

Exercises

- 5.1** File E5-1.csv contains the voltage and current waves at a single-phase load location. Both voltage and current are purely sinusoidal.
- Obtain the average power that is delivered to the load per AC cycle.
 - What is the power factor?
- 5.2** Consider the minutely power consumption measurements in file E5-2.csv.
- Plot the power profile based on the original measurements.
 - Plot the power profile based on the hourly average of the measurements.
 - What is the load factor based on the power profile in Part (a)?
 - What is the load factor based on the power profile in Part (b)?
- 5.3** Consider the minutely power generation measurements in file E5-3.csv that are obtained at a PV generation unit for a period of one day.
- At what time does PV generation start, and at what time does it stop?
 - Obtain the *average* and *variance* of the generated power at *each* hour.
- 5.4** File E5-4.csv contains the active power consumption profile and the reactive power consumption profile for a power distribution feeder.
- Plot the power factor profile.
 - Use the power factor profile in Part (a) to identify any potential capacitor bank switching event that may have occurred on this feeder.
 - Does the distribution substation experience reverse active power flow or reverse reactive power flow at any time? Elaborate your answer.
- 5.5** Consider the definition of active power in (5.5) and the definition of reactive power in (5.18). Show that $S^2 \geq P^2 + Q^2$, where $S = V_{\text{rms}} I_{\text{rms}}$. One option is to apply the Cauchy-Schwarz inequality to the terms in P^2 and Q^2 .
- 5.6** File E5-6.csv contains the voltage and current waves at a single-phase load location. Both voltage and current waves are distorted.
- How much active power is delivered to the load?
 - Obtain the DPF for this load.
 - Obtain the TPF for this load.
- 5.7** A pulse meter generates 20 pulses in a duration of five minutes as shown in Figure 5.25. Each pulse is equivalent to 0.5 kWh.
- How much is the minute-by-minute energy usage?
 - How much is the total energy usage?
- 5.8** File E5-8.csv contains the hourly load profile of a residential customer over a period of one month during the summer. How much is the monthly electricity bill of this customer under the following two different scenarios?
- The price of the electricity is flat at 8.28 ¢/kWh.

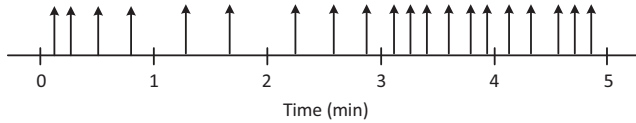


Figure 5.25 The train of pulses generated by a pulse watt-hour meter in Exercise 5.7.

(b) The price of electricity during the on-peak, mid-peak, and off-peak hours is 10.33 ¢/kWh, 8.28 ¢/kWh, and 7.27 ¢/kWh, respectively. The on-peak, mid-peak, and off-peak hours are previously shown in Figure 5.8.

5.9 Peak-load charges, also known as *demand charges*, are additional fees that are applied to the electric bills of commercial and industrial customers based upon the *highest* amount of their *power consumption* during a given time interval, typically 15 minutes, during the monthly billing period. Answer the following questions based on the power consumption measurements in file `E5-9.csv` that are obtained at a commercial building during one month:

(a) What is the monthly peak load during off-peak hours: 9 PM–8 AM?

(b) What is the monthly peak load during mid-peak hours: 8 AM–5 PM?

(c) What is the monthly peak load during on-peak hours: 5 PM–9 PM?

(d) Use the results in Parts (a), (b), and (c) to calculate the monthly demand charge for this commercial customer if the following peak-price rates are applied by the utility for demand charges: 6.88 \$/kW during on-peak hours; 2.74 \$/kW during mid-peak hours; and 1.31 \$/kW during off-peak hours. Note that, these rates are in per kW, not in per kWh. This is because peak-load pricing is done based on peak power usage, not energy usage.

5.10 Recall the “High 5 of 10” method that we discussed for baseline calculation in Section 5.4.2. Other similar methods include the “High 3 of 10” method and the “High 4 of 5” method [395]. In the “High 3 of 10” method, baseline calculation is done based on the *three* days, out of the 10 previous (non-event) days in the baseline window, that have the highest average load for the corresponding duration of the DR event. In the “High 4 of 5” method, baseline calculation is done based on the *four* days, out of the five previous (non-event) days in the baseline window, that have the highest average load for the corresponding duration of the DR event. Answer the following questions based on the load scenario in Example 5.8 and Table 5.3:

(a) Use the “High 3 of 10” method to calculate the baseline.

(b) Use the “High 4 of 5” method to calculate the baseline.

5.11 Consider the load profiles in Figure 5.12 and their features in Table 5.4.

(a) Repeat the clustering but this time solely based on Feature 1.

(b) Repeat the clustering but this time solely based on Feature 2.

5.12 Consider the load profiles in Figure 5.12 and their features in Table 5.4. Repeat the clustering but this time assume that $k = 3$, i.e., consider three sets.

