REACTIVE POWER COMPENSATION USING FC-TCR

Major Project Report

Submitted in Partial Fulfillment of the Requirements for the *Degree of*

MASTER OF TECHNOLOGY

IN

ELECTRICAL ENGINEERING
(Electrical Power Systems)

By

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- Dhruvang R. Gayakwad
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Abstract

Industrial loads are source of disturbances to power system due to more and more non-linearity. Apart from their good functional properties, they are characterized by negative impact on the quality of power. Such loads will cause distortion of supply voltage, unbalance phase loadings, fluctuations, higher neutral current etc. Depending on the load type, such disturbances may occur separately or concurrently. These disturbances are propagated through distribution systems to other users' networks, impair operating conditions of equipment and, in extreme cases, prevent operation of electrical equipment sensitive to such disturbances.

The adverse impact of non-linear loads on a power system can be mitigated by means of compensation equipment like fixed capacitor (FC), thyristor controlled reactor (TCR) - FC/TCR. The purpose of FC-TCR compensator is compensation of the fundamental component of the reactive power and filtering selected current harmonics.The goal is the minimization of the RMS and THD values of the line current by controlling the firing angle value of the TCR branch. For simulation purpose loads are represented by its equivalent R-L circuits. Optimum algorithm is applied in each half cycle of the voltage source, and optimum firing angles are obtained satisfying the condition of minimum rms value of line current such that reactive power is compensated and power factor is maintain near to unity.

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Chapter 1

Introduction

1.1 Introduction

With the increasing non linear load demand day by day on utility distribution side, the waveform of voltage & current is also become more disturbed so the power quality of the overall system is detoriated.

The increase use of efficient, high speed semiconductor devices for switching or power conversion and control have created so many problem to electrical utility. In addition to this the main problem is reactive energy which is required at each and every stage. Nowadays it is necessary to manage this reactive energy to optimize the electrical installation by reducing the energy consumption and improving power quality.

Harmonic is also generated by the nonlinear loads. If this is not compensate by locally, then it will go further to the source side and distorte source voltage and current.

1.2 Literature Survay

So many referances are used to understand the power quality problems and different topologies are used for their solution:

1 THYRISTOR-BASED FACTS CONTROLLERS FOR ELECTRICAL TRANSMISSION SYSTEMS by Mohan Mathur [1] book is the milestone for understanding the basics of svc & different problems associate with the reactive power compensation. The brief design criterion is given for different svc topologies

2 Electrical Power Systems Quality Second Edition Mc-Grow Hill publication book gives best idea about power quality, their causes, their problems. It gives brief detail of different power quality issues.It tells about the harmonic phenomena & their effects on the power system.

3 Understanding Facts by Hingorani is also the good book which gives the quick overview of different types of facts devices, their definations and functions.

4 IEEE TRANSACTION paper on Anti resonance hybrid capacitor bank for power factor correction shows the main objective of the proposed hybrid capacitor bank is to compensate for reactive power without any harmonic resonance. Hybrid capacitor bank is delta connected in series with the small rating of three single phase inverter without matching transformer. This inverter is used to improve the characteristic of the capacitor. This topology is used for PFC in low-voltage power distribution systems. The dc bus voltage required for the inverter is 20 v for power distribution system rated of 380v.

5 A paper on Some important electrical features in a fc-tcr implementation has explained a self-supplied thyristor firing circuit is considered, which can be used in medium to high power applications, avoiding the use of multiple isolated power supplies. It also includes the snubber circuits which help to decrease voltages peaks and avoid critical dV/dt that could fire the device in an inappropriate

time. The self-supplied firing circuit is able to use a small part of the energy that flows through the snubber to fire the thyristor device.This approach is a interesting solution for a FC-TCR trigger circuit, since it avoids the use of isolated power.

6 A paper on Control of an SVC for the Load Balancing and Power Factor Correction with a new Algorithm based on the Power Analysis gives the brief information about the calculation of required compensation susceptance for each phase is obtained by the algorithm. This algorithm is valid for both active passive loads. Only reactive powers and voltages values are measured as feedback signals to control the compensator. Simulation results shows that the TCR also generates harmonics.

7 The article on Research on TCR Type SVC System and MATLAB Simulation shows that voltage PF is maintain by double loop control strategy of svc. Based on instantaneous reactive power theory, the SVC system signals are detected rapidly and precisely. It also gives the design criteria for FC Filter design. voltage-closed loop must be lie in outer-loop to make voltage constant, and inner loop is an admittance compensation loop, it increases the dynamic response speed. When reactive power admittance changed, according to the quantity detected, TCR computes out α to offset it, when the active power admittance of load also changes, the PI regulator produces a given value of admittance to assure the voltage constant.

8 A paper on Performance Analysis of Shunt Reactive Power Compensators offers good solution to the voltage flicker problem with shunt capacitor & SVC. The automatic control of SVC allocates the supply or consumption of VARs on the system with thyristor-controlled switches, thus minimizing voltage fluctuations and increasing line loadability. The alternating current filters (ACF) absorb harmonics generated by the TCR. it shows the cases when to use shunt capacitor & SVC both.

9 An Accurate Formula For The Firing Angle Of The Phase Angle Control In Terms Of The Duty Cycle Of The Integral Cycle Control

10 What should you know about SCR power controllers

11 SCR Power Theory Training Manual

Conclusion: These three papers give the detail methodology of phase angle control & integral angle control method for controlling the thyristor. They also give the comparision between this two methods & according to application we use any of this methods.

12 Psim Help is very useful for simulation purpose.

1.3 Objective of work

The main objective of project is to improve the power quality, minimize the tariff & penalty applied to the industry. Generally main penalty is due to the low power factor of utility so to improve that they use APFC panels, but it gives reactive power compensation in step wise manner not in smooth way, So utility have to adjust with one or two leading or lagging KVAR. We are going to do for such compensation device which gives smooth reactive power variation as load vary.For this purpose we decide to go towards FC-TCR which can smoothly give reactive power compensation & maintain power factor near to unity. To achieve this we are using PSIM software for simulation and analysis. We take the R-L equivalent loads of particular kVAR requirement then compensate it with different value of fixed capacitor and varying the firing angle of the thyristor for getting different VAR output from the inductor.

Chapter 2

Power Quality Problems

2.1 Basic problem of power quality

As IEEE defined power quality disturbances have been organized into seven categories based on wave shape. In industries, commercial and domestic power utilization paten is changed but overall power quality related problems are same just magnitude is altered:

a. Transients

b. Interruptions

c. Sag / under voltage

d. Swell/over voltage

e. Waveform distortion

f. Voltage fluctuations

g. Frequancy analysis

2.2 Voltage flucuation

- Voltage drop across the line impedance caused by large current surges
- Voltage surges developed at the start-up of an induction machine operating from fixed frequency (large induction machines), which produce reactive voltage surges.

2.3 Frequancy Fluctuation

- Large, real power surges during start-up of the induction motor and power fluctuations
- Slow response of the governor control
- Frequency dip when the system is loaded by a sudden, large load or the system is underrated with respect to the load
- Frequency run-away when the generation system produces more power than needed.

2.4 Single phase loads and load imbalance

Single phase loads should be distributed as evenly as possible between the three phases of a three-phase generator set in order to fully utilize its capacity and limit voltage imbalance.

2.5 Power factor

Capacitive loads, overexcited synchronous motors, etc. cause leading power factor, where current leads voltage. Generators have a very limited capacity for supplying leading power factor loads. If not controlled, these can lead to loss of voltage control and damage to the generator. Lagging power factor, where current lags voltage, is more generally the case and is a result of the total inductance of the circuit.

2.6 Motor loads

When starting large motors across the line with a generator set, causing a high sustained inrush current typically six times rated motor running current until the motor reaches rated running speed. This high current demand causes voltage dips that can destabilize the generator. Various types of reduced voltage motor starters & power electronics equipment are available to reduce the starting kVA of a motor in applications.

2.7 Nonlinear variable frequency drives (VFD)

VFDs employ rectifiers on the input to covert AC to DC and an output inverter to produce variable voltage and frequency. Although newer technology drives (such as PWM types) produce lower current harmonics, older technology drives induce significant distortion in generator output voltage. Larger alternators are required to prevent overheating due to the harmonic currents and reduce system voltage distortion by lowering alternator reactance.

2.8 Nonlinear uninterruptible power supplies (UPS)

UPSs use silicon controlled rectifiers or other static devices to convert AC voltage to DC voltage for charging storage batteries. Use the full nameplate rating of the UPS for determining load to allow sufficient capacity for generator set battery charging and accommodating full UPS load capacity.

Chapter 3

Power Quality Solution

3.1 Concept of Facts

Although the concept of FACTS was developed originally for transmission network; this has been extended since last 10 years for improvement of Power Quality (PQ) in distribution systems operating at low or medium voltages. In the early days, the power quality referred primarily to the continuity of power supply at acceptable voltage and frequency. However, the prolific increase in the use of computers, microprocessors and power electronic systems has resulted in power quality issues involving transient disturbances in voltage magnitude, waveform and frequency. The nonlinear loads not only cause PQ problems but are also very sensitive to the voltage deviations. Power Quality problem is defined as "Any problem manifested in voltage, current or frequency deviations that result in failure or misoperation of customer equipment". The PQ problems are categorized as follows

3.1.1 Trasients

1 Impulsive

2 Oscillatory

3.1.2 Short-duration and Long-duration variations

1 Interruptions

2 Sag (dip)

3 Swell

3.1.3 Voltage unbalance

3.1.4 Waveform distortion

1 DC offset

2 Harmonics

3 Inter harmonics

4 Notching

5 Noise

3.1.5 Voltage Flicker

3.1.6 Power frequency variations

3.2 Types of Facts

3.2.1 Series compensation

In series compensation, the FACTS is connected in series with the power system. It works as a controllable voltage source. Series inductance exists in all AC transmission lines. On long lines, when a large current flows, this causes a large voltage drop. To compensate this series capacitors are connected,they decreasing the effect of the inductance.

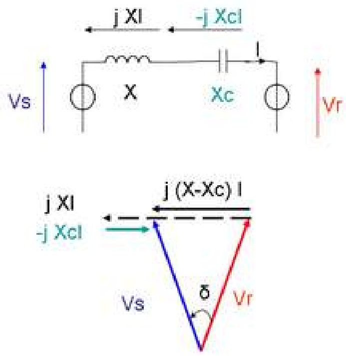


Figure 3.1: series compensation

3.2.2 Shunt compensation

In shunt compensation, power system is connected in shunt (parallel) with the FACTS devices. It acts as a controllable current source.

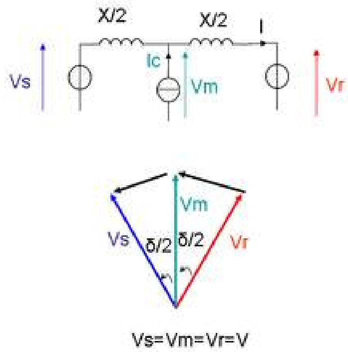


Figure 3.2: shunt compensation

3.2.3 Shunt capacitive compensation

This system is used to improve the power factor. Whenever an inductive load is connected to the transmission line, power factor lags because of lagging load current. To compensate, a shunt capacitor is connected which draws current leading the source voltage. The net result is improvement in power factor. Nowadays this system is modify for distribution sector also.

3.2.4 Shunt inductive compensation

This system is used either when charging the transmission line, or, when there is very low load at the receiving end. Due to very low, or no load very low current flows through the transmission line. Shunt capacitance in the transmission line causes voltage amplification (Ferranti Effect). The receiving end voltage may become double the sending end voltage (generally in case of very long transmission lines). To compensate, shunt inductors are connected across the transmission line.

3.3 3.3 Types of series compensation

3.3.1 Static synchronous series compensator (SSSC)

3.3.2 Thyristor-controlled series capacitor (TCSC)

A series capacitor bank is shunted by a thyristor-controlled reactor.

3.3.3 Thyristor-controlled series reactor (TCSR)

A series reactor bank is shunted by a thyristor-controlled reactor

3.3.4 Thyristor-switched series reactor (TSSR)

A series reactor bank is shunted by a thyristor-switched reactor

3.4 Types of shunt compensation

3.4.1 Static synchronous compensator (STATCOM)

A Static synchronous generator operated as a shunt-connected static var compensator whose capacitive or inductive output current can be controlled independent of the ac system voltage.

3.4.2 Static VAR compensator (SVC)

A shunt-connected static var generator or absorber whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific parameters of the electrical power system (typically bus voltage).

- This is a general term for a thyristor-controlled or thyristor-switched reactor, and/or thyristor-switched capacitor or combination. SVC is based on thyristors without the gate turn-off capability. It includes separate equipment for leading and lagging VARs; the thyristor-controlled or thyristor-switched reactor for absorbing reactive power and thyristor-switched capacitor for supplying the reactive power. SVC is considered by some as a lower cost alternative to STATCOM, although this may not be the case if the comparison is made based on the required performance and not just the MVA size.

3.4.3 Thyristor-controlled reactor (TCR)

Reactor is connected in series with a bidirectional thyristor. A shunt-connected, thyristor-controlled inductor whose effective reactance is varied in a continuous manner by partial-conduction control of the thyristor valve.

- TCR is a subset of SVC in which conduction time and hence, current in a shunt reactor is controlled by a thyristor-based ac switch with firing angle control.

3.4.4 Thyristor-switched reactor (TSR)

Same as TCR but thyristor is either in zero or full conduction.TSR is another a subset of SVC.TSR is made up of several shunt connected inductors which are switched in and out by thyristor switches without any firing angle controls in order to achieve the required step changes in the reactive power consumed from the system. Use of thyristor switches without firing angle control results in lower cost and losses, but without a continuous control.

3.4.5 Thyristor-switched capacitor (TSC)

Capacitor is connected in series with a bidirectional thyristor valve.. A shunt-connected, thyristor-switched capacitor whose effective reactance is varied in a stepwise manner by full or zero conduction operation of the thyristor valve.

- TSC is also a subset of SVC in which thyristor based ac switches are used to switch in and out (without firing angle control) shunt capacitors units, in order to achieve the required step change in the reactive power supplied to the system. Unlike shunt reactors, shunt capacitors cannot be switched continuously with variable firing angle control.

3.4.6 Mechanically-switched capacitor (MSC)

Capacitor is switched by circuit-breaker. It aims at compensating steady state reactive power. It is switched only a few times a day.

Chapter 4

Fixed Capacitor Thyristor Controlled Reactor(FC-TCR)

4.1 Basic of Thyristor controlled reactor (TCR)

4.1.1 Introduction

In an electric power transmission system, a thyristor-controlled reactor (TCR) is a reactance connected in series with a bidirectional thyristor. The thyristor is phase-controlled, which allows the value of delivered reactive power to be adjusted to meet varying system conditions.Thyristor-controlled reactors can be used for limiting voltage rises on lightly-loaded transmission line.
In parallel with series connected reactance and thyristor, there may also be a capacitor bank, which may be permanently connected or which may use mechanical or thyristor switching. The combination is called a static VAR compensator.

4.1.2 Circuit diagram

A thyristor controlled reactor is usually a three-phase assembly, normally connected in a delta arrangement to provide partial cancellation of Harmonics. Often the main

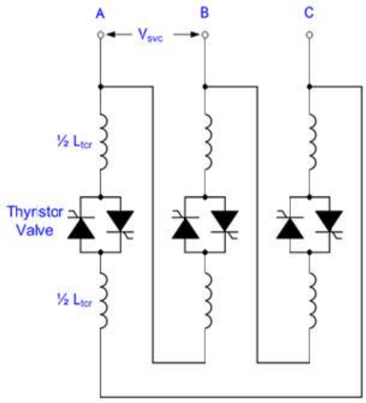


Figure 4.1: Delta Connected TCR

TCR reactor is split into two halves, with the thyristor connected between the two halves. This protects the vulnerable thyristor valve from damage due to flashovers, lightning strikes etc.

