



Synchronization/Power Factor Correction

- ❖ ERCOT area of Texas

This Power Point Presentation was created by:

Joseph David Clement Fournier B.Sc.E.E., M.Sc.E.E.
President and Senior Engineer of AscenTrust, LLC.
Website: <http://ascentrust.com>

Synchronization/Power Factor Correction

❖ Preamble

This Power Point Presentation is primarily an introduction to the Synchronization Project which is being proposed by the Senior Engineer of **AscenTrust, LLC**.

The single and most important reason this project is possible is because the **GRID** in Texas is not under the control of any of the Federal Regulators at FERC and NERC.

This presentation will outline some of the significant problems which have been introduced to the Texas GRID with the passing of the CREZ (Competitive Renewable Energy Zone) initiative by the Texas Legislature in 2005.

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❖ Presentation Index

This Power Point Presentation consists of the following Sections:

1. Resonance
2. Resonance in RLC Circuits
3. Resonance in turbomachines
4. Introduction to Three Phase networks
5. Fourier Transform of a Square Pulse
6. Introduction to transmission Systems
7. Introduction to Series Compensation
8. Introduction to Subsynchronous Resonance
9. SSI in ERCOT

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- ❖ Part One: Resonance: #One

- ❖ **Resonance** describes the phenomenon of increased amplitude that occurs when the frequency of a periodically applied force (or a Fourier component of it) is equal or close to a natural frequency of the system on which it acts. When an oscillating force is applied at a **resonant frequency** of a dynamic system, the system will oscillate at a higher amplitude than when the same force is applied at other, non-resonant frequencies.

- ❖ Frequencies at which the response amplitude is a relative maximum are also known as **resonant frequencies** or **resonance frequencies** of the system. Small periodic forces that are near a resonant frequency of the system have the ability to produce large amplitude oscillations in the system due to the storage of vibrational energy.

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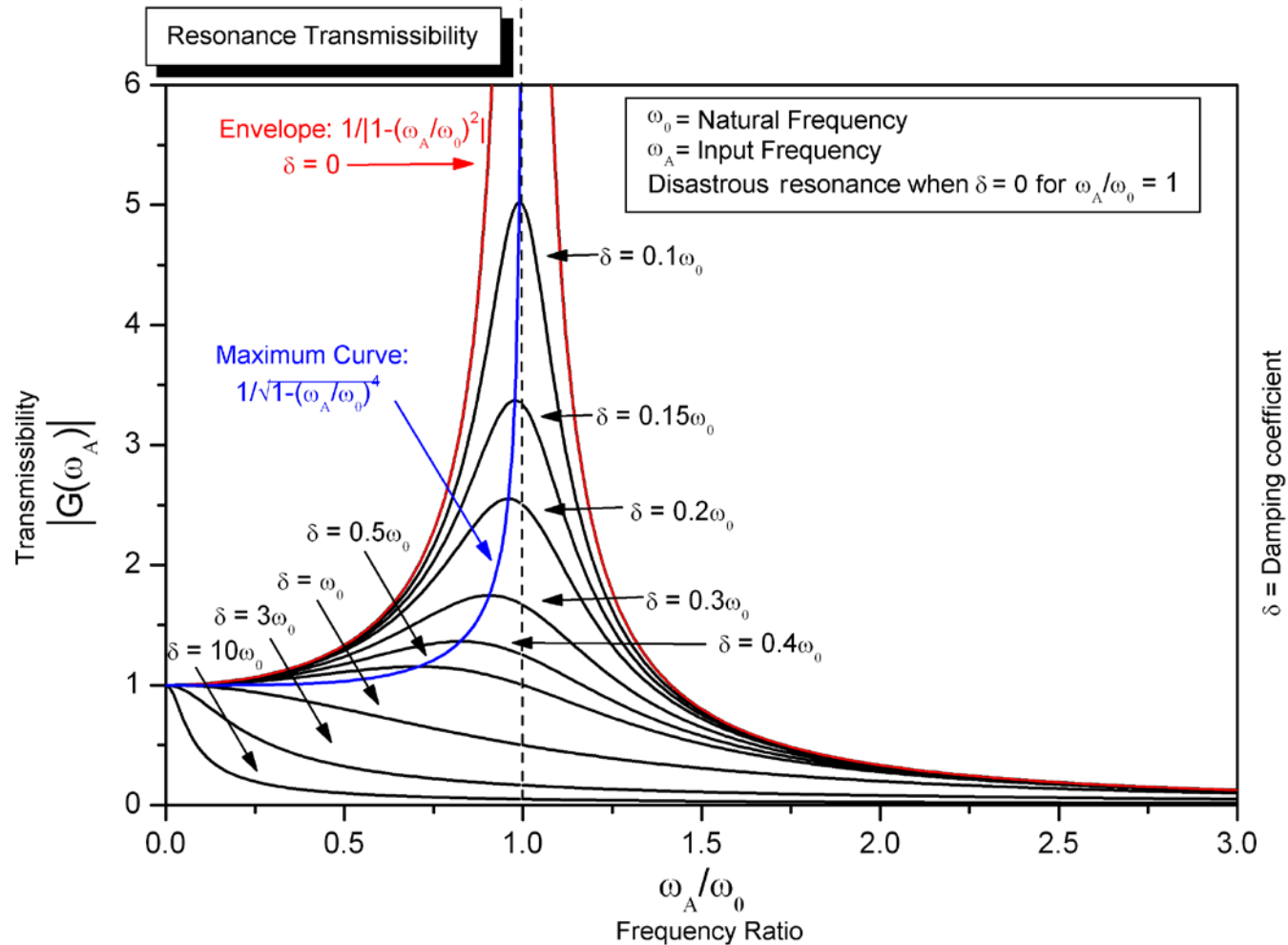


❖ Part One: Resonance: #Two

- ❖ The Resonance phenomena with which we are mainly interested in our Synchronization Project is called Sub-synchronous Resonance.
- ❖ This type of resonance occurs in High Voltage Transmission lines that are specifically built to transfer large amounts of power from renewable sources.
- ❖ Renewable power plants have very poor power factor.
- ❖ To mitigate this power factor problem Series Capacitance is installed on the High Voltage Transmission Line to improve the Power Factor of the line.

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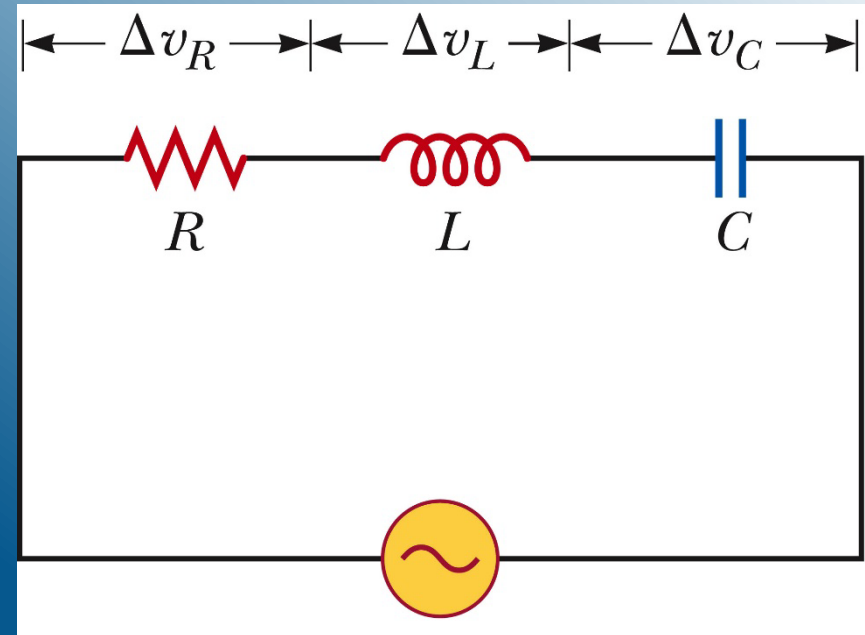
❖ Part One: Resonance: #Three



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❖ Part Two: Resonance in RLC Circuits-1

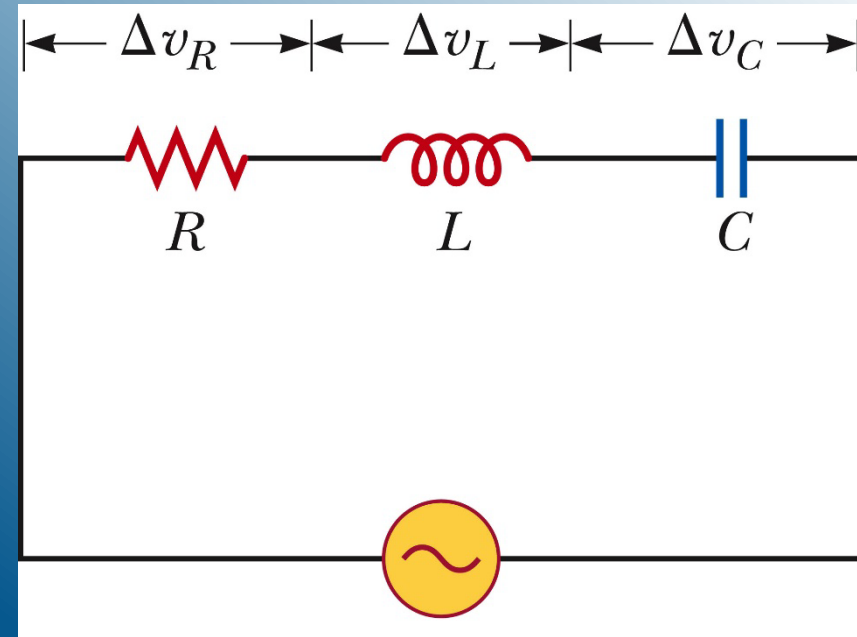
- ❖ The resistor, inductor, and capacitor are the most important passive circuit elements in Electronics.
- ❖ The resistor, inductor, and capacitor can be combined in a circuit.
- ❖ The current and the voltage in the circuit vary sinusoidally with time.



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❖ Part Two: Resonance in RLC Circuits-2

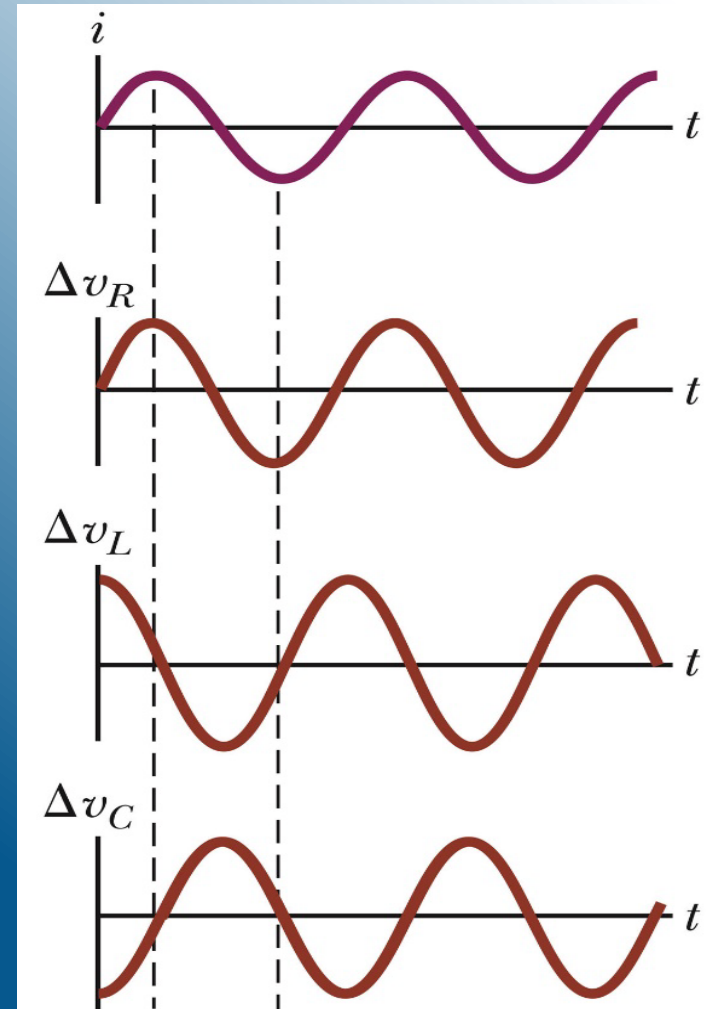
- ❖ The instantaneous voltage would be given by $\Delta v = \Delta V_{max} \sin \omega t$.
- ❖ The instantaneous current would be given by $i = I_{max} \sin (\omega t - \varphi)$.
 - ❖ φ is the **phase angle** between the current and the applied voltage.
- ❖ Since the elements are in series, the current at all points in the circuit has the same amplitude and phase.



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❖ Part Two: Resonance in RLC Circuits-3

- ❖ The instantaneous voltage across the resistor is in phase with the current.
- ❖ The instantaneous voltage across the inductor leads the current by 90° .
- ❖ The instantaneous voltage across the capacitor lags the current by 90° .

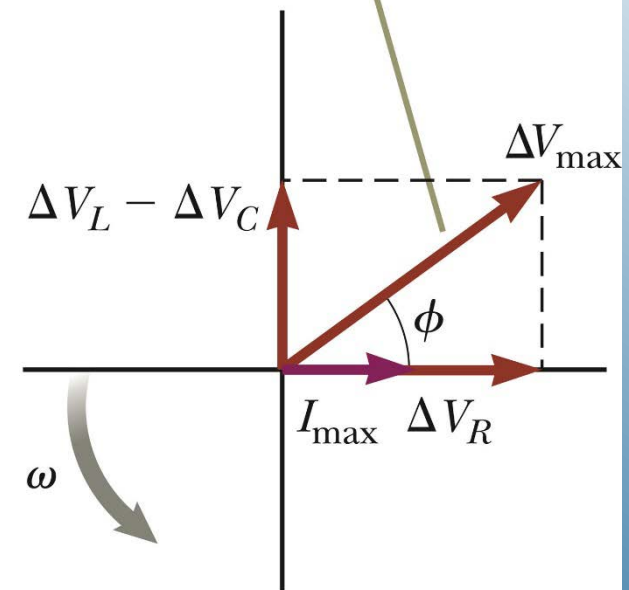


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❖ Part Two: Resonance in RLC Circuits-4

- ❖ Vector addition is used to combine the voltage phasors.
- ❖ ΔV_L and ΔV_C are in opposite directions, so they can be combined.
- ❖ Their resultant is perpendicular to ΔV_R .
- ❖ The resultant of all the individual voltages across the individual elements is ΔV_{max} .
- ❖ This resultant makes an angle of ϕ with the current phasor I_{max} .

The total voltage ΔV_{max} .
Makes an angle of ϕ with
the current phasor I_{max}



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❖ Part Two: Resonance in RLC Circuits-5

The instantaneous voltage across each of the three circuit elements can be expressed as

$$\Delta v_R = I_{\max} R \sin \omega t = \Delta V_R \sin \omega t$$

$$\Delta v_L = I_{\max} X_L \sin \left(\omega t + \frac{\pi}{2} \right) = \Delta V_L \cos \omega t$$

$$\Delta v_C = I_{\max} X_C \sin \left(\omega t - \frac{\pi}{2} \right) = -\Delta V_C \cos \omega t$$

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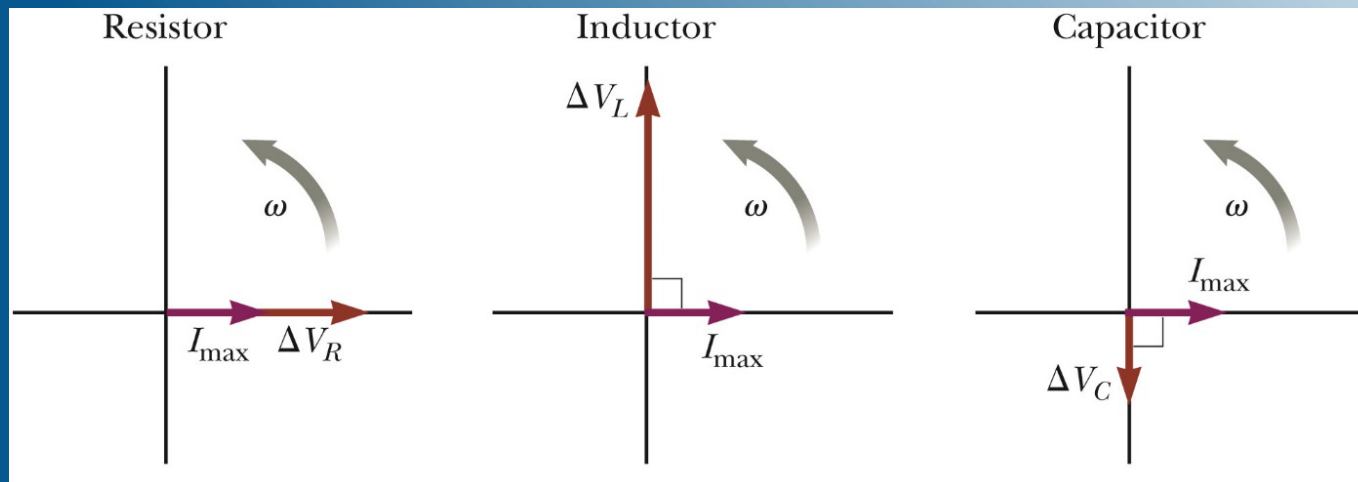
❖ Part Two: Resonance in RLC Circuits-6

Characteristics of Voltage in RLC Circuits

- ❖ ΔV_R is the maximum voltage across the resistor and
$$\Delta V_R = I_{\max} R.$$
- ❖ ΔV_L is the maximum voltage across the inductor and
$$\Delta V_L = I_{\max} X_L.$$
- ❖ ΔV_C is the maximum voltage across the capacitor
and
$$\Delta V_C = I_{\max} X_C.$$
- ❖ The sum of these voltages must equal the voltage from the AC source.
- ❖ Because of the different phase relationships with the current, they cannot be added directly.

