CHAPTER 4

VOLTAGE IMPROVEMENT

4.1 Introduction

In this chapter the methods of voltage improvement technique in order to keep the system voltage within permissible limits are described. The methods described in this thesis will be divided up into the following parts.

- Technical method
- Pricing Policy method

The phenomenon of steady state voltage drop in transmission networks can be conceptualized by taking the simple case of a constan voltage source supplying a load through an external series impedance. (Fig. 4.1)

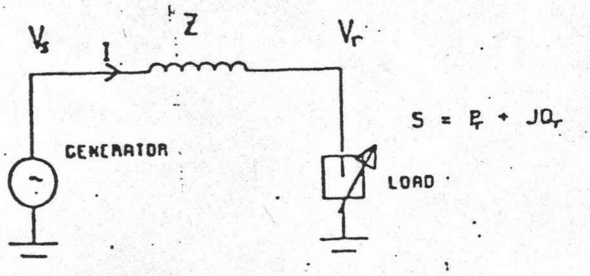


Fig. 4.1 Single Line Diagram Of A Radially Served Load

From Fig. 4.1, it is clear that

$$V_r = V_s - IZ$$

or $$V_s - V_r = IZ$$

where $$Z = R + jX$$

refer to ref [24] we get

$$V_s - V_r = IR\cos\phi + IX\sin\phi \quad \dots (4.1)$$

which is the approximate expression for voltage drop

From eq. (4.1), it is clear that the voltage drop i.e. $V_s - V_r$, depends on the following factors:

- the parameters of the line, R and X
- the load currrent
- the power factor of the load, $\cos\phi$

It is obvious that by controlling the above three factors, the voltage drop $V_s - V_r$ could be controlled, thus keeping the receiving end voltage within desired limits

The parameters R and X is determined by the nature of transmission line. The load current is determined by the nature of the load. A highly inductive load having a low power factor would draw a much larger current than a highly resistive load having a high power factor for the same active power consumed. Thus a low power factor load will result in high voltage drop along the line. An important method of reducing the voltage drop in a line, therefore, is to use a power factor improvement device at the receiving end of the line.

To give a further explanation of how the power factor of the load affects the voltage drop of the line,let us consider eq. 4.1

If the load is purely inductive,i.e. $\phi = 90$,then from eq. 4.1

$$V_s - V_r = IX \qquad \ldots (4.2)$$

If the load is purely resistive,i.e. $\phi = 0$,then from eq. 4.1

$$V_s - V_r = IR \qquad \ldots (4.3)$$

For a transmission line $X \gg R$, thus from eq. 4.2 and eq. 4.3 , it is seen that the value of $V_s - V_r$ (i.e. voltage drop along the line) is very high for reactive loads and very low for unity power factor loads. This means that the voltage drop in the line increases with increased low power factor load (also called reactive power load). Thus, to maintain voltage drop in the line within limits,the reactive power drawn by the consumers should not exceed a certain limit. This ,however, is not under the control of the supply authority because the reactive power drawn by the consumers,who use inductive loads such as induction motors. Therefore, in order to compensate for the reactive power taken by consumers, capacitors or synchronous condensers (also called synchronous compensators) are installed at the receiving end, thus reducing reactive power flow through the line. This reduces the voltage drop in the line and keeps it within limits.

In the following sections are discussed some specific methods used for controlling the voltage at the receiving ends lines.

4.2 System Improvement

4.2.1 Reduce Line Impedance

From eq. 4.1 ,it is clear that if we can reduce transmission line impedance the voltage drop will be reduced. The easiest way to reduce line impedance is to use parallel circuit.

4.2.2 Using Higher System Voltage

From eq. 4.1 , it is clear that one factor that cause the voltage drop is load current, thus,if we can reduce load current the voltage drop will be reduced. Using the higher system voltage will reduce the current in transmission line, thus the voltage drop decrease.

