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POWER FACTOR CORRECTION USING SHUNT COMPENSATION

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ABSTRACT

This paper discusses the Static VAR Compensation (SVC) method as an effective solution for power factor improvement. The need for power factor correction arises to regulate the system voltage and reactive power flow in an electrical system. A MATLAB/GUI model is developed to determine the amount of Var and capacitance required to compensate the power factor and voltage variations occurring under different loading conditions in an Electrical Machines Laboratory. Also to demonstrate the power factor correction using shunt compensation, a MATLAB/SIMULINK model is developed. The various forms of shunt compensation methods like fixed compensation and SVC are implemented and the results are analyzed for the systems without and with shunt compensation.

KEYWORDS: Fixed Capacitors, Power Factor, Reactive Power Compensation, SVC, Thyristor Switched Capacitor, Thyristor Controlled Reactor

INTRODUCTION

Maintaining the stable voltage profile and lossless power system with a high rate of availability and reliability is the most important objective of an electrical network. The interaction between supplier and consumer is the interface where the definition of power quality does not only affect the determination of the electrical equipment but also the economical billing scheme due to the load demand. The occurrence of additional reactive load demand results in poor power factor. In power systems, addition of load leads to an increase in the load current and consequently higher voltage drop and losses along the transmission and distribution network. This reduces the overall performance and efficiency of the network. Hence in case of higher reactive load demand and to transfer the more current, an equivalent design of higher power rating of all current carrying components in the system is to be redesigned. Additionally energy suppliers charge their consumers when his power factor falls below a certain value since the billing scheme is defined for the consumption of active as well as reactive power. Due to all these effects fast load compensation methods are needed. Load compensation can be carried out in different ways depending on the considered aim of improvement.

The methods which are used are: reactive power compensation, unbalanced load compensation and minimization of harmonic distortion. The following study shows the power factor improvement and the stabilization of the supply voltage of a supply network with an increased number of loads over the time by two different reactive power compensation methods. Firstly the behavior of a fixed mechanically switched capacitor bank is observed and secondly thyristor switched capacitors (TSC) and thyristor controlled reactors (TCR) are modeled for static VAr compensation (SVC).

UNDERSTANDING POWER FACTOR

The ratio of the real power used by the load to the apparent power drawn by it from the supply is defined as the power factor of the electrical system.

$$PF = \frac{RealPower(kW)}{ApparentPower(kVA)} \tag{1}$$

The inclusion of heavy inductive loads leads to lagging power factor whereas under light loads causes leading power factor for long transmission line networks [1][2]. Most of the bulk load consumers in a power system use inductive loads like induction furnaces, welding, ovens, lathe machines, drilling machines in industries etc. When such lagging power factor loads are introduced in a circuit, the voltage at the receiving end tends to decrease due to an increase in the load current. This results in an increase in the reactive power demand and losses in the circuit. A reduced power factor is undesirable because it results in poor reliability, safety problems, increases system capacity and higher energy costs.

CAPACITANCE CALCULATION – USING GUI MODEL

In a single phase or a three phase system, the capacitance required for compensation is calculated using the following formulas [3]:

The required capacitive kVar is given by-

$$Q = P(\tan(\phi_1) - \tan(\phi_2)) \tag{2}$$

The Capacitance to be inserted in each phase for compensation is given by-

$$C = \frac{Q}{\omega \cdot V^2} \tag{3}$$

Where,

Cos ϕ_1 is the existing power factor

Cosϕ_2 is the desired power factor. P is in kilowatts

V is the phase to ground voltage.

$\omega = 2\pi f$,

f is supply frequency

The calculation of the required reactive power and the amount of additional capacitance has been carried out by a designed graphic user interface in MATLAB®.

