

## Reactive Power Compensation and Control via Shunt Reactors and Under Ground Power Cables

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### ABSTRACT

In this paper we will cover the techniques used locally to accomplish the reactive power compensation. First, the importance of reactive power compensation is explained through defining the different types of electrical power and showing the effect of power compensation on the electric power network quality. The power under ground cable is the first technique used to compensate for the inductance of overhead transmission lines and power transformers during heavy loading of the network. Then, we explore the application of the two types of shunt reactors in different locations of the network to compensate for the capacitance of the network during light loading. Finally, a conclusion is presented.

**Key words-** compensation, reactive power, shunt reactor, under ground power cable.

### I. INTRODUCTION

Reactive power has been recognized as an important factor in the design and operation of alternating current electric power systems. Since the impedance of the network components are mainly reactive, the transmission of active power requires a difference in angular phase between the voltages at the sending end and the receiving end. While the transmission of reactive power requires a difference in magnitude of these same voltages. Reactive power is consumed not only by most of the network elements, but also by most of the consumer loads. The required reactive power must be supplied somewhere and if we can not transmit it very easily then it must be generated at the point where it is needed. The reactive power must be supplied at the same voltage of the load who requires it.

Reactive power compensation is defined as the management of reactive power flow to improve the performance of the power system. It is related to both the system and customers. Generally we can look to the reactive power compensation from two aspects: load compensation and voltage support. In load compensation the objectives are to increase the value of the system power factor, to balance the real power drawn from the supply, compensate voltage regulation and to eliminate current harmonic components produced by large and fluctuating non linear industrial loads [1], [2]. While voltage support is generally required to reduce voltage fluctuation at a given point of the system.

Recently, reactive power compensation and control acquired more importance for at least four reasons :first, the huge demand on electrical power, second, the need to increase transmission capacity as

much as possible; third, the development of variety of controllable static compensators, and forth due to the sharp increase of the fuel and crude oil needed for electrical power generation. Some of the consumption of reactive power is in the network series elements themselves, for example, in overhead transmission lines and power transformer leakage reactance. Thus, a direct way of increasing power transfer in power transmission systems, and of reducing voltage drop, is to compensate part of the series inductive reactance by series capacitors. Series compensation reduces the series impedance of the line which causes voltage drop and is the most important factor in finding the maximum power transfer [3]. Shunt compensation (parallel) for the transmission line capacitance is also carried out through connecting parallel inductors to absorb the reactive power generated or injected by the line capacitance.

### II. THEORITICAL ASPECTS

The concept of active, reactive, and apparent power plays a major role in electric power technology. The terms active, reactive and apparent power apply to steady-state sinusoidal alternating current circuits. The apparent power  $S$  is expressed in volt-amperes. Apparent power is independent of the phase angle  $\theta$  between voltage and current. While, active power  $P$  is the real power or the true power consumed by the load expressed in watts. Resistors are considered active loads where the voltage and current are in phase. Active power is dependent on the cosine of the phase angle  $\theta$  between the current and the voltage and is composed of series of positive power pulses as in Figure 1 .

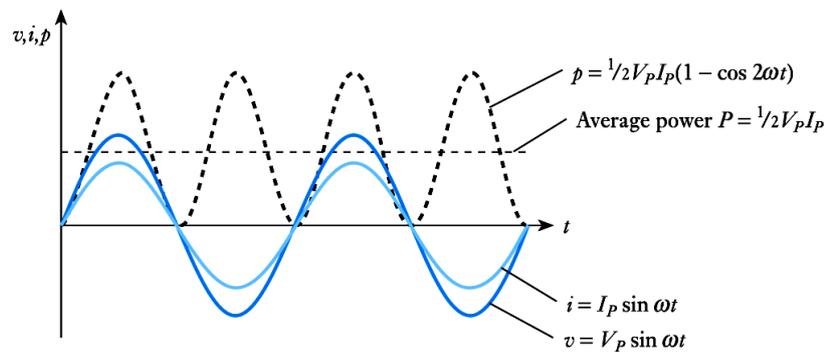


Figure 1. Instantaneous active power in a resistive load .

