REACTIVE POWER COMPENSATION AND MANAGEMENT(BPEBO7)

I M. Tech I semester (Autonomous IARE R-18)

BY

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UNIT - I
LOAD COMPENSATION

Load Compensation

Introduction:

It is necessary to manage the reactive power to improve the power factor and the quality of supply Load compensation is the major player in it.

The main objectives in load compensation are: Improved voltage profile

- Power factor improvement
- Balanced load
- It is important to maintain the voltage profile within +-5% of the rated value.

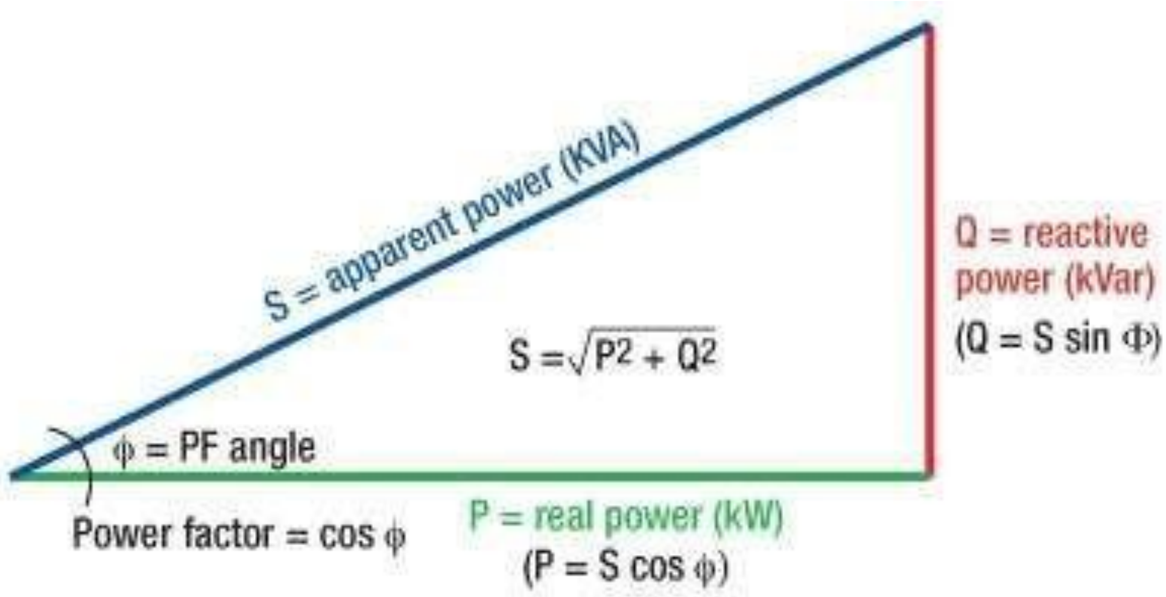
Basic concepts of power

<u>DEFINATIONS OF VARIOUS POWERS</u>

- <u>POWER</u> : POWER can be defined as the rate of flow of energy at a given point of circuit
- <u>REAL POWER</u> :The portion of power that

  ,averaged over a complete cycle of the ac waveform ,results in net transfer of energy in one direction is known as real power
- <u>Reactive power</u> : The portion of power due to stored energy , which returns to the source in each cycle is known as reactive power

Different types of power



P = true power $P = I^2R$ $P = \frac{E^2}{R}$

Measured in units of ***Watts***

Q = reactive power $Q = I^2X$ $Q = \frac{E^2}{X}$

Measured in units of ***Volt-Amps-Reactive (VAR)***

S = apparent power $S = I^2Z$ $S = \frac{E^2}{Z}$ $S = IE$

Measured in units of ***Volt-Amps***

IMPORTANCE OF REACTIVE POWER

- Voltage control in an electrical power system is very important for proper operation for electrical power equipment to prevent damage
- Decreasing reactive power causing voltage to fall while increasing it causing voltage to rise
- When reactive power supply lower voltage,

  as voltage drops current must increase to maintain power supplied , causing system to consume more reactive power which causes cascading failures

- If the voltage drops too low ,some generators will disconnect automatically to protect themselves ,these will cause additional elements of trip , leading further reduction In voltage and loss of the load
- Reactive power is essential to move active power through the transmission and distribution system to the consumer

NCESSITY TO CONTROL VOLTAGE AND REACTIVE POWER

- Three reasons :
- It must maintain adequate voltages throughout the transmission and distribution system for both current and contingency conditions
- It seeks to maintain congestion of real power flows
- It seeks to minimize real power losses

NCESSITY TO CONTROL VOLTAGE AND REACTIVE POWER

- Voltages are controlled by providing sufficient reactive power control margin to supply needs through
- 1.shunt capacitor and reactor compensations
- 2.dynamic compensation
- 3. proper voltage schedule of generation

LIMITATIONS OF REACTIVEPOWER

- Reactive power does not travel very far
- Usually necessary to produce it close to the location where it is needed
- A supplier/source close to the location of the need is In a much better position to provide reactive power versus one that is located far from the location of the need
- Reactive power supplies are closely tied to the availability to deliver real or active power

EFFECTS OF REACTIVE POWER ON POWER SYSTEM

- 1.Generation
- 2.synchronous condensors
- 3. capacitors & inductors
- 4.static var compensators (svcs)
- 5.distributed generation
- 6.transmission side

TYPES OF FACTS DEVICES

- Static VAR compensator
- Static compensator(STATCOM)
- Series compensation
- Thyristor controlled series CAPACITORS
- SSSC

INTRODUCTION OF POWER FACTOR

- What is power factor
- What causes low power factor
- Why should I improve my power factor
- How should I correct (Improve) my power factor

KW is Working Power (also called Actual Power or Active Power or Real Power). It is the power that actually powers the equipment and performs useful work.