The GUI has 3 panels. Within the first panel "Selection" the user can select the type of the power system and the given input data. In the second panel "Input Data" the user can edit the data numbers of his former input selection as well as for the mandatory parameters which have been given a default value. After pressing the "Compute"-button the output data:

- Required reactive power $Q_{required}$ in kV
- Additional capacitance Ci

Figure 1 shows the flowchart for GUI using which per phase requirement of capacitance for various power factors is calculated. Table 1 shows various values of capacitance in µF required for compensating various power factors which are observed from our institute electrical machines laboratory [4].

Table 1: Capacitance Needed in µF for Compensation

		EXISTING POWER FACTOR				
		0.5	0.6	0.7	0.8	0.9
REQ. POWER FACTOR	0.95	51.9	37.15	25.57	15.58	5.75
	0.96	53.27	38.52	26.84	16.95	7.12
	0.97	54.78	40.04	28.46	18.46	8.64
	0.98	56.54	41.8	30.22	20.22	10.4
	0.99	58.78	44.04	32.46	22.46	12.64
	1.0	64.06	49.31	37.73	27.73	17.91

DESIGN AND EVALUATION

In order to analyze the improvement in power factor, data is collected from Electrical Machines Laboratory. Two induction motors of 3 Phase, 415 V, 2 kW are switched ON successively to observe the dip in power factor and the required compensation is provided by Fixed Capacitors and SVC. The single line diagram of the laboratory is shown in Figure 2.

- **Uncompensated System**

Two loads having a rating of 3 Phase, 415 V, 2 kW are connected to the supply via circuit breaker. The loads are introduced successively. For this scenario, the power factor, reactive power and other parameters are noted. The power factor of the system is observed to be 0.55. This value is very less for practical cases and increases losses in the system.

