Palestine Polytechnic University

College Of Engineering and Technology

Electrical Power Engineering Department

Project Title

Modeling of Smart Grid Lab Using MATLAB/Simulink

Project Team

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Certificate

Palestine Polytechnic University

The Project Entitled:

Modeling of Smart Grid Lab Using MATLAB/Simulink

By

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In accordance with the recommendations of the project supervisor, and the acceptance of the examining committee members, this project has been submitted to the Department of Electrical Power Engineering in the college of Engineering and Technology in partial fulfillment of the requirements of the department for the degree of Bachelor of Science in Engineering.

Project Supervisor **Department Chairman**

December-2016

الإهداء

بسم الله الرحمن الرحيم

معلم البشرية ومنبع العلم نبينا محمد (صلّ الله عليه وسلم)

إلـــــى.....

ينابيع العطاء الذين زرعوا في نفوسنا الطموح والمثابر ..... آبائنا الأعزاء

إلـــــى.....

أنهار المحبة التي لا تنضُب .... أمهاتنا الأحبة

إلـــــى.....

من يحملون في نفوسهم ذكريات الطفولة والشباب ..... أخوتنا وأخواتنا

إلـــــى.....

كافة الأهل الأصدقاء

إلـــــى.....

من مهّدوا لنا طريق العلم والمعرفة ...... أساتذتنا الأفاضل

إلـــــى.....

من ضحّوا بحريتهم من أجل حريتنا ..... أسرانا البواسل

إلـــــى.....

من وصلت رائحة دمائهم الزكية إلى السماء الندية ....شهداؤنا الأبرار

"كن عالماً ، فإن لم تستطع فكن متعلماً ، فإن لم تستطع فأحب العلماء ،فإن لم تستطع فلا تبغضهم"

ونخص بالتقدير والشكر:

الدكتور د.مــــــــاهر المغـــــــالسة

الذي نقول له بشراك قول رسول الله صلّ الله عليه وسلم:

"إن الحوت في البحر ، والطير في السماء ، ليصلون على معلم الناس الخير"

للنجاحات أناس يقدرون معناه ، وللإبداع أناس يحصدونه ، فأنت أهل للشكر والتقدير .. فوجب علينا تقديرك .. فلك منا كل الثناء والتقدير

فريق العمل

Abstract

This project concerns the simulation of Renewable Energy Lab at Palestine Polytechnic University. A simulation is done by deriving the equations of each module used in the lab, and simulated as blocks using MATLAB/Simulink. The modules considered are (Power circuit breaker, Maximum power demand, Transmission lines, Loads, Three phase induction generator, PV module, and Inverter module).

Complete design of Renewable Energy Lab was carried out. The design consist of the electrical modules that mentioned earlier, and the modules simulated stand alone to achieve the final form.

Finally several experiments on MATLAB and also practical are done, and a comparison between the results is obtained. After obtaining the comparison, a results validation is done.

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Chapter One Introduction

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1.3 Objectives

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1.7 Expected results

1.1 Overview

The MATLAB/Simulink software is used to model and analyze the dynamic response of various distribution components in form of smart grid lab at Palestine Polytechnic University. The approach taken involves simulating each component stand alone, what will be referred to as “Blocks”, where each block masks the mathematical and dynamic equations of the individual components.

1.2 Motivation

The model will be validated with experimental data. A series of experiments will be conducted on the smart grid system at the Renewable Energy Lab at the Electrical Engineering Department PPU. The developed model will give more details about the effects of the Embedded Generation (EG) unites and the Microturbines (MT) system on the transmission and distribution systems. The model will be used to study the effects of several factors such as the effects of EG and MT on the voltage profile, losses, harmonics, and load flow profile.

1.3 Objectives

- Recognize the electrical units used in the renewable energy laboratory and obtain important information for each electrical unit.
- Modeling each component of Smart grid system in the power lab at Palestine polytechnic university using MATLAB/Simulink.
- Make several practical experiments in energy laboratory located in PPU and compare the results with the results we have obtained using MATLAB.
- Develop a Smart grid Model for Education purposes.

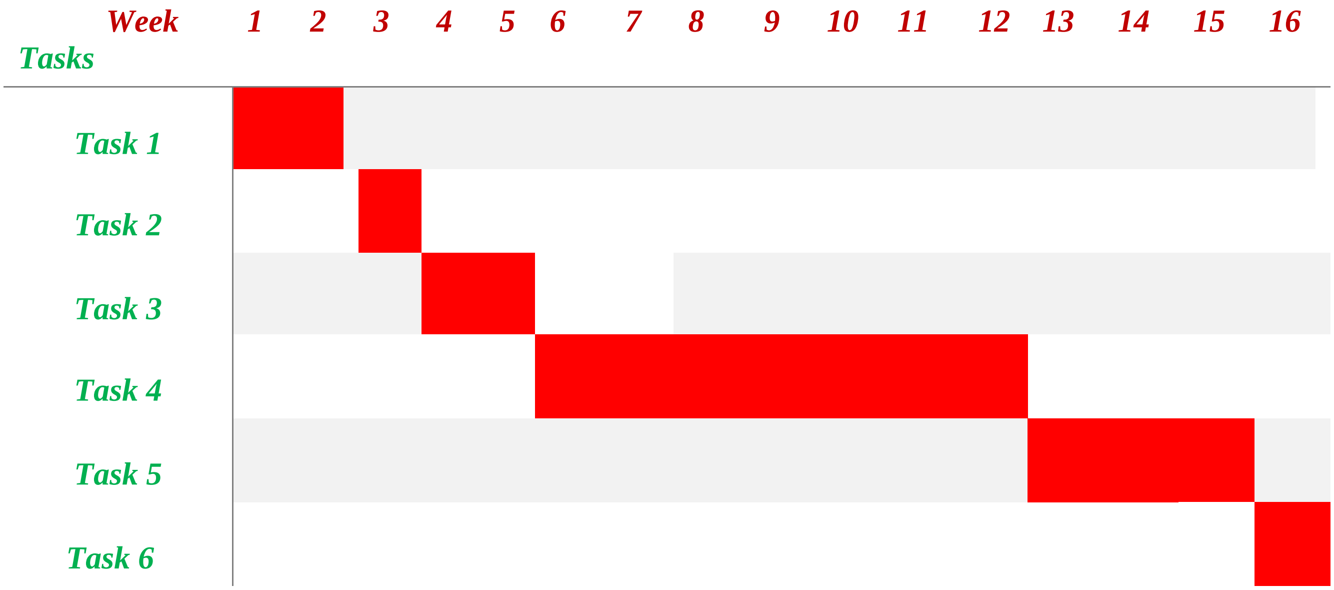
1.4 Challenges

- Limited knowledge of the MATLAB program due to lack of course education program which has led to the self-learning.
- Lack of case studies about our project.
- Communications between each component in the smart grid is extremely important to maximize the use of available electrical power in a reliable and cost effective way. Therefore, how to efficiently manage the new, intelligent power system and integrate it into the existing system has become one of the main challenges for the smart grid infrastructure.

1.5 Importance

- Develop a numerical Model for a smart grid system to be experimentally validated.
- The Model will be developed for the educational purpose.
- The Model will give more details about the system behavior and performance.
- Make this project "LAB" as one of the requirements for Graduation, and name the class as "Renewable energy lab".

1.6 Time schedule



Task 1: Prepare the mathematical and dynamic equations necessary for the project to be modeled and simulated using MATLAB software.

Task 2: Collection of datasheets for every module used in the project.

Task 3: Collection Data and information on the subject of the project.

Task 4: Simulate electrical units using MATLAB/Simulink according to the modules used in the library at PPU.

Task 5: Finishing the graduation project book and make several practical experiments in energy laboratory located in PPU.

Task 6: Prepare the presentation.

1.7 Expected outcomes

The modeling and simulation of distribution system components pertinent to a smart grid was presented in this project. The components considered in this work included PV arrays, with used Inverter module, Transmission lines, and Power measurements kit, several types of three phase loads (R, L, and C), three phase induction machine implemented as wind turbines simulator, and power circuit breaker. The methodology involves deriving the equations of the components and creating modules in Simulink that mask the relevant components equations.

2

Chapter Two Smart Grid Lab

2.1 Smart Grid Lab Modules

2.1.1 Introduction
2.1.2 Power circuit breaker
2.1.3 Maximum demand meter
2.1.4 Line models
2.1.5 Three phase transformer & Supply unit.

2.2 Power Electronics and Machinery modules

2.2.1 Dc/ac converter (Inverter)
2.2.2 Three phase induction machine
2.2.3 Loads (R,L,C)

2.3 Renewable energy modules

2.3.1 PV simulator module

2.4 Summary

2.1 Smart Grid Lab Modules

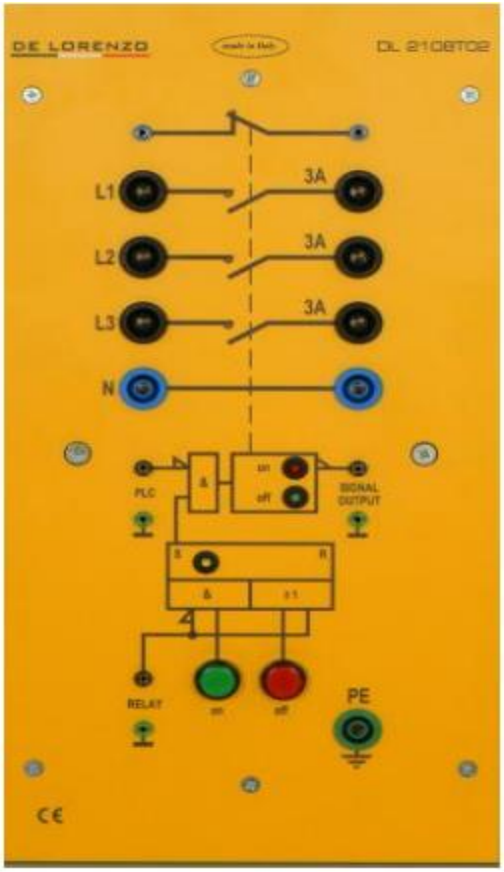
2.1.1 Introduction

In this Chapter, a brief overview of all modules have been taken in the project to be modeled and simulated using MATLAB/Simulink. Taking into account that all the information have been taken from the modules used in the lab at Palestine Polytechnic University.

Smart grid lab consists of the following modules that will be simulated using MATLAB:

1) Power circuit breaker.
2) Maximum demand meter.
3) Line models.
4) Three phase transformer/Auto transformer.
5) Inverter grid.
6) Three phase induction machine.
7) PV simulator module.
8) Loads.

2.1.2 Power circuit breaker



Three-phase power circuit breaker with normally closed (DL 2108T02) or normally open (DL 2108T02A) auxiliary contact. [1]

- Contact load capability: 400 Vac, 3 A.
- Supply voltage: single-phase from mains.

Power circuit breaker used for two operations: used to connect or disconnect the contacts by using a specific control scheme as shown on the module.

> ON button: to close the contacts.

> OFF button: to open the contacts.

SR flip flop used to achieve such a controlling procedure.

Figure 2.1: Power circuit breaker.

2.1.3 Maximum demand meter

Figure 2.2: Maximum demand meter.

The power measurements module is a very important module used a power analyzer for many measurements, the procedure of modeling and simulation of such module is described later in chapter 3. [1]

- Input voltage: 500 V (max 800 Vrms).
- Input current: 5 A (max 20 Arms).
- Operating frequency: 47 ÷ 63 Hz.

- Auxiliary supply: single-phase from mains.

2.1.4 Line models

Two types of line models are used in the lab which represents:

1- Transmission line model.
2- Distribution line model.

Keeping in mind that line models can be used as three different types of lines: short, medium, and long.

The functionality can be changed by connecting or disconnecting capacitors in parallel with lines.

1) Transmission line model

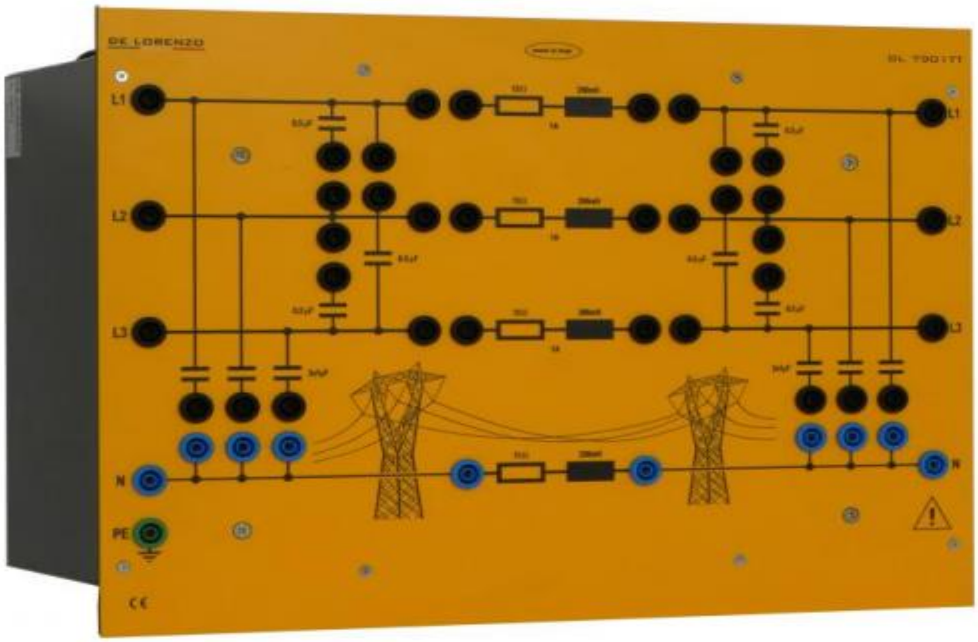


Figure 2.3: Transmission line model.

Three-phase model of an overhead power transmission line 360 km long, voltage 380 kV and current 1000 A. [1]

- Scale factor: 1:1000
- Short line: is done by connecting the lower capacitors.
- Medium line: is done by connecting the upper capacitors.
- Long line: is done by connecting both upper and lower capacitors.

2) Distribution line model

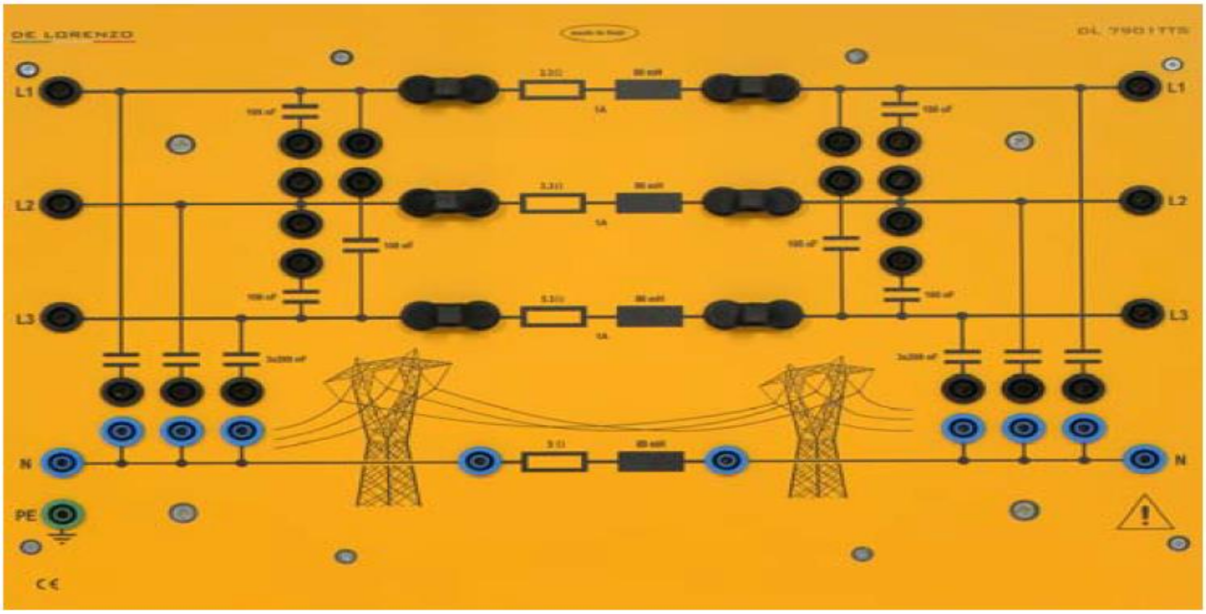


Figure 2.4: Distribution line model.

Three-phase model of an overhead power distribution line 110 km long, voltage 380 kV and current 1000 A. [1]

• Scale factor: 1:1000

2.1.5 Three phase transformer & supply unit

Figure 2.5: Three phase transformer. [1]

Three phase transformer provides voltage to transmission lines.

Primary

• 3 x 380 V windings with tap at 220 V
• Star or delta connection

Secondary

• 3 x 220 V windings.
• Star connection for 3 x 380 V
• Rated power: 800 VA

Figure 2.6: Three phase supply unit.

Three phase supply unit represents electrical power generation for both power plants and renewable energies i.e. Wind turbines and PV cells.

Three phase supply unit provides mainly 5 outputs:

1) Three phase output voltage L1, L2, L3.
2) Protection earth PE.
3) Neutral N.

Datasheet: [1]

* 25A current operated earth leakage circuit breaker, sensitivity 30 mA.
* Three-phase indicator lamps.
* Switch for simulation of wind or photovoltaic energy power source.

2.2 Power Electronics and Machinery modules

2.2.1 Dc/ac converter (Inverter)

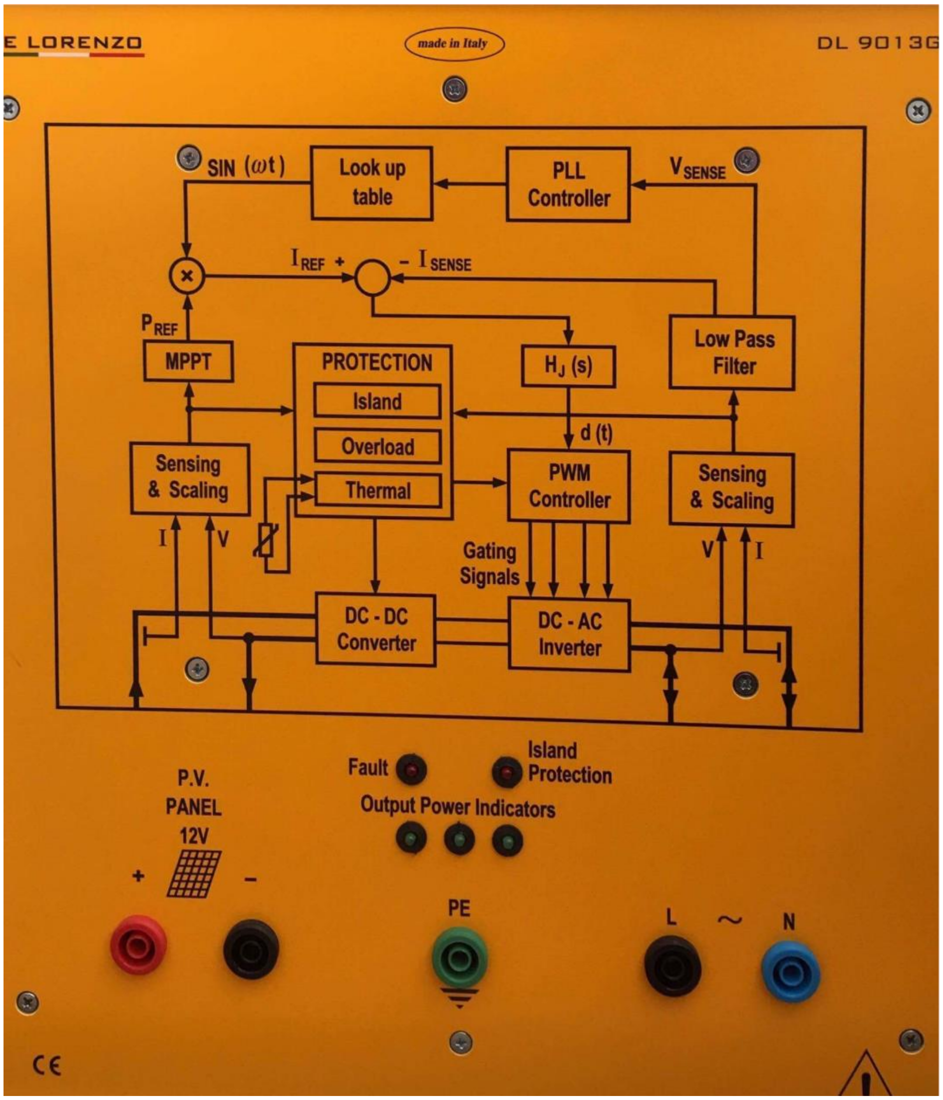


Figure 2.7: Inverter grid.

Inverter grid module uses a connection of many power electronic elements to be connected with the PV cell to grid. The input to the inverter 12V from the PV source and provides ac voltage as the datasheet as following: [1]

- Current max.: 30A
- Voltage: 12V
- Power: 360W

2.2.2 Three phase induction machine

The following induction motor is implemented to be three phase induction generator by connecting prime mover to the rotor to simulate Wind turbine generation stage.

Datasheet: [1]

- Power: 1.5 kW
- Voltage: 220/380 V Δ/Y
- 4 poles
- Rated speed: 1500 rpm, 50 Hz
- Rated speed: 1800 rpm, 60 Hz

Figure 2.8: Three phase induction machine.

2.2.3 Loads (R,L,C)

1) R load:

Datasheet: [1]

Single or three-phase resistive step-variable load.

- Max. Power: 3 x 400 W
- Max. Voltage: 220/380 V Δ/Y

Figure 2.9: Resistive load.

2) **L load:**

Datasheet: [1]

Single or three-phase inductive step-variable load.
• Max. Power: 3 x 300 VAR
• Max. Voltage: 220/380 V Δ/Y

Figure 2.10: Inductive load.

3) **C load:**

Datasheet: [1]

Single or three-phase capacitive step-variable load.
• Max. Power: 3 x 275 VAR
• Max. Voltage: 220/380 V Δ/Y

Figure 2.11: Capacitive load.

2.3 Renewable energy modules

2.3.1 PV simulator module

Figure 2.12: Photovoltaic simulator module.

Photovoltaic simulator used for measurement of the radiation and
It has a solar and a temperature sensors.

Datasheet: [1]

Tilting photovoltaic module.

- Max. Power: 85 Watt.
- Max. Voltage: 12 Volt.

2.3 Summary

A brief overview to the modules has been taken in this chapter in order to be simulated later in chapter 3 & 4.

3

Chapter Three Modules Simulation 1

3.1 Smart grid modules modeling

3.1.1 Circuit breaker

3.1.2 Power Measurements

3.2 Power analysis and theory

3.2.1 Harmonics

3.2.2 Linear and non-Linear loads

3.2.3 Power factor

3.3 Summary

3.1 Smart grid Modules modeling

This chapter contains circuit breaker and power measurements modules that designed according to harmonic and power factor analysis with linear and non-linear loads.

3.1.1 Circuit breaker

Power circuit breaker designed and simulated using MATLAB software according to Datasheet and specific control scheme in order to achieve the desired operation. This section will show the operation of circuit breaker stand alone and also when connected to load.

The following figure shows the circuit breaker module.