Capacitors and inductors are considered reactive loads and reactive power Q is measured in VARs. According to present AIEE convention volt-amperes reactive are absorbed by inductive loads and Q for inductive load is considered positive. While, volt-amperes are supplied by capacitive loads and Q for capacitive load is considered negative. Equipment on the network that considered inductive loads are: inductive reactance (XL), induction motors, welding transformer, all inductive loads, series reactance, and under excited synchronous motors. While, coactive loads on the network are: shunt capacitors, series capacitors, capacitance of transmission line, over-

excited synchronous condenser/motor, cables and transmission lines on low loads [4].

For capacitors the current leads the voltage by 90° while for inductors the current lags the voltage also by 90°. Therefore, the current of the capacitor is 180° out of phase with the current of the inductor. Figure 2. shows the waveforms of the reactive power due to connecting an inductor to an alternating source. The reactive power is composed of series positive and negative loops. The positive loops of the reactive power are corresponding to the instantaneous power delivered from the source to the inductor and the negative loops represent the instantaneous power delivered from the inductor to the source.

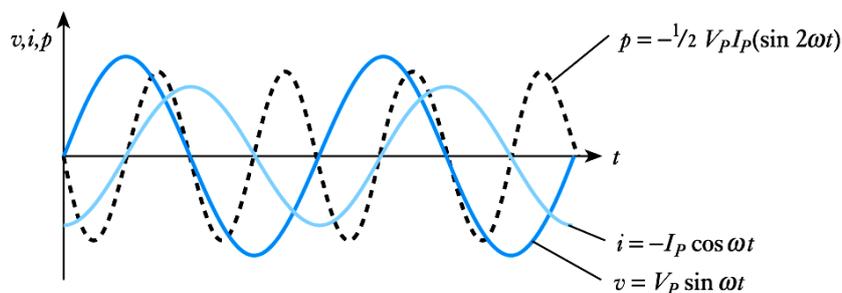


Figure 2. Instantaneous reactive power in an inductive load .

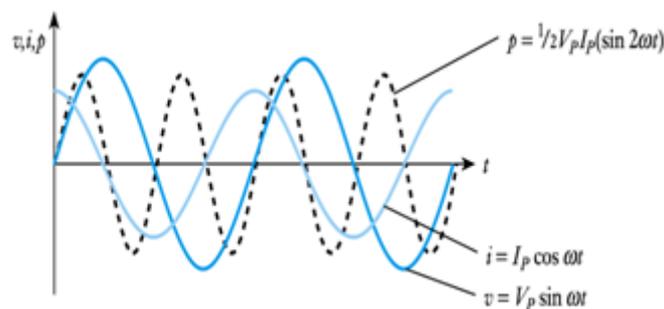


Figure 3. Instantaneous reactive power in a capacitive load .

The three types of power for single phase can be expressed as follows

$$S = I E^* \tag{1}$$

$$P = I E \cos \theta \tag{2}$$

$$Q = I E \sin \theta \tag{3}$$

The relation between these powers is expressed in (4) and shown in Fig. 4.

$$S = P \pm jQ \tag{4}$$

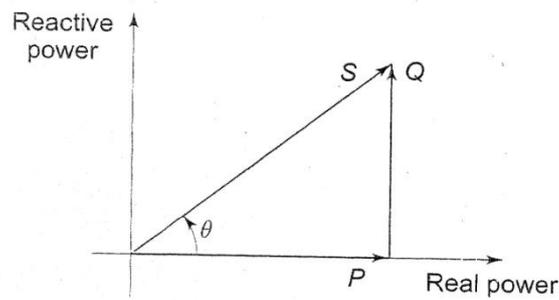


Figure 4. Phase representation of complex power for lagging power factor load

Figure 5. shows the distributed impedance of the transmission line. The transmission line in general can be represented by its lumped model as in Figure 6. The value of R, XL, and XC depends on the line length and characteristics. The series inductance reduces the line transfer capability and also results in voltage drop. The series inductance absorbs reactive power from the network and it must be supplied