4.2.3 Synchronous Compensators (SCs)

When a transmission line is supplying full load, the power factor is comparatively low because of a large number of inductive loads connected to it, thus the voltage drop in the line becomes large. On the other hand, when supplying light loads, the capacitance of the transmission lines is sufficient to compensate for the inductive effect of the load causing the power factor remain sufficiently high. Thus, the voltage drop in the line remains low. However, at very low loads, the capacitive effect of the line may dominate over the inductive effect of the load causing a leading power factor and resulting in voltage rise in the line. The receiving end voltage will then be higher than the sending end voltage.

Synchronous compensators are connected at the receiving end of transmission lines and are run overexcited when the lines are fully loaded. Overexcited synchronous compensators generate reactive power thus correcting the line power factor to near unity. When the lines are running lightly loaded, the synchronous compensators connected at the receiving end are run underexcited. Underexcited synchronous compensators consume reactive power thus compensating for the predominantly capacitive effect of the line at extremely light loads. Synchronous compensators can be provided with built-in voltage regulators by which the compensator will automatically run overexcited at high load and underexcited at light load.

Action of synchronous compensator shown in Fig 4.2 a,b and c .

Fig. 4.2a. show the position without a synchronous compensator The load draws active power P and reactive power Q , both of which flow through the transmission line. Considering full load condition, when the power factor is comparatively low, Q will be large. Hence the voltage drop in the line will be large.

Fig. 4.2b. shows a synchronous compensator connected at the receiving end of the line. When the line is supplying full load ,the SCs would be overexcited thus supplying leading reactive power, Q_{sc}. Thus the power flowing through the transmission line would be the active power P and the reactive power $(Q - Q_{sc})$. It is seen that the reactive power flowing through the line is thus reduced from Q to $(Q - Q_{sc})$. This reduces the voltage drop in the line.

Fig. 4.2c. shows the condition at light loads. The power p at light loads is very small and the reactive power at light loads is neglected (i.e. $Q = 0$). The reactive power, Q_{LC} , owing to line capacitance is now significant as compared to active power, p. If Q_{LC} is sufficiently large, it may result in the receiving end voltage becoming higher than the sending end voltage. This is often called Ferranti effect. This may cause damage to equipments at the receiving end. Therefore for this condition, the SC is run underexcited, whereby it consumes reactive power q_{sc}. The total reactive power flow in the line is now $-Q_{LC} + Q_{SC}$. This causes the power factor to improve from the leading position towards unity. Thus the voltage at the receiving end is maintained within permissible limits.

The great advantage of using an SC for the voltage control of transmission lines is the flexibility of operation at all load conditions. The disadvantage is that it is quite expensive.

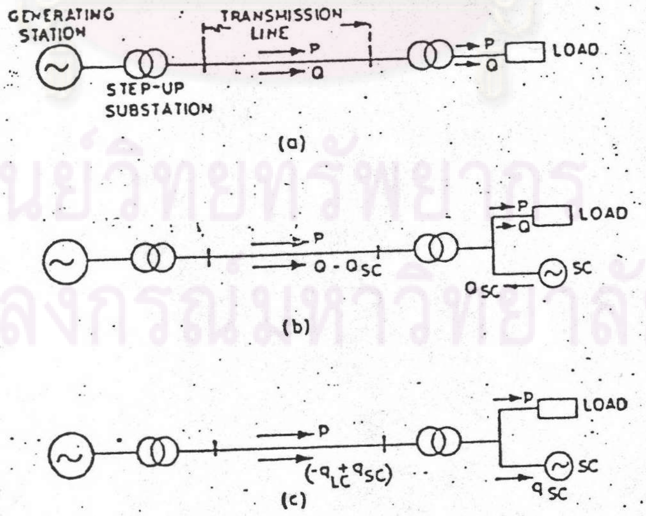


Fig. 4.2 A Transmission Line supplying Load:

a) without SCs

b) with overexcited SCs

c) with underexcited SCs

4.2.4 Shunt Capacitors

In the preceding paragraphs, the use of an SC for controlling the voltage drop in a line was discussed. SCs are expensive and their use on subtransmission and distribution systems is not economical. Capacitors are therefore used here for the same purposes. Capacitors are usually shunted across the line at the receiving end. In case of three phase lines, capacitors may be connected in grounded star, ungrounded star, delta, etc. Since capacitors of required capacity are not always available,therefore they are usually connected in banks.

