Analysis of Dynamic Power Factor Correction Using Flexible Ac Transmission Systems

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Abstract In many big industries, Commercial and industrial electrical loads include induction motor driven equipment such as elevators, pumps, presses, DC motors, power transformers, welding machines, and arc furnaces are mostly inductive in nature. Inductive load consumes reactive power (magnetizing power) in addition to the active power to do useful work. Reactive power required by inductive loads increases the amount of apparent power (measured in kVA) in the distribution system. This is important because a low power factor can waste energy, result in inefficient use of electrical power, and often result in higher energy bills.

But mechanical switching of capacitors is too slow to cope with the rapid and frequent changes in reactive power. In addition, the switching mechanism generates high transient currents that can disrupt micro-processor-based equipment and processes.To overcome the above problem we are using Static Var Compensator (SVC) and Thyristor Controlled Reactor (TCR) along with Microcontroller. Power factor and reactive power of the load is calculated using micro controller. Based on the high reactive load and frequency of the system the triggering angle of TCR is calculated The SVC regulates voltage at its terminal by controlling the amount of reactive power injected into or absorbed from the power system. When system voltage is low, the SVC generates reactive power (SVC capacitive). When system voltage is high, it absorbs reactive power (SVC inductive). The variation of reactive power is performed by switching three-phase capacitor banks and inductor banks. Each capacitor bank is switched on and off by three thyristor switches

(Thyristor Switched Capacitor or TSC) and Microcontroller signal. Reactors are either switched on-off (Thyristor Switched Reactor or TSR) or phase-controlled (Thyristor Controlled Reactor or TCR).

Keywords — Dc Motors, Svc, Tcr, Tsc, Tsr.

INTRODUCTION

In order to compensate the following
1. High reactive power.
2. Low power factor.
3. Harmonics.

CRM employs fixed reactive power compensation of 15MVAR whereas HRM employs dynamic reactive power compensation of +5MVAR to 25 MVAR capacity. This above correction of power factor is achieved using FACT devices which connected to the bus supply of the plant. The fact device which we use here is SVC

THE ABOVE FIGURE SHOWS THE VIEW OF INDUCATIVE LOAD

There are two types of Power Factor Correction Capacitors: Fixed and Automatic. Automatic capacitors are also known as switched capacitors. Automatic capacitors vary the amount of correction (KVAR) supplied to an electrical system, while fixed capacitors supply a constant amount of correction (KVAR). Under certain conditions, switching fixed capacitors can cause motor self-excitation and network resonance. So normally capacitor type compensation is used mostly where the load pattern is smooth. Many heavy industries like Cold Rolling Mills uses fixed capacitor banks to improve the power factor where the reactive power variation is smooth. The answer to this varies with each installation. If you have just a limited number of motors that need correction, it would be advisable to put a fixed capacitor at each motor. If you have a large plant with varying loads and numerous motors, an automatic capacitor may be better.Automatic capacitors are made up of banks that are switched off and on by a microprocessor controller based on the plant electrical load at any given time. Automatic capacitors are installed at the main incoming power source, while fixed capacitors are generally installed at individual motor loads throughout a plant.

Very large electricity users like Hot Rolling Steel Mills whose load pattern swings drastically due to the change in rolling temperature of successive passes, material composition, rolling technique etc according to the nature of load. They have successfully adapted static VAR compensation (SVC) - a technology originally developed to address voltage and transient stability on high-voltage transmission lines. SVC uses a capacitor bank in parallel with a thyristors-controlled reactor (TCR) to provide a dynamic, cycle-by-cycle response to the changing reactive demands of a load.The technology is quick and reliable, but is prohibitively expensive for most users. The Static VAR Compensator (SVC) is advanced power electronics equipment, which provides fast and continuous capacitive and inductive reactive power supply to the power system.