4.1.3 Operating principles

The current in the TCR is varied from maximum (determined by the connection voltage and the inductance of the reactor) to almost zero by varying the "Firing Delay Angle"(α). α is defined as the delay angle from the point at which the voltage becomes positive to the point at which the thyristor valve is turned on and current starts to flow.
Maximum current is obtained when α is 90°, at which point the TCR is said to be in "full conduction" and the rms current is given by:

$$I_{TCR-MAX}(z) = \frac{V_{SVC}}{2\pi * f * L_{TCR}}$$

Where:

V_{svc} is the rms value of the line-to-line busbar voltage to which the SVC is connected.
L_{TCR} is the total TCR inductance per phase.

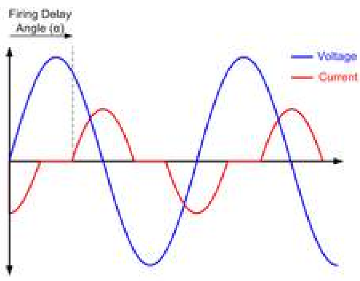


Figure 4.2: Waveform

The current lags 90° behind the voltage in accordance with classical AC circuit theory. As firing angle(α) increases above 90°, up to a maximum of 180°, the current decreases and becomes discontinuous and non-sinusoidal as shown in fig 4.2. The TCR current, as a function of firing angle, is then given by:

$I_1(\alpha)$=V$B_{TCR}(\alpha)$

where $B_{TCR}(\alpha) = B_{max}(1 - (\frac{2\alpha}{\pi}) - (\frac{sin2\alpha}{\pi}))$

In this

$$B_{max} = \frac{1}{wL} \tag{4.1}$$

The firing angle is related to the conduction angle , as follows:

$\alpha + (\frac{\sigma}{2}) = \pi$

so above equation can be written as

$I_1(\sigma)$= V$B_{max}(\sigma$-sin$\sigma\ \pi)$

or

$I_1(\sigma)$= V$B_{TCR}(\sigma)$

4.2 Basic of Fixed Capacitor Thyristor Controlled Reactor

4.2.1 Introduction

A static VAR compensator (or SVC) is an electrical device for providing fast-acting reactive power on high-voltage electricity transmission networks. SVCs are part of the Flexible AC transmission system device family, regulating voltage and stabilizing the system. Unlike a synchronous condenser which is a rotating electrical machine, a static VAR compensator has no significant moving parts (other than internal switchgear). Prior to the invention of the SVC, power factor compensation was the preserve of large rotating machines such as synchronous condensers or switched capacitor banks.

The SVC is an automated impedance matching device, designed to bring the system closer to unity power factor. SVCs are used in two main situations:

- Connected to the power system, to regulate the transmission voltage ("Transmission SVC")
- Connected near large industrial loads, to improve power quality ("Industrial SVC")

In transmission applications, the SVC is used to regulate the grid voltage. If the power system's reactive load is capacitive (leading), the SVC will use thyristor controlled reactors to consume VARs from the system, lowering the system voltage. Under inductive (lagging) conditions, the capacitor banks are automatically switched in, thus providing a higher system voltage. By connecting the thyristor-controlled reactor, which is continuously variable, along with a capacitor bank step, the net result is continuously-variable leading or lagging power.

In industrial applications, SVCs are typically placed near high and rapidly varying loads, such as arc furnaces, where they can smooth the flicker voltage.

4.2.2 Principle

Typically, an SVC comprises one or more banks of fixed or switched shunt capacitors or reactors, of which at least one bank is switched by thyristor. Elements which may be used to make an SVC typically include:

1 Thyristor controlled reactor (TCR), where the reactor may be air or iron cored.

2 Thyristor switched capacitor (TSC)

3 Harmonic filter(s)

4 Mechanically switched capacitors or reactors (switched by a circuit breaker)

By means of phase angle modulation switched by the thyristor, the reactor may be variably switched into the circuit and so provide a continuously variable MVAR injection (or absorption) to the electrical network. In this configuration, coarse voltage control is provided by the capacitors; the thyristor-controlled reactor is to provide smooth control. Smoother control and more flexibility can be provided with thyristor-controlled capacitor switching.

The thyristors are electronically controlled. Thyristors, like all semiconductors, generate heat and deionized water is commonly used to cool them. Chopping reactive load into the circuit in this manner injects undesirable odd-order harmonics and so banks of high-power filters are usually provided to smooth the waveform. Since the filters themselves are capacitive.

More complex arrangements are practical where precise voltage regulation is required. Voltage regulation is provided by means of a closed-loop controller. Remote supervisory control and manual adjustment of the voltage set-point are also common.

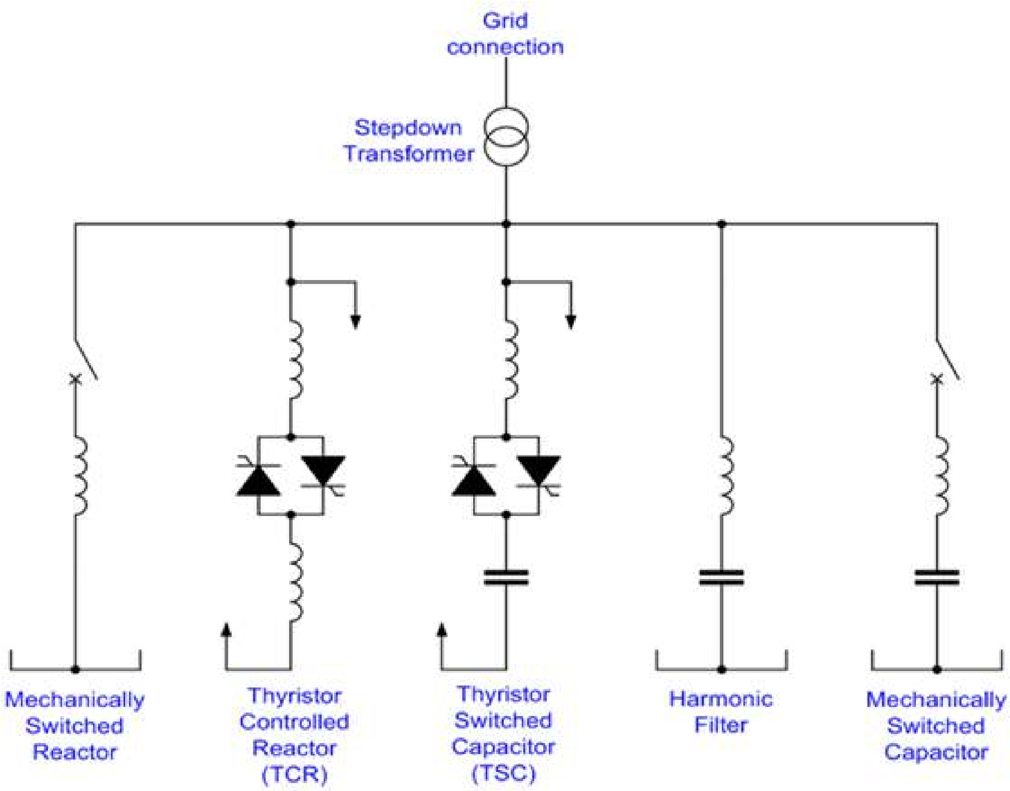


Figure 4.3: Different SVC circuit

4.2.3 Advantages

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 maximize the reactive power correction they can rapidly provide when required.

They are, in general, cheaper, higher-capacity, faster and more reliable than dynamic compensation schemes such as synchronous condensers. However, static VAR compensators are more expensive than mechanically switched capacitors, so many system operators use a combination of the two technologies (sometimes in the same installation), using the static VAR compensator to provide support for fast changes and the mechanically switched capacitors to provide steady-state VARs.

4.3 Basic control modes

The power delivered to the load is controlled by the thyristor controllers using two methods either by phase angle control or by integral control method (zero cross method). Each mode has its own advantages and disadvantages, according to suitable application it should be decided which mode is to be used.

4.3.1 Phase Angle Control

In phase angle control method each thyristor of back to back connection is on for variable period of time in each half cycle according to angle given to it. The waveform of phase angle control is shown in fig 4.4.

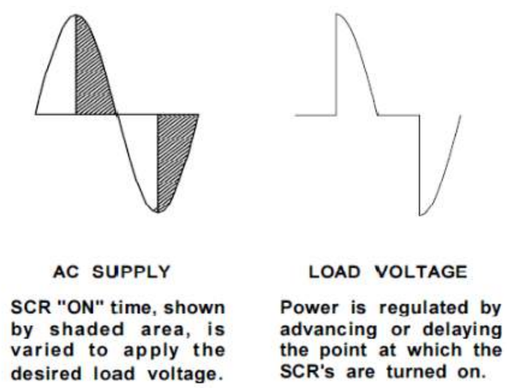


Figure 4.4: phase angle control

Power is controlled by advancing or delaying the firing angle (point at which scr is turn on within each half cycle). Light dimmers are best examples of phase angle control. Phase angle control gives fine resolution of controlled power and it is used to control fast responding loads in which resistance changes as a function of temperature e.g. tungsten filament lamp.Phase angle controlled is required if the load is transformer coupled.

Phase angle controller is costly than zero cross controller because it requires more sophistication than zero cross controller. Phase angle control of three phase power requires scr in all three legs it is appreciably more expensive than zero cross controller in which only requires scr in two of three legs.

4.3.2 Integral Angle Control

In this method scr turn on only when the instantaneous value of sinusoidal waveform is zero. In this method power is applied for no of continuous half cycles and then removed from no of continuous half cycle to achieve the desired load power as shown in fig.4.5.
The frequency of on-off is very fast because there is no limit how many times no of switching operation scr can perform.

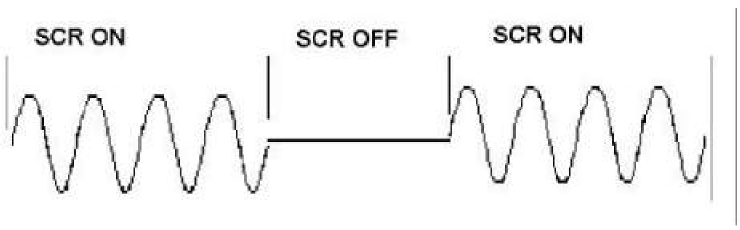


Figure 4.5: Integral Angle Control

1 TIME PROPOTIONAL

In this method total time base is fixed means total power on time + total power off time equal to total fix time. This control method is used when very large amount of current can cause voltage variation which effect the lighting or other equipment. Let take the time base is 1 second as shown in fig.4.6, if 50% o/p is required then output will be on for 0.5 sec and off for 0.5 seconds, same for 75% output is required then power on for 45 cycles and off for 15 cycle. Here 1 second =60 cycles.

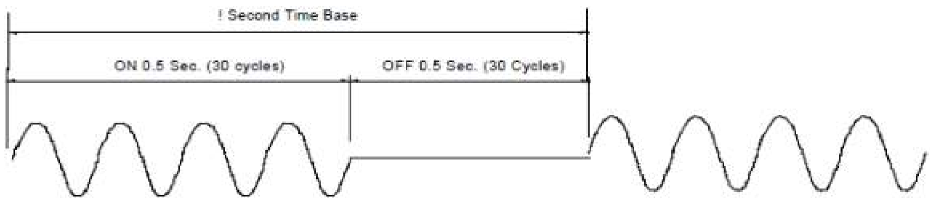


Figure 4.6: TIME PROPOTIONAL CONTROLl

Drawback of this method is load temperature varies considerably to the on-off cycles, due to this life of heater element is reduced and also the accuracy of precise control will be reducing.

2 DEMAND ORIENTED TRANSFER (DOT)

The difference in this method is only that the time base is not fixed.

For lower power requirement power is on for 3 cycle and off for appropriate cycles and higher power level scr off for 3 cycle and on for appropriate cycles. For 50% output total time base is 2 cycle (1 cycle is off 1 is on). SCR operated in anti-parallel, the minimum time base is 1 cycle, which is approximately equal to 16.6667 ms when used on 60 Hz AC supply.

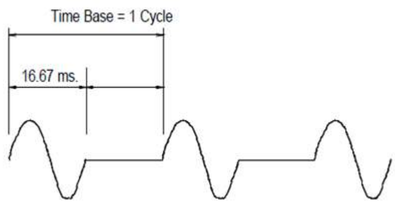


Figure 4.7: DEMAND ORIENTED TRANSFER

4.3.3 COMPARISION

If both the methods required to produce 50% output power, time proportional metod takes 0.5 sec on & off (one second time base) and for DOT method takes 16.667ms on &off. DOT method will gives faster control & less deviation from the set point. Heater life is also extended using DOT firing scheme.

Zero cross applied only for resistive load which has no significant change with temperature and directly coupled to transformer. It should not be used for large power control because it can create a problem of voltage fluctuation.

4.3.4 PHASE ANGLE /ZERO CROSS COMBINATION CONTROL

Combination firing packages can be utilized on higher end microprocessor based power controls which utilize both phase angle and zero fire. If a process requires Soft Start on start-up, but will operate on zero fire proportional control once up and running, the advantages of both methods may be realized. The Soft Start is programmed into the controller for a specific time. Once the time has elapsed the controller automatically switches over to proportional zero cross firing scheme.

Soft start using phase angle for starting few no of cycles, then continue with

COMPARISON OF PHASE-ANGLE AND ZERO-CROSS		
PARAMETER	**PHASE-ANGLE**	**ZERO-CROSS**
Cost: 1-phase	Slightly more	Slightly less
Cost: 3-phase	Appreciably higher	2-leg control is appreciably less due to lower circuit cost and because only 2 of the 3 supply lines require SCR's. 3-leg control is slightly less because of circuit cost.
Type of loads:	Transformer coupled loads, fast responding loads, loads with large resistance changes, loads requiring current limiting, or soft start.	Resistive loads only. Power can not be applied to a transformer. Moderately fast loads can be controlled with distributive control.
Power factor: (Ref Section 5)	Theoretical value equals (% of applied power/100)$^{0.5}$. Power factor observed on typical utility meter is very close to theoretical power.	Resistive loads only. Power can not be applied to a transformer. Moderately fast loads can be controlled with distributive control. Theoretical value equals (% of applied power/100)$^{0.5}$ Power factor observed on typical utility meter approaches unity.
RFI and Harmonics: (Ref Section 5)	Higher harmonics are generated and the potential for RFI is higher.	Harmonics and RFI are very low.
Reliability:	Lower than zero-cross	Higher than phase-angle because fewer components are required and because the SCR turns on when the voltage and current are zero.
Serviceability:	More complex	Easier because of fewer components.

Figure 4.8: Comparision

zero fire scheme is best of all as shown in fig.4.8...

Phase angle firing is not used all the time...

In this method when thyristor is on at that time voltage across the scr is not zero. It has some value, in some cases it may be the peak value 679 V in 480 V ac system. It creates large amount of electrical of noise or RFI (radio frequency interference). The case when phase angle control is necessary, great care should be taken in shielding all appropriate wiring to minimise the RFI.

Here we have to compare both the methods practically. So first we have to perform THD analysis on both the methods. After doing this we can decide which method is best suitable.

For that we are following the formula describe below

In case of integral angle control,

The voltage source is connected to the load for N no cycles & disconnected for

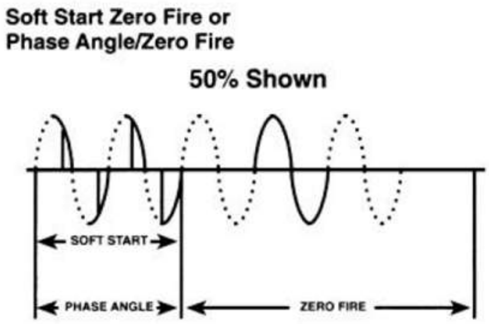


Figure 4.9: COMBINATION CONTROL

the M no of cycles, then the rms output voltage can be found as follow:

$Vo = \sqrt{\frac{N}{2\pi(N+M)}\int_0^{2\pi} 2V_s^2 \sin^2 \omega t dt}$

$Vo = Vs\sqrt{\frac{N}{N+M}}$

$Vo = Vs\sqrt{K}$

Where K=N/(N+M) and it is called the duty cycle.