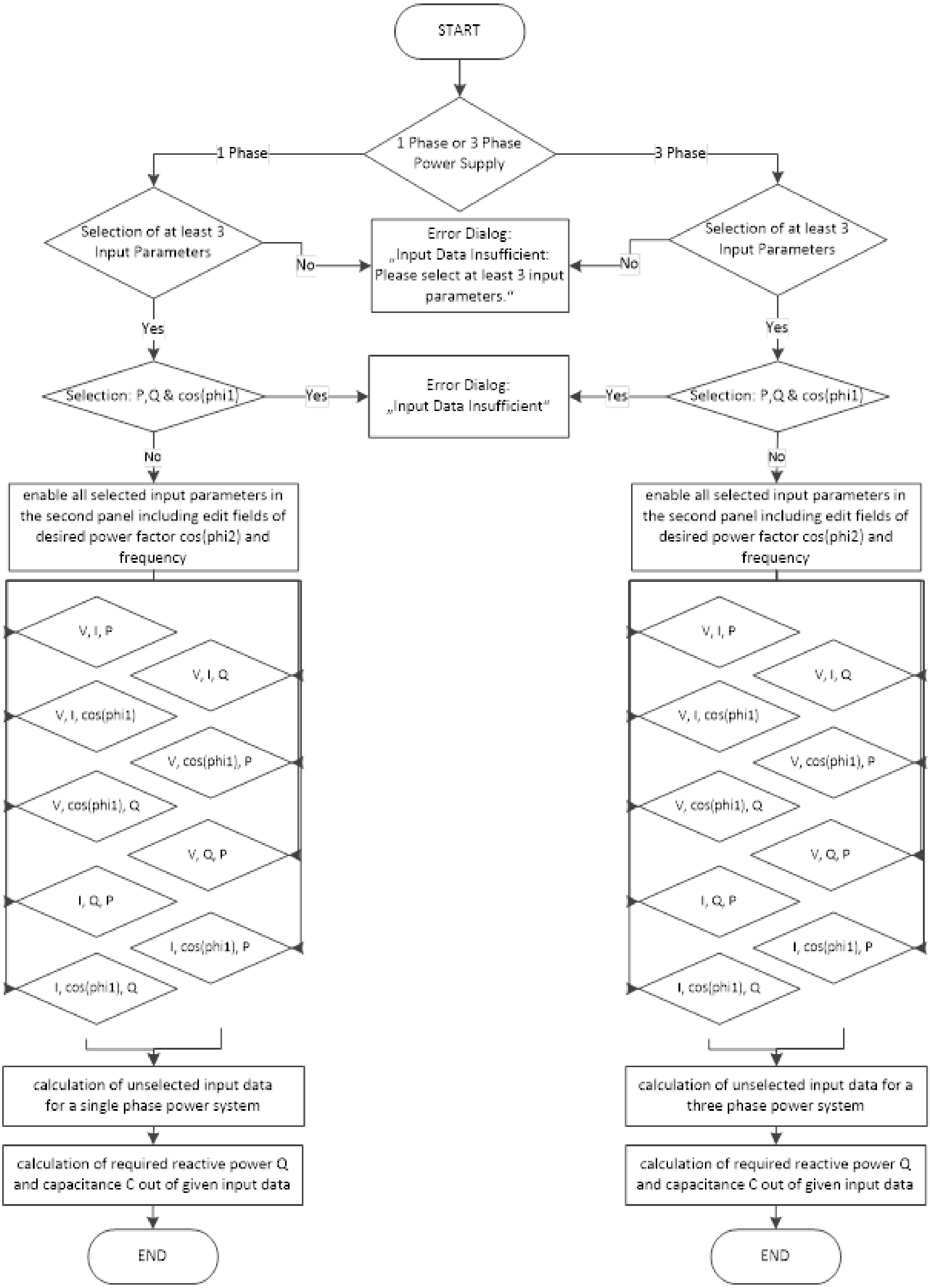

Figure 1: Flowchart Representing the Calculations Done in GUI

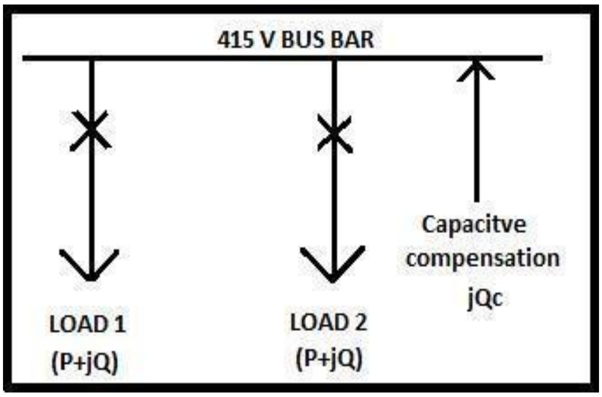

Figure 2: Single Line Diagram of Laboratory under Study

Hence there is a need to improve the power factor. The waveforms of active power, reactive power, power factor and current for the uncompensated system are shown in Figure 3. The figure depicts that with the increasing load, the reactive power, and current demand of the load also increase.

Table 2: Inductive Load Specifications

Specification	Rating
Rated Power (VA)	3605
Real Power (W)	2000
Reactive Power (kVAr)	3000
RMS Current (A)	5.02
Phase Angle	56.63
Power factor	0.55

