

ECSE 362 - Fundamentals of Power Engineering

Lab 2: AC Power Transmission

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Lab section: 003

Introduction:

The experiment is divided into two distinct segments. The first section is dedicated to explore the power transmission scenarios in cases where both the sending and receiving ends are able to regulate voltage. The angle difference between the power supply and the synchronous machine are both measured and calculated for comparison purposes. In addition, the effect of impedance over power transmission will be observed. The subsequent section investigates power transmission cases where the voltage is floating at the receiving end.

Analysis

Part I: Slack to PV node

| Table 1: Transmission Line Performance for a 60 Ω line | | | | | | | |
|---|----------------|-----------------|-------|---------|--------------------|------------------------------|---------------------------|
| Electrodyn. Power(W) | $V_{sup.}$ (V) | $V_{mach.}$ (V) | P (W) | Q (var) | $\Delta\delta$ (°) | $\widehat{\Delta\delta}$ (°) | ΔV (60 Ω) |
| 53 | 210.9 | 208 | 73.23 | -5.437 | 5.626 | 5.75 | 2.9 |
| 70 | 210.9 | 208 | 90.11 | -11.46 | 8.438 | 7.08 | 2.9 |
| 140 | 211.0 | 208 | 168.8 | -35.34 | 14.06 | 13.35 | 3.0 |
| 210 | 210.8 | 208 | 252.6 | -69.79 | 22.5 | 20.23 | 2.8 |
| 250 | x | 208 | x | x | x | x | x |
| 53 | 211.5 | 198 | 71.67 | 30.11 | 5.627 | 5.90 | 13.5 |
| 70 | 211.2 | 198 | 88.17 | 25.68 | 8.435 | 7.27 | 13.2 |
| 140 | 210.5 | 198 | 168.1 | -2.909 | 14.06 | 14.01 | 12.5 |
| 210 | 211.0 | 198 | 251.0 | -39.36 | 22.5 | 21.14 | 13.0 |
| 250 | 211.4 | 198 | 301.7 | -67.02 | 28.13 | 25.64 | 13.4 |
| 53 | 210.9 | 218 | 75.2 | -44.64 | 5.626 | 5.63 | -7.1 |
| 70 | 210.1 | 218 | 92.29 | -48.54 | 8.432 | 6.95 | -7.9 |
| 140 | 211.1 | 218 | 169.8 | -68.71 | 14.06 | 12.80 | -6.9 |
| 210 | x | 218 | x | x | x | x | x |
| 250 | x | 218 | x | x | x | x | x |

Figure 1: Transmission Line Performance for a 60 Ω Line.

| Table 2: Transmission line performance for a 120 Ω line | | | | | | | |
|--|----------------|-----------------|-------|---------|--------------------|------------------------------|----------------------------|
| Electrodyn. Power(W) | $V_{sup.}$ (V) | $V_{mach.}$ (V) | P (W) | Q (var) | $\Delta\delta$ (°) | $\widehat{\Delta\delta}$ (°) | ΔV (120 Ω) |
| 53 | 210.8 | 208 | 71.02 | -10.05 | 11.25 | 11.21 | 2.8 |
| 70 | 210.8 | 208 | 89.05 | -16.68 | 14.06 | 14.11 | 2.8 |
| 140 | 211.2 | 208 | 166.5 | -54.33 | 28.13 | 27.07 | 3.2 |
| 200 | | 208 | | | | | |
| 0 | 211.4 | 198 | 68.92 | 8.036 | 11.25 | 11.40 | 13.4 |
| 70 | 211.0 | 198 | 86.98 | 0.811 | 14.07 | 14.48 | 13.0 |
| 140 | 211.0 | 198 | 165.6 | -39.54 | 28.12 | 28.42 | 13.0 |
| 210 | | 198 | | | | | |
| 280 | | 198 | | | | | |
| 53 | 211.0 | 218 | 72.55 | -29.46 | 11.25 | 10.92 | -7.0 |
| 70 | 210.8 | 218 | 90.52 | -34.97 | 14.06 | 13.68 | -7.2 |
| 140 | 211.0 | 218 | 167.8 | -71.63 | 28.12 | 25.97 | -7.0 |
| 160 | | 218 | | | | | |

Figure 2 Transmission Line Performance for a 120 Ω Line.

| Table 3: Transmission line performance for a 180 Ω line | | | | | | | |
|--|----------------|-----------------|-------|---------|--------------------|------------------------------|----------------------------|
| Electrodyn. Power(W) | $V_{sup.}$ (V) | $V_{mach.}$ (V) | P (W) | Q (var) | $\Delta\delta$ (°) | $\widehat{\Delta\delta}$ (°) | ΔV (180 Ω) |
| 53 | 211 | 208.4 | 69.77 | -14.35 | 16.87 | 16.60 | 2.6 |
| 70 | 211.4 | 208 | 86.57 | -20.08 | 22.51 | 20.77 | 3.4 |
| 140 | 211.4 | 208.4 | 164.5 | -81.06 | 47.82 | 42.25 | 3.0 |
| 150 | | 208 | | | | | |
| 53 | 211.4 | 198.3 | 68.22 | -2.183 | 16.96 | 17.04 | 13.1 |
| 70 | 211.1 | 198.3 | 85.92 | -10.53 | 22.58 | 21.69 | 12.8 |
| 140 | 211.2 | 198 | 164.9 | -75.4 | 47.8 | 45.24 | 13.2 |
| 150 | | 198 | | | | | |
| 53 | 211.1 | 218.6 | 71.49 | -27.24 | 16.87 | 16.20 | -7.5 |
| 70 | 211.2 | 217.9 | 88.12 | -33.33 | 22.5 | 20.17 | -6.7 |
| 140 | | 218 | | | | | |
| 150 | | 218 | | | | | |

Figure 3 Transmission Line Performance for a 180 Ω Line

7.

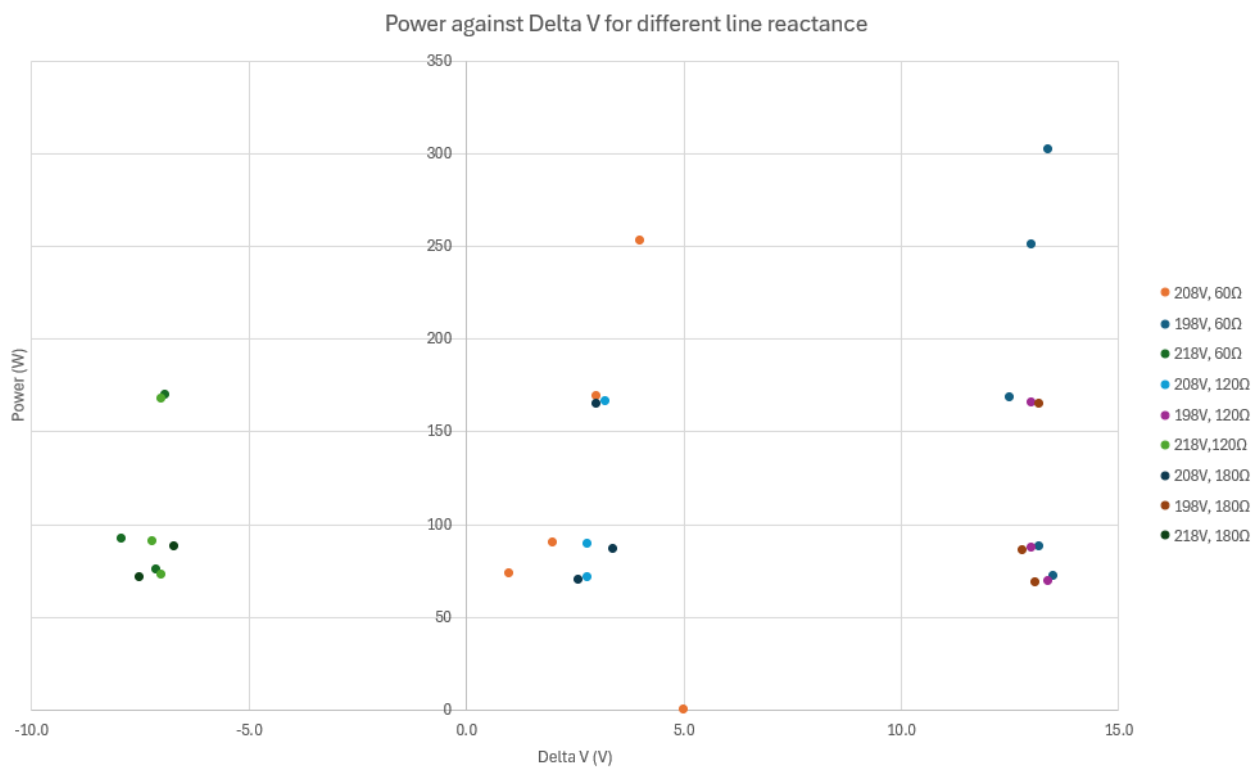


Figure 4 Power against Delta V for different line reactance

8. How do you observe angle difference values vary from theoretical values?

The measured values and calculated/theoretical values are close to each other.

9.

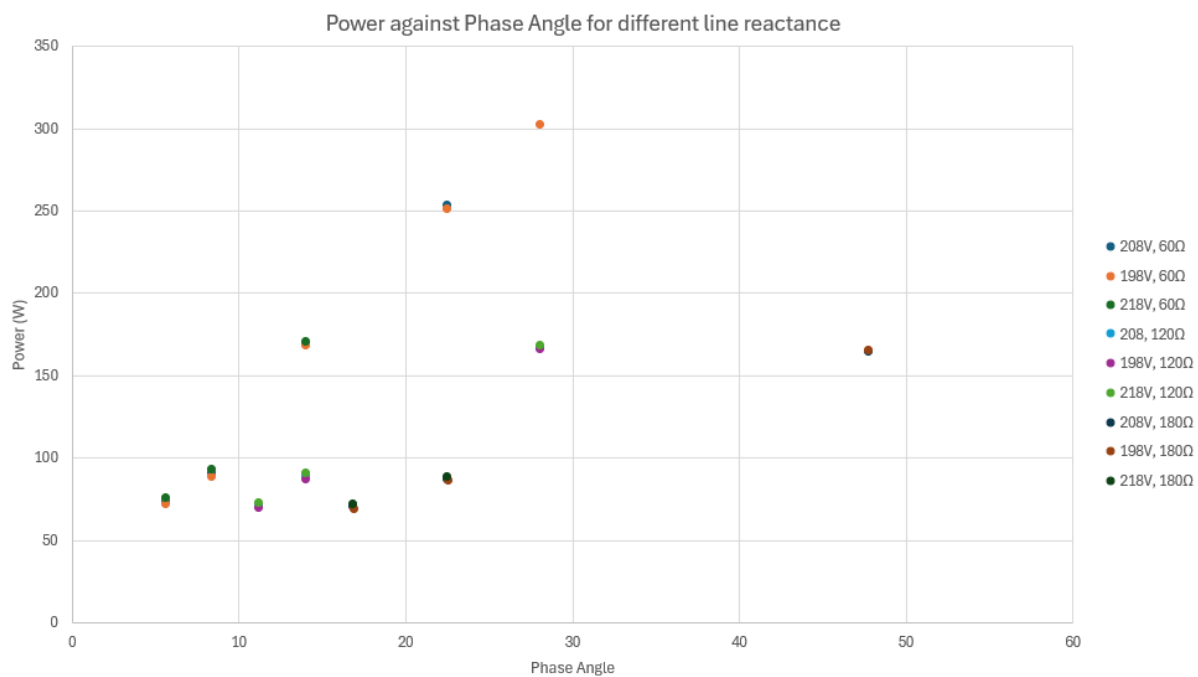


Figure 5 Power against Phase Angle for different line reactance

10.