Hence the output power (average power) can be found from

$Po = \frac{Vo^2}{R} = K * \frac{Vs^2}{R}$

On the other hand, in case of phase angle control, if the delay angle (firing angle) α is $(0° < \alpha < 180°)$, then the rms output voltage can be found from

$Vo = \sqrt{\frac{2}{\pi}\int_\alpha^\pi (\sqrt{2}Vs)^2 \sin^2 \omega t d w t}$

$Vo = Vs\sqrt{\frac{1}{\pi}(\pi - \alpha + \frac{\sin 2\alpha}{2})}$

And the output power can be found from

$Po = \frac{Vs^2}{\pi R}[\pi - \alpha + \frac{\sin 2\alpha}{2}]$

If it is required to produce the same avg output power from both methods, then the following equation can be found,

$K = \frac{1}{\pi}[\pi - \alpha + \frac{\sin 2\alpha}{2}]$

The relation between the duty cycle (K) and the firing angle (α) is not linear.

In case of if the firing angle (α) is given and it is required to find the value of the duty cycle (K) for the same average output power, above equation can be easily used.

But in case of if it is required to find the firing angle (α) for a given duty cycle (K), it needs time consuming iterative solution.

This difficulty has been solved by using the following new developed equation

$\alpha = -4.499k^3 + 6.79k^2 - 4.68k + 2.77$

To verify the validity of the above developed formula , the exact waveform for the relation between the firing angle (α) and the duty cycle (K) has been obtained from the previous equation and compared with that obtained from the new developed formula.
This comparison is shown in figure 4.10 Examination of the above figure clearly

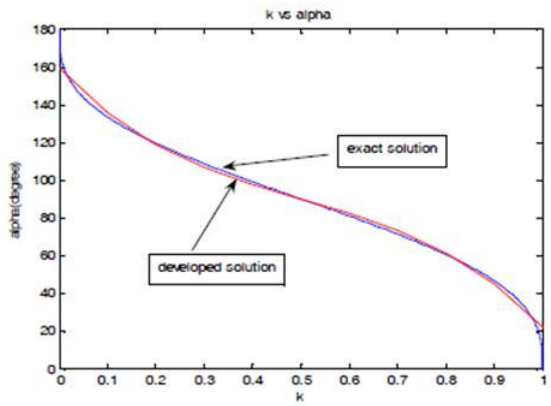


Figure 4.10: comparision of two equation

indicates that the developed formula gives reasonable accuracy results. The overall error over the entire firing angle (α) range computed for any value of the exact value was found to be less than 2 degree as shown in figure 4.11.

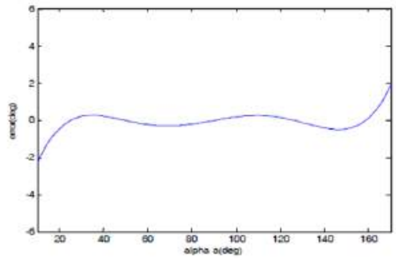


Figure 4.11: error in degree

Now we are going towards simulation and first we try to measure THD with phase angle method. For that the ckt is as shown below. Here we set α =99°

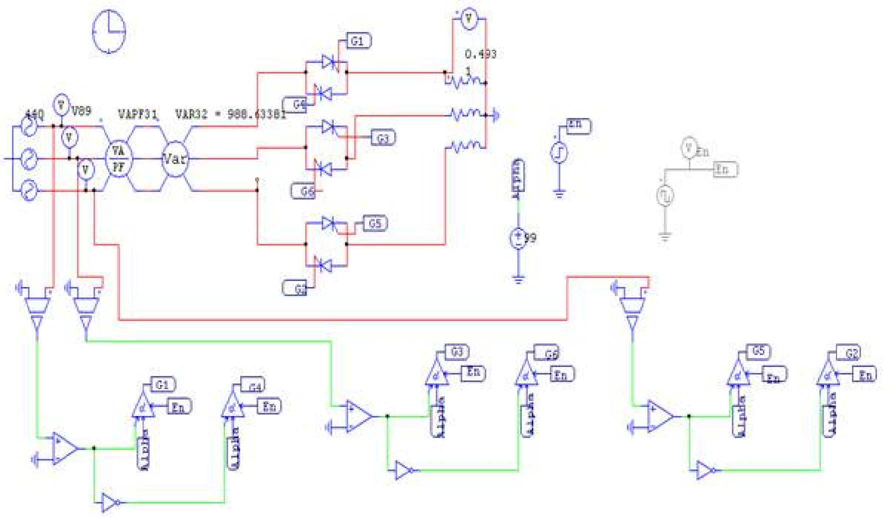


Figure 4.12: TCR FIRING

THD= 1.0446411e-001

Similarly for integral angle control we calculate duty cycle=0.449 from the above formula, we have to disable the step voltage source α=0. we get the

THD=1.5660952e+000

4.4 Detuned Reactor

A consumer whose load includes a high proportion of variable speed motor drives or other harmonic generating loads may require a detuned capacitor system.It is connected in series with the capacitor bank which is used for power factor correction. As the supply impedance is generally considered to be inductive, the network impedance increases with frequency while the impedance of a capacitor decreases.

In systems where harmonics are present, power factor correction should be done by means of detuned filters. These consist of capacitors and reactors connected in series, and are capable of compensating reactive power at fundamental frequency without amplifying the harmonics.Each step of a detuned filter consists of a capacitor and a reactor connected in series. These components form a series resonant circuit tuned at a frequency below the lowest harmonic frequency present in the system, normally the 5th(250 or300 Hz).

Less than the tuned frequency of the resonant circuit, for example at fundamental frequency (50Hz), the detuned filter is capacitive, generating reactive power. Above the tuned frequency the detuned filter is inductive, which means that it cannot amplify any common harmonics, including the 5th, 7th and 11th. A detuned filter also removes lower order harmonics from the system to some extent.

The harmonics that would be generated are 5th,7th, 11th and 13th and so on. The lowest harmonic frequency which would occur in the system is the fifth harmonic i.e. 300 Hz. If the series resonant circuit is tuned to a frequency of 245 Hz, then at all the harmonic frequencies the filter acts as an inductive component and the possibility of resonance at the fifth harmonic is eliminated.

By using these types of detuned reactors it is possible to avoid following negative effects on system.

1 Overcurrent during switching on the capacitor banks.

2 Overload of capacitor banks because of the harmonic resonance.

3 Short lifetime on capacitors.

4 Overheating of the utility transmission cables.

5 Overheating of the distribution transformer.

6 Unintended triggering of the protective devices.

7 Distortion of utility voltage waveform and problems on voltage sensitive devices.

8 Interferences on data transmission systems.

9 Unexplainable faults in electronic boards.

Chosing the correct detuned filter reactor and capacitor value on detuned power factor correction systems is very important. To obtain optimum performance form a detuned power factor correction system following criteria must be controlled and met during the pairing of the reactors and capacitors.

1 The resonance frequency must be chosen according to harmonic analysis of the system.

2 The voltage across the terminals of the capacitor will increase because of the inductive reaction of the reactor. The rated voltage of the capacitors must be chosen according to the resonance frequency.

3 In detuned power factor correction systems, presence of higher voltage rated capacitors and reactors causes a difference between rated capacitor power and obtained reactive power. The obtained power must be calculated in order to avoid low compensation.

4 The reactors will generate extensive heat due to heavy harmonic load on Them. The cabinets must be designed to disperse this heat.

In a detuned filter application, the voltage across the capacitors is higher than the nominal system voltage. Then, capacitors must be designed to withstand higher voltages. Depending on the selected tuning frequency, part of the harmonic currents is absorbed by the detuned capacitor bank. Then, capacitors must be designed to withstand higher currents, combining fundamental and harmonic currents.

4.4.1 APPLICATION

The detuned reactors are designed to protect the capacitors against harmonics and avoid parallel resonance and amplification of harmonics flowing on the network. The connection of these reactors in series with capacitors causes a shift of the resonance frequency of the circuit composed by feeding transformer-reactors- capacitors so that the resulting self-resonance frequency is well below the line harmonics.

The blocking factor p% is expressed by the ratio between inductive reactance and capacitive reactance it corresponds to the increase of voltage applied to capacitors, with respect to line voltage, due to circulation of capacitive current in the reactor.

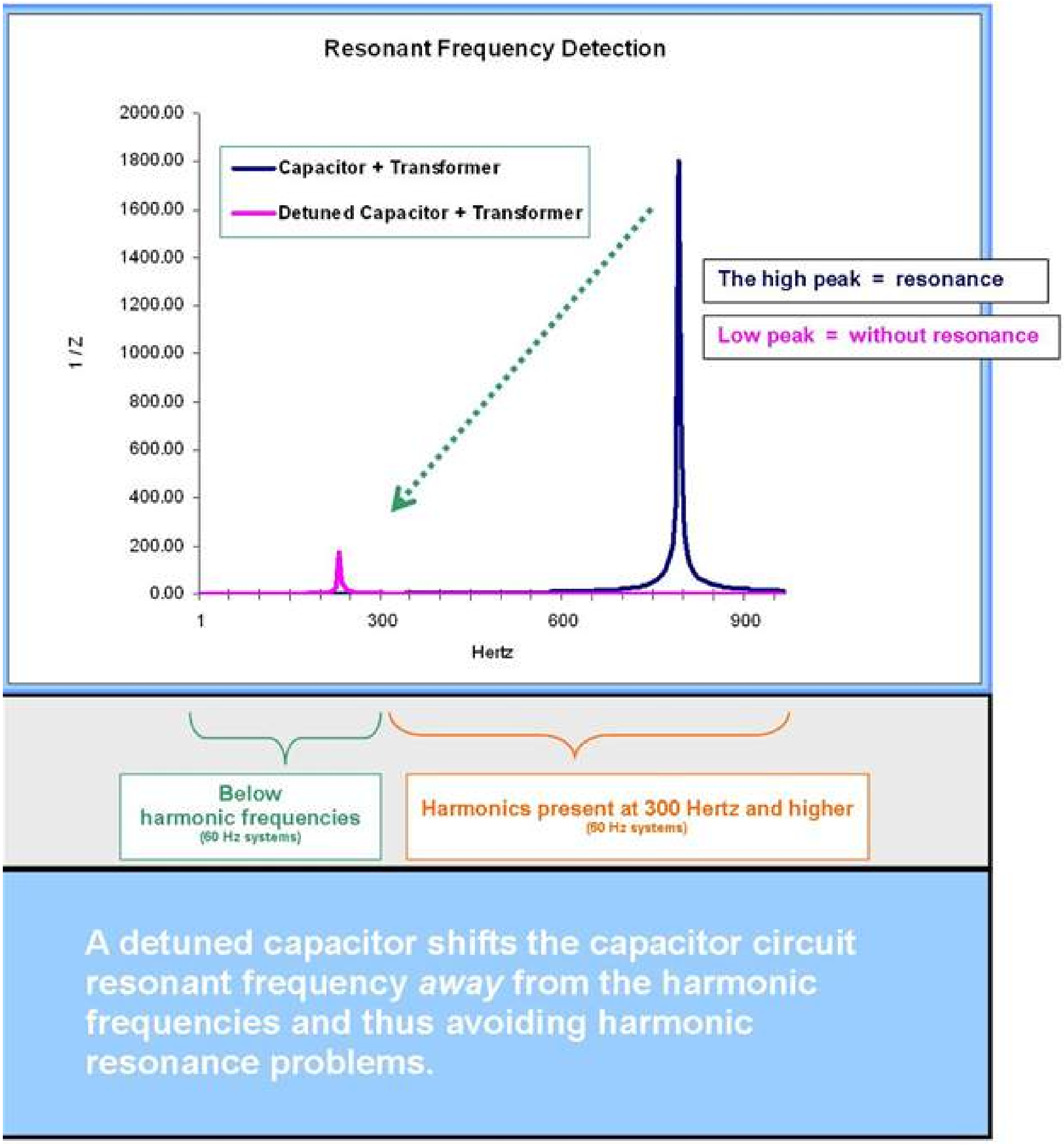


Figure 4.13: RESONANT FREQUANCY

Chapter 5

Simulation Result & Analysis

5.1 For Single Phase 500 VAR Load

We need to find out R & L, then we compensate it by FC-TCR model.

Suppose Q=500 VAR V_m =230V V_{rms} =162.635V Take P=1200 W

So total Apperant Power S=1300VA

P.F.=0.9231

$Z = \frac{V_{rms}}{S}$

$Z^2 = R^2 + Xl^2$

$\sin\phi = \frac{Xl}{Z}$

so

$R = Z\sqrt{1 - \sin\phi^2}$

Similarly we can find L from Xl.

Now by simulation data Q before capacitor =508.84VAR

$Q = \frac{V_{rms}^2}{X_c}$

$C = \frac{Q}{V_{rms}^2 * 2\pi * f}$

C=60.372μf

To get smooth compensation by FC TCR we have to take higher VAR for e.g. 550VAR.

For that value of C=66.189μf

So for remaining Q=550-508.84=41.16VAR.

We have to provide lagging compensation by inductor. Here we can vary the range of the inductor so we can take higher range of it e.g. 100VAR.

So

$Q = \frac{V_{rms}^2}{X_l}$

L=0.8419h

5.2 Capacitor as load

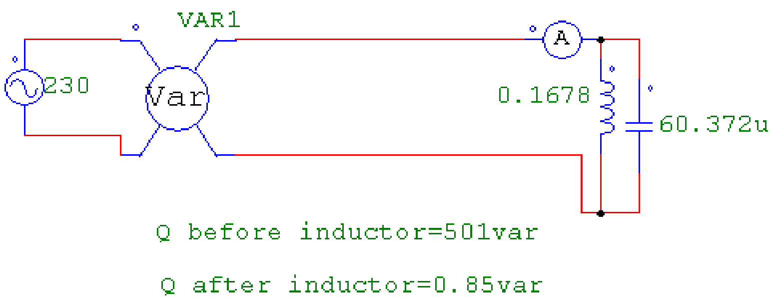


Figure 5.1: Capacitor as a load

Here capacitor & inductor both designed according to 10 KVAR.

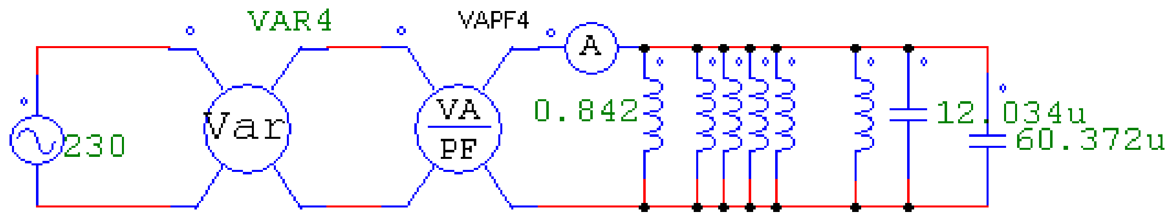


Figure 5.2: Capacitor compensation

In above figure one 60.372 μF capacitor gives 500 VAR & remainng 100 VAR provided by 12.034 μf capacitor.

Total capacitor give 600 VAR.

This is compensated by the 6 inductors each of 0.842 H , which will give total 600 VAR.We can see this from fig 5.3.