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❖ Part Two: Resonance in RLC Circuits-7



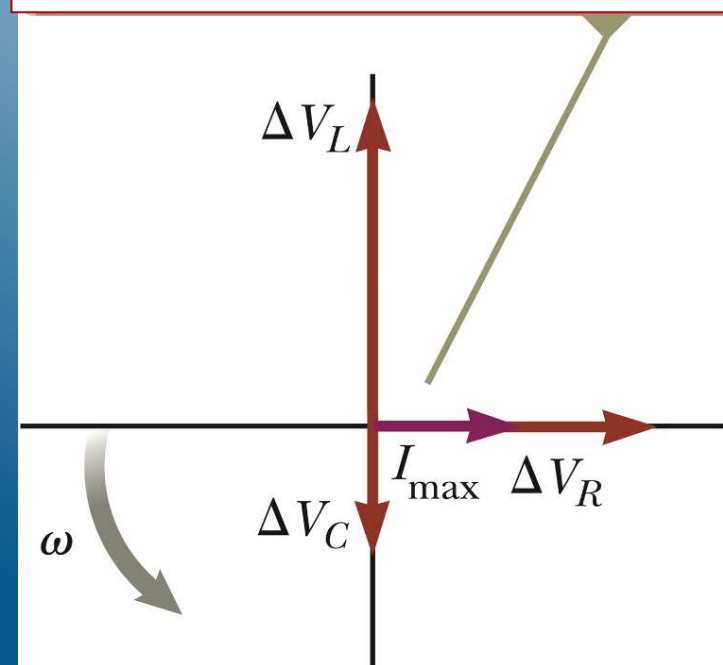
- ❖ To account for the different phases of the voltage drops, vector techniques are used.
- ❖ Remember the phasors are rotating vectors
- ❖ The phasors for the individual elements are shown.

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❖ Part Two: Resonance in RLC Circuits-8

- ❖ The individual phasor diagrams can be combined.
- ❖ Here a single phasor I_{\max} is used to represent the current in each element.
 - ❖ In series, the current is the same in each element.

The current and voltage phasors are combined on a single set of axes.

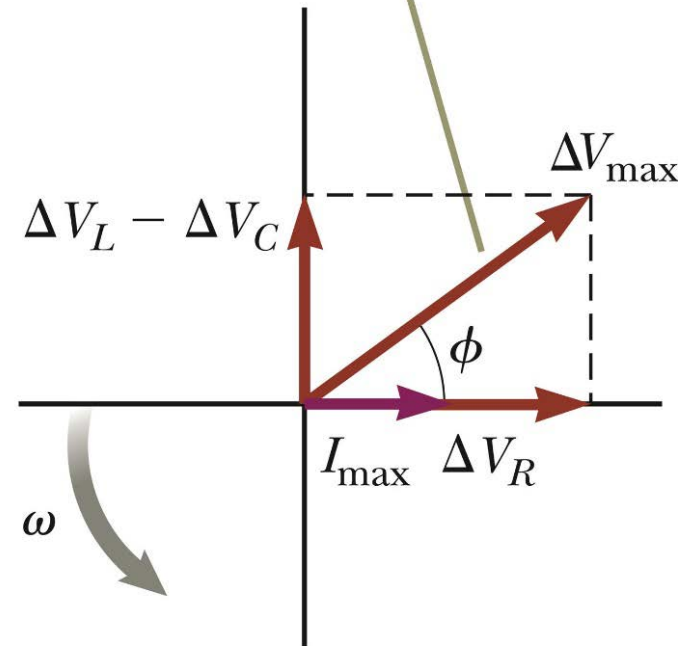


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❖ Part Two: Resonance in RLC Circuits-9

- ❖ Vector addition is used to combine the voltage phasors.
- ❖ ΔV_L and ΔV_C are in opposite directions, so they can be combined.
- ❖ Their resultant is perpendicular to ΔV_R .
- ❖ The resultant of all the individual voltages across the individual elements is Δv_{max} .
- ❖ This resultant makes an angle of ϕ with the current phasor I_{max} .

The total voltage Δv_{max} makes an angle of ϕ with I_{max}



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❖ Part Two: Resonance in RLC Circuits-10

❖ The current in an *RLC* circuit is

$$I_{\max} = \frac{\Delta V_{\max}}{\sqrt{R^2 + (X_L - X_C)^2}} = \frac{\Delta V_{\max}}{Z}$$

❖ Z is called the impedance of the circuit and it plays the role of resistance in the circuit, where

$$Z \equiv \sqrt{R^2 + (X_L - X_C)^2}$$

❖ Impedance has units of ohms

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❖ Part Two: Resonance in RLC Circuits-11

- ❖ The right triangle in the phasor diagram can be used to find the phase angle, ϕ .

$$\phi = \tan^{-1} \left(\frac{X_L - X_C}{R} \right)$$

- ❖ The phase angle can be positive or negative and determines the nature of the circuit.
- ❖ The phase angle in transmission lines is referred to as the Power Factor

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❖ Part Two: Resonance in RLC Circuits-12

- ❖ If ϕ is positive
 - ❖ $X_L > X_C$ (which occurs at high frequencies)
 - ❖ The current lags the applied voltage.
 - ❖ The circuit is *more inductive than capacitive*.
- ❖ If ϕ is negative
 - ❖ $X_L < X_C$ (which occurs at low frequencies)
 - ❖ The current leads the applied voltage.
 - ❖ The circuit is *more capacitive than inductive*.
- ❖ If ϕ is zero
 - ❖ $X_L = X_C$
 - ❖ The circuit is *purely resistive*.

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❖ Part Two: Resonance in RLC Circuits-13

- ❖ The average power delivered by the AC source is converted to internal energy in the resistor.
 - ❖ $P_{\text{avg}} = \frac{1}{2} I_{\text{max}} \Delta V_{\text{max}} \cos \phi = I_{\text{rms}} \Delta V_{\text{rms}} \cos \phi$
 - ❖ $\cos \phi$ is called the power factor of the circuit
- ❖ We can also find the average power in terms of R.
 - ❖ $P_{\text{avg}} = I_{\text{rms}}^2 R$
- ❖ When the load is purely resistive, $\phi = 0$ and $\cos \phi = 1$
 - ❖ $P_{\text{avg}} = I_{\text{rms}} \Delta V_{\text{rms}}$

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❖ Part Two: Resonance in RLC Circuits-14

- ❖ The average power delivered by the source is converted to internal energy in the resistor.
- ❖ No power losses are associated with pure capacitors and pure inductors in an AC circuit.
 - ❖ In a capacitor, during one-half of a cycle, energy is stored and during the other half the energy is returned to the circuit and no power losses occur in the capacitor.
 - ❖ In an inductor, the source does work against the back emf of the inductor and energy is stored in the inductor, but when the current begins to decrease in the circuit, the energy is returned to the circuit.
- ❖ The power delivered by an AC circuit depends on the phase.
- ❖ Some applications include using capacitors to shift the phase to heavy motors or other inductive loads so that excessively high voltages are not needed.

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❖ Part Two: Resonance in RLC Circuits-15

- ❖ *Resonance* occurs at the frequency ω_0 where the current has its maximum value.
 - ❖ To achieve maximum current, the impedance must have a minimum value.
 - ❖ This occurs when $X_L = X_C$
 - ❖ Solving for the frequency gives

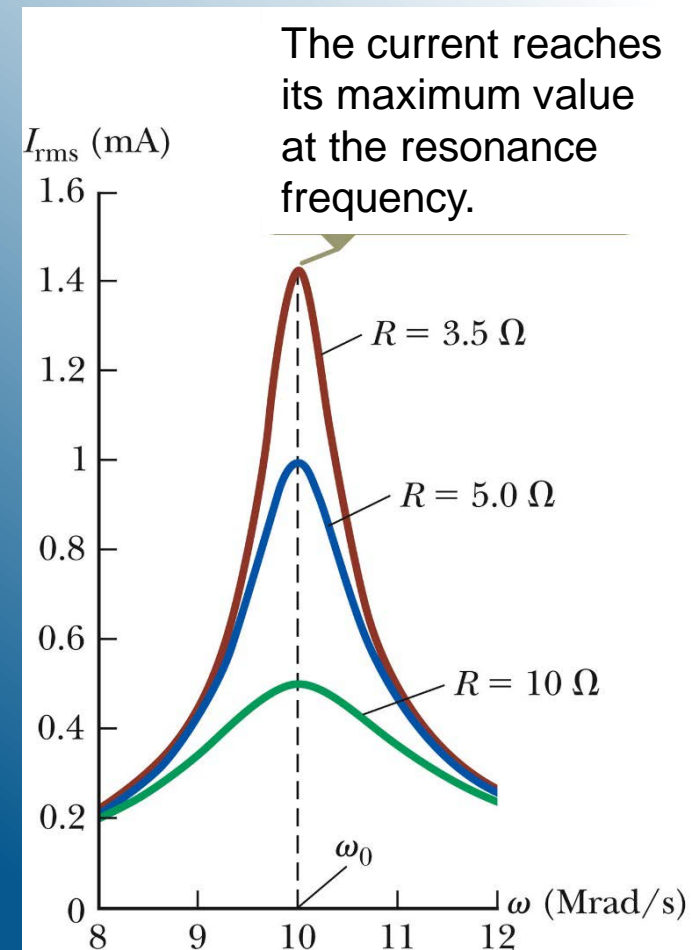
$$\omega_0 = \frac{1}{\sqrt{LC}}$$

- ❖ The resonance frequency also corresponds to the natural frequency of oscillation of an *LC* circuit.
- ❖ The rms current has a maximum value when the frequency of the applied voltage matches the natural oscillator frequency.
- ❖ At the resonance frequency, the current is in phase with the applied voltage.

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❖ Part Two: Resonance in RLC Circuits-16

- ❖ Resonance occurs at the same frequency regardless of the value of R .
- ❖ As R decreases, the curve becomes narrower and taller.
- ❖ Theoretically, if $R = 0$ the current would be infinite at resonance.
 - ❖ Real circuits always have some resistance.



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❖ Part Three: Resonance in turbomachines: #One

The dictionary definition of torsion is the twisting of a body about a longitudinal axis by the application of torque applied at a free end when the other end is fixed, or the twisting that results from torques applied at each end. In the static case, the torques at each end must be equal and opposite to preserve equilibrium.

In this presentation we will consider two types of turbine-generator torques. The first type is the applied torque that is approximately uniform along the length of the generator body, and is often referred to as the generator air-gap torque. This is the electromagnetic stimulus torque and causes the machine torsional vibration. In general the air-gap torque has a DC component and components at several harmonics of the electrical system (grid) frequency when the turbine-generator is in operation and subjected to transient disturbances in the grid.

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❖ Part Three: Resonance in turbomachines: #Two

The second type is the response torque in the various axial sections of the turbine-generator that are caused by the air-gap torque. In general, following disturbances, the response torque will have frequency components corresponding to harmonics of the electrical system frequency, as well as components corresponding to the torsional natural frequencies of the machine. At any instant of time, the response torque in a shaft segment will equal the shaft segment stiffness times the instantaneous twist in the shaft segment.

In the case of turbine-generators, the steady-state torque in a shaft is of course developed by the power transfer process from the turbines to the generator, and numerically this torque equals the power transferred in the shaft segment divided by the rotational speed. The oscillating response torques in the machine shafting result from torsional vibration which are produced by many mechanisms.

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❖ Part Three: Resonance in turbomachines: #Three

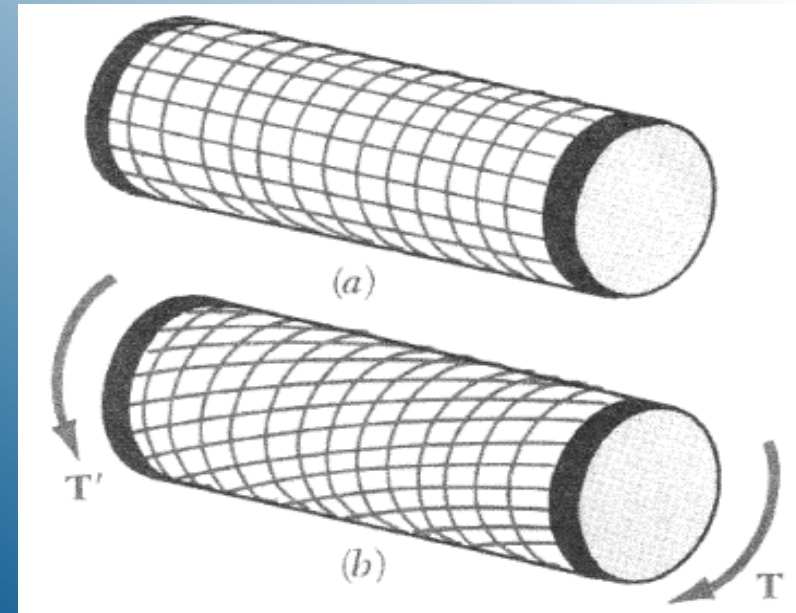
In the case of turbine-generators, the steady-state torque in a shaft is of course developed by the power transfer process from the turbines to the generator, and numerically this torque equals the power transferred in the shaft segment divided by the rotational speed. The oscillating response torques in the machine shafting result from torsional vibration which are produced by many mechanisms.

Consider first the simple case of a uniform annular segment of shaft with static torques applied at each end as shown on the next slide. The shaft will twist to an amount controlled by the torsional stiffness of the shaft segment. This stiffness arises because the elements making up the shaft deform (the square grids on the surface become rhombi due to shearing of one cross section relative to a neighboring one) thereby resisting the twisting motion due to the material elasticity. For shafts of annular cross section, each axial plane does not warp, meaning the plane remains flat.

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❖ Part Three: Resonance in turbomachines: #Four

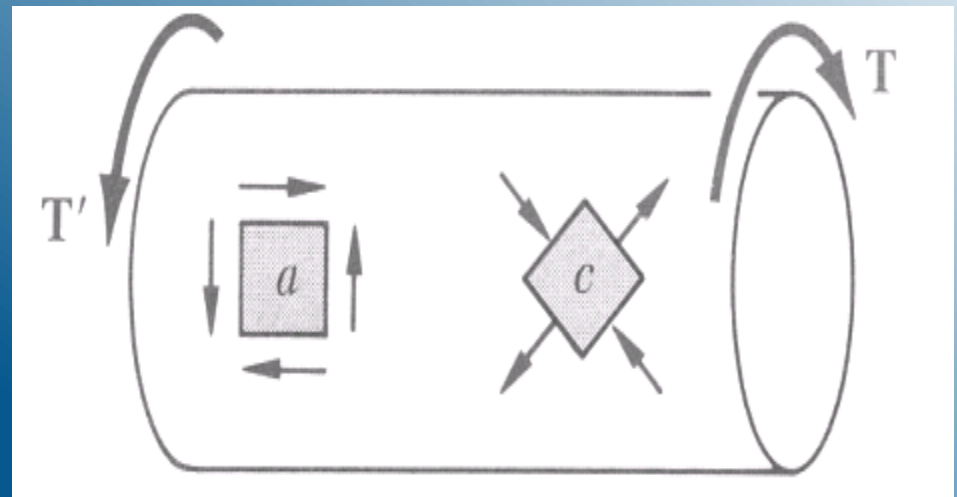
Calculations show that the stiffness of a shaft segment is proportional to its rigidity modulus (a material property) and its second polar moment of area, and is inversely proportional to the segment length. The value of the second polar moment of area of a circular cross section is proportional to the fourth power of its diameter. Hence, making a small change to a shaft outside diameter can dramatically alter its stiffness.



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❖ Part Three: Resonance in turbomachines: #Five

- ❖ Resonance occurs at the same frequency regardless of the value of R .
- ❖ As R decreases, the curve becomes narrower and taller.
- ❖ Theoretically, if $R = 0$ the current would be infinite at resonance.
 - ❖ Real circuits always have some resistance.