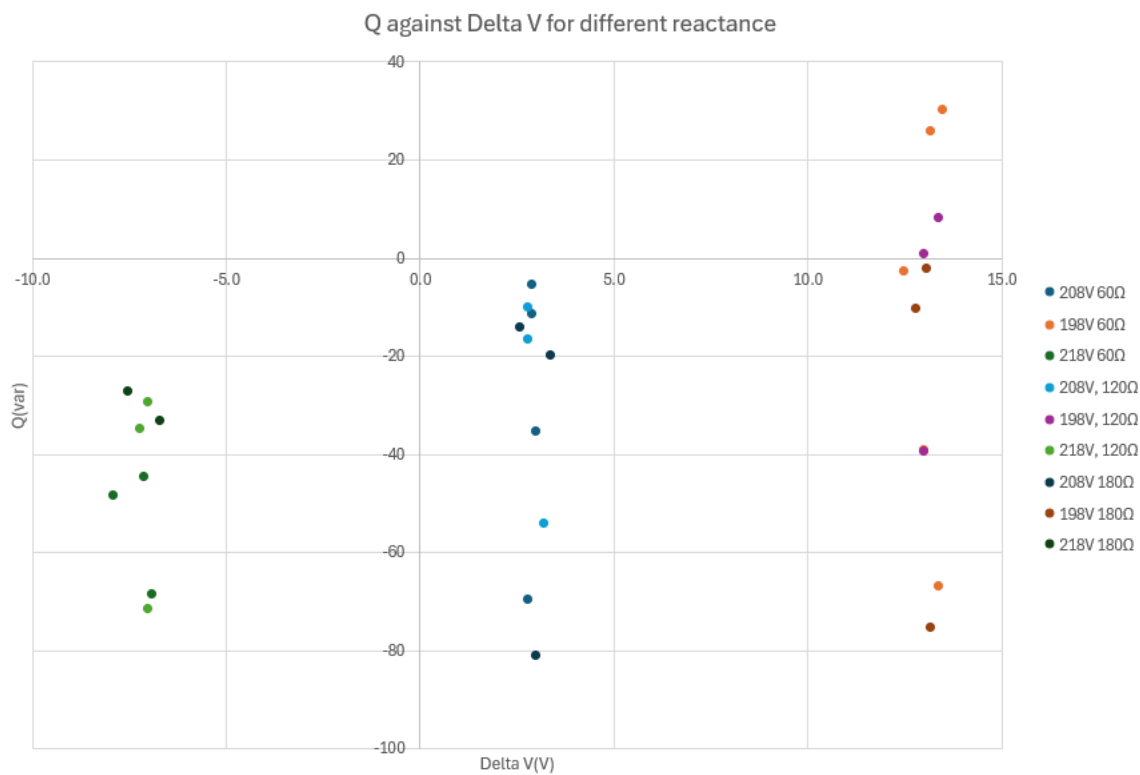
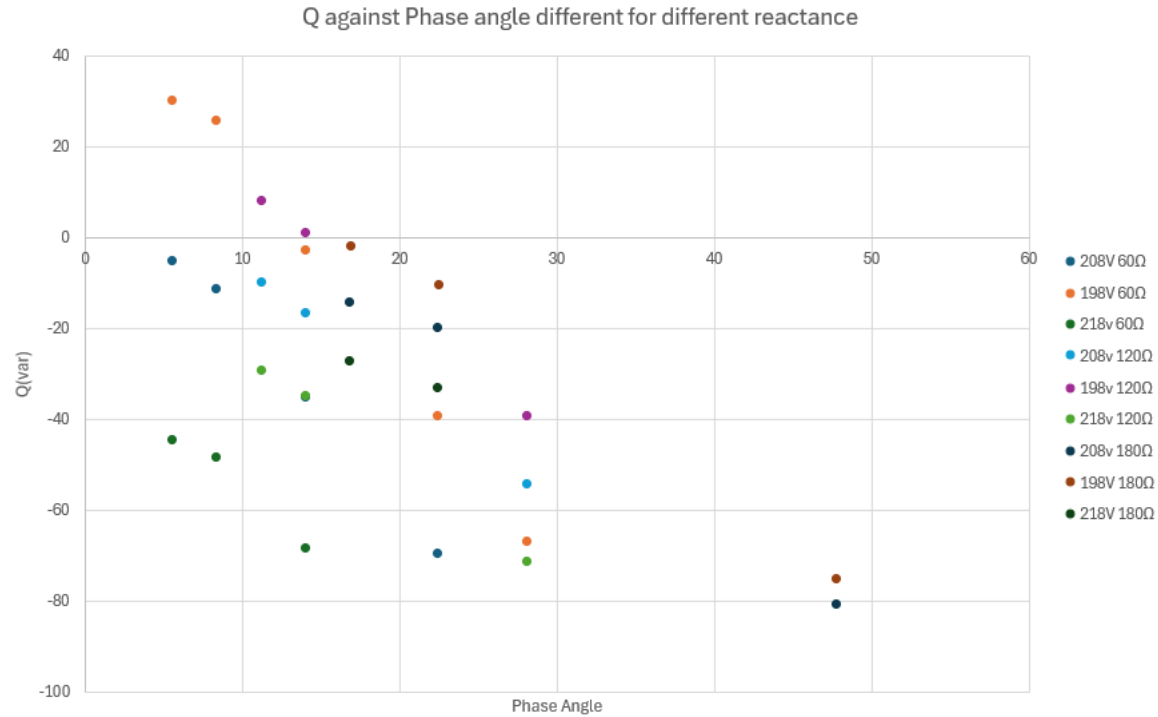


Figure 6 Q against delta V for different line reactance

11.

Figure 7 *Q against phase angle difference for different line reactance*

12. As X increases from 60Ω to 120Ω , both active power and reactive power decreases. But from 120Ω to 180Ω , there is no major difference. The active power is not affected by ΔV . The reactive power increases as ΔV increases. As $\Delta\delta$ increases, active power increases and the reactive power decreases.

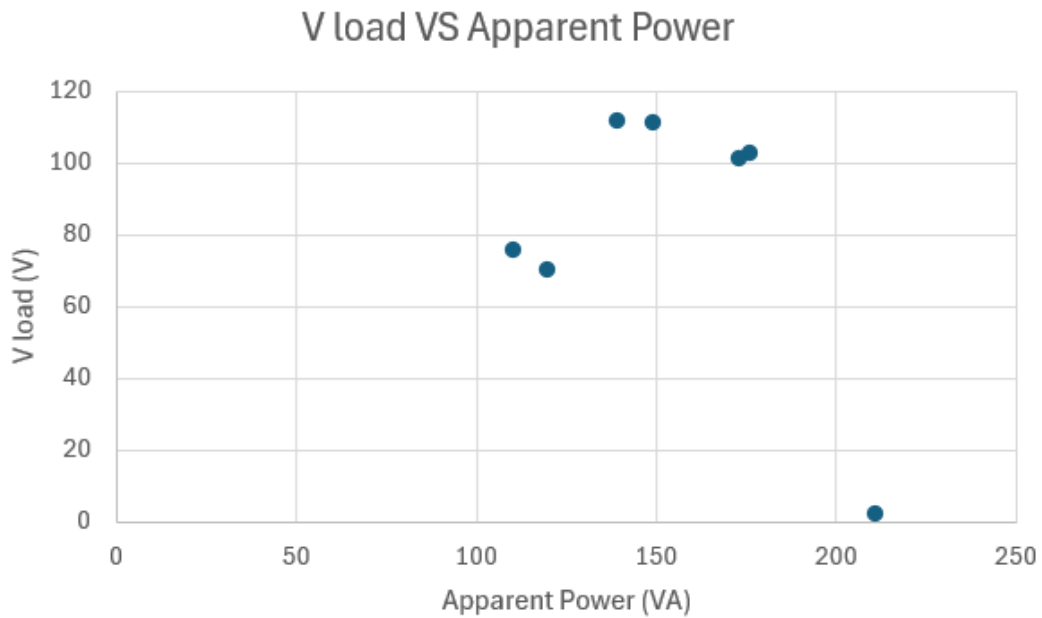
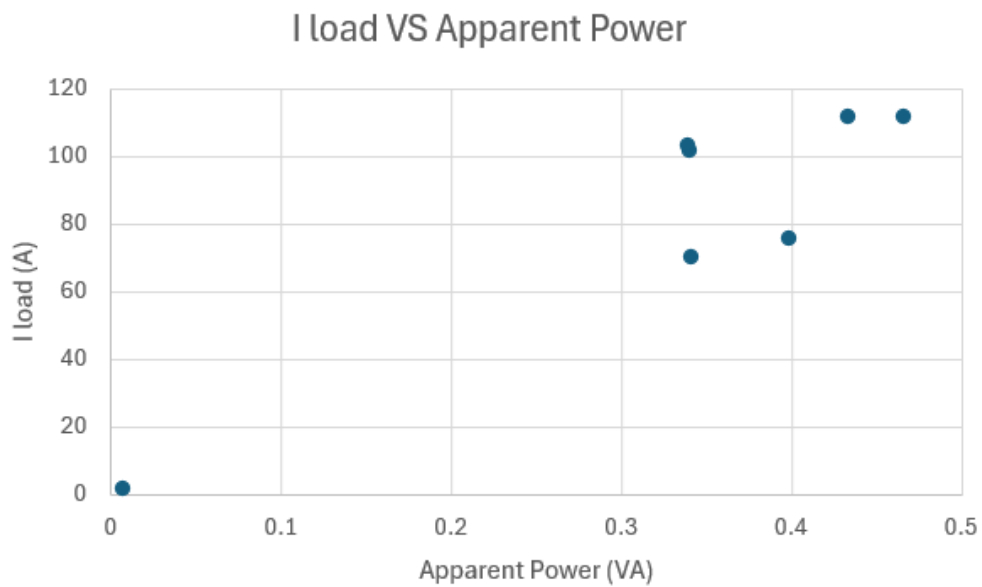
13. For the flow of active and reactive power to be in opposite directions, they need to have different signs. The case when electrodynamic power is $70W$ and machine voltage is $208V$ is an example that satisfies this requirement. ΔV is a negative value of -7.5 and $\Delta\delta$ is measured to be 16.87 degrees which is very close to the calculated desire value.

