simple techniques does not cancel the reactive power at harmonic frequencies.

Hence there is a need for a sophisticated technique to correct or improve the power factor for non-linear loads. One of the best methods for power

factor correction for both linear and non-linear loads is by using a Static VAR Compensator (SVC).

## A. STATIC VAR COMPENSATOR

A Static VAR Compensator (SVC) is an electrical device for providing fast-acting reactive power compensation on high voltage transmission networks. The SVC behaves like a shunt connected reactance, which either generates or absorbs reactive power, thus controlling the power factor.

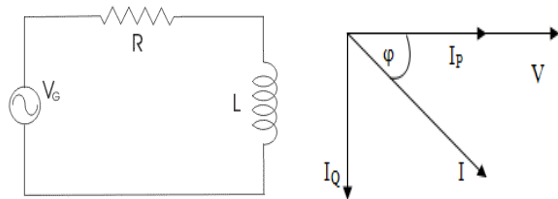


Fig. 1. Series RL Circuit

Fig. 2. Phasor Diagram

Consider a series R-L circuit fed by an AC source as shown in Fig. 1.

The real power  $P$  dissipated in the AC load is only across the resistor. It is measured in watts and is given by:

$$P = I_p^2 R \quad (1)$$

The reactive power  $Q$  dissipated in the AC load is only across the reactive element (inductor). It is measured in volt ampere reactive and is given by:

$$Q = I_Q^2 X_L \quad (2)$$

The apparent power is the product of voltage and current. It is measured in volt-amperes and is given by:

$$S = VI \quad (3)$$

The power factor of this circuit is given by the ratio of active power ( $P$ ) to the apparent power ( $S$ ). Hence we have,

$$\text{Power factor} = \cos \phi = \frac{P}{S} \quad (4)$$

Fig.2 shows the phasor diagram for the circuit indicating the voltage across the load ( $V$ ), current through the resistor ( $I_p$ ) & the current through the inductor ( $I_Q$ ). The current ( $I_p$ ) is always in phase with the voltage  $V$ . The resultant of the two currents  $I_p$  &  $I_Q$  is represented by  $I$ . For a series R-L circuit, the angle  $\phi$  between the two vectors  $V$  &  $I$  is always

positive i.e. the resultant current  $I$  lags the load voltage  $V$  by an angle  $\phi$ . Hence the power factor is termed as lagging in nature and the angle  $\phi$  is called as the power factor angle.

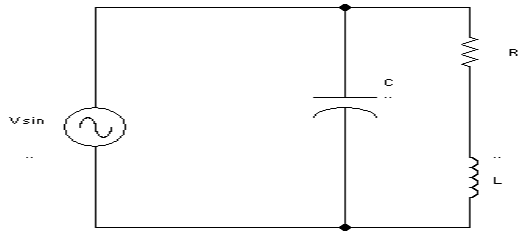


Fig. 3. Series RL circuit with a shunt capacitance

The aim of an SVC is to obtain improved power factor in an AC circuit. This can be done by reducing the reactive power  $Q$  produced by the reactive element in the load (inductor), which makes the real power equal to the apparent power, hence increasing the power factor.

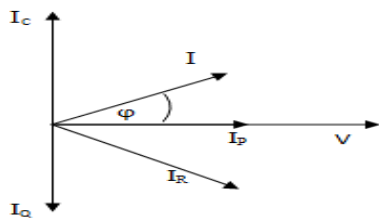


Fig. 4. Phasor diagram for Series RL circuit with a shunt capacitance

In order to balance the reactive power, it is required to bring the resultant current  $I$  in phase with the voltage  $V$ , such that the power factor angle ( $\phi$ ) is 0 degrees. To achieve this, a current component of equal magnitude ( $I_c$ ) should be introduced opposite to the current  $I_Q$ , and hence a capacitor is connected in parallel to the series RL connection as shown in Fig.3. The voltage across the resistor ( $V_R$ ), the current through the load inductor ( $I_Q$ ) and the current through the capacitor ( $I_C$ ) are plotted in the phasor diagram as shown in Fig. 4.