KVA is Apparent Power. It is the "vectorial summation" of KVAR and KW.

KVAR is Reactive Power. It is the power that magnetic equipment (transformer, motor and relay) needs to produce the magnetizing flux.

What causes Low Power Factor?

What causes Low Power Factor?

Low power factor results when KW is small in relation to KVA.

Remembering our beer mug analogy, this would occur when KVAR (foam, or Mac's shoulder height) is large.

- **What causes a large KVAR in a system? The answer is…inductive loads.**
- **Transformers**
- **Induction motors**
- **Induction generators (wind mill generators)**
- **High intensity discharge (HID) lighting**

Why should I Improve my Power Factor?

Lower the Utility bill

Why should I Improve my Power Factor?

inductive loads require reactive power, caused your low power factor. This increase in required reactive power (KVAR) causes an increase in required apparent power (KVA), which is what the utility is supplying.

So, a facility's low power factor causes the utility to have to increase its generation and transmission capacity in order to handle this extra demand.

By raising your power factor, you use less KVAR. This results in less KW, which equates to savings from the utility.

- Increased system capacity and reduced system losses

By adding capacitors (KVAR generators) to the system, the power factor is improved and the KW capacity of the system is increased.

Reduces I2R losses in conductors

UNIT II

STEADYSTATE REACTIVE POWER COMPENSATION IN TRANSMISSION SYSTEM

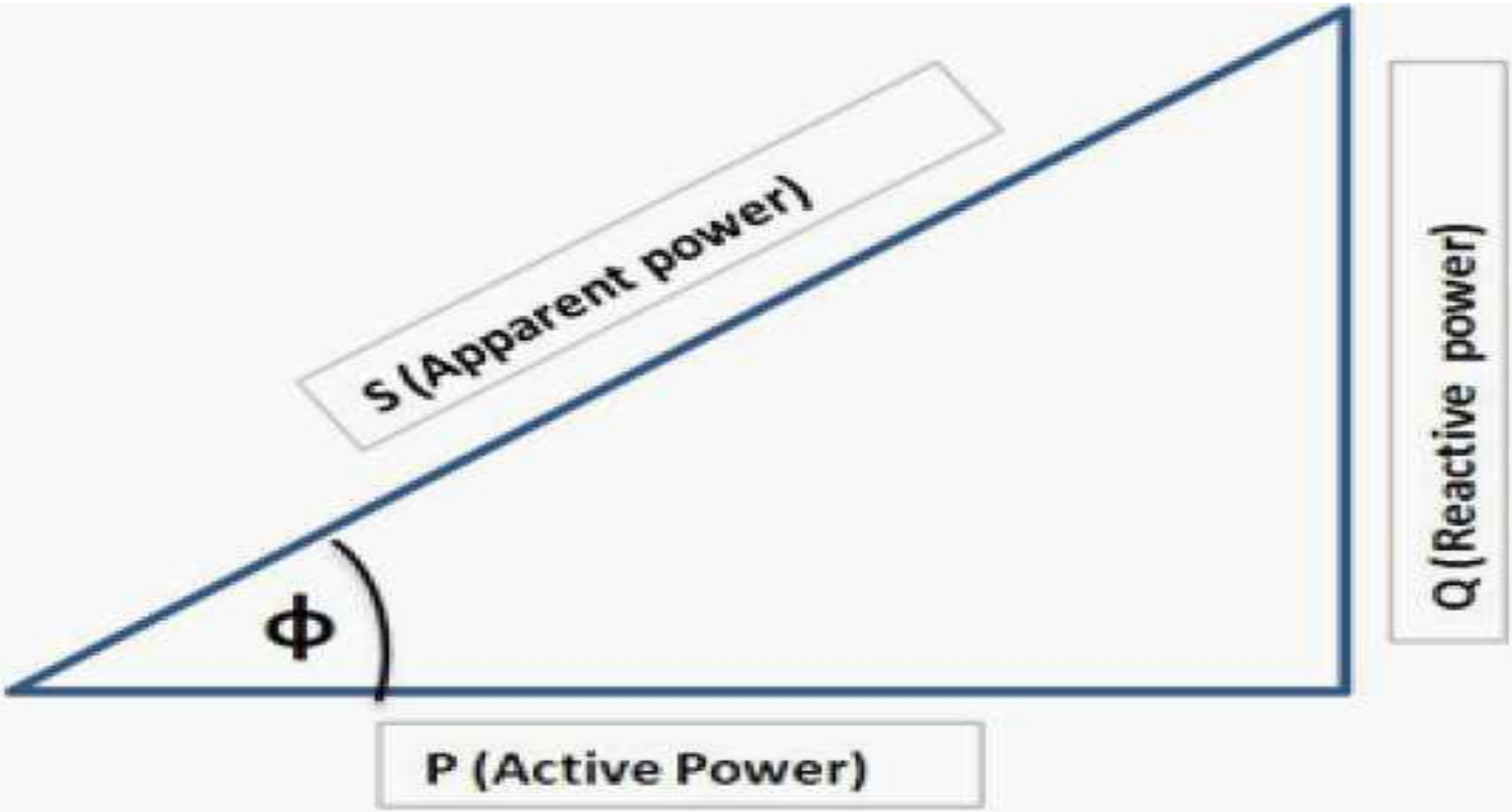
Introduction

- The demand of the reactive power is mainly originated from inductive load connected to the system .
- These inductive loads generally electromagnetic circuit of electric motors, electrical transformers, distribution networks and induction furnaces etc.
- Reactive power compensation is the defined as the management of reactive power to improve the
- performance of AC system . There are two aspects : -

  1. Load compensation

  2. Voltage support

Power traingle



ϕ is the phase angle

The cosine of ϕ gives the Power factor

- Active Power (P) : - It is the power that actuallypowers the equipment and performs useful work . Unitof it W .
- Reactive Power (Q) : - It is the power that magneticequipment{ transformer , motor etc. } needs to produce the magnetizing flux . Unit of it VAr .
- Apparent Power (S) : - It is the “ vectorial summation ” ofactive power (P) and reactive power (Q) . Unit of it VA .

