Electrical Power Systems

Group 4 Project Report

CAIRO UNIVERSITY
FACULTY OF ENGINEERING
Electrical Power Engineering

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Introduction

Voltage stability is a major concern when planning and operating a modern power system. The last decade has seen several widespread blackouts in large power systems. These occurrences indicate that the subject of power system collapse still needs further investigation. One cause of system failure is voltage collapse.

Transmission lines have different configurations and in order to deal with them, one must know the values of their specifications. So, the first part of our program is made to compute these values depending on the formation of the T.L.

After knowing the parameters of the system, the problem of knowing the system performance arise, the second part of our program calculates approximate model constants and based on them calculates the system performance.

Lastly, after knowing the system performance it's required to control the voltage, that can be done by shunt compensation of reactive power element, to know such value, the third part of our program computes the required reactive power to compensate increase or decrease in voltage level using numerical methods and linkage with Simulink.

Objective of the program as a whole is to control the voltage level of transmission line from the first principles.

Software used is MATLAB Guide package which has many functions regarding the properties of added interactable objects.

User Interface

Run the “M” file or open the app “MLAPP” File to launch the program

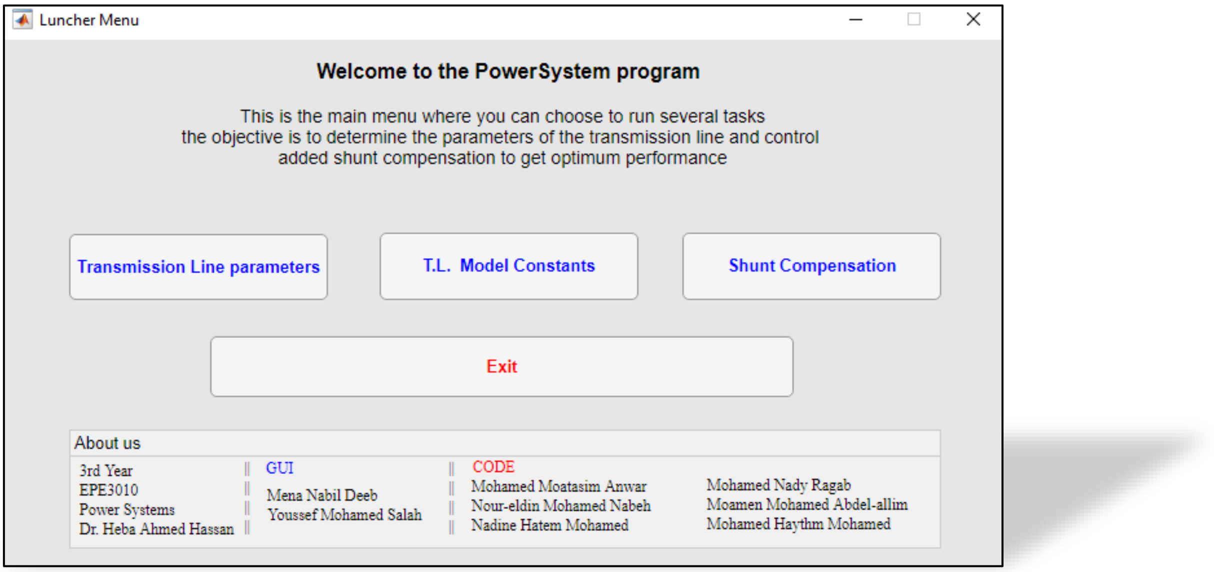


Figure 1. User Interface

From the Launcher Main menu, you can browse through the three tasks

First	L & C calculations for different shapes
Second	approximate Model Constants and system performance
Third	Voltage control using shunt compensation

1. Transmission Line Parameters

In order to compute the Inductance and Capacitance of Transmission Line, Certain inputs are required :

- Type of Configuration
- Frequency
- Diameter of the conductor
- Distances between centers for different configurations
- Spacing between bundles if exists
- Permeability
- Permittivity

The program calculates particular parameters according to the configuration

Single-Phase Outputs

$Internal\ inductance\ (L_{int})$	(H/m)
$Conductor\ inductance\ (L_1)$	(H/m)
$Complete\ circuit\ inductance\ (L_{ct})$	(H/m)
$Total\ inductive\ reactance\ (X_L)$	(Ω/km)
$Two-wire\ capacitance\ (C_{ab})$	(F/m)
$Capacitance\ to\ neutral\ (C_n)$	$(F/km) toneutral$
$Capacitive\ reactance\ (X_c \cdot km)$	$(\mathrm{k}\Omega \cdot km)$

Three-Phase Outputs

Internal inductance $(\boldsymbol{L_{int}})$	(H/m per phase)
Phase inductance $(\boldsymbol{L_a}$	(H/m per phase)
Inductive reactance per phase $(\boldsymbol{X_l})$	(Ω/km)
Capacitance to neutral $(\boldsymbol{C_n})$	(F/km) to neutral
Capacitive reactance $(\boldsymbol{X_c})$	$(k\Omega \cdot km)$

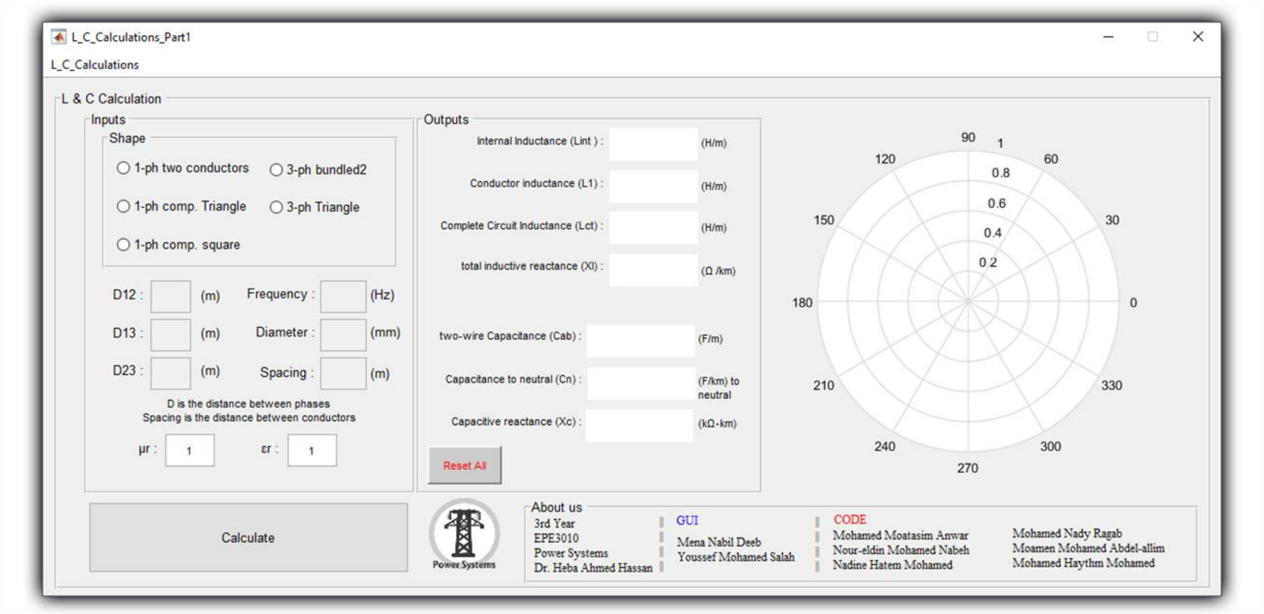


Figure 2. First program screen

The Program is divided into three sections

Inputs: Where the user enters the data about the model

Outputs: the computed data from the program

Plot: to see how the configuration is interpreted in the program

The computations are code-induced, the code contains the following Equations:

1.1. Single Phase Calculation [1]

1.1.1. Two Conductors

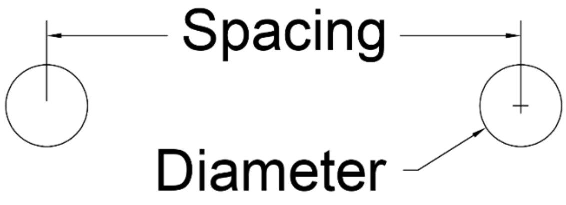


Figure 3. 1-ϕ two conductors

Precalculations in all cases

$$r' = D_s = \frac{D}{2} \times 10^{-3} \times e^{-0.25}$$

$$r = D_{sc} = \frac{D}{2} \times 10^{-3}$$

$$k = 8.85 \times 10^{-12} \times \epsilon_r$$

$$GMD = \text{ the spacing value}$$

Output Values of (L)

$$L_{int} = 0.5 * 10^{-7} * \mu_r \qquad (H/m)$$

$$L_1 = 2 * 10^{-7} * \mu_r * Ln\left(\frac{GMD}{r'}\right) \qquad (H/m)$$

$$L_{ct} = 2L_1 \qquad (H/m)$$

$$X_l = 2\pi * F * L_{ct} * 1000 \qquad (\Omega/km)$$

Output Values of (C)

$$C_{ab} = \frac{\pi k}{Ln\left(\frac{GMD}{r}\right)} \qquad (F/m)$$

$$C_n = \frac{2\pi k}{Ln\left(\frac{GMD}{r}\right)} * 1000 \qquad (F/km)$$

$$X_c = \frac{1}{2\pi * F * c_n * 1000} \qquad (k\Omega \cdot km)$$

1.1.2. Composite Triangle

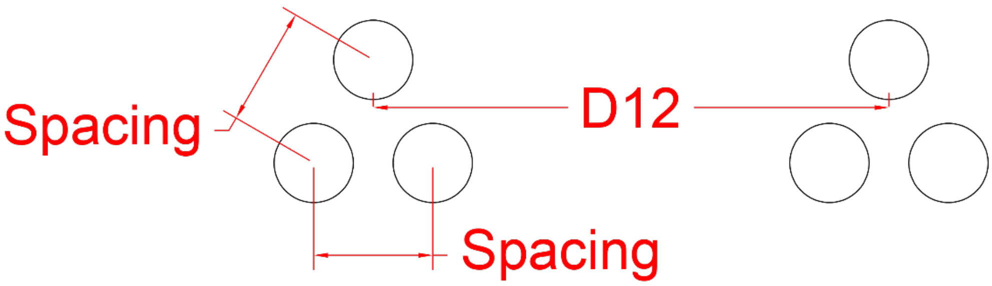


Figure 4. 1-ϕ Composite Triangle

Precalculations

$$GMD = D12$$

$$GMR = \sqrt[3]{D_s * d^2}$$

$$GMR_c = \sqrt[3]{D_{sc} * d^2}$$

Output Values of (L)

$$L_{int} = 0.5 * 10^{-7} * \mu_r \qquad (H/m)$$

$$L_1 = 2 * 10^{-7} * \mu_r * Ln\left(\frac{GMD}{GMR}\right) \qquad (H/m)$$

$$L_{ct} = 2L_1 \qquad (H/m)$$

$$X_l = 2\pi * F * L_{ct} * 1000 \qquad (\Omega/km)$$

Output Values of (C)

$$C_{ab} = \frac{\pi k}{Ln\left(\frac{GMD}{GMR_c}\right)} \qquad (F/m)$$

$$C_n = \frac{2\pi k}{Ln\left(\frac{GMD}{GMR_c}\right)} * 1000 \qquad (F/km)$$

$$X_c = \frac{1}{2\pi * F * c_n * 1000} \qquad (k\Omega \cdot km)$$

1.1.3. Composite Square

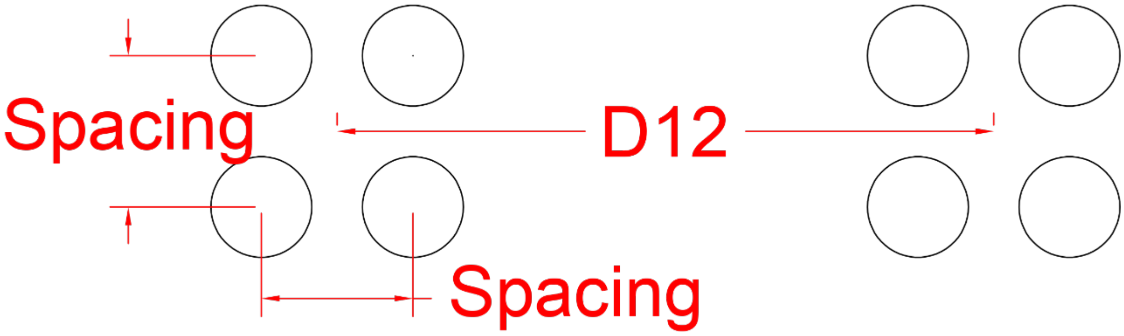


Figure 5. 1-ϕ Composite Square

Precalculations

$$GMD = D12$$

$$GMR = 1.09 * \sqrt[4]{D_s * d^3}$$

$$GMR_c = 1.09 * \sqrt[4]{D_{sc} * d^3}$$

Output Values of (L)

$$L_{int} = 0.5 * 10^{-7} * \mu_r \qquad (H/m)$$

$$L_1 = 2 * 10^{-7} * \mu_r * Ln\left(\frac{GMD}{GMR}\right) \qquad (H/m)$$

$$L_{ct} = 2L_1 \qquad (H/m)$$

$$X_l = 2\pi * F * L_{ct} * 1000 \qquad (\Omega/km)$$

Output Values of (C)

$$C_{ab} = \frac{\pi k}{Ln\left(\frac{GMD}{GMR_c}\right)} \qquad (F/m)$$

$$C_n = \frac{2\pi k}{Ln\left(\frac{GMD}{GMR_c}\right)} * 1000 \qquad (F/km)$$

$$X_c = \frac{1}{2\pi * F * c_n * 1000} \qquad (k\Omega \cdot km)$$

1.2. Three Phase Calculation [1]

1.2.1. Two Bundle

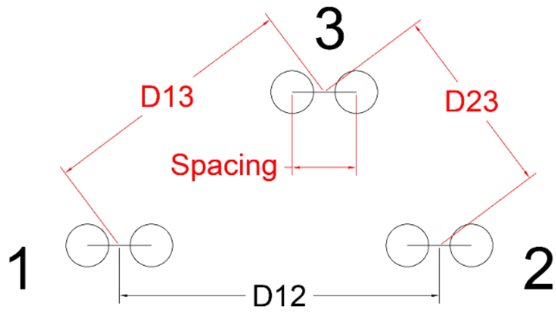


Figure 6. 3-ϕ Two Bundle

According to distance values it can be further modified to

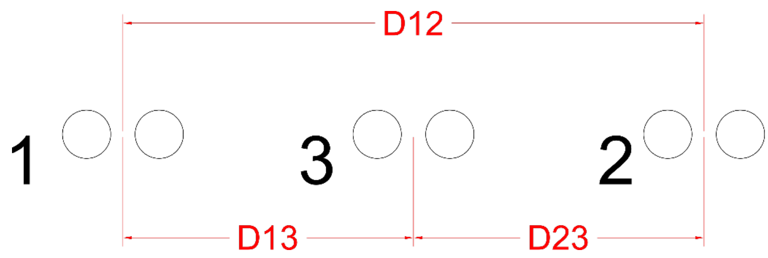


Figure 7. 3-ϕ Two Bundle with D12=D13+D23

$$GMD = \sqrt[3]{D_{12}D_{13}D_{23}}$$

$$GMR = \sqrt{D_s * d}$$

$$GMR_c = \sqrt{D_{sc} * d}$$

Output Values of (L)

$$L_{int} = 0.5 * 10^{-7} * \mu_r \qquad (H/m)$$

$$L_a = 2 * 10^{-7} * \mu_r * Ln\left(\frac{GMD}{GMR}\right) \qquad (H/m)$$

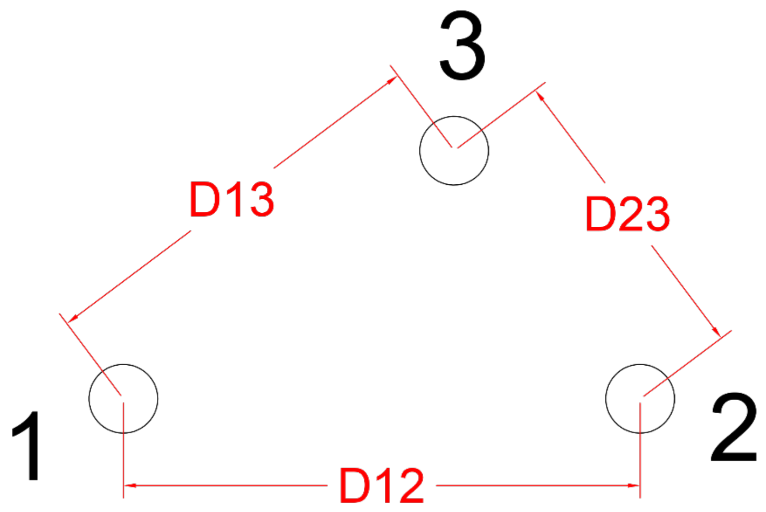
$$X_l = 2\pi * F * L_{ct} * 1000 \qquad (\Omega/km)$$