The resultant current of  $I_P$  and  $I_Q$  is  $I_R$ , which lags the voltage  $V$ . The resultant current of  $I_C$  and  $I_Q$  is  $I$ , which now leads the voltage  $V$  by an angle  $\phi$ , and hence the power factor is found to be leading in nature. But this arrangement provides a fixed amount of reactive power through the capacitor. Also the load voltage  $V$  and current  $I$  are still not in phase. So this arrangement of the fixed shunt capacitor is not suitable when the VAR requirement of the load is variable in nature. This leads to the need of producing variable reactive power in order to reduce or eliminate the net reactive power. This is achieved by connecting an inductor, to absorb the extra VAR produced by the shunt capacitor, as shown in the circuit in Fig.5.

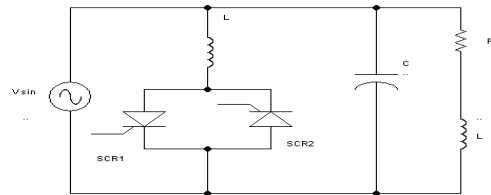
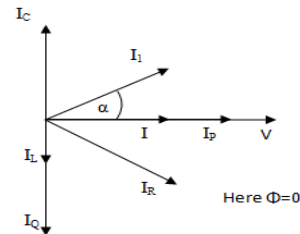


Fig.5. Static VAR Compensator (SVC)

A simple diagram of the SVC is shown in Fig.5. The SVC regulates voltage at its terminals by controlling the amount of reactive power absorbed by the system. The main principle of SVC is to supply a varying amount of reactive power (VAR) according to the system voltage requirements. When the system voltage is low, the SVC generates reactive power and is known as SVC capacitive. When the system voltage is high, the SVC absorbs reactive power and is known as SVC inductive. In other words, it is easy to remember, inductive load absorbs (needs) VAR, while a capacitive load generates (delivers) VAR.

The two thyristors (SCRs) are placed in an anti-parallel manner. The flow of current through the inductor is varied by controlling the firing angle of the SCRs i.e.  $\alpha$  from  $90^\circ$  to  $180^\circ$ .

Fig.6 shows the phasor diagram of the SVC indicating the voltage across the load ( $V$ ), the current through the load resistor ( $I_P$ ), the current through the load inductor ( $I_Q$ ) and the current through the



capacitor ( $I_C$ ).

Fig.6. Phasor diagram for SVC

The resultant of  $I_P$  and  $I_Q$  is represented by  $I_R$ . The resultant of  $I_C$  and  $I_R$  is represented by  $I_1$  which leads the voltage  $V$  by an angle  $\alpha$ . A small current component  $I_L$ , required to bring the current  $I_1$  in phase with  $V$ , is introduced opposite to  $I_C$ . The resultant of  $I_L$  and  $I_1$  is represented by  $I$ , which is found to be in phase with the load voltage  $V$ . The power factor angle  $\phi$  now becomes zero ( $\phi=0$ ), resulting in improved power factor.

## II. SIMULATION RESULTS

### A. Simulation of RL load

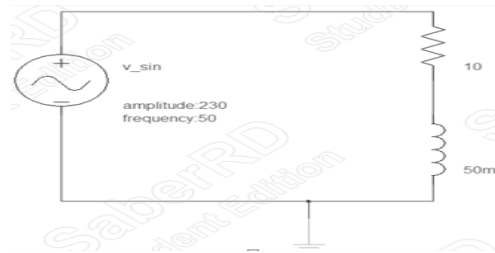


Fig.7. Schematic of RL load

Fig.7 shows the schematic of R-L Load for simulation using Saber RD software. Fig.8 displays the source voltage waveform (n\_39) and the source current waveform (i(m)). The source current is lagging the source voltage. The peaks of the waveforms are found and their phase difference is calculated, cosine of which yields the power factor.

$$\text{Phase difference } \phi = X_{\max}[i(m)] - X_{\max}[n_1] = 0.5085 - 0.5047 = 0.00377$$

Converting the phase difference from time domain to degrees,

$$\text{Phase difference } \phi = \frac{0.00377 * 360}{0.02} = 67.86$$

Where 0.02 is the time period of the waves. Hence the power factor obtained in a circuit with R-L load is 0.377.