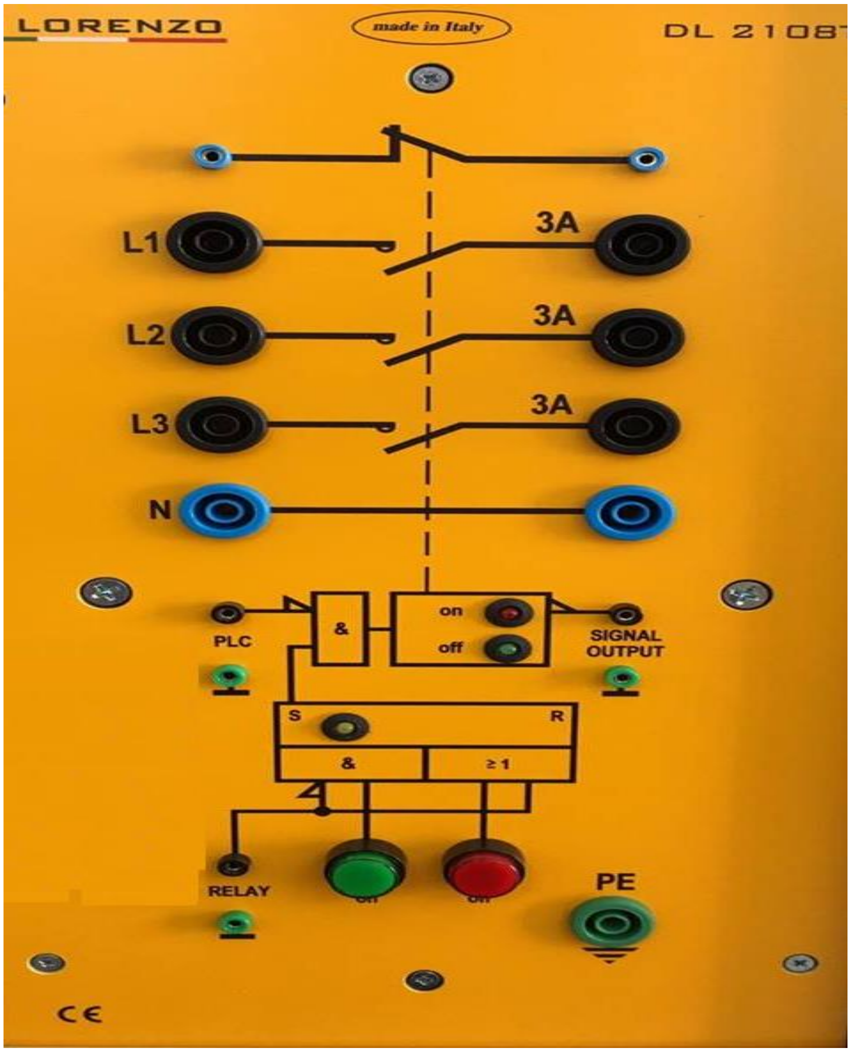


Figure 3.1: Circuit breaker module.

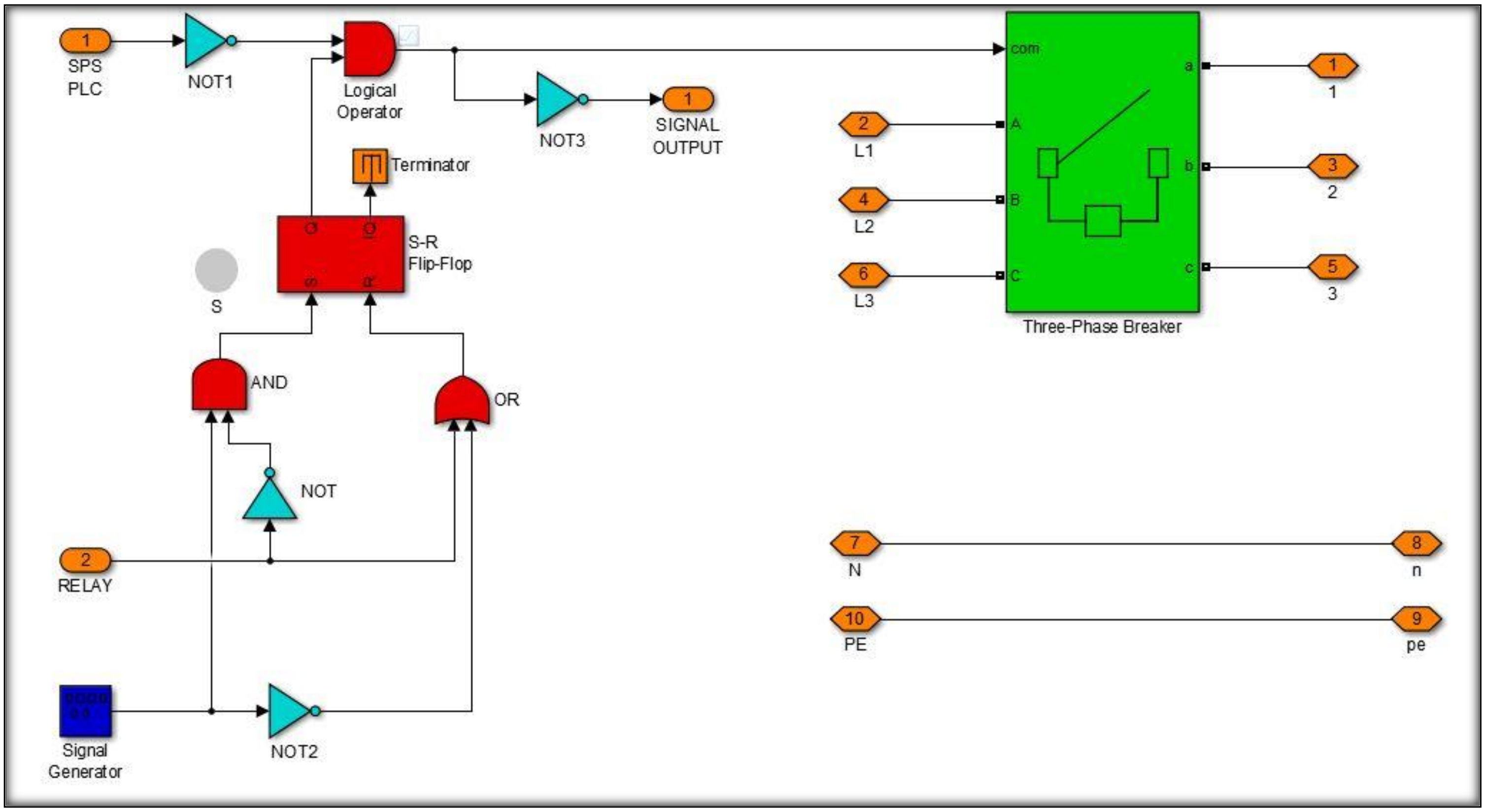


Figure 3.2: Internal control scheme for Circuit Breaker.

The following figures show the circuit breaker module simulated using Simulink software in case of ON and OFF operating states:

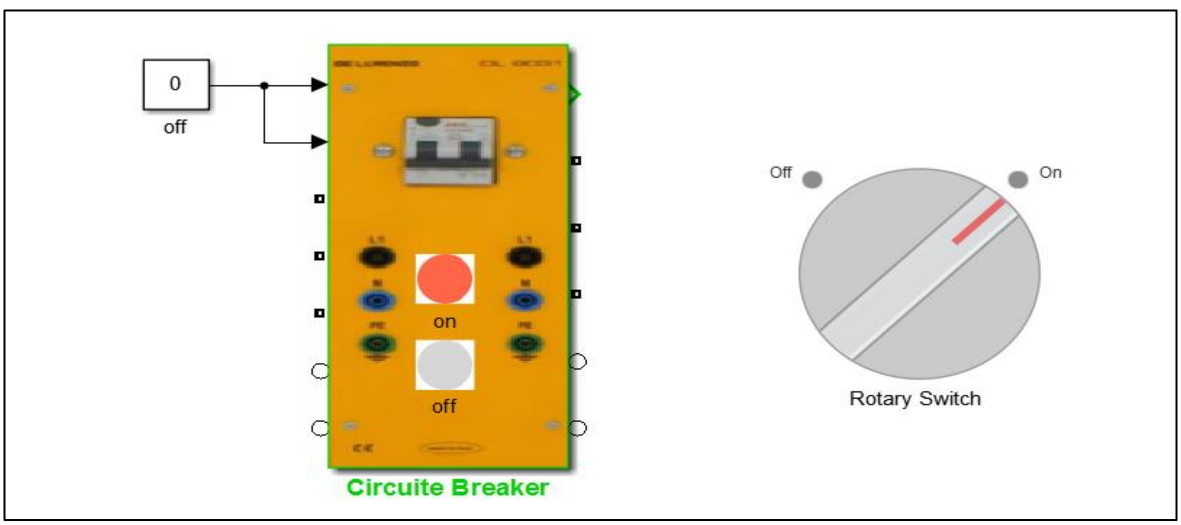


Figure 3.3: Circuit breaker ON state.

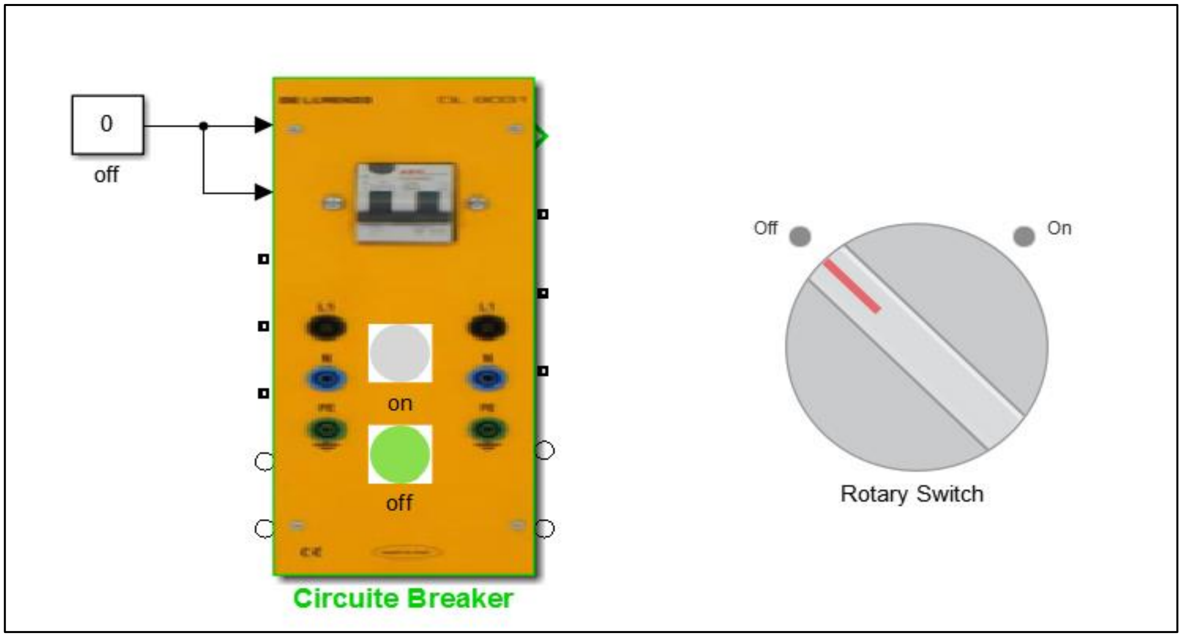


Figure 3.4: Circuit breaker OFF state.

The following figures show the simulation of circuit breaker module in case of ON and OFF operating states when connected to three phase load:

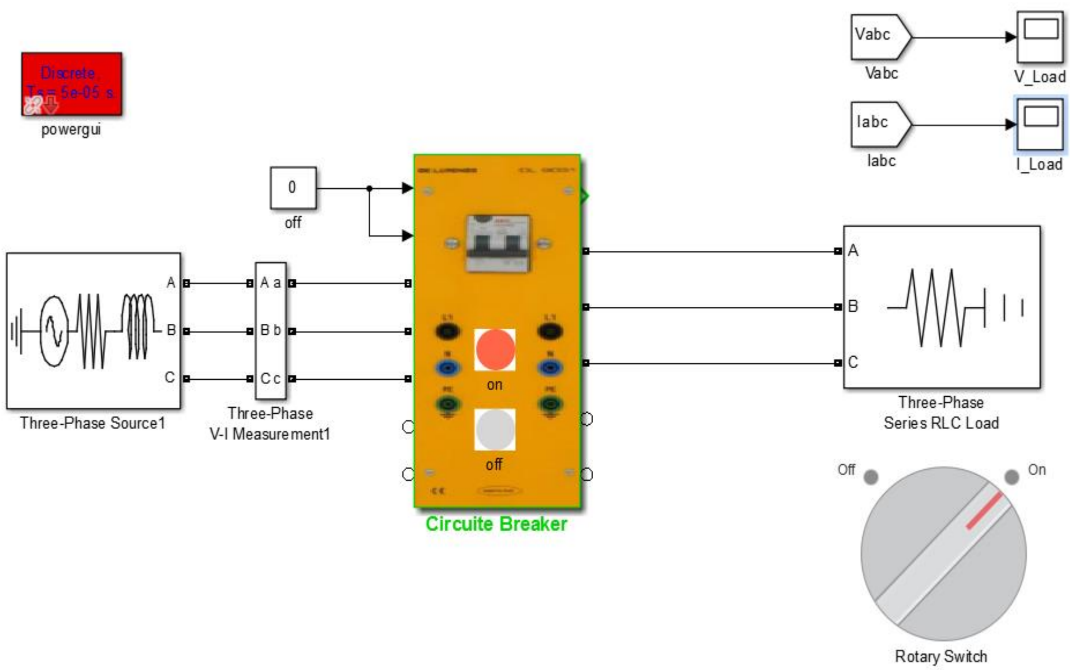


Figure 3.5: Circuit breaker Simulation connected to three phase load.

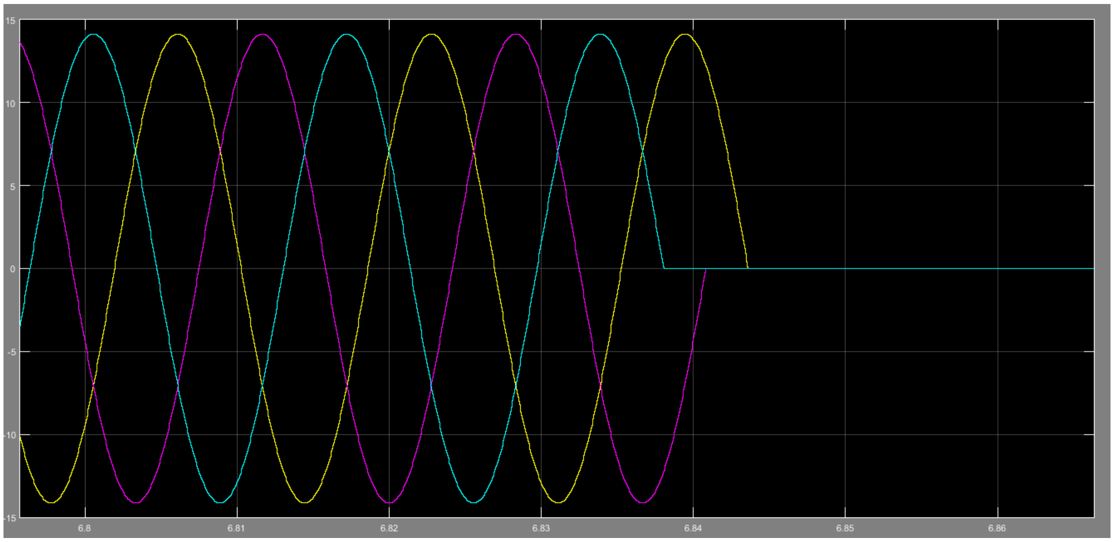


Figure 3.6: ON and OFF circuit breaker output voltage simulation.

3.1.2 Power Measurements:

Power measurements designed and simulated using MATLAB software according to Datasheet, harmonics, and power factor theories (described later in 3.2). In order to achieve the desired operation, this section will show the operation of Power measurements stand alone and also when connected to load and the inner content of simulated module.

The following figure shows the power measurements module and datasheet.

Microprocessor controlled three-phase power analyzer.
Measurement of voltages, currents, frequencies, active
Power, reactive power, apparent power, THD, power factor.
• Input voltage: 500 V (max 800 Vrms)
• Input current: 5 A (max 20 Arms)
• Operating frequency: 50Hz

Figure 3.7: Power measurement module.

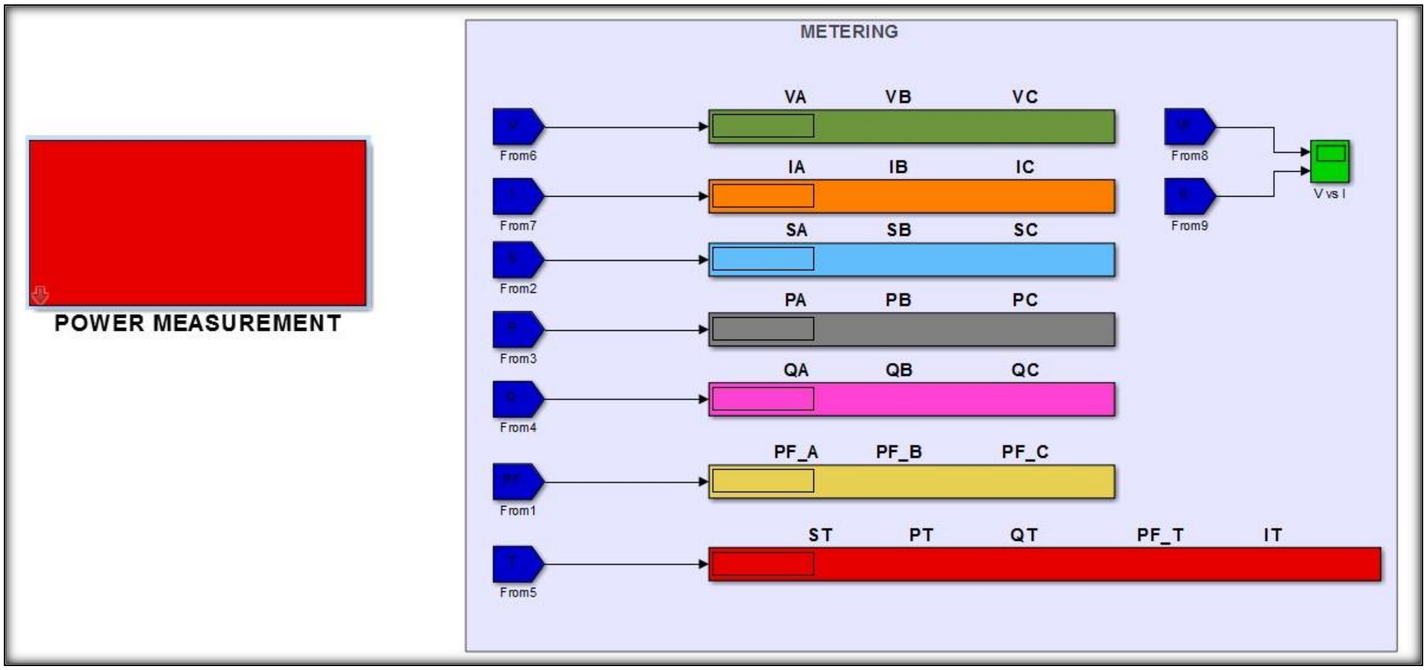


Figure 3.8: Power measurement main block.

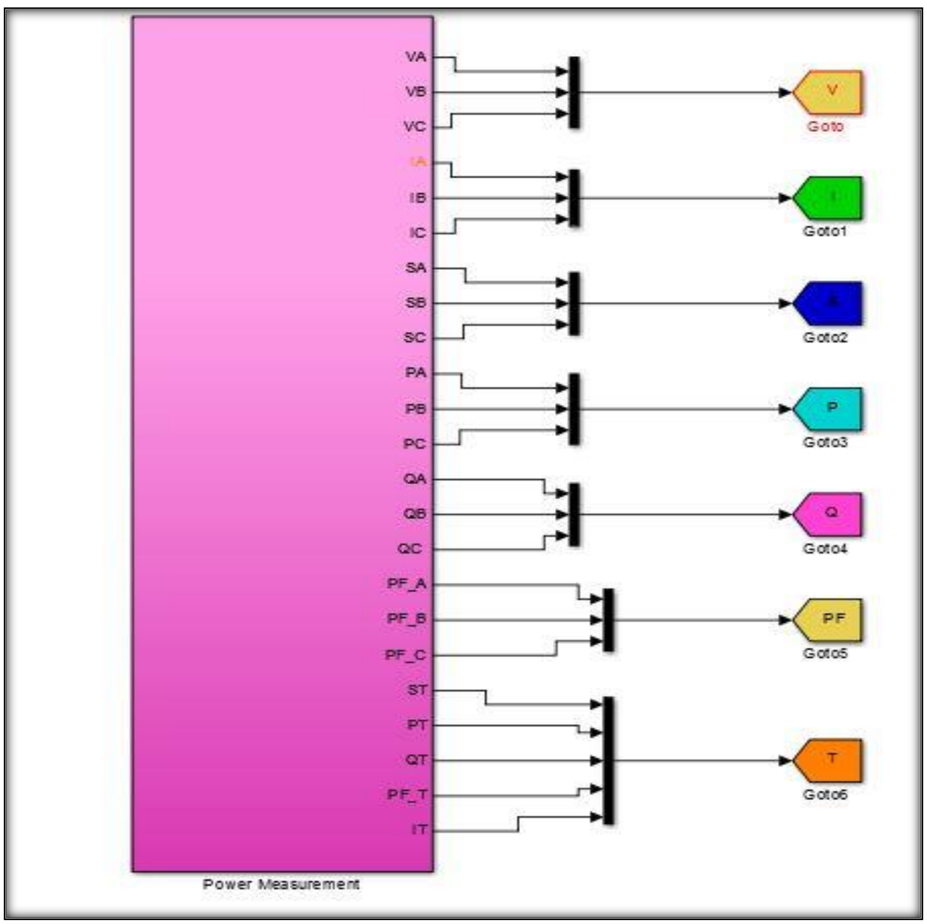


Figure 3.9: Inner content of power measurement main block.

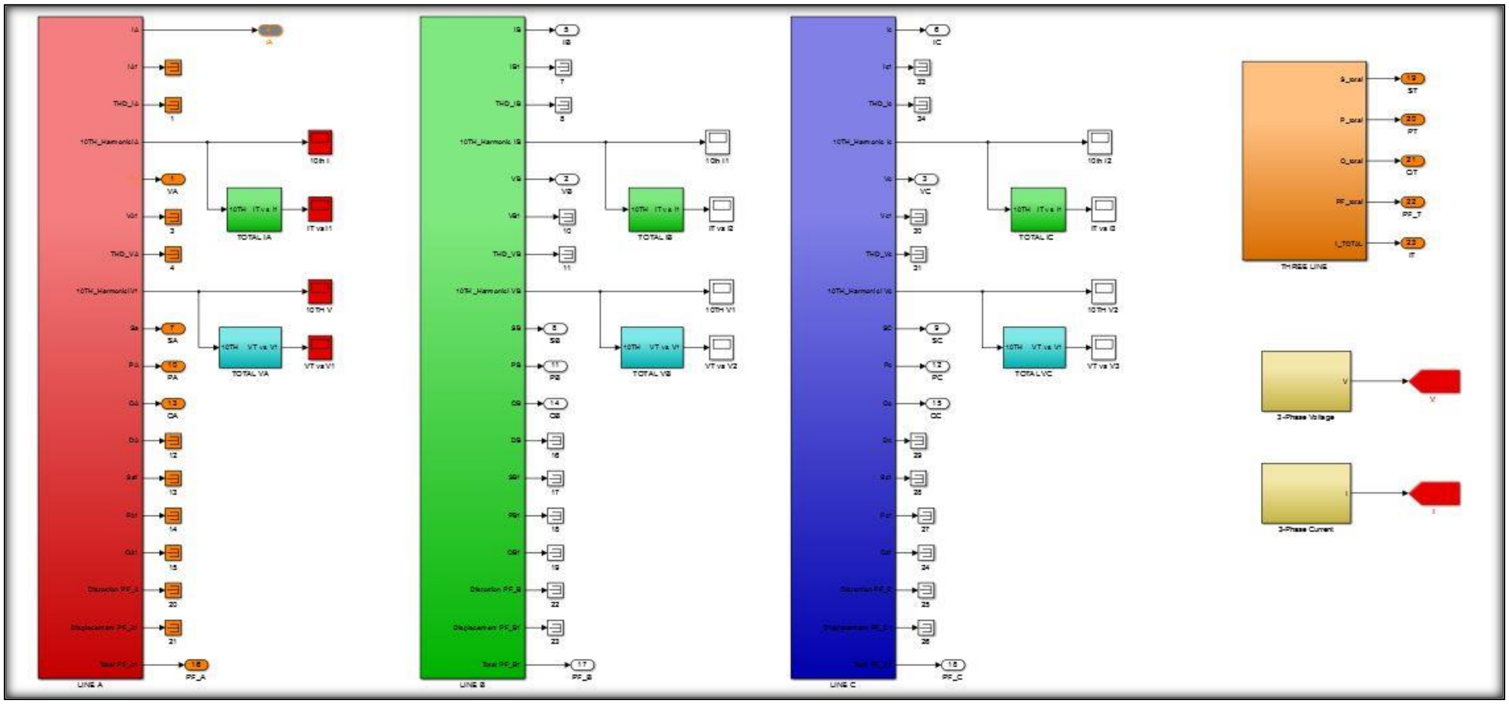


Figure 3.10: Inside (figure 3.9) power measurement block.