4.2.5 Tap-Changing Transformers

The methods of controlling the receiving end voltage of a line by using either SC or shunt capacitor cause the power factor to be so altered as to minimize the voltage drop in the line and hence maintain the receiving end voltage close to the permissible value. However, the voltage drop in the line,besides being affected by the power factor, also depends on current flowing through the line which is determined by the load. Therefore, depending upon the load, there will be a voltage drop along the line even after the power factor has been appropriately improved. To keep the distribution voltage within permissible limits, means must be provided to increase the voltage when it is low and decrease it when it is high. One of the most widely used methods of adjusting the line voltage is to alter the ratio of transformation by tapping the windings of the receiving end distribution transformer. This process is termed tap-changing. It may be done when the transformer is not in the circuit (i.e. off-load) or when the transformer is in the circuit (i.e. on-load).

4.2.6 Static VAR Compensator

The previous sections describe methods of reducing the voltage drop along the line. But some be useful for the situation where the voltage drop occurs over a long period of time in the order of minuits to hours. Because the mechanical response is too slow to cope with the fast transient voltage collapse phenomena associated with loads of major induction motor content. For this situation, the injection of fast variable reactive power near the load centers can effectively alleviate all voltage degradations and prevent the voltage collapse. This can be achieved by the recently available thyristor-controlled static VAR compensators which react almost instantaneously; within 2 cycles.

4.2.6.1 Basic Configulation

These devices contain standard fixed shunt elements (reactors, capacitors), however, controlled by thyristors. Fig. 4.3 shows the fundamental circuit configulations for SVC systems which can be divided into two basic categories:

- System with fixed capacitors and thyristor-controlled reactors (FC/TCR types)
- System with thyristor-switched capacitors and thyristor-controlled reactors (TSC/TCR types)

4.2.6.2 SVC Model

A unified model for representing all types of SVC and their controllers is shown in Fig. 4.4. The SVC is represented as a controlled current source I, at fundamental frequency, in parallel with a fixed reactance X_t. In this thesis following four types of regulator are used.

- Proportional regulator
- Proportional-integral regulator
- Lead-lag regulator
- Integral regulator