Output Values of (C)

$$C_n = \frac{2\pi k}{Ln\left(\frac{GMD}{GMR_c}\right)} * 1000 \qquad (F/km)$$

$$X_c = \frac{1}{2\pi * F * c_n * 1000} \qquad (k\Omega \cdot km)$$

1.2.2. Triangle (single conductor)



$$GMD = \sqrt[3]{D_{12}D_{13}D_{23}}$$

$$GMR = D_s$$

$$GMR_c = D_{sc}$$

Output Values of (L)

$$L_{int} = 0.5 * 10^{-7} * \mu_r \qquad (H/m)$$

$$L_a = 2 * 10^{-7} * \mu_r * Ln\left(\frac{GMD}{GMR}\right) \qquad (H/m)$$

$$X_l = 2\pi * F * L_{ct} * 1000 \qquad (\Omega/km)$$

Output Values of (C)

$$C_n = \frac{2\pi k}{Ln\left(\frac{GMD}{GMR_c}\right)} * 1000 \qquad (F/km)$$

$$X_c = \frac{1}{2\pi * F * c_n * 1000} \qquad (k\Omega \cdot km)$$

1.3. Examples on first program

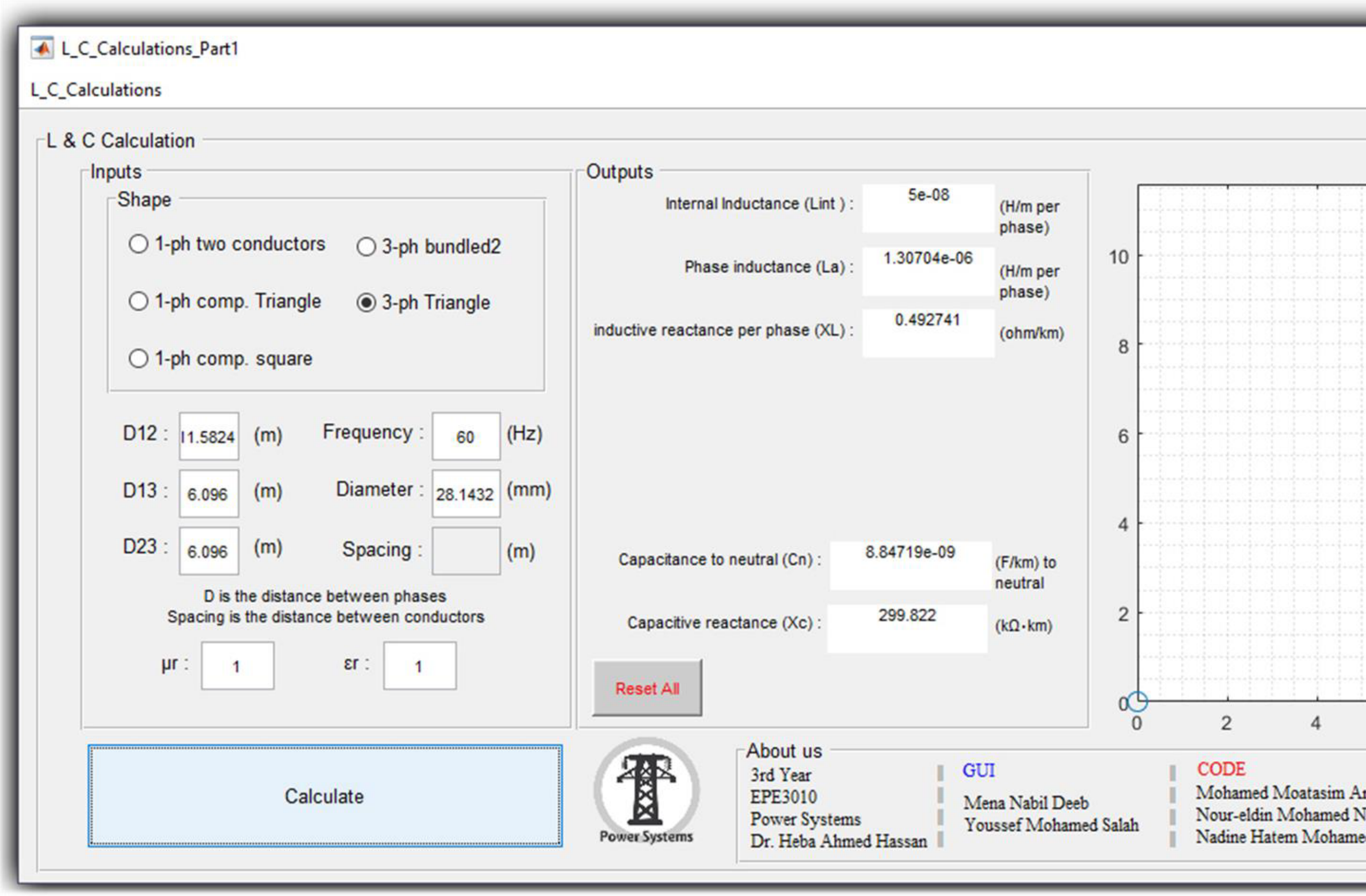


Figure 8. Lecture (9) Dr. Heba

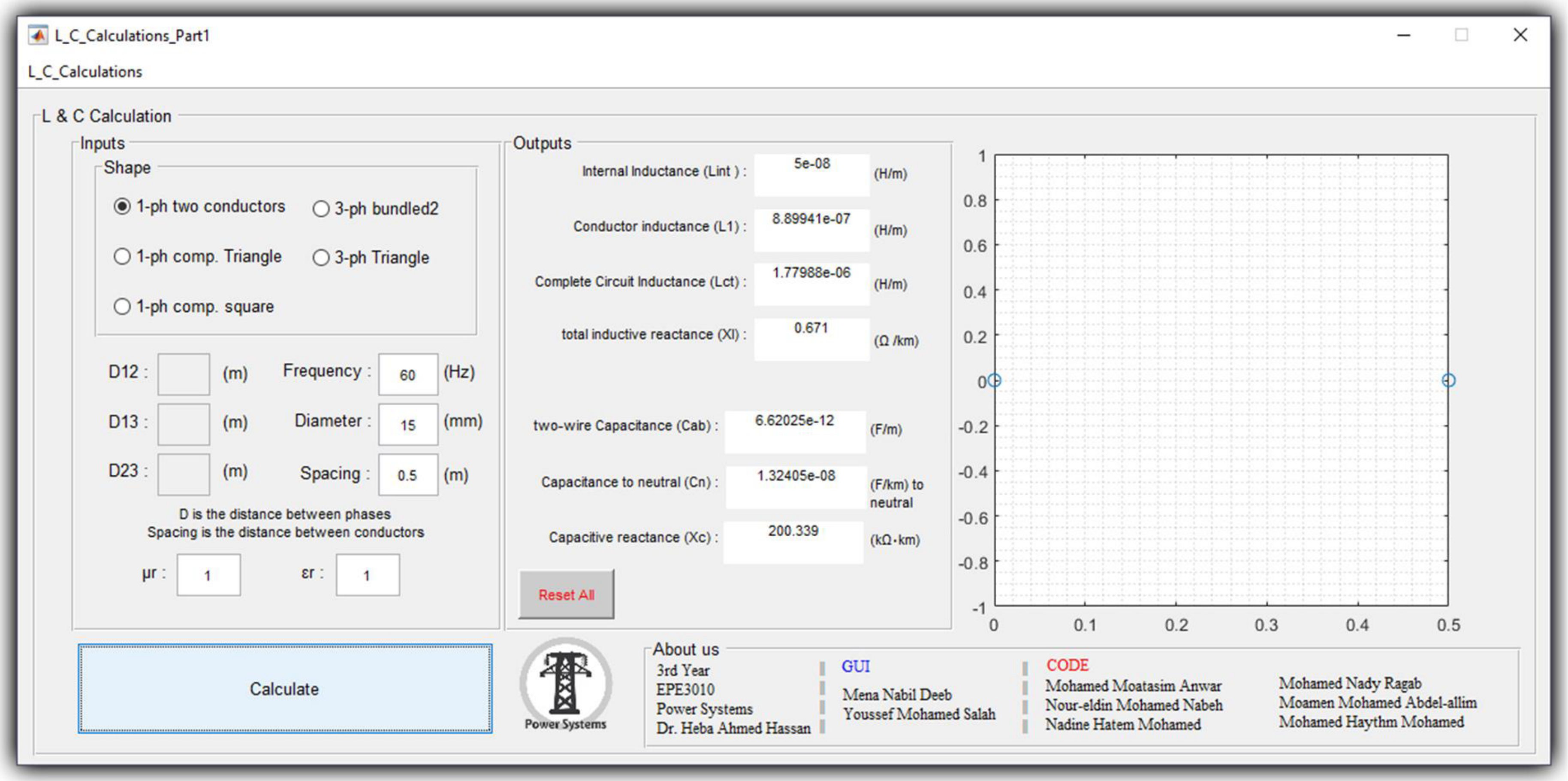


Figure 9. Problem 1 Sheet 2

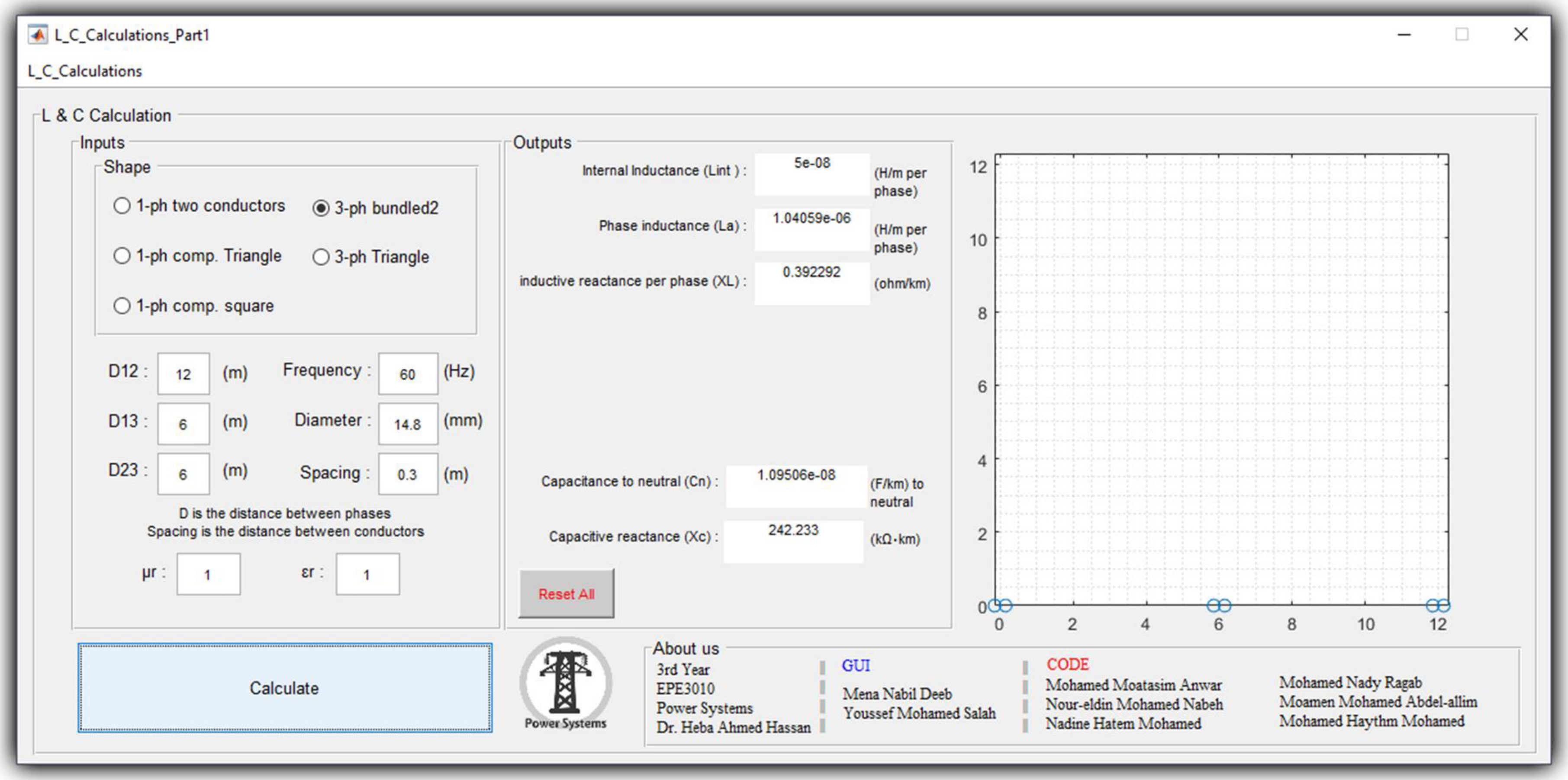


Figure 10. Problem 6-7 Sheet 2

2. Model Constants

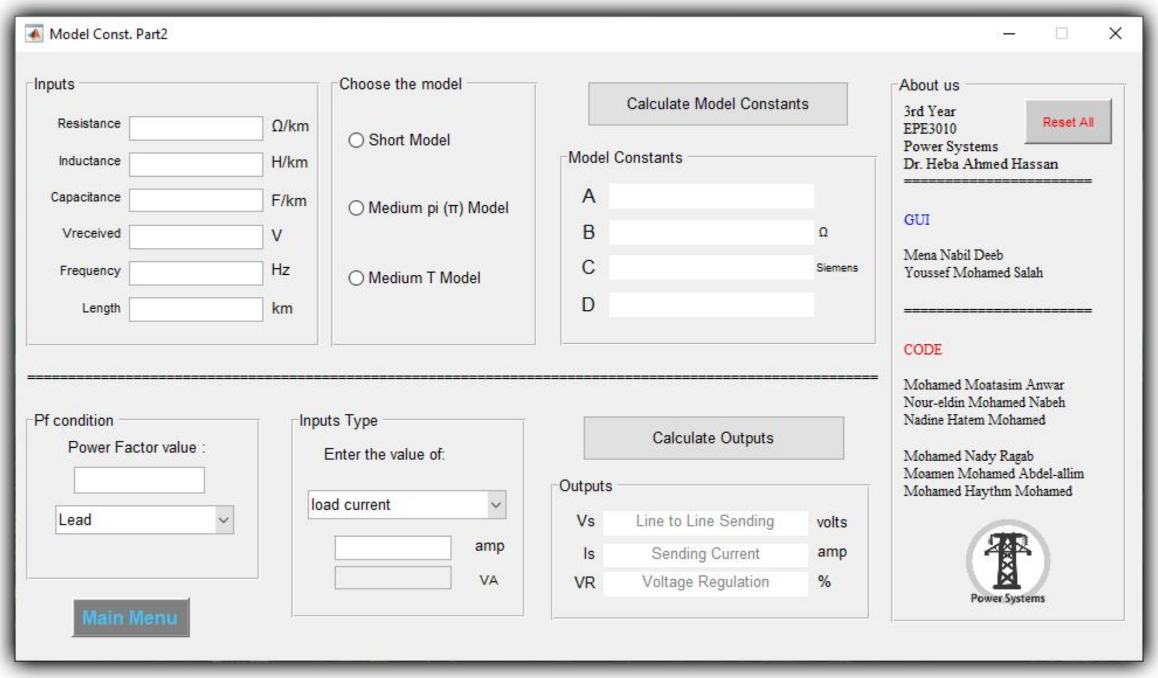


Figure 11. Second program screen

Second Program is divided into two sections

- Model Constants Section
- System performance Section

This part calculates the main circuit parameters of the transmission line model; short and medium (pi and T models) depending on the system frequency, the resistance of the transmission, the inductance, the capacitance and surely the total length of T.L.