through the generating power stations or supplied locally. The shunt capacitance draws a charging current or it injects reactive power to the network. Therefore, a series capacitor is added to the transmission line to supply the transmission line inductance with the reactive power it needs and a shunt inductance is added to the system to absorb the reactive power injected by the shunt capacitance.

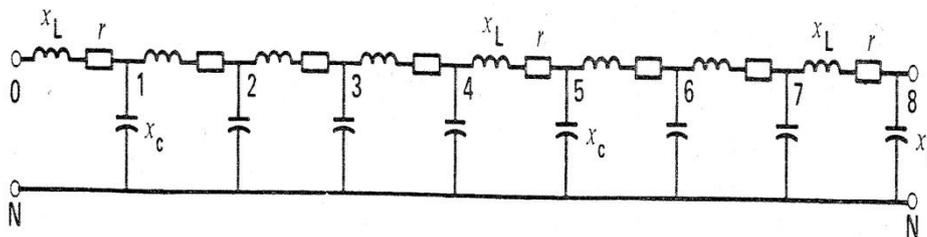


Figure 5. Distributed impedance of a transmission line.

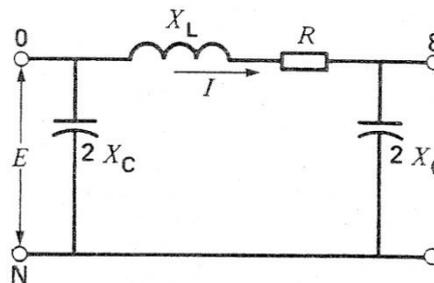


Figure 6. Equivalent lumped model of a transmission line

### III. COMPENSATION VIA POWER UNDER GROUND CABLES

The capacitance of power under ground cables is very high compared to that for the over head transmission line and that's because of the small distance between the different phases of the under ground cable. Therefore the capacitive reactance of under ground cables XC is very small compared to that of over head transmission line. While, inductive reactance of over head transmission line XL is large compared to that of the under ground cable. For our local network power under ground cables are dominant and they are more than 40000 km in length for different voltage levels. While overhead

transmission lines are just 9000 km. The effect of under ground cables capacitance during light loading of the network and the inductance of over head transmission lines during heavy loading must be considered. Table 1 shows a typical values of these impedances [5].

Table 1. Typical impedance values per kilometer for 3-phase 60 Hz Lines

Type of Line	$X_L$ ( $\Omega$ )	$X_C$ ( $\Omega$ )
Over Head Transmission Line	0.5	300000
Under Ground Cable	0.1	3000

In our local electrical net work where the climate is very hot during most of the year. The main residential consumer loads are air conditioning with a poor lagging power factor where a lot of reactive power to be absorbed by these loads in addition to the reactive power required by the inductance of the overhead transmission lines and power transformers. Therefore, the reactive power needed must be generated through the power generating stations and transmitted through the transmission and distribution stages which would result in overheating and over loading to the network components. Hence, the reactive power generated locally for the consumer loads ( residential or industrial ) by adding shunt capacitance units in the premises of the consumers. But for the reactive power required by power transformers and over head transmission lines is generated locally by under ground power cables. Normally, for the security of the electrical network and for the maintenance requirement there is at least one extra under ground power cable between two different electrical substations is available. These under ground cables normally is opened from both substations when they are not needed and connected from both sides when needed. These under ground cables if connected from on side only they will be energized and works as a capacitor and injecting reactive power to the net work. The reactive power generated from each under ground power cable depends on the voltage level and the cable length and other specifications. Therefore, in summer time where the net wok is very loaded and reactive power is needed , these under ground cables are energized by the national control center engineers and according to the reactive power compensation needed and at the place needed. Control engineer can chose between the different power cables available according to the reactive power they can inject to the network to satisfy the requirements in terms of reactive power and other variables of the network.