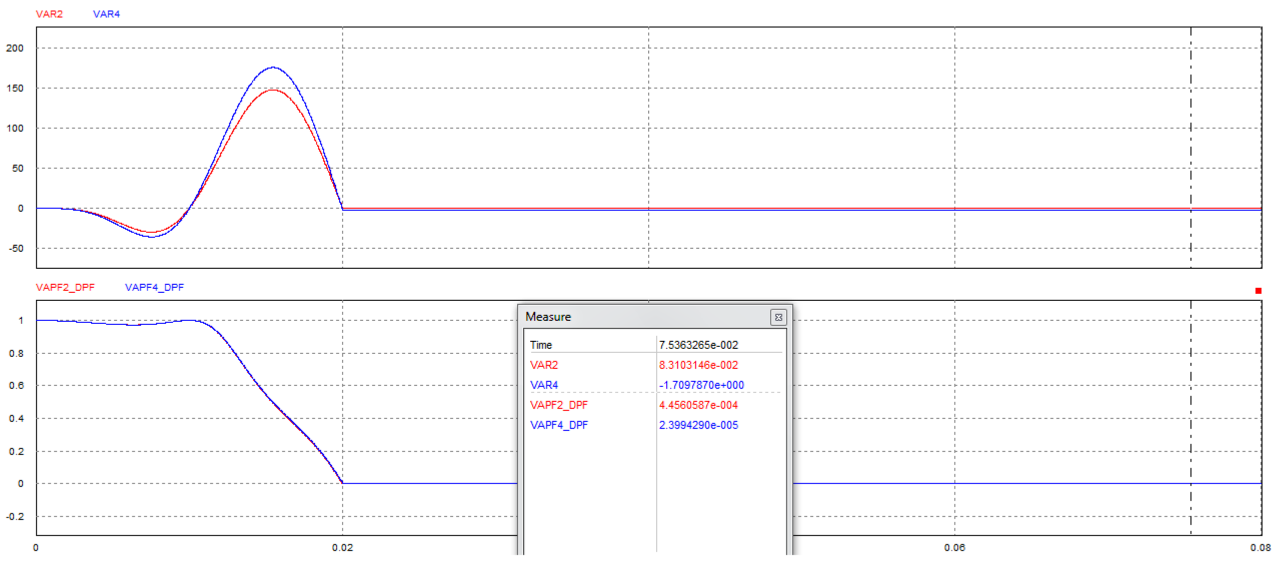


Figure 5.3: waveform of VAR PF

5.3 Inductor As Load

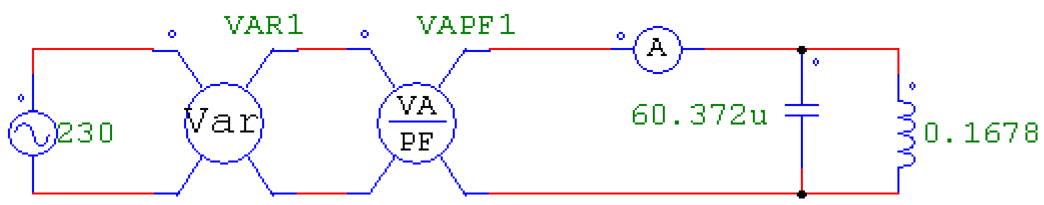


Figure 5.4: L compensated BY C

In figure 5.4 inductor is of 0.1678 H.

It act as a load here.

Capacitor of 60.372 μF used for compensation which also provide 10 KVAR.

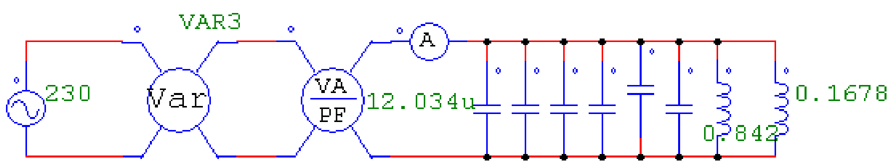


Figure 5.5: Inductor compensated by L C

Now we go towards compensation in steps.

One 100 VAR inductor is added of 0.843 H. So we have total 600 VAR load.

We compensate this by using 6 capacitors each of providing 100 VAR so we get finally perfact compensation which is shown by graph in figure 5.6.

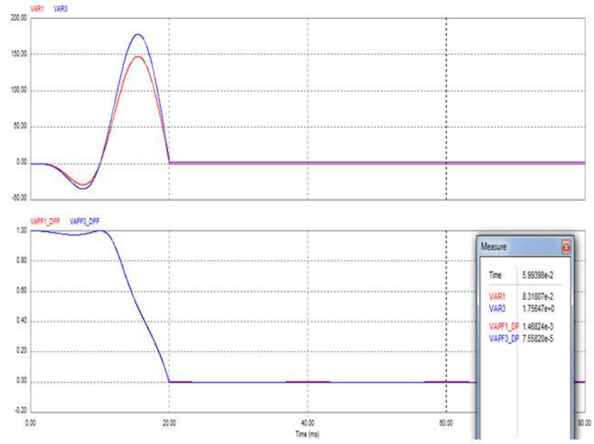


Figure 5.6: waveform of VAR PF

Actual load is not in the form of pure L or C. So now we take R-L load which is equivalent of 500 VAR. By simulation it shows 508.84 VAR value.

This equivalent R & L is calculated from previous equations.

So one capacitor of 60.372 μF is added which provide 500 VAR, so we can get the perfact compensation.

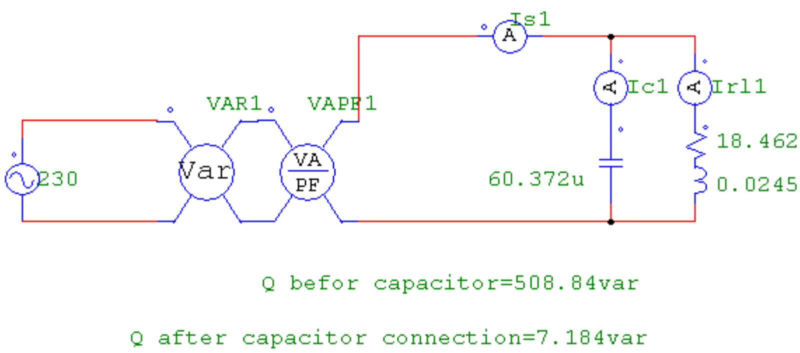


Figure 5.7: R-L load compensated by L C

For applying the concept of FC-TCR we have to add one reactor, by changing phase angle(α) of thyristor we are changing current passing into it.

So we can vary its reactive power absorbtion capacity.

To use this concept we have to take addition VAR rating capacitor which will provide 550 VAR insted of 500 VAR.

For that we are taking capacitor of 66.18 μF .

Now to absorb this addition VAR we have to take higher capacity of reactor than exactly needed VAR value.

For e.g. 100 VAR so that we can compensate additon 50 VAR given by the capacitor by controlling the phase angle of 100 VAR inductor.

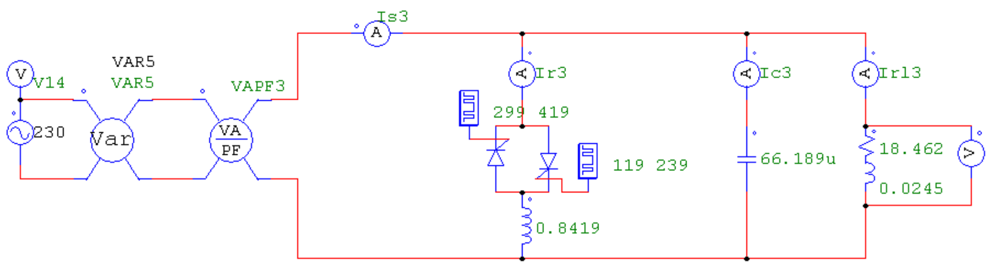


Figure 5.8: R-L compensated by FC TCR

The waveform of VAR (Reactive power) & PF(Power Factor) of above two circuits are shown in figure 5.9.

In first case we cannot get the perfact compensation because capacitor value is fix & load may vary some time. So we have to use TCR(Thyristor Controlled Reactor) to adust additoinal VAR given by the capacitor.

Here smaller the value of L larger the var we can control. Generally the value of L is chosen as the half of the smallest capacitor. Now firing angle is chosen in such a way that it can compensate the additional leading VAR of the capacitor.

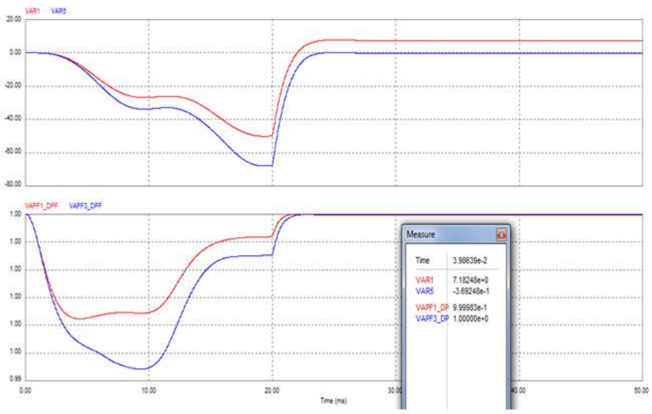


Figure 5.9: waveform of VAR & PF

By doing simulation with different firing angles, it is to be noted that firing angle of 119° gives the best result for TCR.

Net reactive is now only 0.3 VAR as it was before compensation 500VAR.

5.4 Calculation for 10KVAR Load

We have to find equivalent R & L series load

Q=10 KVAR

Assume P=25KW

S= $(P^2 + Q^2)$ =26.93KVA

P.F.=0.9284

V_L=440V

V_{ph}=254.034V

S=$\sqrt{3} * V_L * I_L$

$S = 3 * V_{ph} * I_{ph}$

$I_L = I_{PH} = S/3 * V_{ph}$

$= 3 * V_{ph}^2/S$

$Z_{ph}^2 = R^2 + (sin\phi{*}Z_{ph})^2$

$R = Zph * \sqrt{(1 - sin\phi^2)}$

$R = 6.673034$

$XL = \sqrt{(Z^2 - R^2)} = 2.6692138$

$L = 8.4964mh$

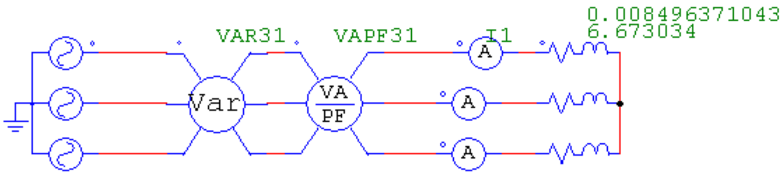


Figure 5.10: 10 Kvar R-L load

The waveform of above circuit is shown in fig 5.11

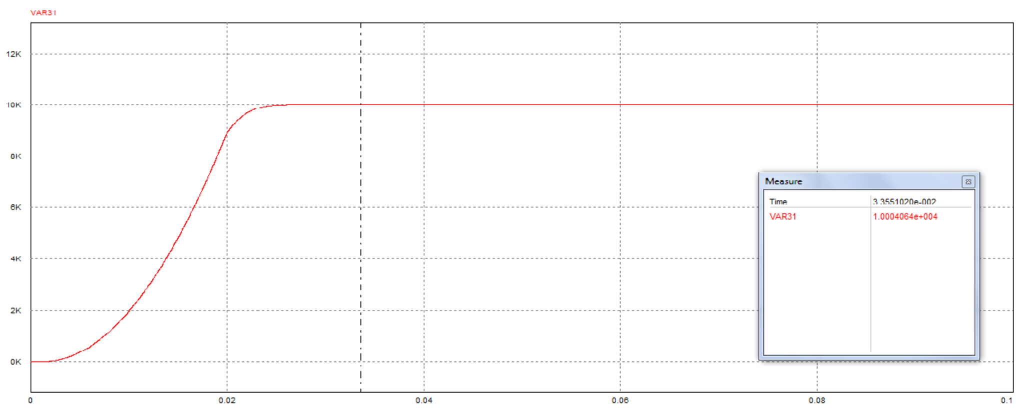


Figure 5.11: 10 Kvar waveform

This 10 KVAR is compensated by capacitor connected in delta.

Here we design the capacitor for additional 1000 VAR, means total 11000 VAR

Now for capacitor value for delta connection

$Q_{total} = 3 * V_{LL}^2 / X_c$

$X_c = 3 * V_{LL}^2/Qtotal$

$C_{delta} = Q_{total}/(3 * V_{LL}^2 * 2*\pi*\mathrm{f})$

$\mathrm{C}_{delta} = 60.286\mu\mathrm{f}$

$\mathrm{C}_{delta} = Cstar/3$

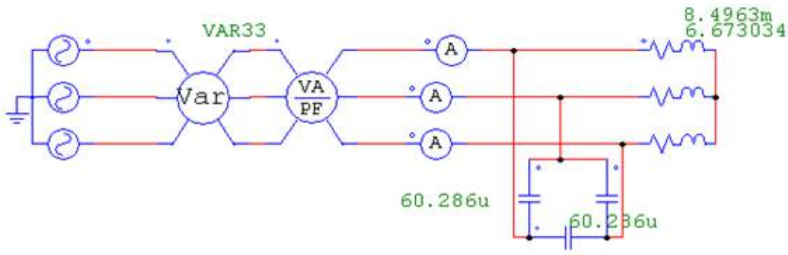


Figure 5.12: PF Correction By Strar Capacitor

For delta $V_{ph} = V_{LL}$

For star $V_{ph} = V_{LL}/3$

Here we are using star connected TCR instead of delta because we are using FC-TCR device at LT side (440v).

So here voltage is very low , it is difficult to get star connected capacitor which can withstand with such line voltage because current is so high.

Therefore we are using delta connected capacitor star connected TCR. TCR has no problem like capacitor.

We can see the additional 1000 VAR in the below waveform. Then after it is compensated by TCR.

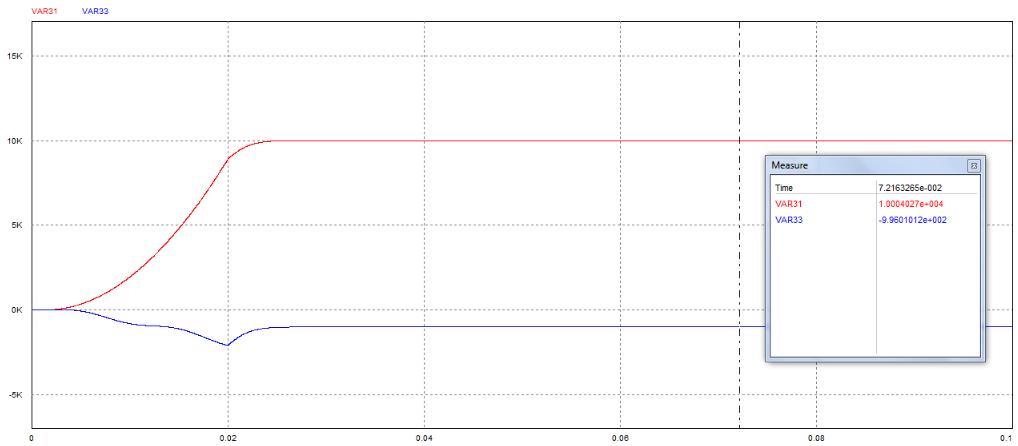


Figure 5.13: over compensation

To compensate this additional KVAR we need to design TCR for 1250 VAR, so than after we can vary its VAR according to various firing angle.

Now for capacitor value for star connection

$Q_{total} = V_{LL^2}/X_c$

$X_c = V_{LL^2}/Q_{total}$

$C_{star} = Q_{total}/(V_{LL}^2 * 2*\pi*\text{f})$

Now for inductor value for star connection

$Q_{total} = V_{LL}^2/XL$

$XL = V_{LL}^2/Q_{total}$

$L = V_{LL}^2/(Q_{total} * 2 * \pi * 50)$

$L_{star} = 0.493H$

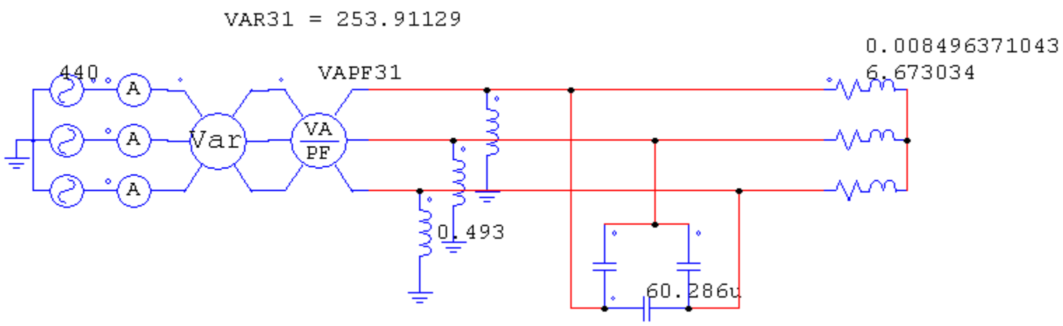


Figure 5.14: fix TCR & fix capacitor

So waveform of additional 250 VAR is shown in the figure 5.15.