Also, if the receiving end voltage, power factor and receiving end current or load apparent power are known, the user can get the performance values

Required Inputs

The Resistance per phase per km in Ω/km :	R	The length of transmission line in km :	l
The Inductance per phase per km in H/km :	L	The load power factor. (Lagging, leading, unity):	pF
The Capacitance per phase per km in F/km :	C		
The Load line Voltage in V [1]:	Vr	The load current in A **OR**	Ir
The frequency in Hz :	f	the load apparent Power in VA	Sr

[1] Vr taken as a reference

2.1. Model Constants Calculation

Precalculations

$w = 2\pi f\,(rad/s)$

$Z = l * [R + jwL]\ (total\ impedance\ in\ \Omega)$

$Y = l * [jwC]\ \left(total\ addmitance\ in\ \Omega^{-1}\ (S)\right)$

Outputs [2]

Short T.L.

$A = 1\,, B = Z\,, C = 0\,, D = 1$

$\boldsymbol{\pi - model}$

$$A = 1 + \frac{ZY}{2}\,, B = Z\,, C = Y\left[1 + \frac{ZY}{4}\right]\,, D = 1 + \frac{ZY}{2}$$

$\boldsymbol{T - model}$

$$A = 1 + \frac{ZY}{2}\,,, B = Z\left[1 + \frac{ZY}{4}\right], C = Y\,, D = 1 + \frac{ZY}{2}$$

GIVEN I_r

Lagging p.f.	Leading p.f	Unity p.f
$\overline{I_r} = I_r[p.f. - j\sin((\cos^{-1} p.f.))]$	$\overline{I_r} = I_r[p.f. + j\sin((\cos^{-1} p.f.))]$	$\overline{I_r} = I_r$

GIVEN S_r

Lagging p.f.	Leading p.f	Unity p.f
$\overline{S_r} = \frac{S_r}{3}[p.f. + j\ \sin((\cos^{-1} p.f.))]$	$\overline{S_r} = \frac{S_r}{3}[p.f. - j\ \sin((\cos^{-1} p.f.))]$	$\overline{S_r} = \frac{S_r}{3}(p.f.)$
$\overline{I_r} = \frac{\overline{S_r}^*}{V_r/\sqrt{3}}$	$\overline{I_r} = \frac{\overline{S_r}^*}{V_r/\sqrt{3}}$	$\overline{I_r} = \frac{\overline{S_r}^*}{V_r/\sqrt{3}}$

$$\overline{V_s} = A\frac{\overline{V_r}}{\sqrt{3}} + B\overline{I_r}\quad \&\ \overline{I_s} = C\frac{\overline{V_r}}{\sqrt{3}} + D\overline{I_r}$$

$$\therefore\ |\overline{\boldsymbol{V}}_{\boldsymbol{s}_{L-L}}| = \sqrt{\boldsymbol{3}} * |\overline{\boldsymbol{V}_{\boldsymbol{s}}}| \quad \& \quad \left|\left(\overline{\boldsymbol{I}}_{\boldsymbol{s}_{line}}\right)\right| = |\overline{\boldsymbol{I}}_{\boldsymbol{s}}|$$

[2] note A,B,C,D are phasors

2.2. Examples on Second program

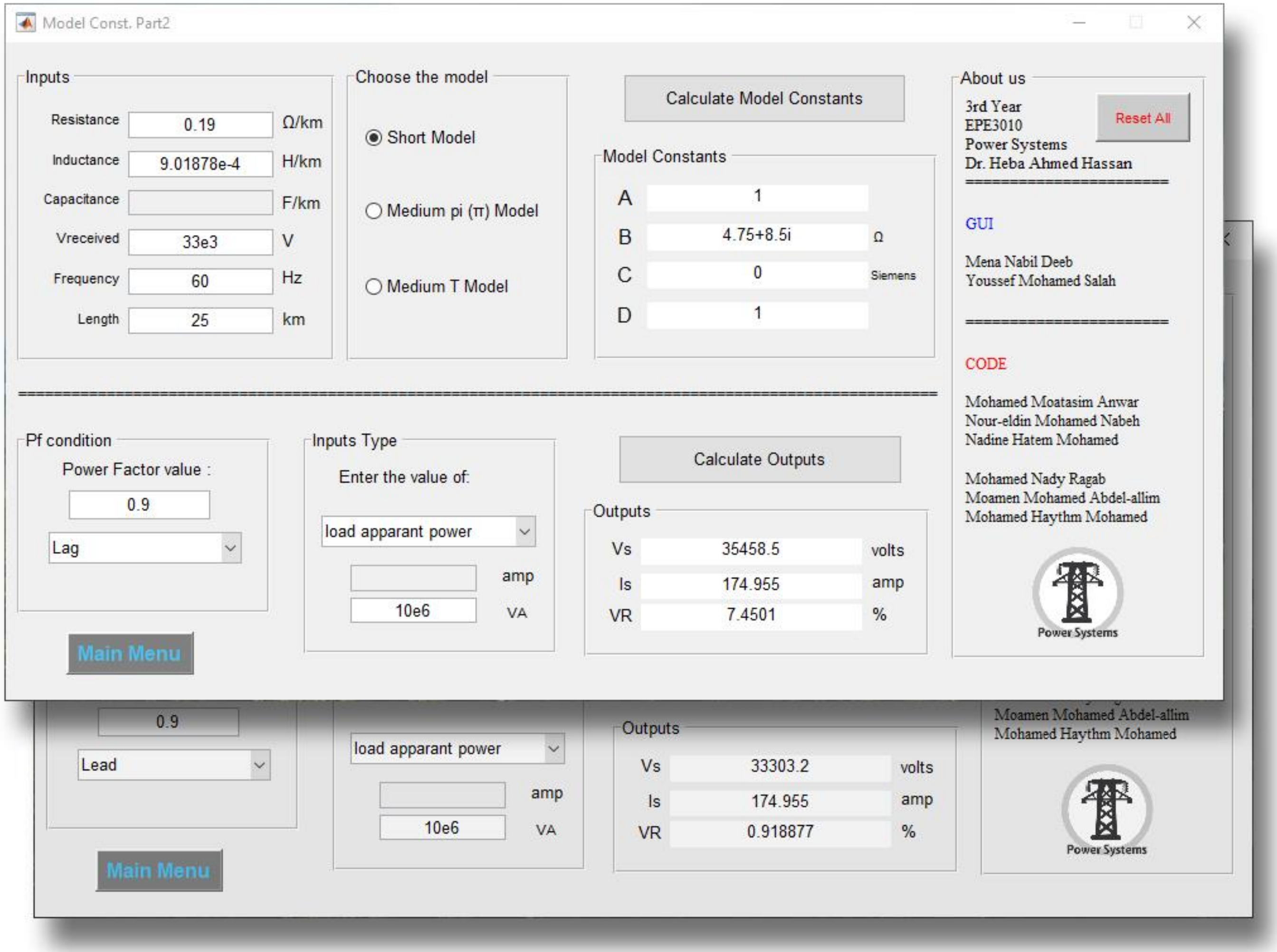


Figure 12. Problem 1 Sheet 4 (both power factors)