#### IV. COMPENSATION VIA SHUNT REACTORS

Under light or no-load conditions , charging current should be kept less than the rated full-load current of the line. The charging current is approximately given by  $BC |V|$  where  $BC$  is the total capacitive susceptance of the line and  $|V|$  is the rated voltage to neutral. If the total inductive susceptance is  $B_l$  due to several inductors connected from line to neutral at appropriate places along the line, then the charging current can be expressed as in (5)

$$I_{chg} = (BC - B_l) |V| = BC |V| (1 - B_l / BC) \quad (5)$$

Reduction of the charging current is by the factor of  $(1 - B_l / BC)$  and  $B_l / BC$  is the shunt compensation factor. Shunt compensation at no-load also keeps the receiving end voltage within limits. Thus shunt reactors should be introduced as load is removed for proper voltage control.

Shunt reactors used in our local network is composed of two types. The first type is used with conjunction of 300MVA power transformers used at the voltage level of 300KV where the main windings of the power transformer are step down 300KV/132KV and a third tertiary winding is added as 33KV to be used as a shunt reactor absorbing reactive power. The second type of shunt reactors are just a three phase primary winding and is available at different var ratings and at different voltage levels. Therefore, var compensation is carried out in the main and the interconnected substations using shunt reactors and according to the voltage level.

On the 300/132 KV substations where 300 MVA power transformers are used with three windings , the tertiary winding voltage is 33 KV and used as a shunt reactor of 45 MVAR a shown in Fig. 7.

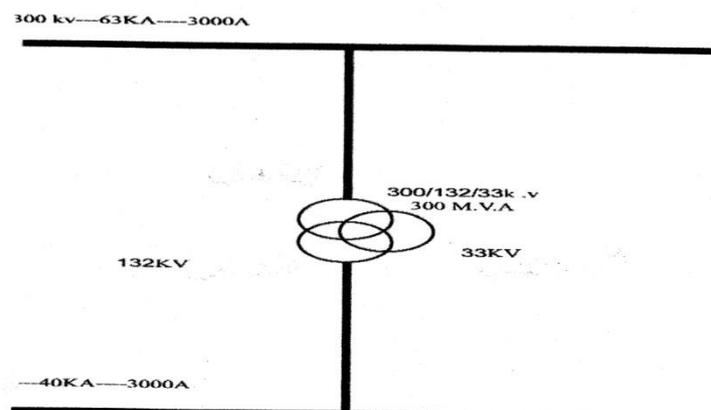


Figure 7. Shunt reactor as a tertiary winding for 300 MVA power transformer

For 300 KV long over head transmission lines a shunt reactor of 250 MVAR is installed as in Fig. 8 to compensate for the shunt capacitance of the transmission line.

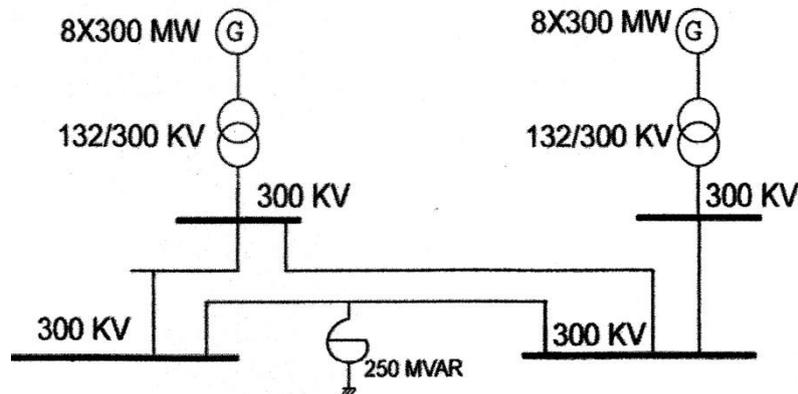


Figure 8. Shunt reactor installed for 300 KV over head transmission line .