The above Fig (3.10) consists of the following contents:

- Phase A subsystem.
- Phase B subsystem.
- Phase C subsystem.
- Three Phases subsystem.

Let's Start with Phase A subsystem, since Phase B and C are the same construction except the going and incoming flag signal, that can be shown in the next figure.

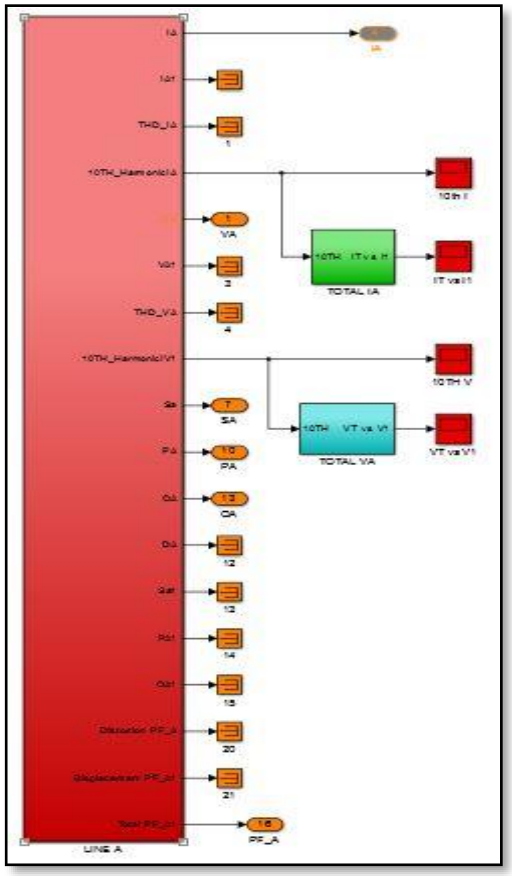


Figure 3.11: Phase A subsystem.

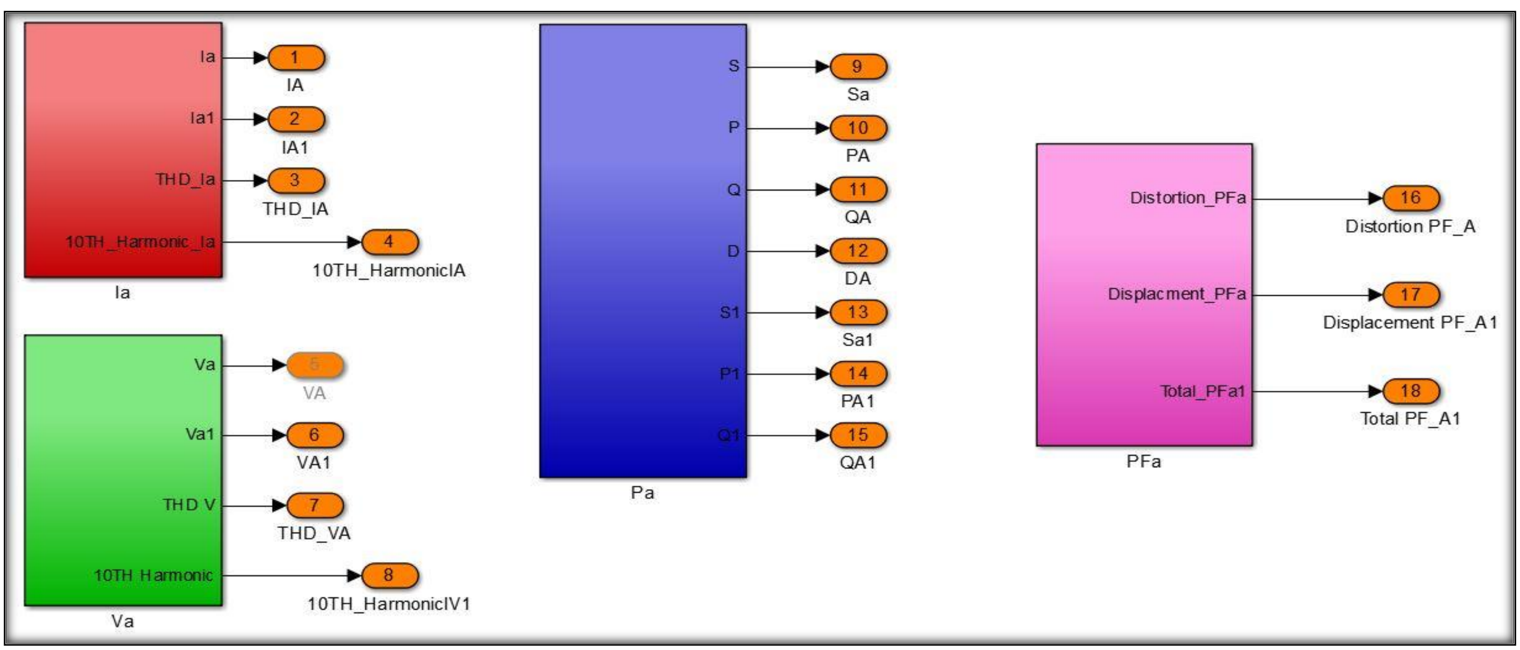


Figure 3.12: Inside Phase A subsystem

Phase A subsystem consist of the following subsystem blocks:

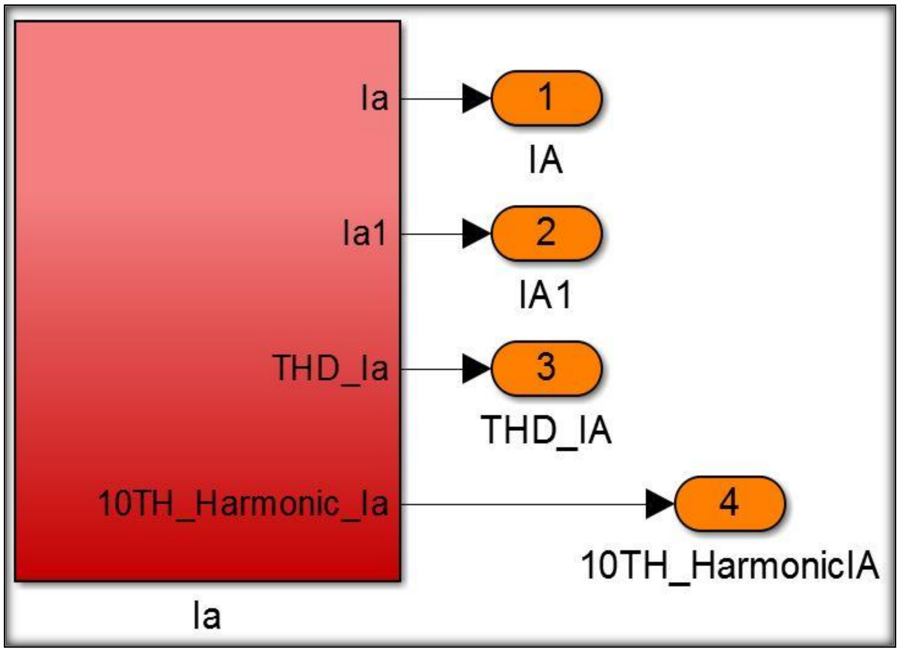


Figure 3.13: IA subsystem.

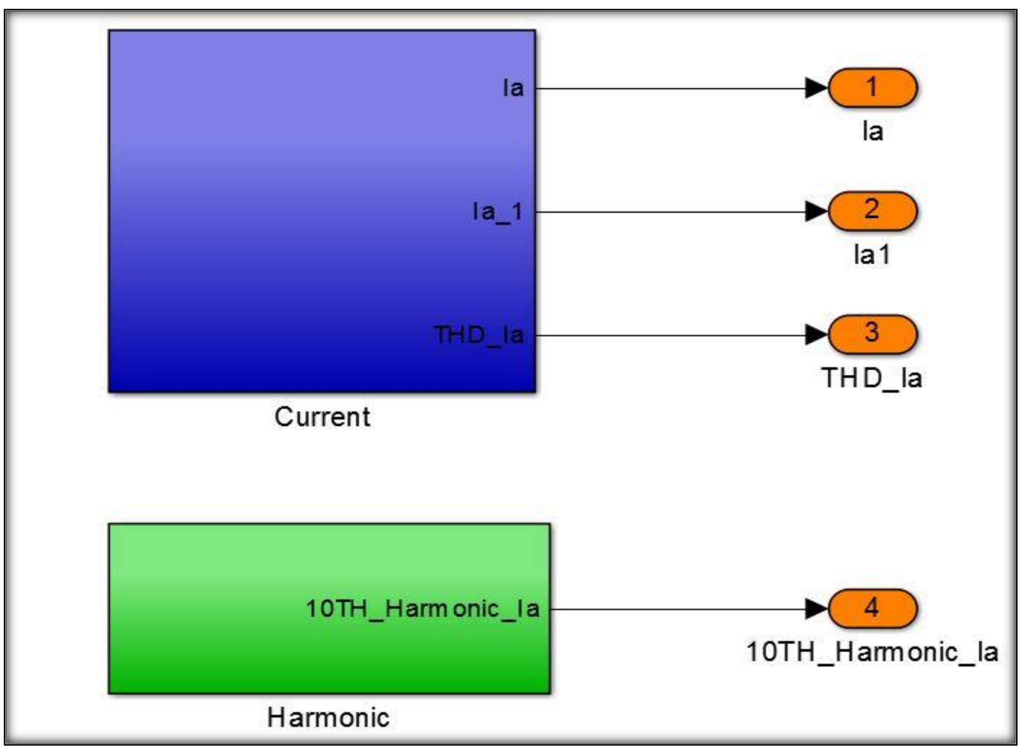


Figure 3.14: Inside IA subsystem.

IA subsystem consists of two subsystems.

1- Current subsystem.

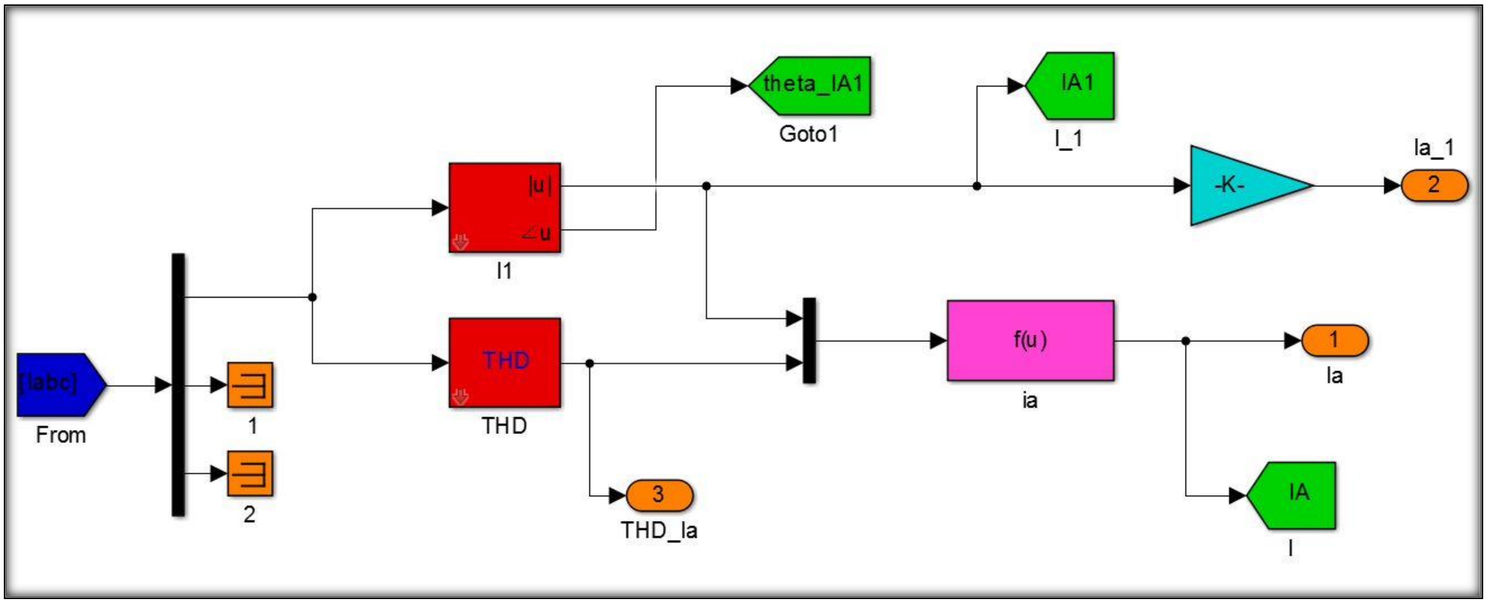


Figure 3.15: Inside current subsystem.

2- Harmonic subsystem.

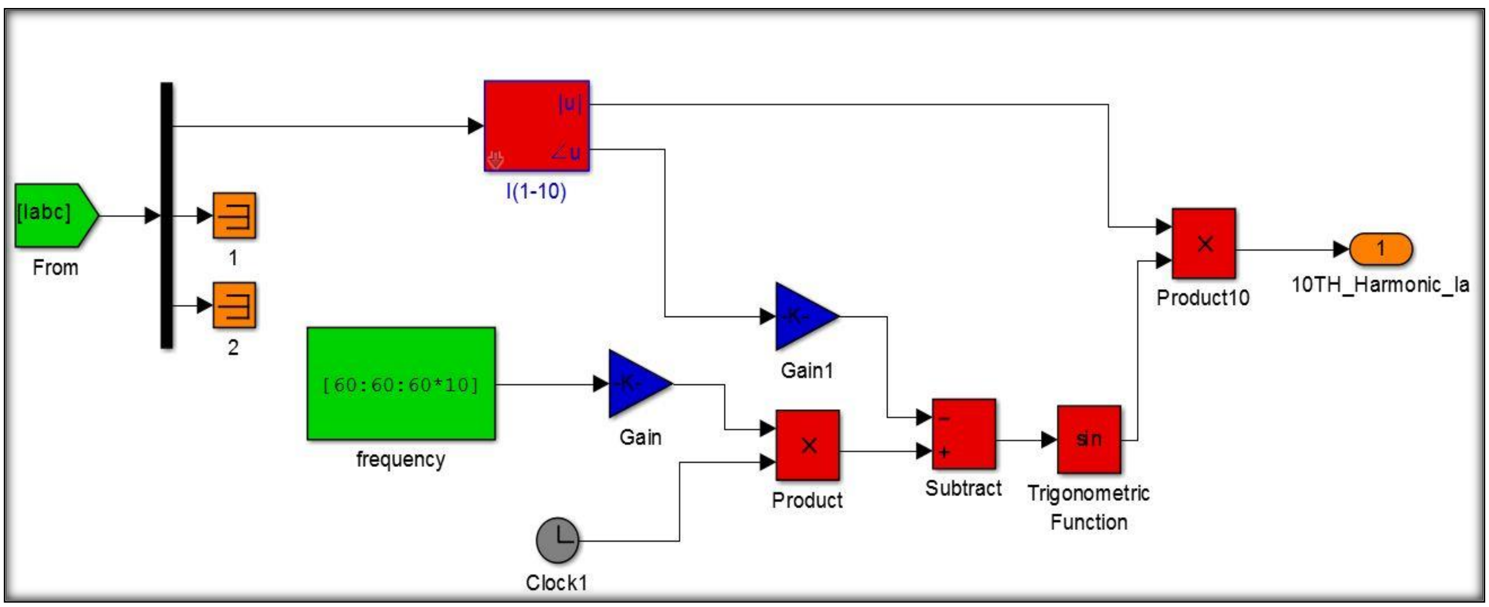


Figure 3.16: Inside Harmonic subsystem.

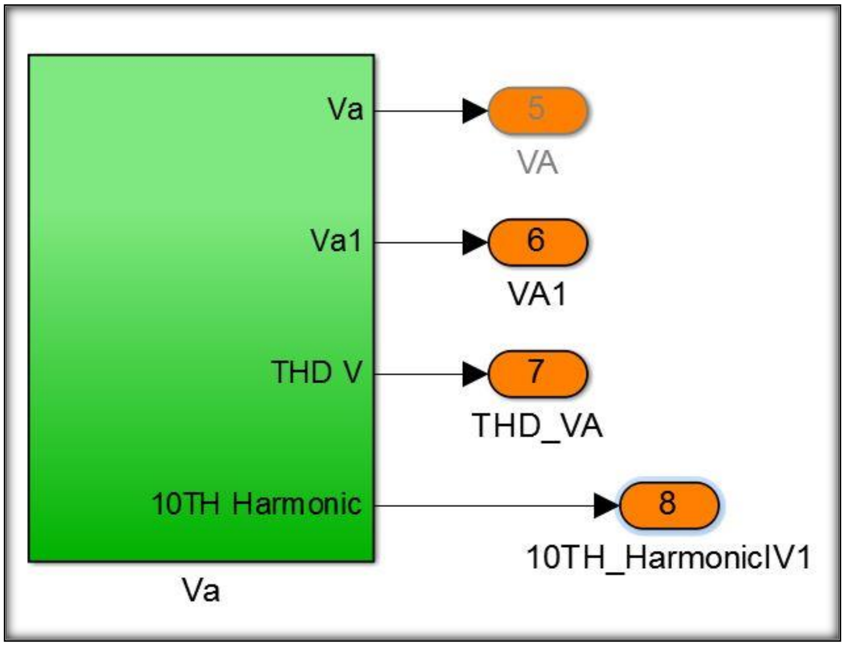


Figure 3.17: VA subsystem.

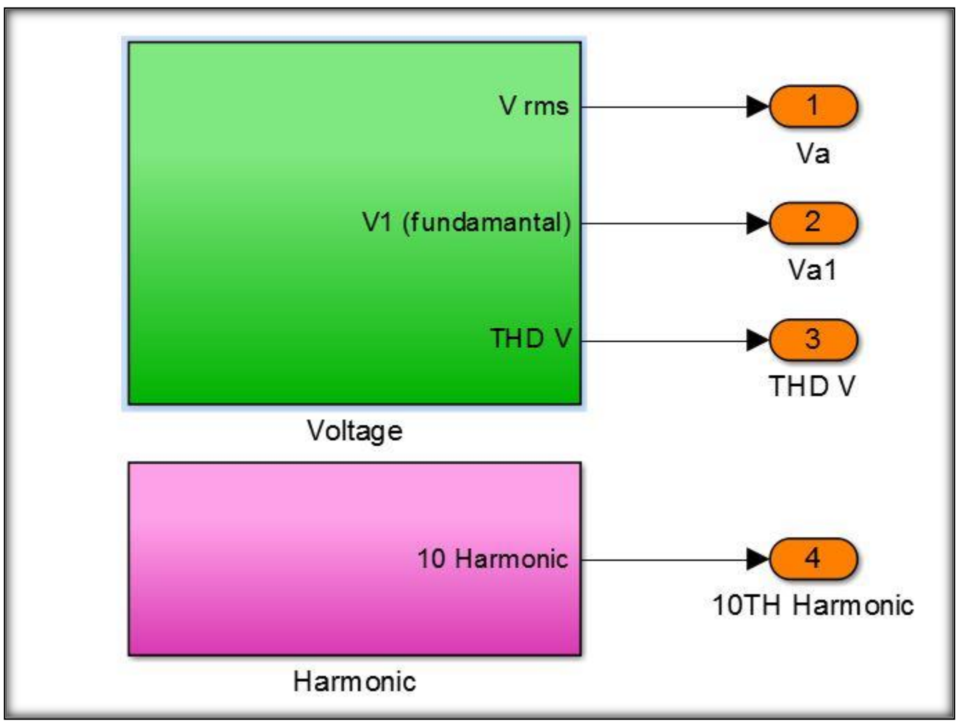


Figure 3.18: Inside VA subsystem.

VA subsystem consists also of two subsystems.

1- Voltage subsystem.

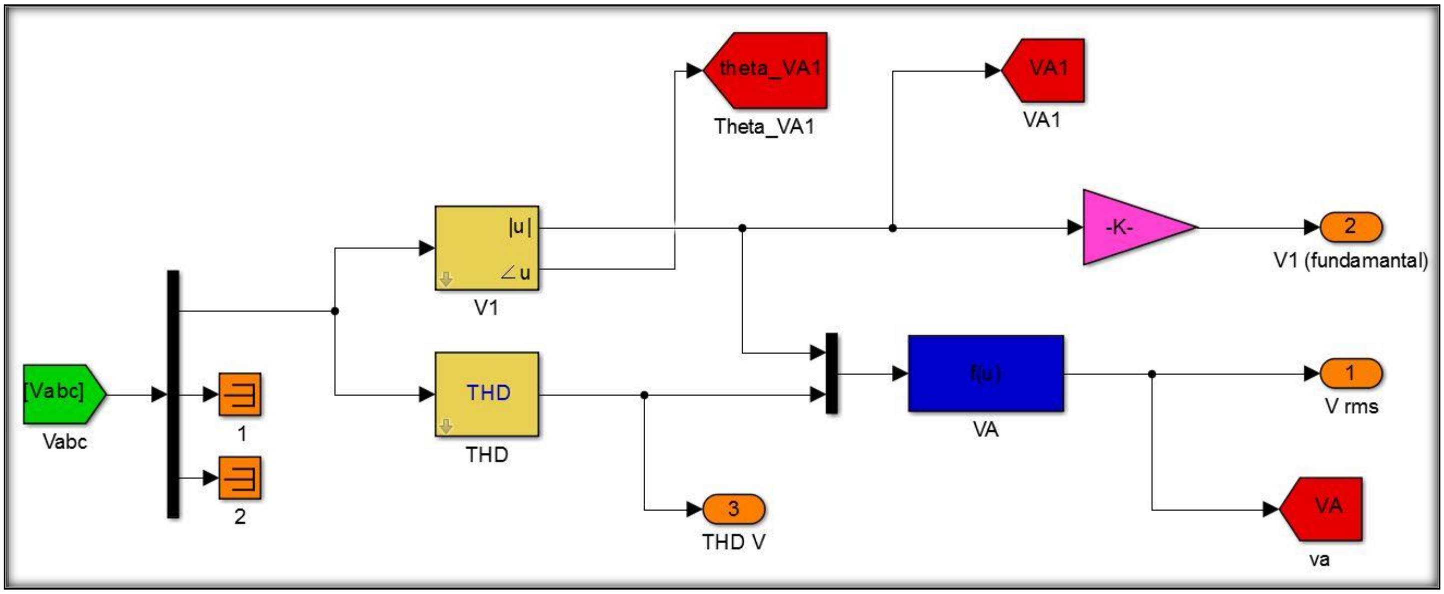


Figure 3.19: Inside voltage subsystem.

2- Harmonic subsystem.

