Lab 2

Power Factor Correction

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ECE 347L
Power Systems I Laboratory

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1 Introduction

In this lab, we establish how to manipulate the reactance of a given three-phase inductive load. We will see why it is necessary to manipulate the reactance in the load. A little insight is that inductive loads alter the current magnitude undesirably. Therefore, this process was made to fruition. There will be a demonstration of the process of manipulation. The process is called power factor correction. Correcting a power factor to our benefit.

Later in the lab, there is a demonstration of the process utilizing software. In this case, it will be MATLAB. Providing a function that can calculate the capacitive reactance needed to correct the power factor within the given requirements. These requirements will be established in the corresponding section.

The power factor measures how effectively incoming power is used within an electrical system. This is a ratio between the Real Power (P) compared to the total Apparent Power (S) within the system. In this case, the Real Power is the amount of power that actually drives equipment. Reactive Power (Q) is used to strongly influence voltage levels within a system to produce a magnetic field, however doesn't perform actual work on the system. Lastly, the Apparent Power is the combination of Real and Reactive Power.

Power factor correction increases the power factor observed upon a load. This correction increases the efficiency distributed throughout the system. Generally, a capacitor is treated as supplying reactive power in a system, while an inductor consumes reactive power. A linear load like an inductive motor can be corrected by utilising capacitors in parallel to offset the inductive load. When an inductor and capacitor are configured in parallel, the current flowing through these components cancel each other. This a vital way to control the power factor within a load to perform at an optimal way.

2 Calculations, Analysis, and Discussion

Observations

Load (Ω)	$\mathbf{V}_{Bus}$	$\mathbf{I}_{line}(A)$	Freq (Hz)	P (W)	Q (VAR)	PF
$600 \parallel -j171$	120.4∠0°	0.781∠74.24°	60.01	23.58	-85.51	0.251
$600 \parallel -j200$	120.4∠0°	0.692∠71.87°	60.01	24.56	-73.28	0.295
$600 \parallel -j240$	120.5∠0°	0.599∠68.45°	60.00	24.45	-61.09	0.339
$600 \parallel -j300$	120.4∠0°	0.510∠63.81°	59.98	23.57	-48.32	0.383
$600 \parallel -j400$	120.5∠0°	0.427∠56.77°	59.99	24.56	-36.96	0.478
$600 \parallel -j600$	120.4∠0°	0.324∠26.83°	59.98	24.05	-24.82	0.605
$600 \parallel -j1200$	120.3∠0°	0.233∠26.83°	59.96	23.75	-11.94	0.849
Open	120.3∠0°	0.199∠0°	59.98	23.92	-0.028	0.999

Table 1: Observed Values with $Z_L = 600\Omega$

Load (Ω)	$\mathbf{V}_{bus}(V)$	$\mathbf{I}_{line}(A)$	Freq (Hz)	P (W)	Q (VAR)	PF
(300+j300) $\parallel -j171$	120.4∠0°	0.625∠68.36°	60.03	23.92	-62.86	0.330
(300+j300) $\parallel -j200$	120.4∠0°	0.539∠63.92°	60.02	24.58	-50.73	0.379
(300+j300) $\parallel -j240$	120.4∠0°	0.455∠57.01°	60.02	24.53	-38.23	0.448
(300+j300) $\parallel -j300$	120.4∠0°	0.386∠46.57°	60.04	24.80	-26.30	0.534
(300+j300) $\parallel -j400$	120.4∠0°	0.322∠29.81°	60.03	24.78	-14.39	0.639
(300+j300) $\parallel -j600$	120.4∠0°	0.262∠4.95°	60.02	25.02	-2.323	0.793
(300+j300) $\parallel -j1200$	120.4∠0°	0.235∠-22.36°	60.02	24.94	10.35	0.878
Open	120.5∠0°	0.278∠-41.92°	60.01	24.93	22.40	0.744

Table 2: Observed Values with $Z_L = 300 + j300\Omega$

Calculations

The proceeding tables were established through calculations. Here $V_{Bus} = 120$ V for all of the ensuing calculations.