For 132KV long over head transmission lines a 50MVAR shunt reactor is connected as shown in Fig. 9.

While for 33/11 KV substations a shunt reactor is installed as a feeder panel with a reactive power of 35 MVAR.

For 132/11 KV substations a shunt reactor is installed as a feeder panel with a reactive power of 45

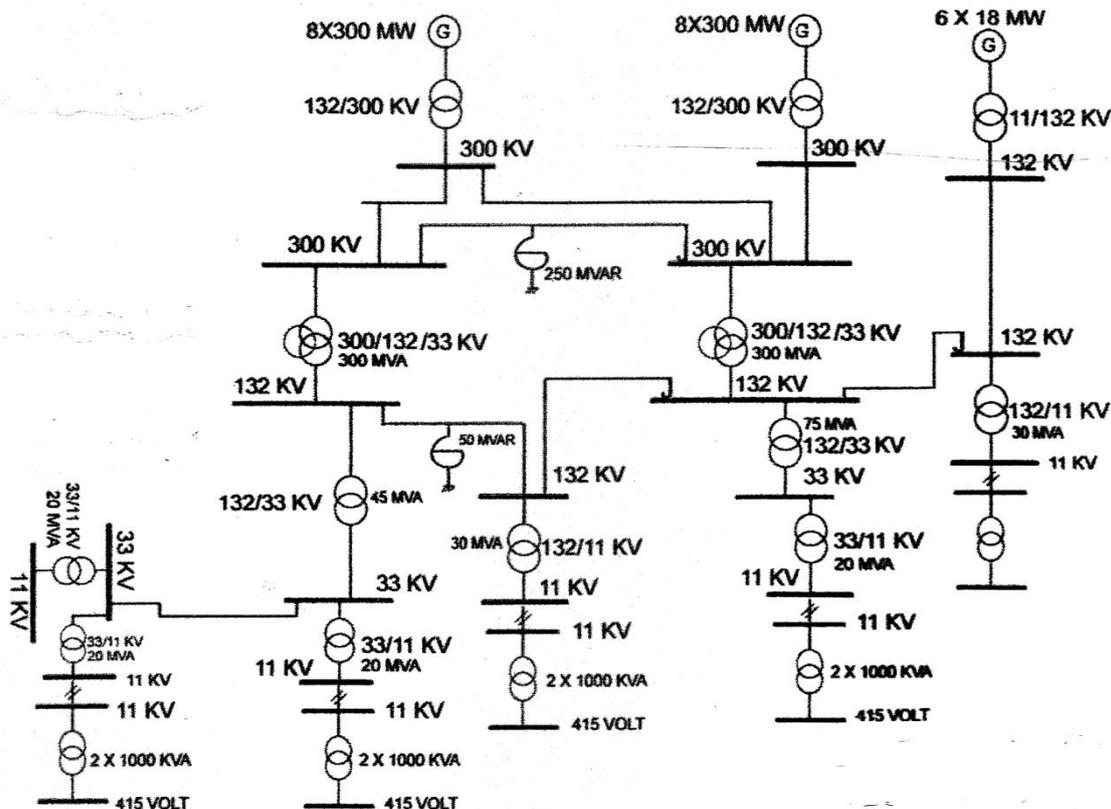


Figure 9. Different shunt reactors at different locations of the network

## V. CONCLUSION

Reactive power compensation through the basic methods shown in this paper even though they are simple in terms of control but they are effective in

terms of reactive power compensation. Harmonics resulting from thyristors used in control of modern reactive power compensators are avoided.

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