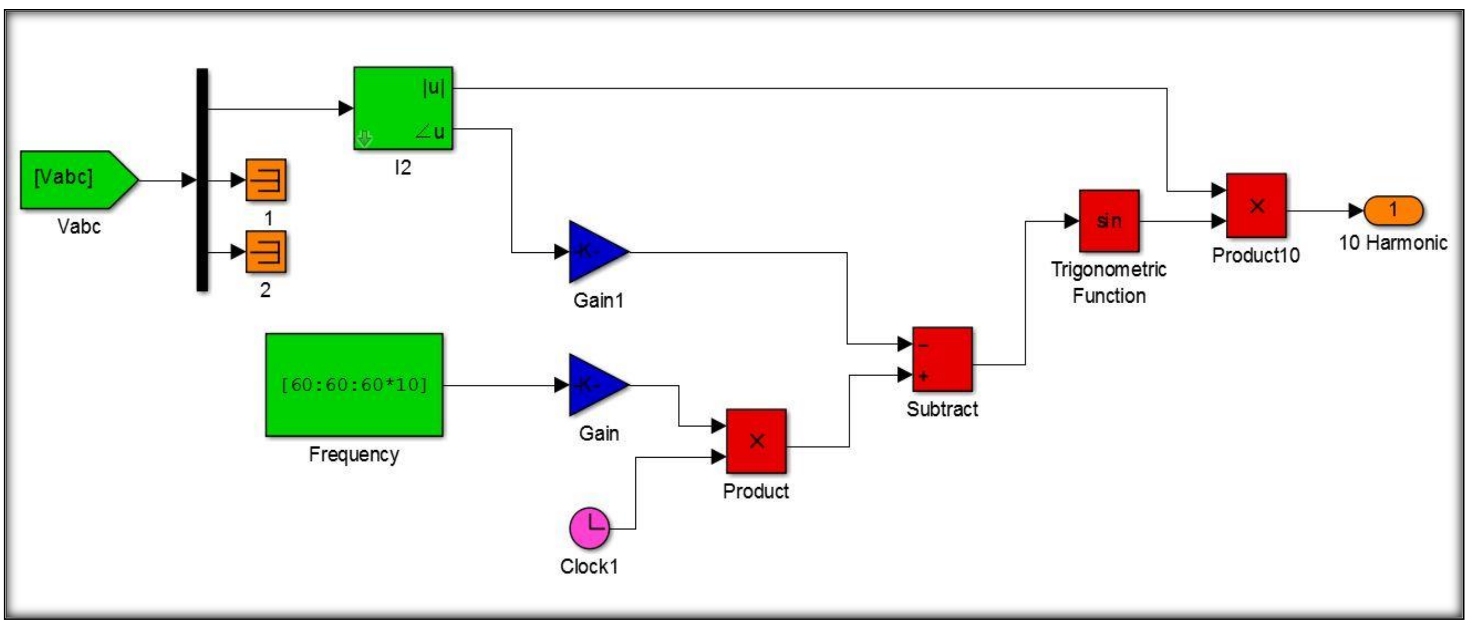


Figure 3.20: Inside harmonic subsystem.

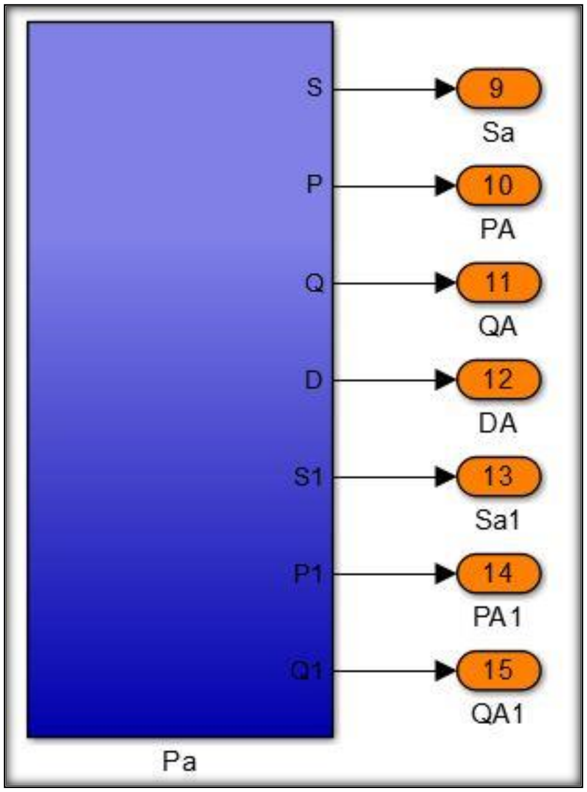


Figure 3.21: Phase A power subsystem (Pa).

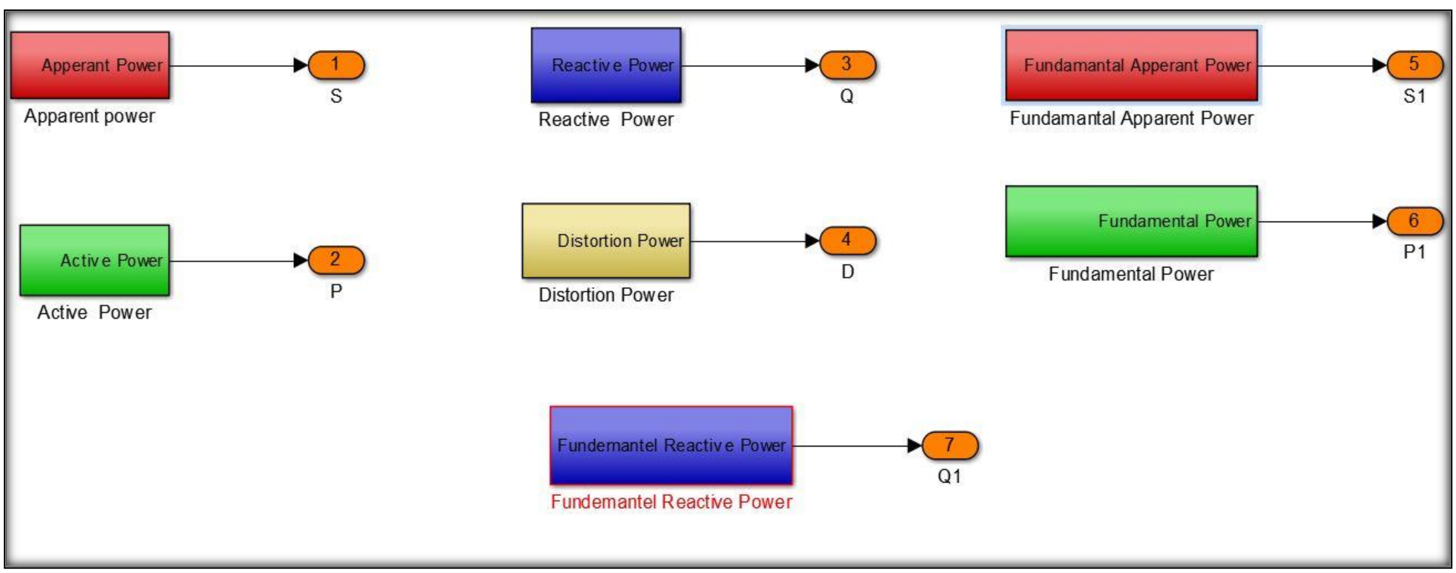


Figure 3.22: Inside Pa subsystem.

PA subsystem consists of seven subsystems.

1- Apparent power subsystem.

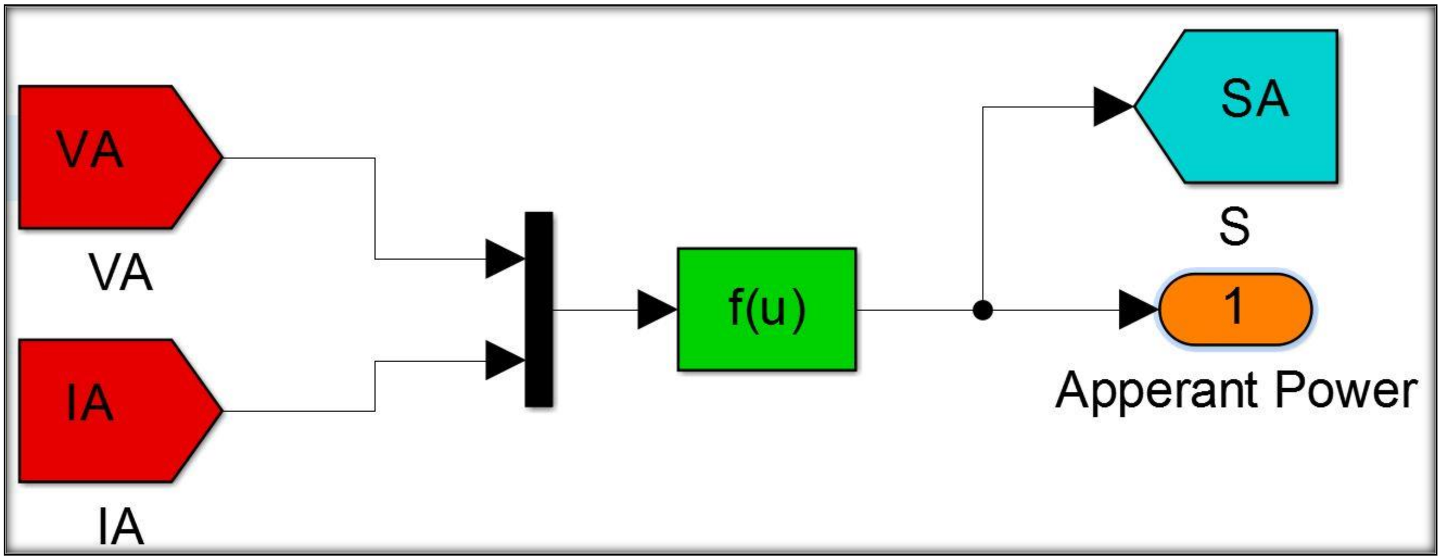


Figure 3.23: Apparent Power subsystem.

2- Real power subsystem.

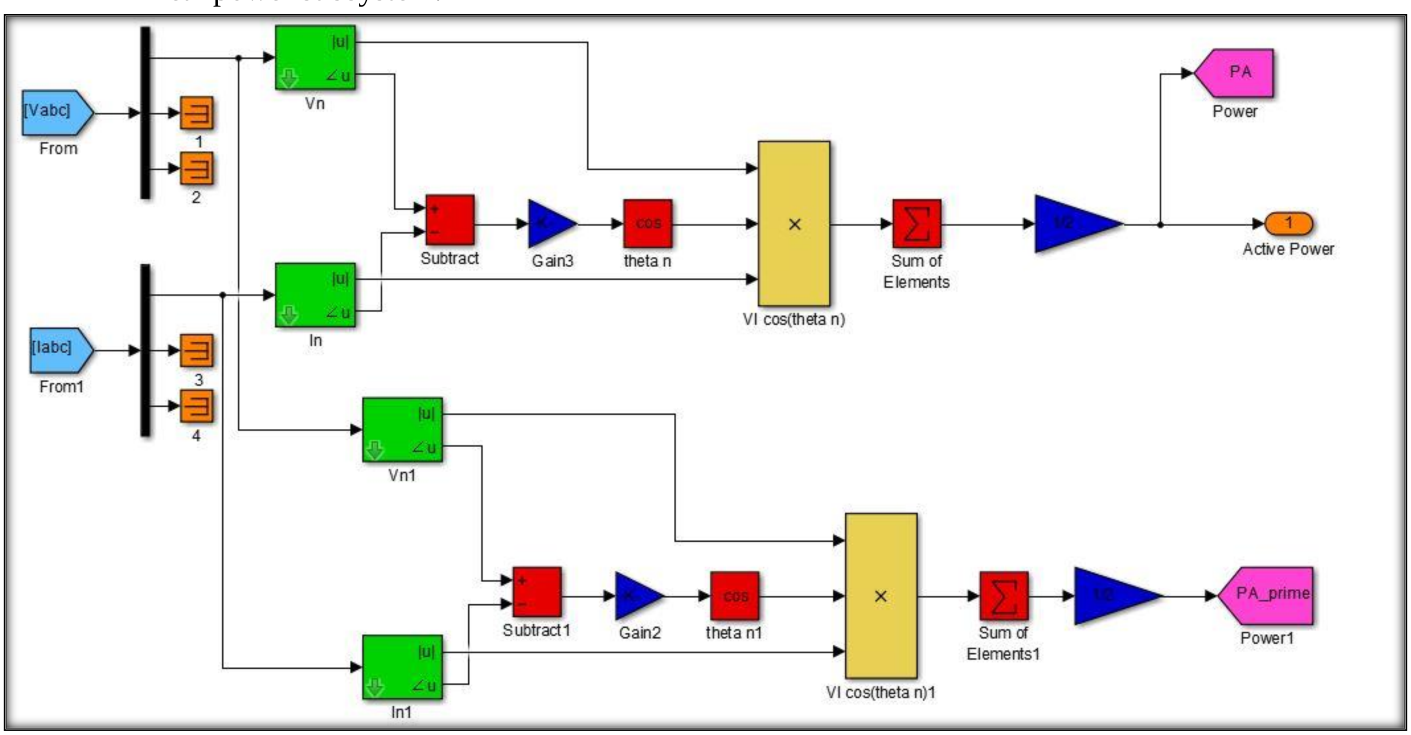


Figure 3.24: Real Power subsystem.

3- Reactive power subsystem.

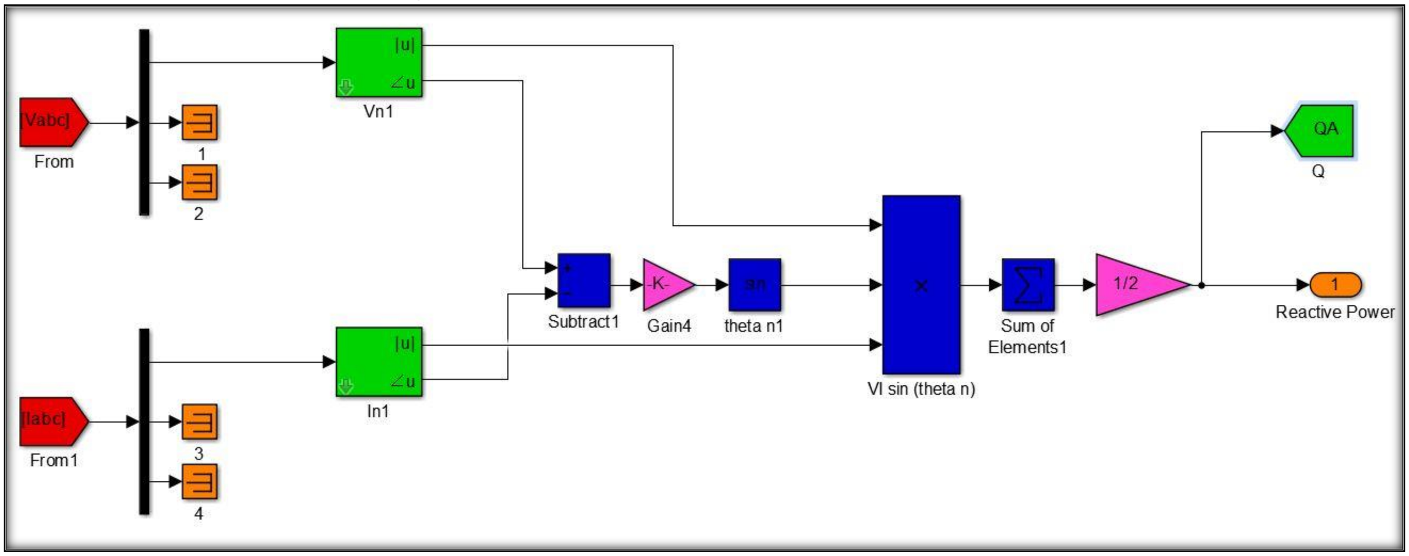


Figure 3.25: Reactive power subsystem.

4- Distortion power subsystem.

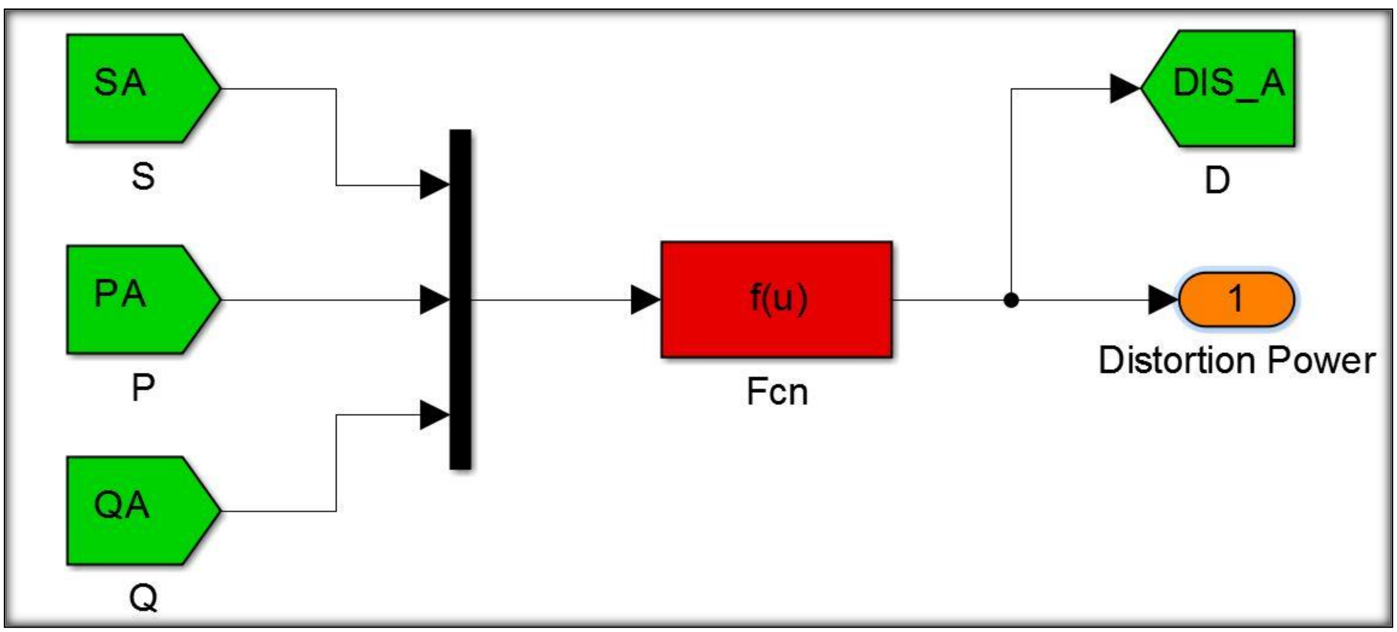


Figure 3.26: Distortion power subsystem.

5- Fundamental apparent power.

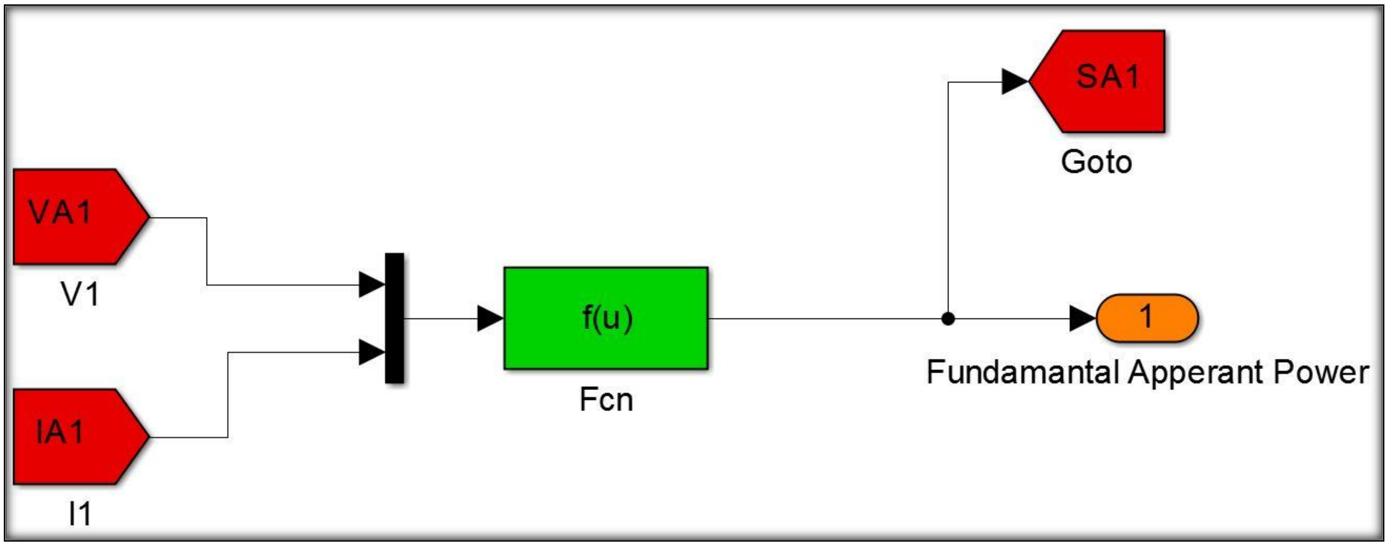


Figure 3.27: Fundamental Apparent power subsystem.

6- Fundamental active power.

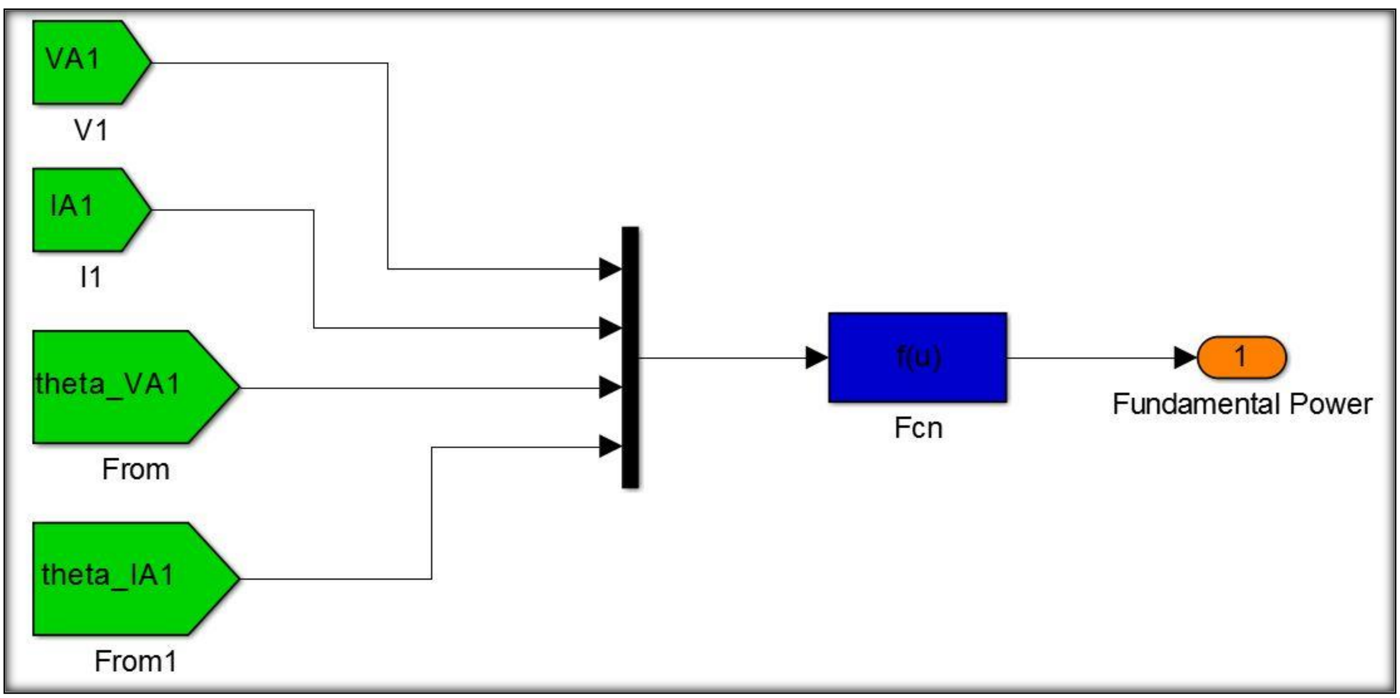


Figure 3.28: Fundamental active power subsystem.

7- Fundamental reactive power.