In the early 70's, the SVC based on thyristor technology was developed. The SVC configuration consists of Thyristor Controlled Reactors connected in parallel with fixed harmonic filters. The filters function to generate required reactive power and to reduce harmonics generated by the load and the TCR. SVC is used most frequently for compensation of disturbances generated by the Electrical Arc Furnaces. With a well-designed SVC, disturbances such as flicker from the EAF are mitigated, though the thyristor main circuit limits the size of the mitigation. In addition to mitigation of disturbances, increased furnace production will be achieved. The increased arc power increase is obtained by stabilizing the voltage support at the furnace bus.

The Static VAR Compensator (SVC) is a device of the Flexible AC Transmission Systems (FACTS) family using power electronics to control power flow on power grids. The SVC regulates voltage at its terminal by controlling the amount of reactive power injected into or absorbed from the power system. When system voltage is low, the SVC generates reactive power (SVC capacitive). When system voltage is high, it absorbs reactive power (SVC inductive). The variation of reactive power is performed by switching three-phase capacitor banks and inductor banks connected on the secondary side of a coupling transformer. Reactors are either switched on-off (Thyristor Switched Reactor or TSR) or phase-controlled (Thyristor Controlled Reactor or TCR)

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STATIC VAR COMPENSATOR CONNECTED TO BUS TERMINALS

When system voltage is low, the SVC generates reactive power (SVC capacitive). When system voltage is high, it absorbs reactive power (SVC inductive). The variation of reactive power is performed by switching three-phase capacitor banks and inductor banks connected on the secondary side of a coupling transformer. Each capacitor bank is switched on and off by three thyristor switches (Thyristor Switched Capacitor or TSC). Reactors are either switched on-off (Thyristor Switched Reactor or TSR) or phase-controlled (Thyristor Controlled Reactor or TCR).

The figure below shows a single-line diagram of a static var compensator and a simplified block diagram of its control system.
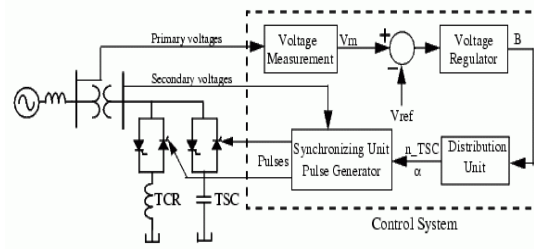
SINGLE-LINE DIAGRAM OF AN SVC AND ITS CONTROL SYSTEM BLOCK DIAGRAM

The control system consists of A measurement system measuring the positive-sequence voltage to be controlled

A voltage regulator that uses the voltage error (difference between the measured voltage Vm and the reference voltage Vref) to determine the SVC susceptance B needed to keep the system voltage constant

A distribution unit that determines the TSCs (and eventually TSRs) that must be switched in and out, and computes the firing angle α of TCRs

A synchronizing system and a pulse generator that send appropriate pulses to the thyristors The Static Var Compensator block is a phasor model, and you must use it with the phasor simulation method, activated with the Powergui block. It can be used in three-phase power systems together with synchronous generators, motors, and dynamic loads to perform transient stability studies and observe impact of the SVC on electromechanical oscillations and transmission capacity. This model does not include detailed representations of the power electronics, the measurement system, or the synchronization system. These systems are approximated rather by simple transfer functions and delays that yield a correct representation at the system's fundamental frequency.
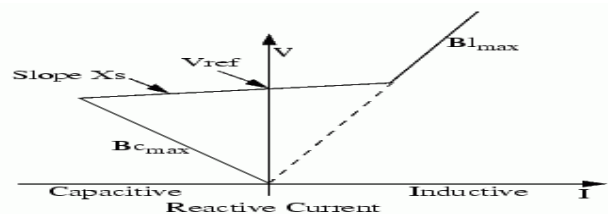
SVC (V-I) Characteristic

The SVC can be operated in two different modes:

In voltage regulation mode (the voltage is regulated within limits as explained below)

In var control mode (the SVC susceptance is kept constant)

When the SVC is operated in voltage regulation mode, it implements the following V-I characteristic.