These equations were used to solve for the case where $Z_L = 600\ \Omega$:

$$Z = 600 \parallel jX_c = \frac{600}{600^2 + X_c^2} * [X_c^2 + j600X_c] \tag{1}$$

$$\theta = arctan(\frac{600}{X_c}) \tag{2}$$

$$PF = cos(\theta) \tag{3}$$

$$\bar{I}_{line} = \frac{\bar{V}}{\bar{\bar{Z}}} \tag{4}$$

$$\bar{S}_{Total} = \bar{V} * \bar{I}^*_{line} \tag{5}$$

$$P = S_{Total} * cos(\theta) \tag{6}$$

$$Q_c = S_{Total} * sin(\theta) \tag{7}$$

$$Q_{Total} = Q_c \tag{8}$$

$$\bar{I}_L = \frac{\bar{V}}{600} \tag{9}$$

$$\bar{S}_L = \bar{V} * \bar{I}^*_L \tag{10}$$

Load (Ω)	$\mathbf{Z}_L(\Omega)$	$\mathbf{I}_{line}(A)$	P(W)	$Q_c(VAR)$	$Q_{Total}(VAR)$
$600 \parallel -j171$	164.45∠-74.09°	0.729∠74.09°	24	-84.13	-84.13
$600 \parallel -j200$	189.74∠-71.57°	0.632∠71.57°	24	-71.95	-71.95
$600 \parallel -j240$	222.83∠-68.20°	0.539∠68.20°	24	-60.05	-60.05
$600 \parallel -j300$	268.33∠-63.43°	0.447∠63.43°	24	-48.39	-48.39
$600 \parallel -j400$	332.82∠-56.31°	0.361∠56.31°	24	-36.04	-36.04
$600 \parallel -j600$	424.26∠-45°	0.283∠45°	24	-24.01	-24.01
$600 \parallel -j1200$	536.66∠-26.57°	0.224∠26.57°	24	-12.02	-12.02
Open	600∠0°	0.2∠0°	24	0	0

Table 3: Calculated Values with $Z_L = 600\Omega$ Table One

Load (Ω)	$\mathbf{S}_{Total}(VA)$	$\mathbf{S}_L(VA)$	PF	PF Angle
$600 \parallel -j171$	87.48∠-74.09°	24∠0°	0.274	-74.09°
$600 \parallel -j200$	75.84∠-71.57°	24∠0°	0.316	-71.57°
$600 \parallel -j240$	64.68∠-68.20°	24∠0°	0.371	-68.20°
$600 \parallel -j300$	53.64∠-63.43°	24∠0°	0.447	-63.43°
$600 \parallel -j400$	43.32∠-56.31°	24∠0°	0.555	-56.31°
$600 \parallel -j600$	33.96∠-45°	24∠0°	0.707	-45°
$600 \parallel -j1200$	26.88∠-26.57°	24∠0°	0.894	-26.57°
Open	24∠0°	24∠0°	1.000	0°

Table 4: Calculated Values with $Z_L = 600\Omega$ Table Two

The following equations were used to solve for the case where Z_L = 300+j300 Ω and the capacitive bank was not connected:

$$\bar{Z} = 300 + j300 \tag{11}$$

$$\theta = arctan(\frac{300}{300}) \tag{12}$$

$$\bar{I}_L = \frac{\bar{V}}{\bar{Z}} \tag{13}$$

Using equation (10) above to find $\bar{S}_L$ one can find the following:

$$P = S_L * cos(\theta) \tag{14}$$

$$Q = S_L * sin(\theta) \tag{15}$$

Now for the equations when the capacitive bank is connected:

$$\bar{Z}' = (300 + j300) \parallel jX_c = \frac{300}{300^2 + 300 + X_c^2} * [X_c^2 + j(600 + X_c) * X_c] \tag{16}$$

$$\theta' = arctan(\frac{600 + X_c}{X_c}) \tag{17}$$

$$PF = cos(\theta') \tag{18}$$

Using equations (4) and (5) above to find $\bar{I}_{line}$ and $\bar{S}_{Total}$ respectively. One can find the results from the following equations:

$$Q^{'} = S_{Total} * sin(\theta^{'}) \tag{19}$$

$$Q_{Total} = Q^{'} \tag{20}$$

$$Q_c = Q^{'} - Q \tag{21}$$

Load (Ω)	$\mathbf{Z}_L(\Omega)$	$\mathbf{I}_{line}(A)$	P(W)	$Q_c(VAR)$	$Q_{Total}(VAR)$
(300+j300) $\parallel -j171$	222.16∠-68.27°	0.540∠68.27°	24	-84.21	-60.20
(300+j300) $\parallel -j200$	268.33∠-64.43°	0.447∠64.43°	24	-72.40	-48.39
(300+j300) $\parallel -j240$	332.82∠-56.31°	0.361∠56.31°	24	-60.05	-36.04
(300+j300) $\parallel -j300$	424.26∠-45°	0.283∠45°	24	-48.02	24.01
(300+j300) $\parallel -j400$	536.66∠-26.57°	0.224∠26.57°	24	-36.03	-12.02
(300+j300) $\parallel -j600$	600∠0°	0.2∠0°	24	-24.01	0
(300+j300) $\parallel -j1200$	536.66∠26.57°	0.224∠-26.57°	24	-11.99	12.02
Open	424.26∠45°	0.283∠-45°	24	0	24.01