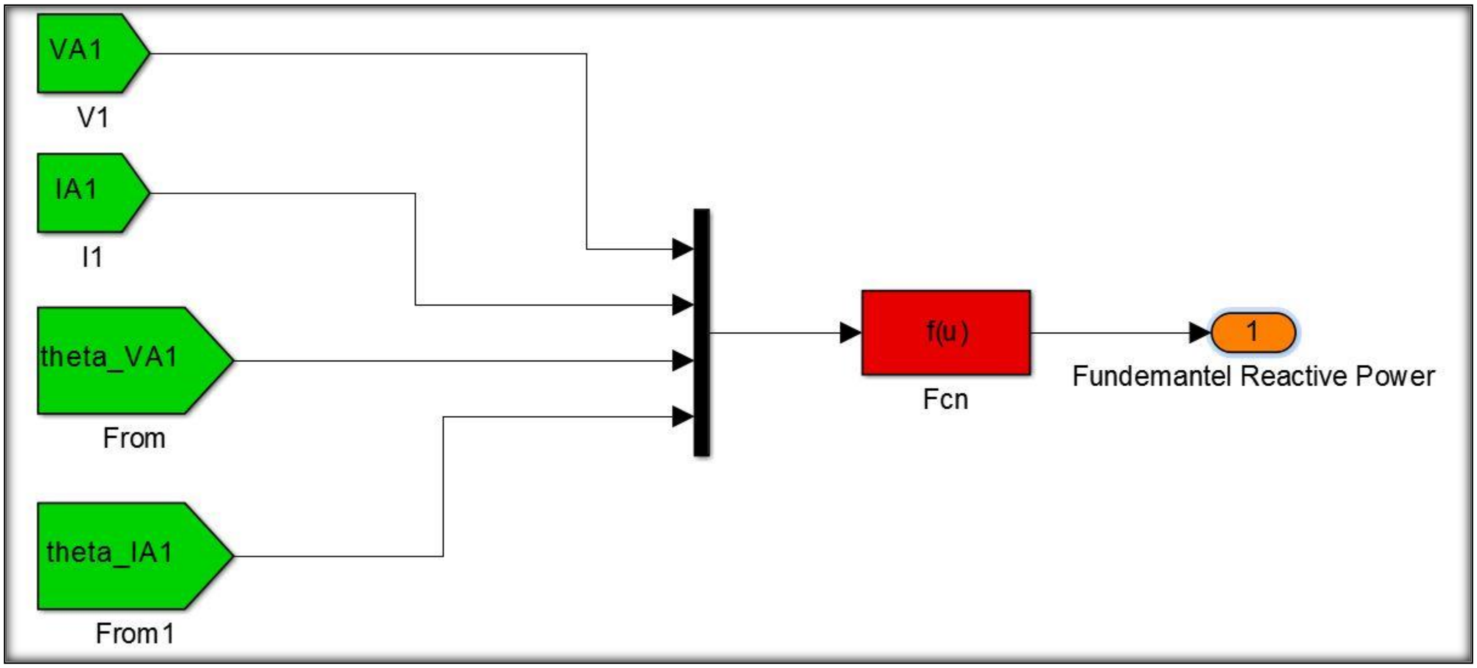


Figure 3.29: Fundamental reactive power subsystem.

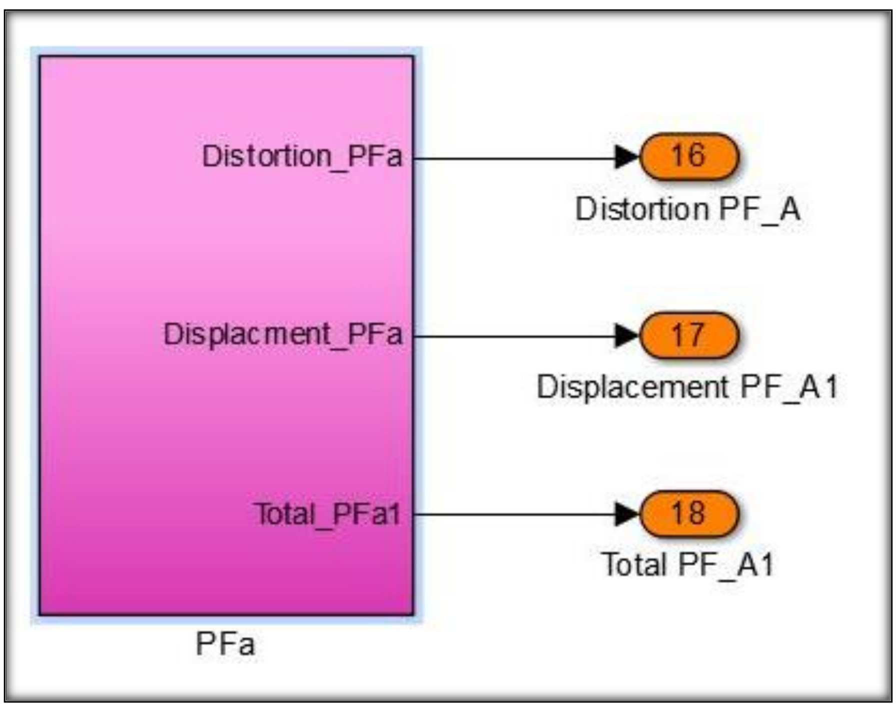


Figure 3.30: Phase A power factor subsystem (PFa).

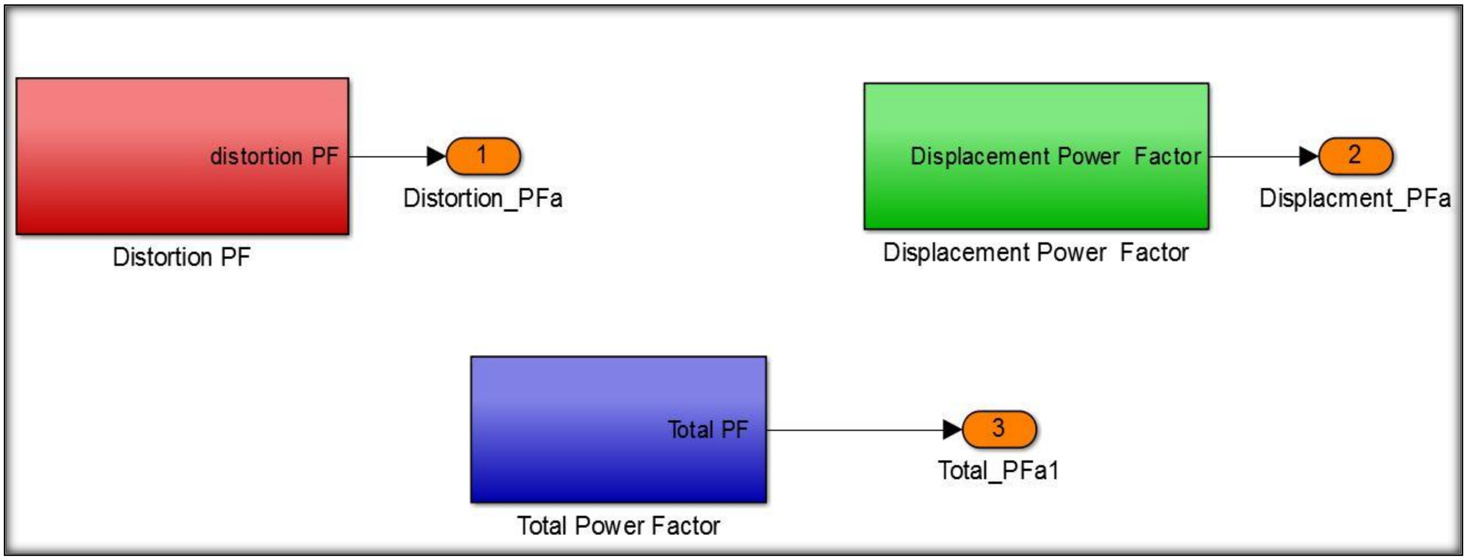


Figure 3.31: Inside PFa subsystem.

PFa subsystem consists of three subsystems.

1- Distortion power factor.

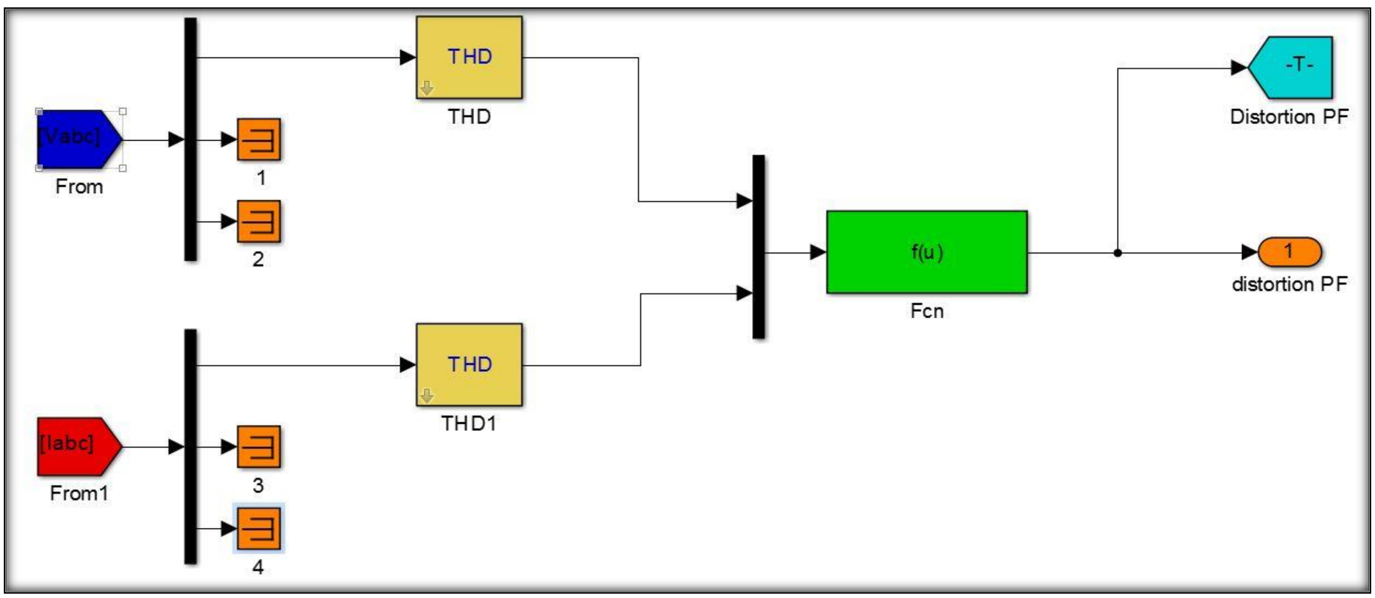


Figure 3.32: Distortion power factor subsystem.

2- Displacement power factor.

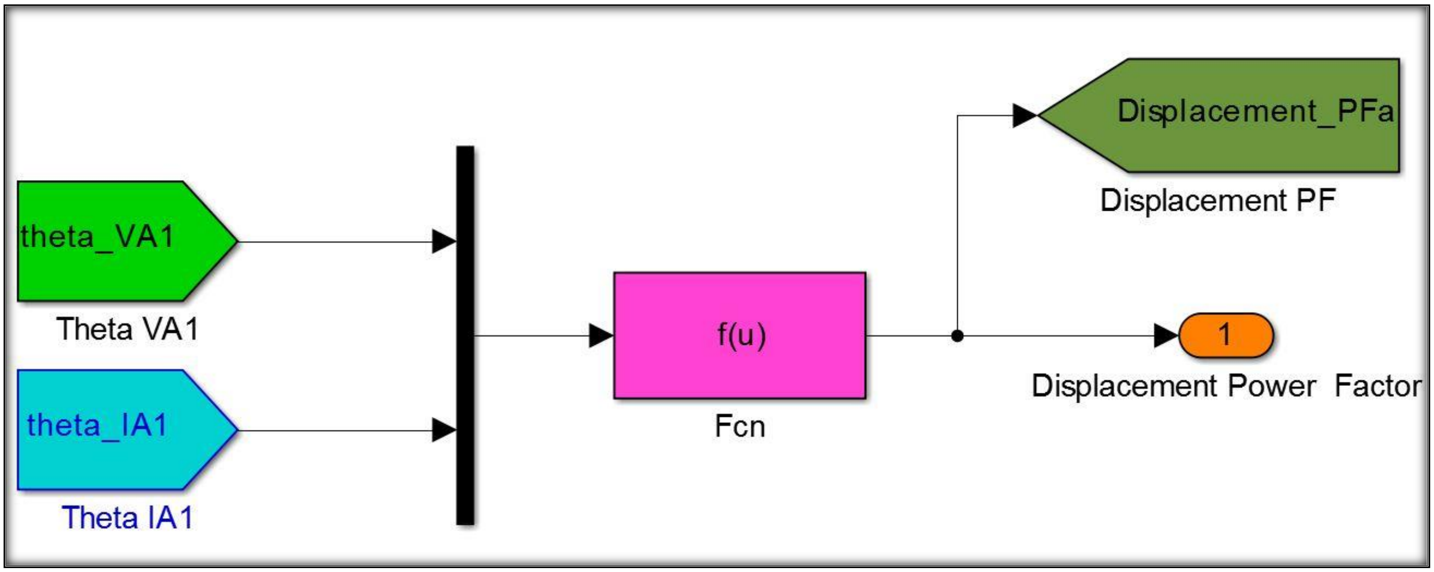


Figure 3.33: Displacement power factor subsystem.

3- Total power factor.

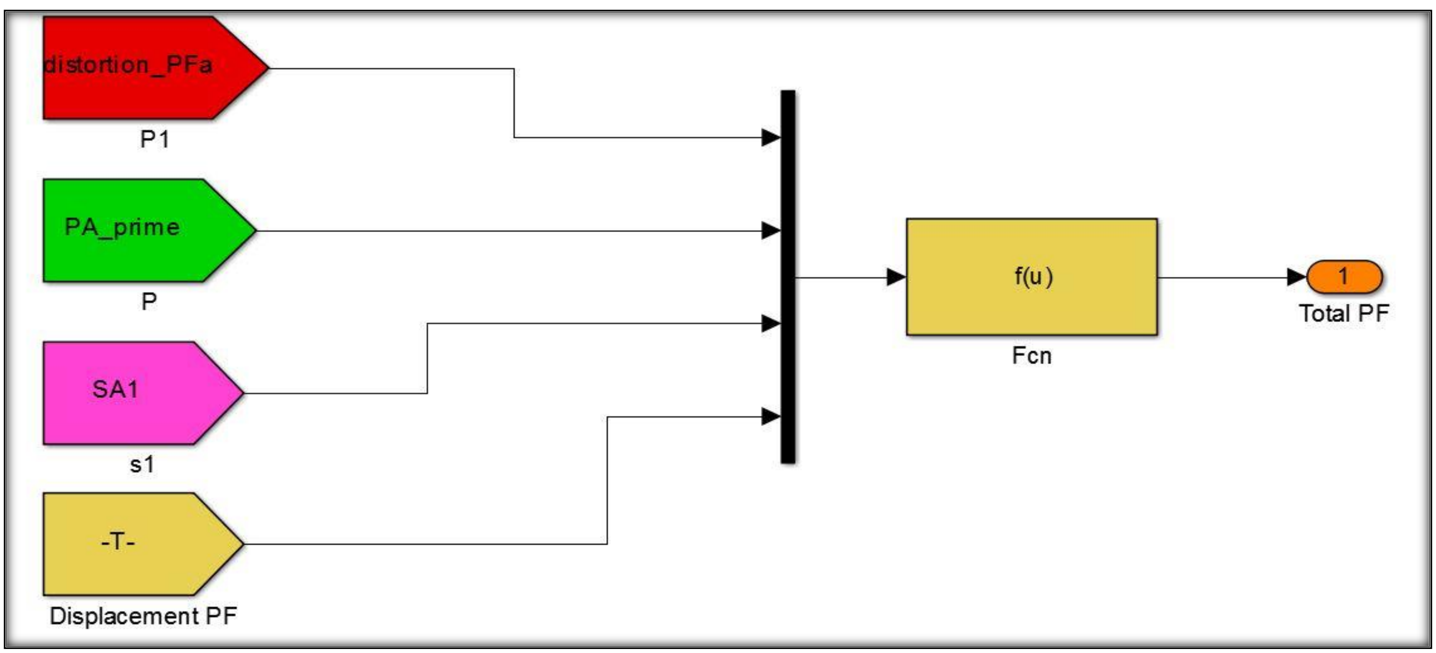


Figure 3.34: Total power factor subsystem.

And the above figures are the same as Phases B, and C.

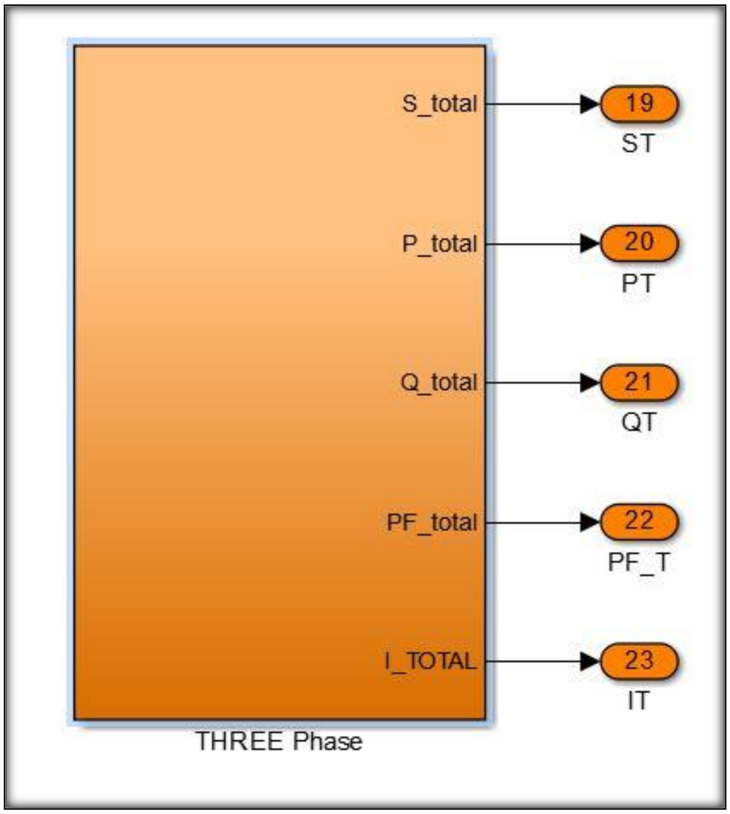


Figure 3.35: Three phase subsystem.

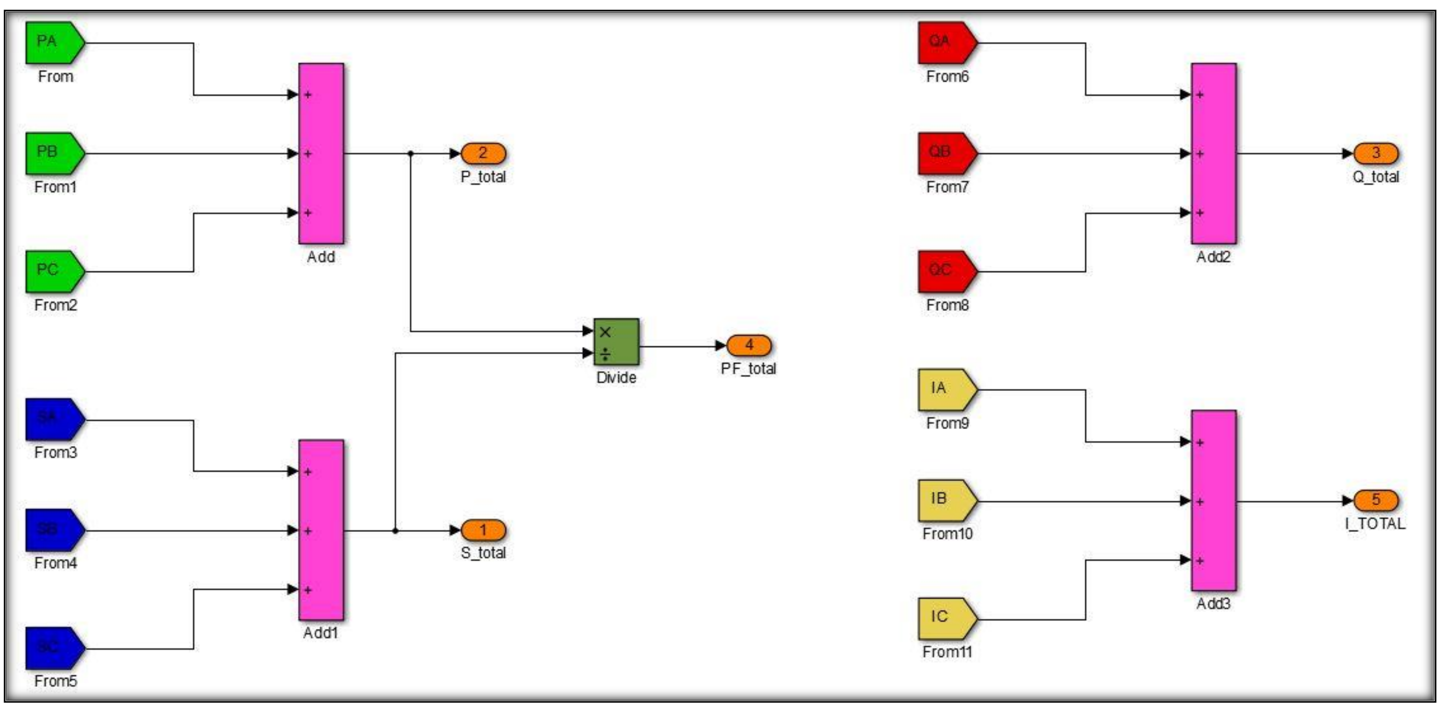


Figure 3.36: Inside of Three phase subsystem.

The following figures show the simulation of power measurement module with and without loading.

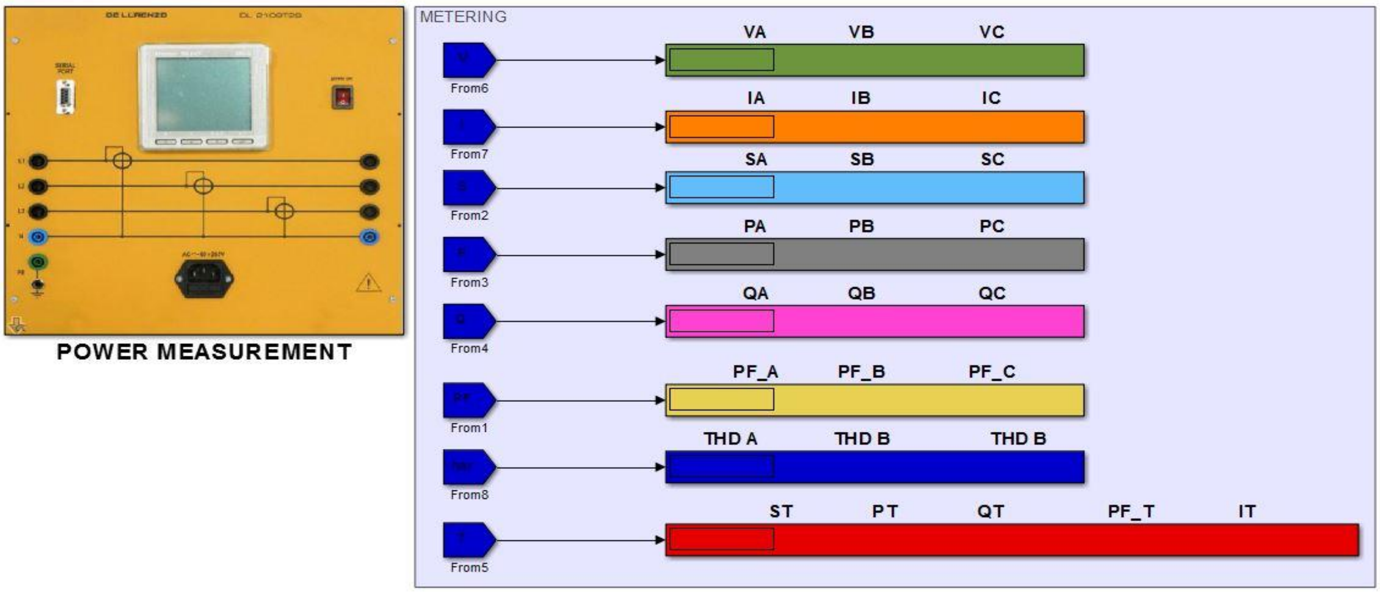


Figure 3.37: Simulation of power measurements module with multifunction.