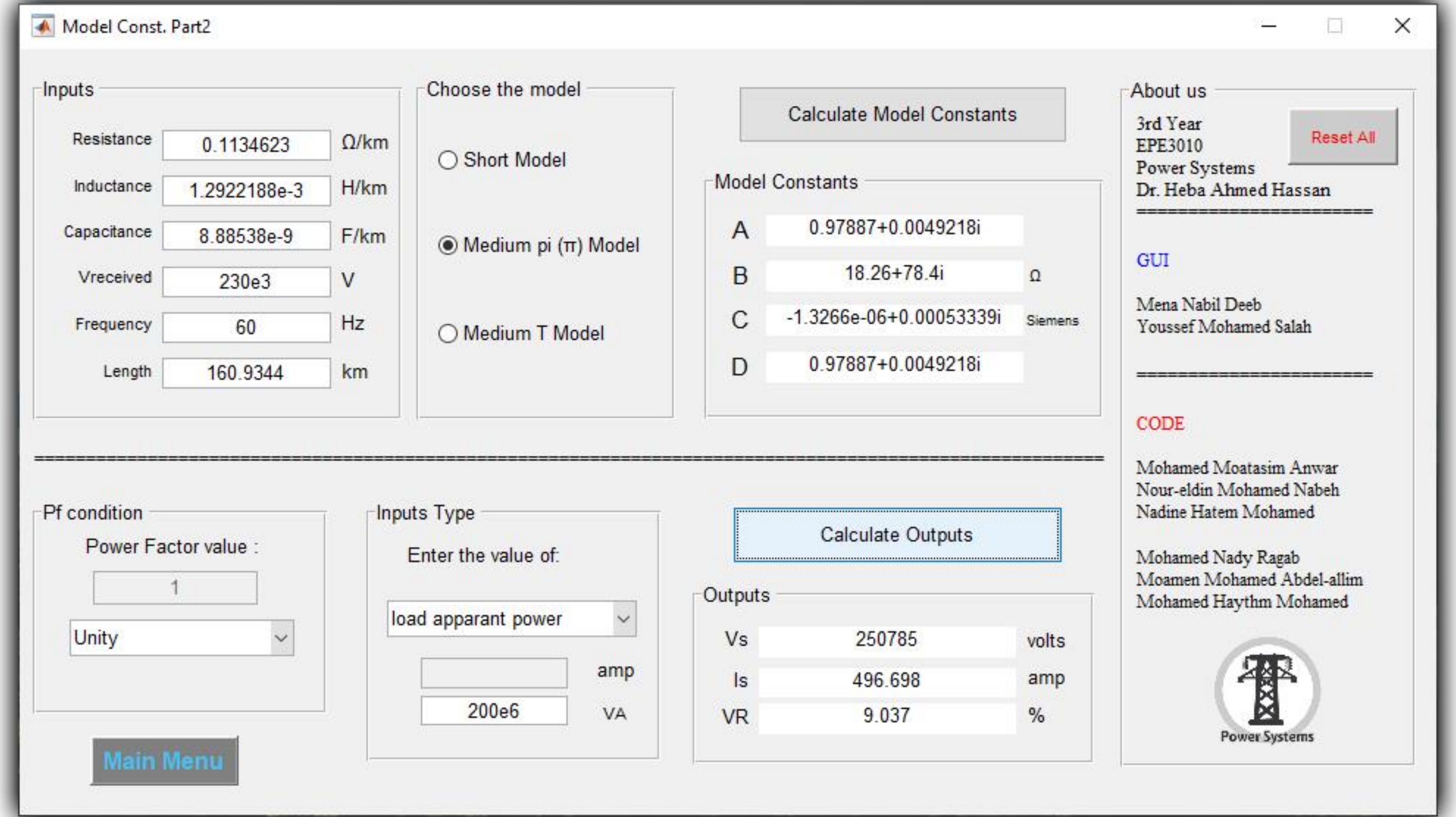


Figure 13. Problem 3 Sheet 4

3. Shunt Compensation

In power systems, voltage is supposed to be constant in order for it to remain constant, we have to control it; most of the devices, apparatus, electrical machines, consumer appliances etc. are all designed to function at a specified voltage. When voltage variates, this may cause errors in operation, malfunctioning or performance deterioration. It is preferable that the consumers receive power at constant voltage. [1]

Methods Of Voltage Control in Power System

1. By using tap changing transformers
2. By using shunt reactors
3. By using shunt capacitors

Voltage Control by Using Tap-Transformers

controlling voltage in transmission lines by using tap changing transformers. The voltage in the line is customized by changing the secondary voltage of the transformer and this is done by changing the number of secondary turns and since the voltage of a transformer is directly proportional to the number of turns. Therefore, the secondary voltage can be changed by variating the turns ratio of the transformer. Secondary number of turns can be varied with the help of tappings provided on the winding.

Voltage Control by Using Shunt Reactors

adding shunt reactors which are inductive elements, at sending end and receiving end of long EHV and UHV transmission lines. Shunt reactors are switched in the line, compensate the line and control the voltage and this happens when a transmission line has no load or has a light load, therefore, the line capacitance predominates and receiving end voltage becomes greater than the sending end voltage and this causes the effect known as Ferranti effect. [3]

Voltage Control by Using Shunt Capacitors

installing shunt capacitors when the load is highly inductive, at the receiving end substations or near industrial loads. Since most of the industrial loads draw inductive current, therefore the power factor is lagging The line voltage drop due to this lagging current. When we switch to shunt capacitors, they help compensate this inductive reactance, therefore, the voltage drop caused by the lagging current IXL decreases.

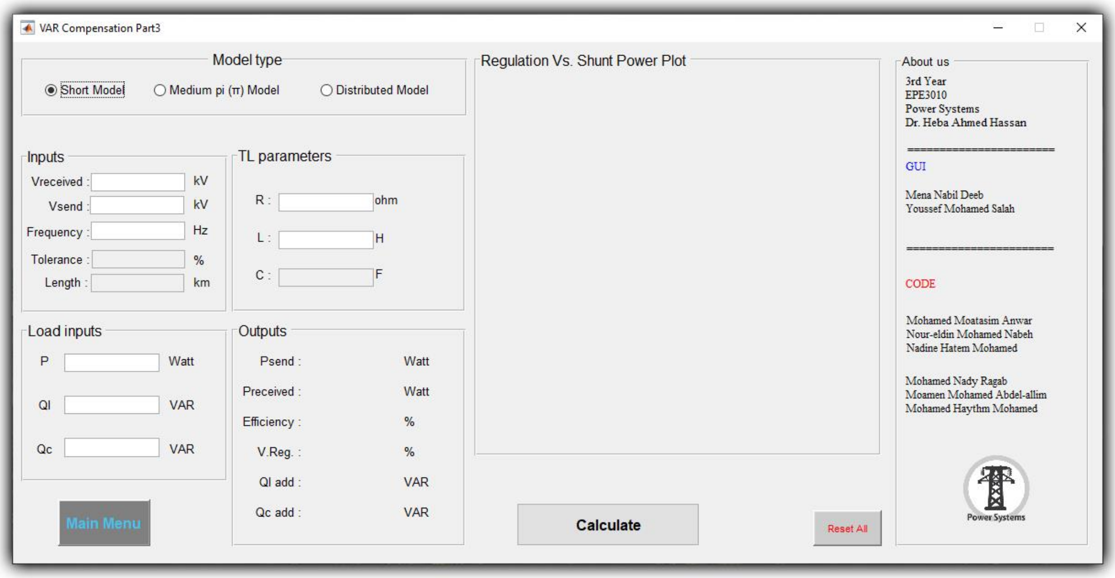


Figure 14. Third program screen

Third Program is divided into three sections :

- Short Model Simulink regular simulation
- Medium (π) Model Shunt compensation
- Long (Distributed) Model Shunt compensation

We originally made the program for medium and long models to calculate the required reactive power to be added to the system to minimize the voltage regulation below a certain limit defined as tolerance.

The program uses numerical mathematical method (False-Position) to obtain the value of added reactive power by simulating and getting a value closer each time till it gets a value below the specified tolerance, or till it completes five iterations.

Furthermore, we figured since we connected our program with Simulink, might as well make a short model but it's far less accurate and almost the same computation time to calculate the required VAR, so we settled for just a regular simulation as the 2nd Program did but this time with simulation from Simulink.

Limitation:

The Simulink block can't accept zero values, so if reactive power is added, a small negligible capacitive power will be added as well and vice versa.

The number of iterations we settled for in the numerical calculation is 5 times as a precaution if the value of tolerance is not acceptable (too small) the program doesn't enter a Long (or infinite) loop.