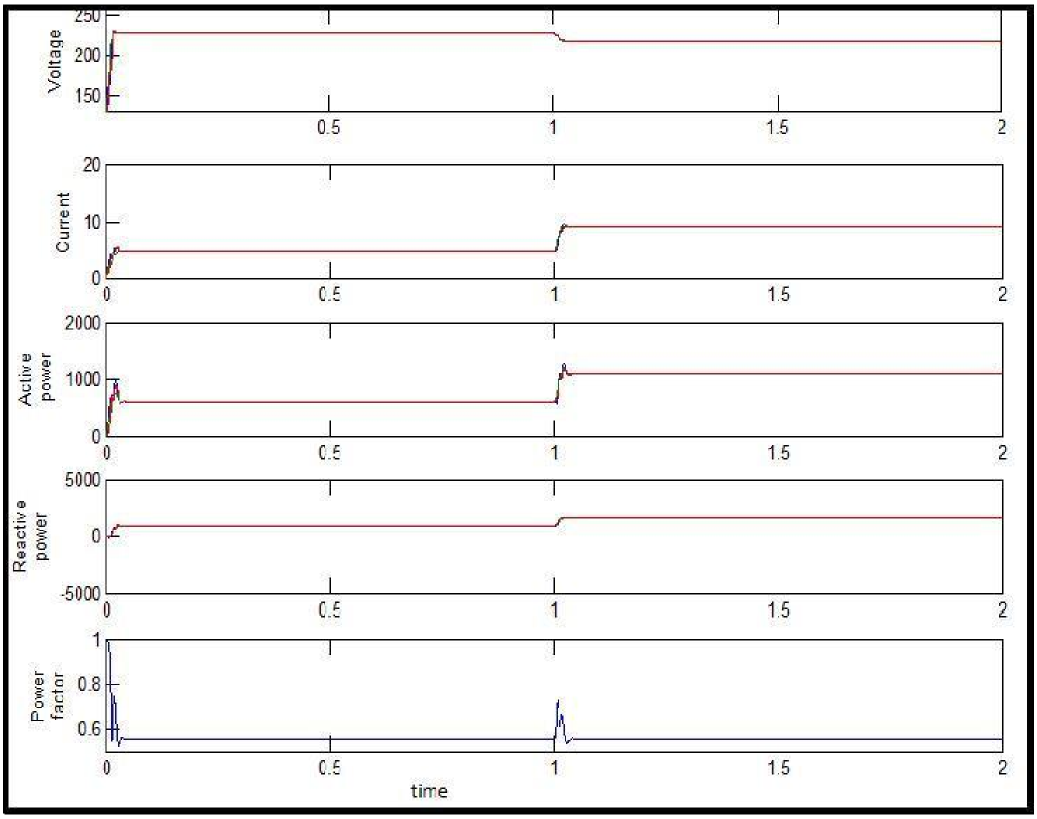

Figure 3: From Top to Bottom - Voltage, Load Current, Active Power, Reactive Power, Power Factor of Phase a

- **Compensated System Using Fixed Capacitors**

It is observed that when both the loads are on, the reactive power demand is approximately 6 kVAr. To supply this reactive power, two capacitor banks are connected in parallel via externally monitored circuit breakers for each phase. A feedback loop is designed to automatically turn on the capacitor banks whenever there is an increase in the load current and a reduction in the power factor, as shown in Figure 4. The rms value of the load current and power factor are compared with a reference value using a comparator. If the current entering the comparator exceeds the reference current, and the power factor is less than 1, the respective capacitor bank turns on. Following this rule, when load 1 is turned on, capacitor bank 1 becomes active to provide compensation.

Further as load 2 turns on, capacitor bank 2 also turns on along with 1 to provide compensate the dip in the power factor. Therefore, when both the loads are switched in the circuit, all the capacitor banks are active thus providing full compensation to the system and correcting the power factor to 1. The capacitance required for different combinations of loads and the associated reactive power is shown in the table 3. Figure 4 shows the block diagram of the system under study with fixed capacitors and the related waveforms are shown in Figure 5.