Part II: Slack to PQ node

| Table 4 : Transmission line performance for a 180Ω line; PQ receiving end | | | | | | | | |
|--|-------------|---------------|----------------|----------------|--------|----------|--------------------------|---------|
| $R(\Omega)$ | $X(\Omega)$ | $V_{sup.}(V)$ | $V_{load.}(V)$ | $I_{load.}(A)$ | $P(W)$ | $Q(var)$ | $\Delta\delta(^{\circ})$ | $S(VA)$ |
| 0 | 0 | 210.4 | 210.5 | 0.007 | 0.227 | -0.119 | 0 | 2.09 |
| 300 | 0 | 210.8 | 172.9 | 0.34 | 101.7 | -0.597 | 28.1 | 101.7 |
| 0 | 300 | 210.5 | 175.9 | 0.339 | 8.856 | 102.7 | 0 | 103.2 |
| 300 | 300 | 210.5 | 119.5 | 0.341 | 52.71 | 46.99 | 22.52 | 70.64 |
| 2 | 0 | 210.2 | 149 | 0.433 | 111.7 | -0.751 | 39.35 | 111.7 |
| 200 | 300 | 210.4 | 110.2 | 0.398 | 64.64 | 39.74 | 30.94 | 75.91 |
| 171 | 0 | 210.2 | 139 | 0.466 | 112.1 | -0.738 | 45 | 112.1 |

Figure 8 *Transmission line performance for a 180Ω Line, PQ receiving end*

4.

*Figure 9 V load vs. Apparent Power**Figure 10 I load VS Apparent power*

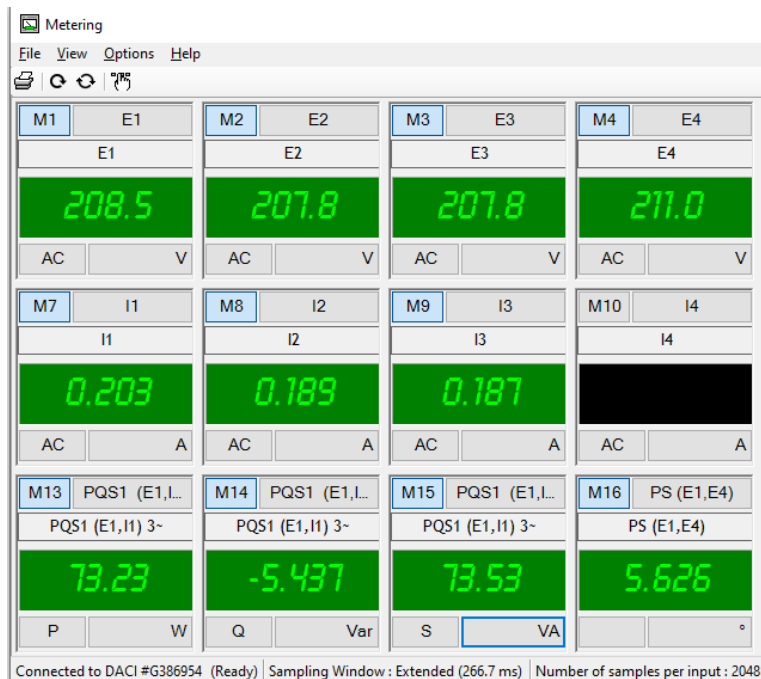
As the current I increases, apparent power increases. As the voltage V increases, apparent power decreases.

5. The active and reactive power are consistently in opposite direction in Part I of the experiment for 180 Ohm line. For a floating voltage in this section, it is not necessarily true. The general principles of ac power flow are the same regardless of the transmission line termination.

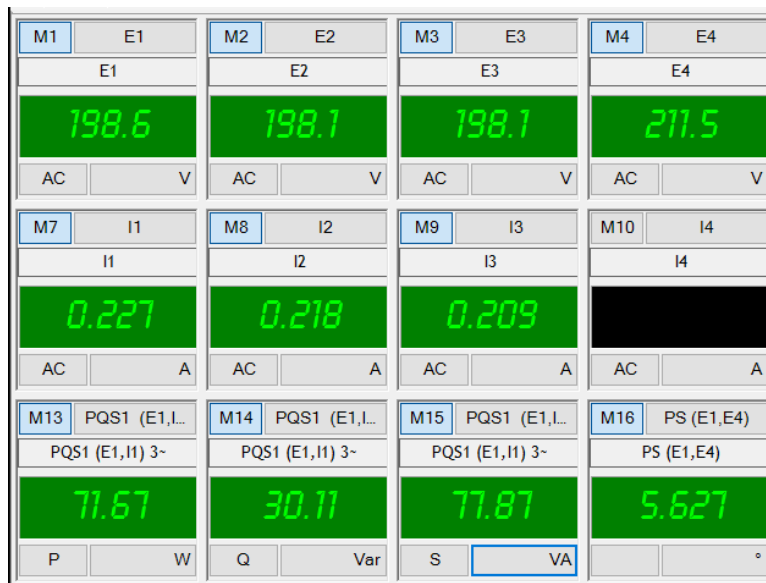
Appendix

1. $R_{\text{line}} = 60 \, \Omega$

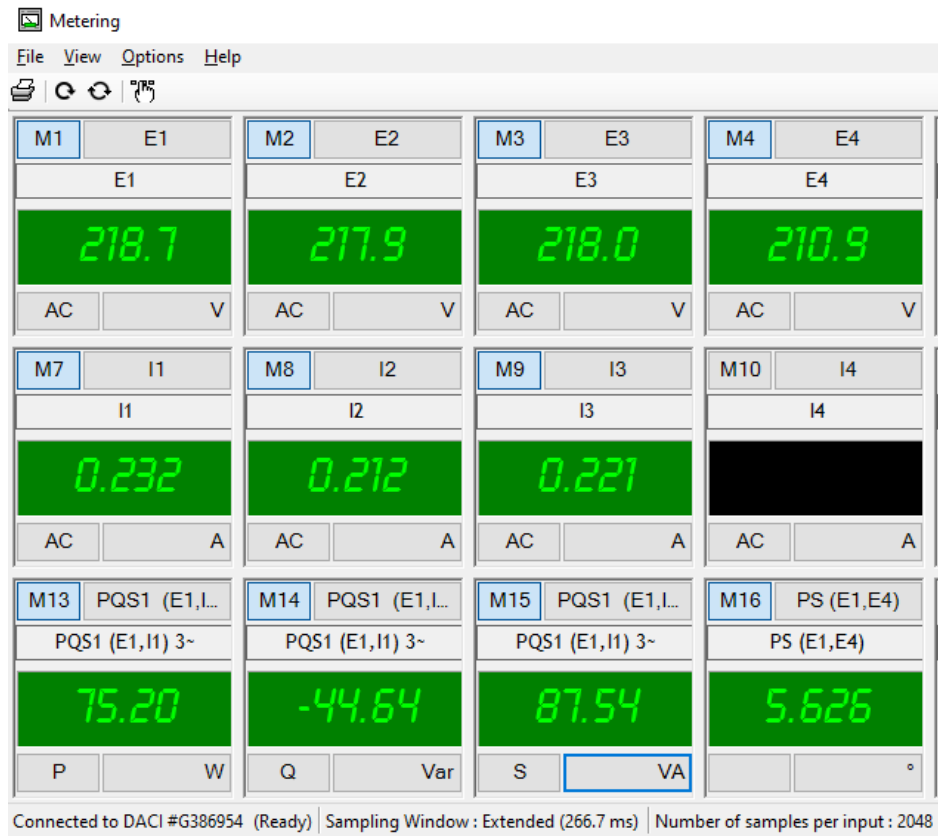
$P_{\text{dynamometer}} = 53.12 \, \text{W}$, $V_{\text{mach}} = 208 \, \text{V}$



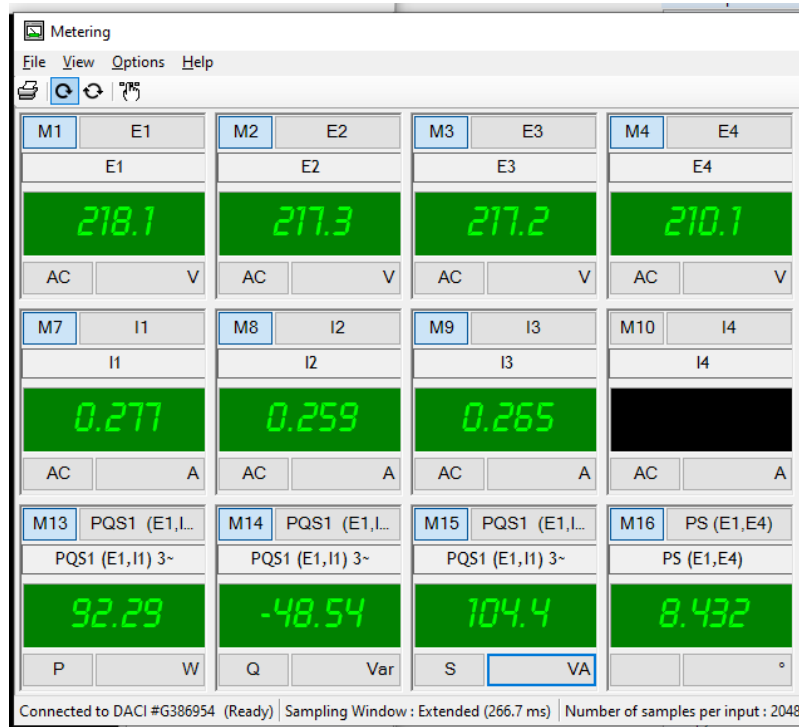
$P_{\text{dynamometer}} = 53.13 \, \text{W}$, $V_{\text{mach}} = 198 \, \text{V}$



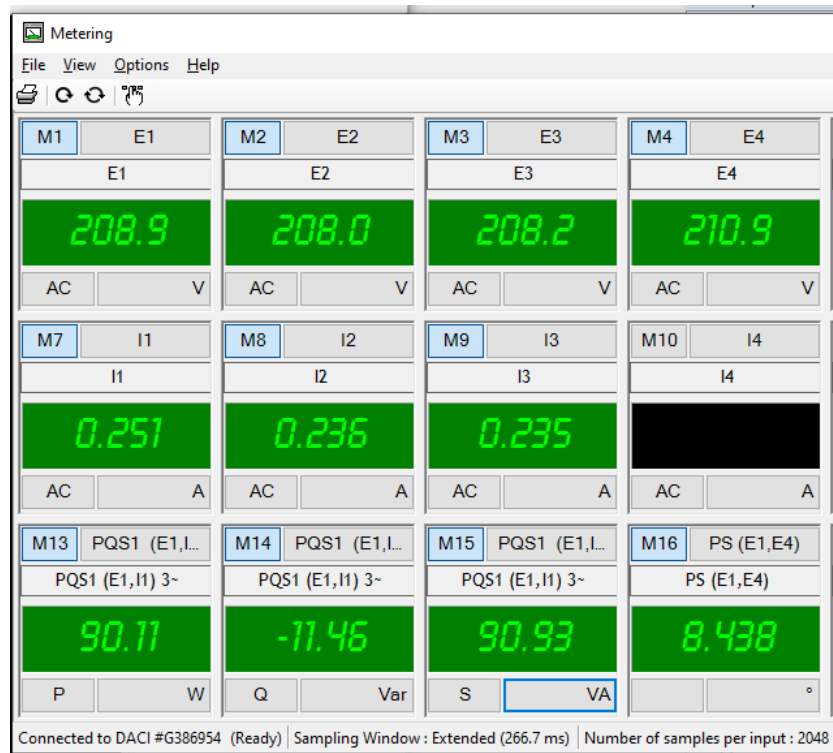
$P_{\text{dynamometer}} = 53.12\text{W}$, $V_{\text{mach}} = 218\text{ V}$