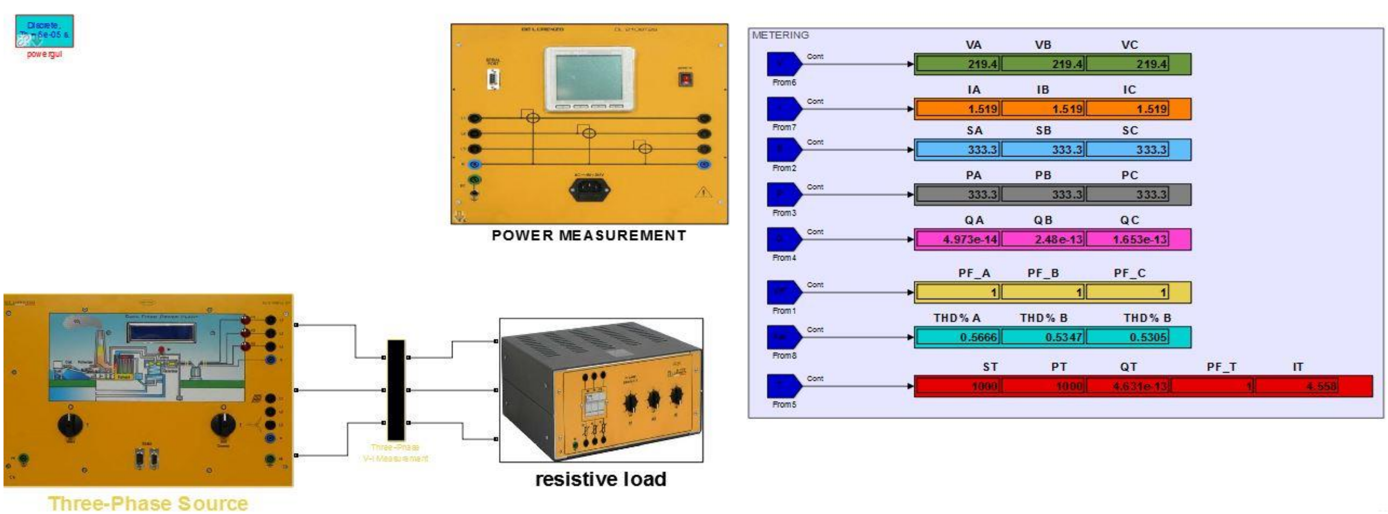


Figure 3.38: Simulation of power measurements module connected to three-phase load.

And the next figure shows the power measurement simulation when connected to non-linear load.

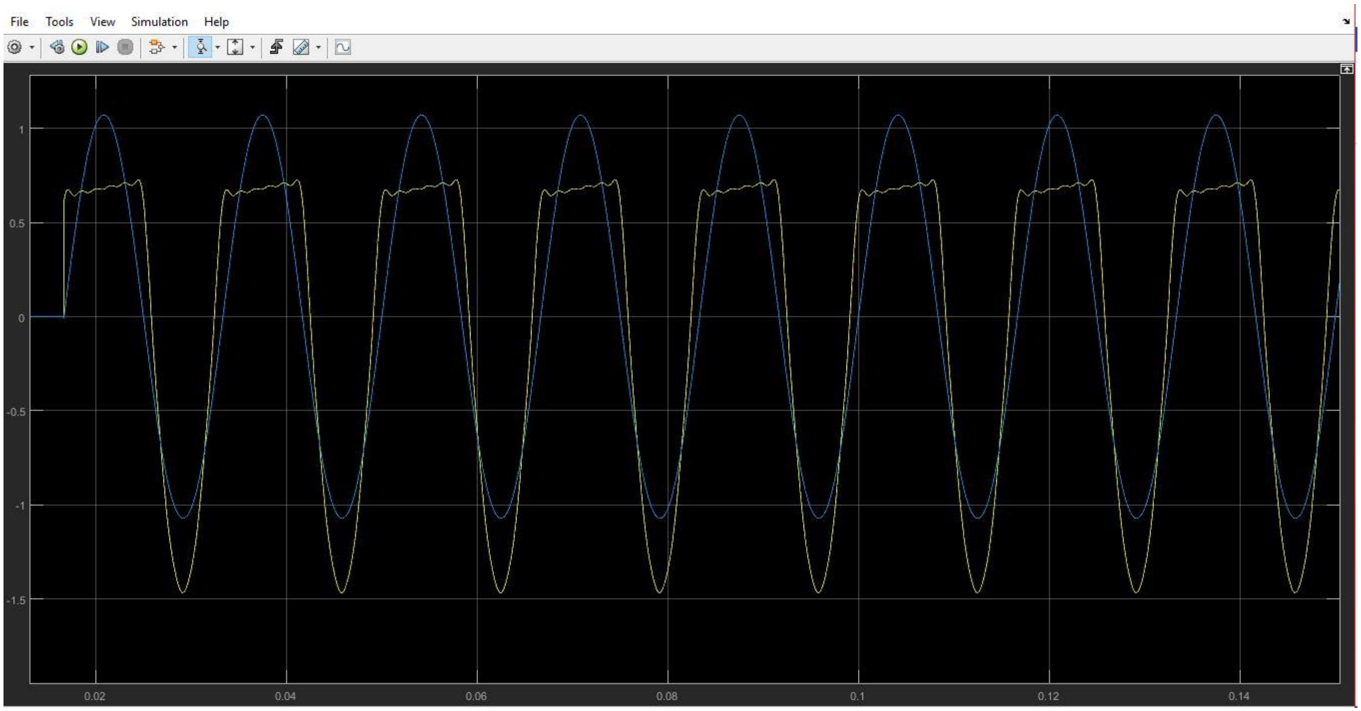


Figure 3.39: Simulation of power measurements module connected to non-linear three-phase load.

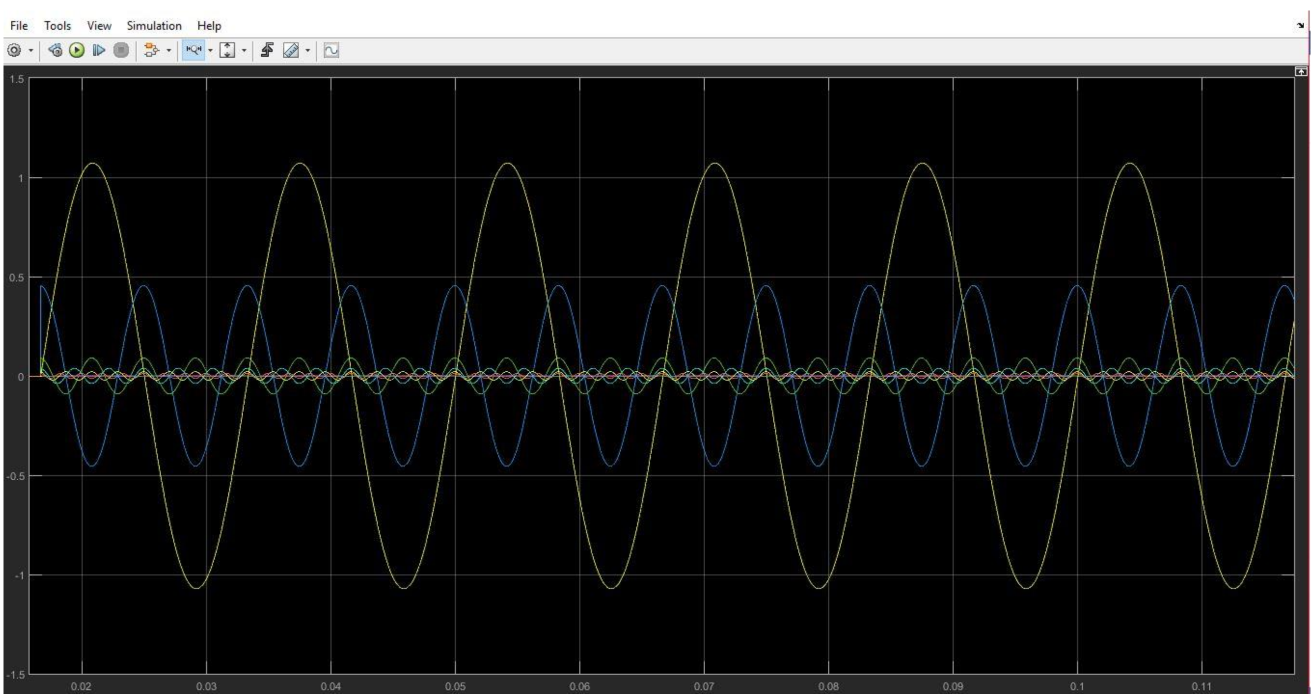


Figure 3.40: First 10th order of harmonics current on phase A.

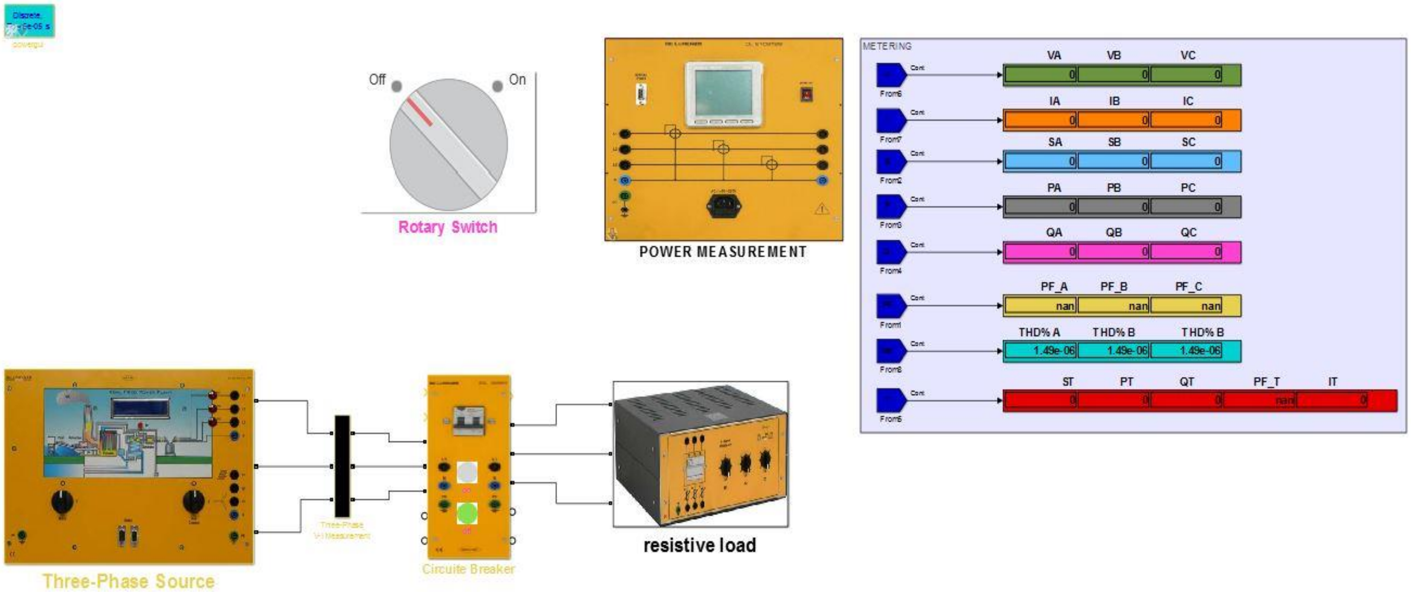


Figure 3.41: Combination modeling of Circuit Breaker and Power Measurement.

3.2 Power analysis and theory

This section demonstrates harmonic, power factor, and (linear and non-linear loads) theories that used in power measurements modeling using Simulink.

3.2.1 Harmonics:

The deviation of the voltage and current waveforms from sinusoidal is described in terms of the waveform distortion, often expressed as harmonic distortion.

Harmonics theory: A harmonic component in an AC power system is defined as a sinusoidal component of a periodic waveform that has a frequency equal to an integer multiple of the fundamental frequency of the system. Harmonics in voltage or current waveforms can then be conceived as perfectly sinusoidal components of frequencies multiple of the fundamental frequency: [2]

$$F(h) = (h) \times (\text{fundamental frequency}) \quad (3.1)$$

Where h is an integer

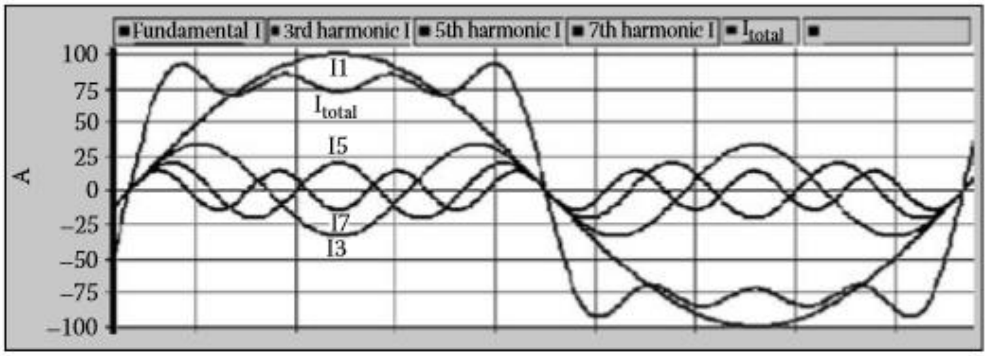


Figure 3.42: Shows an ideal 60-Hz waveform with a peak value of around 100 A.

Which can be taken as one per unit. Likewise, it also portrays waveforms of amplitudes (1/7), (1/5), and (1/3) per unit and frequencies seven, five, and three times the fundamental frequency, respectively. This behavior showing harmonic components of decreasing amplitude often following an inverse law with harmonic order is typical in power system [2]

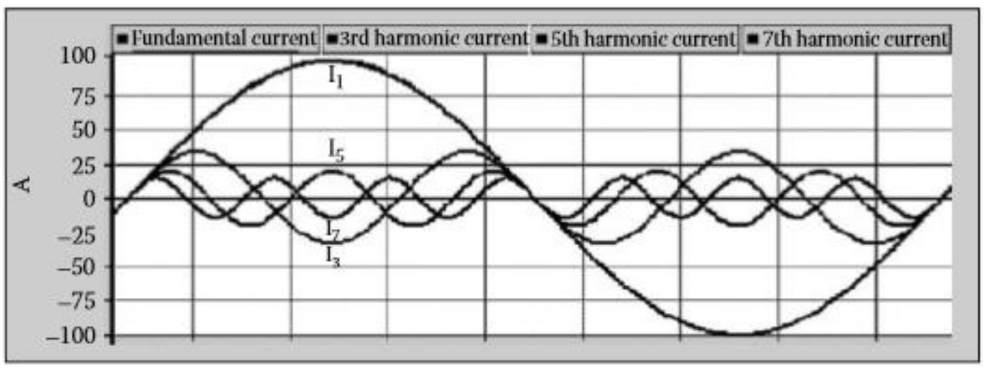


Figure 3.43: Ideal 60Hz waveform with harmonic components.

These waveforms can be expressed as:

$i_1 = I_{m1} \sin \omega t$ (3.2)

$i_3 = I_{m3} \sin(3 \omega t - \delta_3)$ (3.3)

$i_5 = I_{m5} \sin(5 \omega t - \delta_5)$ (3.4)

$i_7 = I_{m7} \sin(7 \omega t - \delta_7)$ (3.5)

Where I_{mh} is the peak RMS value of the harmonic current h . [2]

If we take only the first three harmonic components, the figure shows how a distorted current waveform at the terminals of a six-pulse converter would look. There would be additional harmonics that would impose a further distortion. The resultant distorted waveform can thus be expressed as:

$$I_{total} = I_{m1} \sin \omega t + I_{m3} \sin(3\omega t - \delta_3) + I_{m5} \sin(5\omega t - \delta_5) + I_{m7} \sin(7\omega t - \delta_7) \quad (3.6)$$

In this way, a summation of perfectly sinusoidal waveforms can give rise to a distorted waveform. Conversely, a distorted waveform can be represented as the superposition of a fundamental frequency waveform with other waveforms of different harmonic frequencies and amplitudes.

3.2.2 Linear and non-Linear loads:

From the discussion in this section, it will be evident that a load that draws current from a sinusoidal AC source presenting a waveform like that of Figure 3.43 cannot be conceived as a linear load.

- **Linear loads:**

Linear loads are those in which voltage and current signals follow one another very closely, such as the voltage drop that develops across a constant resistance, which varies as a direct function of the current that passes through it. This relation is better known as Ohm's law and states that the current through a resistance fed by a varying voltage source is equal to the relation between the voltage and the resistance, as described by:

$$I(t) = \frac{V(t)}{R} \quad (3.7)$$

This is why the voltage and current waveforms in electrical circuits with linear loads look alike. Therefore, if the source is a clean open circuit voltage, the current waveform will look identical, showing no distortion. Circuits with linear loads thus make it simple to calculate voltage and current waveforms

Resistive elements	Inductive elements	Capacitive elements
• Incandescent lighting • Electric heaters	• Induction motors • Current limiting reactors • Induction generators (wind mills) • Damping reactors used to attenuate harmonics • Tuning reactors in harmonic filters	• Power factor correction capacitor banks • Underground cables • Insulated cables • Capacitors used in harmonic filters

Figure 3.44: Example for linear loads.

- **Non-Linear loads:**

Nonlinear loads are loads in which the current waveform does not resemble the applied voltage waveform due to a number of reasons, for example, the use of electronic switches that conduct load current only during a fraction of the power frequency period.

Among the most common nonlinear loads in power systems are all types of rectifying devices like those found in power converters, power sources, uninterruptible power supply (UPS) units, and arc devices like electric furnaces and fluorescent lamps. Figure 3.45 provides a more extensive list of various devices in this category.

Power electronics	ARC devices
• Power converters • Variable frequency drives • DC motor controllers • Cycloconverters • Cranes • Elevators • Steel mills • Power supplies • UPS • Battery chargers • Inverters	• Fluorescent lighting • ARC furnaces • Welding machines

Figure 3.45: Example for nonlinear loads.

3.2.3 Power factor:

Traditional methods of Power Factor Correction typically focus on displacement power factor and therefore do not achieve the total energy savings available in facilities having both linear and non–linear loads. Only through Total Power Factor Correction can the savings and power quality be maximized.

When the loads are non–linear and the voltage is distorted the active, reactive and apparent power cannot be calculated using traditional methods

The active power is the mean (or average) value of the instantaneous power. If the phase angles of the voltage harmonics are neglected, the active power can be calculated as:

$$P = \sum_{n=1}^{N} V_n I_n \cos(\varphi_n) \tag{3.8}$$

Now, the power factor can be calculated using equation

$$pf = \frac{\sum_{n=1}^{N} V_n I_n \cos(\varphi_n)}{VI} \tag{3.9}$$

But, the voltage rms value is a function of the total harmonic voltage distortion and the rms value of the fundamental component of voltage:

$$V = V_1 \sqrt{1 + THD_V{}^2} \tag{3.10}$$

And Therms value of current is a function of the total harmonic current distortion and the rms value of the fundamental component of current

$$I = I_1 \sqrt{1 + THD_I{}^2} \tag{3.11}$$

Using equations (3.11), (3.10) and (3.9), the power factor can be calculated as follows:

$$pf = \frac{P}{S_1} \times \frac{1}{\sqrt{1+THD_I^{\,2}}\sqrt{1+THD_V^{\,2}}} \tag{3.12}$$

There are two terms involved in the calculation of the power factor. The term $\frac{P}{S_1}$ is the relationship between the total active power (including harmonics) and the apparent fundamental power. This term should not be called displacement power factor because it involves the active power caused by the fundamental components and harmonics. The term

$\frac{1}{\sqrt{1+THD_I^{\,2}}\sqrt{1+THD_V^{\,2}}}$ Is the distortion power factor (PF dist), which depends on the distortion of voltage and current. The power factor calculated as the product of the distortion power factor and the proportion of the total active power to the fundamental apparent power is the total power factor (TPF)

$$pf_T = \frac{P}{S_1} pf_{dist} \tag{3.13}$$

The term $\frac{P}{S_1}$ can be expressed as:

$$\frac{P}{S_1} = \frac{V_1 I_1 \cos(\varphi_1)}{S_1} + \frac{\sum_{n=2}^{N} V_n I_n \cos(\varphi_n)}{S_1} \tag{3.14}$$

Where $\frac{V_1 I_1 \cos(\varphi_1)}{S_1}$ is the displacement power factor (pf_{disp}), so the total power factor can be calculated as follows:

$$pf_T = \left(pf_{disp} + \frac{\sum_{n=2}^{N} V_n I_n \cos(\varphi_n)}{S_1} \right) pf_{dist} \qquad (3.15)$$

In a similar way to the case of the non–linear loads and sinusoidal voltage, if the reactive power of the loads increases, the displacement angle between the fundamental components of voltage and current also increases and the total power factor decreases. If the distortion of current and voltage increases the distortion power factor decreases and the total power factor decreases as well.

3.3 Summary

In this chapter a simulation is done for power circuit breakers and power measurements modules using Simulink as blocks. The other modules will be simulated in chapter 4 same way as this chapter in order to get all needed modules to be simulated and to study the behavior and dynamic characteristics when connected together for educational purposes.

4

Chapter Four Modules Simulation 2

4.1 Loads and Transmission modules

4.1.1 Load modules

4.1.2 Transmission line modules

4.2 Power electronics modules

4.2.1 Dc-to-AC converter (inverter)

4.2.2 Buck-Boost converter

4.2.3 Maximum power point tracker

4.2.4 Filter

4.3 Renewable energy modules

4.3.1 PV panel module

4.3.2 Three phase induction machine

4.4 Final Form

4.1 Loads and Transmission modules

4.1.1 Load modules

In this section a simulation of loads modules and their Datasheets are shown in figure 4.1:

Figure 4.1: Three phase loads modules (R, L, and C).

1. **Resistive load:**

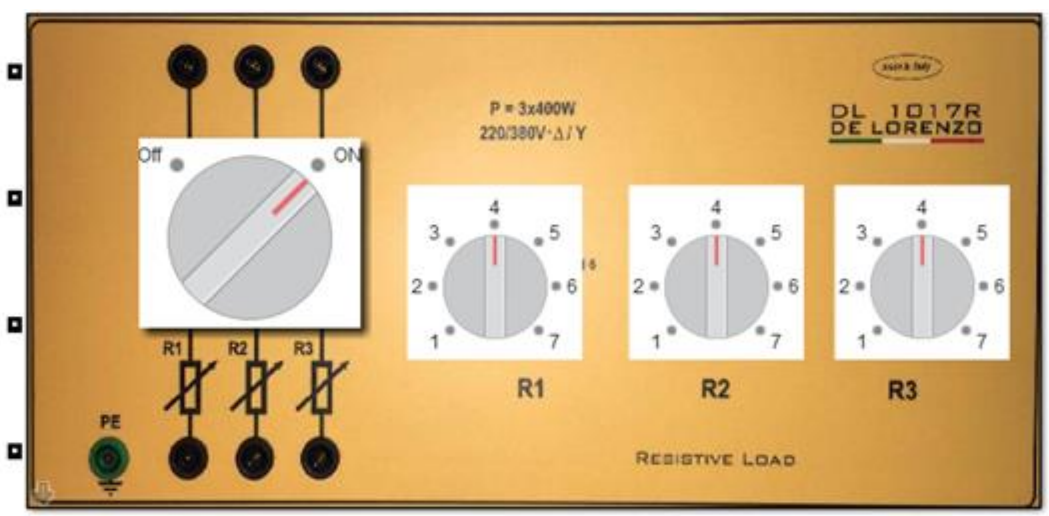


Figure 4.2: Three phase R load module.

- Datasheet and the values of R (R1, R2, and R3) switches are shown: [6]

Position	Resistance	Max power per phase
1	1050 Ohm	46 W
2	750 Ohm	65 W
3	435 Ohm	110 W
4	300 Ohm	160 W
5	213 Ohm	230 W
6	150 Ohm	330 W
7	123 Ohm	400 W

Table 4.1: Resistive load Datasheet given as Ohm and Watt.