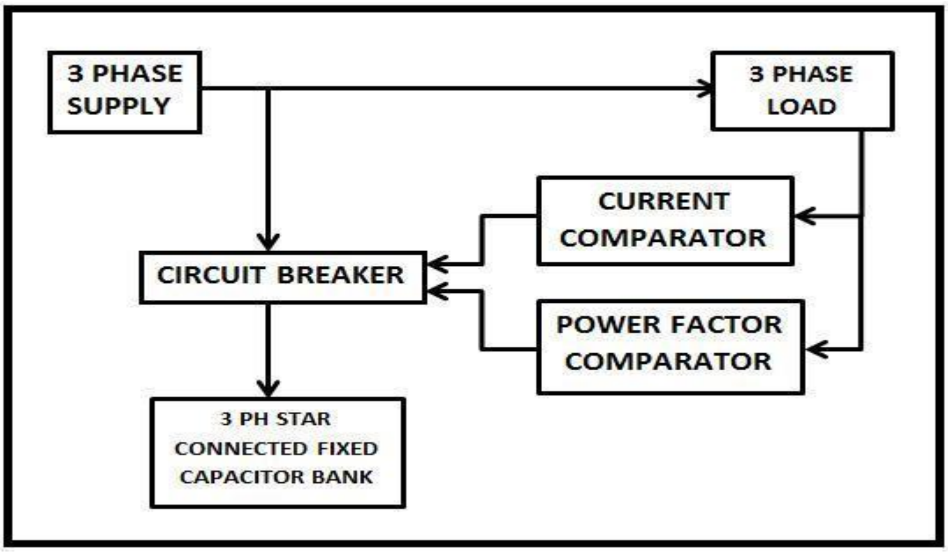

Figure 4: Block Diagram of Compensated System with Fixed Capacitors

As the loads and capacitance banks are switched on, the variation of power factor is observed, as shown in Figure 5. Also it is noted that when the unity power factor is obtained the reactive power falls to approximately zero, whereas there is no significant change in the active power due to the use of the compensation technique. Hence the inductive reactive power of the load is completely balanced by the capacitive reactive power of system. Also the current demand is reduced which further reduces the losses, thus enhancing the system efficiency.

Table 3: Capacitance Required after Switching on of Each Load for Compensation

Load	PF	Q (Var)	Reqd. Capacitance (μF)
First Load	0.55	3000	55.4
Both Loads	0.80	3012	55.4

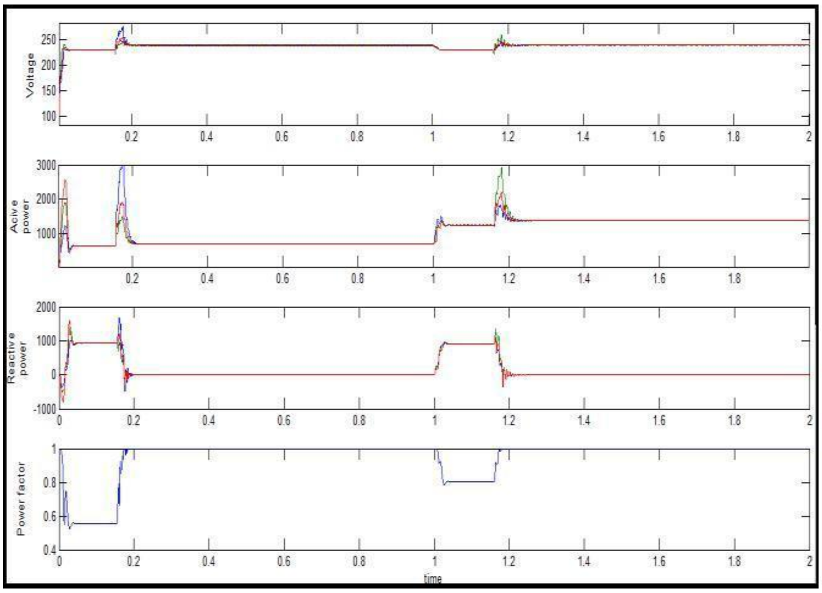

Figure 5: From Top to Bottom- Voltage, Active Power, Reactive Power, Power Factor of Phase a