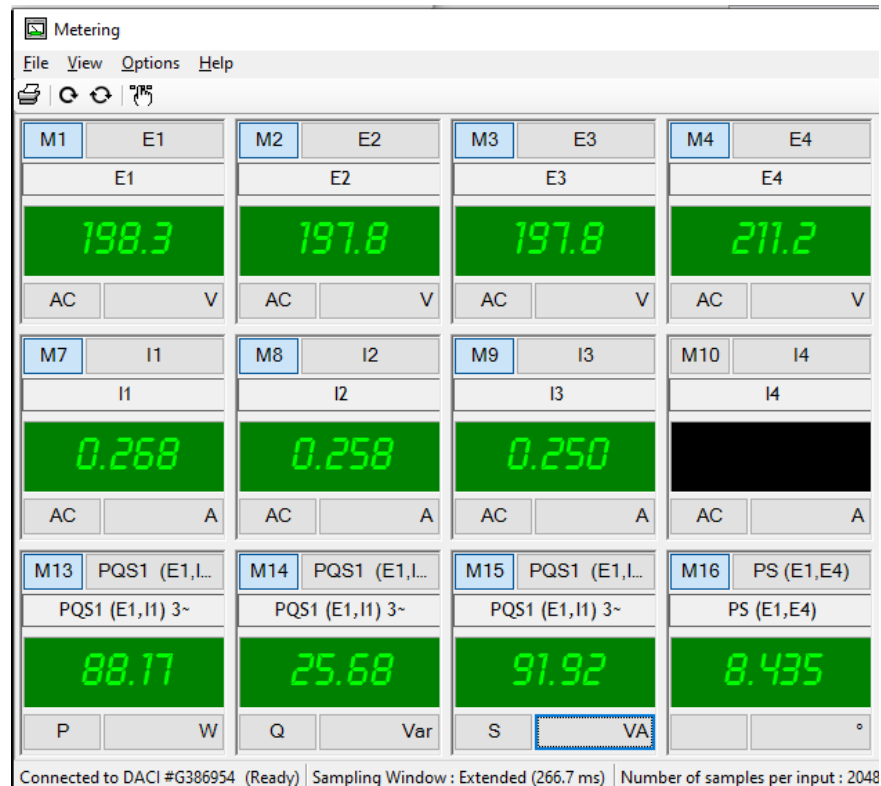
$P_{\text{dynamometer}} = 70\text{W}$, $V_{\text{mach}} = 218\text{ V}$



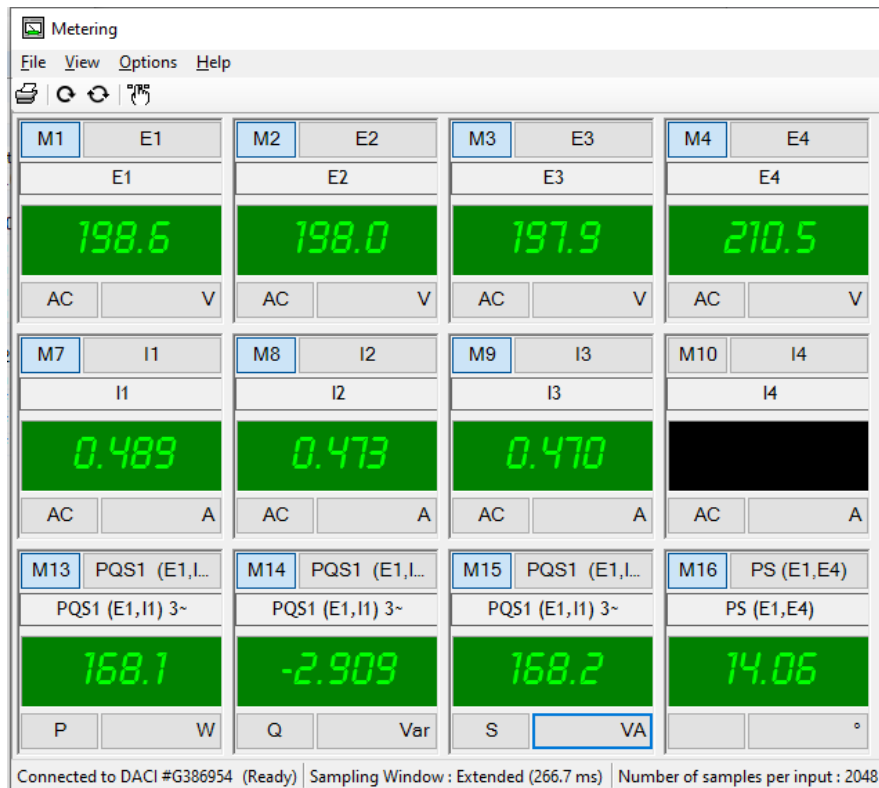
$P_{\text{dynamometer}} 70\text{W}$, $V_{\text{mach}} = 208\text{ V}$



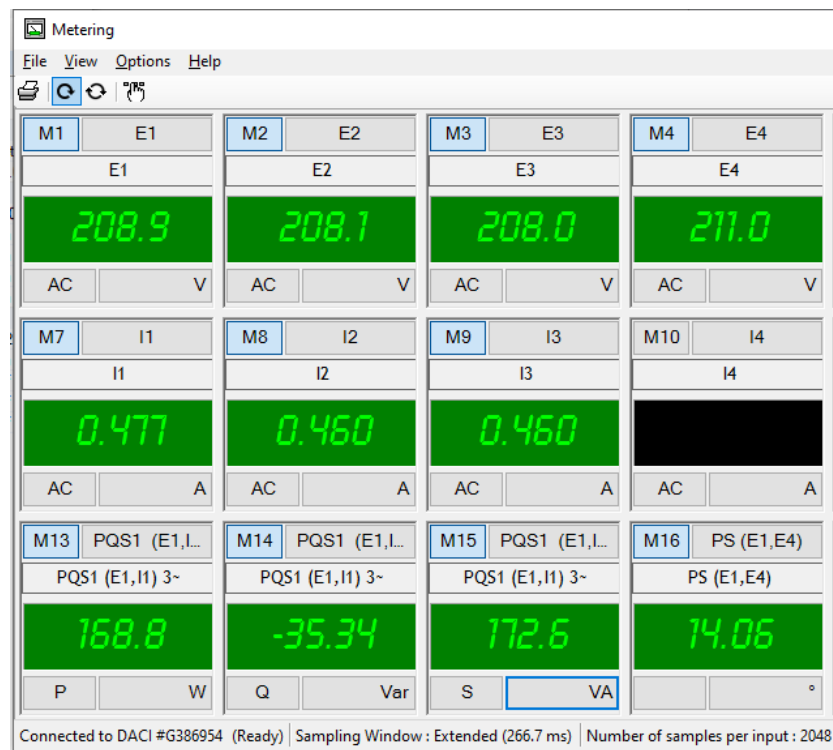
$P_{\text{dynamometer}} 70\text{W}$, $V_{\text{mach}} = 198\text{ V}$



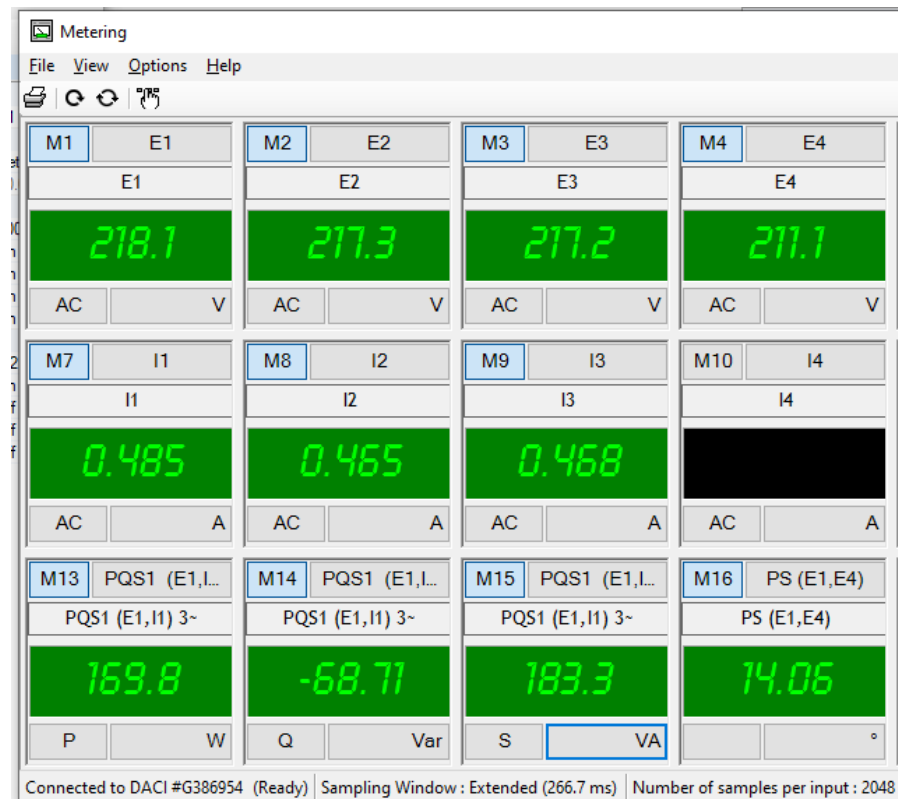
$P_{\text{dynamometer}} 140\text{W}$, $V_{\text{mach}} = 198\text{ V}$