Reactive Power

- The portion of power flow that is temporarily stored in the form of magnetic or electric fields , due to inductive or capacitive network element and then returned to source is known as reactive power .
- Reactive power can best be described as thequantity of “unused” power that is stored in reactive components , such as inductors or capacitors . In other words , the reactive circuit returns as muchpower to the supply as it consumes .

Why do we need reactive power

- In resistive loads the current produces the heat energy which produces the desired output but incase of inductive loads the current creates the magnetic field which further produces the desired work.
- Therefore reactive power is the non working power caused by the magnetic current to operate and sustain magnetism in the device .
- Reactive power (vars) is required to maintain the voltage to deliver active power (watts) through transmission lines.
- When there is not enough reactive power the voltage sags down and it is not possible to deliver the required power to load through the lines.

Need for reactive power compensation

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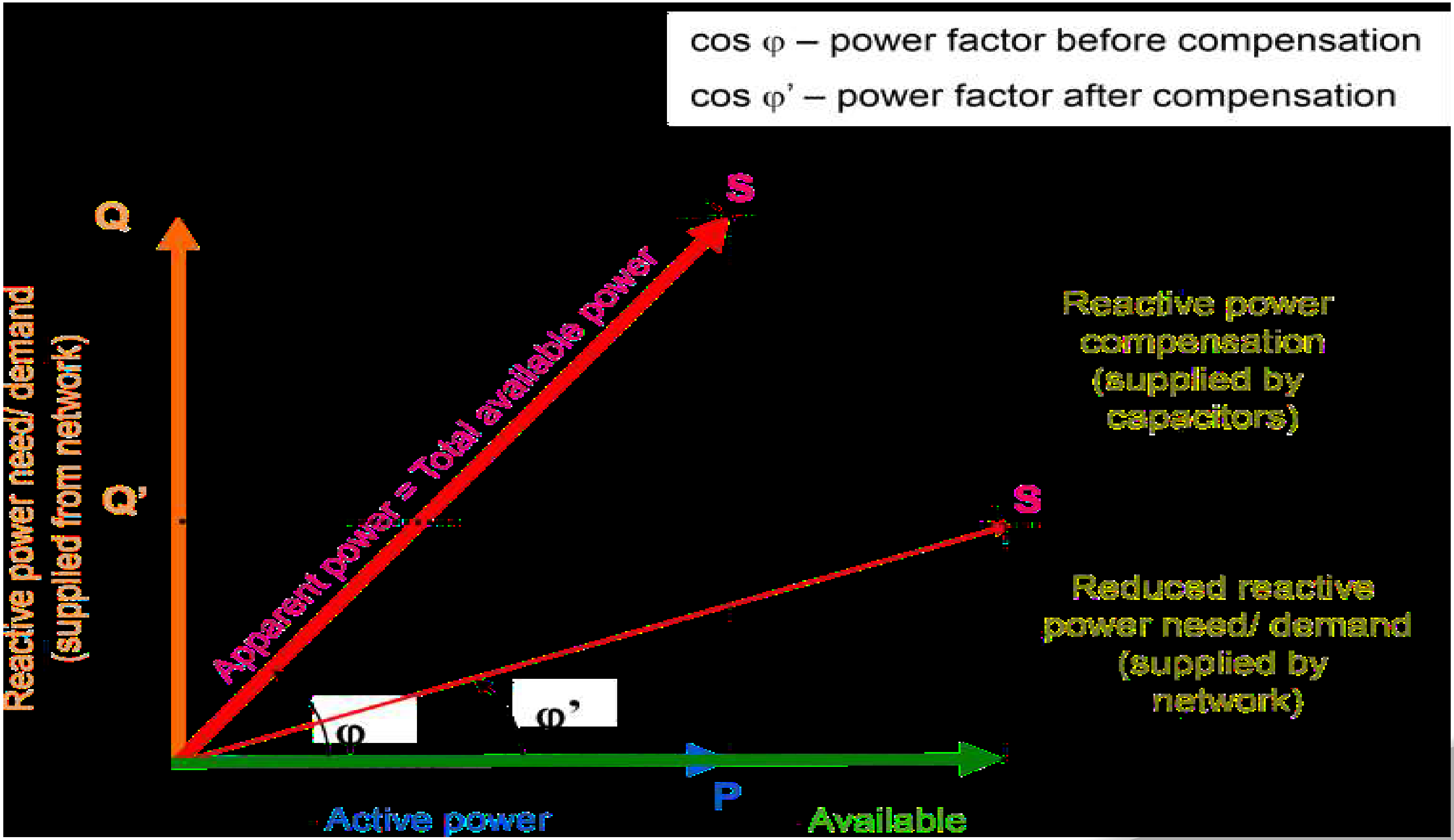
- Reactive power generated by the ac power source is stored in a reactor during a quarter of a cycle and in the next quarter of the cycle it is sent back to the power source.
- Therefore the reactive power oscillates between the ac source and the reactor at a frequency equals to two times the rated value (50 or 60 Hz). So to avoid the circulation between the load and source it needs to be compensate t o improve system power factor .