With the purpose of running the simulation, Certain inputs are required :

Inputs

V receiving, Line value(kV)	Resistance (Ω) (Ω/km for med, long)
V sending, Line value (kV)	Inductance(H) (H/km for med, long)
Frequency (Hz)	Capacitance (F/km only in med, long)
Length (km only in med, long)	Active Load Power (Watt)
Voltage regulation Tolerance (% only in med, long)	Inductive Load Power (VAR)
	Capacitive load power (VAR)

The program calculates the following:

Outputs

Power at sending end	(Watt)	Compensating inductive power	(VAR)
Power at receiving end	(Watt)		
Efficiency	(%)	Compensating Capacitive power	(VAR)
Voltage regulation	(%)		

3.1. Reactive Power Calculation

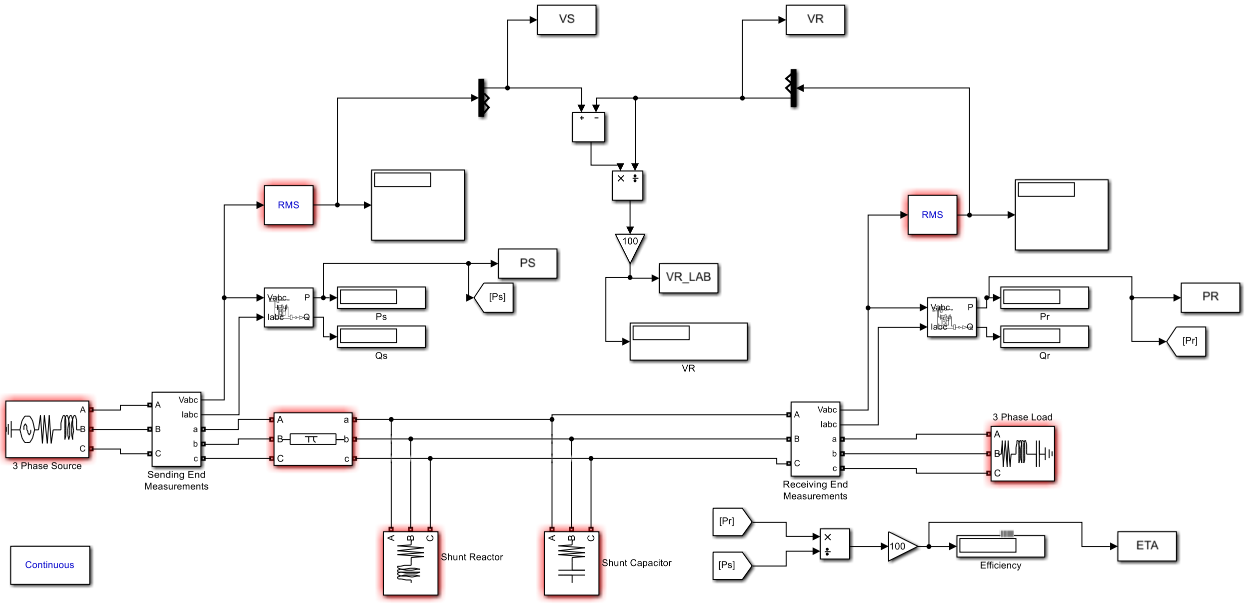


Figure 15. Simulink model with compensating reactive power

Using False position Method, the program tries two boundary reactive power values (no problem if they didn't include the Reactive value between them)

And after carrying iterations of recording the Voltage regulation the program will stop after the voltage regulation value falls below the specified tolerance value.

False Position Method (regula falsi):

Let boundary points be a_k, b_k

$$y - f(b_k) = \frac{f(b_k) - f(a_k)}{b_k - a_k}(x - b_k)$$

$$To\ know\ the\ x\ value\ let\ it\ = C_k, y = 0$$

$$f(b_k) + \frac{f(b_k) - f(a_k)}{b_k - a_k}(c_k - b_k) = 0$$

$$c_k = b_k - f(b_k)\frac{b_k - a_k}{f(b_k) - f(a_k)} \quad \text{(Formula Used)}$$

$$= \frac{a_k f(b_k) - b_k f(a_k)}{f(b_k) - f(a_k)}.$$

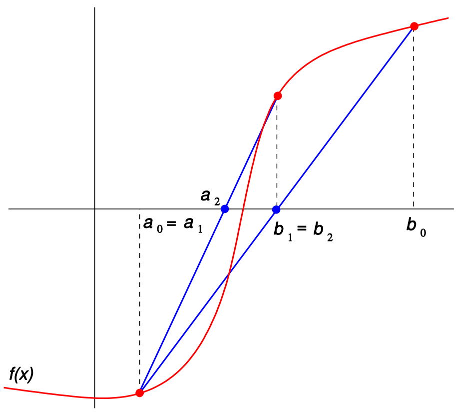


Figure 16. False position method

3.2. Examples on Third program

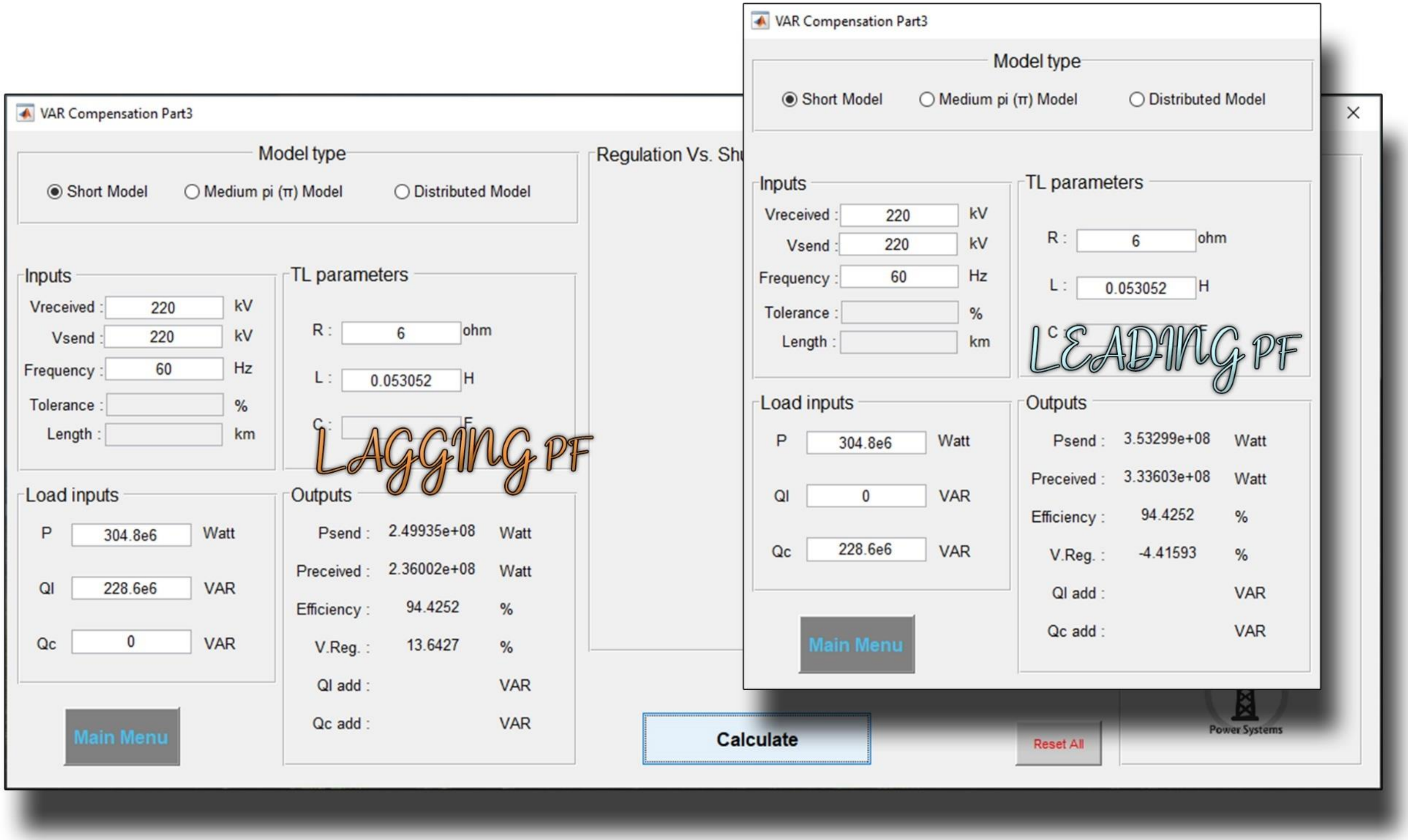


Figure 17. Lab2 Exercise (both Power Factors)