Table 5: Calculated Values with $Z_L = 300 + j300\Omega$ Table One

Load (Ω)	$\mathbf{S}_{Total}(VA)$	$\mathbf{S}_L(VA)$	PF	PF Angle
(300+j300) $\parallel -j171$	64.80∠-68.27°	33.96∠45°	0.370	-68.27°
(300+j300) $\parallel -j200$	53.64∠-64.43°	33.96∠45°	0.447	-64.43°
(300+j300) $\parallel -j240$	43.32∠-56.31°	33.96∠45°	0.555	-56.31°
(300+j300) $\parallel -j300$	33.96∠-45°	33.96∠45°	0.707	-45°
(300+j300) $\parallel -j400$	26.88∠-26.57°	33.96∠45°	0.894	-26.57°
(300+j300) $\parallel -j600$	24∠0°	33.96∠45°	1	0°
(300+j300) $\parallel -j1200$	26.88∠26.57°	33.96∠45°	0.894	26.57°
Open	33.96∠45°	33.96∠45°	0.707	45°

Table 6: Calculated Values with $Z_L = 300 + j300\Omega$ Table Two

Analysis and Discussion

Case 1

In this case, Q_c is Q_{total} . The reason is that reactive power is generated by passive components. There is only a capacitance in this circuit. As a result, Q_c is Q_{total}.

- $\bar{V}_{bus}$ does not change with Q_c.
- For $\bar{I}_{line}$: $|\bar{I}_{line}|$ decreases as Q_c increases. The phase angle of $\bar{I}_{line}$ decreases as Q_c increases.
- PF increases as Q_c increases.
- PF Angle increases as Q_c increases.
- P_{total} has few variations with different value of Q_c, but all of P_{total} are almost same. Hence, P_{total} doesn't change with Q_c.
- Q_{total} is as same as Q_c. How does the Q_c change, how does Q_{total} change.

Along with the calculations, we figure out what happened.

- $\bar{V}_{bus}$ does not vary as a function of Q_c. It only depends on power supply.
- $|\bar{I}_{line}|$ decreases as Q_c increases. The reason is that firstly, Q_c is equal to $\frac{(\bar{V}_{bus})^2}{X_c}$ (Note: X_c is a negative value), which means Q_c is in inverse proportion to X_c. Q_c increases as X_c decreases and decreases as X_c increases. Additionally, $|\bar{I}_{line}|= \frac{|\bar{V}_{bus}|}{|Z|}$ and $\frac{1}{|Z|} = |\frac{1}{600} + \frac{1}{j*X_c}| = |\frac{1}{600} - j\frac{1}{X_c}| = \sqrt{(\frac{1}{600})^2 + (-j\frac{1}{X_c})^2} = \sqrt{(\frac{1}{600})^2 - (\frac{1}{X_c})^2}$ (Note: X_c is a negative value), $\frac{1}{|Z|}$ increases as X_c increases. Then, $|\bar{I}_{line}|$ decreases as $\frac{1}{|Z|}$ decreases and increases $\frac{1}{|Z|}$ increases if the voltage is constant. Therefore, $|\bar{I}_{line}|$ is proportional to X_c. As a result, $|\bar{I}_{line}|$ is inversely proportional to Q_c.
  The phase angle of $\bar{I}_{line}$ increases as Q_c increases. According to $\bar{I}_{line} = \frac{\bar{V}}{\bar{Z}}$, the phase angle of $\bar{I}_{line}$ is an opposite number to the impedance angle which is also called PF Angle. PF Angle is proportional to Q_c. In conclusion, The phase angle of $\bar{I}_{line}$ is in inverse proportion to Q_c.
- PF increases as Q_c increases. Reason: PF is equal to $\cos(\theta)$. According to $cos(\theta) = \frac{P}{S} = \frac{P}{\sqrt{P^2+Q_c^2}}$ (Note: Q_c is a negative value), PF is proportional to Q_c.