- Reduce losses associated with the system .
- Improves the voltage regulation in the network .
- Increased system stability .
- Reactive power levels have an effect on voltage
- collapse .

compensation



Compensation Techniques

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- Synchronous Condenser
- Shunt Compensation
- Series Compensation

Synchronous Condenser

- Synchronous condensers are the active shunt compensators and have been used to improve the voltage profile and system stability . It is installed at the receiving end of the line .
- When machine is overexcited , it acts as shunt capacitor as it supplies VAr to the system and when under excited it acts as a shunt coil as it absorbs reactive power to maintain terminal voltage.

Shunt Compensation

- The device that is connected in parallel with the transmission line for reactive power compensation is called the shunt compensator
- It can be provided by either a current source, voltage source or a capacitor.If $XC = 1/\omega C$ be the reactance of the shunt capacitorthen the reactive power generated of leading VAr

Transmission line with shunt compensation

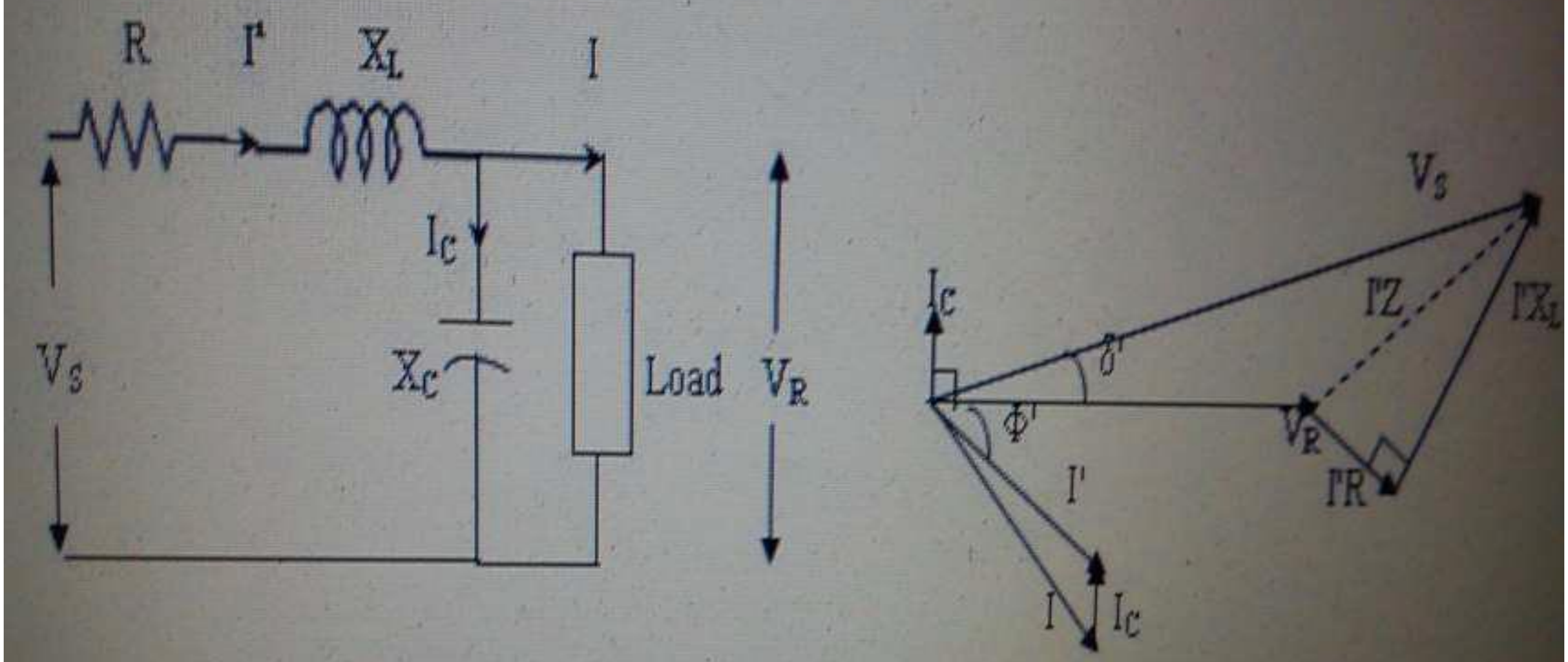


Figure 3: Single-line diagram of a shunt compensated transmission line and its phasor diagram.

Series Compensation

- Capacitor are connected in series in the lines and are used mainly for boosting the receiving end voltage, increase in transmission capacity and reduction in losses in the lines .
- The capacitive reactance of series capacitor neutralizes the inductive reactance of the line hence ,reduces effective reactance of the line. Thereby , voltage regulation of the system is improved .