Reactive current vector diagram

As long as the SVC susceptance B stays within the maximum and minimum susceptance values imposed by the total reactive power of capacitor banks (Bc_{max}) and reactor banks (Bl_{max}), the voltage is regulated at the reference voltage Vref. However, a voltage droop is normally used (usually between 1% and 4% at maximum reactive power output), and the V-I characteristic has the slope indicated in the figure. The V-I characteristic is described by the following three equations:

$$V = Vref + Xs \cdot I \qquad \text{SVC is in regulation range } (-Bc_{max} < B < Bl_{max})$$

$$V = -\frac{I}{Bc_{max}} \qquad \text{SVC is fully capacitive } (B = Bc_{max})$$

$$V = \frac{I}{Bl_{max}} \qquad \text{SVC is fully inductive } (B = Bl_{max})$$

where

V	Positive sequence voltage (p.u.)
I	Reactive current (p.u./Pbase) (I > 0 indicates an inductive current)
Xs	Slope or droop reactance (p.u./Pbase)
Bcmax	Maximum capacitive susceptance (p.u./Pbase) with all TSCs in service, no TSR or TCR
Blmax	Maximum inductive susceptance (p.u./Pbase) with all TSRs in service or TCRs at full conduction, no TSC
Pbase	Three-phase base power specified in the block dialog box

SVC Dynamic Response

When the SVC is operating in voltage regulation mode, its response speed to a change of system voltage depends on the voltage regulator gains (proportional gain Kp and integral gain Ki), the droop reactance Xs, and the system strength (short-circuit level).

For an integral-type voltage regulator (Kp = 0), if the voltage measurement time constant Tm and the average time delay Td due to valve firing are neglected, the closed-loop system consisting of the SVC and the power system can be approximated by a first-order system having the following closed – loop time constant

$$T_c = \frac{1}{Ki \cdot (Xs + Xn)}$$

where

Tc	Closed loop time constant
Ki	Proportional gain of the voltage regulator (p.u._B/p.u._V/s)
Xs	Slope reactance p.u./Pbase
Xn	Equivalent power system reactance (p.u./Pbase)

This equation demonstrates that you obtain a faster response speed when the gain is increased or when the system short-circuit level decreases (higher Xn values). If you take into account the time delays due to voltage measurement system and valve firing, you obtain an oscillatory response and, eventually, instability with too weak a system or too large a regulator gain.

MERITS OF SVC OVER OTHER COMPENSATORS

The total (or apparent) power required by an inductive device comprises the following:

1. Real power (measured in kilowatts, kW)
2. Reactive power , the non-working power caused by the magnetizing current required to operate & sustain the magnetism in the device (KVAR)

The ratio of active power to the resultant power, called power factor, implies that because of greater demand for reactive power, the percentage of useful utilization of the total generated power starts diminishing. Simply stated, power factor is the percentage of consumed power(KW) versus supplied power(KVA). This is important because a low power factor can waste energy, result in inefficient use of electrical power, and often result in higher energy bills.

More the inductive nature more will be the power factor angle, which consumes more reactive power. This increases the active power range, which demands more current from the source and makes the source to load more than the capacity. Therefore, transformers and cables are forced to carry more useless power than the real demand power, which overrates the capacity of transformer, cables and switchgears.

In addition, the price of overcoming disadvantages arising out of low power factor has to be paid ultimately by the consumer by higher rates and penalty imposed by electricity board authorities.

The reactive power not only causes voltage swings, but also displaces transmission capacity, increasing energy losses in the system. It is essential to balance the supply and demand of active and reactive power in an electrical system.
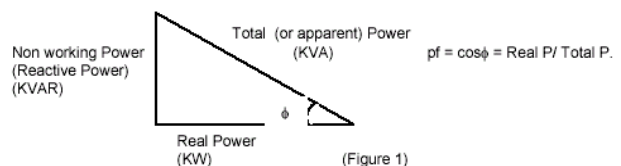
Vector diagram of reactive power

The lagging reactive power that makes the power factor poor is compensated by means of VAR Compensators.

The different types of VAR Compensators are:
i)   Fixed capacitor banks
ii)   Switched capacitors
iii)   Synchronous condensers
iv)   Self Saturated reactor / Fixed capacitor
v)   Static compensators

Fixed capacitor banks:
Fixed Shunt capacitors banks were first employed for power factor correction in 1914. The lagging current drawn by the inductive load compensates the leading current drawn by the shunt capacitor.