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❖ Part Three: Resonance in turbomachines: #Six

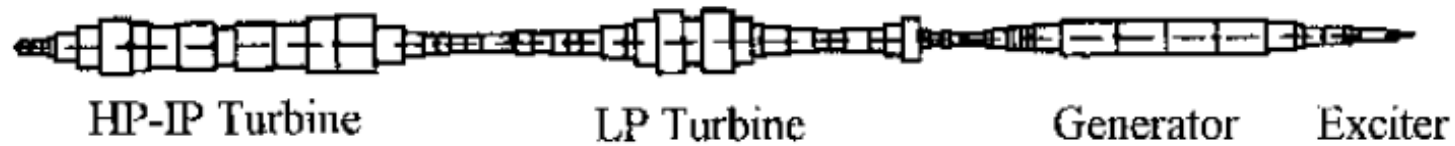
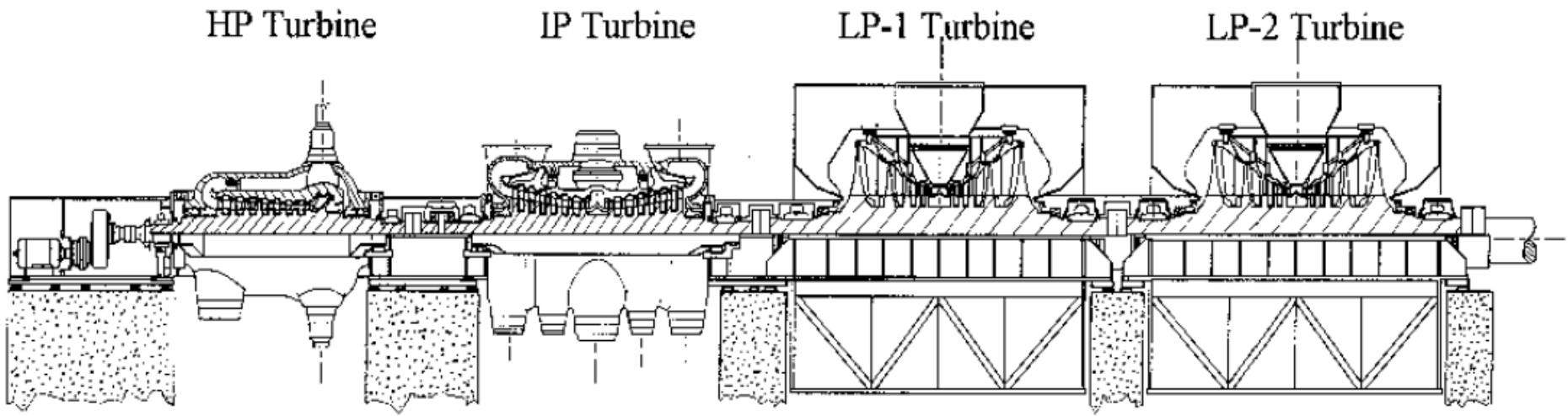
Lateral rotor vibration (LRV) is radial-plane orbital motion of the rotor spin axis. *Transverse rotor vibration* is used synonymously for LRV. Figure 1 shows a sketch of a complete steam turbine-generator rotor (minus turbine blades) and a sample of its computed LRV vibration orbits, shown grossly enlarged. Actual LRV orbits are typically only a few thousandths of an inch across (a few hundredths of a millimeter). LRV is an important design consideration in many types of rotating machinery, particularly turboelectrical machines such as steam and combustion gas turbine-generator sets, compressors, pumps, gas turbine jet engines, turbochargers, and electric motors. Thus, LRV affect several major industries

Usually, but not always, the potential for rotor dynamic beam-bending-type deflections significantly contributes to the LRV characteristics. The significance of LRV rotor bending increases with bearing-to-rotor stiffness ratio and with rotor spin speed.

A rotor's flexibility and mass distributions and its bearings' flexibilities combined with its maximum spin speed essentially determine whether or not residual rotor unbalance can produce forced LRV resonance. That is, these factors determine whether the rotor-bearing system has one or more *lateral natural frequency* modes below the operating speed.

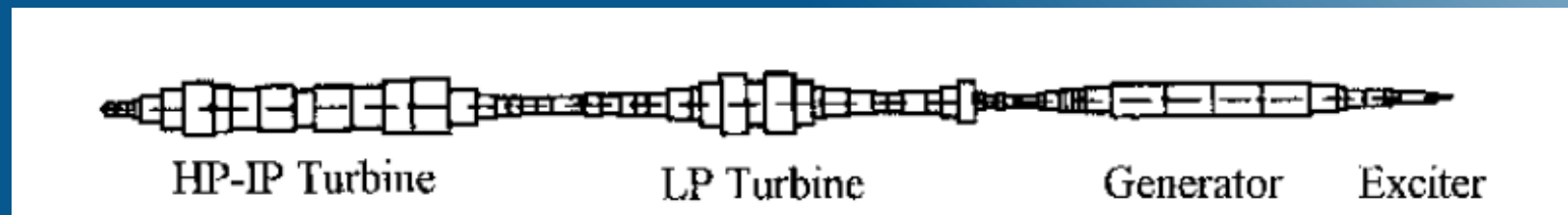
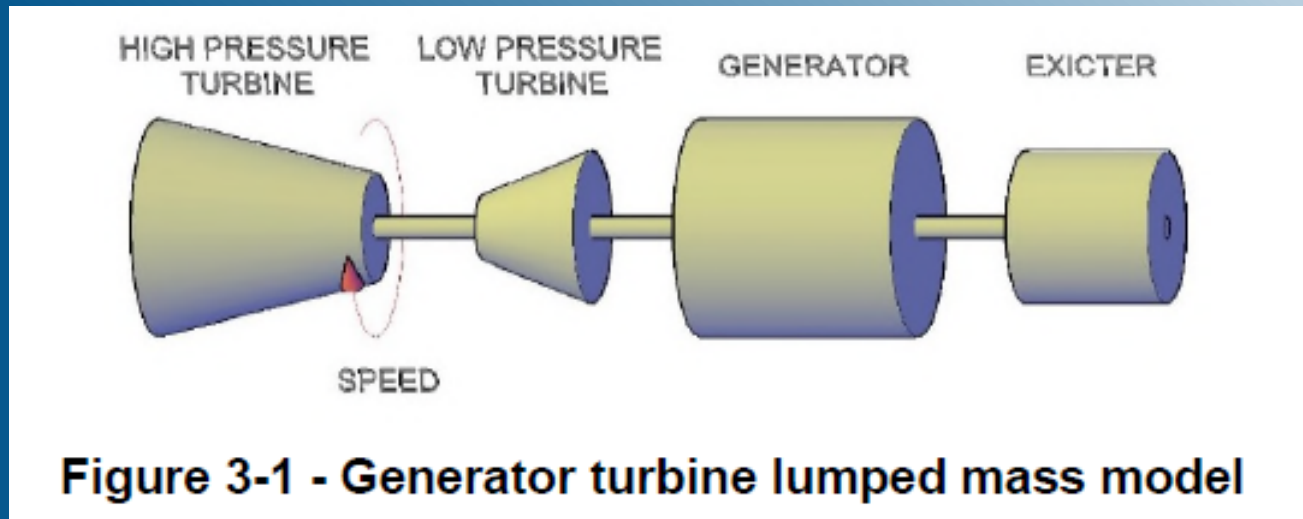
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- ❖ Part Three: Resonance in turbomachines: #Seven



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- ❖ Part Three: Resonance in turbomachines: #Eight



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❖ Part Four: Three Phase Systems-One



Three-phase electric power is a common method of alternating current electric power generation, transmission, and distribution. It is a type of polyphase system and is the most common method used by electrical grids worldwide to transfer power.

It is also used to power large motors and other heavy loads.

A three-wire three-phase circuit is usually more economical than an equivalent two-wire single-phase circuit at the same line to ground voltage because it uses less conductor material to transmit a given amount of electrical power.

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❖ Part Four: Three Phase Systems-Two



A synchronous generator is an electrical generator that converts mechanical energy to electrical energy in the form of alternating current. Due to the need for frequency stability in the production of three phase electrical power, most alternators use a rotating magnetic field with a stationary armature. Occasionally, a linear alternator or a rotating armature with a stationary magnetic field is used.

In principle, any AC electrical generator can be called an alternator, but usually the term refers to small rotating machines driven by automotive and other internal combustion engines.

Alternators in power stations driven by steam turbines are called synchronous generators. Large 50 or 60 Hz three-phase alternators in power plants generate most of the world's electric power, which is distributed by electric power grids.

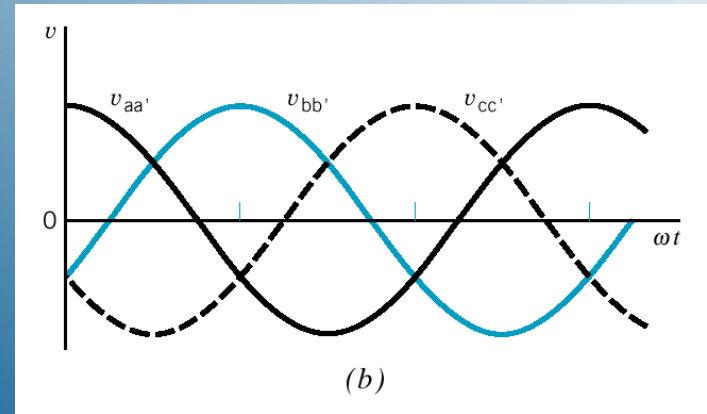
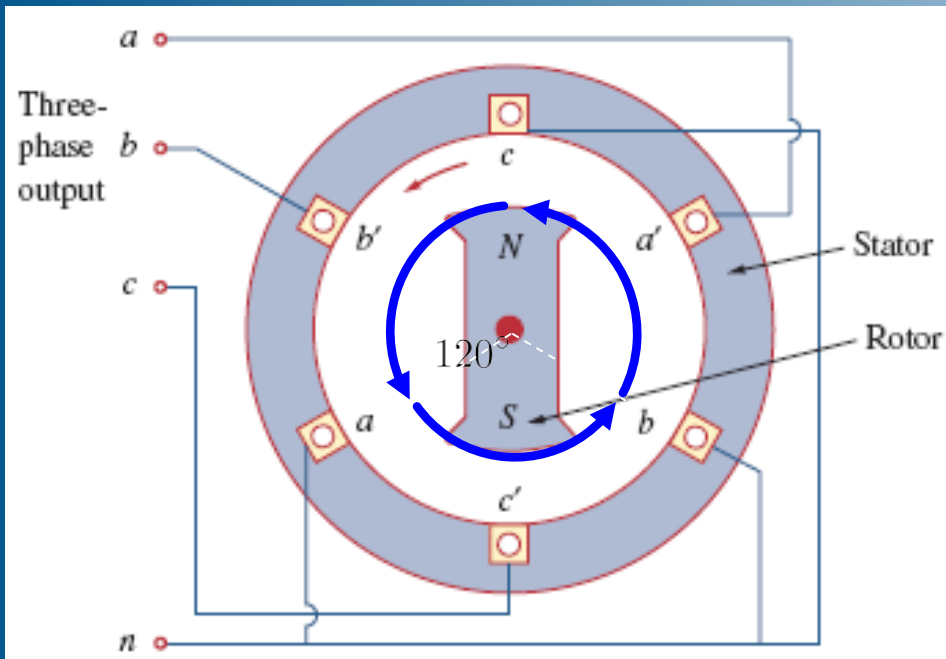
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❖ Part Four: Three Phase Systems-Three

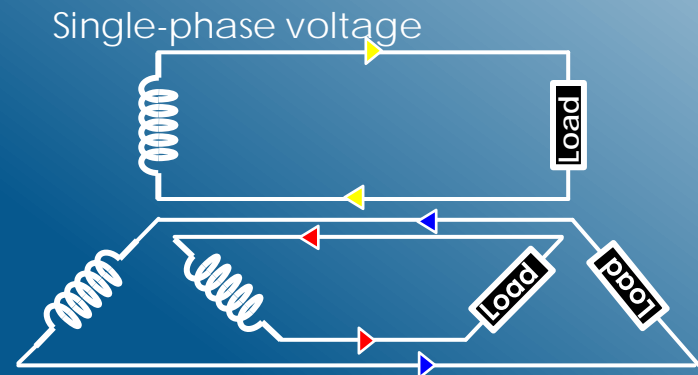
$$V_{aa'} = \sqrt{2}V \cos \omega t$$

$$V_{bb'} = \sqrt{2}V \cos(\omega t - 120^\circ)$$

$$V_{cc'} = \sqrt{2}V \cos(\omega t - 240^\circ)$$

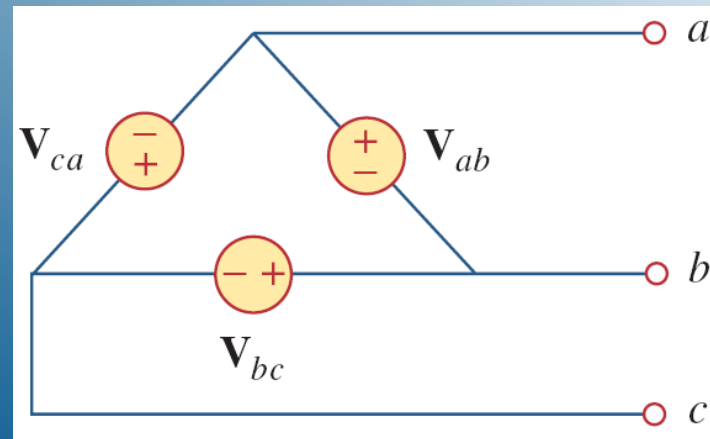
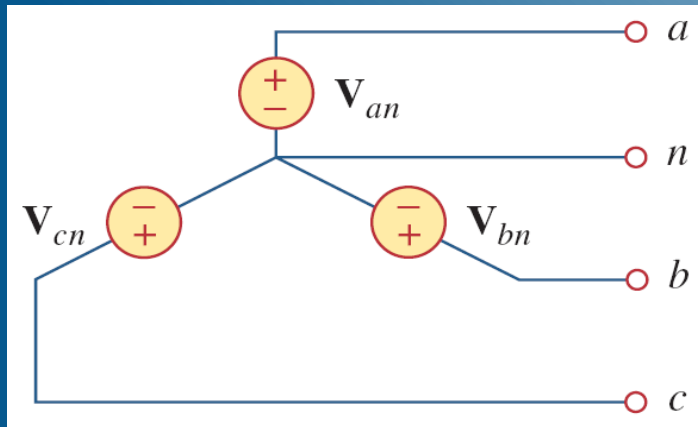


- Three-phase voltage can be also generated with three single-phase voltage



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❖ Part Four: Three Phase Systems-Four



$$V_{an} = V_p \angle 0^\circ = V_p \cos(0^\circ) + V_p \sin(0^\circ) = V_p$$

$$V_{bn} = V_p \angle -120^\circ = V_p \cos(-120^\circ) + V_p \sin(-120^\circ) = V_p(-0.5 - 0.866j)$$

$$V_{cn} = V_p \angle -240^\circ = V_p \angle 120^\circ = V_p \cos(-240^\circ) + V_p \sin(-240^\circ) = V_p(-0.5 + 0.866j)$$

$$V_{an} + V_{bn} + V_{cn} = 0$$

⇒ voltages between the **lines** a,b,c and the **neutral line** n: **phase voltages**.

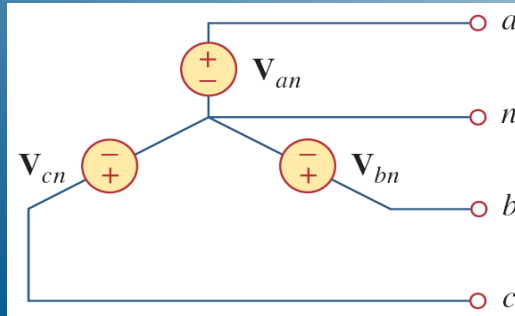
⇒ voltages between the **lines** V_{ab} , V_{bc} , V_{ca} : **phase voltages**.

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❖ Part Four: Three Phase Systems-Five

- ❖ Balanced phase voltages are equal in magnitude and are out of phase with each other by 120°
- ❖ There are two possible ways in which a source can be balanced

$$\begin{aligned} V_{an} &= V_p \angle 0^\circ \\ V_{bn} &= V_p \angle -120^\circ \\ V_{cn} &= V_p \angle -240^\circ = V_p \angle +120^\circ \end{aligned}$$

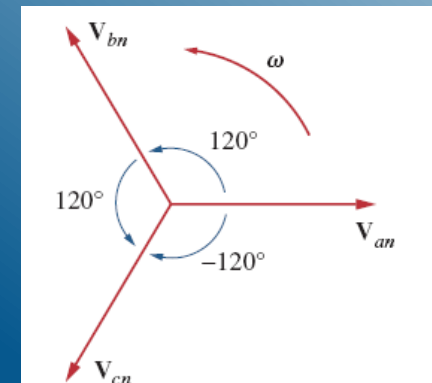
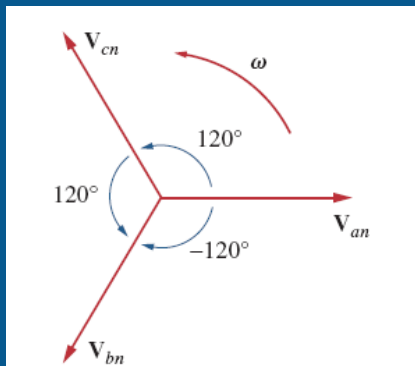


$$\begin{aligned} V_{an} &= V_p \angle 0^\circ \\ V_{cn} &= V_p \angle -120^\circ \\ V_{bn} &= V_p \angle -240^\circ = V_p \angle +120^\circ \end{aligned}$$

Positive or abc sequence

The phase sequence may also be regarded as the order in which the phase voltages reach their peak (or maximum) values with respect to time.