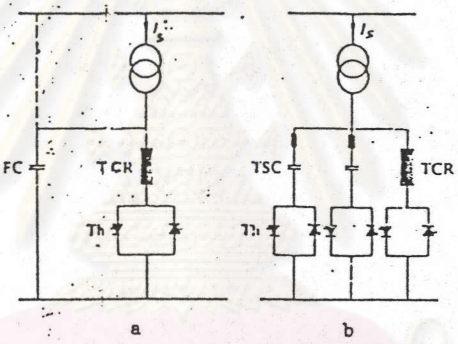


Fig. 4.3 Basic Configulation Of SVC

a) FC/TCR   b) TSC/TCR

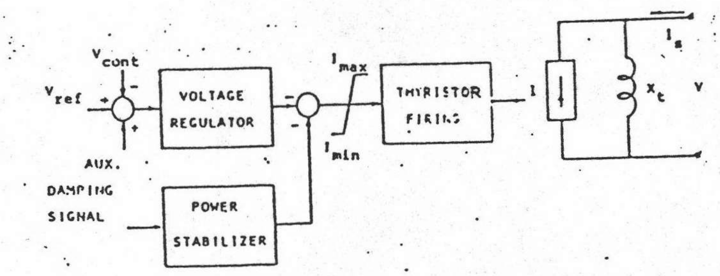


Fig. 4.4 Unified Model For SVC

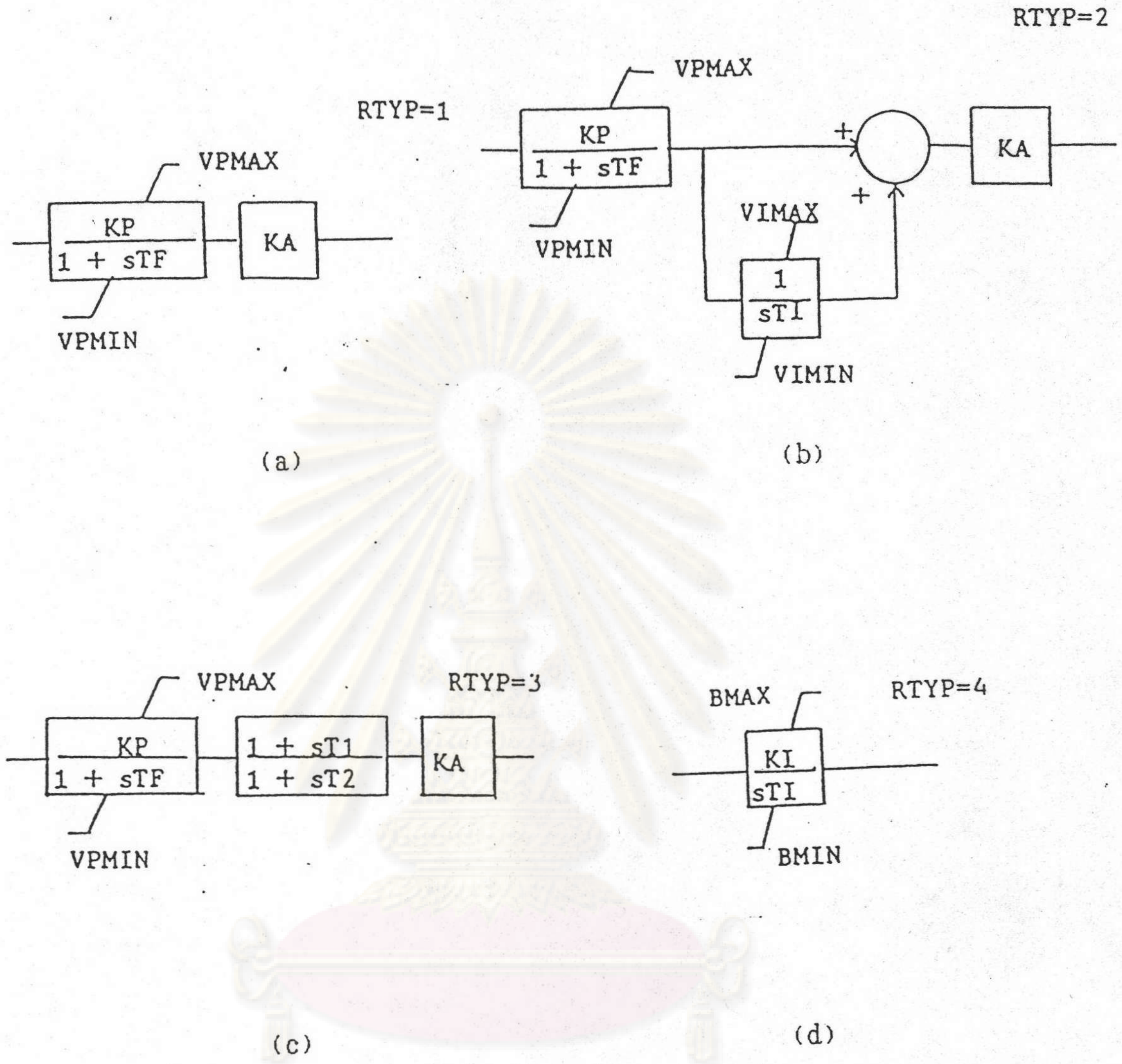


Fig 4.5 Type Of SVC

(a) SVC with proportional regulator (SVC type 1)

(b) SVC with proportional-integral regulator (SVC type 2)

(c) SVC with lead-lag regulator (SVC type 3)

(d) SVC with integral regulator (SVC type 4)

4.2.6.3 SVC Selection

In selection of static VAR compensator, the power system planers should determine these following factor:

(i) SVC configulation

For such an application of alleviation transient voltage collapse, the SVC is mainly desinged to generate a fast variable capacitive VARs at the instant when the voltage collapse appears. During normal steady state conditions, the SVC reactive power output may be set to zero. The SVC should also have enough VARs in the inductive range to limit any dynamic over voltages following load rejections. To fulfill these requirements, a TSC/TCR SVC configulation would be the best technical alternative but more expensive.