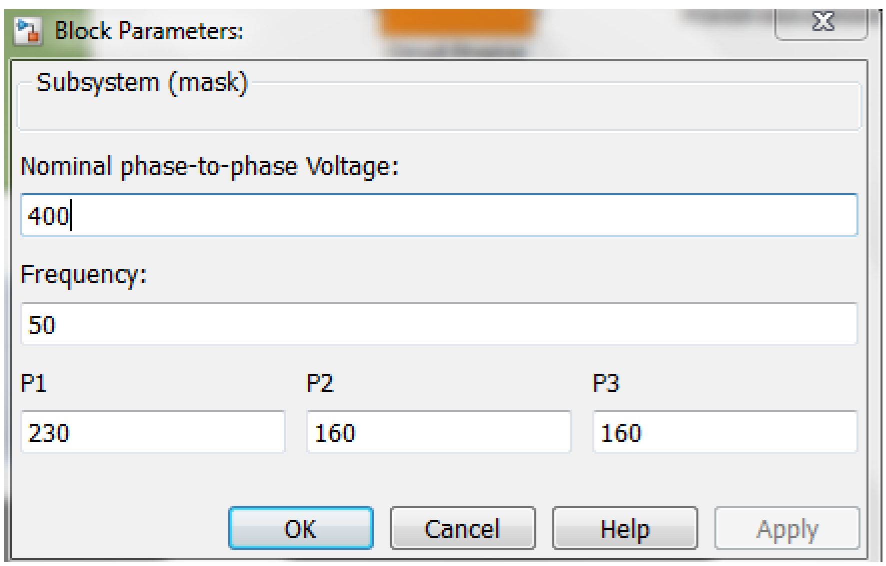


Figure 4.3: Resistive load dialog box controlled values.

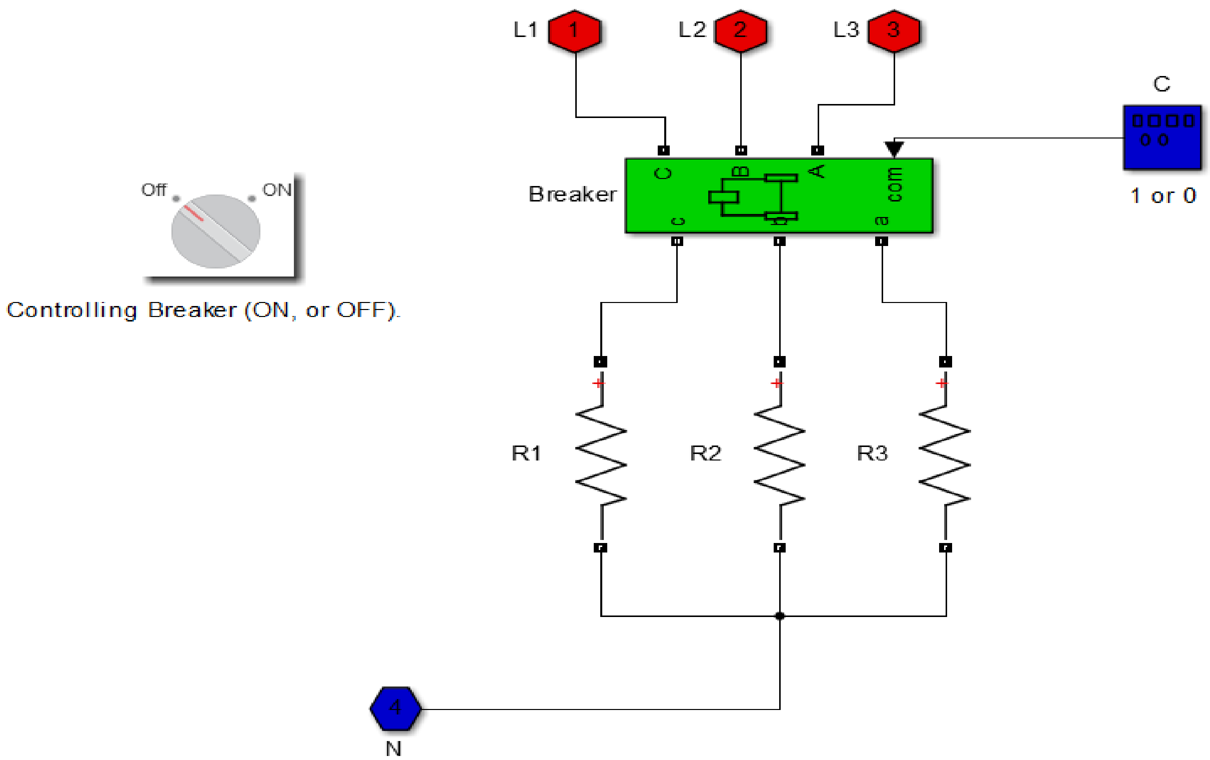


Figure 4.4: Internal content of Resistive load module.

2. Inductive load:

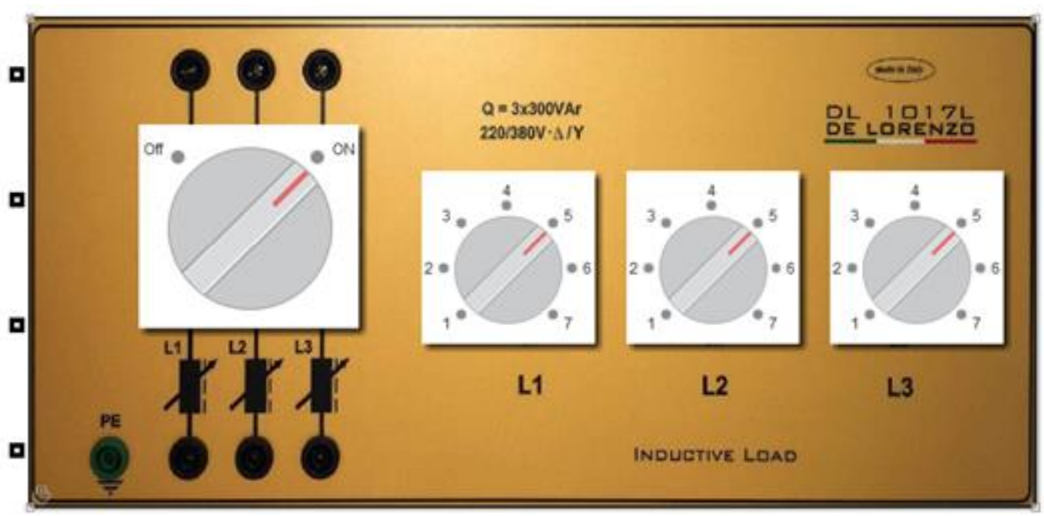


Figure 4.5: Three phase L load module.

- Datasheet and the values of L (L1, L2, and L3) switches are shown: [6]

Position	Inductance	Max power per phase
1	4.46 H	34 VAr
2	3.19 H	48 VAr
3	1.84 H	83 VAr
4	1.27 H	121 VAr
5	0.90 H	171 VAr
6	0.64 H	242 VAr
7	0.52 H	297 VAr

Table 4.2: Inductive load Datasheet given as Henry and VAr.

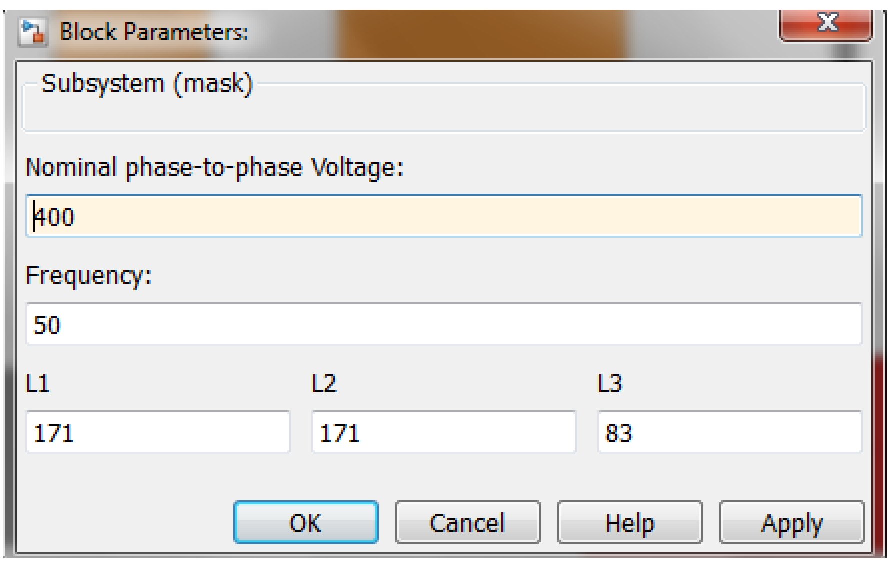


Figure 4.6: Inductive load dialog box controlled values.

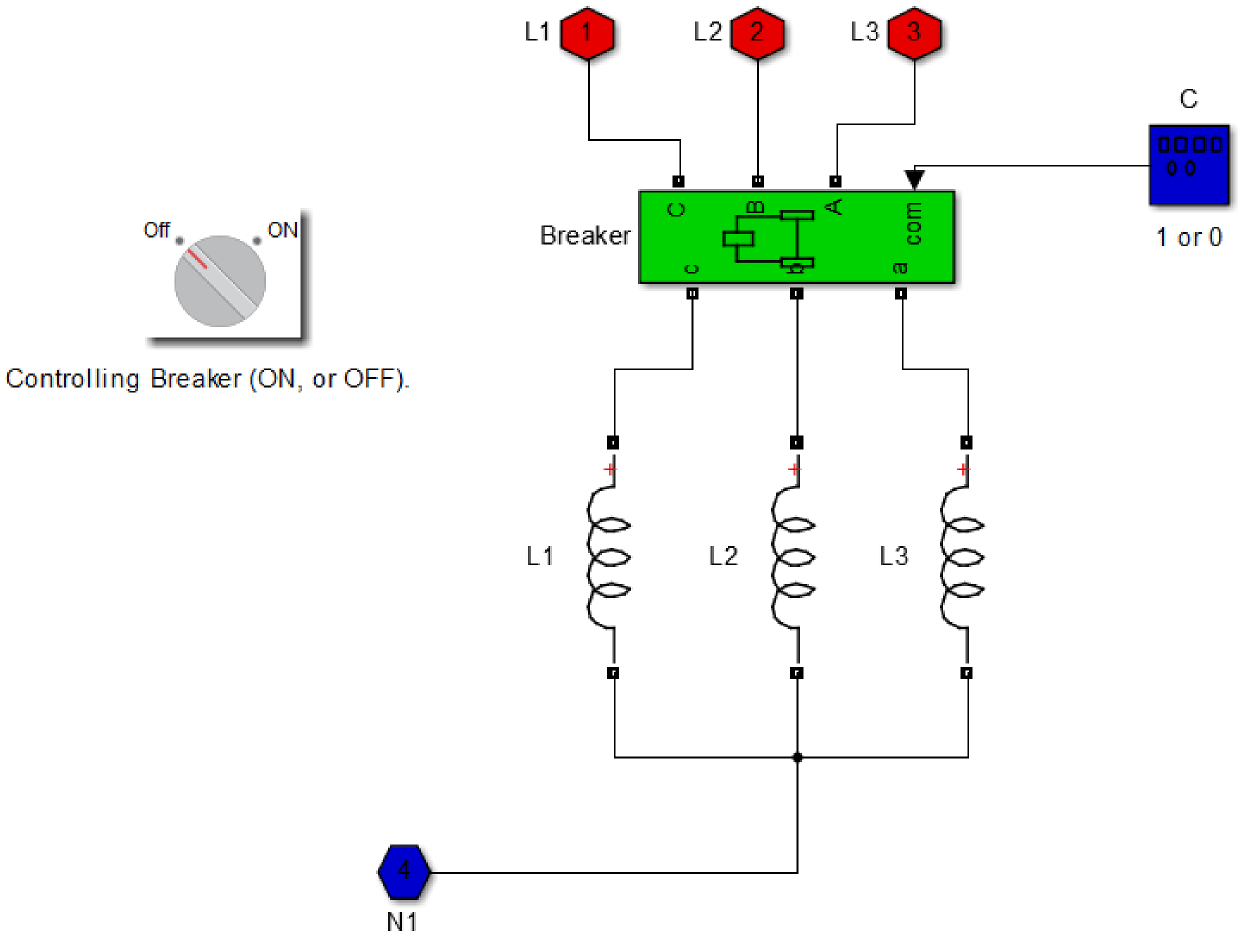


Figure 4.7: Internal content of Inductive load module.

3. Capacitive load:

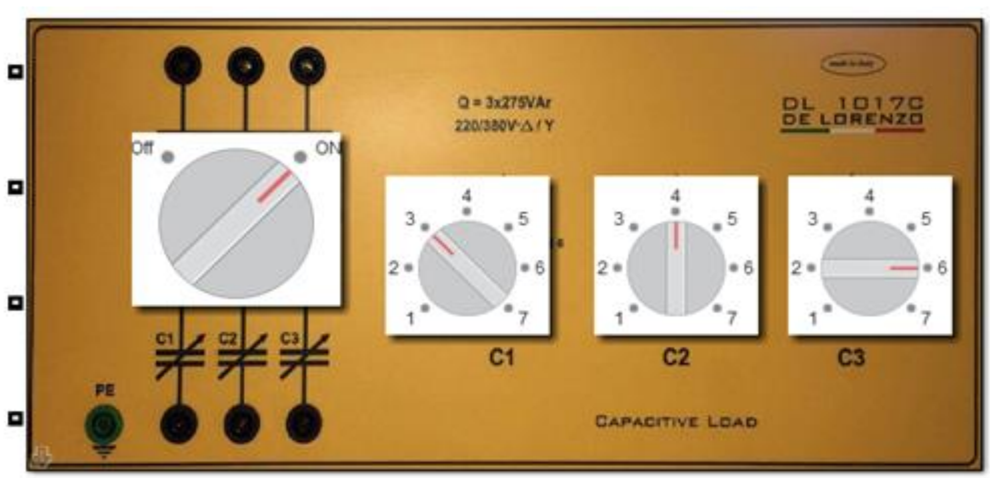


Figure 4.8: Three phase C load module.

- Datasheet and the values of C (C1, C2, and C3) switches are shown: [6]

Position	Capacitance	Max power per phase
1	2 µF	30 VAr
2	3 µF	45 VAr
3	5 µF	76 VAr
4	7 µF	121 VAr
5	10 µF	152 VAr
6	13 µF	197 VAr
7	18 µF	275 VAr

Table 4.3: Capacitive load Datasheet given as Farad and VAr

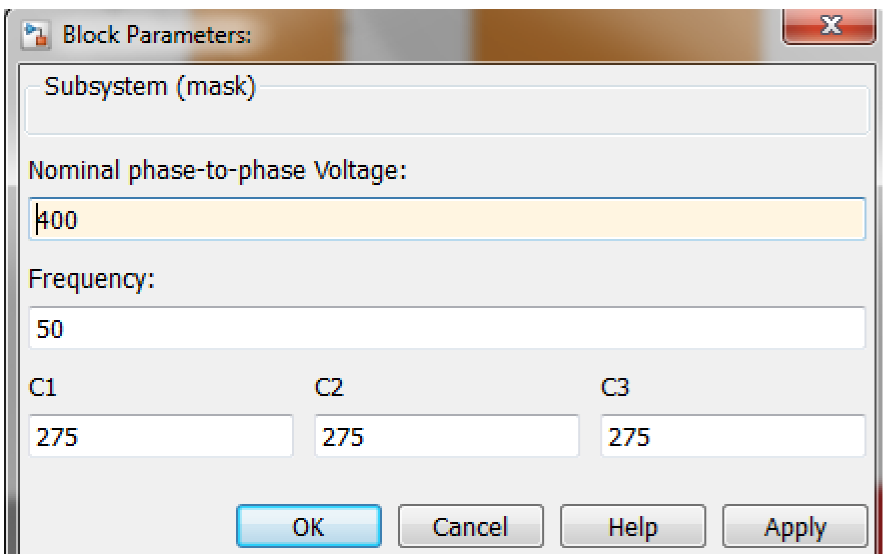


Figure 4.9: Capacitive load dialog box controlled values.

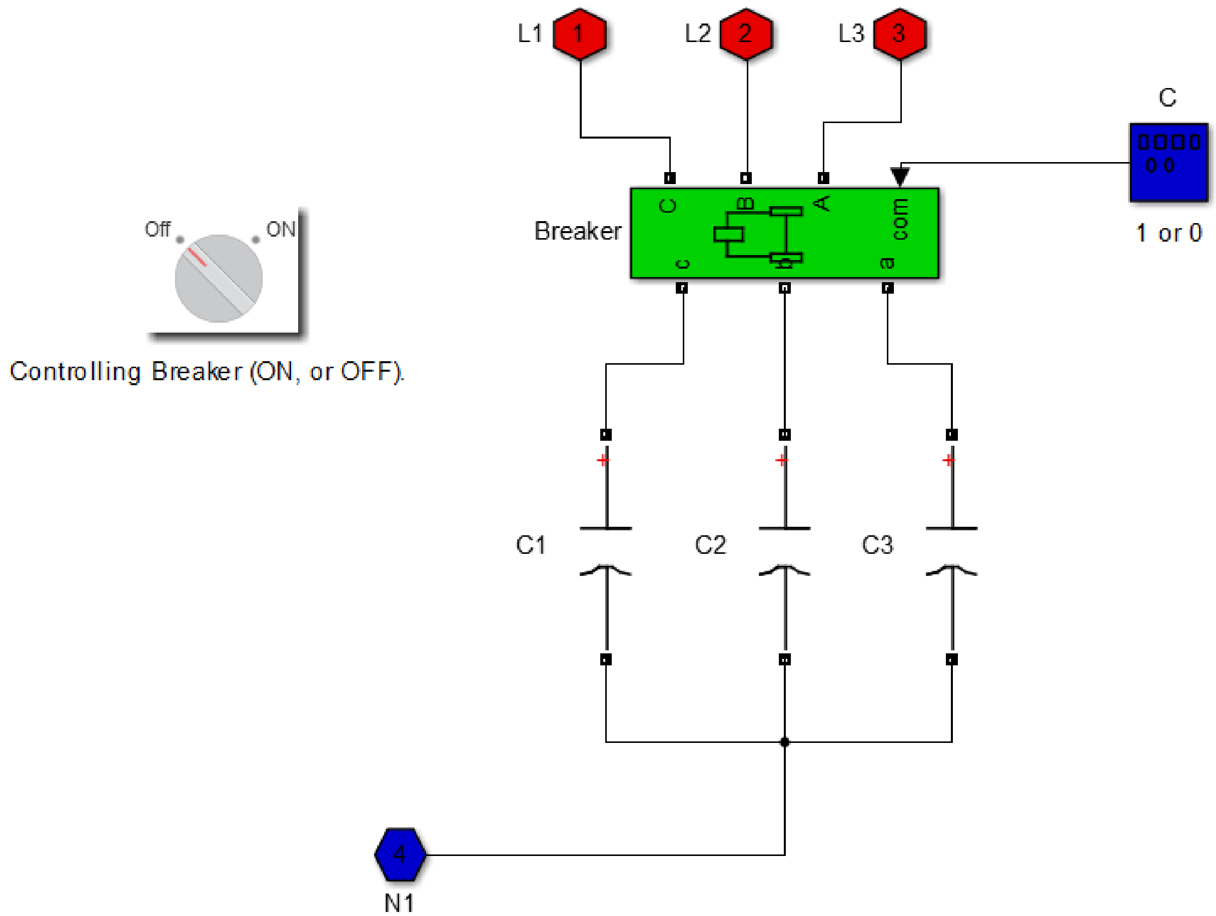


Figure 4.10: Internal content of capacitive load module.

4.1.2 Transmission line modules

1. Transmission line model 1

This module is a three-phase model of an overhead power transmission line of 360 km, voltage 380 kV and current line 1000 A. The scale factor is 1:1000 for both, current and voltage so the actual nominal values are 380 V and 1 A.[6]

Table 4.4 shows the Datasheet of Transmission line 1 used for simulation.

Resistance	13 Ω
Inductance	290 mH
Earth capacitance	1 μF
Mutual capacitance	0.5 μF
Earth return resistance	11 Ω
Earth return inductance	250 mH

Table 4.4: Datasheet given for Transmission line 1 model.[6]

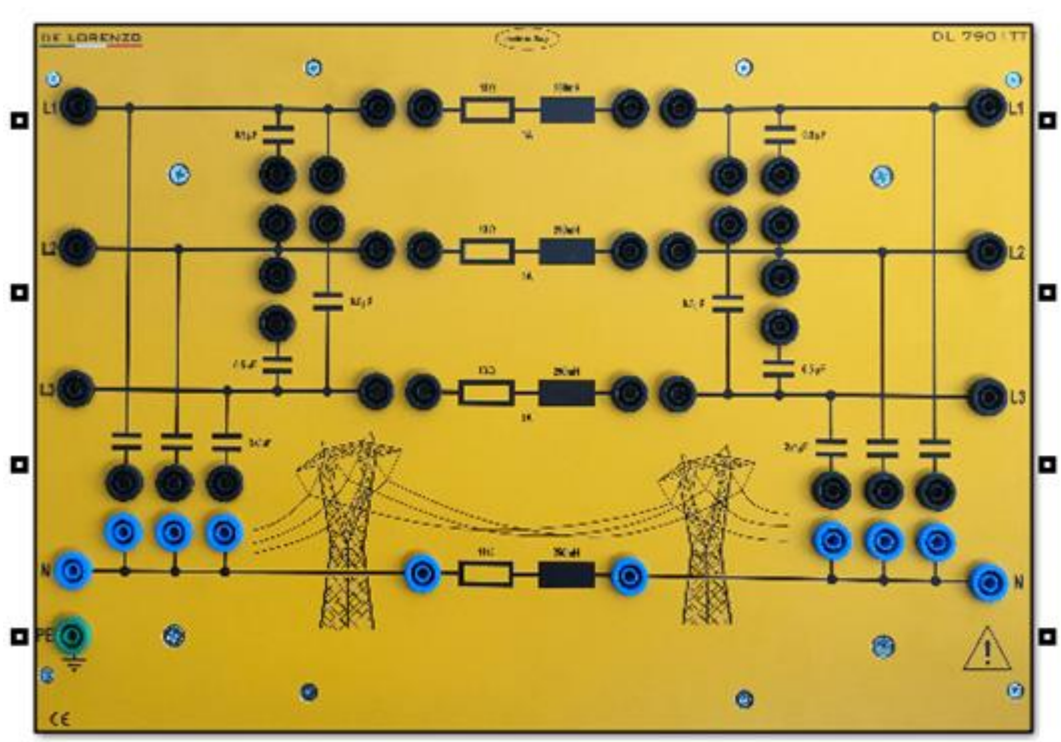


Figure 4.11: Transmission line 360Km module.

The transmission line is presented as an equivalent "π" circuit with concentrated parameters. If all the plugins are connected the capacitance value respect to neutral is 2.5 μF.

2. Transmission line model 2

This modulus is a three-phase model of an overhead power transmission line of 100 km, voltage 380 kV and current line 1000 A. The scale factor is 1:1000 for both, current and voltage so the actual nominal values are 380 V and 1 A.

Table 4.5 shows the Datasheet of Transmission line 1 used for simulation.

