

- 3.12 Suppose a utility charges its large industrial customers \$0.08/kWh for energy plus \$10/mo per peak kVA (demand charge). Peak kVA means the highest level drawn by the load during the month. If a customer uses an average of 750 kVA during a 720-h month, with a 1000-kVA peak, what would be their monthly bill if their power factor (PF) is 0.8? How much money could be saved each month if their real power is the same but their PF is corrected to 1.0?

$$\text{MONTHLY ENERGY USAGE} = (750 \text{ kVA})(720)$$

$$\begin{aligned} P &= VI \cos \theta = VI(\text{p.f.}) \\ &= 750 \text{ kVA}(0.8) \\ &= 600 \text{ kW} \end{aligned}$$

$$\begin{aligned} W &= P \cdot \text{TIME} = (600 \text{ kW})(720) \\ &= 432,000 \text{ kWh} \end{aligned}$$

$$\begin{aligned} \$W &= (432,000)(0.08) = \\ &= \$34,560 \end{aligned}$$

$$\$KVA_{\text{PEAK}} = \$10 \times \underbrace{(1000)}_{\text{PEAK KVA}} = \$10,000$$

$$\text{TOTAL} = \$34,560 + \$10,000 = \underline{\underline{\$44,560}} \text{ ANS.}$$

IF P.F. CORRECTED TO 1.0,

$$\begin{aligned} P &= (600 \text{ kW})(720) \\ &= \$34,560 \leftarrow \text{REAL POWER UNCHANGED} \end{aligned}$$

$$\begin{aligned} \$KVA_{\text{PEAK}} &= W / \text{PF} = 1, \text{ THEN PEAK KVA} = \text{PEAK KW} \\ &= 800 \text{ KW} \end{aligned}$$

$$\$KVA = \$10 \cdot 800 \text{ KW} = \$8,000$$

$$\begin{aligned} \text{TOTAL} &= \$34,560 + 8,000 = 42,560 \\ &\Rightarrow \underline{\underline{\$2,000 \text{ SAVED}}} \text{ ANS} \end{aligned}$$

3.13 Consider a synchronous generator driven by a microturbine that delivers power to a strong, balanced, three-phase, wye-connected, 208-V grid (that 208 V is the line voltage). As shown, we will analyze it as if it consists of three separate single-phase circuits.

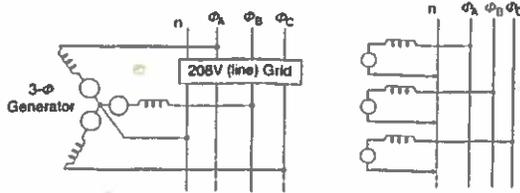


FIGURE P3.13a

a) $V^{1\phi} = \frac{208}{\sqrt{3}} = 120 \text{ V}$ ANS

- a. What is the phase voltage ($V_{\text{PHASE, GRID}}$) for the grid?
- b. The following vector (phasor) diagram for one of the phases shows the way the generator is currently operating. Its field current is creating an emf (E_{GEN}) of 130 V at a power angle $\delta = 6.9^\circ$. The current I_L delivered to the grid has a phase angle of 30° lagging with respect to the grid. The inductive reactance of the generator armature (stator) windings is $X_L = 0.5 \Omega$, which means the voltage drop across that inductance is $V_L = I_L X_L = 0.5 I_L$. And, of course, current through the inductance lags the voltage across the inductance by 90° (ELI the ICE man).

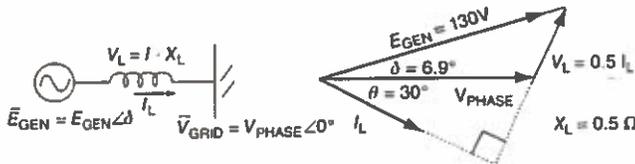


FIGURE P3.13b

Under the above conditions, find the following:

- b1. The current I_L through the inductive reactance (this means you need to solve the above triangle).
- b2. The real power P (W) delivered to the grid by this phase.
- b3. The reactive power Q (VAR) delivered to the grid by this phase.
- b4. Find the total real power P , reactive power Q , and apparent power S , delivered by the all three phases of the three-phase generator.