$$\text{Power factor} = \cos(\text{phase diff}) = \cos \phi = \cos 67.86 = 0.377$$

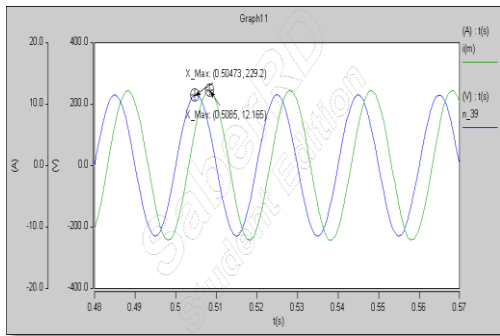


Fig.8. Voltage and current waveforms for RL load

Fig.9 shows the schematic of R-L Load with shunt capacitance using Saber. Fig.10 displays the source voltage waveform (n\_1) and the source current waveform (i(m)). The source current is lagging the source voltage. The peaks of the waveforms are found and their phase difference is calculated, cosine of which yields the power factor.

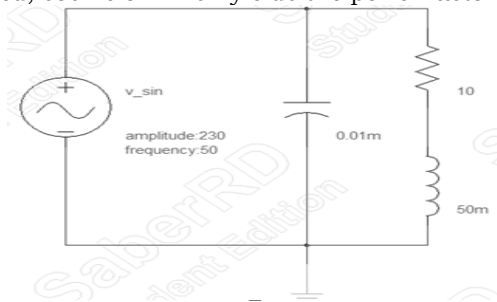


Fig.9. Schematic of RL load with shunt capacitance

**B. Simulation of RL load with shunt capacitance**

$$\text{Phase difference } \phi = X_{\max}[i(m)] - X_{\max}[n_1] = 0.40794 - 0.40503 = 0.00291$$

Converting the phase difference from time domain to degrees,

$$\text{Phase difference } \phi = \frac{0.00291 * 360}{0.02} = 52.38$$

Where 0.02 is the time period of the waves.

$$\text{Power factor} = \cos(\text{phase diff}) = \cos \phi = \cos 52.38 = 0.61$$

Hence the power factor obtained in a circuit with R-L load with shunt capacitance is 0.61

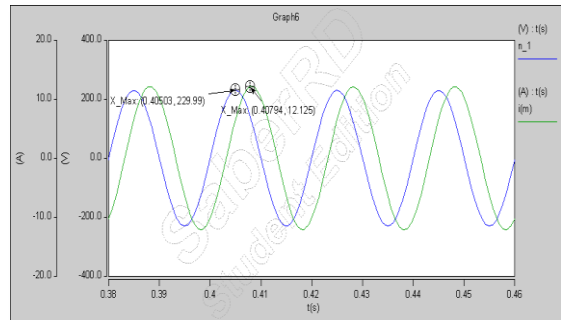


Fig.10. Voltage and current waveforms for RL load with shunt capacitance

**C. Simulation of SVC**

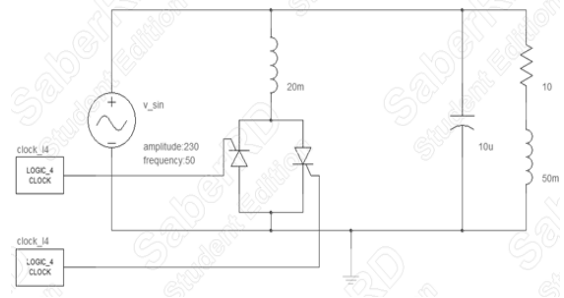


Fig.11. Simulation of SVC

Fig. 11 shows the schematic of SVC using Saber.

Fig. 12 shows waveforms of the source current, source voltage, FFT analysis of source current and instantaneous power.

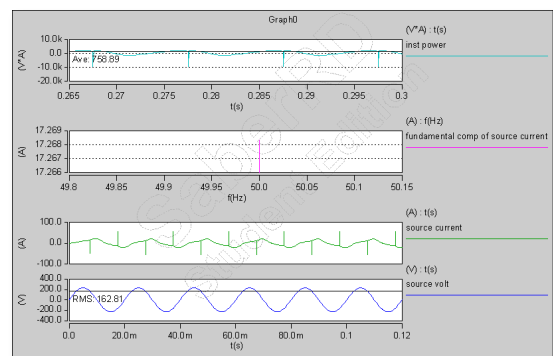


Fig.12. Resulting waveforms from Saber RD

The first waveform shows the instantaneous power found by multiplying the waveforms of source voltage and source current. Average of the instantaneous power is found out which is equal to 758.89W.