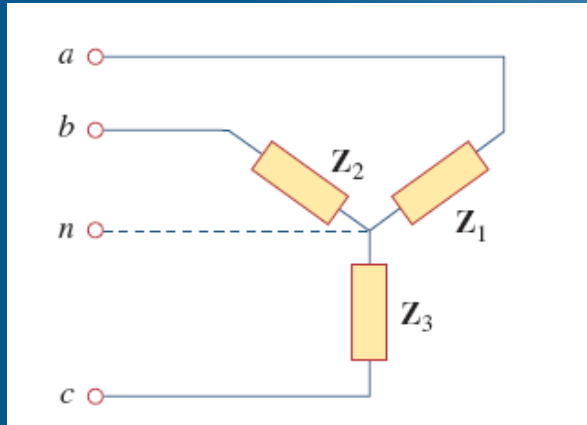
Negative or acb sequence



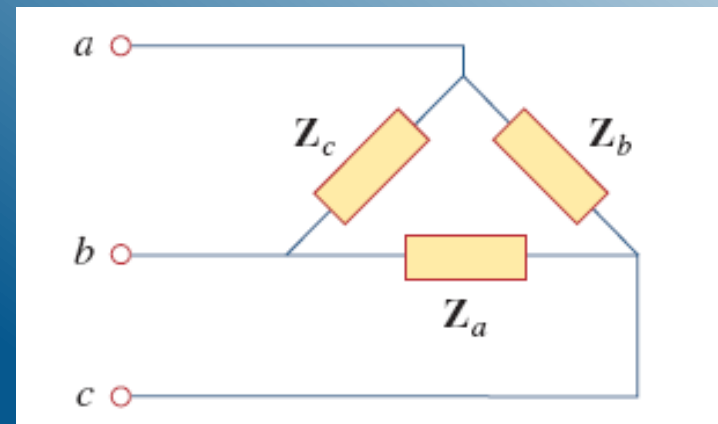
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❖ Part Four: Three Phase Systems-Six

- ❖ Similar to the source, the load can also be Delta or Wye connected.
- ❖ A balanced load: the phase impedances are equal in magnitude and in phase.



$$Z_1 = Z_2 = Z_3 = Z_Y$$

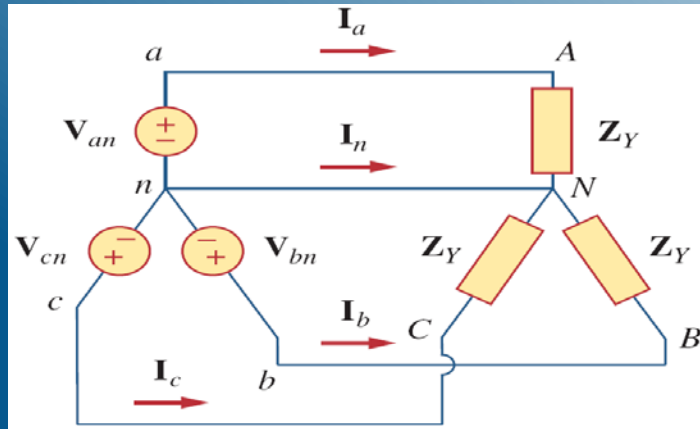


$$Z_a = Z_b = Z_c = Z_\Delta$$

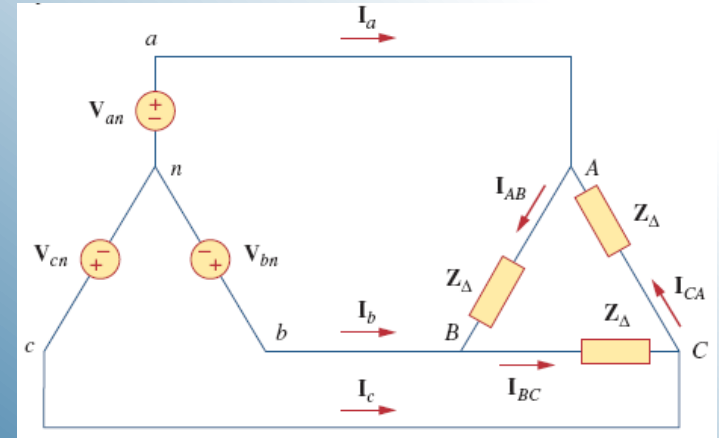
$$Z_\Delta = 3Z_Y \quad \text{or} \quad Z_Y = \frac{1}{3}Z_\Delta$$

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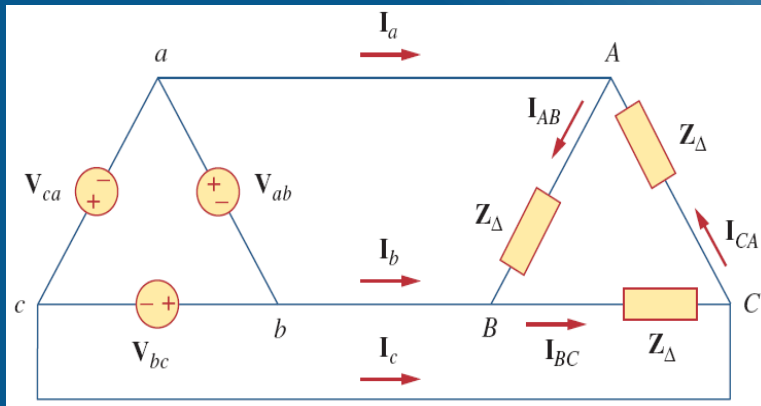
❖ Part Four: Three Phase Systems-Seven



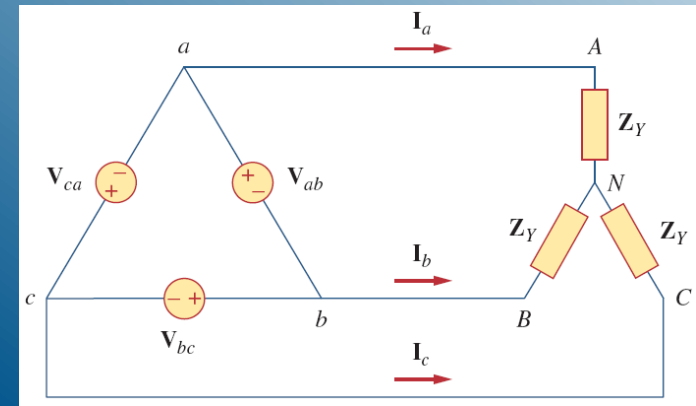
Balanced Y-Y connection



Balanced Y-Δ connection



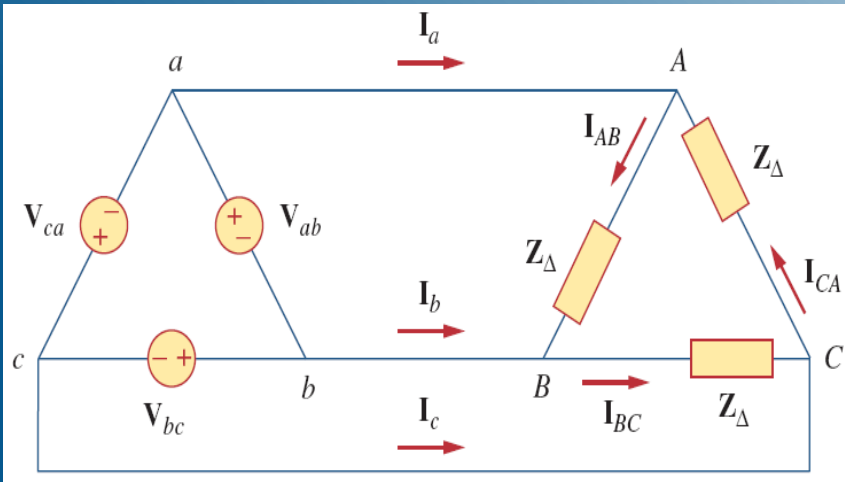
Balanced Δ-Δ connection



Balanced Δ-Y connection

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❖ Part Four: Three Phase Systems-Eight



Assuming a positive sequence, the phase voltages for a delta-connected source are

$$\mathbf{V}_{ab} = V_p \angle 0^\circ \quad \mathbf{V}_{bc} = V_p \angle -120^\circ \quad \mathbf{V}_{ca} = V_p \angle +120^\circ$$

⇒ The line voltages are the same as the phase voltage

The phase currents

$$\mathbf{V}_{ab} = \mathbf{V}_{AB}, \quad \mathbf{V}_{bc} = \mathbf{V}_{BC}, \quad \mathbf{V}_{ca} = \mathbf{V}_{CA}$$

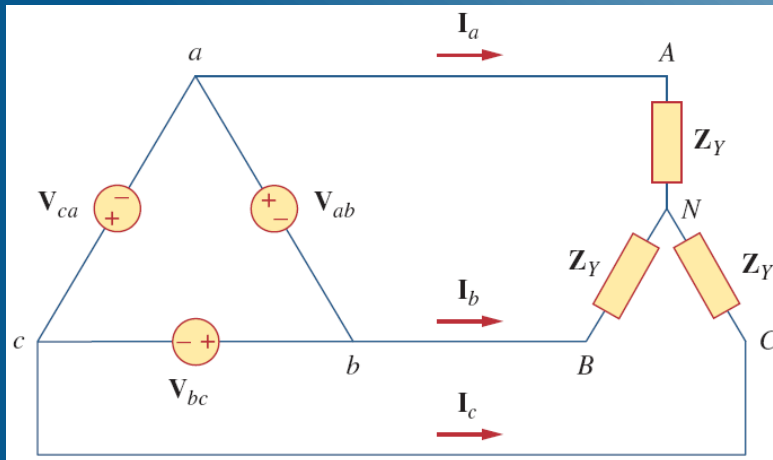
$$\mathbf{I}_{AB} = \frac{\mathbf{V}_{AB}}{Z_\Delta} = \frac{\mathbf{V}_{ab}}{Z_\Delta} \quad \mathbf{I}_{BC} = \frac{\mathbf{V}_{BC}}{Z_\Delta} = \frac{\mathbf{V}_{bc}}{Z_\Delta} \quad \mathbf{I}_{CA} = \frac{\mathbf{V}_{CA}}{Z_\Delta} = \frac{\mathbf{V}_{ca}}{Z_\Delta}$$

The line currents are obtained from the phase currents by applying KCL at nodes A, B, and C

$$\mathbf{I}_c = \mathbf{I}_{CA} - \mathbf{I}_{BC} \quad \mathbf{I}_b = \mathbf{I}_{BC} - \mathbf{I}_{AB} \quad \mathbf{I}_a = \mathbf{I}_{AB} - \mathbf{I}_{CA}$$

Synchronization/Power Factor Correction

❖ Part Four: Three Phase Systems-Nine



Assuming the *abc* sequence, the phase voltages of a delta-connected source are

These are also the line voltages as well as the phase voltages.

$$\mathbf{V}_{ab} = V_p \angle 0^\circ$$

$$\mathbf{V}_{bc} = V_p \angle -120^\circ$$

$$\mathbf{V}_{ca} = V_p \angle +120^\circ$$

In order to get the line current, apply KVL to loop *aANBba*,

$$-\mathbf{V}_{ab} + \mathbf{Z}_Y \mathbf{I}_a - \mathbf{Z}_Y \mathbf{I}_b = 0$$

$$\Rightarrow \mathbf{Z}_Y (\mathbf{I}_a - \mathbf{I}_b) = \mathbf{V}_{ab} = V_p \angle 0^\circ$$

$$\Rightarrow \mathbf{I}_a - \mathbf{I}_b = \frac{V_p \angle 0^\circ}{\mathbf{Z}_Y}$$

\mathbf{I}_b lags \mathbf{I}_a by 120° , since we assumed the *abc* sequence.

Synchronization/Power Factor Correction

❖ Part Four: Three Phase Systems-Ten



For a Y-connected load, the phase voltages are

(V_p (rms) of the phase voltage)

$$v_{AN} = \sqrt{2}V_p \cos \omega t$$

$$v_{BN} = \sqrt{2}V_p \cos(\omega t - 120^\circ)$$

$$v_{CN} = \sqrt{2}V_p \cos(\omega t + 120^\circ)$$

If $\mathbf{Z}_Y = Z/\theta$,

the phase currents lag behind their corresponding phase voltages by θ

$$i_a = \sqrt{2}I_p \cos(\omega t - \theta)$$

$$i_b = \sqrt{2}I_p \cos(\omega t - \theta - 120^\circ)$$

$$i_c = \sqrt{2}I_p \cos(\omega t - \theta + 120^\circ)$$

The total instantaneous power in the load is the sum of the instantaneous powers in the three phases

$$\begin{aligned} p &= p_a + p_b + p_c = v_{AN}i_a + v_{BN}i_b + v_{CN}i_c \\ &= 2V_p I_p [\cos \omega t \cos(\omega t - \theta) + \cos(\omega t - 120^\circ) \cos(\omega t - \theta - 120^\circ) + \cos(\omega t + 120^\circ) \cos(\omega t - \theta + 120^\circ)] \end{aligned}$$

Synchronization/Power Factor Correction

❖ Part Four: Three Phase Systems-Eleven

▶ Consider an amount of power P_L being transmitted at the same line voltage V_L using

- ▶ Single phase supply
- ▶ 3-phase balanced supply

▶ Power dissipation in transmission

$$I_L = \frac{P_L}{V_L}$$

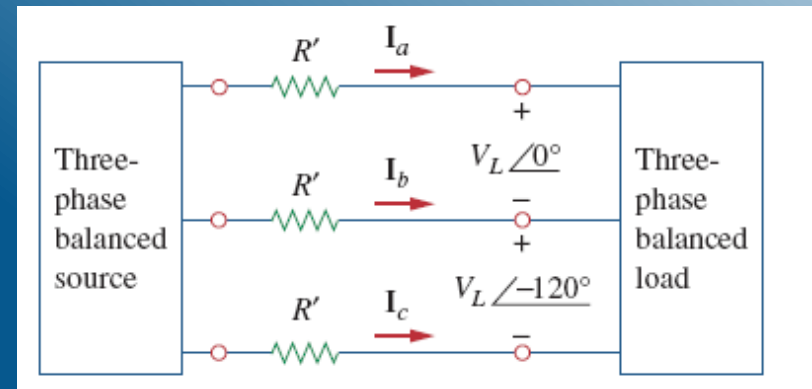
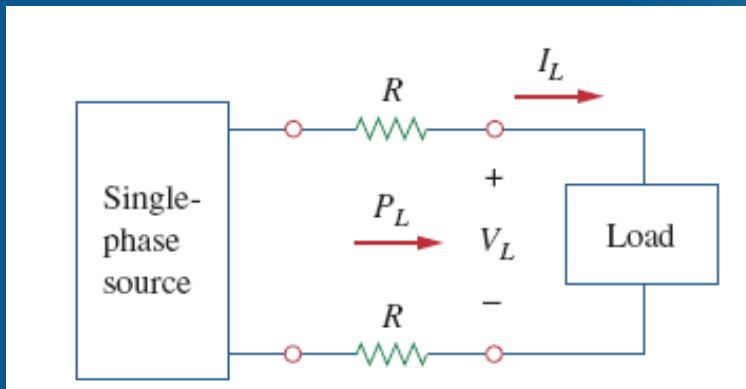
$$P_{loss} = 2I_L^2 R = 2R \frac{P_L^2}{V_L^2}$$

$$I'_L = |\mathbf{I}_a| = |\mathbf{I}_b| = |\mathbf{I}_c| = P_L / (\sqrt{3}V_L)$$

$$P'_{loss} = 3(I'_L)^2 R' = 3R' \frac{P_L^2}{3V_L^2} = R' \frac{P_L^2}{V_L^2}$$

$$I'_L = |\mathbf{I}_a| = |\mathbf{I}_b| = |\mathbf{I}_c| = P_L / (\sqrt{3}V_L)$$

$$P'_{loss} = 3(I'_L)^2 R' = 3R' \frac{P_L^2}{3V_L^2} = R' \frac{P_L^2}{V_L^2}$$



Synchronization/Power Factor Correction

❖ Part Five: Fourier Transform of Square Pulse-One



This Power Point Presentation consists of the following Sections:

1. Fourier Transform of a Square Pulse
2. Introduction to transmission Systems
3. is primarily an introduction to the Synchronization Project which is being proposed by the Senior Engineer of **AscenTrust, LLC.**

Synchronization/Power Factor Correction



❖ Part Five: Fourier Transform of Square Pulse-2

In Electrical Engineering, a **Fourier transform (FT)** is a mathematical transform that decomposes functions depending on space or time into functions depending on spatial or temporal frequency.