(ii) SVC rating

The capacitive rating of the SVC is determined on a steady state basis, i.e. it is the capacitive reactive power required to maintain the load voltage at the value which is a defined stable margin when sudden change in load is occur. This value has been obtained from a load flow study.

(iii) SVC location

The thyristor controlled reactor is a current rated device, i.e. current rating of the thyristors is a fixed quantity based on the thyristor type. Knowing the SVC MVA rating as explained before, the required SVC voltage that makes full utilization of thyristor current capabilities can be determined. For practical MVA ratings, such voltage is relatively small. Therefore, a step-down transformer is always required to connect the SVC with the HV network. As the load is usually connected to the network by a power transformer, the best economic choice would be to install a tertiary winding to this transformer with a voltage that matches the SVC required voltage. This choice realizes the maximum use of transformer circuits and the optimum utilization of SVC components.

(iv) SVC controller

Controller parameters are optimized through a scanning procedure using eigenvalues. The criteria for optimizing the parameters are :

- fast and stable response
- no occurance of any control loop instability
- no adverse interaction between the SVC and the power system modes of oscillations.

4.3 Motor Starting Procedure Improvement

The methods of reducing system voltage drop during starting up induction motor, described in this thesis are to adjust starting up procedure. The motor starters can reduce the effects of motor starting on the system. The various methods available for starting induction motors are described in the following paragraphs.

4.3.1 Full-Voltage Starting

4.3.1.1 Direct On Line Starting (DOL)

This is the simpliest and lowest-cost method of starting. It produces maximun starting torque and minimum accelerating time. But it also produces the maximum disturbance to the electric distribution system. Thus this method should be avoided.

4.3.1.2 Rotor Resistor Starting

This method employs series resistor in each phase of the motor rotor circuit. In selecting polyphase induction motors for specific duties, attention must be paid to such items as degree of enclosure, duty cycle, speed and many other factors. Included here are such considerations as starting torque and starting current. On this basis alone, the rotor resistance value may have to be modified.

It has been shown that, when considered at standstill as a simple, equivalent series impedance would have a starting current as follow

$$I = V / Z_e$$

wherein applied volts and equivalent impedance are phase values. Numerically:

$$Z_e = [(R_1+R_2)^2+(X_1+X_2)^2]^{1/2}$$

The starting torque will vary with the design, service, size and number of poles. By the rotor resistor starting method , the starting current will be reduced and the staring torque be increased. In the other hand, a reduction of the starting current and an increase in the starting torque can be obtained by using larger values of rotor resistance. The stator winding resistance and the total leakage reactances are kept the same, as they would otherwise modify the maximum torque. On this basis the rotor resistance should be high.

The series resistance will be connected to the rotor circuit through the slip ring, thereby offering a large value of rotor resistance for starting. The heat generated at starting is thus, in part, kept out of the motor. The maximum possible starting torque is equal to the breakdown value. Once in operation, these resistances are shorted circuit, reducing rotor resistance for efficient load operation to a value limited by winding resistance alone. By proper choice of resistance elements, large torques can be obtained at nearly all speeds, and rapid accelerations can be obtained.

4.3.2 Reduced Voltage Starting

4.3.2.1 Auto-Transformer Starting

The principal advantage of this starting method is the high value of torque produced per unit of starting current. Motor current is reduced in proportion to the voltage applied to the motor terminals. Line current, however, is reduced in proportion to the square of the terminal voltage. The transformer windings are removed from the circuit once starting has been accomplished.

4.3.2.2 Primary Resistor Starting

This method employs series resistors in each phase of the motor primary circuit. The values of the resistance is reduced in one or more steps to meet inrush requirements until full voltage is applied to the motor terminals. Starting torque magnitudes are high the torque efficiency is low, being equal to the per unit value of voltage appearing at the motor terminals. Motor terminal voltage increases automatically during acceleration as the line current decreases.