The second waveform shows the FFT analysis of source current which gives the fundamental value of the source current at the fundamental frequency (i.e, 50 Hz) = 17.2682A.

The last waveform shows the source voltage. The root mean square value of the source current is found as 162.81A.

$$\text{Avg. Instantaneous power} = V_{rms} * \frac{I_{peak}}{\sqrt{2}} * \cos \phi$$

$$758.89 = 162.81 * \frac{17.268}{\sqrt{2}} * \cos \phi$$

$$\cos \phi = 0.38$$

Hence the power factor obtained in a SVC circuit is 0.38. Firing angle of the SCR is varied to get required power factor.

IV. ALGORITHM FOR CODE

1. Read the output of zero crossing detector (ZCD) at any input pin of the microcontroller & keep monitoring the input pin.
2. If the input pin goes high, start a certain delay at a port, corresponding to the delay angle (α) of SCR1.
3. At the end of the delay, make the port high till the input pin (output of ZCD) goes low.
4. If the input pin goes low, start a certain delay at another port, corresponding to the delay angle (α) of SCR2.
5. At the end of the delay, make the port high till the input pin (output of ZCD) goes high.
6. Repeat steps 2-5 in an infinite loop.

Fig.13 shows the hardware implementation of the SVC circuit. The hardware circuit comprises of the following components:



Fig.13. Hardware Testing of the SVC circuit

I. HARDWARE RESULTS

OFF BOARD: 230 V, 50 Hz AC supply, Autotransformer, 0-5A AC ammeter, 0-150V and 0-5A AC single phase wattmeter, 0-150V AC voltmeter, 10Ω 12A Rheostat, 230/30 V transformer (inductor L1) with inductance of 48.5mH at secondary winding, 240V, 1.15A, 125W Choke (inductance L2) with inductance of 0.5H, Regulated Power supply (RPS) for +15V, -15V and +5V and a Cathode Ray Oscilloscope (CRO).

ON BOARD: 230/12 V transformer, integrator and comparator circuit, ATMEGA 32A board, drive circuit for the SCRs, 2 SCRs mounted on heat sinks and 440V AC, 50 Hz, 10uF capacitor.

The integrator circuit converts the sine wave to a cosine wave. Thus the delay in angle gets shifted by 90 degrees. Its output goes to the comparator circuit which generates a pulsating output at every zero crossing of the wave.

The program is compiled and uploaded on the AVR microcontroller which generates the required delay (in ms) and this output from microcontroller is multiplied with a high frequency pulse from the 555 timer circuit and the output is fed to the drive circuit. The drive circuit consists of a pair of n-p-n transistors connected in Darlington configuration to amplify the input pulse. The pulse is then given to a 1:1 pulse transformer which is used to isolate the power circuit from the microcontroller. The diodes are connected in anti-parallel to ensure that only positive pulses are given to the gate and cathode. A capacitor is connected at the output to reduce the noise. The output of the drive circuit triggers the SCR and it starts conducting. There are 2 drive circuits for 2 SCRs connected in anti-parallel. Both the SCRs are mounted on heat sinks. The power circuit comprises of the RL load with shunt capacitance and the SVC. An AC ammeter and AC wattmeter is connected in series with the source which measures the source current and the average power. The RL load comprises of a 10 Ω 12A Rheostat, 230/30 V transformer (inductor L1) which has a current carrying capacity of 2A. The capacitor value is 10 μF and its current carrying capacity is calculated as 1.38A. Thus the voltage from the autotransformer is set accordingly not to exceed the current capacities and the readings are tabulated.

Fig.15. gives the different set of readings for the voltage set at 44V and power at 40W. The first 2 readings give the power factor for a basic RL load and for a RL load with a shunt capacitance in parallel. From the above table, power factor improves when shunt capacitance is added in parallel. The next set of readings is taken for SVC. As the delay angle increases, the current decreases and hence the power factor increases.