- PF Angle increases as Q_c increases. Reason: With $\theta = arctan(\frac{600}{X_c})$, PF is inversely proportional to X_c. According to the discussion in $|\bar{I}_{line}|$, Q_c is inversely proportional to X_c. Conclusively, PF Angle is proportional to Q_c.
- P_{total} is not changed by Q_c. Reason: Real power is only generated by resistance. In this circuit, The resistance is always a same value so P_{total} will not be changed.
- Q_{total} is Q_c. The reason is that reactive power is generated by passive components. There is only a capacitance in this circuit. As a result, Q_c is Q_{total} .

Case 2

Because we do not have Q_c in observation, we draw the following conclusions combining with calculation data.

- $\bar{V}_{bus}$ does not change with Q_c.
- PF Angle increases as Q_c increases.
- PF increases as Q_c increases if the absolute value of Q_c is bigger than Q_L, and decreases as Q_c increases if the absolute value of Q_c is smaller than Q_L.
- For $\bar{I}_{line}$: $|\bar{I}_{line}|$ decreases as Q_c increases. The phase angle of $\bar{I}_{line}$ decreases as Q_c increases.
- P_{total} does not vary as Q_c increases.
- Q_{Total} increases as Q_c increases.

The specific reasons are as follows.

- $\bar{V}_{bus}$ does not vary as a function of Q_c. It only depends on power supply.
- PF Angle increases as Q_c increases. Reason: With $\theta = arctan(\frac{600}{X_c})$, PF is inversely proportional to X_c. In addition, Q_c is equal to $\frac{(\bar{V}_{bus})^2}{X_c}$ (Note: X_c is a negative value), which means Q_c is in inverse proportion to X_c. Conclusively, PF Angle is proportional to Q_c. In other words, PF angle increases as Q_c increases.

- PF increases as Q_c increases if the absolute value of Q_c is bigger than Q_L, and decreases as Q_c increases if the absolute value of Q_c is smaller than Q_L. Reason: PF is equal to cos(θ). According to $cos(\theta) = \frac{P}{S} = \frac{P}{\sqrt{P^2+(Q_c+Q_L)^2}}$ (Note: Q_c is a negative value), if the absolute value of Q_c is bigger than Q_L, PF increases as Q_c increases. If the absolute value of Q_c is smaller than Q_L, PF decreases as Q_c increases. In conclusion, PF is proportional to Q_c if the absolute value of Q_c is bigger than Q_L, and is inversely proportional to Q_c if the absolute value of Q_c is smaller than Q_L.

- $|\bar{I}_{line}|$ decreases as Q_c increases. Additionally, according to $\bar{I}_{line}= \frac{\bar{V}_{bus}}{|Z|}$ and $\frac{1}{|Z|} = |\frac{1}{300+j300}+\frac{1}{j*X_c}| = |\frac{1}{300+j300}-j\frac{1}{X_c}| = \sqrt{(\frac{1}{300+j300})^2+(-j\frac{1}{X_c})^2} = \sqrt{(\frac{1}{300+j300})^2-(\frac{1}{X_c})^2}$, $\frac{1}{|Z|}$ increases as X_c increases. As discussing in PF Angle, Q_c is in inverse proportion to X_c. Therefore, $Q_c$is inversely proportional to $\frac{1}{|Z|}$. Then, $\bar{I}_{line}$ increases as $\frac{1}{|Z|}$ increases if the voltage is a constant. As a result, $\bar{I}_{line}$ is inversely proportional to Q_c.
  The phase angle of $\bar{I}_{line}$ decreases as Q_c increases. According to $\bar{I}_{line} =\frac{\bar{V}}{\bar{Z}}$, the phase angle of $\bar{I}_{line}$ is opposite number to the impedance angle which is also called PF Angle. PF Angle is proportional to Q_c, according to the discussion in No.2. In conclusion, The phase angle of $\bar{I}_{line}$ decreases as Q_c increases.

- P_{total} does not change by Q_c. Reason: Real power is only generated by resistance. The resistance does not change so P_{total} will not be changed.

- Q_{total} increases as Q_c increases. Because of $Q_c = Q_{total}$ - Q_l, Q_{total} is equal to Q_l + Q_c. When Q_c increases, Q_{total} increases (Note: Q_c is a negative value). Therefore, Q_{total} is proportional to Q_c.

In conclusion, we found that the analysis agrees with the theory as discussed in lecture. Although there is a slight difference between the magnitudes of I_{line}. The calculations are smaller than expected from the observations, but both display similar behavior. We don't know the specific tolerances of each load, therefore that might skew our calculations some.