5.13 Consider the load profile in Table 5.8.

Table 5.8 Load profile in Exercise 5.13.

| Hour | Load (kWh) | Hour | Load (kWh) | Hour | Load (kWh) |
|------|------------|------|------------|------|------------|
| 1 | 2.5545 | 9 | 0.8779 | 17 | 5.7395 |
| 2 | 2.0274 | 10 | 0.3607 | 18 | 5.6652 |
| 3 | 1.2027 | 11 | 0.6034 | 19 | 5.4435 |
| 4 | 0.9802 | 12 | 0.6359 | 20 | 4.2713 |
| 5 | 0.6986 | 13 | 0.6309 | 21 | 3.6523 |
| 6 | 1.0191 | 14 | 0.9193 | 22 | 2.3570 |
| 7 | 0.6980 | 15 | 3.3302 | 23 | 2.3303 |
| 8 | 1.1005 | 16 | 3.0359 | 24 | 2.6320 |

Table 5.9 Load parameters in Exercise 5.17.

| Appliance | P_0 | Q_0 | α_Z | α_I | α_P | β_Z | β_I | β_P |
|----------------|-------|-------|------------|------------|------------|-----------|-----------|-----------|
| Coffeemaker | 1413 | 13 | 0.13 | 1.62 | -0.75 | 3.89 | -6 | 3.11 |
| Microwave | 1366 | 451 | 1.39 | -1.96 | 1.57 | 50.1 | -93.6 | 44.5 |
| Vacuum | 855 | 221 | 1.18 | -0.38 | 0.2 | 4.1 | -5.87 | 2.77 |
| Air Compressor | 1109 | 487 | 0.71 | 0.46 | -0.17 | -1.33 | 4.04 | -1.7 |

(a) Extract its features based on Features 1 and 2 in Section 5.4.3.

(b) Cluster this load profile together with the load profiles in Table 5.4.

- 5.14** Consider the residential customer in Example 5.9. The total power usage of this customer is measured at 9.7 kW. What are the possible scenarios for the combinations of the major loads that can be on?
- 5.15** Consider a household which includes eight major appliances and equipment as we saw in Figure 5.16. Suppose we detect a *positive sharp edge* in both active power consumption, at 640 W, and reactive power consumption, at 95 VAR. Which appliance or equipment do you think has switched on?
- 5.16** Show that the optimization problem in (5.37) is the same as the following:

$$\min_{\alpha_Z, \alpha_I, \alpha_P} \sum_{i=1}^n \left[P_i - P_0 \left(\alpha_Z \left(\frac{V_i}{V_0} \right)^2 + \alpha_I \left(\frac{V}{V_0} \right) + \alpha_P \right) \right]^2. \quad (5.100)$$

- 5.17** Consider the list of load parameters for multiple appliances and equipment in Table 5.9. The rated voltage for all these appliances and equipment is $V_0 = 120$ V. Plot the active power consumption profile and the reactive power consumption profile for each appliance or equipment assuming that the voltage varies based on the voltage measurements in file E5-17.csv.
- 5.18** Use the problem formulation in (5.47) to obtain γ_P and γ_Q for the load in Example 5.10. Recall that the measurements are provided in Table 5.5.
- 5.19** Obtain the formulation of the measurement Jacobian matrix \mathbf{H} in Example 5.12. You need to calculate the partial derivative of active and reactive power injection

Table 5.10 Apparent power measurements in Exercise 5.20.

| Line # | Apparent Power (p.u.) | Line # | Apparent Power (p.u.) |
|--------|-----------------------|--------|-----------------------|
| 1,2 | $0.8346 + j0.4537$ | 3,5 | $-0.9700 - j0.1380$ |
| 1,4 | $1.0885 + j0.6647$ | 4,1 | $-1.0792 - j0.5355$ |
| 2,1 | $-0.8392 - j0.3812$ | 4,2 | $-0.2595 - j0.1800$ |
| 2,3 | $0.7801 + j0.1985$ | 4,5 | $-0.4559 - j0.1846$ |
| 2,4 | $0.2590 + j0.1894$ | 5,2 | $0.2022 + j0.0121$ |
| 2,5 | $-0.2022 - j0.0085$ | 5,3 | $0.9772 + j0.2233$ |
| 3,2 | $-0.7770 - j0.1417$ | 5,4 | $0.4558 + j0.2055$ |

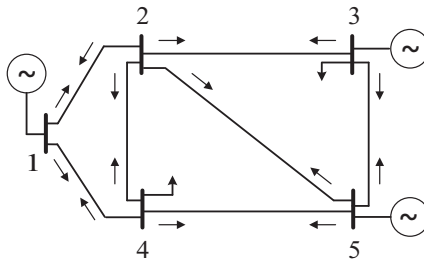


Figure 5.26 The power transmission network in Exercise 5.20.

at all buses and active and reactive power flow at all lines with respect to the voltage magnitude and voltage phase angle at all buses.