The term *Fourier transform* refers to both the frequency domain representation and the mathematical operation that associates the frequency domain representation to a function of space or time.

The Fourier transform of a function of time is a complex-valued function of frequency, whose magnitude (absolute value) represents the amount of that frequency present in the original function, and whose argument is the phase offset of the basic sinusoid in that frequency.

The Fourier transform is not limited to functions of time, but the domain of the original function is commonly referred to as the *time domain*.

There is also an *inverse Fourier transform* that mathematically synthesizes the original function from its frequency domain representation.

Synchronization/Power Factor Correction



- ❖ Part Five: Fourier Transform of Square Pulse-3
- ❖ Periodic signals can be represented with the Fourier series
- ❖ **Aperiodic signals** are analyzed in terms of frequency components by the substitution of Fourier Transforms instead of Fourier Series
- ❖ The Fourier transform provides the tool for this analysis
- ❖ The major difference w.r.t. the line spectra of periodic signals is that the **spectra of aperiodic signals** are defined for all real values of the frequency variable ω not just for a discrete set of values

Synchronization/Power Factor Correction

❖ Part Five: Fourier Transform of Square Pulse-4

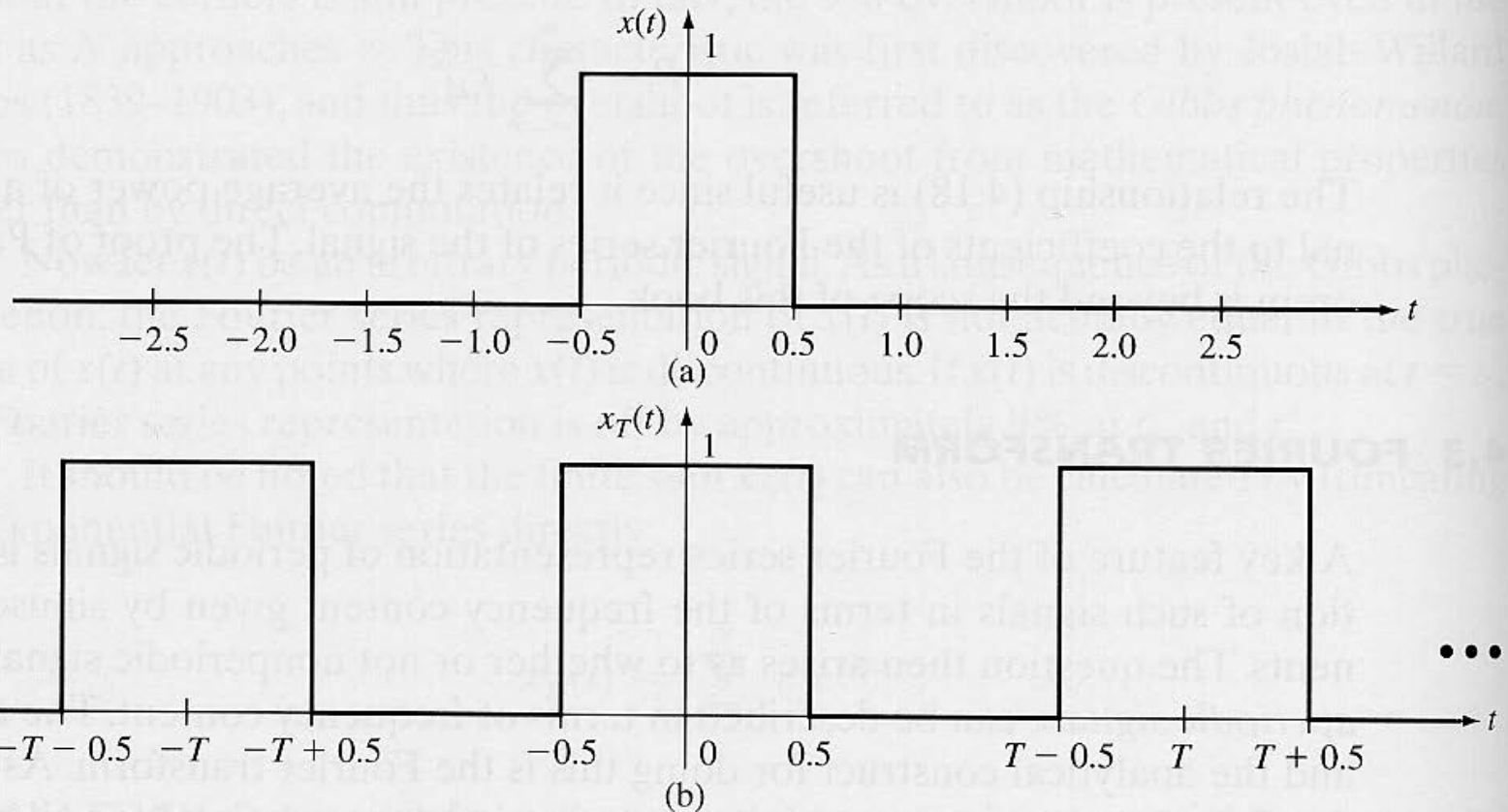


Figure 4.12 Plots of the (a) one-second rectangular pulse and (b) pulse train.

Synchronization/Power Factor Correction



❖ Part Five: Fourier Transform of Square Pulse-5

- ▶ Since $x_T(t)$ is periodic with period T , we can write

$$x_T(t) = \sum_{k=-\infty}^{\infty} c_k e^{jk\omega_0 t}$$

where

$$c_k = \frac{1}{T} \int_{-T/2}^{T/2} x(t) e^{-jk\omega_0 t} dt, \quad k = 0, \pm 1, \pm 2, \dots$$

Synchronization/Power Factor Correction

❖ Part Five: Fourier Transform of Square Pulse-6

plots of $T |c_k|$
vs. $\omega = k\omega_0$
for $T = 2, 5, 10$

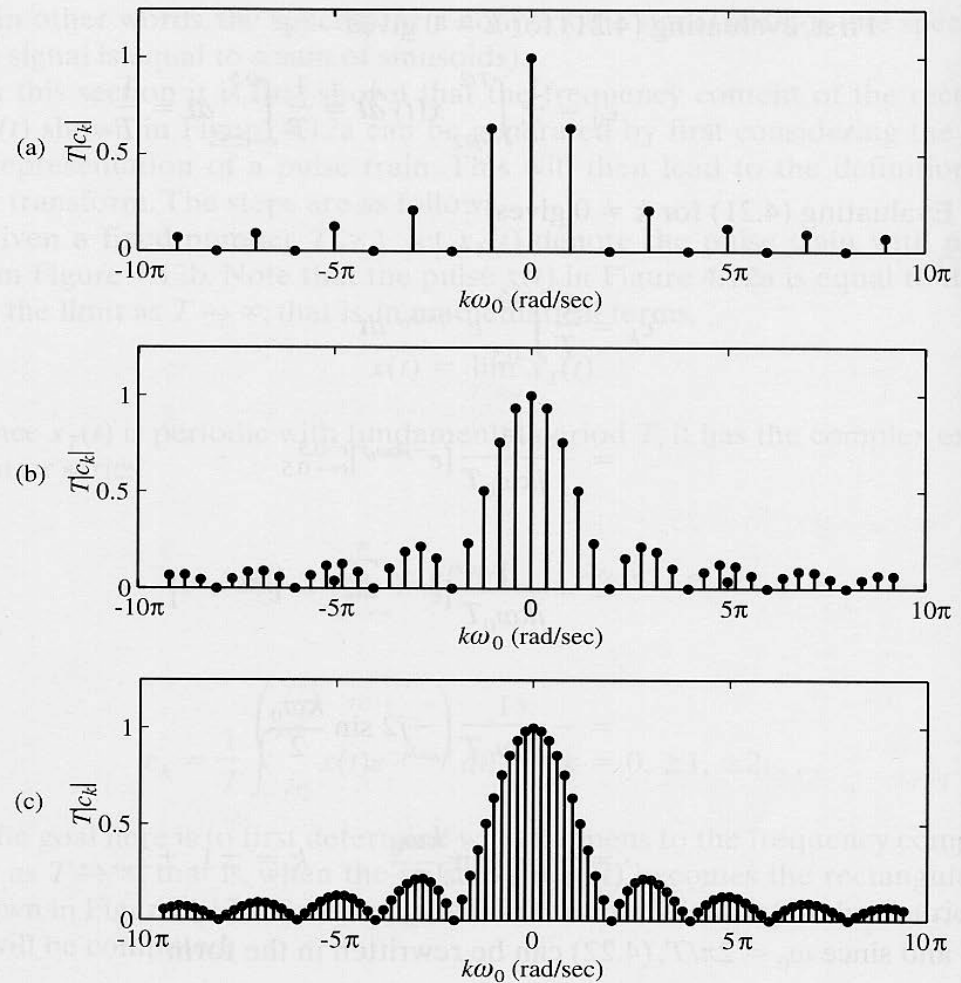


Figure 4.13 Plot of scaled spectrum of $x_T(t)$ for (a) $T = 2$, (b) $T = 5$, and (c) $T = 10$.

Synchronization/Power Factor Correction



❖ Part Six: Transmission Line Theory-One

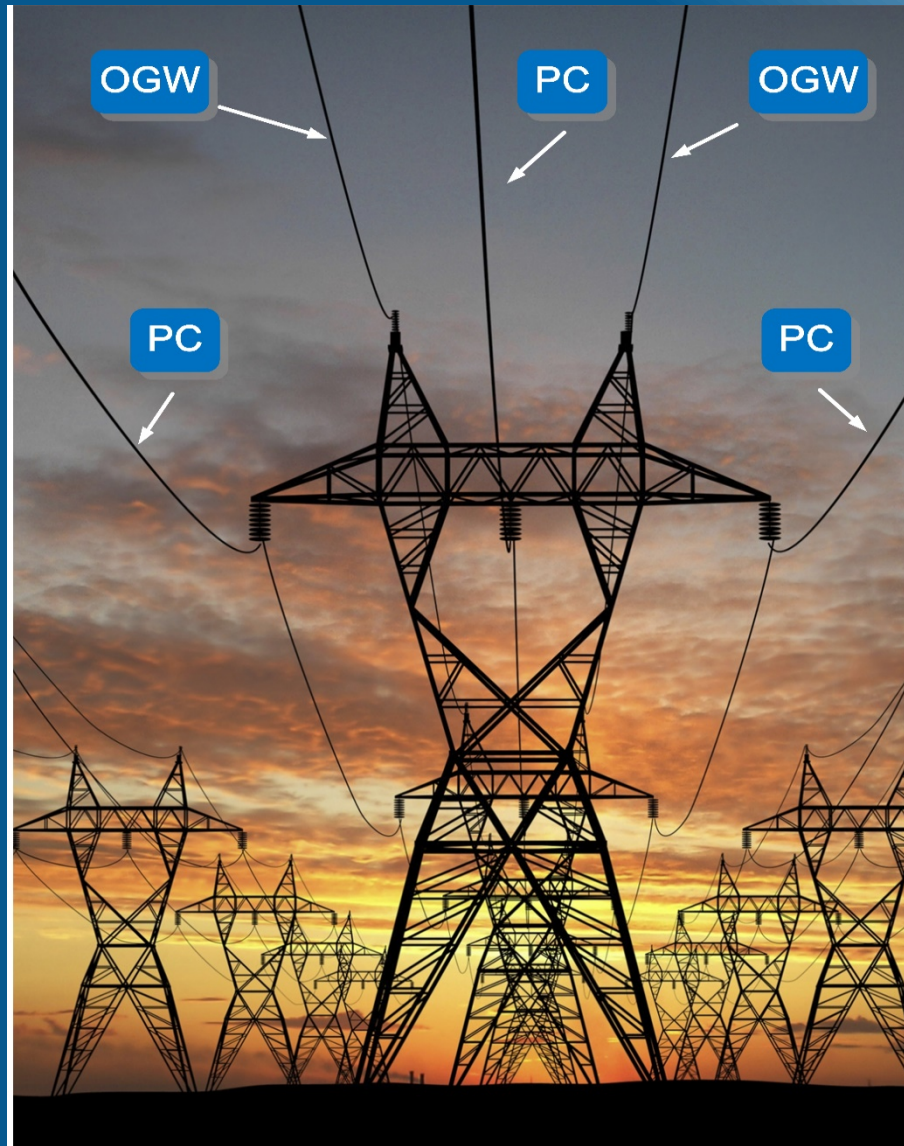
Electric power transmission is the bulk movement of electrical energy from a generating site (power plant), to an electrical substation. The interconnected lines which facilitate this movement are known as a *transmission network*. This is distinct from the local wiring between high-voltage substations and customers, which is typically referred to as electric power distribution. The combined transmission and distribution network is part of electricity delivery, known as the electrical grid.

Efficient long-distance transmission of electric power requires high voltages. This reduces the losses produced by heavy current. Transmission lines use high-voltage alternating current. The voltage level is changed with transformers, stepping up the voltage for transmission, then reducing voltage for local distribution and then use by customer

The wide area synchronous grid of Texas, also known as an "interconnection" directly connects many generators delivering AC power with the same relative *frequency* to many consumers. This GRID falls under the jurisdiction of the PUC of Texas and the Electric Reliability Council of Texas (ERCOT) grid).

Synchronization/Power Factor Correction

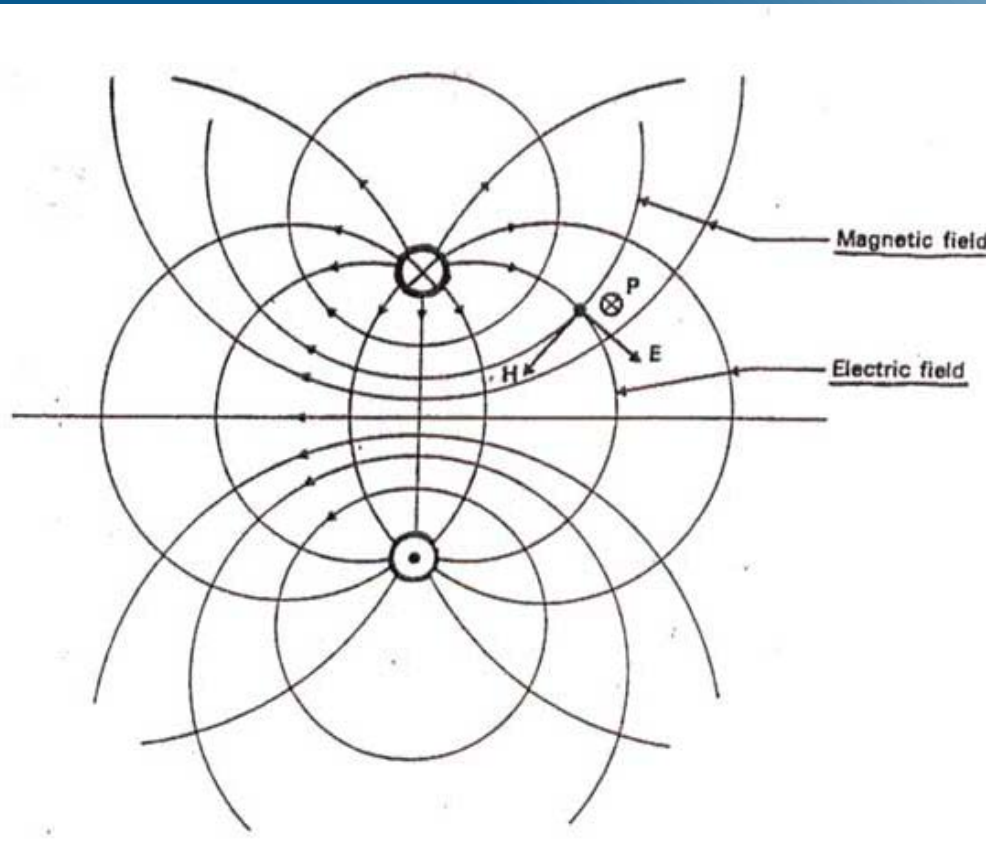
❖ Part Six: Transmission Line Theory-Two



Power Transmission Lines each having Three Phase Conductors (Labelled PC on the left) suspended on Metallic Steel Towers using ceramic insulators and (in this case two overhead Ground Wires labelled OGW) Installed above the phase conductors for lightning protection

Synchronization/Power Factor Correction

❖ Part Six: Transmission Line Theory-Three



Electric and magnetic fields around a two-wire transmission line (Transverse ElectroMagnetic (TEM) field structure)

Synchronization/Power Factor Correction

❖ Part Six: Transmission Line Theory-Four

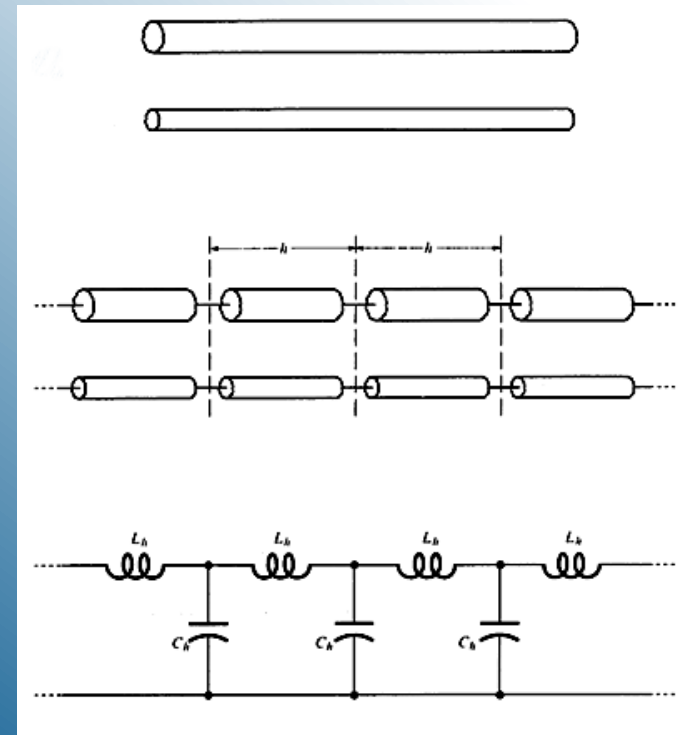


At its simplest the single phase transmission line consists of two parallel and uniform conductors, not necessarily identical.

$$L_h = Lh$$

$$C_h = Ch$$

Where L and C are the inductance and capacitance per unit length of the line, respectively.