3 Engineering Design

Results

The Program can be observed on the Appendix with the Program Requirements, Program Description, and User Manual.

S_{Load} [MVA]	Calculated Power Factor	Q_C for PF = 0.95 (rounded) [MVAR]	Q_C for PF = 1.00 [MVAR]
1+j1	0.7071	-0.6713 (-0.7500)	-1.000
1+j2	0.4472	-1.6713 (-1.7500)	-2.000
1+j3	0.3162	-2.6713 (-2.7500)	-3.000
2+j1	0.8944	-0.3426 (-0.2500)	-1.00
2+j2	0.7071	-1.3426 (-1.2500)	-2.000
2+j3	0.5547	-2.3426 (-2.2500)	-3.000
3+j1	0.9487	-0.0139 (0.0000)	-1.000
3+j2	0.8321	-1.0139 (-1.000)	-2.000
3+j3	0.7071	-2.0139 (-2.000)	-3.000
4+j2	0.8944	-0.6853 (-.7500)	-2.000
4+j3	0.800	-1.6853 (-1.7500)	-3.000

Table 7: Sample Computation From Power Factor Correction Program

To demonstrate the functionality of the program we listed some example computations based on a certain cases of S_{Load}. Table 7 displays the Power Factor before correction and the required capacitor reactance needed to correct the power factor to the design requirements. From this small sample size of computations done from the MATLAB program, this table displays a repeating behavior between the Q_C to achieve a Power Factor of 0.95 lagging and 1.00 (unity). If the Real Power remains unchanged, but the Reactive Power increases by a factor of 1 each time, we observed the capacitor reactance required for a Power factor of 0.95 lagging also increases by a factor of 1. For example, an apparent load of 4+j2 has a Power Factor of 0.8944 and needs a capacitor reactance of -0.6853 MVAR, but if the the Reactive Power (Q_L) is increased to 3MVAR then the capacitor required is increased to -1.6853 MVAR. Since a load at a Power Factor of unity has no reactive element, that's why we observed that the capacitive load will match regardless of the inductive load on the system. This way the reactive elements in parallel will cancel each other out, and this results in a purely Real Power system.

```
The current S_Load = 5.0000 + j3.0000

Power_Factor =

    0.8575

The Q_Uncorrected = 3.0000 MVAR and the Q_corrected = 1.6434 MVAR for desried Power Factor = 0.950
The required Capacitor Reactive Power (Q_C) = -1.2500 MVAR in parallel for a corresponding Power Factor = 0.950

The Q_Uncorrected = 3.0000 MVAR and the Q_corrected = 0.0000 MVAR for desried Power Factor = 1.000
The required Capacitor Reactive Power (Q_C) = -3.0000 MVAR in parallel for a corresponding Power Factor = 1.000

The Reactive Power of the Capacitor should approximately be between -1.2500 and -3.0000 MVAR
```

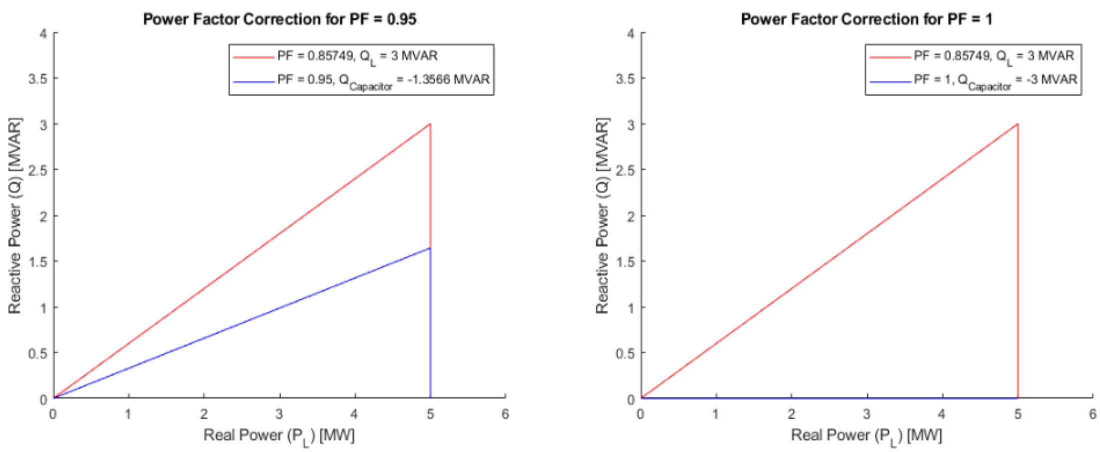

Figure 1: Example MATLAB Result for S_{Load} = 5+j3 MVA

```
The current S_Load = 9.0000 + j5.0000

Wrong Option! |S_Load| > 10 MVA
```