$P_{\text{dynamometer}} 140\text{W}$, $V_{\text{mach}} = 208\text{ V}$

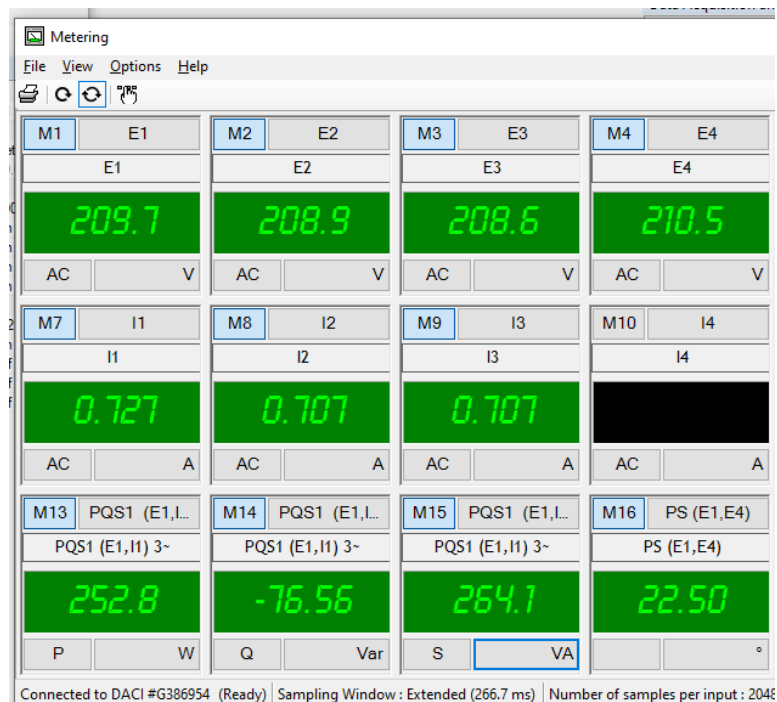


$P_{\text{dynamometer}} = 140\text{W}$, $V_{\text{mach}} = 218\text{ V}$

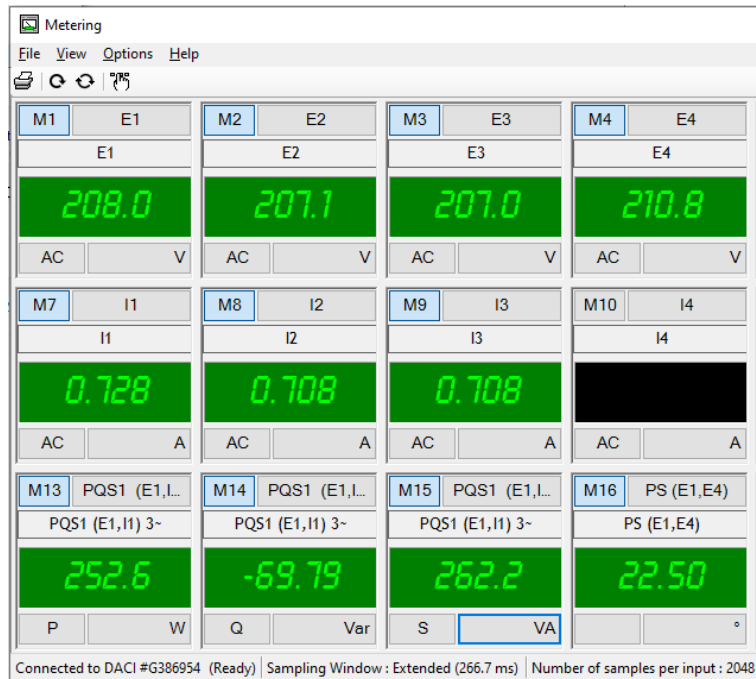


$P_{\text{dynamometer}} = 210\text{W}$, $V_{\text{mach}} = 218\text{ V}$

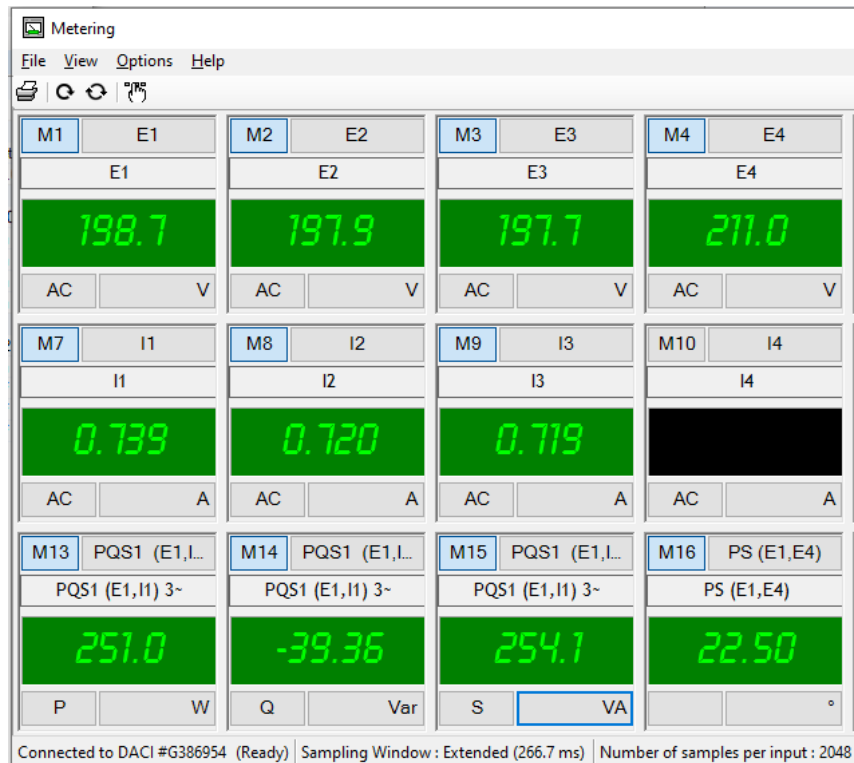
X because we can't turn anymore



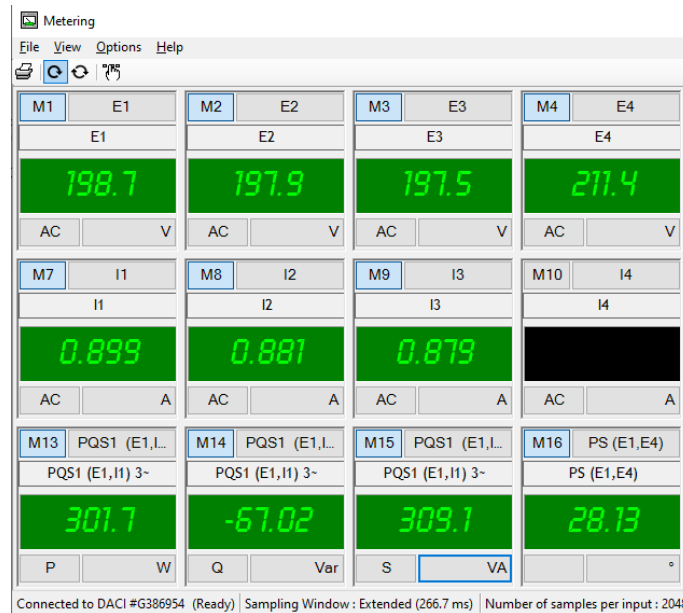
$P_{\text{dynamometer}} = 210\text{W}$, $V_{\text{mach}} = 208\text{ V}$



$P_{\text{dynamometer}} = 210\text{W}$, $V_{\text{mach}} = 198\text{ V}$



$P_{\text{dynamometer}} = 250\text{ W}$, $V_{\text{mach}} = 198\text{ V}$



$P_{\text{dynamometer}} = 250\text{ W}$, $V_{\text{mach}} = 208\text{ V}$

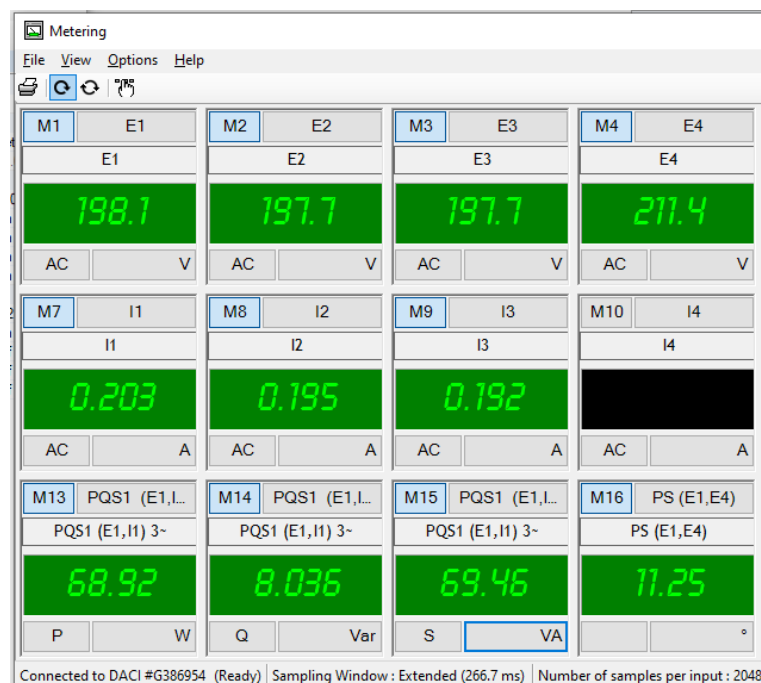
X

$P_{\text{dynamometer}} = 250\text{ W}$, $V_{\text{mach}} = 218\text{ V}$

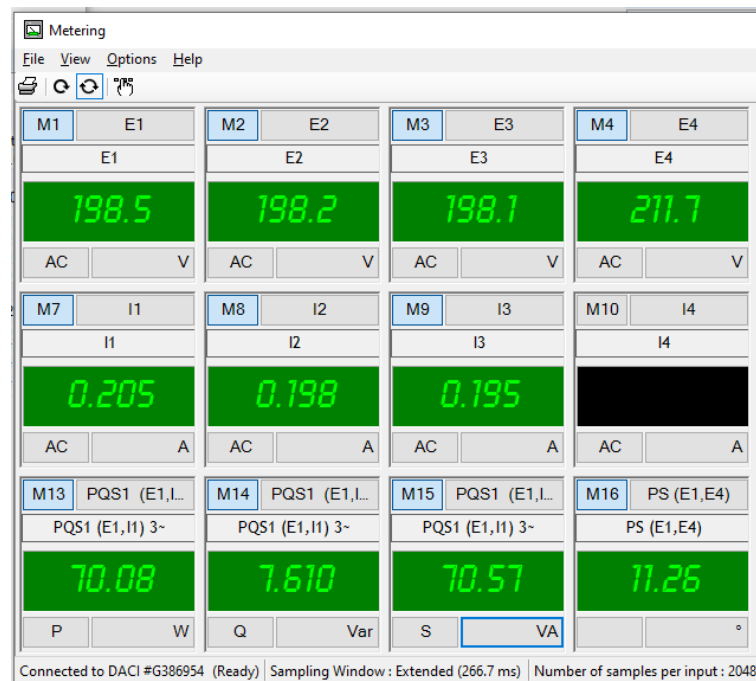
X

2. $R_{\text{line}} = 120\ \Omega$

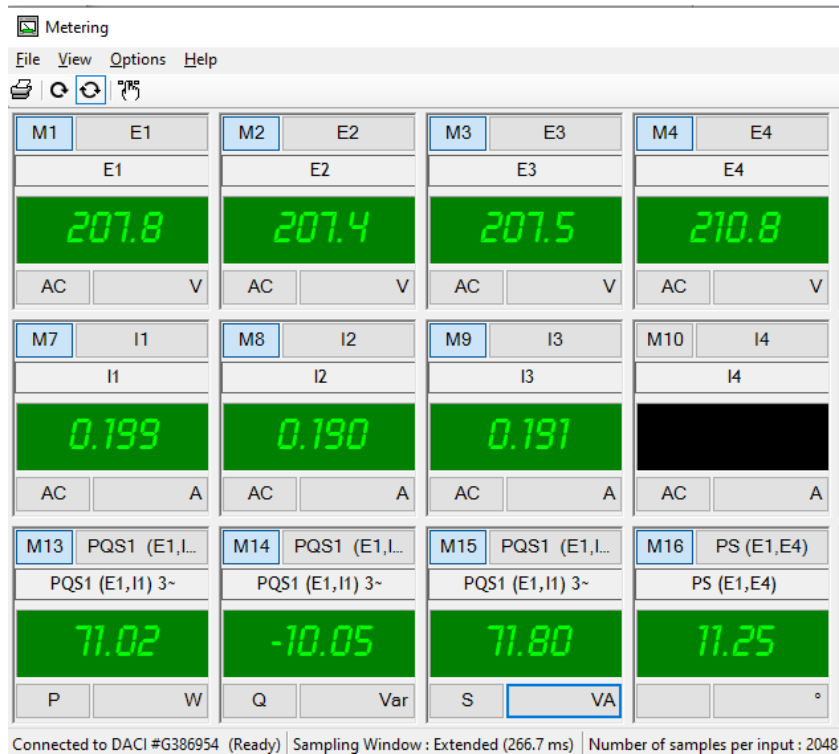
$P_{\text{dynamometer}} = 0\text{ W}$, $V_{\text{mach}} = 198\text{ V}$