Synchronization/Power Factor Correction



❖ Part Six: Transmission Line Theory-Five

$$L \frac{\partial}{\partial t} i(z) = - \lim_{h \rightarrow 0} \left[\frac{v(z+h) - v(z)}{h} \right]$$

1st TL equation

$$L \frac{\partial}{\partial t} i(z) = - \frac{\partial}{\partial z} v(z)$$

Since h is an arbitrary small distance, we can let h approach zero

Applying Kirchhoff's current law, we get

$$i_{NS} = C_h \frac{dV_N}{dt} = i_{N-1} - i_N$$

from which

$$C \frac{\partial}{\partial t} v(z) = - \frac{\partial}{\partial z} i(z)$$

2nd TL equation

Synchronization/Power Factor Correction



❖ Part Six: Transmission Line Theory-Six

All cross-sectional information about the particular line is contained in L and C

Where L and C are the inductance and capacitance per unit length of the line, respectively.

$$L \frac{\partial^2 i}{\partial t \partial z} = - \frac{\partial^2 v}{\partial z^2} \qquad C \frac{\partial^2 v}{\partial t^2} = - \frac{\partial^2 i}{\partial z \partial t}$$

$$\frac{\partial^2 v}{\partial t^2} - \frac{1}{LC} \frac{\partial^2 v}{\partial z^2} = 0$$

Wave Equation for voltage

Synchronization/Power Factor Correction

❖ Part Seven: Series Compensation-One

Series Compensation

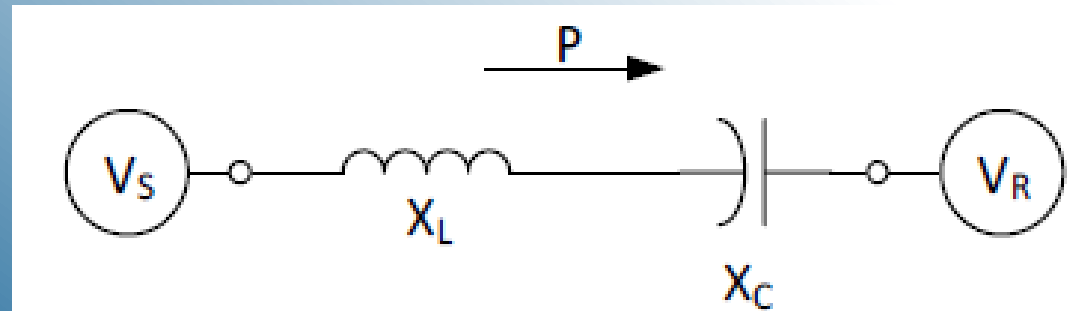
- ❖ Benefits
 - ❖ Increase in Power Factor
 - ❖ Increase the Power Transfer ability of the Transmission Line
- ❖ Drawbacks
 - ❖ Creates a resonance circuit on the Transmission Line
 - ❖ Interaction of Series Compensators with Synchronous Generators causes Sub-synchronous Interaction



Synchronization/Power Factor Correction

❖ Part Seven: Series Compensation-Two

Since transmission lines are mostly inductive, adding series capacitance decreases its total reactance. Reducing X_L increases P_R .



$$P_R = \frac{V_R V_S}{X_L - X_C} \sin \delta = \frac{V_R V_S}{X_L (1 - K)} \sin \delta$$

Compensation Level K is defined as the percent of X_L offset by the series capacitor

Example: For $X_L = 1$ ohm, 30% compensation produces $X_L - X_C = .7$ ohm

Synchronization/Power Factor Correction



❖ Part Eight: Subsynchronous Resonance-One

- ❖ **Resonance** describes the phenomenon of increased amplitude that occurs when the frequency of a periodically applied force (or a Fourier component of it) is equal or close to a natural frequency of the system on which it acts. When an oscillating force is applied at a **resonant frequency** of a dynamic system, the system will oscillate at a higher amplitude than when the same force is applied at other, non-resonant frequencies.
- ❖ Frequencies at which the response amplitude is a relative maximum are also known as **resonant frequencies** or **resonance frequencies** of the system.^[3] Small periodic forces that are near a resonant frequency of the system have the ability to produce large amplitude oscillations in the system due to the storage of vibrational energy.
- ❖ The Resonance phenomena with which we are mainly interested in our Synchronization Project is called Sub-synchronous Resonance. This type of resonance occurs in Transmission system which have poor power factor and Series Capacitance is used on the High Voltage Transmission Line to improve the Power Factor of the line.

Synchronization/Power Factor Correction



❖ Part Eight: Subsynchronous Resonance-Two

- ❖ The Electrical GRID is a highly non-linear system consisting, on the production end, of Synchronous Generators whose frequency is stabilized by the inertia of the rotor and generator shafts which are often milled out of a single casting and can weigh up to 75 Tons.
- ❖ Synchronous Generators have significant exposure to low frequency harmonics of the type which are created when an in-line capacitor is installed on the highline side of their transformers.
- ❖ A power system's natural electrical frequencies are a function of its inductance and capacitance.
- ❖ All cross-sectional information about the particular line is contained in L and C
- ❖ Where L and C are the inductance and capacitance per unit length of the line, respectively.
- ❖ When new capacitance is added, new natural electrical frequencies result and the system natural frequency approaches the fundamental frequency f_0 .

Synchronization/Power Factor Correction



❖ Part Eight: Subsynchronous Resonance-Three

- ❖ Subsynchronous Interaction – A general term describing the condition where two or more parts of the power system exchange energy at one or more frequencies below the fundamental frequency (60 Hz).
- ❖ Subsynchronous Oscillation - An SSO is a condition where the electric network exchanges significant energy with a turbine generator at one or more of the natural frequencies of the combined system below the synchronous frequency of the system following a disturbance from equilibrium.
- ❖ SSI can lead to SSOs that must be damped before outage or damage to network equipment occurs
- ❖ Subsynchronous Resonance (SSR) – A type of SSI where the electric power system, most often a series compensated transmission line, exchanges energy with a turbogenerator at one or more natural frequencies below the fundamental 60Hz frequency (three types of SSR)
- ❖ Torsional Interaction (SSR-TI) – interaction between the mechanical system (turbogenerator) and a series compensated power system when small disturbances occur. This is the classic SSR condition.

Synchronization/Power Factor Correction



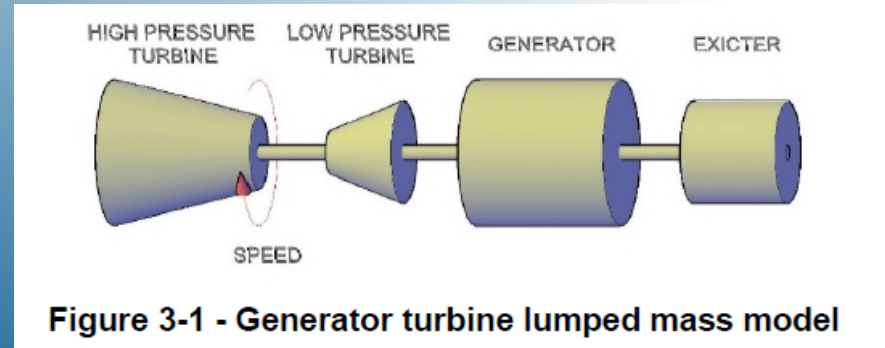
❖ Part Eight: Subsynchronous Resonance-Four

- ❖ Induction Generator Effect (IGE) – This is self-excitation of a series compensated power system. This is independent of the generator shaft torsional modes. Purely electric resonance condition.
- ❖ Torque Amplification (TA) – amplification of turbogenerator shaft system stress by transient torques on generator rotors caused by severe disturbances in a series compensated power system.
- ❖ Subsynchronous Control Interactions (SSCI) – A condition where a power electronic device (HVDC, SVC, STATCOM, Wind turbine control, etc) interacts with the electric power system containing nearby series compensated transmission .
- ❖ Subsynchronous Torsional Interaction (SSTI) – A condition where there is a control interaction between power electronic device and the mechanical mass system of a turbogenerator. Does not interaction with series compensation.

Synchronization/Power Factor Correction

❖ Part Eight: Subsynchronous Resonance-Five

The electromechanical interaction (torque) in the turbine-generator machine occurs in the air gap of the generator.

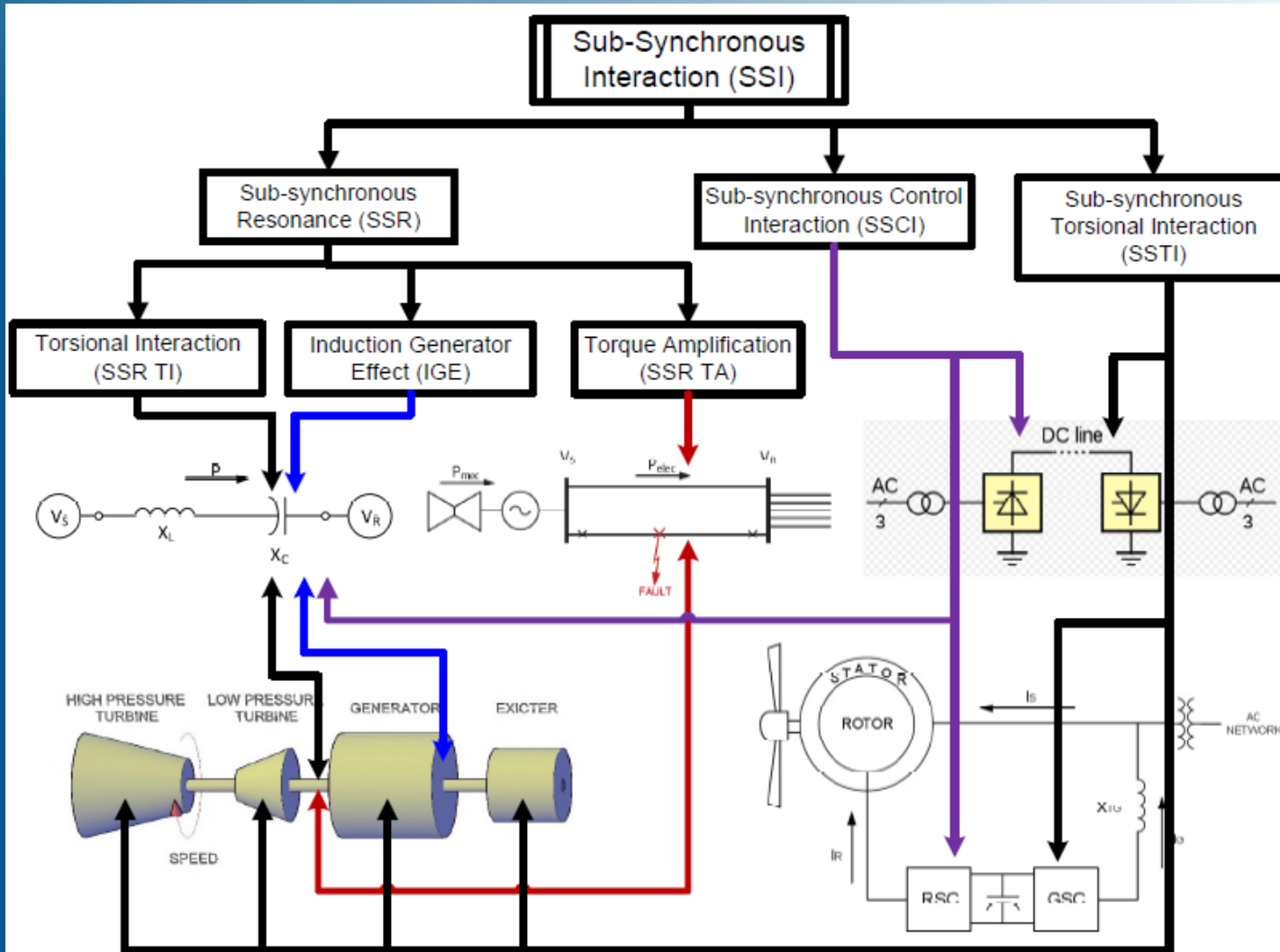


The first type is the applied torque that is approximately uniform along the length of the generator body, and is often referred to as the generator air-gap torque. This is the electromagnetic stimulus torque and causes the machine torsional vibration.

In general the air-gap torque has a DC component and components at several harmonics of the electrical system (grid) frequency when the turbine-generator is in operation and subjected to transient disturbances in the grid

Synchronization/Power Factor Correction

❖ Part Eight: Subsynchronous Resonance-Six



Synchronization/Power Factor Correction



❖ Part Eight: Subsynchronous Resonance-Seven

SSR – TI (Torsional Interaction)

- ❖ When a small disturbance occurs, simultaneous excitation of all natural frequencies (modes) of oscillation occurs in both the electrical system and the generator
- ❖ If the electrical and mechanical natural frequencies are close to one another, sustained or growing rotor oscillations can occur resulting in possible torsional fatigue damage to the turbine generator shaft. This is classic SSR-TI.

SSR – TA (Torsional Amplification)

- ❖ When a large disturbance occurs, the subsynchronous transient current frequency may be close to the generator natural torsional frequency
- ❖ Can lead to prolonged generator shaft oscillations with high amplitude causing increased stress and accelerated loss of life.

Synchronization/Power Factor Correction



❖ Part Eight: Subsynchronous Resonance-Eight

IGE (Induction Generator Effect)

- ❖ Purely electrical resonance effect
- ❖ Combined generator and electric power system results in a negative effective rotor resistance at a natural frequency below 60 hz
- ❖ If the negative rotor resistance is greater than the apparent stator plus network resistance, self –excited, subsynchronous current and electromagnetic torque can result

SSCI – (Control Interaction) ERCOT 2009 Event

- ❖ Event between wind generators and series compensated transmission line
- ❖ 2 pu overvoltage damaged rotor side protection circuits
- ❖ Wind farm became radially connected through series capacitor
- ❖ 1.5 seconds before capacitor was bypassed
- ❖ Resonance between Capacitor and Wind Turbine Converter/Control
- ❖ Only Type 3 and Type 4 Turbines Can Be Affected
- ❖ See report for ERCOT's SSI study process for new wind generation

Synchronization/Power Factor Correction

- ❖ Part Eight: Subsynchronous Resonance-Nine
 - ❖ 1971 SSR-TI Event

Mohave generator: 1,580 MW coal-fired in NV.

Gradually growing vibration that eventually fractured a shaft section.

First investigations incorrectly determined cause. After 2nd failure in 1971 cause was identified as Subsynchronous Resonance.

An electrical resonance at 30.5 Hz excited a mechanical resonance at 30.1 Hz.

Problem was solved by reducing compensation and installing a torsional relay.