V. TABULATION OF RESULTS AND GRAPHICAL REPRESENTATIONS

VOLTAGE (V)	CURRENT (I in A)	POWER (P in W)	DELAY (in ms)	POWER FACTOR	LOAD TYPE
40	1.65	30	--	0.4545	RL
40	1.55	30	--	0.4838	RLC
40	675	30	0	0.4477	SVC
40	1.65	30	1	0.4545	SVC
40	1.6	30	2	0.4687	SVC
40	1.575	30	3	0.4761	SVC
40	1.55	30	4	0.4838	SVC
40	1.525	30	5	0.4919	SVC

Fig.15. Readings for voltage V= 40V

These readings are plotted in gnu plot software whose plot is shown in Fig.16. It denotes the variation of the power factor with respect to the delay angle at different powers.

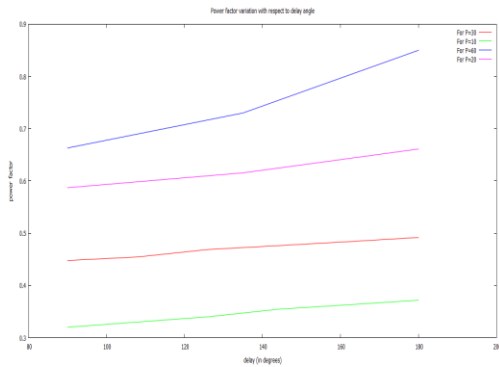


Fig.16. Variation of power factor with delay angle at different powers.

VI. APPLICATIONS AND BENEFITS OF SVC

Static VAR compensators are primarily used to mitigate voltage fluctuations, as well as the resulting flicker. Nowadays, large industries, particularly the steel-making plants typically apply SVCs for flicker compensation in electric arc furnace installations.

The main advantage of SVCs over simple mechanically switched compensation schemes is their near-instantaneous response to changes in the system voltage. For this reason they are often operated at close to their zero-point in order to maximise the reactive power correction they can rapidly provide when required. They are cheaper, higher-capacity, faster and more reliable than dynamic compensation schemes such as synchronous condensers.

In addition, Static VAR Compensators are installed at suitable points in the electric power system to augment its transfer capability by improving voltage stability, while keeping a smooth voltage profile under different system conditions. SVCs can also mitigate active power oscillations through voltage amplitude modulation. Moreover, as an automated impedance matching device, they have the added benefit of bringing the system power factor close to unity.

Therefore, SVC is usually installed near high and rapidly varying loads, such as electric arc furnaces, welding plants and other industries prone to voltage fluctuations and flicker.

Furthermore, other benefits of the SVC include:

- Maximized power compensation.
- Near-instantaneous response to system voltage variations.
- Increased customer’s economic benefits.
- Eliminate harmonics and reduce voltage distortion with appropriate shunt filters.
- Load balancing on three-phase systems.
- Less transmission losses.
- Enhanced transmission capacity, so more power can be transferred.
- Higher transient stability limit.

- Damping of small disturbances.
- Reduced voltage fluctuations and light flicker.

CONCLUSION

The RL load circuit is simulated with 230 V which gives a power factor of 0.37. Then the RL load is simulated with a shunt capacitance which gives an improved power factor of 0.61. The SVC is simulated which gives a power factor 0.57 which can be improved by changing the L2 value.

The same is executed with hardware setup which gives a power factor of 0.689 for RL load and 0.728 for RL load with a shunt capacitance. Thus, when a shunt capacitance is added in parallel with the RL load, the power factor is improved.

To further improve the power factor, SCR in series with an inductor is added in parallel with the RL load with shunt capacitance which gives a power factor of 0.85. From the tabulation of results in Fig.15 it is observed that the power factor increases with the increase in delay angle which is varied through the program.

Hence the project is successful in improving the power factor with the change in the delay angle.

FUTURE SCOPE

The variable shunt compensation using SVC can be extended to the large rating machines and Large Interconnected Power Systems. The SVC can also be fabricated by using IGBT’s and testing can also be performed using DSP. TSC-TCR based SVC can also be implemented for SMSL Test System.

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