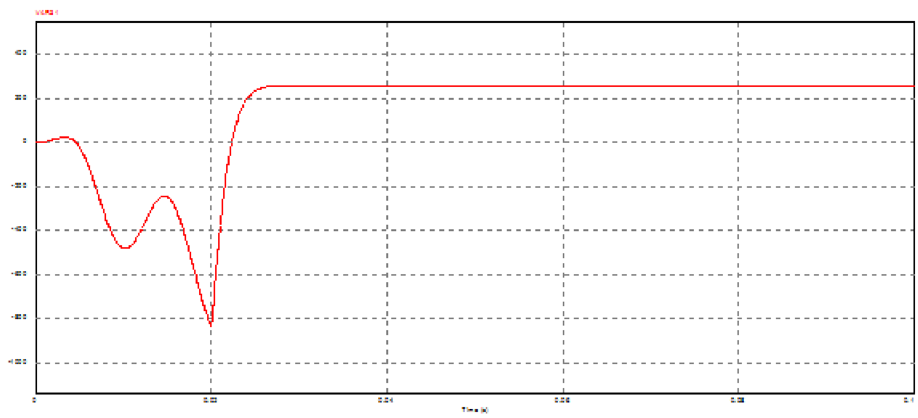


Figure 5.15: VAR Waveform of fix TCR & fix capacitor

Now by varing different firing angle(α) we can see the changes in the VAR value.

By setting different α values among which the 99°gives best results.

Here firing angle of each phase is given by $+120° interval$.

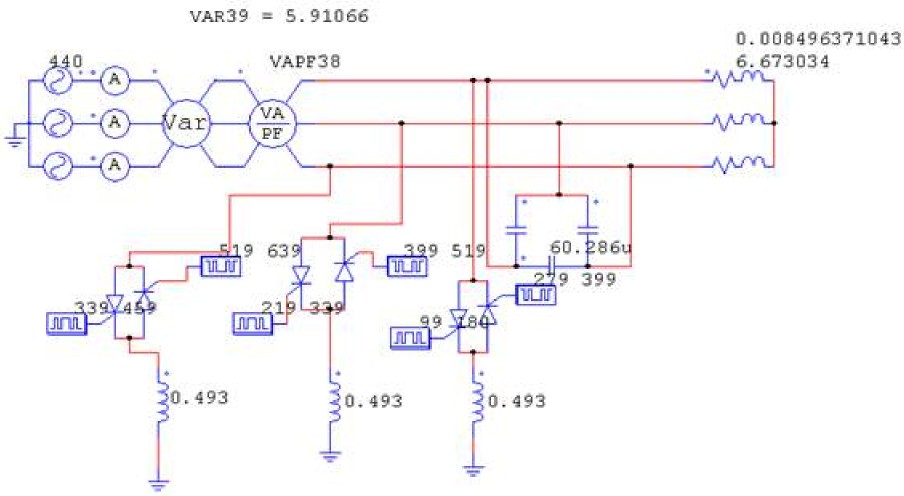


Figure 5.16: Final Fc Tcr

And remaining anti parallel thyristor have given firing angle as per 180° interval of that possitive thyristor.

Any firing angle is given as per this format.

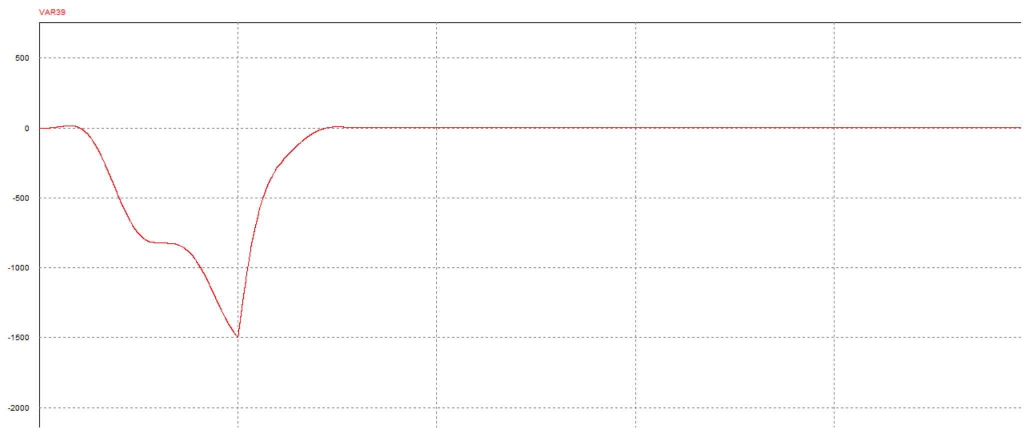


Figure 5.17: final VAR Waveform

Alpha controller block is used to set the firing angle of the tcr. In this voltage sensor is used in each phase to sense the voltage, then this signal is given to the comparator positive node, negative node is grounded. So the output of comparator circuit gives positive pulse when positive cycles come & remain zero for negative cycle.

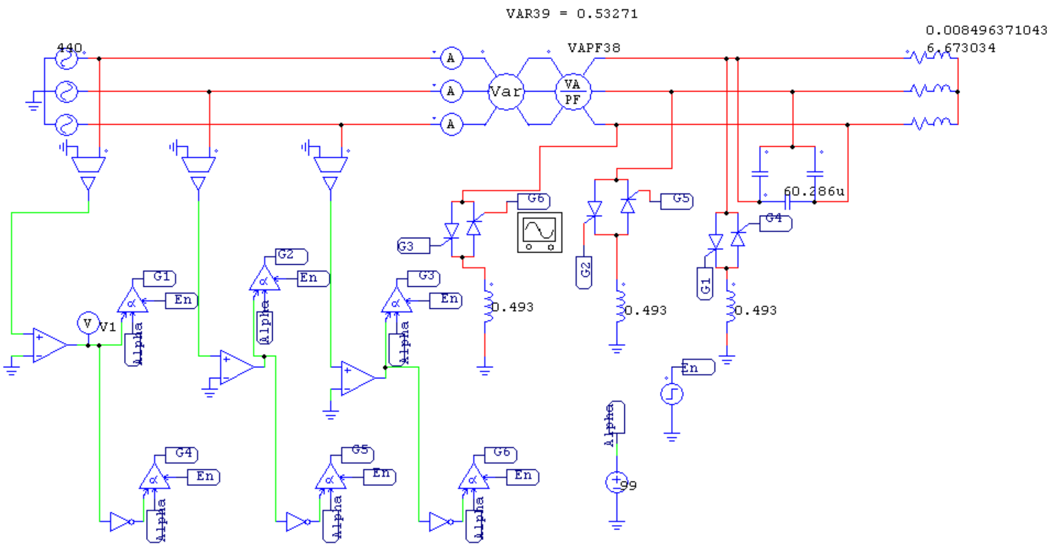


Figure 5.18: Final FC-TCR Sensor

This circuit is more accurate & more flexible.

The reactive power for this circuit is 0.53271 VAR which is less than previous case it is 5.91066 VAR. The benefit of this circuit is that we have to change α in only one phase rather than previous case where we have to change in each thyristor pair.

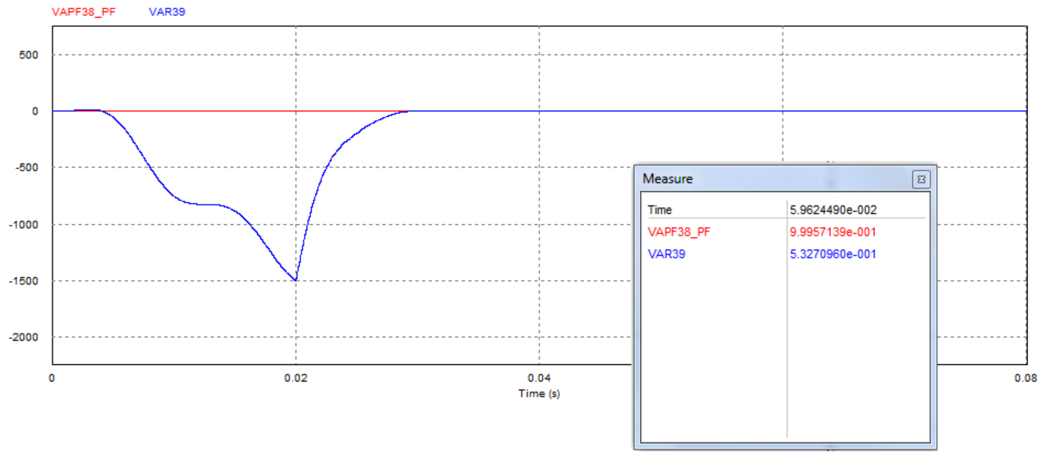


Figure 5.19: Final Fc Tcr VAR & PF Waveform

The waveform of Tcr current of each phase at 99°is shown in figure.

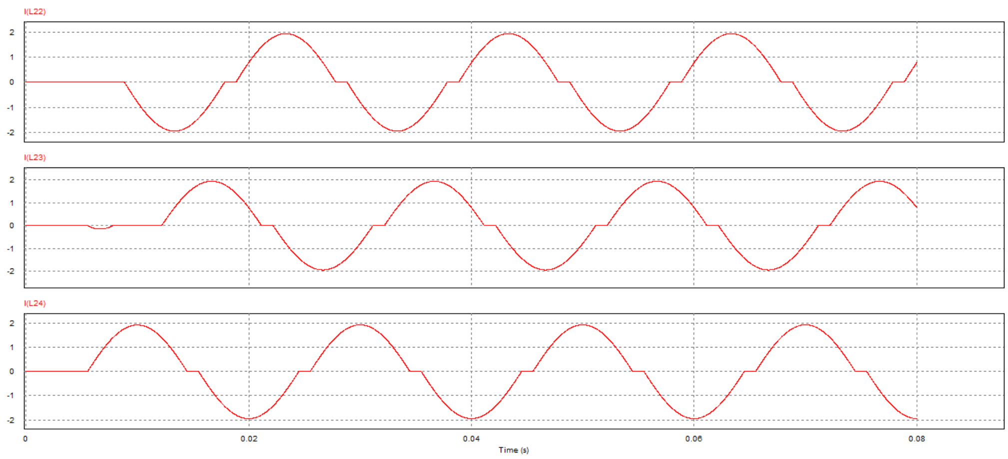


Figure 5.20: Tcr Current Waveform

5.4.1 ALPHA CONTROLLER

Delay Angle Alpha Angle Controller

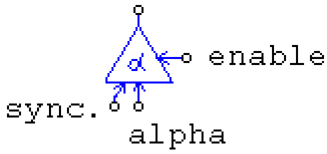


Figure 5.21: Alpha Angle Controller

Parameters:

Frequency- Operating frequency of the controlled switch or switch module, in Hz

Pulse Width- On-time pulse width of the gating signal, in deg.

The alpha controller is used for the delay angle control of thyristor switches or bridges. There are three input for the controller:

- alpha value, in degree (at the center bottom)

- synchronization signal (at the left bottom)

- enable/disable signal (at the middle right)

The alpha controller is enabled (or disabled) if the enable/disable signal is high (or low). The transition of the synchronization signal from low to high (from 0 to 1) provides the synchronization and this moment corresponds to when the delay angle alpha equals zero. A gating pulse with a delay of alpha degrees is generated and sent to the thyristors. The alpha value is updated instantaneously.

5.5 CLOSE LOOP CONTROL

In a close loop control the reactive power is compensated by FC-TCR automatically such that power factor is to be maintain near to unity. For this here load is taken from 1 to 10 KVAR in integer step by step..

Here one look up table is developed in which For each load, VAR is to be controlled near to zero by varying firing angle(α) & that α is to be written in simplified c block.

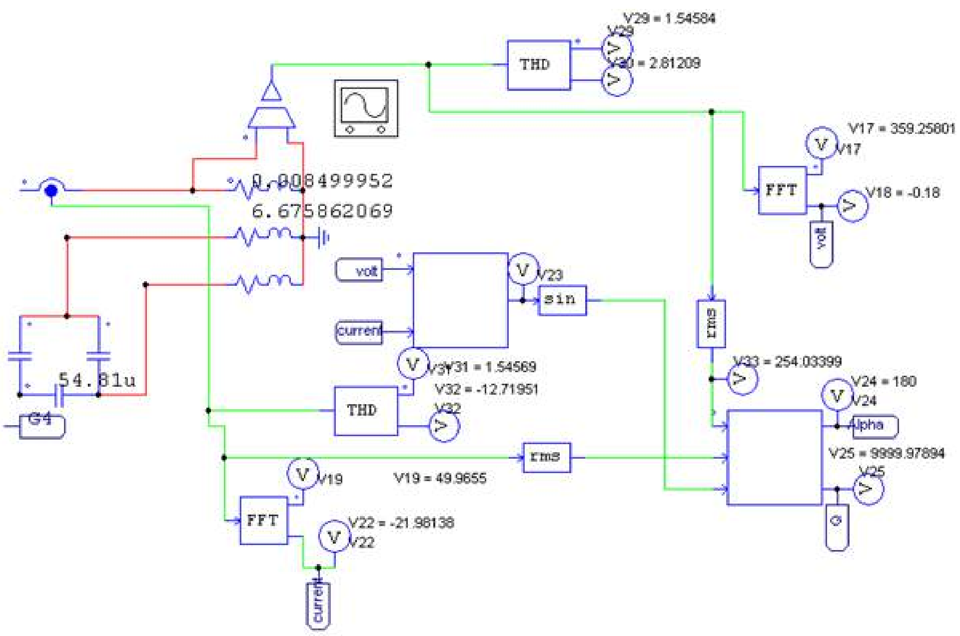


Figure 5.22: Close Loop

Here reactive power of load is measured by the equation p=3*v*i*sinϕ

So this can be measured by terms of sensing the voltage across the load & current of the load respectively. To sense the voltage and current we are using voltage sensor &

current sensor.

To get the exact angle between volt & current, here we can use FFT (Fast Fourier Transform) block the output of that block will be the magnitude (upper node) and the phase angle(second node) of the fundamental input waveform.

In simplified c block calculation is done as shown in figure below 5.23.