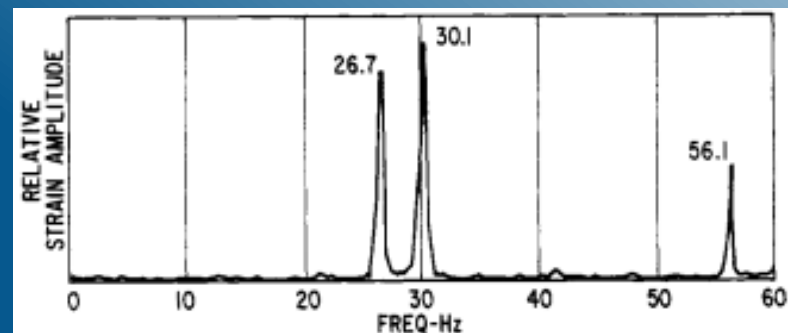


Fig. 7. Synchronization Frequency Analysis

Synchronization/Power Factor Correction



- ❖ Part Eight: Subsynchronous Resonance-Ten
 - ❖ Risk Assessment

Frequency Scan Screening

- ❖ Calculates apparent impedance from generator from 0 to 60 hz
- ❖ Can identify potential IGE, SSR-TI, SSR-TA, and SSCI problems

Eigenvalue Analysis

- ❖ System model linearized, small perturbations examined
- ❖ Identifies torsional mode damping characteristics
- ❖ Used to study SSR-TI and SSCI problems

Damping Torque Analysis

- ❖ EMT type software used for analysis
- ❖ Examines electrical torque response to small change in generator speed to determine damping characteristic
- ❖ Practical for evaluating SSR-TI

Time Domain Analysis

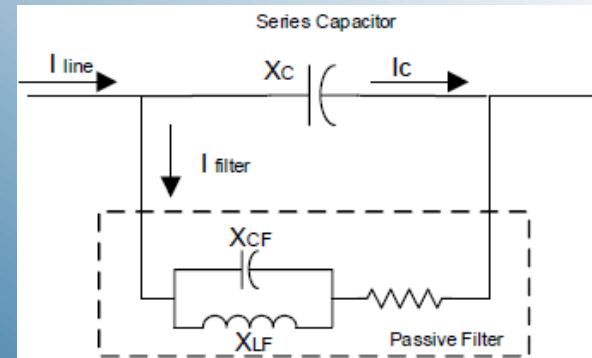
- ❖ EMT type software used for analysis
- ❖ Most useful in studying SSR-TA problems

Synchronization/Power Factor Correction

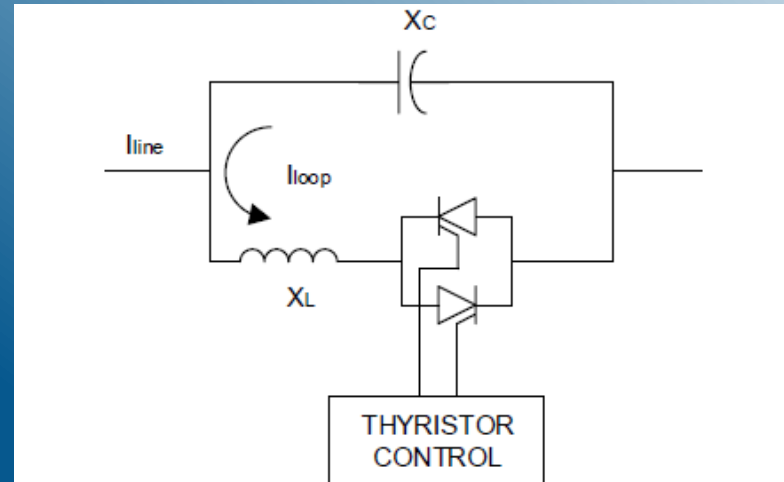
- ❖ Part Eight: Subsynchronous Resonance-Eleven
- ❖ SSI Mitigation Measures-One

Preventative Measures to Reduce a Known Risk of SSI

- ❖ Operational Procedure
 - ❖ Alter the network configuration or generation dispatch
 - ❖ Bypass the Capacitor or reduce its compensation level
- ❖ Passive Filter Damping for series resonance network condition
 - ❖ Shunt or Series
 - ❖ Shunt and Series
- ❖ FACTS Active Shunt Filter Damping
 - ❖ STATCOM or SVC
- ❖ FACTS Active Series Filter Damping
 - ❖ Thyristor Controlled
 - ❖ Series Compensation (TCSC)
- ❖ Unified Power Flow Controller (UPFC)



Passive filter in parallel with series capacitor

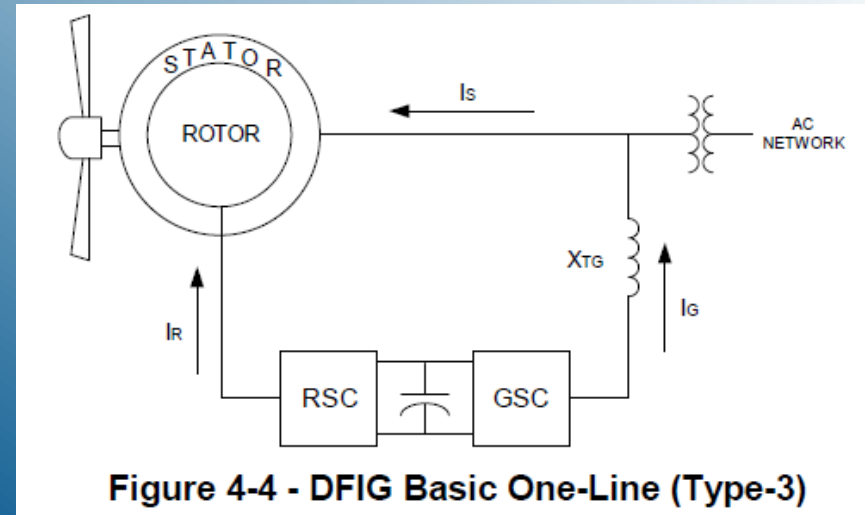


- Primary components of a TCSC

Synchronization/Power Factor Correction

- ❖ Part Eight: Subsynchronous Resonance-Twelve
- ❖ SSI Mitigation Measures-Two

- ❖ Generator Based Preventative Measures to Reduce a Known Risk of SSI
- ❖ Passive Filter Damping
- ❖ Active Filter Damping (FACTS devices such as TCR or STATCOM)
- ❖ Supplemental Excitation Control Damping
- ❖ Wind Turbine Control Damping
- ❖ Type 3 and 4 turbines use VSC as basis for control
- ❖ Newer controls since 2009 mitigate SSI



Synchronization/Power Factor Correction



- ❖ Part Eight: Subsynchronous Resonance-Thirteen
 - ❖ SSI Mitigation Measures-Three
 - ❖ Protective Relays-One

Protective Relays in Series Compensated Networks

- ❖ Voltage and current inversion due to nearby fault
- ❖ Measured Impedance of Distance Protection when series compensation switched in and out
- ❖ Subsynchronous Transient Signal Impacts on apparent impedance
- ❖ Adjacent Line Impacts
- ❖ Unbalanced Line and Mutual Impedance Impacts
- ❖ Automatic Reclosing for Series Compensated Transmission Lines
- ❖ Series Capacitor Switching
- ❖ Three Phase Automatic Reclosing
- ❖ Single Phase Automatic Reclosing
- ❖ Spurious Bypass Operation

Synchronization/Power Factor Correction



- ❖ Part Eight: Subsynchronous Resonance-Fourteen
 - ❖ SSI Mitigation Measures-Four
 - ❖ Protective Relays-Two

- ❖ Advanced Relays for Series Compensation Application
 - ❖ Memory Polarization
 - ❖ Special Series Compensation Logic
 - ❖ Sequence Component Impedance for Directional Discrimination
- ❖ Protection Schemes
 - ❖ Line Current Differential Protection
 - ❖ Directional Comparison Protection
 - ❖ Permissive Overreach Scheme
 - ❖ Underreaching Direct Trip and Direct Transfer Trip Scheme
 - ❖ Protection Design and Performance Verification
 - ❖ EMT simulation of various system conditions recommended for the chosen protection scheme

Synchronization/Power Factor Correction



- ❖ Part Eight: Subsynchronous Resonance-Fifteen
 - ❖ SSI Mitigation Measures-Five
 - ❖ Protective Relays-Three

Relay	Signal Input	Comments
Torsional Motion (Stress) Relay	Shaft Speed	Developed and applied in the late 1970s. Speed is processed by band-pass filters to calculate conditions at particular sub-synchronous frequencies of interest. <u>Torsional Stress Relays (TSR) have been applied at several generator units and are still available.</u> Newer torsional motion relays are micro-processor based. <u>Appears to be the most widely applied measure to protect generators from the potential of SSI due to proximity of HVDC or series compensated lines.</u>
S. California Edison patent	Terminal voltage	Micro-processor relay that uses exclusive time domain analysis on wave parameters of successive half cycles. More research is recommended as to the application of this 1986 patent, performance information, and current status.
ABB Research Ltd. patent	Generator Terminal voltage	Micro-processor based relay developed in the 2011 timeframe.
ERLPhase Power Technologies	Generator Terminal voltage and currents	Micro-processor based relay is used to perform frequency spectrum analysis on the inputs to compare sub-synchronous frequency components with fundamental component.
Relay Application Innovation	Armature current	Micro-processor based relay. Developed in late 2009 and applied in 2010 by AEPSC at two locations as backup generator protection.

Synchronization/Power Factor Correction

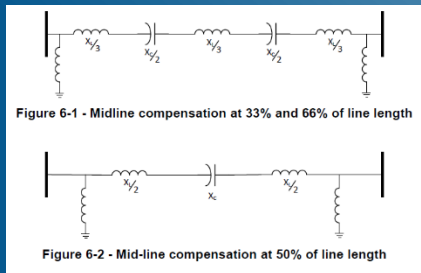
- ❖ Part Eight: Subsynchronous Resonance-Sixteen

- ❖ SSI Mitigation Measures-Six

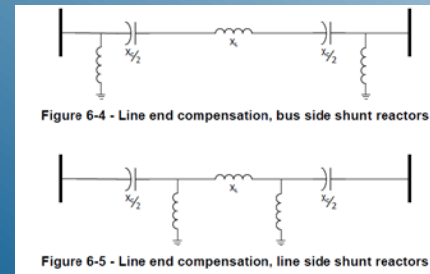
- ❖ Project Planning-One

- ❖ Location of Series Compensation – affects effectiveness, voltage profile, protections settings, future configuration, operation and maintenance

- Mid-Line Installation



- Line Ends Installation



- ❖ Modularity of Series Compensation for staged development

- ❖ Design for Future Network Modifications

- ❖ Operations and Maintenance Considerations

- ❖ FSC - majority of equipment used is already likely found in the system

- ❖ TCSC – redundant power electronic modules allows replacement of faulty modules

- ❖ Operations and Reliability

- ❖ Remote control functionality

Synchronization/Power Factor Correction



- ❖ Part Nine: SSI in ERCOT-One
 - ❖ ERCOT-One

The **Electric Reliability Council of Texas, Inc. (ERCOT)** is an American organization that operates Texas's electrical grid, the Texas Interconnection, which supplies power to more than 25 million Texas customers and represents 90 percent of the state's electric load. ERCOT is the first independent system operator (ISO) in the United States and one of nine ISOs in North America. ERCOT works with the Texas Reliability Entity (TRE), one of eight regional entities within the North American Electric Reliability Corporation (NERC) that coordinate to improve reliability of the bulk power grid.

The ERCOT area of the GRID IN Texas is completely independent of FERC (Federal Energy Regulatory Commission(FERC)and operates under the authority of the State of Texas through the Public Utility Commission (PUC).

Synchronization/Power Factor Correction



- ❖ Part Nine: SSI in ERCOT-Two
 - ❖ ERCOT-Two

The United States Energy Information Administration Electric Power Monthly published the following detailed report regarding Texas' Net Generation by Energy Source: Total (All Sectors), 2010-December 2020, (Thousand Megawatthours), for the Month of December 2020:

- ❖ Coal: 78,700 MWh;
- ❖ Petroleum Liquids: 909 MWh;
- ❖ Petroleum Coke: 742 MWh;
- ❖ Natural Gas: 125,704 MWh;
- ❖ Other Gas: 972 MWh;
- ❖ Nuclear: 69,871 MWh;
- ❖ Hydroelectric Conventional: 23,086 MWh;
- ❖ Solar: 5,381 MWh;
- ❖ Renewable Sources Excluding Hydroelectric and Solar: 38,812 MWh;

Synchronization/Power Factor Correction



- ❖ Part Nine: SSI in ERCOT-Three
 - ❖ ERCOT-Three

ERCOT is a membership-based 501(c)(4) nonprofit corporation,^{[14][15]} and its members include consumers, electric cooperatives, generators, power marketers, retail electric providers, investor-owned electric utilities (transmission and distribution providers), and municipally owned electric utilities.^[16]

- ❖ ERCOT ISO manages the flow of electric power to 23 million Texas customers - representing 85 percent of the state's electric load.
- ❖ Performs financial settlement for the competitive wholesale bulk-power market
- ❖ Enables retail electric choice for Texas customers

Synchronization/Power Factor Correction



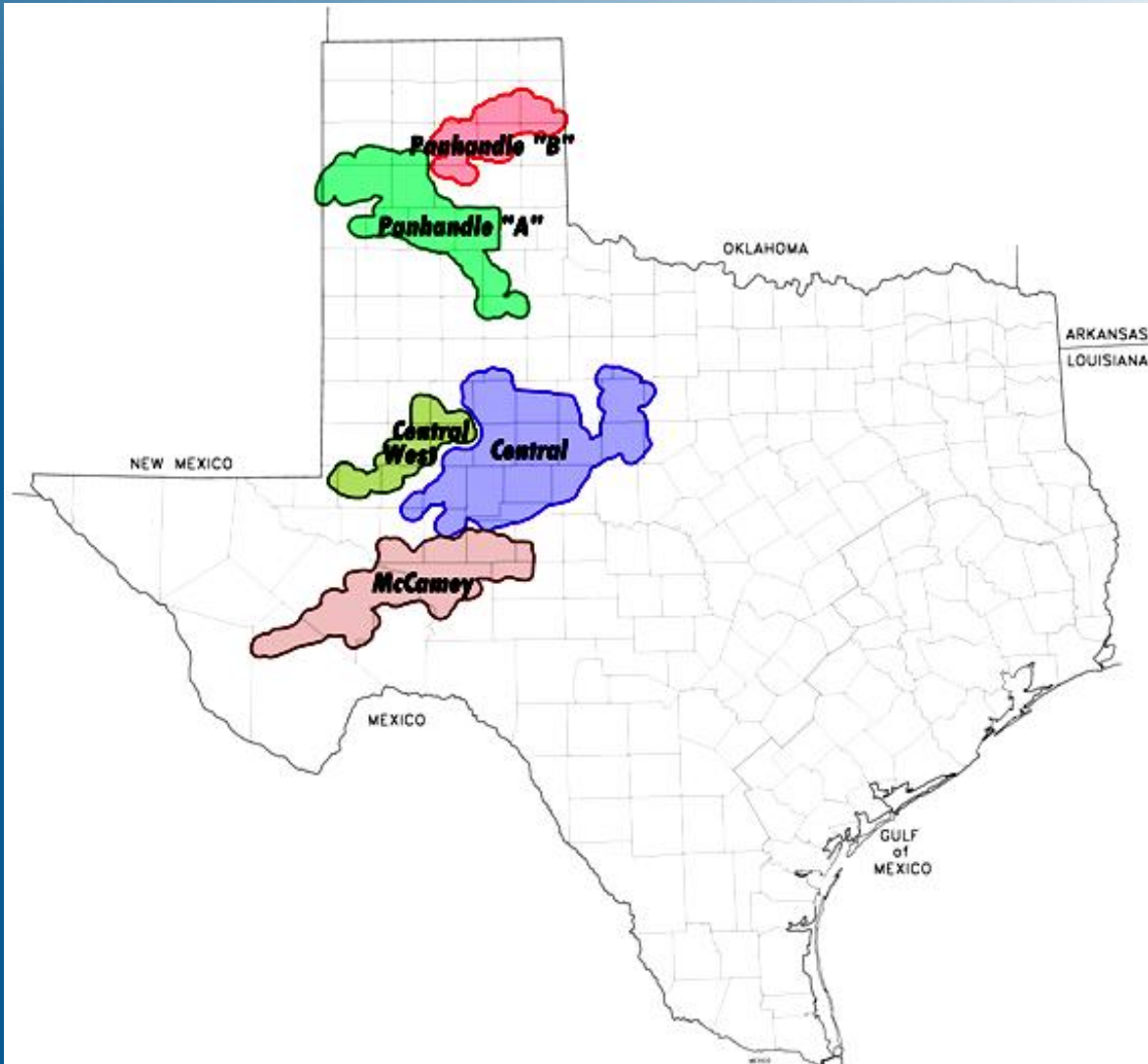
- ❖ Part Nine: SSI in ERCOT-Four
 - ❖ CREZ-One

Competitive Renewable Energy Zone (CREZ) – a geographic area in the state of Texas initially identified by AWS Truewind (as ERCOT’s consultant) as an area suitable for multiple 100 MW wind development projects. Of the original 25 zones the Public Utility Commission (PUC) chose a small set based on input from potential windfarm developers.

- ❖ New CREZ 345kV lines built both inside ERCOT load-serving areas and far into areas where load is served by SPP.
- ❖ CREZ will not add any new connections between ERCOT and SPP.
- ❖ CREZ areas are Panhandle A, Panhandle B, Central, West, and McCamey.