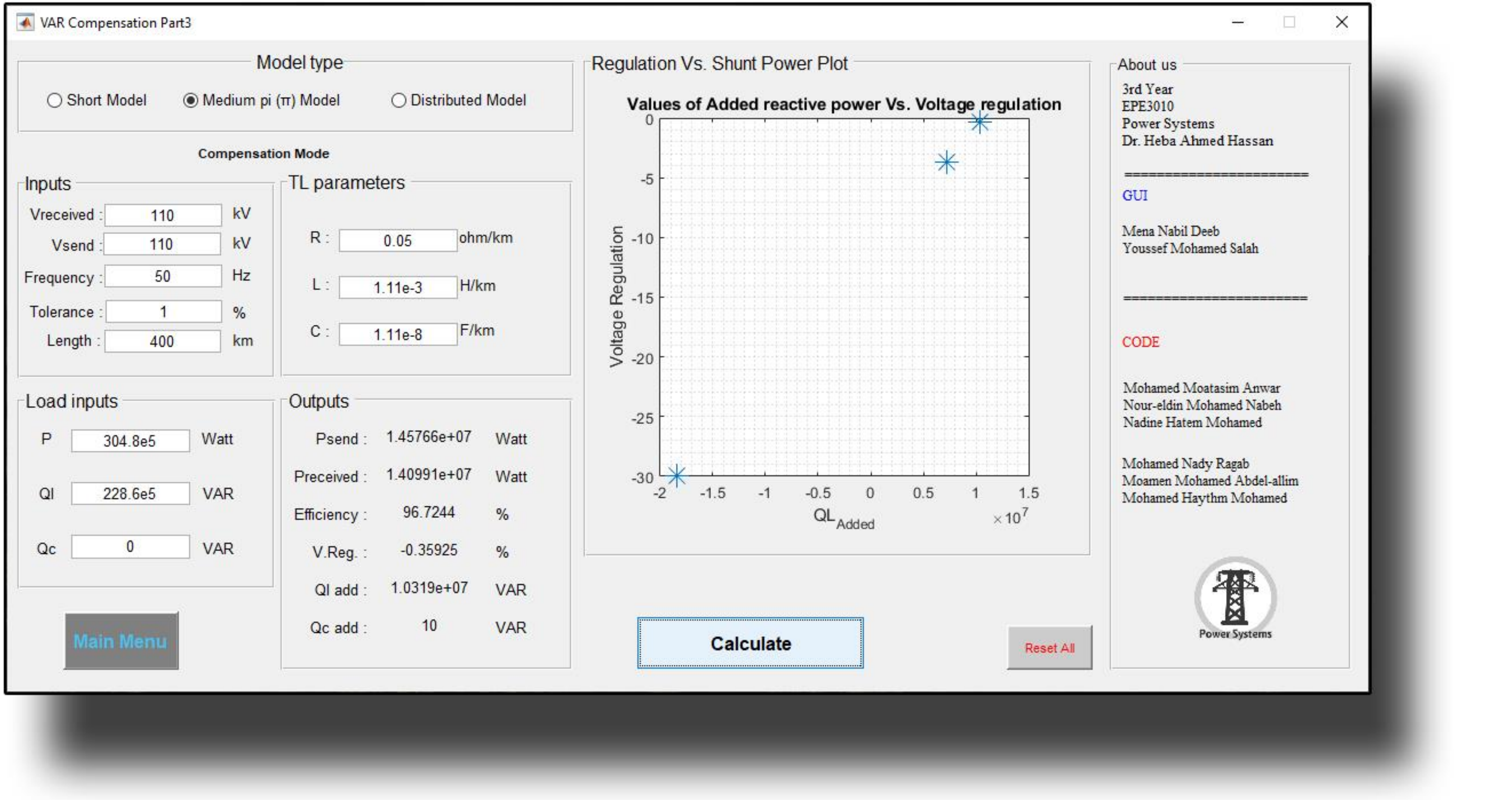


Figure 18. Example on voltage compensation (not enough inductive load)

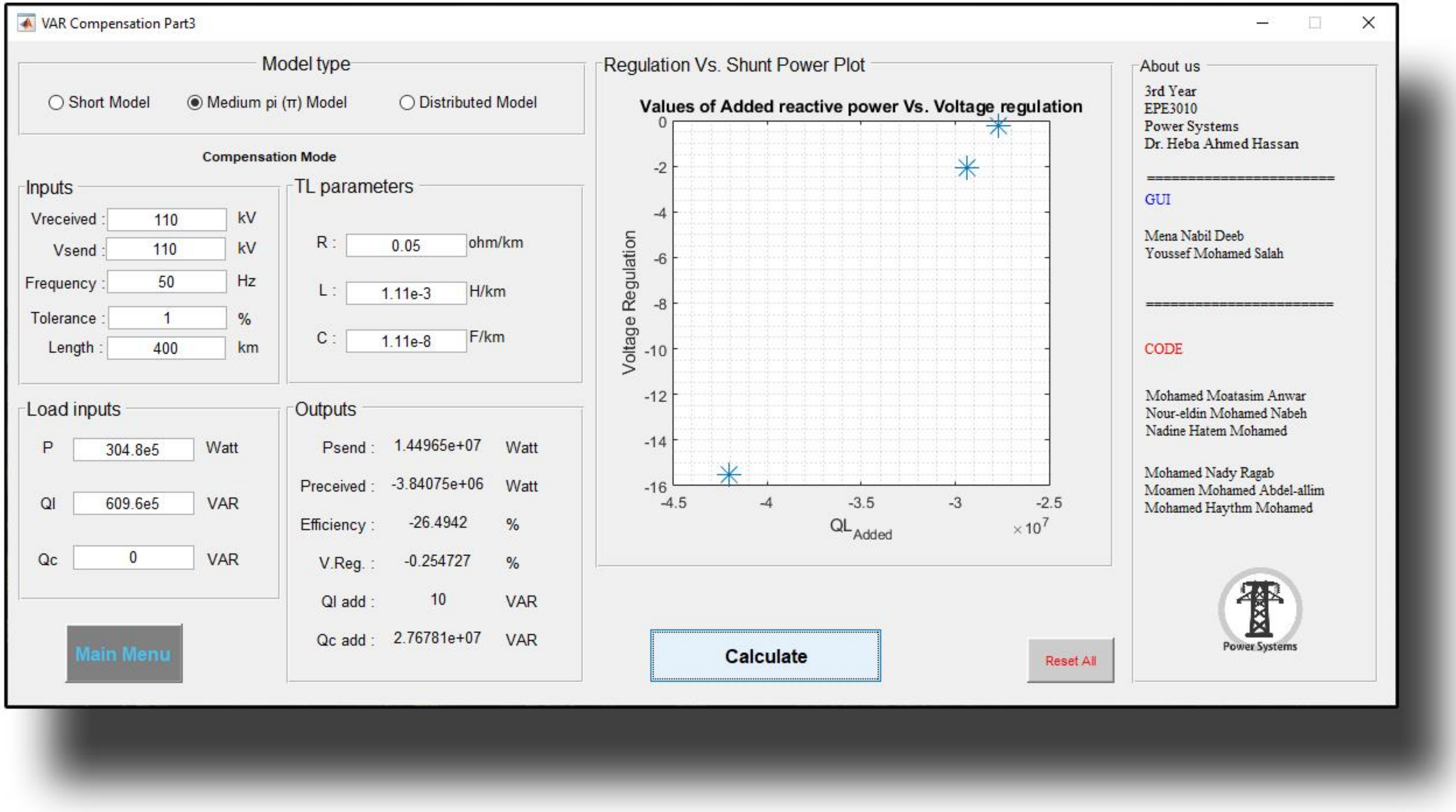


Figure 19. Compensation of huge inductive load

4. Conclusion

Simulink can be used to estimate the value of reactive power needed, and it can be used to direct a controller on a thyristor-controlled capacitor bank and a Thyristor-controlled reactor to maintain a stable voltage and avoid voltage collapse

To have the data of the transmission line system to carry out the simulation, a program was made to calculate such specs. first.

Checking on system performance help grasp the magnitude of the values at hand, such as the power at both ends, the efficiency of the system, and the voltage regulation.

References

[1] Dr. Heba Ahmed Hassan, "Electrical Power Systems Lecture," 2021.

[2] K. Daware. [Online]. Available: https://www.electricaleasy.com/2018/04/voltage-control-in-power-system.html.

[3] Notes for engineering, "Voltage Control," 6 August 2021. [Online]. Available: https://www.notesforengineering.com/voltage-control/.