Althrough transient switching current peaks are not a problem ,large values of starting current can be experienced depending upon the timing of the resistance-reduction steps. The inrush current of a normal induction motor remains at a fairly high level until relatively high speeds are attained. If the step reductions are quickly accomplished there may not be a great reduction in the maximum inrush current. In many case the limiting factor is not the total current magnitude but the incremental current increase allowed by the utility. In this situation, the starter may have performed its function well if all the resistance steps are shorted before breakaway is achieved, provided that excessive motor heating does not occur.

4.3.2.3 Primary Reactor Starting

This method is quite similar to resistor starting. It is generally more applicable to larger motors and at voltages above 600 volts. There is little power consumption in the reactor as contrasted to the resistor method. The reactor method does not improve the starting power factor of the supply system since the starting current is largely reactive in the first place. However the improvement in mortor power factor with speed increase automatically raises the motor terminal voltage during acceleration. Starting characteristics can be adjusted by tap selection. Increment starting requires seperate reactors for each step since a portion of a single reactor can not be shorted in the same manner as a resistor.

4.3.2.4 Part Winding Starting

This method is attractive in its simplicity and is generally the least expensive of the reduced starting current methods. Torque efficiency is low for high-speed motors, it approaches unity for low-speed motors. Motors torque-speed curves tend to dip at certain speeds, especially one-half speed, when operated on part winding. The possibility that the motor may not accelerate to rated speed because of torque dips requires careful consideration. This method often is not suitable for starting high-inertia loads or equipment requireing relatively large torques during acceleration.

4.3.2.5 Y-D Starting

Starting torque is only one-third of the value at rated voltage. Torque efficiency is unity. This method is desirable only where low starting torque is acceptable. The motor must run with a delta connection.

4.4 Pricing Policy Method

4.4.1 Introduction

Prevention of disturbances as part of an agreement between the supplier and the consumer.

The electricity authority charges for the supply of electric energy to the customers by the tariff.

The dictionary gives the meaning of the word tariff as schedule of rates or charges. Tariff, in the case of electricity supply, means the rates to be charged for the supply of electric energy to the consumers. The electricity supply authorities, therefore, frame the rules according to which tariffs may be fixed for different types of consumers. In this chapter, we shall discuss how supply authorities charge consumers for electrical energy.

4.4.2 Main Principles For Pricing Of Electricity

According to economic theories, the most important function of prices is to contribute to an efficient use of society's resources, i.e. labour, raw material, capital and energy. To achieve this objective, buyers of a special product should by means of prices receive correct information about the costs of delivering a product. The suppliers then receive information about willingness of the buyers to pay for the product through the development of demand for the product. Prices should also lead to a balance between supply and demand, so that allocation mechanisms such as queues and rationing normally may be avoided.

The electricity supply industry has some special characteristics which influence pricing principles:

a) The buyers have the freedom to consume electricity as they choose. Sellers at all times have to produce electricity to match the total momentary demand by consumers, because electricity can not be stored.

b) The electric power production system must have the capability not only to generate total electricity consumed within a specific period, but also sufficient capacity to supply with reliability the maximum momentary demand for electricity occuring during the same period.

c) Electricity has to be transmitted and distributed to consumers via transmission and distribution systems. These systems must have enough capacity to match the demand of the consumers with required reliability.

d) The importance of capital and the long term nature of capital investments.

From the above follows that the utility; a generating or a distributing undertaking must build production, transmission and distribution systems in advance, which are capable of supplying the maximum total demand from the consumers with the required system reliability. From the utility point of view, the services provided into two parts. The utility must :