Figure 2: Example MATLAB Error Results for S_{Load} = 9+j4 MVA

These are the possible results from the designed MATLAB program. If the $|S_{Load}|$ is less than 10 MVA then it'll display the results from Figure 1. These results will include a printing of the respective S_{Load} and the corresponding Power Factor associated from the inductive load. Initially it calculates and displays the $Q_{Uncorrected}$ and $Q_{Corrected}$ required to determine the minimum capacitance required for a Power Factor of 0.95 lagging. Then it repeats these calculations for a unity Power Factor and again displays the results. Along with the presented results it displays a visual aid in the form of two plots that displays Q_C as a function of P_L and Q_L.

The two plots display the power triangle of the load before and after Power Factor Correction. The red triangle is the power triangle of the load before correction. To correct the Power Factor, it's required to place a capacitor in parallel to load. This capacitor generates Reactive Power (negative reactance) that is applied to the load. Therefore, this negative reactance combined with the reactance of the inductive load produces less total Reactive Power experience to the load while increasing the Power Factor. This combination can be observed in the blue power triangle for the corrected Power Factor, since the total Q_L after the addition of the capacitor will be less than what was tested previously. For a desired unity Power Factor the load has no Reactive elements and the plot generated by the MATLAB displays this to be true. Whatever the initial reactance of the load tested is, the reactance of the capacitor will match this Reactive Power of Q_L. The most important function of this MATLAB program is to display the acceptable ranges that the reactance of the capacitor (Q_C) needs to be to achieve a Power Factor range of 0.95 lagging $\leq DesiredPowerfactor \leq 1.00(unity)$.

Due to the constraint that S_{Load} is exclusive of $S_{Load} > 10$ MVA, if a load exceeds this constraint then the result from Figure 2 is displayed to the user. This result is displayed in the form of an error message alerting the user that they inputted an $|S_{Load}|$ outside the program requirements. The user will have to input a more appropriate load to satisfy the constraint to observe a result seen in Figure 1.

4 Conclusion

In this experiment, it explores how a power factor of an inductive load can be adjusted by adding a capacitor in parallel to the load bus. The lab test two different loads with the following impedance; $Z_L = 600\ \Omega$ and $Z_L = 300 + \text{j}300\ \Omega$ in a Wye configuration. Then it adds a Wye connected capacitor load bank in parallel to the two load cases to observe how the power factor changes as the capacitive load changes. The second portion of the lab is devise and build a MATLAB program to determine the range of reactance of an capacitor necessary to correct the power factor of an inductive load to 0.95 lagging to 1.00 unity. This program has to display this power factor change visually through a plot of Q_C as a function of P_L and Q_L.

For the first case of tested impedances, we had a strictly resistive load of 600 Ω. Once we add a capacitive load in parallel to our resistive load then we would expect to be supplying reactive power to our load. From both the observation and the calculated data seen in Table 1,3, and4 verifies this fact. As the resistive load remains unchanged, but the capacitor reactance increases we observed that the the effect of the capacitor plays a more insignificant role upon the load. This change inherently increases the power factor observed. Due to the Wye connection we observed no flucuation in the line voltages. However, we observed significant flucuation in the line current. For a capacitive load, the current leads the voltage, but as the increased capacitor reactance on the load had a reduced effect we starting observing that the current slowly became more in phase with the voltage.

For the second case we have a complex load that has a resistive and inductive elements. When capacitors and inductors are in parallel, they neutralize each other due to the difference in polarity of their reactances. Therefore, we would expect that there would be an equalizing point where the load is purely real power with a power factor of unity. Initially when -j171 was placed in parallel to the inductive load, we observed a mostly capacitive load that's supplying reactive power to the system. From the observations we observed that this point was closest when the -j600 VAR reactance was placed in parallel to the inductive load. As expected this is when the total reactance was at its lowest value. Once the load past this equilibrium we observed that load behaved inductively again and was consuming reactive power.

Overall, the theory described in lecture verifies the observations and calculated values from this section of the lab.

Lastly, the MATLAB program designed provided a good visual representation of the power triangle as the power factor corrected to a desired range. Due to the constraints listed in the lab requirements, the program was designed to only test values below $|S_{Load}| < 10$ MVA. The program verifies the behavior observed with the observations and calculations observed from Part 1, but with a single line load. The plots generated displays that to correct the power factor of a specific load we want to get the reactive power of the load to be as minimum as possible. That's why when we observed that the higher the reactive power of the initial load is, we need to offset it by having as much of the opposite polarity as possible.