Transmission line with series compensation

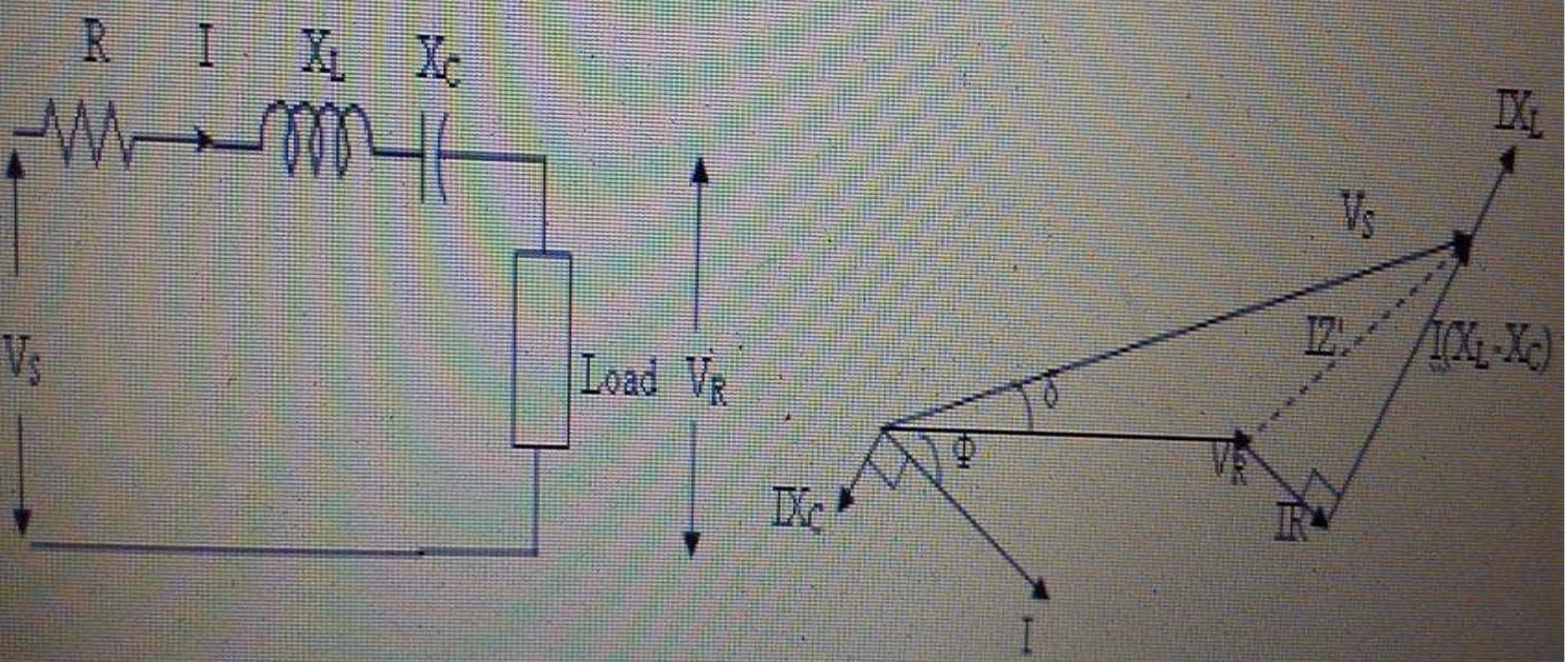


Figure 4: Single-line diagram of a series compensated transmission line and its phasor diagram.