$V^{1\phi} = 120.08 \angle 0^\circ$

$\bar{I}_L = |I_L| \angle -30^\circ$

$\bar{E}_{\text{GEN}} = 130 \angle 6.9^\circ$

b1. $\bar{E}_{\text{GEN}} = \bar{I}_L (jX_L) + \bar{V}^{1\phi}$

$\bar{I}_L = \frac{1}{jX_L} [\bar{E}_{\text{GEN}} - \bar{V}^{1\phi}]$

$|I_L| \angle -30^\circ = \frac{1}{j \cdot 0.5} [130 \angle 6.9^\circ - 120.0 \angle 0^\circ]$

$I_L = \frac{1}{1 \angle -30^\circ} 36.109 \angle -30.14^\circ$

$\approx \underline{\underline{36.2 \text{ A}}}$ (I(L) * V/a)

(I(L) * V/a)

$$\begin{aligned} \underline{b2} \quad P^{1\phi} &= |V| |I_L| \cos \theta = 120 (36.2) \cos(30^\circ) \\ &= \underline{\underline{3762 \text{ W}}} \text{ Ans To GRID} \end{aligned}$$

$$\begin{aligned} \underline{b3} \quad Q^{1\phi} &= |V| |I_L| \sin \theta = (120)(36.2) \sin(30^\circ) \\ &= \underline{\underline{2172 \text{ KVAR}}} \text{ Ans To GRID} \end{aligned}$$

$$\begin{aligned} \underline{b4} \quad P_{\text{GEN}}^{1\phi} &= |V_{\text{GEN}}| |I_L| \cos(69 - (-30)) \\ &= (120)(36.2) () \\ &= \underline{\underline{3762 \text{ kW}}} \end{aligned}$$

$$P_{\text{GEN}}^{3\phi} = (3)(3762) = 11,29 \text{ kW}$$

$$\begin{aligned} Q_{\text{GEN}}^{1\phi} &= |V_{\text{GEN}}| |I_L| \sin(69 - (-30)) \\ &= 2826 \text{ KVAR} \end{aligned}$$

$$Q_{\text{GEN}}^{3\phi} = (3) Q_{\text{GEN}}^{1\phi} = 8,476 \text{ KVAR}$$

$$\begin{aligned} S^{3\phi} &= 3 (P_{\text{GEN}}^{1\phi} + Q_{\text{GEN}}^{1\phi}) = 3 (S_{\text{GEN}}^{1\phi}) \\ &= 3 (4704 \angle 36.9^\circ) \\ &= \underline{\underline{14.112 \text{ KVA}}} \text{ Ans.} \end{aligned}$$

- 3.14 A small wind turbine is trying to deliver 30 kW of real power through a 480-V (277-V phase voltage), three-phase power line to a load having a 0.95 lagging power factor. The power line phase has an impedance of $0.05 + j0.1 \Omega$. What voltage does the turbine have to provide at its end of the power line?

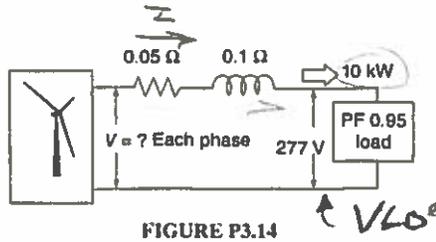


FIGURE P3.14

ELI

$$\theta = \cos^{-1}(0.95) = 18.19^\circ$$

$$\bar{I} = 38 \angle$$

AT LOAD

$$\begin{aligned} & \rightarrow 10 \text{ kW} = \\ & = 277 \angle 0^\circ \\ & \bar{I} \angle -18.19^\circ \\ & = 38 \angle -18.19^\circ \end{aligned}$$



$$P = VI \cos \theta; \text{ pf} = \cos \theta$$

$$\bar{I} = \frac{P}{V \cos \theta} \quad \theta = (\theta_r - \theta_i)$$

$$\bar{I} = \frac{P}{V \cos \theta}$$

$$= \frac{10 \text{ kW}}{(277)(0.95)} = 38 \text{ A}$$

$$\bar{V}_t = \bar{I} \bar{Z}_{TL} + \bar{V}_{LOAD}$$

$$= 38 \angle -18.19^\circ (0.05 + j0.1) + 277 \angle 0^\circ$$

$$= 4.24 \angle 45.24^\circ + 277 \angle 0^\circ$$

$$= 280 \angle 0.617^\circ$$

$$V_{t,LL} = \sqrt{3} (280) = \underline{\underline{484 \text{ V.r.p.}}} \text{ Ans.}$$

AT WIND TURBINE (l.n)

$$\begin{aligned} & \bar{V}_t = 280 \angle 0.617^\circ \\ & \bar{I} = 38 \angle -18.19^\circ \end{aligned}$$

1. T. Edison and G. Westinghouse advocated AC and DC power systems respectively. Outline their reasoning (pros and cons for each). Why did AC become the standard?