- **Compensated System Using SVC**

Static Var compensator consists of two compensator - Thyristor Switched Capacitor (TSC) and Thyristor Controlled Reactor (TCR). A TSC's can be either switched on or off whereas TCR"s can be smoothly controlled by varying firing angles of the thyristor pair. The value of TSC's capacitor is chosen such that it generates leading Vars to compensate the effect of the inductive load and to attain unity power factor (using developed GUI model). If due to the TSC any overcompensation is caused then it is corrected by the TCR. TCR with the help of bidirectional thyristors injects the inductive power in the system in case of overcompensation. To avoid heavy oscillatory currents during turning on of TSC, the firing angle of the thyristors should be carefully chosen. Therefore, TSC should be switched on/off when the applied voltage is at its peak. Also it is required that the capacitor should be pre-charged to the peak value of the applied voltage before switching [5]. In case of TCR, the firing angle is variable depending upon the overcompensation occurring due to TSC.

For the demonstration of reactive power control using SVC, same two reactive loads of 3 Phase 415 V, 2 kW, 0.55 power factor lagging are taken for study. In 3 Phase, two TSCs per phase are star connected for each load. The anti-parallel thyristors are fired at the peak of the applied voltage. For phase a the thyristors are fired at Π/2 and 3Π/2. Similarly for phases "b and c" the firing angle for the thyristor pair is set at (7Π/6, 13Π/6) and (11Π/6, 17Π/6) respectively.

Simultaneously the load current and power factor are monitored, which provide a feedback to the thyristors of TSC. So by comparing these values, with the reference value the thyristors of TSC are fired, keeping in mind the firing should take place at the peak of input voltage. This process is shown by the block diagram in Figure 6. With proper firing of thyristors and a proper selection of capacitors (refer table 3), the power factor is corrected from 0.55 to 1. For TCR firing, the output reactive power is monitored. When the capacitive reactive power starts increasing, i.e. in case of overcompensation, the thyristors of the TCR are turned on by getting a signal from reactive power monitor. Therefore capacitive reactive power is balanced [6]. The waveform of active and reactive power and power factor is given in Figure 7. It is evident that SVC is effective in reducing the losses by reducing the reactive power and current.

RESULTS AND OBSERVATIONS

It is observed that both the methods successfully correct the power factor from 0.55 to 1 and reduce the net reactive power demand to zero by injecting leading vars in the system. It is also observed that the current comes down to a small value, hence reducing the losses in the system. The results of the compensation obtained through fixed capacitors and TSC-TCR are given in Table 4 below.