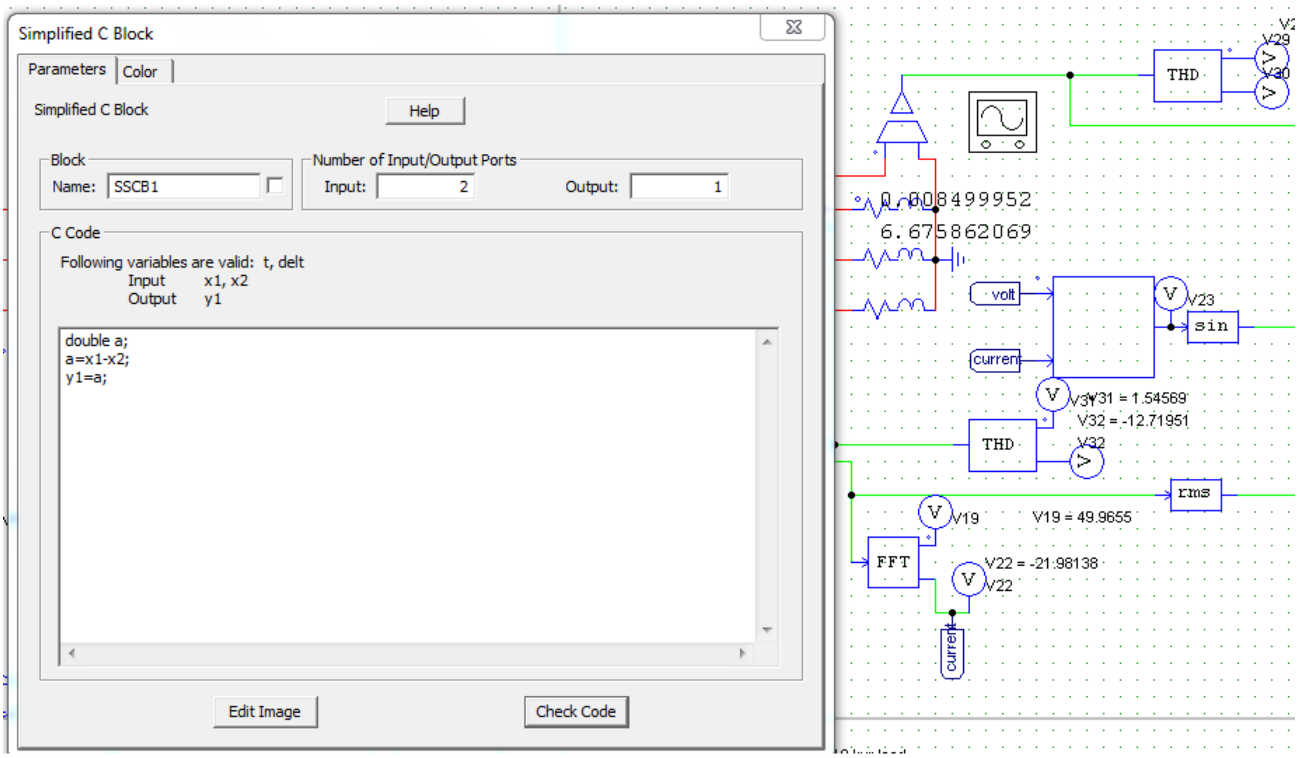


Figure 5.23: sin c block

After that the rms block is used here to get the rms value of the voltage current for the calculation.

The measured angle ϕ is multiplied by the sin block to get the value of sinϕ.

This three input rms volt, current & sinϕ is as input to the second simplified c block In that the first output will show the value of reactive power of the load which we have measured from previous equation.

After getting the reactive power of the load, fix capacitors are continuously provide 10 KVAR.

To know how much amount of reactive power we want from the TCR for the remaining KVAR we have to subtract the load KVAR from the capacitor KVAR. By doing this we come to know how much amount of Q is needed from the TCR to achieve the zero VAR from the supply side. After getting this value we have to adjust alpha such that we can get this Q value from TCR.

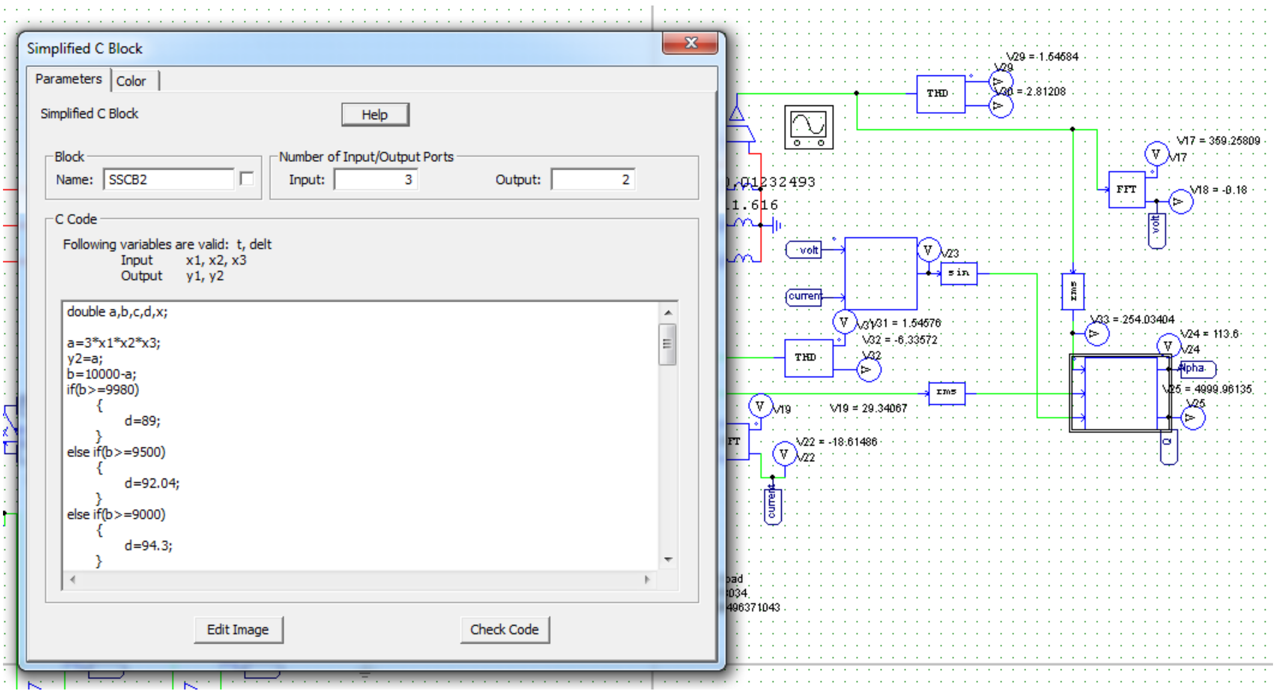
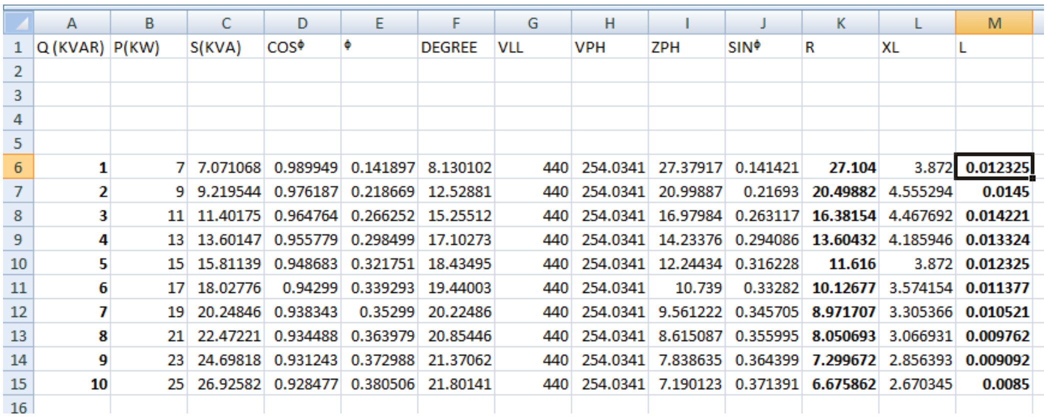


Figure 5.24: Lookup Table C Block

Here to get the different value of R & L from Q (Reactive power), One excel sheet is prepared as shown in figure 5.25.

This code is written as per reading which is taken at different load up to 1 to 10 KVAR integer value. Alpha(α) is noted when minimum reactive power is obtained .



	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Q (KVAR)	P(KW)	S(KVA)	COSϕ	ϕ	DEGREE	VLL	VPH	ZPH	SINϕ	R	XL	L
2													
3													
4													
5													
6	**1**	7	7.071068	0.989949	0.141897	8.130102	440	254.0341	27.37917	0.141421	**27.104**	3.872	**0.012325**
7	**2**	9	9.219544	0.976187	0.218669	12.52881	440	254.0341	20.99887	0.21693	**20.49882**	4.555294	**0.0145**
8	**3**	11	11.40175	0.964764	0.266252	15.25512	440	254.0341	16.97984	0.263117	**16.38154**	4.467692	**0.014221**
9	**4**	13	13.60147	0.955779	0.298499	17.10273	440	254.0341	14.23376	0.294086	**13.60432**	4.185946	**0.013324**
10	**5**	15	15.81139	0.948683	0.321751	18.43495	440	254.0341	12.24434	0.316228	**11.616**	3.872	**0.012325**
11	**6**	17	18.02776	0.94299	0.339293	19.44003	440	254.0341	10.739	0.33282	**10.12677**	3.574154	**0.011377**
12	**7**	19	20.24846	0.938343	0.35299	20.22486	440	254.0341	9.561222	0.345705	**8.971707**	3.305366	**0.010521**
13	**8**	21	22.47221	0.934488	0.363979	20.85446	440	254.0341	8.615087	0.355995	**8.050693**	3.066931	**0.009762**
14	**9**	23	24.69818	0.931243	0.372988	21.37062	440	254.0341	7.838635	0.364399	**7.299672**	2.856393	**0.009092**
15	**10**	25	26.92582	0.928477	0.380506	21.80141	440	254.0341	7.190123	0.371391	**6.675862**	2.670345	**0.0085**
16													

Figure 5.25: Table of R L from Q

Here as describe in previous chapter we can find the equivalent R & L from the Q (Reactive power) We can observe from the table that as reactive power increases the value of resistance decreases. With the help of this excel sheet we can find the value of R & L for any KVAR value.

To compensate this VAR we have to adjust the reactive power such that total reactive power consumption from the source side is zero. For that we have to adjust firing angle (α) to get that required reactive power(KVAR) from TCR.

To make this arrangement we can continue with the above circuit by disable the load & fix capacitor.

By doing so the main figure shows like this.

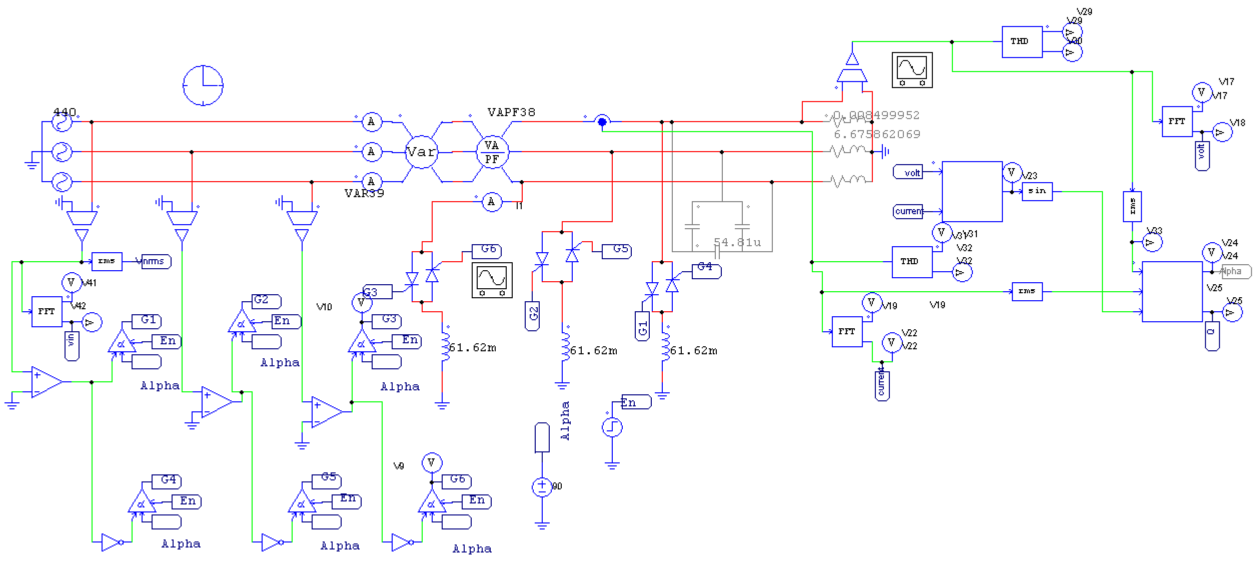


Figure 5.26: TCR ONLY

Here we have to disable the alpha label at the output side of simplified c block & enable the alpha label at the dc source.

Here the reading is taken at each & every degree from 90° to 180°, and corresponding to that reactive power value is measured in meter as well as at the output side of simplified c block.

There is a slight variation between this two values so we cannot get the except zero value of var.

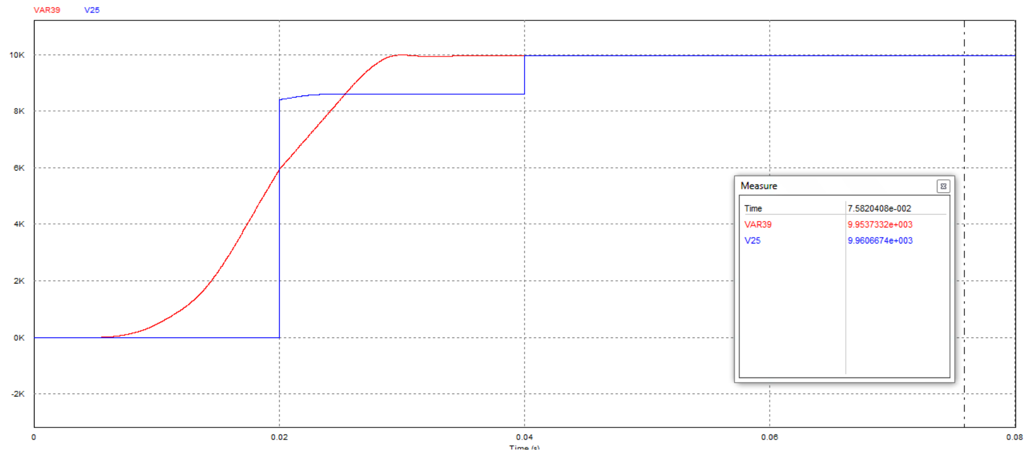


Figure 5.27: VARIATION IN Q MEASUREMENT

For different value of α THD(Total Harmonic Distortion) analysis is carried out of the following load.
As we can see from the table THD level is increases as the firing angle(α) increases. Here example of 5 KVAR load is shown whose α is 113.6° & THD is 0.280%. here all the load is linear so our THD value is less compare to the non-linear load.

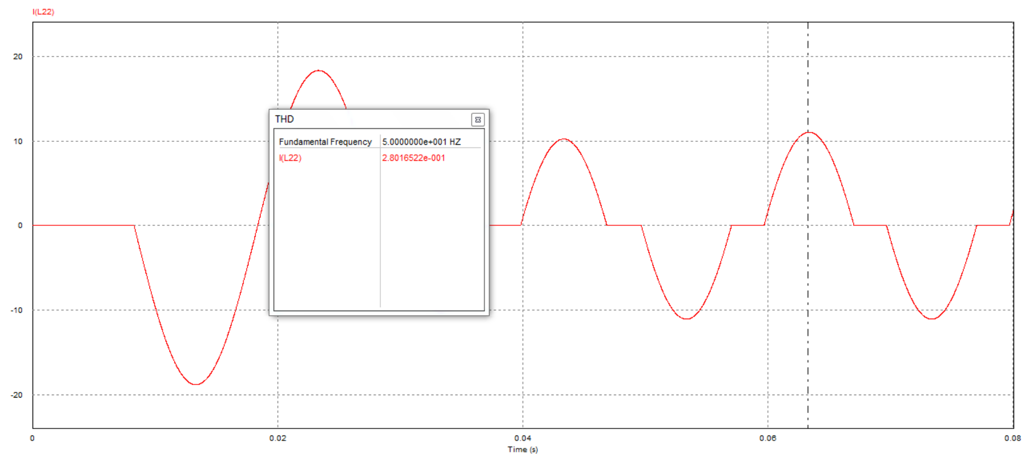


Figure 5.28: THD

Table in fig 5.29 shows all the data including THD value.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Q (KVAR)	P(KW)	S(KVA)	COSϕ	ϕ	DEGREE	VLL	VPH	ZPH	SINϕ	R	XL	L	ALPHA	THD
2															
3															
4															
5															
6	**1**	7	7.071068	0.989949	0.141897	8.130102	440	254.0341	27.37917	0.141421	**27.104**	3.872	**0.012325**	94.3	5.00E-02
7	**2**	9	9.219544	0.976187	0.218669	12.52881	440	254.0341	20.99887	0.21693	**20.49882**	4.555294	**0.0145**	99.08	1.04E-01
8	**3**	11	11.40175	0.964764	0.266252	15.25512	440	254.0341	16.97984	0.263117	**16.38154**	4.467692	**0.014221**	103.55	1.55E-01
9	**4**	13	13.60147	0.955779	0.298499	17.10273	440	254.0341	14.23376	0.294086	**13.60432**	4.185946	**0.013324**	108.44	2.15E-01
10	**5**	15	15.81139	0.948683	0.321751	18.43495	440	254.0341	12.24434	0.316228	**11.616**	3.872	**0.012325**	113.6	2.80E-01
11	**6**	17	18.02776	0.94299	0.339293	19.44003	440	254.0341	10.739	0.33282	**10.12677**	3.574154	**0.011377**	119.25	3.57E-01
12	**7**	19	20.24846	0.938343	0.35299	20.22486	440	254.0341	9.561222	0.345705	**8.971707**	3.305366	**0.010521**	125.6	4.51E-01
13	**8**	21	22.47221	0.934488	0.363979	20.85446	440	254.0341	8.615087	0.355995	**8.050693**	3.066931	**0.009762**	133.19	5.77E-01
14	**9**	23	24.69818	0.931243	0.372988	21.37062	440	254.0341	7.838635	0.364399	**7.299672**	2.856393	**0.009092**	143.41	7.87E-01
15	**10**	25	26.92582	0.928477	0.380506	21.80141	440	254.0341	7.190123	0.371391	**6.675862**	2.670345	**0.0085**	180	1.96E+13

Figure 5.29: ALPHA VS THD

5.5.1 AUTOMATIC CLOSE LOOP CONTROL

By using following equation the current from TCR is measured.The relation between the fundamental component of the reactor current, and the phase-shift angle α is given by

$I1 = (V_{rms} \div (\pi\omega L)) * (2\pi - 2\alpha + \sin(2\alpha))$

After that total reactive power of star connected TCR =3*V*I.