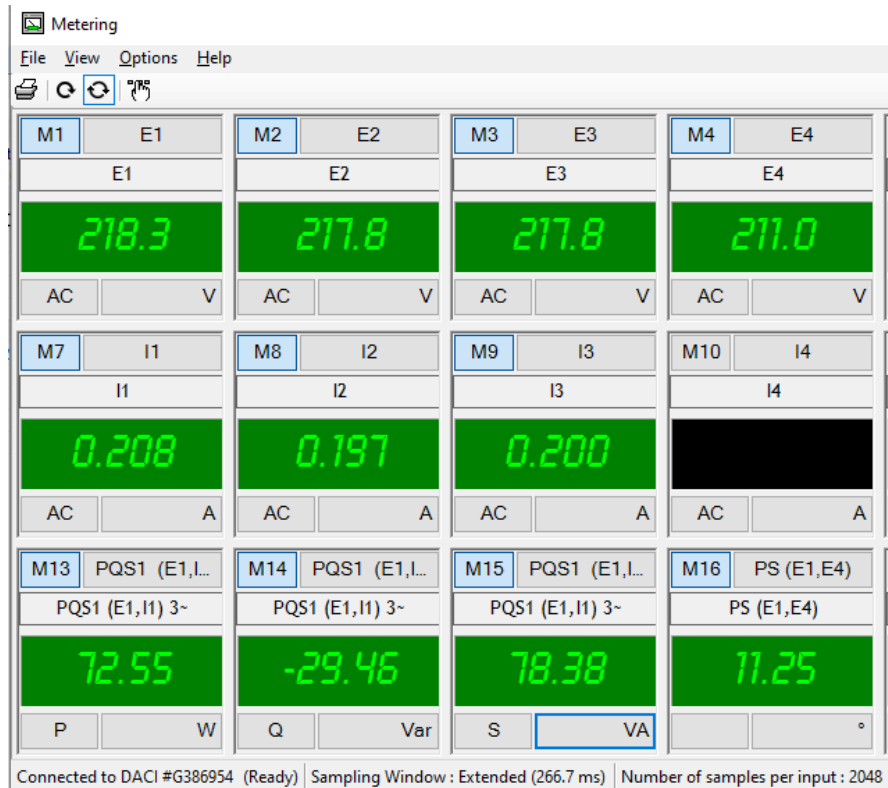
$$P_{\text{dynamometer}} = 53 \text{ W}, V_{\text{mach}} = 198 \text{ V}$$



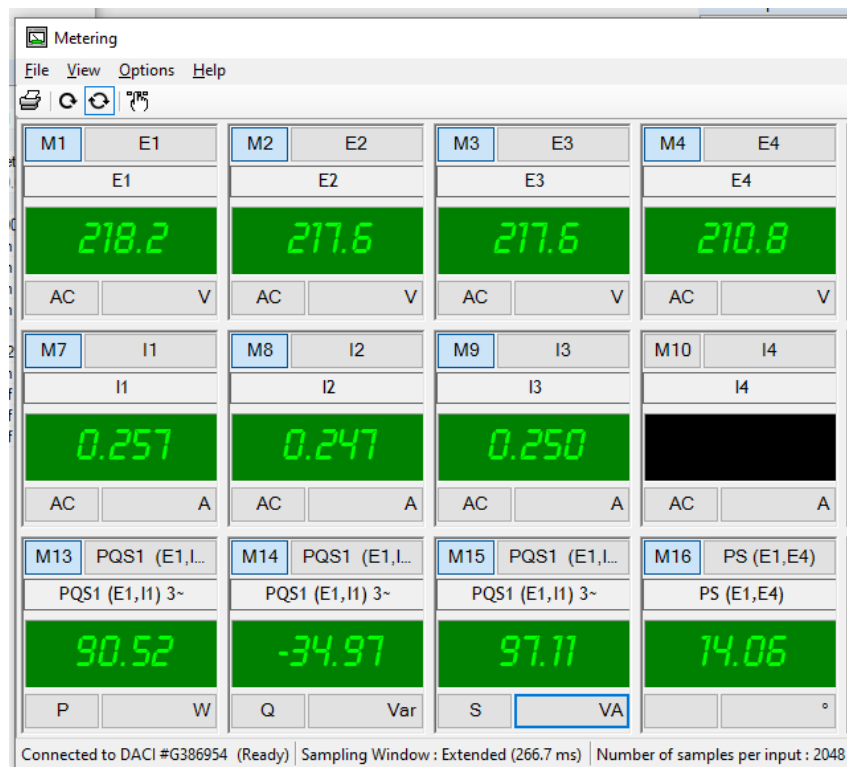
$$P_{\text{dynamometer}} = 53 \text{ W}, V_{\text{mach}} = 208 \text{ V}$$



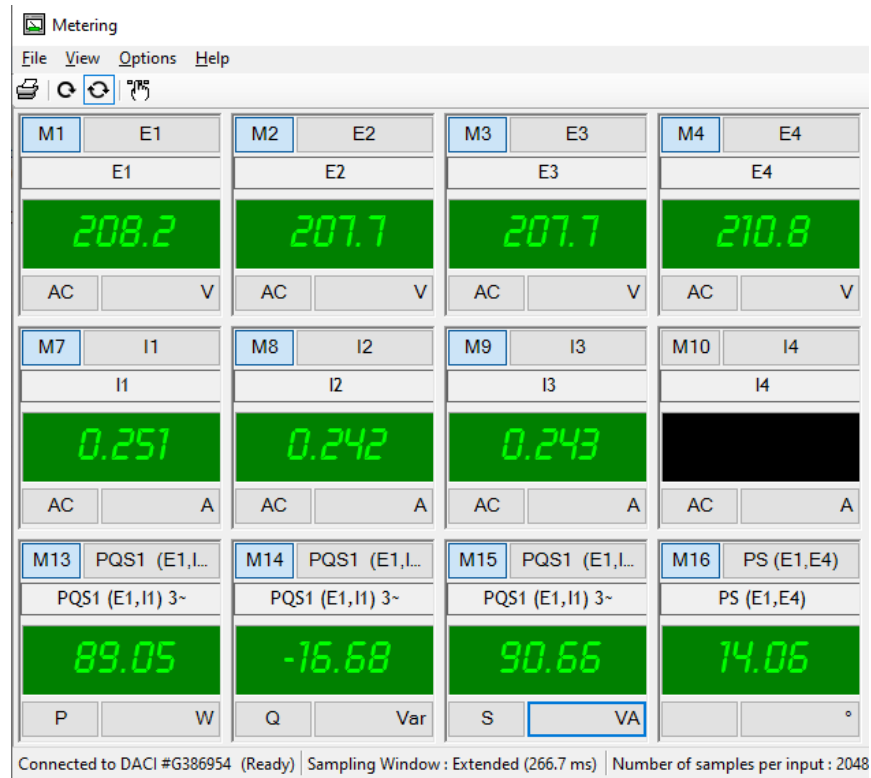
$$P_{\text{dynamometer}} = 53 \text{ W}, V_{\text{mach}} = 218 \text{ V}$$



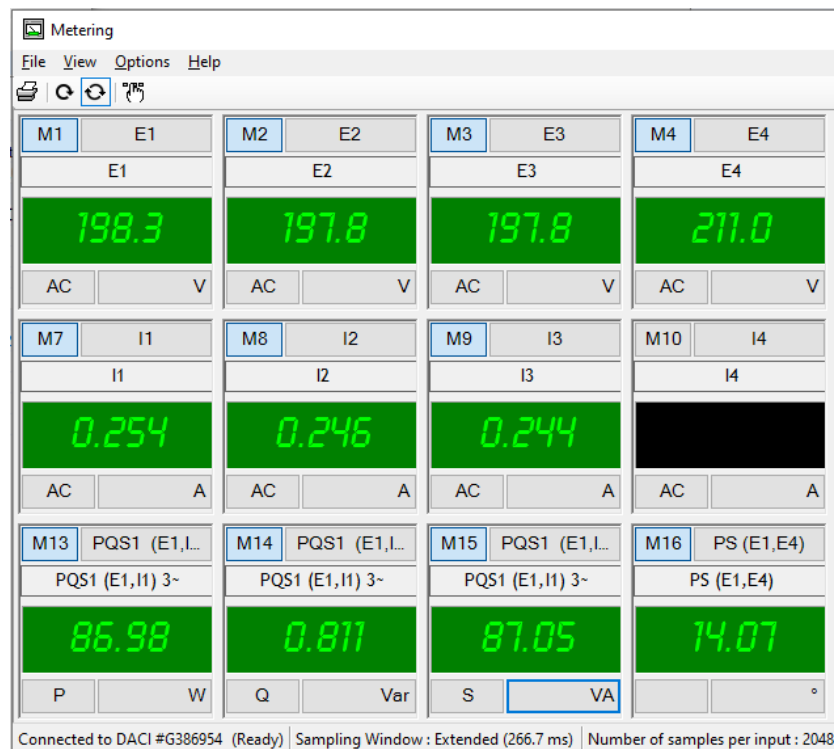
$$P_{\text{dynamometer}} = 70 \text{ W}, V_{\text{mach}} = 218 \text{ V}$$



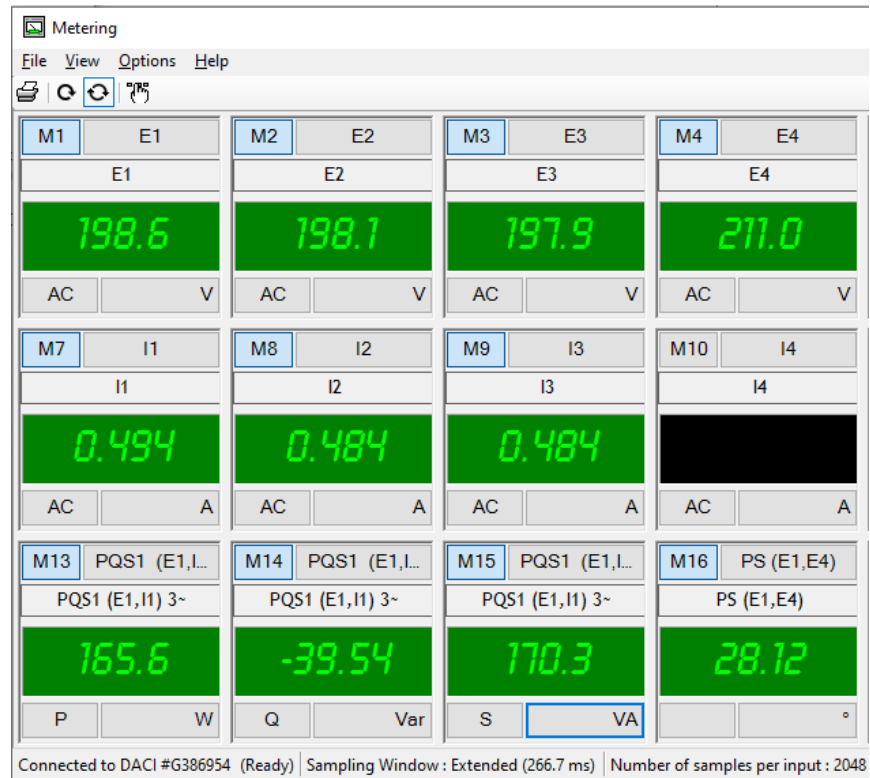
$$P_{\text{dynamometer}} = 70 \text{ W}, V_{\text{mach}} = 208 \text{ V}$$