VOLTAGE WAVEFORM

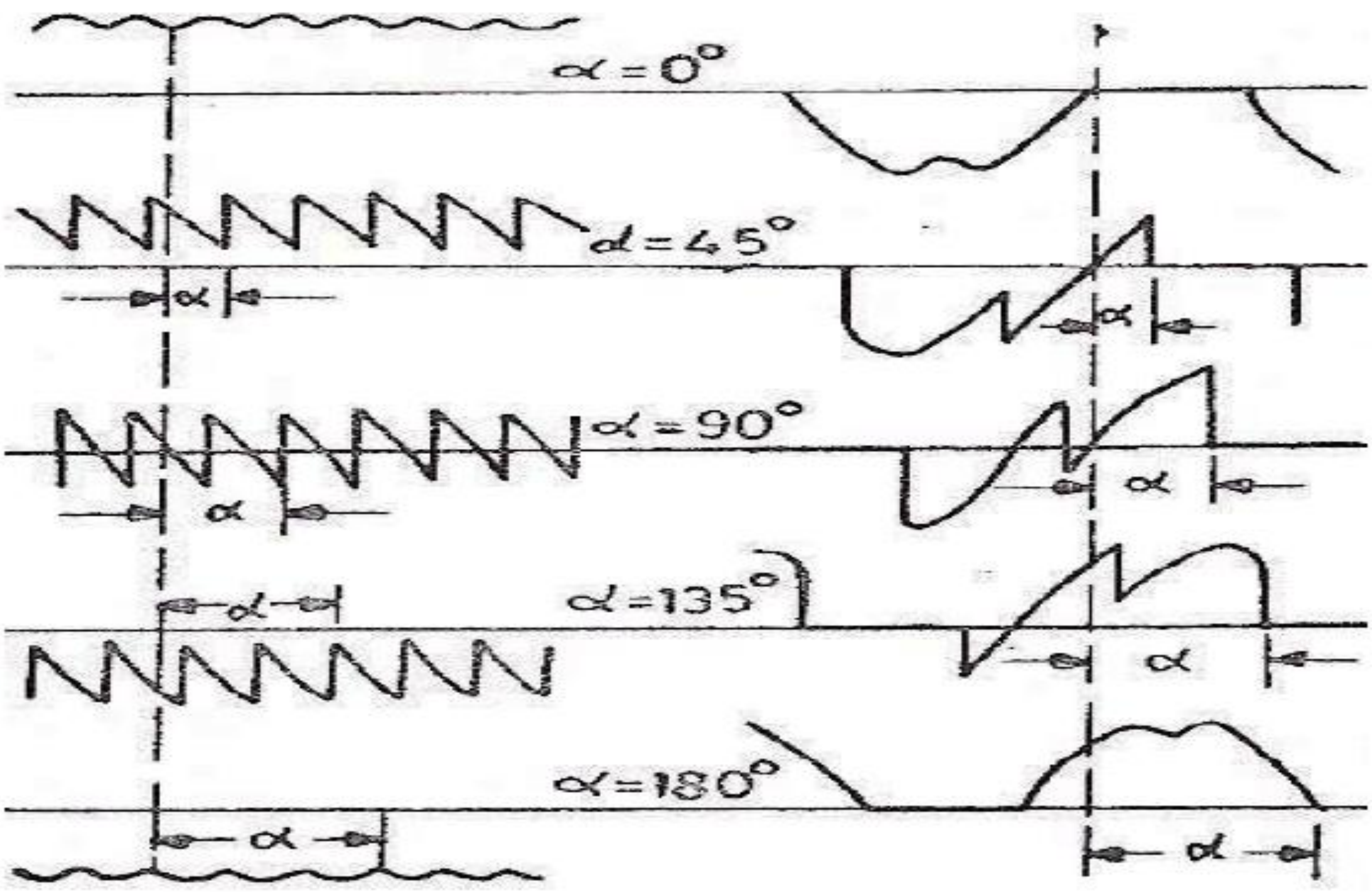


Fig 9: Thyristor voltage waveforms

UNIT III

REACTIVE POWER COORDINATION

Control objectives contributing to efficient an reliable operation of power system:

- Voltage at terminals of all equipment are within acceptable limits
  - both utility and customer equipment designed to operate at certain voltage rating
  - prolonged operation outside allowable range could cause them damage

- System stability is satisfactory
  - voltage levels and reactive power control have significant impact on stability

- The reactive power flow is minimized so as to reduce I^2R and I^2X losses to a practical minimum
- ensures transmission system operates efficiently

Production and Absorption of Reactive Power (Q)

- Synchronous Generators
  - can generate or absorb Q depending on excitation
  - capability limited by field current, armature current, and end-region heating limits
  - automatic voltage regulator continuously adjusts excitation to control armature voltage
  - primary source of voltage support!

- Overhead lines
  - at loads below natural or surge impedance load (SIL), produce Q
  - at loads above SIL, absorb Q

Production and Absorption of Q

- Transformers
  - absorb Q due to shunt magnetizing reactance and series leakage inductance
- Loads
  - a typical "load bus" is composed of a large number of devices
  - composite characteristics are normally such that a load bus absorbs Q
  - industrial loads usually have shunt capacitors to improve power factor

Methods of Voltage Control

- **Control of voltage levels is accomplished by controlling the production, absorption, and flow of reactive power at all levels in the system**

- **Generating units provide the basic means of voltage control**

Methods of Voltage Control

- Shunt capacitors and reactors, and series capacitors provide passive compensation
  - are either permanently connected to the transmission and distribution system, or switched
  - contribute to voltage control by modifying the network characteristics
- Synchronous condensers and SVCs provide active compensation; the reactive power absorbed/ supplied by them are automatically adjusted so as to maintain voltages of the buses to which they are connected

Objectives of Reactive Power Compensation

To control voltage and/or improve maximum power transfer capability

Shunt Reactors

- Used to compensate the undesirable voltage effects associated with line capacitance
  - limit voltage rise on open circuit or light load
- Shunt compensation with reactors:

Shunt Capacitors

- Used in transmission systems to compensate for I^2X losses
- Connected either directly to H.V. bus or to tertiary winding of transformers
- Normally distributed throughout the system so as to minimize losses and voltage drops
- Usually switched: a convenient means of controlling voltage
- Shunt capacitor compensation of transmission lines in effect
  - decreases Z_C
  - increases θ, i.e., electrical length
- Advantages: low cost and flexibility of installation and operating

Series Capacitors

- Connected in series with the line
- Used to reduce effective inductive reactance of line
  - increases maximum power
  - reduces I^2X loss
- Series capacitive compensation in effect reduces both:
  - characteristic impedance Z_C, and
  - electrical length θ
- Reactive power produced increases with increasing power transfer
  - Self regulating !

Synchronous Condenser

- A synchronous machine running without a prime mover or a mechanical load
- Depending on field excitation, it can either absorb or generate vars
- With a voltage regulator, it can automatically adjust vars to maintain constant voltage
- Started as an induction motor and then synchronized
- Normally connected to tertiary windings of transformers
- Unlike a SVC, a synchronous condenser has an internal voltage

Static VAR Compensators (SVC)

- Shunt connected static var generators and/or absorbers whose outputs are varied so as to control specific power system quantities

- The term static is used to denote that there are no moving or rotating components

- Basic types of SVCs:
  - thyristor-controlled reactor
  - thyristor-switched capacitor
  - saturated reactor