Thomas Alva Edison who, in 1879, created the first workable incandescent lamp. Edison's system was based on DC, which he preferred in part because it not only provided flicker-free light, but also because it enabled easier speed control of DC motors.

The downside of DC was that it was very difficult to change the voltage from one level to another. Power line losses are proportional to the square of the current flowing through them, while the power delivered is the product of current and voltage. Given DC's low voltage transmission constraint, Edison's customers had to be located within just a mile or two of a generating station.

George Westinghouse recognized the advantages of AC for transmitting power over greater distances and, utilizing AC technologies developed by Tesla. The transformer's invention in 1883 made stepping voltage up/down comparatively simple.

Meanwhile, the flicker problem for incandescent lamps with AC was resolved by trial and error with various frequencies until it was no longer a noticeable problem. Surprisingly, it was not until the 1930s that 60 Hz finally became the standard in the United States.

2. What was Samuel Insull's electric power industry insight and how did it lead to public utility commissions?

Samuel Insull shaped the modern electric utility by bringing the concepts of regulated utilities with monopoly franchises into being. It was his realization that the **key to making money was to find ways to spread the high fixed costs of facilities over as many customers as possible**. One way to do that was to aggressively market the advantages of electric power, especially, for use during the daytime to complement what was then the dominant nighttime lighting load. In previous practices, separate generators were used for industrial facilities, street lighting, street cars, and residential loads, but Insull's idea was to integrate the loads so that he could use the same expensive generation and transmission equipment on a more continuous basis to satisfy them all.

With more customers, more evenly balanced loads, and modest transmission losses, it made sense to build bigger power stations to take advantage of economies of scale, which also contributed to decreasing electricity prices and increasing profits. Large, centralized facilities with long transmission lines required tremendous capital investments; to raise such large sums, Insull introduced the idea of selling utility common stock to the public.

Insull also recognized the inefficiencies associated with multiple power companies competing for the same customers, with each building its own power plants and stringing its own wires up and down the streets. The risk of the monopoly alternative, of course, was that without customer choice, utilities could charge whatever they could get away with. To counter that criticism, he helped establish the concept of regulated monopolies with established franchise territories and prices controlled by *public utility commissions* (PUCs). The era of regulation had begun

3. What led to the PUHCA of 1935 and what was the Act's aim?

In the early part of the twentieth century, as enormous amounts of money were being made, utility companies began to merge and grow into larger conglomerates. A popular corporate form emerged, called a *utility holding company*. A holding company is a financial shell that exercises management control of one or more companies through ownership of their stock. Holding companies began to purchase each other and by 1929, 16 holding companies controlled 80% of the U.S. electricity market, with just three of them owning 45% of the total.

When the stock market crashed in 1929, the resulting depression drove many holding companies into bankruptcy causing investors to lose fortunes.

In response to these abuses, Congress created the *Public Utility Holding Company Act of 1935* (PUHCA) to regulate the gas and electric industries and prevent holding company excesses from reoccurring.

4. What led to the PURPA of 1978? What were the Act's two key provisions? How did the Act impact the renewable energy industry?

With the country in shock from the oil crisis of 1973 and with the economies of scale associated with ever larger power plants having pretty much played out, the country was drawn toward energy efficiency, renewable energy systems, and new, small, inexpensive gas turbines. The Public Utility Regulatory Policies Act of 1978 (PURPA) was designed to encourage these systems promoting energy efficiency.

The two key PURPA provisions:

- 1) PURPA allows certain industrial facilities and other customers to build and operate their own, small, on-site generators while remaining connected to the utility grid.
- 2) it also required utilities to purchase electricity from certain qualifying facilities (QFs) at a "just and reasonable price." The purchase price of QF electricity was to be based on what it would have cost the utility to generate the power itself or to purchase it on the open market.

5. What was the main thrust common to PURPA and EAct?

The whole thrust of both PURPA and EAct was to begin the opening up of that grid to allow generators to compete for customers, thereby hopefully driving down costs and prices.

6. What were the main provisions of EISA of 2007 ?

The [Energy Independence and Security Act of 2007](#) highlights:

- Increased automaker's fleetwide average automobile and light truck gas mileage requirement to 35 mpg
- Required vehicle electrification (hybrid and electric vehicles) including related technologies (batteries).
- Set requirements for using renewable biofuels ... e.g. mandating mixing ethanol in gasoline.
- Set requirements for appliance and lighting efficiency. Mandated incandescent light phase-out.
- Set requirements for residential, commercial, industrial building efficiency.
- [Set U.S. "Smart Grid" policy.](#)

See https://en.wikipedia.org/wiki/Energy_Independence_and_Security_Act_of_2007 accessed 6 Feb 18

7. EISA 2007 Title 13 institutionalized the term "Smart Grid"? What were major Title 13 provisions relating to "Smart Grid"?