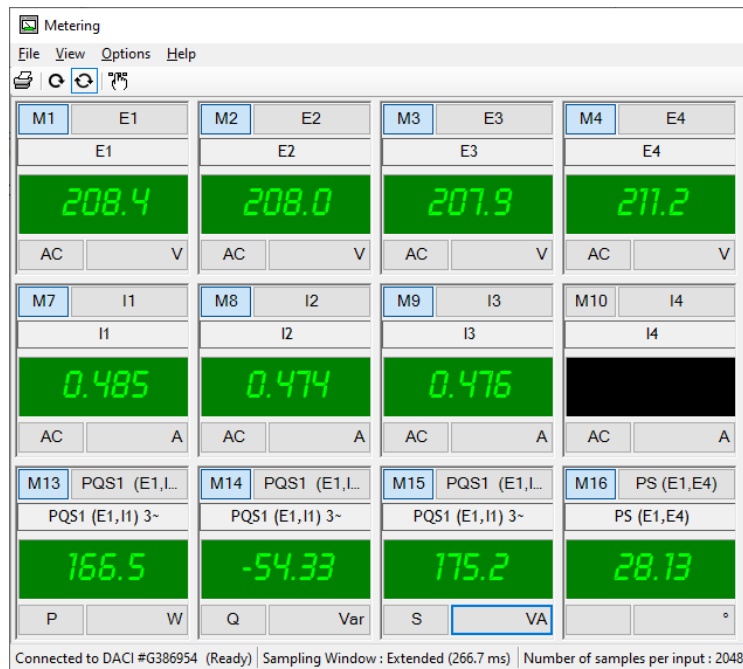
$$P_{\text{dynamometer}} = 70 \text{ W}, V_{\text{mach}} = 198 \text{ V}$$



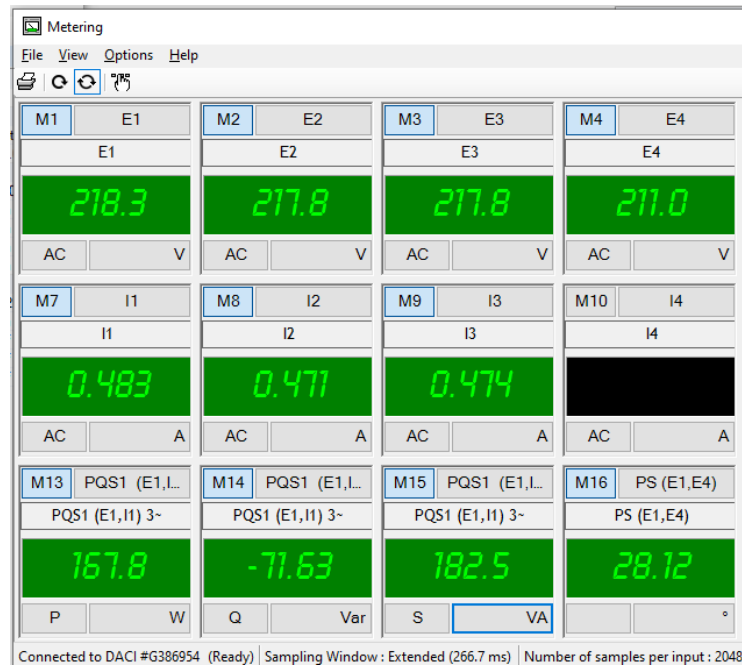
$$P_{\text{dynamometer}} = 140 \text{ W}, V_{\text{mach}} = 198 \text{ V}$$



$$P_{\text{dynamometer}} = 140 \text{ W}, V_{\text{mach}} = 208 \text{ V}$$



$$P_{\text{dynamometer}} = 140 \text{ W}, V_{\text{mach}} = 218 \text{ V}$$



$$P_{\text{dynamometer}} = 160 \text{ W}, V_{\text{mach}} = 218 \text{ V}$$

X

$$P_{\text{dynamometer}} = 200 \text{ W}, V_{\text{mach}} = 208 \text{ V}$$

X

$$P_{\text{dynamometer}} = 210 \text{ W}, V_{\text{mach}} = 218 \text{ V}$$

X

$$P_{\text{dynamometer}} = 280 \text{ W}, V_{\text{mach}} = 198 \text{ V}$$

X

3. $R_{\text{line}} = 180 \, \Omega$

$P_{\text{dynamometer}} = 53 \, \text{W}$, $V_{\text{mach}} = 198 \, \text{V}$

| | | | | | | | |
|-----------------|-----------------|-----------------|---------------|-----|---------------|-----|------------|
| M1 | E1 | M2 | E2 | M3 | E3 | M4 | E4 |
| E1 | E2 | E3 | E4 | | | | |
| 198.3 | 198.1 | 198.0 | 211.4 | | | | |
| AC | V | AC | V | AC | V | AC | V |
| M7 | I1 | M8 | I2 | M9 | I3 | M10 | I4 |
| I1 | I2 | I3 | I4 | | | | |
| 0.199 | 0.193 | 0.192 | | | | | |
| AC | A | AC | A | AC | A | AC | A |
| M13 | PQS1 (E1,I... | M14 | PQS1 (E1,I... | M15 | PQS1 (E1,I... | M16 | PS (E1,E4) |
| PQS1 (E1,I1) 3~ | PQS1 (E1,I1) 3~ | PQS1 (E1,I1) 3~ | PS (E1,E4) | | | | |
| 68.22 | -2.183 | 68.31 | 16.96 | | | | |
| P | W | Q | Var | S | VA | | ° |

$P_{\text{dynamometer}} = 53 \, \text{W}$, $V_{\text{mach}} = 208 \, \text{V}$

| | | | | | | | |
|-----------------|-----------------|-----------------|---------------|-----|---------------|-----|------------|
| M1 | E1 | M2 | E2 | M3 | E3 | M4 | E4 |
| E1 | E2 | E3 | E4 | | | | |
| 208.4 | 208.0 | 208.0 | 211.0 | | | | |
| AC | V | AC | V | AC | V | AC | V |
| M7 | I1 | M8 | I2 | M9 | I3 | M10 | I4 |
| I1 | I2 | I3 | I4 | | | | |
| 0.198 | 0.190 | 0.191 | | | | | |
| AC | A | AC | A | AC | A | AC | A |
| M13 | PQS1 (E1,I... | M14 | PQS1 (E1,I... | M15 | PQS1 (E1,I... | M16 | PS (E1,E4) |
| PQS1 (E1,I1) 3~ | PQS1 (E1,I1) 3~ | PQS1 (E1,I1) 3~ | PS (E1,E4) | | | | |
| 69.77 | -14.35 | 71.31 | 16.87 | | | | |
| P | W | Q | Var | S | VA | | ° |

$P_{\text{dynamometer}} = 53 \text{ W}$, $V_{\text{mach}} = 218 \text{ V}$

| | | | | | | | |
|-----------------|-----------------|-----------------|---------------|-----|---------------|-----|------------|
| M1 | E1 | M2 | E2 | M3 | E3 | M4 | E4 |
| E1 | E2 | E3 | E4 | | | | |
| 218.6 | 218.0 | 218.0 | 211.1 | | | | |
| AC | V | AC | V | AC | V | AC | V |
| M7 | I1 | M8 | I2 | M9 | I3 | M10 | I4 |
| I1 | I2 | I3 | I4 | | | | |
| 0.202 | 0.195 | 0.197 | | | | | |
| AC | A | AC | A | AC | A | AC | A |
| M13 | PQS1 (E1,I... | M14 | PQS1 (E1,I... | M15 | PQS1 (E1,I... | M16 | PS (E1,E4) |
| PQS1 (E1,I1) 3~ | PQS1 (E1,I1) 3~ | PQS1 (E1,I1) 3~ | PS (E1,E4) | | | | |
| 71.49 | -27.24 | 76.55 | 16.87 | | | | |
| P | W | Q | Var | S | VA | | ° |

$P_{\text{dynamometer}} = 70 \text{ W}$, $V_{\text{mach}} = 198 \text{ V}$

| | | | | | | | |
|-----------------|-----------------|-----------------|---------------|-----|---------------|-----|------------|
| M1 | E1 | M2 | E2 | M3 | E3 | M4 | E4 |
| E1 | E2 | E3 | E4 | | | | |
| 198.3 | 197.9 | 197.8 | 211.1 | | | | |
| AC | V | AC | V | AC | V | AC | V |
| M7 | I1 | M8 | I2 | M9 | I3 | M10 | I4 |
| I1 | I2 | I3 | I4 | | | | |
| 0.252 | 0.246 | 0.245 | | | | | |
| AC | A | AC | A | AC | A | AC | A |
| M13 | PQS1 (E1,I... | M14 | PQS1 (E1,I... | M15 | PQS1 (E1,I... | M16 | PS (E1,E4) |
| PQS1 (E1,I1) 3~ | PQS1 (E1,I1) 3~ | PQS1 (E1,I1) 3~ | PS (E1,E4) | | | | |
| 85.92 | -10.53 | 86.60 | 22.58 | | | | |
| P | W | Q | Var | S | VA | | ° |

$P_{\text{dynamometer}} = 70 \text{ W}$, $V_{\text{mach}} = 208 \text{ V}$

| | | | | | | | |
|-----------------|-----------------|-----------------|--------------|-----|--------------|-----|------------|
| M1 | E1 | M2 | E2 | M3 | E3 | M4 | E4 |
| E1 | E2 | E3 | E4 | | | | |
| 208.0 | 207.6 | 206.7 | 211.4 | | | | |
| AC | V | AC | V | AC | V | AC | V |
| M7 | I1 | M8 | I2 | M9 | I3 | M10 | I4 |
| I1 | I2 | I3 | I4 | | | | |
| 0.248 | 0.241 | 0.241 | | | | | |
| AC | A | AC | A | AC | A | AC | A |
| M13 | PQS1 (E1,I1) | M14 | PQS1 (E1,I1) | M15 | PQS1 (E1,I1) | M16 | PS (E1,E4) |
| PQS1 (E1,I1) 3~ | PQS1 (E1,I1) 3~ | PQS1 (E1,I1) 3~ | PS (E1,E4) | | | | |
| 86.57 | -20.08 | 88.93 | 22.51 | | | | |
| P | W | Q | Var | S | VA | | ° |