Switched Capacitors:
For dynamic compensation we are going for switched capacitors. Depending on the VAR requirement, a number of capacitors can be switched into or switched out of the system by means of relays and mechanical switches.

Synchronous Condensers:
All synchronous machines can give continuous variable var compensation. When over excited the machine generates and is operating in a stable condition. When under excited it absorbs vars with a reducing stability down to zero excitation.

Self saturated reactor/fixed capacitors:
Saturated reactor is a fixed voltage device. It does not pose any stability problem in the system. It consists of a variable reactor and a capacitor as shown in figure (3). By choosing proper values of L and C, we can achieve smooth and steeples control of var from lagging and leading.

Static compensators
After the advent of thyristors, fast reactive power compensation is possible. As the response time is very less, static reactive power compensation is becoming increasing popular. These static compensators

Thyristor Controlled Reactor (TCR)
A reactor and a thyristor valve are incorporated in each single-phase branch. The power is changed by controlling the current through the reactor by means of the thyristor valve. Delaying the firing of the thyristor valve in relation to the natural current zero controls the on-state interval. A TCR is used together with a fixed capacitor bank when reactive power generation is required.
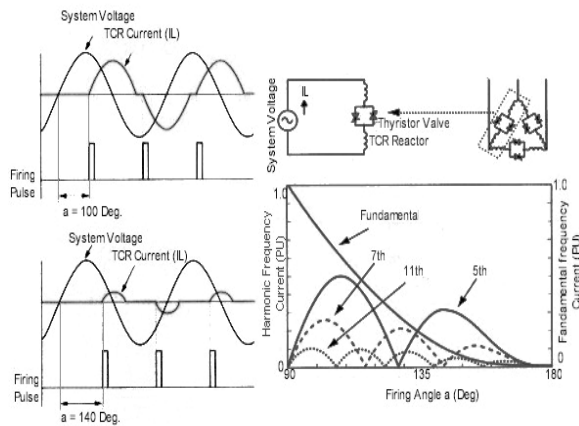

wave form of firing angle

The characteristics of a TCR are:

1. Continuous control
2. No transients
3. Generation of harmonics

Thyristor Switched Capacitor (TSC)

A shunt capacitor bank is divided into a suitable number of branches. Each branch is individually switched in or out by means of a valve with antiparallel connected thyristors. All switching takes place when the voltage across the thyristor valve is zero, thus providing almost transient-free switching.

Disconnection is effected by suppressing the firing pulses to the thyristors, which will block when the current reaches zero.
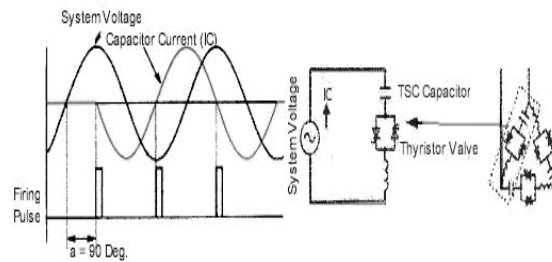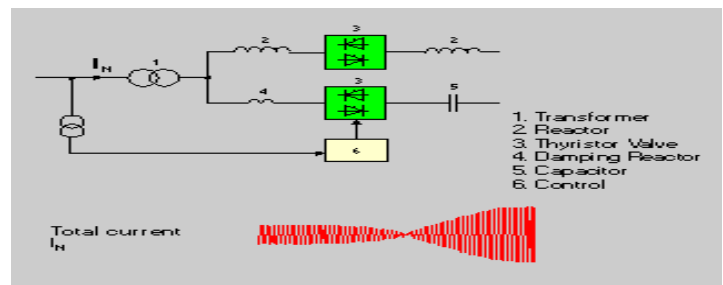

Firing angle of TSC

The characteristics of a TSC are:

Stepwise control, No transients

No harmonics, Low losses

Redundancy and flexibility

Thyristor Switched Capacitor / Thyristor controlled Reactor (TSC / TCR)

A combination of TSC and TCR is, in the majority of cases, the optimum solution. With a combined TSC/TCR compensator.

continuously variable reactive power is obtained throughout the complete control range as well as full control of both the inductive and the capacitive parts of the compensator. This is a very advantageous feature permitting optimum performance during large disturbances in the power system.