Title XIII defines U.S. "Smart Grid" policy as follows:

- (1) Increased use of **digital information and controls technology** to **improve reliability, security, and efficiency** of the electric grid.
- (2) Dynamic **optimization of grid operations and resources**, with full cyber-security.
- (3) **Deployment and integration of distributed resources** and generation, including renewable resources.
- (4) **Development and incorporation of demand response**, demand-side resources, and energy-efficiency resources.
- (5) Deployment of **'smart' technologies** (real-time, automated, interactive technologies that optimize the physical operation of appliances and consumer devices) **for metering, communications concerning grid operations and status, and distribution automation**.
- (6) Integration of **'smart' appliances** and **consumer devices**.
- (7) **Deployment and integration** of **advanced electricity storage** and peak-shaving technologies, including plug-in electric and hybrid electric vehicles, and thermal storage air conditioning.
- (8) **Provision to consumers of timely information** and control options.
- (9) **Development of standards** for **communication** and **interoperability** of appliances and equipment connected to the electric grid, including the infrastructure serving the grid.
- (10) **Identification and lowering of unreasonable or unnecessary barriers** to adoption of smart grid technologies, practices, and services."

See https://en.wikipedia.org/wiki/Smart_grid accessed 6 Feb 18

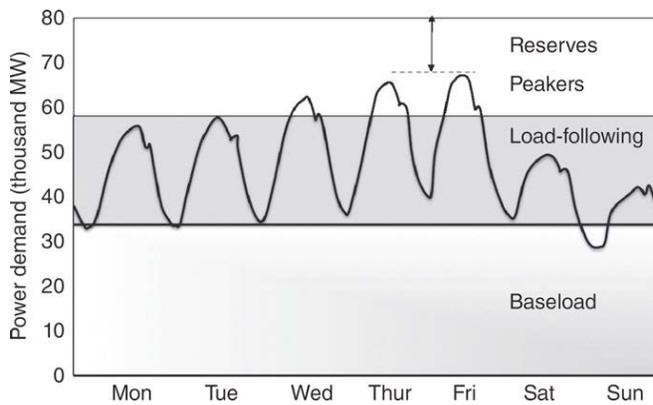
8. Outline the concept of balancing energy supply and demand. Describe normal load fluctuations and the affect that energy imbalances have on system frequency.

Managing the power grid is a constant struggle to balance power supply with customer demand.

If demand exceeds supply, turbine generators, which can be very massive, slow down just a bit, converting some of their kinetic energy (inertia) into extra electrical power to help meet the increased load. Since the frequency of the power generated is proportional to the generator's rotor speed, increasing load results in a drop in frequency.

Similarly, if demand decreases, turbines speed up a bit before they can be brought back under control.

9. Explain the roles that "must run – baseload", "load-following", "peakers", "reserves", and "renewable" power plants have in the power system. Give examples of each. What role does "demand response" play?



Ramp rates (how fast they can respond) as well as marginal operational costs (mostly fuel related) can determine which plants get dispatched first.

Some plants, such as nuclear reactors, are designed to run continuously at close to full power; so they are sometimes described as **baseload** (“must-run”) plants.

The intermittency of renewables means they are normally allowed to run whenever the wind is blowing or the sun is shining since they have almost zero marginal costs.

Most fossil-fueled plants and hydroelectric facilities can easily slowly ramp up and down to track the relatively smooth, predictable diurnal changes in load. These are **load-following** intermediate plants.

Some small, cheap to build, but expensive to run, plants, sometimes referred to as **peakers**, are mostly used only a few tens of hours per year to meet the highest peak demands. Some plants are connected to the grid, but deliver no power until they are called upon, such as when another plant suddenly trips off line – referred to as **spinning reserves**.

10. Describe how grid instabilities occur.

During normal operations, the grid responds to slight imbalances in supply and demand by automatically adjusting the power delivered by its generation facilities to bring system frequency back to acceptable levels. Small variations are routine; however, large deviations in frequency can cause the rotational speed of generators to fluctuate, leading to vibrations that can damage turbine blades and other equipment. Power plant pumps delivering cooling water and lubrication slow down as well.

Significant imbalances can lead to automatic shutdowns of portions of the grid, which can affect thousands of people. When parts of the grid shut down, especially when that occurs without warning, power that surges around the outage can potentially overload other parts of the grid causing those sections to go down as well. Avoiding these calamitous events requires fast-responding, automatic controls supplemented by fast operator actions.