$P_{\text{dynamometer}} = 70 \text{ W}$, $V_{\text{mach}} = 218 \text{ V}$

| | | | | | | | |
|-----------------|-----------------|-----------------|--------------|-----|--------------|-----|------------|
| M1 | E1 | M2 | E2 | M3 | E3 | M4 | E4 |
| E1 | E2 | E3 | E4 | | | | |
| 217.9 | 217.5 | 217.5 | 211.2 | | | | |
| AC | V | AC | V | AC | V | AC | V |
| M7 | I1 | M8 | I2 | M9 | I3 | M10 | I4 |
| I1 | I2 | I3 | I4 | | | | |
| 0.250 | 0.242 | 0.244 | | | | | |
| AC | A | AC | A | AC | A | AC | A |
| M13 | PQS1 (E1,I1) | M14 | PQS1 (E1,I1) | M15 | PQS1 (E1,I1) | M16 | PS (E1,E4) |
| PQS1 (E1,I1) 3~ | PQS1 (E1,I1) 3~ | PQS1 (E1,I1) 3~ | PS (E1,E4) | | | | |
| 88.12 | -33.33 | 94.29 | 22.50 | | | | |
| P | W | Q | Var | S | VA | | ° |

$P_{\text{dynamometer}} = 140 \text{ W}$, $V_{\text{mach}} = 218 \text{ V}$

x

$P_{\text{dynamometer}} = 140 \text{ W}$, $V_{\text{mach}} = 208 \text{ V}$

| | | | | | | | |
|-----------------|-----------------|-----------------|---------------|-----|---------------|-----|------------|
| M1 | E1 | M2 | E2 | M3 | E3 | M4 | E4 |
| E1 | E2 | E3 | E4 | | | | |
| 208.4 | 208.1 | 207.7 | 211.4 | | | | |
| AC | V | AC | V | AC | V | AC | V |
| M7 | I1 | M8 | I2 | M9 | I3 | M10 | I4 |
| I1 | I2 | I3 | I4 | | | | |
| 0.509 | 0.501 | 0.501 | | | | | |
| AC | A | AC | A | AC | A | AC | A |
| M13 | PQS1 (E1,I... | M14 | PQS1 (E1,I... | M15 | PQS1 (E1,I... | M16 | PS (E1,E4) |
| PQS1 (E1,I1) 3~ | PQS1 (E1,I1) 3~ | PQS1 (E1,I1) 3~ | PS (E1,E4) | | | | |
| 164.5 | -81.06 | 183.5 | 47.82 | | | | |
| P | W | Q | Var | S | VA | | ° |

$P_{\text{dynamometer}} = 140 \text{ W}$, $V_{\text{mach}} = 198 \text{ V}$

| | | | | | | | |
|-----------------|-----------------|-----------------|---------------|-----|---------------|-----|------------|
| M1 | E1 | M2 | E2 | M3 | E3 | M4 | E4 |
| E1 | E2 | E3 | E4 | | | | |
| 198.0 | 197.5 | 197.3 | 211.2 | | | | |
| AC | V | AC | V | AC | V | AC | V |
| M7 | I1 | M8 | I2 | M9 | I3 | M10 | I4 |
| I1 | I2 | I3 | I4 | | | | |
| 0.529 | 0.521 | 0.521 | | | | | |
| AC | A | AC | A | AC | A | AC | A |
| M13 | PQS1 (E1,I... | M14 | PQS1 (E1,I... | M15 | PQS1 (E1,I... | M16 | PS (E1,E4) |
| PQS1 (E1,I1) 3~ | PQS1 (E1,I1) 3~ | PQS1 (E1,I1) 3~ | PS (E1,E4) | | | | |
| 164.9 | -75.40 | 181.3 | 47.80 | | | | |
| P | W | Q | Var | S | VA | | ° |

$$P_{\text{dynamometer}} = 150 \text{ W}, V_{\text{mach}} = 198 \text{ V}$$

x

$$P_{\text{dynamometer}} = 150 \text{ W}, V_{\text{mach}} = 208 \text{ V}$$

x

$$P_{\text{dynamometer}} = 150 \text{ W}, V_{\text{mach}} = 218 \text{ V}$$

x

4. Part II: $R_{\text{line}} = 180 \Omega$

$$R = 0 \Omega, X = 0 \Omega$$



$R = 300\ \Omega$, $X = 0\ \Omega$

| | | | | | | | |
|-----------------|-----------------|-----------------|---------------|-----|---------------|-----|------------|
| M1 | E1 | M2 | E2 | M3 | E3 | M4 | E4 |
| E1 | E2 | E3 | E4 | | | | |
| 172.9 | | | 210.8 | | | | |
| AC | V | AC | V | AC | V | AC | V |
| M7 | I1 | M8 | I2 | M9 | I3 | M10 | I4 |
| I1 | I2 | I3 | I4 | | | | |
| 0.340 | | | | | | | |
| AC | A | AC | A | AC | A | AC | A |
| M13 | PQS1 (E1,I... | M14 | PQS1 (E1,I... | M15 | PQS1 (E1,I... | M16 | PS (E1,E4) |
| PQS1 (E1,I1) 3~ | PQS1 (E1,I1) 3~ | PQS1 (E1,I1) 3~ | PS (E1,E4) | | | | |
| 101.7 | -0.597 | 101.7 | 28.10 | | | | |
| P | W | Q | Var | S | VA | | ° |

 $R = 0\ \Omega$, $X = 300\ \Omega$

| | | | | | | | |
|-----------------|-----------------|-----------------|---------------|-----|---------------|-----|------------|
| M1 | E1 | M2 | E2 | M3 | E3 | M4 | E4 |
| E1 | E2 | E3 | E4 | | | | |
| 175.9 | | | 210.5 | | | | |
| AC | V | AC | V | AC | V | AC | V |
| M7 | I1 | M8 | I2 | M9 | I3 | M10 | I4 |
| I1 | I2 | I3 | I4 | | | | |
| 0.339 | | | | | | | |
| AC | A | AC | A | AC | A | AC | A |
| M13 | PQS1 (E1,I... | M14 | PQS1 (E1,I... | M15 | PQS1 (E1,I... | M16 | PS (E1,E4) |
| PQS1 (E1,I1) 3~ | PQS1 (E1,I1) 3~ | PQS1 (E1,I1) 3~ | PS (E1,E4) | | | | |
| 8.856 | 102.7 | 103.2 | 0.000 | | | | |
| P | W | Q | Var | S | VA | | ° |

$R = 300 \, \Omega$, $X = 300 \, \Omega$

| | | | | | | | |
|-----------------|-----------------|-----------------|-----------------|------------|---------------|-----|------------|
| M1 | E1 | M2 | E2 | M3 | E3 | M4 | E4 |
| E1 | E2 | E3 | E4 | | | | |
| 119.5 | | | 210.5 | | | | |
| AC | V | AC | V | AC | V | AC | V |
| M7 | I1 | M8 | I2 | M9 | I3 | M10 | I4 |
| I1 | I2 | I3 | I4 | | | | |
| 0.341 | | | | | | | |
| AC | A | AC | A | AC | A | AC | A |
| M13 | PQS1 (E1,I... | M14 | PQS1 (E1,I... | M15 | PQS1 (E1,I... | M16 | PS (E1,E4) |
| PQS1 (E1,I1) 3~ | PQS1 (E1,I1) 3~ | PQS1 (E1,I1) 3~ | PQS1 (E1,I1) 3~ | PS (E1,E4) | | | |
| 52.71 | 46.99 | 70.64 | 22.52 | | | | |
| P | W | Q | Var | S | VA | | ° |

$R = 200 \, \Omega$, $X = 0 \, \Omega$

| | | | | | | | |
|-----------------|-----------------|-----------------|-----------------|------------|---------------|-----|------------|
| M1 | E1 | M2 | E2 | M3 | E3 | M4 | E4 |
| E1 | E2 | E3 | E4 | | | | |
| 149.0 | | | 210.2 | | | | |
| AC | V | AC | V | AC | V | AC | V |
| M7 | I1 | M8 | I2 | M9 | I3 | M10 | I4 |
| I1 | I2 | I3 | I4 | | | | |
| 0.433 | | | | | | | |
| AC | A | AC | A | AC | A | AC | A |
| M13 | PQS1 (E1,I... | M14 | PQS1 (E1,I... | M15 | PQS1 (E1,I... | M16 | PS (E1,E4) |
| PQS1 (E1,I1) 3~ | PQS1 (E1,I1) 3~ | PQS1 (E1,I1) 3~ | PQS1 (E1,I1) 3~ | PS (E1,E4) | | | |
| 111.7 | -0.751 | 111.7 | 39.35 | | | | |
| P | W | Q | Var | S | VA | | ° |

$R = 200 \, \Omega$, $X = 300 \, \Omega$

| | | | | | | | |
|-----------------|-----------------|-----------------|-----------------|------------|---------------|-----|------------|
| M1 | E1 | M2 | E2 | M3 | E3 | M4 | E4 |
| E1 | E2 | E3 | E4 | | | | |
| 110.2 | | | 210.4 | | | | |
| AC | V | AC | V | AC | V | AC | V |
| M7 | I1 | M8 | I2 | M9 | I3 | M10 | I4 |
| I1 | I2 | I3 | I4 | | | | |
| 0.398 | | | | | | | |
| AC | A | AC | A | AC | A | AC | A |
| M13 | PQS1 (E1,I... | M14 | PQS1 (E1,I... | M15 | PQS1 (E1,I... | M16 | PS (E1,E4) |
| PQS1 (E1,I1) 3~ | PQS1 (E1,I1) 3~ | PQS1 (E1,I1) 3~ | PQS1 (E1,I1) 3~ | PS (E1,E4) | | | |
| 64.64 | 39.74 | 75.91 | 30.94 | | | | |
| P | W | Q | Var | S | VA | | ° |

$R = 171 \, \Omega$, $X = 0 \, \Omega$

| | | | | | | | |
|-----------------|-----------------|-----------------|-----------------|------------|---------------|-----|------------|
| M1 | E1 | M2 | E2 | M3 | E3 | M4 | E4 |
| E1 | E2 | E3 | E4 | | | | |
| 139.0 | | | 210.2 | | | | |
| AC | V | AC | V | AC | V | AC | V |
| M7 | I1 | M8 | I2 | M9 | I3 | M10 | I4 |
| I1 | I2 | I3 | I4 | | | | |
| 0.466 | | | | | | | |
| AC | A | AC | A | AC | A | AC | A |
| M13 | PQS1 (E1,I... | M14 | PQS1 (E1,I... | M15 | PQS1 (E1,I... | M16 | PS (E1,E4) |
| PQS1 (E1,I1) 3~ | PQS1 (E1,I1) 3~ | PQS1 (E1,I1) 3~ | PQS1 (E1,I1) 3~ | PS (E1,E4) | | | |
| 112.1 | -0.738 | 112.1 | 45.00 | | | | |
| P | W | Q | Var | S | VA | | ° |