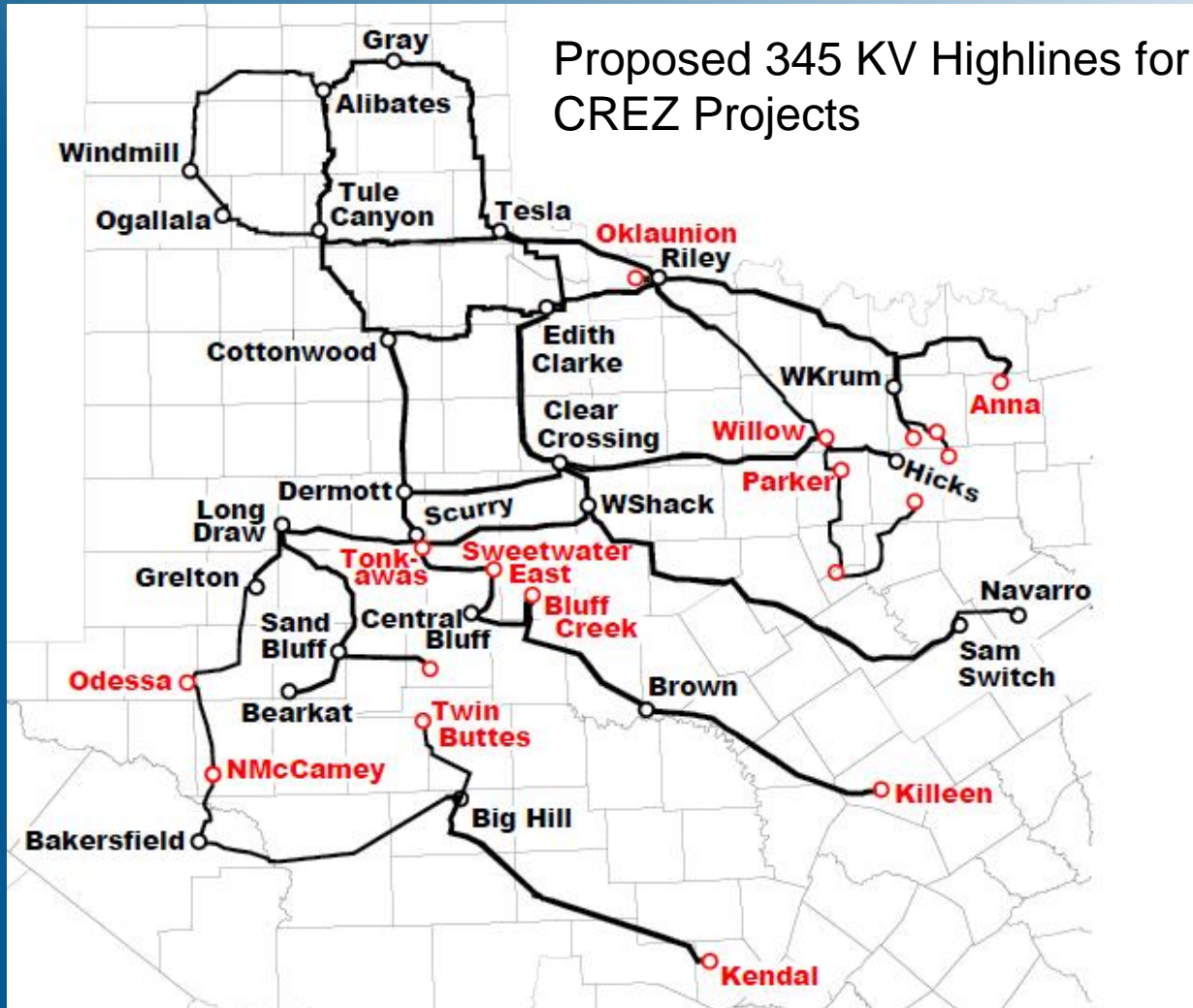
Synchronization/Power Factor Correction

- ❖ Part Nine: SSI in ERCOT-Five
- ❖ CREZ-Two



Synchronization/Power Factor Correction

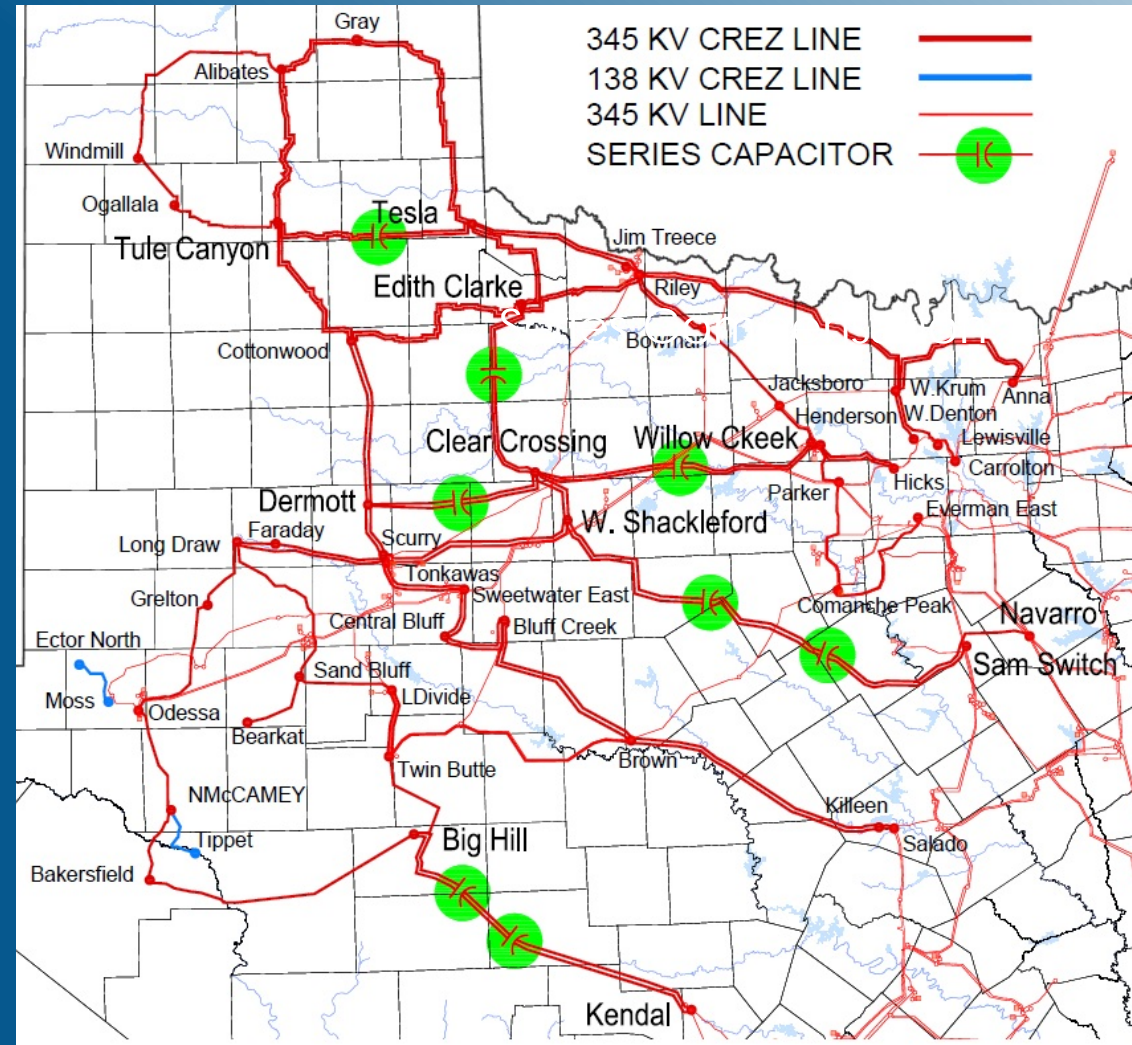
- ❖ Part Nine: SSI in ERCOT-Six
- ❖ CREZ-Three



Synchronization/Power Factor Correction



- ❖ Part Nine: SSI in ERCOT-Seven
- ❖ Series Compensation in ERCOT

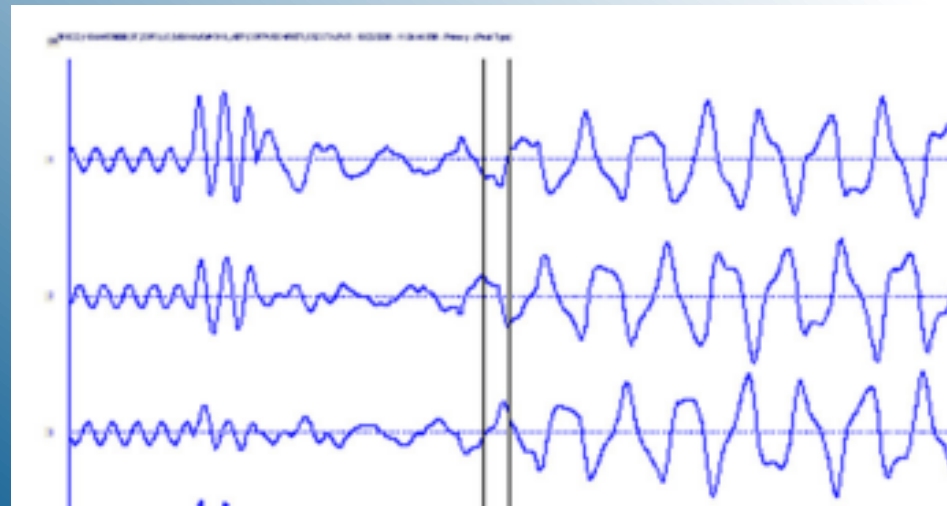


- CREZ
 - Tule Canyon – Tesla
 - Edith Clarke – Clear Crossing
 - Dermott – Clear Crossing
 - West Shackleford – Sam Switch/Navarro
 - Big Hill – Kendall
 - Clear Crossing – Willow Creek (2016)
- Rio Grande Valley
 - Lon Hill – Rio Hondo
 - Lon Hill – Edinburg
 - Lobo – Edinburg (2016)
- HorseHollow GenTie

Synchronization/Power Factor Correction

- ❖ Part Nine: SSI in ERCOT-Eight
 - ❖ SSR Event in ERCOT (2009)-One

- ❖ A fault occurred on the Ajo to Nelson Sharpe line.
- ❖ Fault cleared in 2.5 cycles by opening this line.
- ❖ The wind farms were then radially connected to the Ajo to Rio Hondo series compensated transmission line.
- ❖ Undamped oscillations at 22 Hz.
- ❖ Voltages at generator **doubled** in ~150 ms.
- ❖ Damage to wind generators and series capacitors occurred.



Synchronization/Power Factor Correction

- ❖ Part Nine: SSI in ERCOT-Nine
 - ❖ SSR Event in ERCOT (2009)-Two
- ❖ Series capacitors installed on long 345 kV lines to adjust the power factor and allow full loading.
- ❖ 1,000 MW of wind farms connected to Ajo.



Synchronization/Power Factor Correction

- ❖ Part Nine: SSI in ERCOT-Ten
 - ❖ SSR Event in ERCOT (2009)-Three



Lessons Learned

- ❖ Wind farms are vulnerable to SSO due to nearby series capacitors.
- ❖ Understanding and analysis techniques have advanced considerably.
- ❖ Wind farms are now routinely analyzed for risk.
- ❖ AEP resolved this problem by installing protection to automatically trip the wind farm.

Synchronization/Power Factor Correction



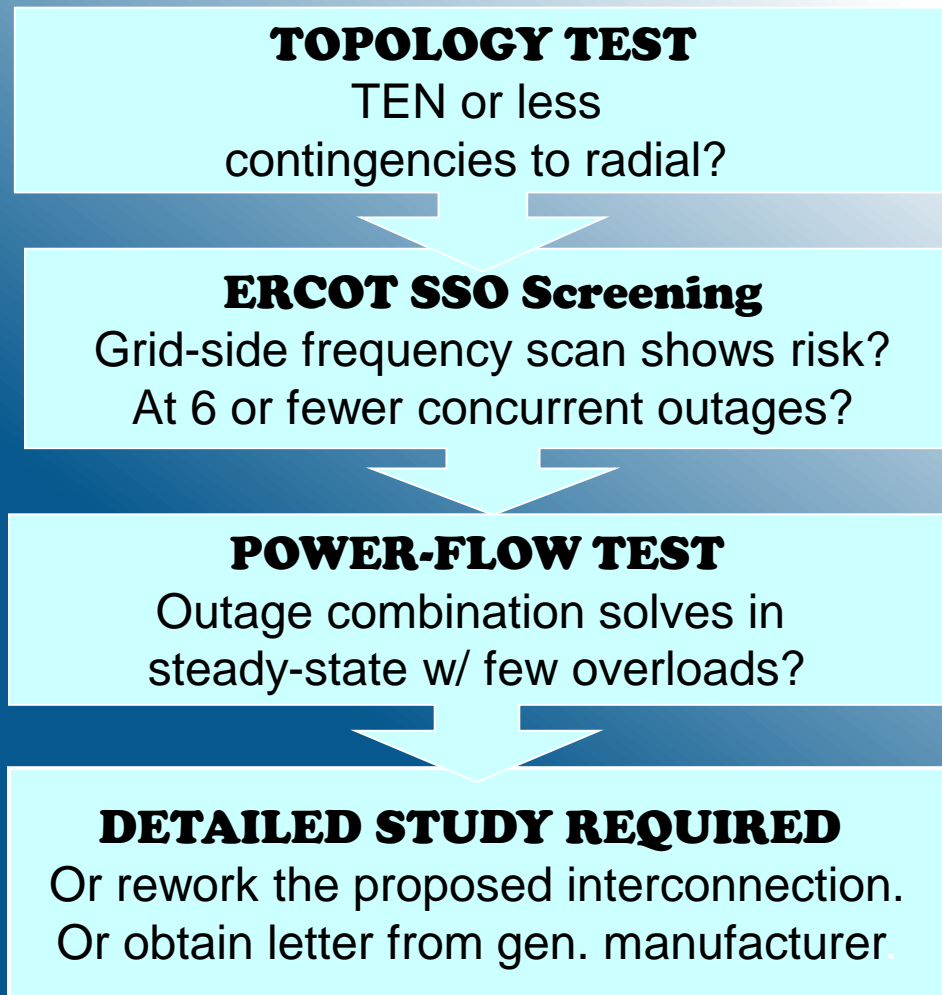
- ❖ Part Nine: SSI in ERCOT-Eleven
- ❖ SSR Event in ERCOT (2009)-Four

This simple test is performed by inspection: Does it take ten or fewer outages to make a generator radial to a series cap? This test will clear many projects, especially those far from the series capacitors and those connecting to the lower voltage network.

This tests whether the network electrical characteristics are conducive to resonance. ERCOT performs this test as part of the transmission planning and GINR process.

This tests the affected outage combinations to see whether they solve in a min load case. If the case doesn't solve or has many overloads, the outage isn't credible.

If credible SSR risk exists, then a study should be performed. In lieu of a study, generator resources may obtain a letter from their manufacturer or they may also rework their proposed interconnection to reduce risk exposure.



Synchronization/Power Factor Correction



- ❖ Part Nine: SSI in ERCOT-Twelve
 - ❖ SSR Event in ERCOT (2009)-Five

❖ Protection

- ❖ Involves forced tripping (removal of generator or series capacitor).
- ❖ Disruptive for a system that is already in a weakened state due to outages (“double blow”).
- ❖ Generally recommended as backup means of defense.

❖ Mitigation

- ❖ Involves reducing exposure to SSO risk.
- ❖ Generally allows the resource to continue operating, even when outages place the unit in stronger electrical coupling with a series capacitor.
- ❖ In many cases, may completely eliminate risk.
 - ❖ E.g. Horse Hollow Energy Center installed mitigation which allowed the wind turbines to operate radially to the series-compensated transmission line owned by NextEra.

Synchronization/Power Factor Correction



- ❖ Part Nine: SSI in ERCOT-Thirteen
 - ❖ SSR Event in ERCOT (2009)-Six

ERCOT System Planning

- ❖ ERCOT planning performs coordinated planning studies with input from NERC registered Transmission Planners (TPs), Transmission Owners (TOs) and other stakeholders to address region-wide reliability and economic transmission
- ❖ Performs transmission studies/assessment (both near-term and long-term planning horizon) to meet ERCOT and NERC standards (TPL-001-004, PRC-023, FAC-013)
- ❖ Assesses resource availability of existing units and future generators
- ❖ Load forecasting for the near-term and long-term Planning Horizon

Synchronization/Power Factor Correction

- ❖ Part Nine: SSI in ERCOT-Fourteen
 - ❖ SSR Event in ERCOT (2009)-Seven



Regional Transmission Plan (RTP) - Objective

- ❖ Regional Transmission Plan is developed annually by ERCOT in coordination with the Regional Planning Group (RPG) and the Transmission Service Providers (TSPs)
- ❖ Annual assessment to identify transmission needs of ERCOT system over the next six years
- ❖ Projects identified to meet the ERCOT/NERC reliability requirements (Reliability projects) and to reduce system congestion (Economic projects) that meet the ERCOT economic criteria