Overall, this lab was straight forward in the objectives, but it was an important representation on how we can replicate more ideal load conditions by manipulating a capacitive load in parallel to an inductive load. By observing how the slight changes in a 3-phase and a single-phase system can drastically improve the behavior of the system and achieve a more ideal power factor.

A Appendix: Published MATLAB Program

Bill of materials (BoM)

	Item	Vendor	Part Number	Quantity	List Price	Net Price
1	Power Supply, Var. 3ph, 24Vac	Lab-Volt	8821-20	1	$2,870.00	$2,870.00
2	Inter Data Acq Ctr for model 9069-1	Lab-Volt	9063-B0	1	$3,499.00	$3,499.00
3	Resistance Load Module, 3 Ph.	Lab-Volt	8311-00	1	$445.00	$445.00
4	Inductance Load Module, 3 Ph.	Lab-Volt	8321-00	1	$781.00	$781.00
5	Capacitance Load Module, 3 Ph.	Lab-Volt	8331-00	1	$560.00	$560.00
6	Black-36.0" (914.40mm) Banana Plug, Single, Stackable To Banana Plug, Single, Stackable Patch Cord 5000VDC (5kV)	Pomona Electronics	B-36-0	3	$6.09	$18.27
7	Red-36.0" (914.40mm) Banana Plug, Single, Stackable To Banana Plug, Single, Stackable Patch Cord 5000VDC (5kV)	Pomona Electronics	B-36-2	4	$6.09	$24.36
8	Blue-36.0" (914.40mm) Banana Plug, Single, Stackable To Banana Plug, Single, Stackable Patch Cord 5000VDC (5kV)	Pomona Electronics	B-36-6	3	$6.09	$18.27
9	White-36.0" (914.40mm) Banana Plug, Single, Stackable To Banana Plug, Single, Stackable Patch Cord 5000VDC (5kV)	Pomona Electronics	B-36-9	6	$6.09	$36.54
				Total Price	$8,179.36	$8252.44

Table 8: Bill of Materials

The following documents can be observed on the next page:

- Program Requirements
- Program Description
- User Manual
- Program Code

Team 3 - Kai Boldt, Ryan Nand, Lihong Zhao

EE347L Lab 2 - Power factor Correction

Contents

Program Requirements

Design a power factor correction function that calculates required reactive power for a given load according to the following specifications

1) The function arguments shall be $S_{Load} = P_L + jQ_L$ = [1+j0:10+j10], exclusive of $|S_Load|$ > 10MVA

2) The function shall return the capaciatance Q_C , required to maintain 0.95 lagging <= PF <= 1.0 for given S_Load

3) The function be limited to discrete values in ncrements of 0.25 Mvar

4) Plot of Q_C as a function of P_L and Q_L given the ranges and constraints noted above

Program Description

The program takes an user inputted P_L (Real Power) and Q_L (Reactive Power), and format the user inputs into the appropriate $S_{Load} = P_L + jQ_L$

Then either will complete one of two different actions:

1) If $|S_{Load}|$ <= 10 MVA

Then the program will calculate the Original Power Factor and the Angle Θ based on the user inputs

$$PF = \frac{P_L}{|S_{Load}|}$$

$$\Theta = cos^{-1}(PF)$$

- Then will proceed to enter a for loop that'll determine the Q_C for a Power Factor = 0.95 lagging and a Power Factor = 1.00 (Unity). To execute this, the program will determine the $Q_{Uncorrected}$ and the respective Θ with $Q_{Corrected}$ desired for that respective Power Factor. The program will determine the Reactive Power of the Capacitor parallel to the load, by taking the difference of the $Q_{Uncorrected}$ and $Q_{Corrected}$

$$Q_{Uncorrected} = Ptan\left(\Theta_{Current_{PF}}\right)$$

$$Q_{Corrected} = Ptan\left(\Theta_{Desired_{PF}}\right)$$

$$Q_{Cap} = Q_{Uncorrected} - Q_{Corrected} = P\left[tan\left(\Theta_{Current_{PF}}\right) - tan\left(\Theta_{Desired_{PF}}\right)\right]$$

*Lastly, the program will plot the calculated Capacitive Reactances Q_C in parallel as a function of P_L and Q_L. These will be given as Power Triangle plots displaying the before and after the Capacitive Load effect on the Power factor