To match this both value we rotate one loop in which α is continuously vary from 90°-180° by 0.01 incremental steps.

The loop will be stop at particular value of α when both the value of Q will be matched & α angle freeze.

After that total reactive power of star connected TCR =3*V*I.

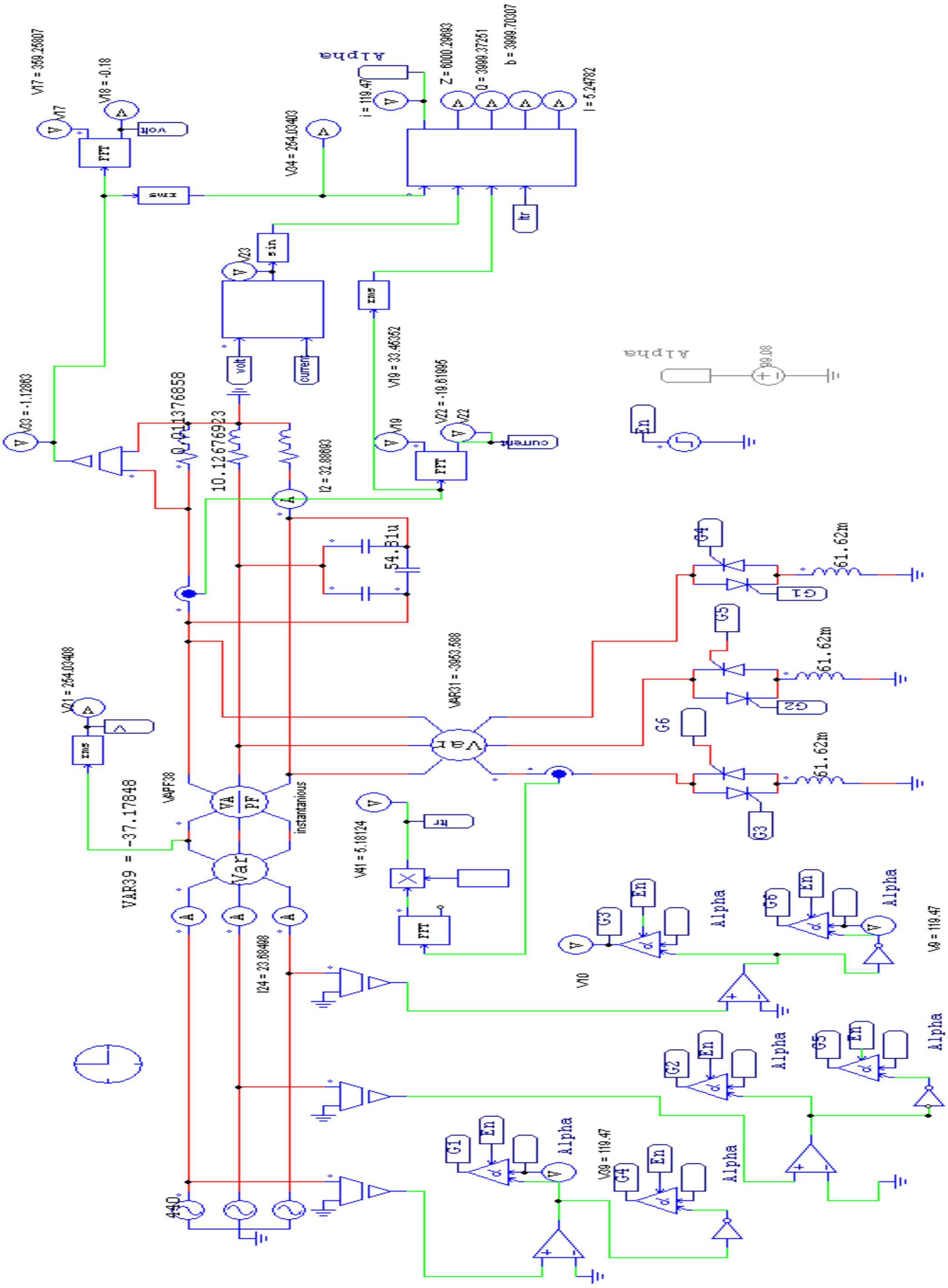


Figure 5.30: Automatic Control of FC-TCR

To match this both value we rotate one loop in which α is continuously vary from 90°-180° by 0.01 incremental steps.

The loop will be stop at particular value of α when both the value of Q will be matched & α angle freeze.

Here this value of current is fundamental component .So here we can not directly measrure the TCR current , the direct measurement of current has harmonic content because as α is varies continuously. So FFT block is used whose output gives the peak of fundamental value of the TCR current, but we want rms value so dived this by 1.414 so we get rms value.

This current value made as label and given to simplified c block. In this the current is measured by above equation continuously & at the same time reactive power is also measured by 3*V*I*sinϕ.

z = 3*v*I*sinϕ

b = 10000 - z

When this value is matched with b value the α is fixed & it will be displayed at the first output of the c block.

According to this value the triggering pulse is given to the thyristors of TCR.

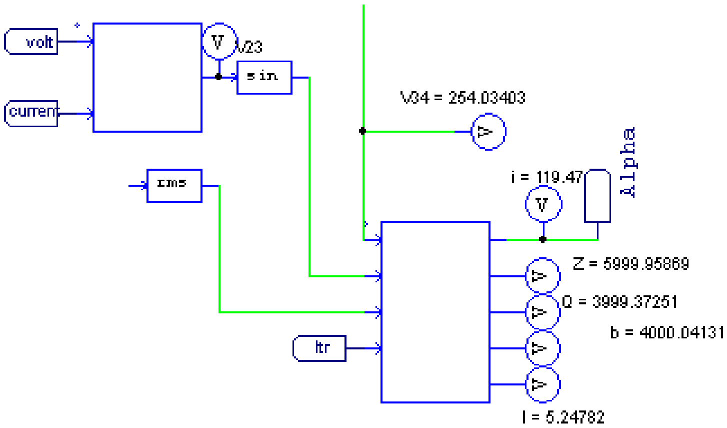


Figure 5.31: Logic block

Let us take example of 6 KVAR load. It can easily measured by calculation as seen in above figure.

The value of z shows load VAR, after that Q shows the value measured by the equation & b shows the value after subtraction from the KVAR value given by capacitor which is 10000 is this case. When this values are same alpha angle is become fix, here α=119.47°.

The last value gives the fundamental component of TCR current which is measured by the previous equation.

The first three inputs are volt, sinϕ & current which are used to measure the reactive power of load. The last input is the fundamental current of TCR which is not necessary to take.

We can see the waveform of power factor, VAR taken from source side & VAR given by TCR

Figure 5.32 shows value after compensation. Load is 6 KVAR & after compensation we get 37 VAR leading as seen from the second waveform indicated as VAR 39. Our capacitor gives 10 KVAR continuously, 4 KVAR is additional so we have to absorb

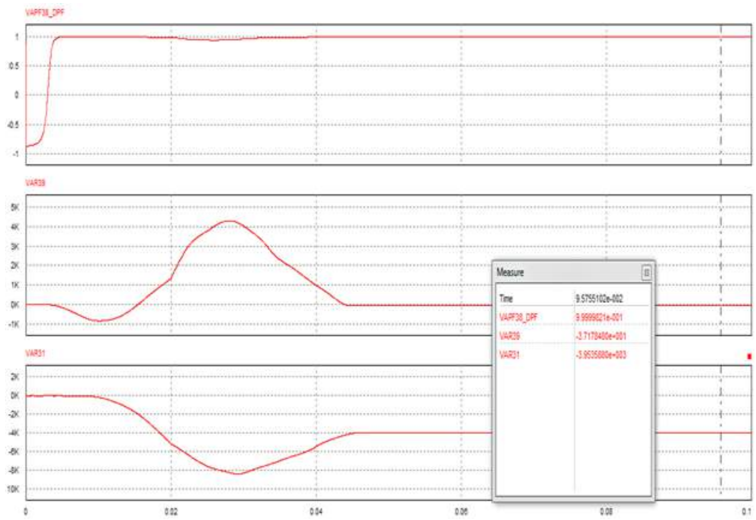


Figure 5.32: PF VAR Waveforms

this additional Kvar by TCR. From the last waveform indicated as VAR 31, we can see TCR absorb the 3953 VAR. first waveform shows the power factor 0.9999.

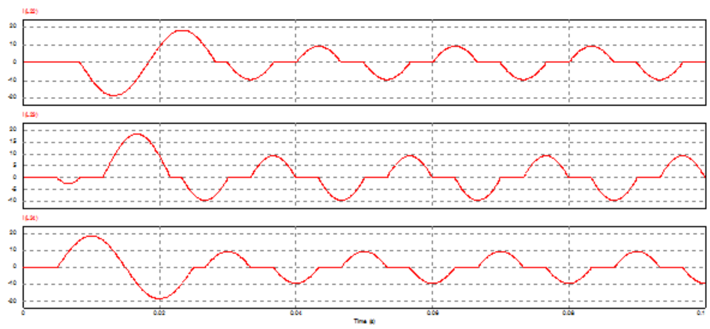


Figure 5.33: TCR Current Waveform

This figure shows the the waveform of current flowing to the TCR at α=119.47°.

Chapter 6

Hardware Implementation

I am going to make hardware of FC-TCR having capacity of 10 kvar.
It consist of 10 kvar delta connected fix capacitor 10 kvar TCR (Thyristor controlled Reactor).
Detuned reactor of 7% is used in series with fix 10 kvar capacitor. It is not necessary to connect the reactor all the time but for safety margin to enhance the capacitor life we are here using it.

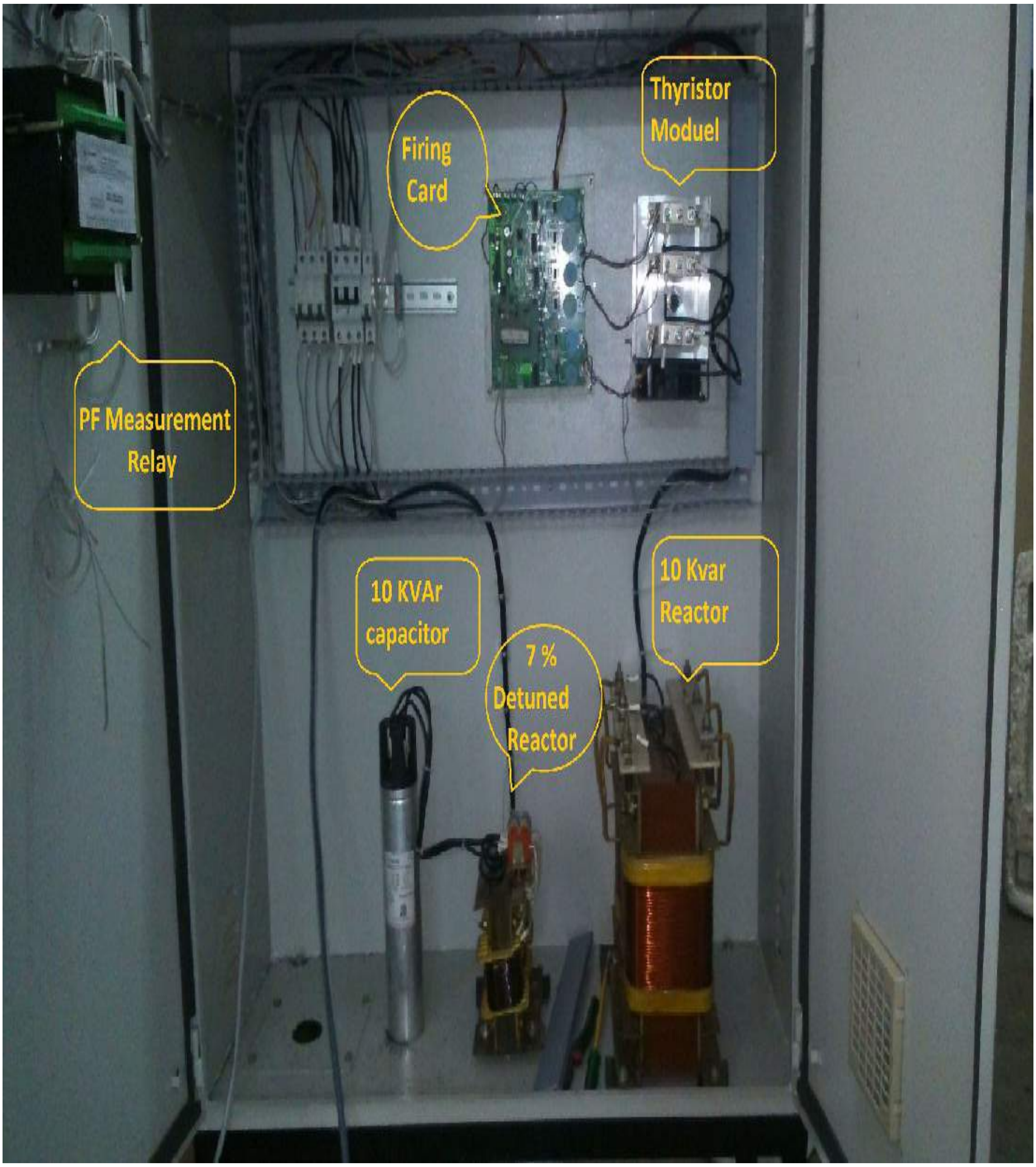


Figure 6.1: FC-TCR

6.1 FLOW CHART

Here we continuously measure PF from the meter & according to that the alpha

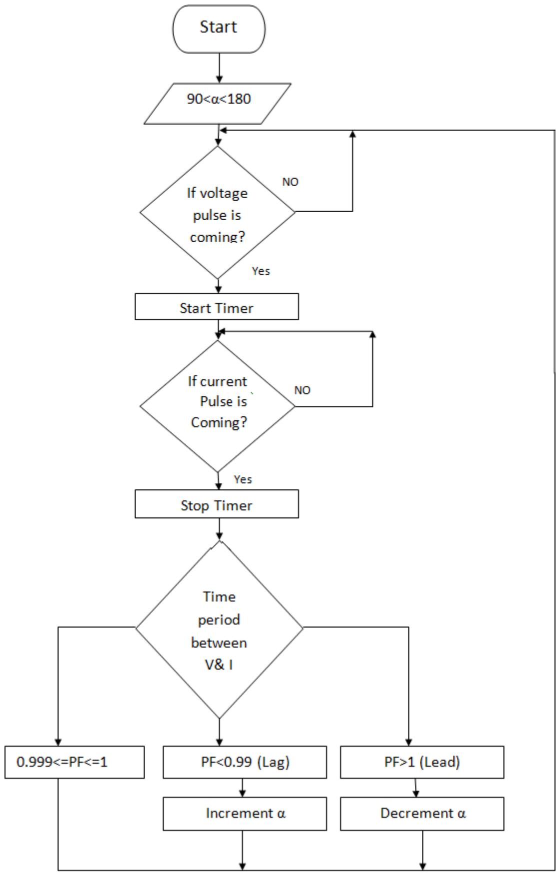


Figure 6.2: Flow chart

angle adjusted to get the minimum var from supply side and to get power factor near to unity(0.999).