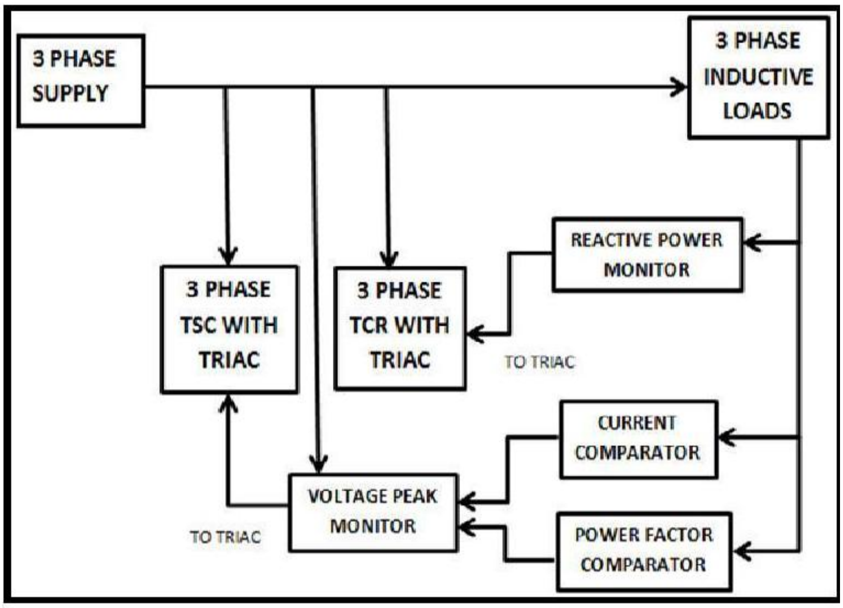

Figure 6: Block Diagram of SVC with Feedback

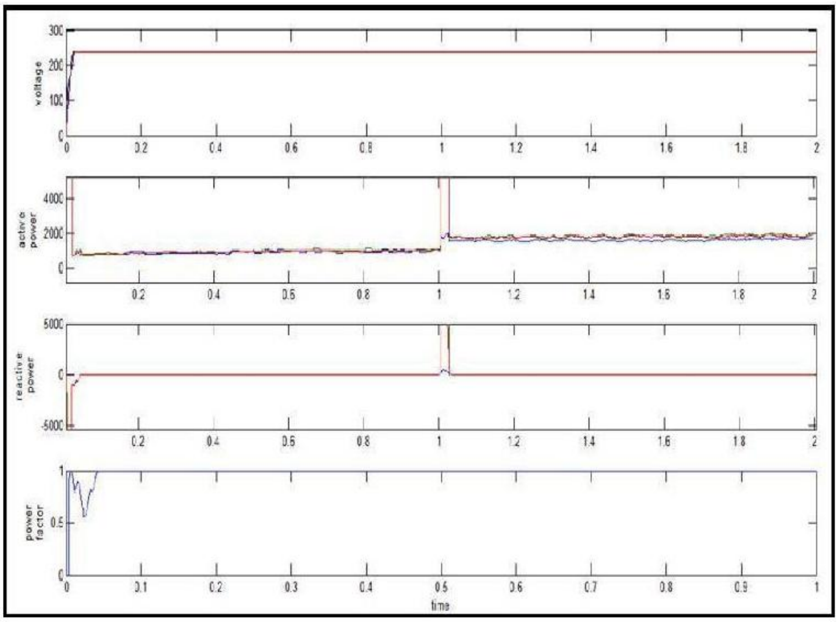

Figure 7: From Top to Bottom- Voltage, Active Power, Reactive Power, Power Factor

Table 4: Comparison of Parameters before and after Compensation

Method \ Load		Load 1	Load 1+2
Without Compensation	Reactive Power (Var)	3000	6000
	Power factor	0.55	0.55
	Current RMS (A)	5.018	10.04
With Fixed Capacitors	Reactive Power (Var)	2.97	-0.84
	Power factor	1	1
	Current RMS (A)	2.85	5.7
With TSC and TCR	Reactive Power (Var)	2.058	12.607
	Power factor	0.9993	0.9999
	Current RMS (A)	4.189	7.084

CONCLUSIONS

The study shows the theoretical principles of power factor improvement and stabilizing of supply voltage by implementing reactive load compensation in a model of 3 phase power supply system. The effects of a fixed capacitor-bank and an SVC have been analyzed regarding their benefits to an uncompensated power supply system. The input data of the conducted simulation model had been taken from an experimental measurement in the Electrical Machines Laboratory of VIT University Vellore (India).

The conducted study shows that for an uncompensated power supply system the supply voltage decreases with an increase of load. Due to the rise of reactive power demand the power factor decreases with the load. By implementing a fixed capacitor bank which had been attuned to the arising load, a successful compensation was reached with a power factor of unity.

The prediction of necessary capacitance for the compensation is very important. For this purpose, a MATLAB GUI model is prepared to calculate the capacitance required for compensation. In case of widely fluctuating loads a fixed capacitor bank will lead to either overcompensation or under-compensation. Therefore a variable VAR compensation is needed. Nowadays thyristor switched capacitances are combined with thyristor controlled reactor banks to minimize the effect of harmonic distortion by acting as a filter system.

For this purpose, a model of TSC-TCR was prepared which allowed full compensation of the system leading to a power factor of unity. Moreover due to the development of self-commutated power electronic devices various other compensation methods have been developed in order to achieve a more accurate compensation with the inherent ability of providing leading and lagging reactive power.

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