Total current controlled by varying firing angle
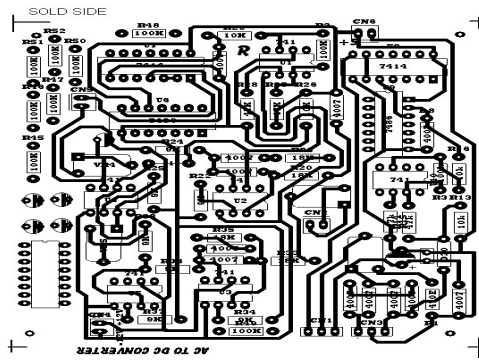
The characteristics of a TSC/TCR combination are:

• Continuous control, No transients
• Low generation of harmonics
• Low losses, Redundancy

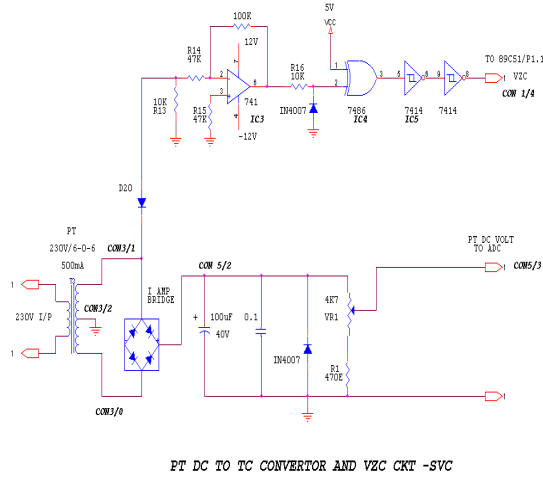The Static VAR Compensator (SVC) installed at Salem Steel is designed primarily to
• Reduction of lagging reactive load.
• Elimination of Harmonics.
• To provide stable power supply in all the production units.
The SVC will also reduce the harmonic emission and improves the power factor. The SVC consists of one Thyristor Controlled Reactor

(TCR) of 20 MVAR capacity, a 5th harmonic filter (FC 5), a 7th harmonic filter (FC 7), a 11th harmonic filter (FC 11) and a 13th harmonic filter (FC 13) of total capacity of 25 MVAR. In static Var compensation, Thyristor Controlled reactor is employed in which the firing angle is changed. Triggering pulses are generated and given to thyristors in accordance with the reactive power of the load. In this, steady reactive power is obtained. This is achieved dynamically by changing the firing angle to the thyristor and thereby changing the current through the reactor.

Hence this SVC setup is very huge in size we have designed a small model of our project using microcontroller.

PT DC TO TC CONVERTOR AND VZC CKT -SVC

CURRENT AC TO DC CONVERTOR & CZC CKT - SVC

The above circuit diagram shows the voltage zero crossing and current zero crossing and input current is taken from potential transformer and current transformer which connected to the power grid.