UNIT IV

DEMAND SIDE MANAGEMENT

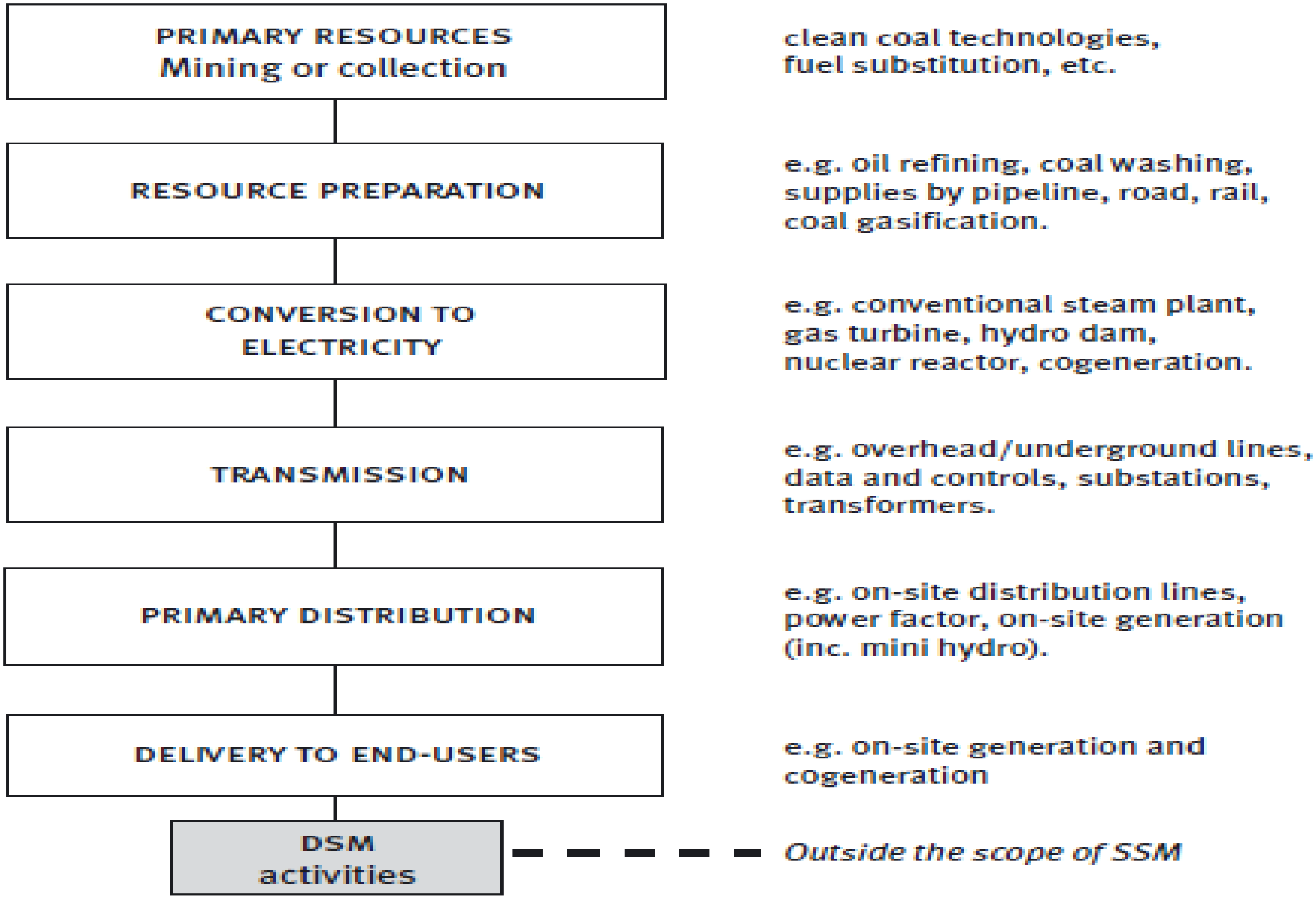
Supply side management:

- Supply-side management (SSM) refers to actions taken to ensure the generation, transmission and distribution of energy are conducted efficiently.
- This has become especially important with the deregulation of the electricity industry in many countries, where the efficient use of available energy sources becomes essential to remain competitive.
- Utility companies may look at means of modifying their load profile to allow their least efficient generating equipment to be used as little as possible.

Why it is necessary?

- To Ensure sustained availability of reliable energy
- To Meet increasing electricity demand
- To reduce environmental impact of energy production and supply

Supply side measures



Resources and resource preparation

1.Clean coal technology

2.Fuel substitution

1.Proper maintenance

2.Data and performance monitoring

3. Combustion control

4.Upgradation of generation unit

Transmission and distribution

1.Transmission lines

2.Data monitoring and control

3. Load aggregation

4. Facts

Important devices power transmission involving FACTS and Power Quality devices:

- SVC (Static Var Compensators),
- Thyristor-Controlled Series Capacitors (TCSC) and Statcom.
- PST (Phase-shifting Transformers),
- IPC (Interphase Power Controllers),
- UPFC (Universal Power Flow Controllers),
- and DVR (Dynamic Voltage Restorers).

Demand Side management

- It is also called as **Energy Demand Management.**
- The modification of consumer demand for energy through various methods such as financial incentives and education is termed as **Demand Side Management.**
- The main goal of demand side management is to **encourage the consumer to use less energy during peak hours, or to move the time of energy use to off-peak times such as night time and weekends.**

- **Definition - DSM (Demand Side Management) is the 'Scientific control of usage and demand of Electricity, for achieving better load factor and economy, by the Licensee/Supplier'.**

Benefits of Demand Side Management

Customer Benefits	Utility Benefits	Social Benefits
Satisfy electricity demands	Lower cost of service	Reduce environmental degradation
Reduce / stabilize costs or electricity bill	Improve operating efficiency, Flexibility	Conserve resources
Maintain/improve productivity	Improve customer service	Protect global environment

The barriers for DSM

i) Monopoly power market structure.

- ii) No competition which leads to traditional and inefficient tariff structure.
- iii) Lack of creating awareness among consumers about the efficient use of energy.
- iv) Lack of energy efficient environment.
- v) Huge gap between supply and demand of energy.
- vi) Lack of proper incentive schemes to consumer on using energy efficient appliances and utility to implement DSM solutions.
- vii) Power system reliability, quality and stability is not able to keep itself in standard position.