- 5.20** Consider the 5-bus transmission network in Figure 5.26. Suppose we measure apparent power flow at both ends of each transmission line. The measurements are given in Table 5.10. Estimate all the states of the system, i.e., the voltage magnitude and phase angle at all buses. Consider bus 1 as the reference bus. The voltage at bus 1 is measured at $1.077\angle 0^\circ$ per unit.
- 5.21** Consider the three-phase load in Figure 5.27. This load has a three-wire delta connection configuration topology. Explain why the sum of the instantaneous power usage that is measured by wattmeters W_1 and W_2 is equal to the total instantaneous power usage across all three phases.
- 5.22** File E5-22.csv contains the RMS voltage, RMS current, active power, and reactive power measurements at a three-phase load.
 - (a) Use the definition in (5.89) to plot the apparent power profile.
 - (b) Use the definition in (5.90) to plot the apparent power profile.
 - (c) Use the definition in (5.91) to plot the apparent power profile.
- 5.23** Consider the reactive power measurements in file E5-23.csv at an unbalanced three-phase distribution feeder. The feeder is equipped with a three-phase capacitor bank. The size of the capacitor bank is unknown. The reactive power measurements are made every minute. Estimate the size of the capacitor bank in

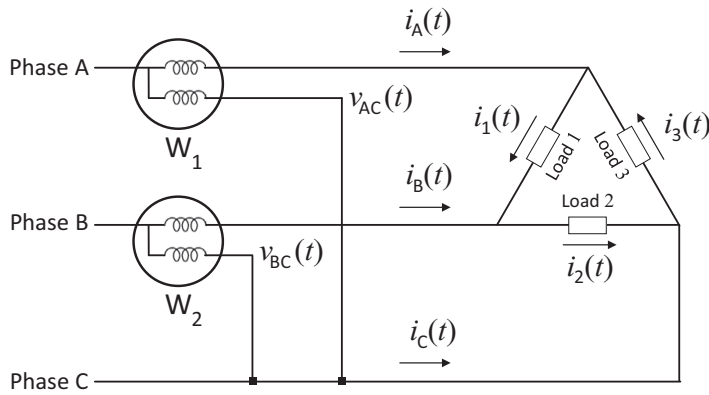


Figure 5.27 The three-phase three-wire delta topology in Exercise 5.21.

kVAR on each phase. Is the operation of the capacitor bank balanced across the three phases?

- 5.24** Consider the energy measurements in Table 5.11. The total energy usage is measured at each phase at feeder head. The individual energy usage is also measured at each load. All loads are single-phase with unknown phase connections. Identify the phase to which each load is connected.
- 5.25** Show that if ϵ_{Shift} is small and it is represented in radian, then we can approximate the error in power factor measurements in (5.94) as follows:

$$\epsilon_{\text{PF}} = 100\% \times |\tan(\theta - \phi) \epsilon_{\text{Shift}}|. \tag{5.101}$$

Table 5.11 Energy usage measurements in Exercise 5.24.

| Energy Usage | Measurements in Each Time Interval (kWh) | | | | | | |
|--------------|--|---------|---------|---------|---------|---------|--------|
| | $t = 1$ | $t = 2$ | $t = 3$ | $t = 4$ | $t = 5$ | $t = 6$ | |
| Load | 1 | 0.8598 | 0.8294 | 1.3148 | 3.7184 | 2.4262 | 2.9662 |
| | 2 | 0.4558 | 0.6994 | 0.5151 | 1.0585 | 1.4045 | 2.3076 |
| | 3 | 0.2922 | 0.2971 | 0.4493 | 0.7204 | 0.6462 | 0.2867 |
| | 4 | 0.9020 | 0.8699 | 1.0159 | 1.6155 | 1.5175 | 1.5944 |
| | 5 | 0.4612 | 0.6485 | 0.4823 | 3.7507 | 3.0228 | 2.0381 |
| | 6 | 0.6658 | 0.3821 | 0.4564 | 1.2185 | 1.5671 | 1.8570 |
| | 7 | 1.1095 | 0.6004 | 0.5992 | 0.4511 | 0.4685 | 3.5088 |
| | 8 | 0.6568 | 0.3187 | 0.3776 | 3.1684 | 4.5471 | 3.9740 |
| | 9 | 0.4605 | 0.4216 | 0.4070 | 2.0804 | 1.7104 | 1.4277 |
| Phase | A | 2.0261 | 1.9042 | 1.9145 | 5.9022 | 7.5384 | 7.9153 |
| | B | 1.4311 | 1.1509 | 1.3320 | 4.0688 | 3.9687 | 3.5694 |
| | C | 2.4473 | 2.0970 | 2.4514 | 8.0223 | 5.9182 | 8.5260 |