Printed Circuit Board for vzc and czc circuit

The voltage and current signal from PT and CT are fed to respective Zero Crossing Detector (ZCD) circuits as shown in fig. The open loop op-amplifier is used to convert the AC sine wave voltage into square waveform, which is then fed to EX.OR circuits to get a sharp pulse at the instance of zero-crossing. The capacitor and resistance network at the input of last stage EX.OR gate helps to get the sharp pulse at the output. Varying the resistor value can vary the duration of pulse. The sharp short period pulse if fed as input to INT0 of μC 89c51.Similarly the current signal is given to int1 of μc after detection so as to calculate the phase angle between V and I. The current and voltage signal are fed to a D latch flip flop to find the Lead and Lag status which can be used for calculation of reactive power. The voltage signal from PT and Current signal from CT are fed to the similar op.amp circuits of RMS to DC converter as shown in fig (a) and (b).The negative half cycle and the positive half cycle waveform is fed to two different DC converters and both are added in a separate op-amp to get the cumulative dc output. The final DC output is filtered by the feedback capacitor. The filtered steady state value is fed to input of ADC for conversion of A to D. The burden resistor in the CT circuit can be changed according to the load condition.
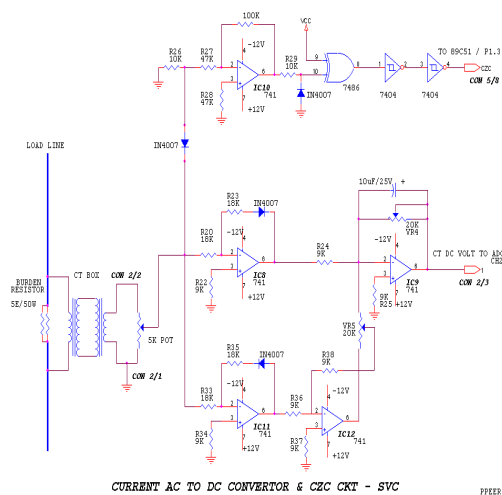
SVC FIRING CHORD

The above board is called firing chord board (or) svc board this board is interfaced with motherboard by 4-pin RMC connectors. This board contains IC TCA 780 which produces generated current error signal which is given to trigger SCR at required time interval as the error signal are in Millie ampere range an pulse transformer is used to amplifies the error signals here we are making and measuring changes by using variable resistor and resistance and by using different types of capacitors.
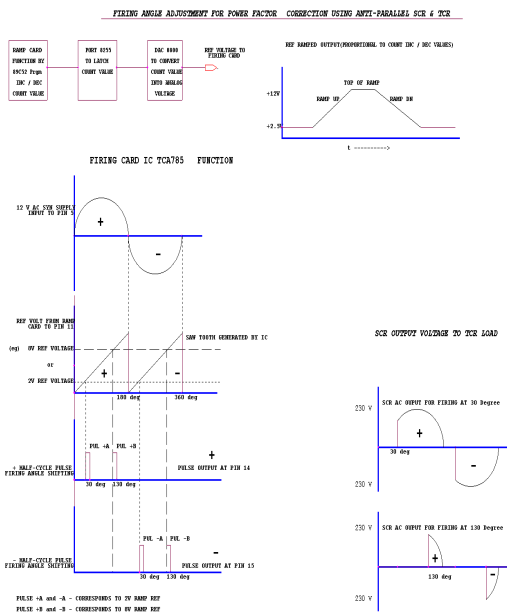
Firing angles of SCR
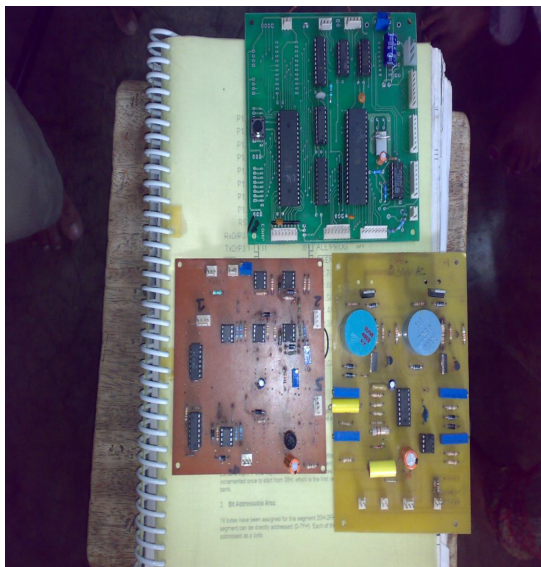
Hardware Implementation

By controlling dynamic power factor of inductive and capacitive loads, wastages of reactive power can be reduced and indeed increases the efficiency of machines. Hence as efficiency is increased production of the plant is increased. By implementing above method power factor could be maintained near to unity which helps to supply constant voltage at required ratings. By this method cost of electric bills can be reduced. This is most economic method to correct dynamic power factor in big industries like Salem steel plant where most of the loads are inductive in nature.

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