2) If $|S_{Load}|$ > 10 MVA

Program spits an error message stating that $|S_Load|$ is outside the given parameters

User Manual

User Input Requirement

Save the program in the current folder directory. The name of the program is currently EE347L_Lab2_PowerFactorCorrection. Therefore, The only requirement for the to run the Power Factor Correction function is typing EE347L_Lab2_PowerFactorCorrection(P_L, Q_L) into the command window with the desired P_L (Real Power)value and Q_L (Reactive Power) value. Then the program will take these two user inputs and solves for the desired reactance of the capacitor needed to acheive a Power Factor between 0.95 lagging and 1 (Unity).

Program Code

```
function Power_Factor_Correction = EE347L_Lab2_PowerFactorCorrection(P_L, Q_L)
%P_L = input('Enter Appropiate Real Power (MW): ');         %User Input for Real Power
%Q_L = input('Enter Appropiate Reactive Power (Mvar): ');   %User Input for Reactive Power

jQ_L = j*Q_L;                                               %Makes Reactive Power Complex

S_Load = P_L + jQ_L;
fprintf('The current S_Load = %.4f + j%.4f \n\n',P_L, Q_L)

if abs(S_Load) <= 10;
    Power_Factor =  P_L/(abs(S_Load))                      %Determine Power Factor (PF = P/S)
    Angle_Theta = acosd(Power_Factor);                     %Theta = cos^-1(PF)

    PF_Desired = [0.95, 1.00];                             %Power Factor of 0.95 lagging and 1 unity

        for i = 1:2
            Q_Uncorrected = P_L*tand(Angle_Theta);         %Q_Uncorrected, should equal Q_L
```

```
            Desired_Theta = acosd(PF_Desired(i));           %Coressponding Theta base on desired Power Factor

            Q_Corrected(i) = P_L*(tand(Desired_Theta));      %Reactive Power correction due to desired angle theta
            Q_Capacitor(i) = Q_Uncorrected-Q_Corrected(i);  %Reactance needed from the capacitor [MVAR]

            fprintf('The Q_Uncorrected = %.4f MVAR and the Q_corrected = %.4f MVAR for desried Power Factor = %.3f\n', Q_Uncorrected, Q_Corrected(i),PF_Desired(i))

            %Round Q_Capacitor to nearest 0.25
            nearestValue = 0.25;
            Round_Q_Capacitor(i) = round(Q_Capacitor(i)/nearestValue)*nearestValue;

            fprintf('The required Capacitor Reactive Power (Q_C) = -%.4f MVAR in parallel for a corresponding Power Factor = %.3f\n\n',Round_Q_Capacitor(i),PF_Desire

            %Plot of Power Triangle for Power Factor Correction
            figure()
            line([0,P_L], [0,Q_L], 'Color', 'r');                    %Plots Apparent Power of Uncorrected S_Load
            line([0,P_L], [0,Q_Corrected(i)], 'Color', 'b');         %Plots Apparent Power of Corrected S_Load
            line([P_L,P_L], [0,Q_L], 'Color', 'r');
            line([P_L,P_L], [0,Q_Corrected(i)], 'Color', 'b');
            title(sprintf('Power Factor Correction for PF = %s', num2str(PF_Desired(i))))
            axis([0,(P_L + 1),0,(Q_L + 1)]);
            xlabel('Real Power (P_{L}) [MW]')
            ylabel('Reactive Power (Q) [MVAR]')
            PF_Orig = ['PF = ', num2str(Power_Factor), ', Q_{L} = ', num2str(Q_L), ' MVAR'];
            PF_Des = ['PF = ', num2str(PF_Desired(i)), ', Q_{Capacitor} = -', num2str(Q_Capacitor(i)), ' MVAR'];
            legend(PF_Orig, PF_Des)

        end
        fprintf('The Reactive Power of the Capacitor should approximately be between -%.4f and -%.4f MVAR\n', Round_Q_Capacitor(1), Round_Q_Capacitor(2))
else
    disp('Wrong Option! |S_Load| > 10 MVA')                %User entered inappropiate value for S_Load
end
end
```

References

[1] S. Chapman, "Electric Machinery and Power System Fundamentals," New York: McGraw-Hill, 2002 pp.241-243

[2] Portland State University Power Lab, *347 Lab2: Power Factor correction* Accessed on: Apr. 6, 2020. [Video File] Available: https://www.youtube.com/watch?v=0vXTMdRARHI

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