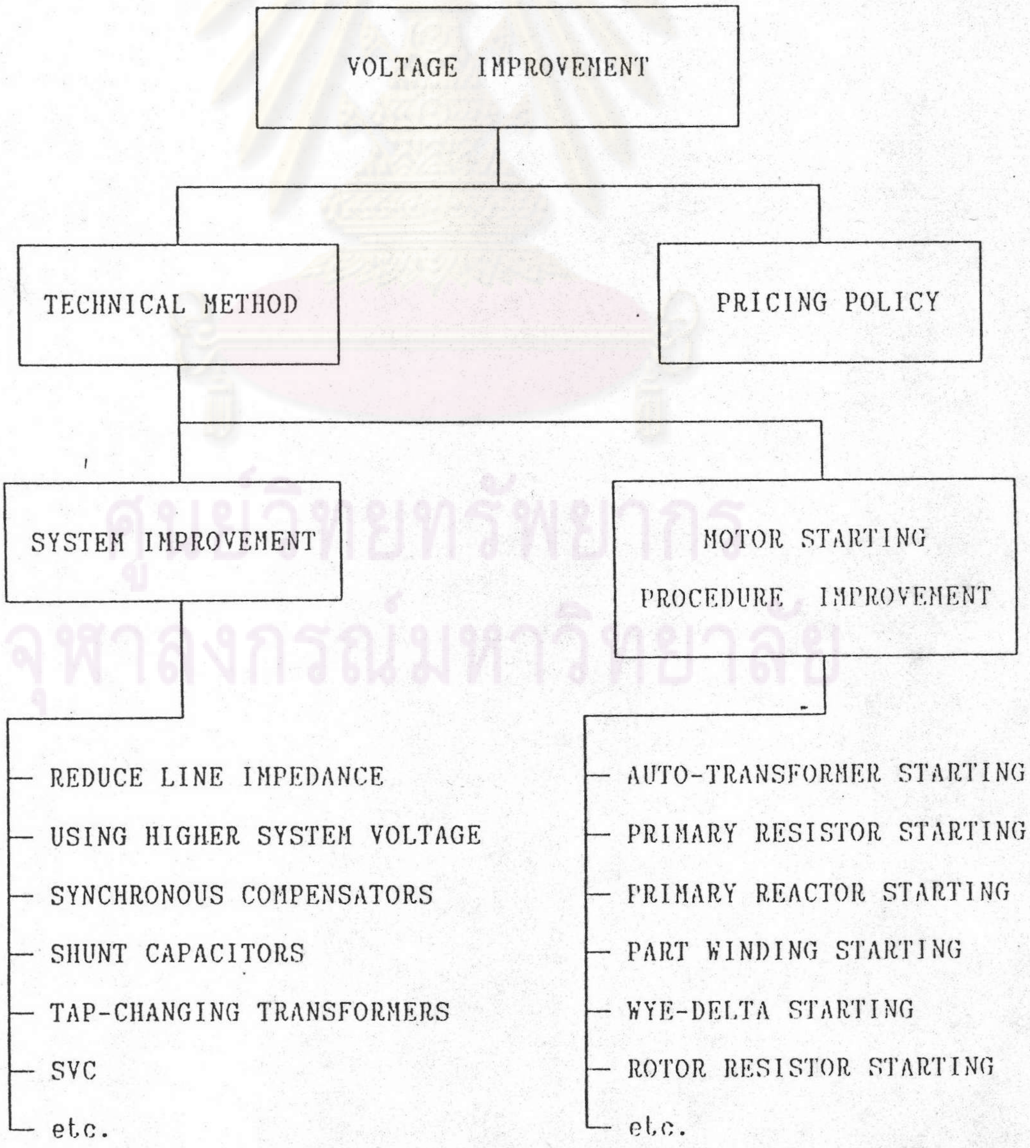
- make available to each customer a maximum capacity which the consumer usually has to subscribe to and pay for;and
- supply to the customer within the subscribed maximum capacity the energy taken out at each moment.

4.4.3 Electricity Authority's Policy On Prevention Of Disturbance

From above, it is clear that there could be no specific rules in tariff policy to prevent disturbances made by customers to affect the system or to other customers. One obvious reason is that it could be difficult to decide who is the source of a specific disturbance. Therefore in practical, the electricity authority will negotiate with the customers and sign a contract with them. The contract would contain paragraphs about:

- If the customer is causing a disturbance to the system or other cutomers he must adjust his system in order to reduce that disturbance.
- The initial usage and customer machines set up is discused during the negotiation. Future major changes should be brought to the notice of the authority.

The above methods can be figured out as follow :



In this thesis, some of the above technical methods are subjected to a closer look in the simulation study. The simulation results are shown in appendix B.