Implementation of DSM

- **Initiative from the consumer side is very important for successful DSM**

- The scope of DSM includes

1. Load shifting/ Load management

2. Energy conservation

3. Increased electrification

Planning & Implementation of DSM

1.Develop end-use Demand forecasting

- **Forecasting by end-use is an essential pre-requisite for effective DSM planning and implementation.**
- Mid- and long-term forecasts of **power demand variations play a very important role in the development of a DSM programme.**
- **Demand forecasting is an exercise that every electricity-generating company should carry out regularly in order to assess its future equipment requirements.**

Planning & Implementation of DSM

2. Undertake Load/ Market Research to identify end-use patterns and market barriers

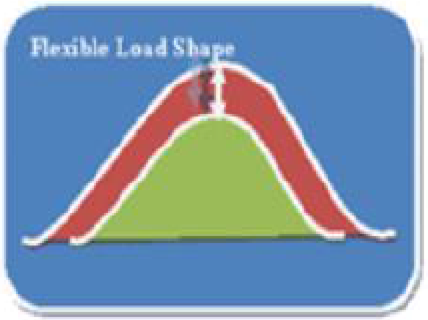
- To design effective DSM programmes it is important to know **how electricity is used and what barriers are preventing customers from using efficient technologies.**
- Load research should be undertaken to estimate load curves for each sector or region, using **local sub-metering, customer bill analysis and customer surveys.**
- Major areas of interest to **DSM programmes include the residential, commercial, industrial, and public utility sectors.**
- Market research is needed to understand the target market, **identify barriers and evaluate possible solutions.**

Planning & Implementation of DSM

Strategic conservation

strategic growth

flexible load shape



- The reduction of utility load, more or less equally, during all or most hours of the day
- Non traditional approaches to load management

- The INCREASE of utility load
- Load-shape change which refers to overall increase in sales

- The interruptible agreements by utility to alter customer energy consumption on an as-needed basis

Planning & Implementation of DSM

4. Identify target sectors, end-uses, and measures

- The **collected information is normally useful in determining a typical load curve for each end-use.**
- Find out load-curve management objectives
- **Choose sectors and end-uses that account for the largest power consumption and peak loads, or will do so in the future.**
- Select DSM measures which will have the largest impact on peak demand and electricity use.

5. Identify sources of financing

- In any DSM programme, **financing is needed for individual projects undertaken by participants.**
- Utilities may also require financing to cover administrative costs and cost sharing investments.
- Government/public fund is required.

6. Review Cost Sharing and Viability Options

- Cost sharing in a DSM programme should **try to maximize viability for each partner (participant, utility, and government).**
- The **wider the differences between tariffs, the higher the utility investment can be, which in turn leads to a higher participation rate.**

7. Programme Selection and Design

- **Identifying a list of programmes for each customer class.**
- **Formation of brief report corresponding to that program**
- Uniform reporting format is required.

8. DSM Cost/Benefit Analysis

- Based on the case study /measurement
- Calculation of financial interest

9. Identify Local Socio-Economic and Environmental Impacts

- Most DSM programmes provide **indirect economic and environmental benefits as well as reducing emissions and other impacts from power supply facilities.**
- Eg. employment is created in the energy services industry

UNIT V

USER SIDE REACTIVE POWER

Methods of voltage control:

Control of voltage and reactive power should satisfy the followingobjectives:

1. Voltages at the terminals of all equipment in the system arewithin acceptable limits.
2. System stability is enhanced to maximize utilization of thetransmission system. Voltage and reactive power control havea significant impact on system stability.

- A. Sources or sinks of reactive power, such as shunt capacitors, shunt reactors, synchronous condensers, and static var compensators (SVCs).B. Line reactance compensators, such as series capacitors. C. Regulating transformers, such as tap-changing transformers and boosters.
- Shunt capacitors and reactors, and series capacitors provide passive compensation. They are either permanently connected to the transmission and distribution system, or switched. They contribute to voltage control by modifying the networkcharacteristics.
- Synchronous condensers and SVCs provide activecompensation; the reactive power absorbed/supplied bythem is automatically adjusted so as to maintain voltagesof the buses to which they are connected.

Shunt capacitor

- Shunt capacitors supply reactive power and boost local voltages.
- They are used throughout the system and are applied in a wide range of sizes
- The principal advantages of shunt capacitors are their low costand their flexibility of installation and operation.

- The principal disadvantage of shunt capacitors is that their
- reactive power output is proportional to the square of the voltage.
- The reactive power output is reduced at low voltages when it is likelyto be needed most.

Application of Tap-Changing Transformers to Transmission Systems

- Transformers with tap-changing facilities constitute an importantmeans of controlling voltage throughout the system at all voltagelevels.
- The taps on transformers provide a convenient means of controlling reactive power flow between subsystems.
- Coordinated control of the tap changers of all the transformers interconnecting the subsystems is required if the general level of voltage is to be changed.
- During high system load conditions, the network voltages are kept at the highest practical level to minimize reactive power requirements and increasethe effectiveness of shunt capacitors and line charging.

- During light load conditions, it is usually required to lower the networkvoltages to reduce line charging and avoid under excited operation of generators.
- Transformers with off-load tap-changing facilities can also help maintainsatisfactory voltage profiles.
- While transformers with ULTC can be used to take care of daily, hourly,and minute-by-minute variations in system conditions, settings of off-loadtap-changing transformers have to be carefully chosen depending on long-term variations due to system expansion, load growth, or seasonal changes.

THANK YOU