Firing card is designed according to this logic.

6.2 FIRING CARD

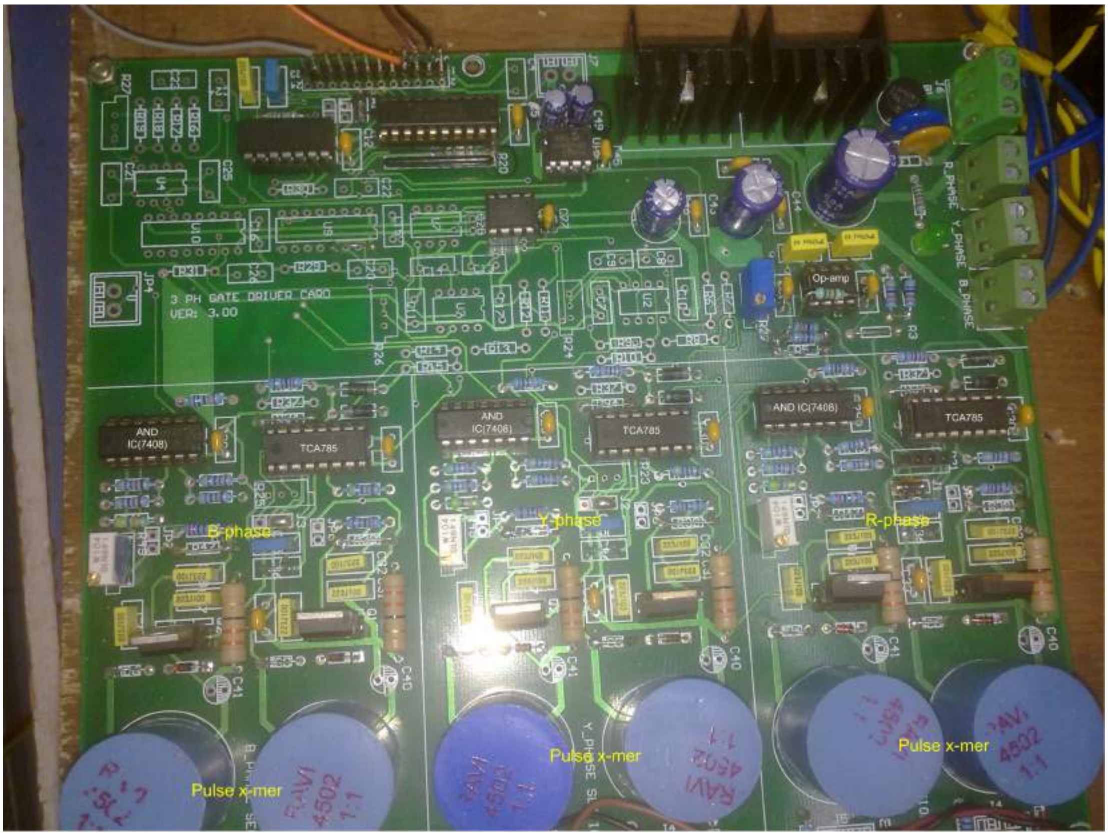


Figure 6.3: FIRING CARD

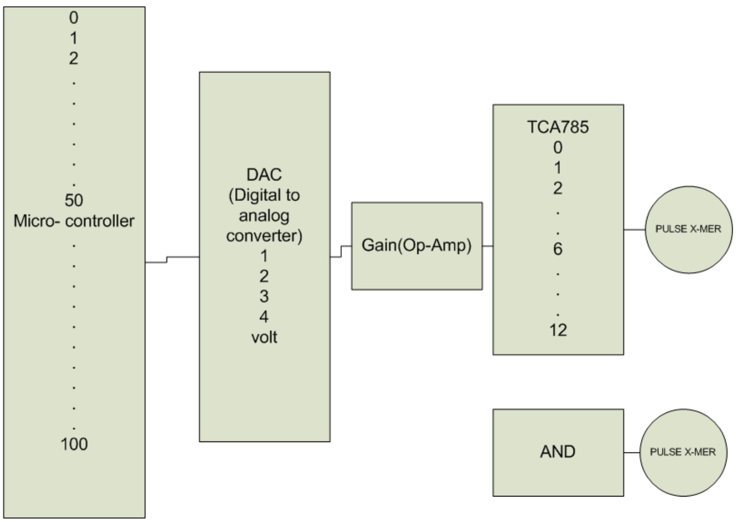


Figure 6.4: BLOCK DIAGRAM

Here the logic is implemented using micro controller. In which the output of micro-controller is given to the Digital-To-Analog convertor, further it is amplified and finally given to the firing ic (TCA785).
According to output of this ic, firing angle is controlled.The output of this ic is 0-12v
Here we can control the firing angle from 0-180° range.
But we require only from 90-180°. So output voltage is controlled between 6-12 v to get the desired firing angle between 90-180°.

As uc varies its count the output of DAC varies between 0-4 V. Let us say total count is vary from 0-100 in Micro controller, so output of DAC is in between 0-4. And according to that output of TCA785 is in between 0-12V. Here we can consider the output of the ic equal to 0-180°. But as per our requirement we require only 90° to 180°, so we have to take output between 6-12V. So we can get alpha from 90° to 180° range.

To set the logic in Micro-controller
For e.g.
Take
variable count;
A=count/25;
If count=50,75,100;

A=2,3,4;

According to this we can vary the output of the DAC.

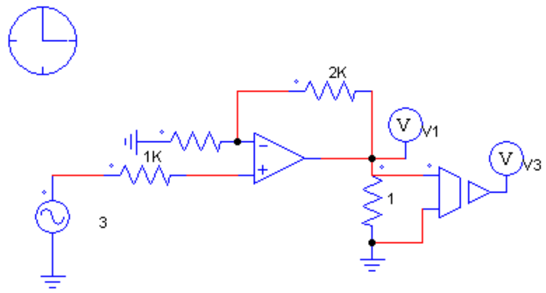


Figure 6.5: OP-AMP AS GAIN

Here op-amp is used to amplify this output & it is given to firing ic.

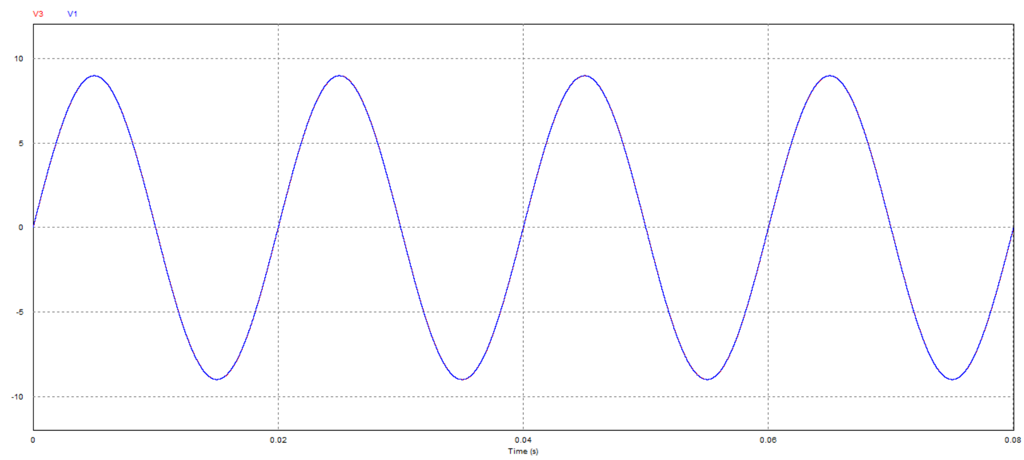


Figure 6.6: OUTPUT WAVWFORM

Here we can see from the figure how the op-amp is used to amplify the voltage. Here input is 3v output is 9v.

So if we give 1v as input it gives 3v to the TCA785 ic as a input.

Similarly

2v$\longrightarrow 6v$

$3v \longrightarrow 9v$

$4v \longrightarrow 12v$

The output of the TCA785 is given to the pulse transformer through transistor. Here transistor is used to provide sufficient amplification of current which is require of gate current which is used to fire the thyristor.

6.3 DETUNED REACTOR

This is a detuned reactor connected in series with the 10 KVAR delta connected capacitor. It value is chosen 7% of capacitive reactance. Here in name plate it is written as 10 KVAR, because it is general practice to write its capacity same as with whom it is to be connected. So here it is given as 10 KVAR.

XL= 7% XC

There is no change in performance of capacitor due to this reactor, it continuously provide reactive power to the system. When load producing harmonic at that time one perticuler harmonic frequency may create resonance so that capacitor provides

Figure 6.7: DETUNED REACTOR

low impedance path for this harmonic so high current will flow in it. It may damage the capacitor so to avoid this detuned reactor is used. Generally load are producing 5th & 7th harmonic, so for that 7% means 189Hz.It will not allow the current to flow in.So 5th & above all harmonic current were eliminated from entering into capacitor.

6.4 10 KVAr REACTOR

This is the three phase choke means reactor of 10 KVAR capacity.

L= 60mh

$I_{max} = 15A$

This is star connected.

Figure 6.8: 10 KVAr REACTOR

6.4.1 Testing of FC-TCR

We tried to test this on motor of approximate of 4 hp. In this case we get the PF near to unity, but problem which occured is PF is not steady, it continuously varying between 0.7 to leading so the sensing is not done properly due to light load condition. Here motor is operated on no load condition.

So now it is necessary to place this panel on actual heavy load condition, so we can conclude exactly about reactive power compensation as well as power factor. For that we need to connect this panel in parallel with distribution board of any utility after the mains supply of GEB (parallel with the outgoing feeder of utility).

Load in industry is varying continuously so we cannot measure actual current before & after compensation. So we have to see the value of power factor to know how much amount of compensation is done.

Figure 6.9: FC-TCR Cabel Connection

6.4.2 APFC RELAY

Here Automatic Power Factor Control Relay of Syntron Company is used. This relay is used in APFC (Automatic Power Factor Correction) panels. Their function is to give high-low signal of power factor to the controller. It senses the power factor continuously with the variation of load. As load goes increases, PF will be lagging so it gives low signal to the micro-controller such that it will try to maintain PF by increasing the capacitor value (here in this case increase the firing angle α by removing the Reactor), similarly it will give high signal as PF goes into leading if load will decrease. In later case controller has to decrease α until the desired PF will be achieved.

The desired PF is set by as per our requirement by adjusting the pointer at 0.99. the range is given from 0.8 to 1. If we set it to 0.99 means it assumes 0.99 as unity below this it will give low signal & above this it will give high signal.

To control firing angle α, there are two possibilities either increase it or decrease it .

Total three wires one for increment & second decrement and third wire is for common path. These three wires are coming from the micro-controller.

Figure 6.10: APFC Relay

Here lots of terminals are given but we have to make a contact close thenafter high low signal is given to micro-controller to maintain PF. So two wires are connected in NO (Normally Open).

NOHI$\longrightarrow$relay will give high PF (lead) signal so in this situation we have to absorb more reactive power by TCR so we need to decrease α. The wire which decreasing α is connected to this terminal (20).

NOLO$\longrightarrow$ relay will give low PF (lag) signal so in this situation we have to supply more reactive power by capacitor & reduce reactive power absorb by TCR, so we need to increase α. The wire which increasing α is connected to this terminal (17).

CLO & CHI is shorted.

Here CT is connected in Y phase & its rating is 100:5 amps.

Terminal 22 & 23 is connected as S_1 & S_2 contact of CT. if we made a wrong connection than sensing will be wrong. We see the 2u error in the display which shows extremely leading condition or sometimes value of PF will be vary lagging. When this type of signal comes then we have reverse the connection.

6.4.3 Brief Explanation

This FC-TCR panel is connected in one industry whose load is approximately 70 amp. They are already using two capacitor of 20 KVAR. First this panel is connected which contains 10 kvar capacitor & 10 kvar TCR, doing so it is shown that PF is not maintain to 0.99 but it moves around 0.95 below. This indicates that industrial load is too much & FC-TCR panel is not sufficient to provide compensation after 50 KVAR capacitor already connected.

So capacity of supplying reactive power need to be increased, so one more capacitor of 12.5 KVAR is added with the existing system. Now total capacitor is of 62.5 KVAR still I was facing the same problem. Then after connected 20 KVAR capacitor with existing 10 KVAR capacitor & that 12.5 kvar capacitor is removed. Now effective change is shown in power factor and it will come near to unity 0.999, it almost 1.000 but load will vary so it has to adjust itself with the load & therefore due to time gap between this it will vary between 0.995 to 1.000.

Snapshot is taken from video recording when PF maintain at unity.

But one problem is occurs in this case if load will fall below a certain level then here our reactor is only 10 KVAR it will not absorb the total 30 KVAR capacitor so reactor is equally design as the capacitor value. When load will fall PF is leading in this case,

Figure 6.11: UNITY PF

over compensation will occur.

Here when our PF shows unity at that time we measure both capacitor current reactor current. At a particular instant the total incoming current to the panel is

I $_{income} = I_{C1} + I_{C2} - I_{TCR}$

Here this current is not simply current taken by the two capacitor but it also depend on how much amount of current TCR is taken. So capacitor current is added together & TCR current is subtracted from that capacitor current. However this phenomenon is not dependant on load, above discussion is true only if load is less means our capacitor provides overcompensation to nullify this TCR takes some amount of current.

If load is high enough means exactly equal to capacity of capacitor than TCR will not draw any current. The total current will be equal to same as capacitor current.

I income= $I_{C1} + I_{C2}$

The power factor of the industry before the FC-TCR connection is 0.8 shows on the main meter's display. After the panel is connected it goes to somewhat leading 1.13 it is because load is flucuating continuously FC-TCR takes some time to maintain it to unity. when it try to keeps the PF unity load changes suddenly so we cannot get excat unity PF.

Chapter 7

CONCLUSION

7.1 Conclusion

The smooth control of reactive power is possible with the help of FC-TCR which is not achieved in APFC. In APFC panel capacitors are used in which somewhat leading or lagging KVAR is present due to fix size of capacitors. By knowing different load & its variation and according to that choosing appropriate rating of FC-TCR perfect reactive power compensation is achieved. By this power factor is also maintain near to unity. Penalty can be avoided from the power distribution company, so tariff will be less.

7.2 Future Enhacement

One can use FC-TCR in parallel with APFC panel so that some amount of capacitors are switched on directly as per variable step by step load increases. This capacitor is selected based on load schedule for e.g. from 10 am to 11 am particular load requirement is 20 KVAR. Then after 11 am, 5 KVAR load drops & again after 2 pm

30 KVAR load requirement is there. The most fluctuating load is 25 to 30 KVAR.

So for particularly this case one can design four number of 5 kvar capacitor means total 20 KVAR APFC panel so in this capacitor are switched on & off as per load requirement & it will provide reactive power compensation. Now only 10kvar load is remaining (20-30 KVAr). One can design 10 KVAr FC-TCR for this. So it will give smooth steeples reactive power compensation.

Same thing is done with the help of TSC-TCR. At LT side it is not used till now.Company using APFC panel which is already available in the market, if cost is not concern than one can directly go toward the TSC-TCR.

To combine this both concept(TSC-TCR), special relay need to be design which can switch on & off the capacitors as per load requirement same as APFC relay and it can also vary the firing angle of reactor as per requirement.

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