Resistance	3.3 Ω
Inductance	80 mH
Earth capacitance	100 nF
Mutual capacitance	200 nF
Earth return resistance	3 Ω
Earth return inductance	69 mH

Table 4.5: Datasheet given for Transmission line 2 model. [6]

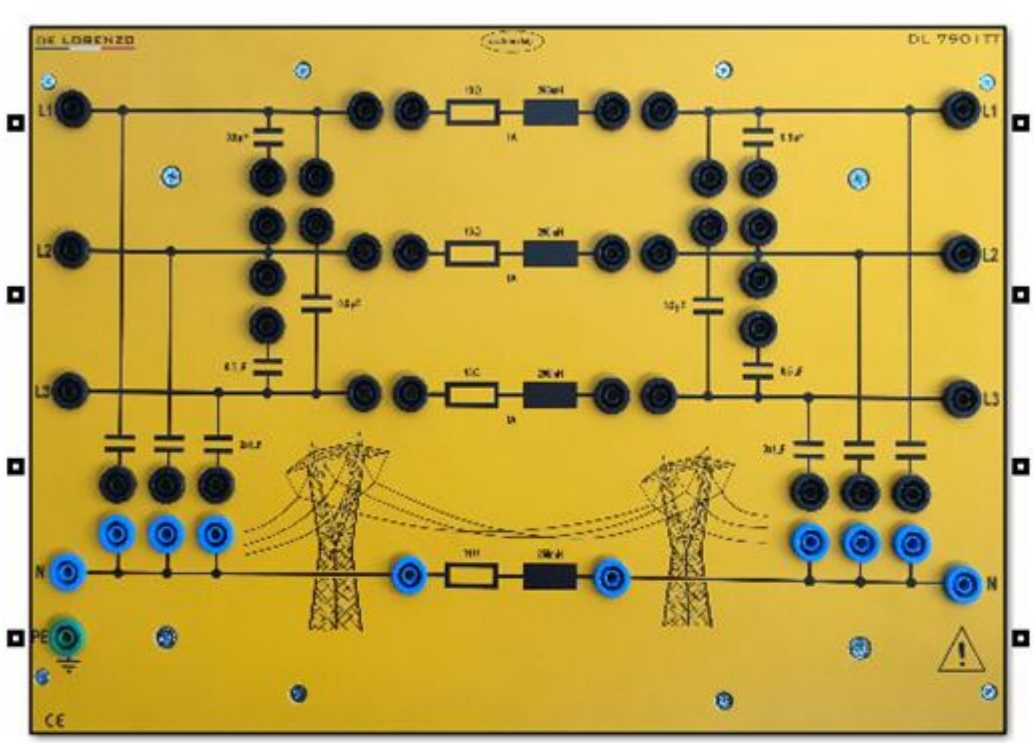


Figure 4.12: Transmission line 100Km module.

The transmission line is presented as an equivalent "π" circuit with concentrated parameters. If all the plugins are connected the capacitance value respect to neutral is 500 nF.

4.2 Power electronics modules

4.2.1 Dc-to-AC converter(inverter)

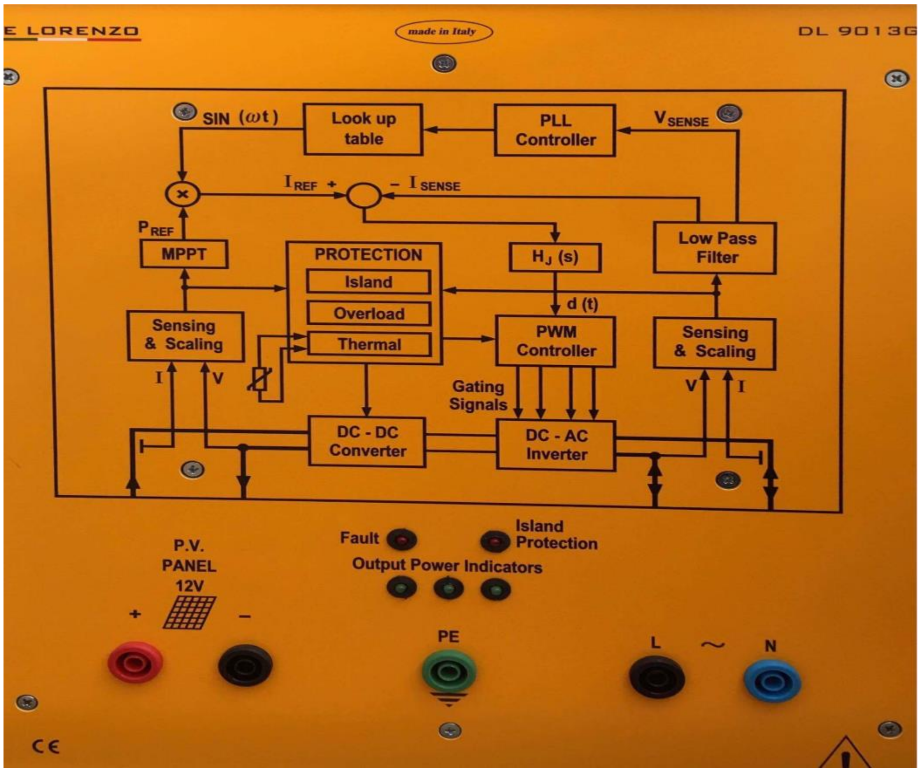


Figure 4.13: DC to AC unit module.

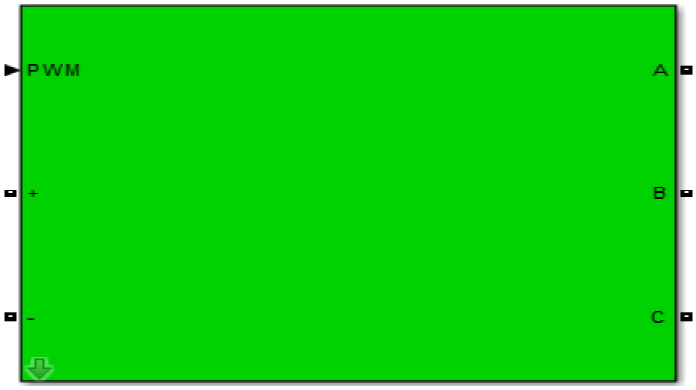


Figure 4.14: DC to AC unit module in MATLAB.

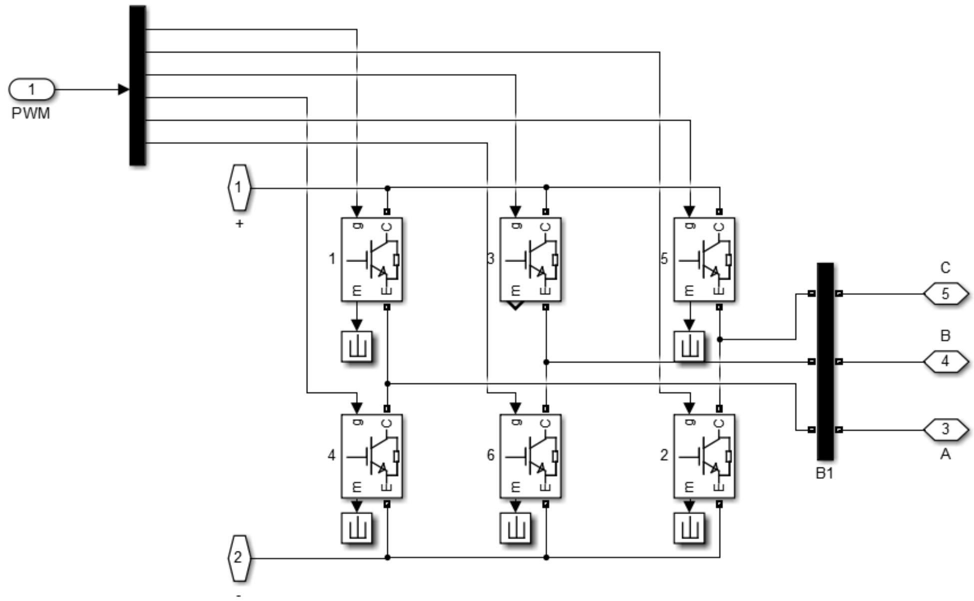


Figure 4.15: Inside DC to AC unit module in MATLAB.[9]

The IGBTs are controlled by using pulse width modulation (PWM) technique.

4.2.2 Buck-Boost converter

Figure 4.16: Buck-Boost converter subsystem block.

Figure 4.17 shows the inner content of the buck-boost converter simulated using MATLAB.

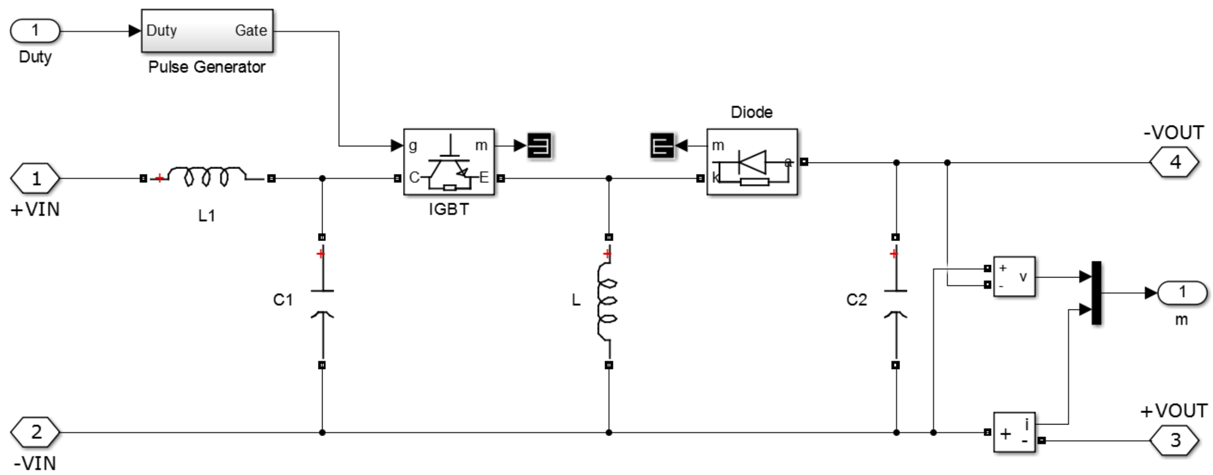


Figure 4.17: Inside Buck-Boost converter subsystem block. [9]

4.2.3 Maximum power point tracker

Figure 4.18 shows MPPT Controller subsystem simulated using Matlab.

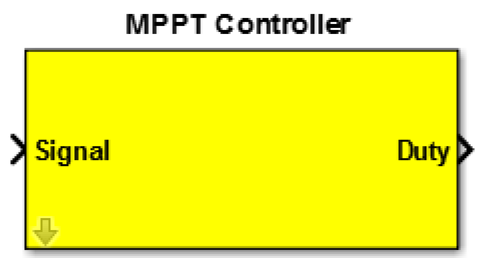


Figure 4.18: MPPT controller subsystem block.

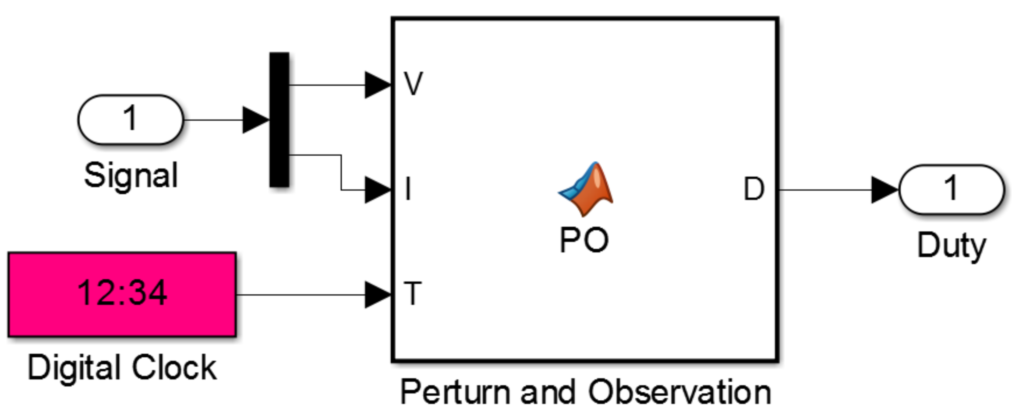


Figure 4.18: Inside MPPT controller subsystem block.

Due to fluctuations of Temperature and irradiation, the maximum power of PV panel needed to be controlled using appropriate controller such as MPPT → MPPT implementations utilize algorithms that frequently sample panel voltages and currents, then adjust the duty ratio as needed. Microcontrollers are employed to implement the algorithms.

The commonly used method to observe the maximum power point is called **Perturb and Observe (P&O).**

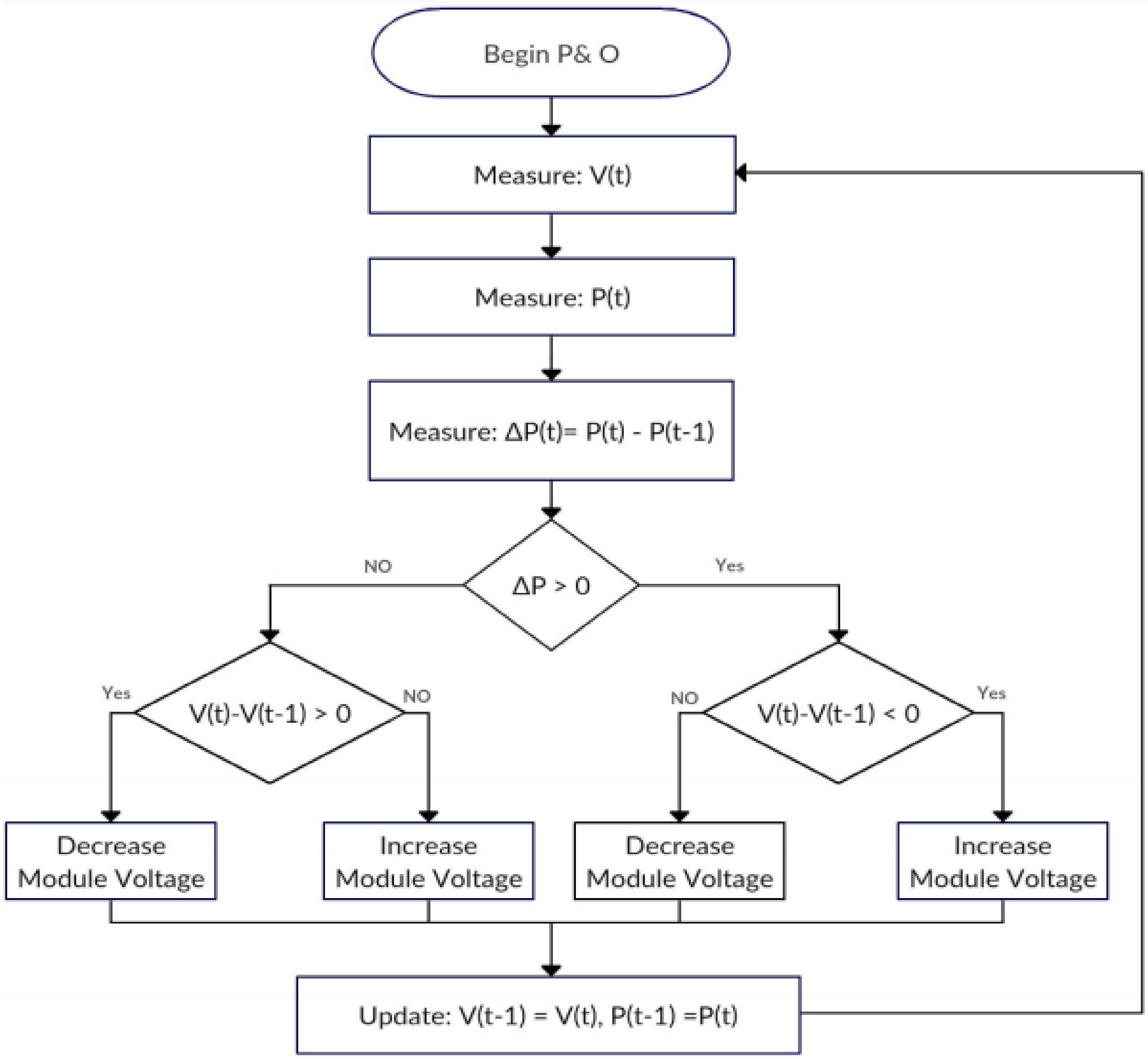


Figure 4.19: Flowchart for P & O Algorithm. [10]

- If the power increases then the perturbation is continued → after the peak power is reached the power at the MPP is zero.
- After that the perturbation reverses → the stable condition is arrived and algorithm oscillates around the peak power point.

4.2.4 Filter

A specific filter is used after the Inverter in order to get a pure sinusoidal output voltage.

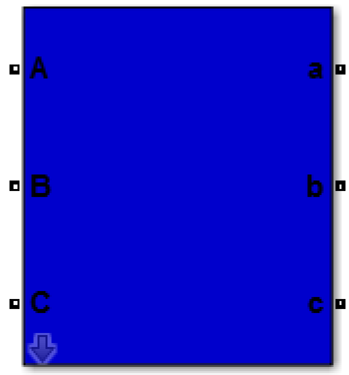


Figure 4.20: Filter subsystem block.

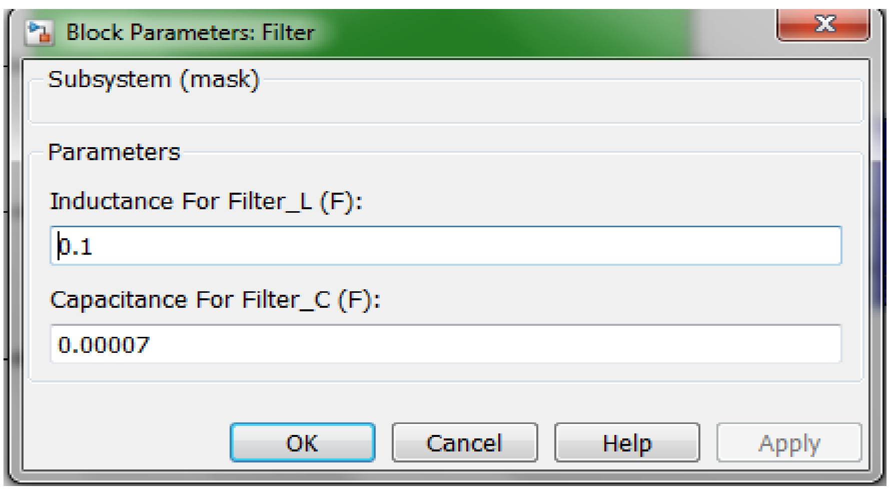


Figure 4.21: Dialog box for Filter subsystem block.

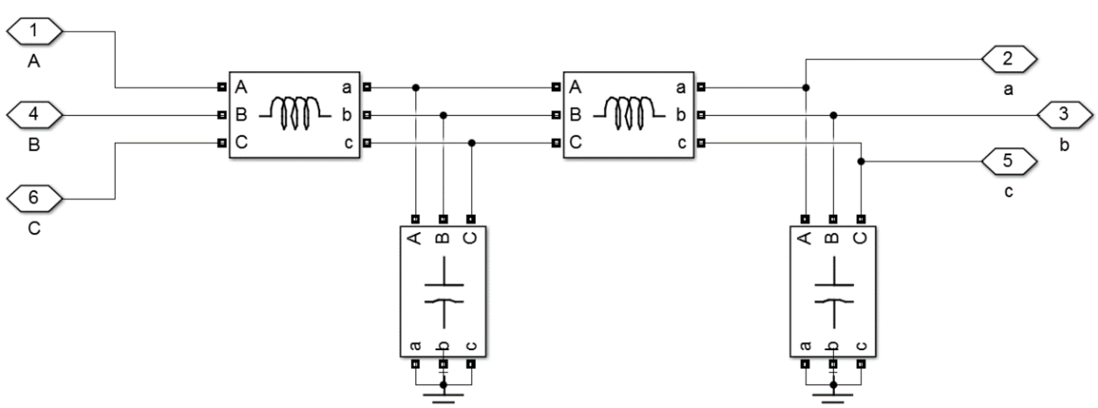


Figure 4.22: Inside filter subsystem block.

4.3 Renewable energy modules

4.3.1 PV panel module

Figure 4.23: PV panel subsystem block.

85W, 12V, full of cell for measurement of the radiation
It has a solar and a temperature sensor.

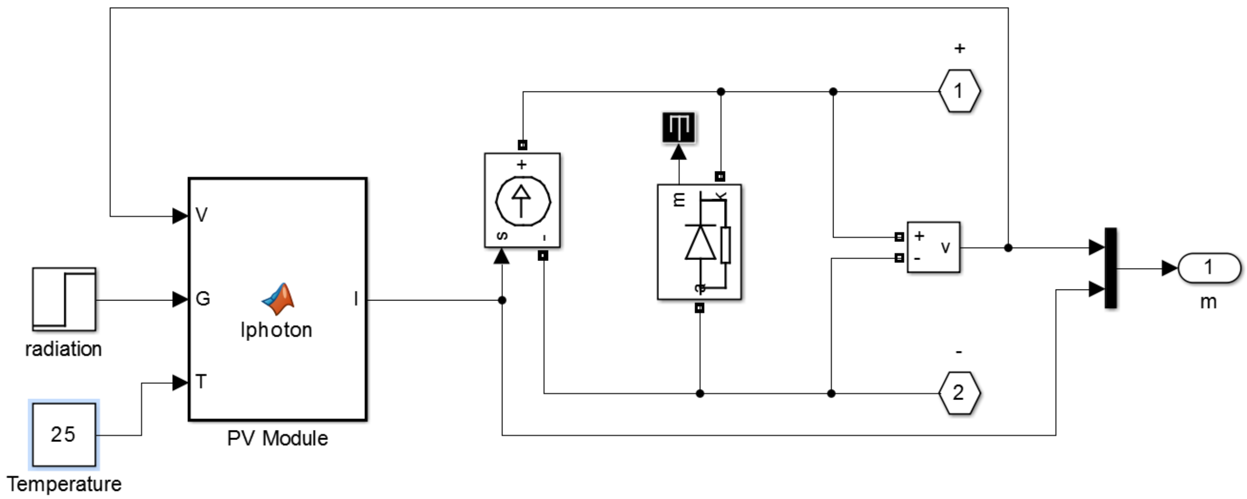


Figure 4.24: Inside PV panel subsystem block.

4.3.2 Three phase induction machine

Three phase induction generator used to simulate Wind turbine generation stage. Figure 4.25 shows the induction machine inside MATLAB.

Figure 4.25: Three Phase induction machine. [6]

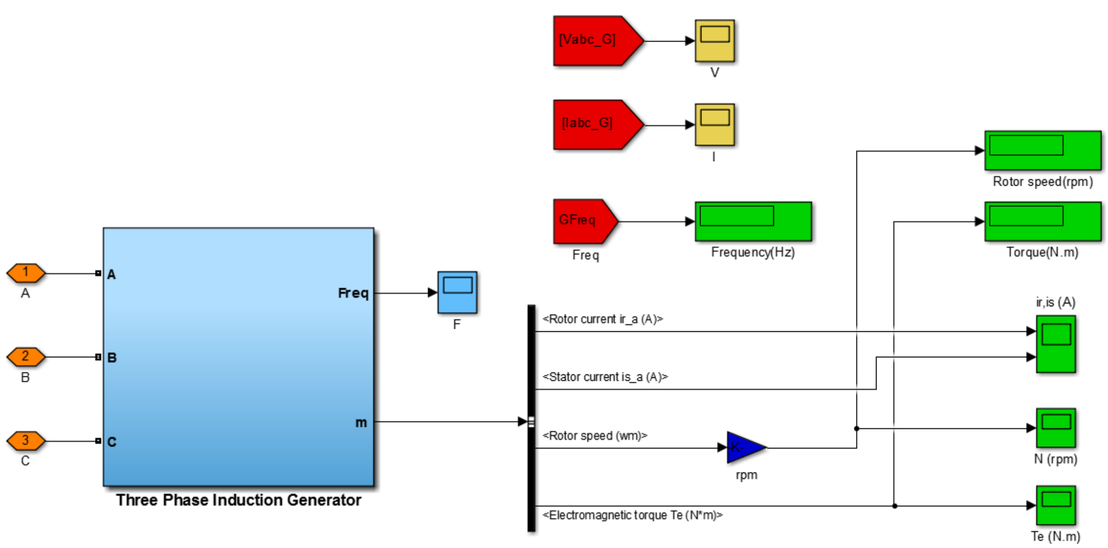


Figure 4.26: Inside three phase induction machine.

Dialog box Figure 4.27 used to enter the operating values for the induction machine.

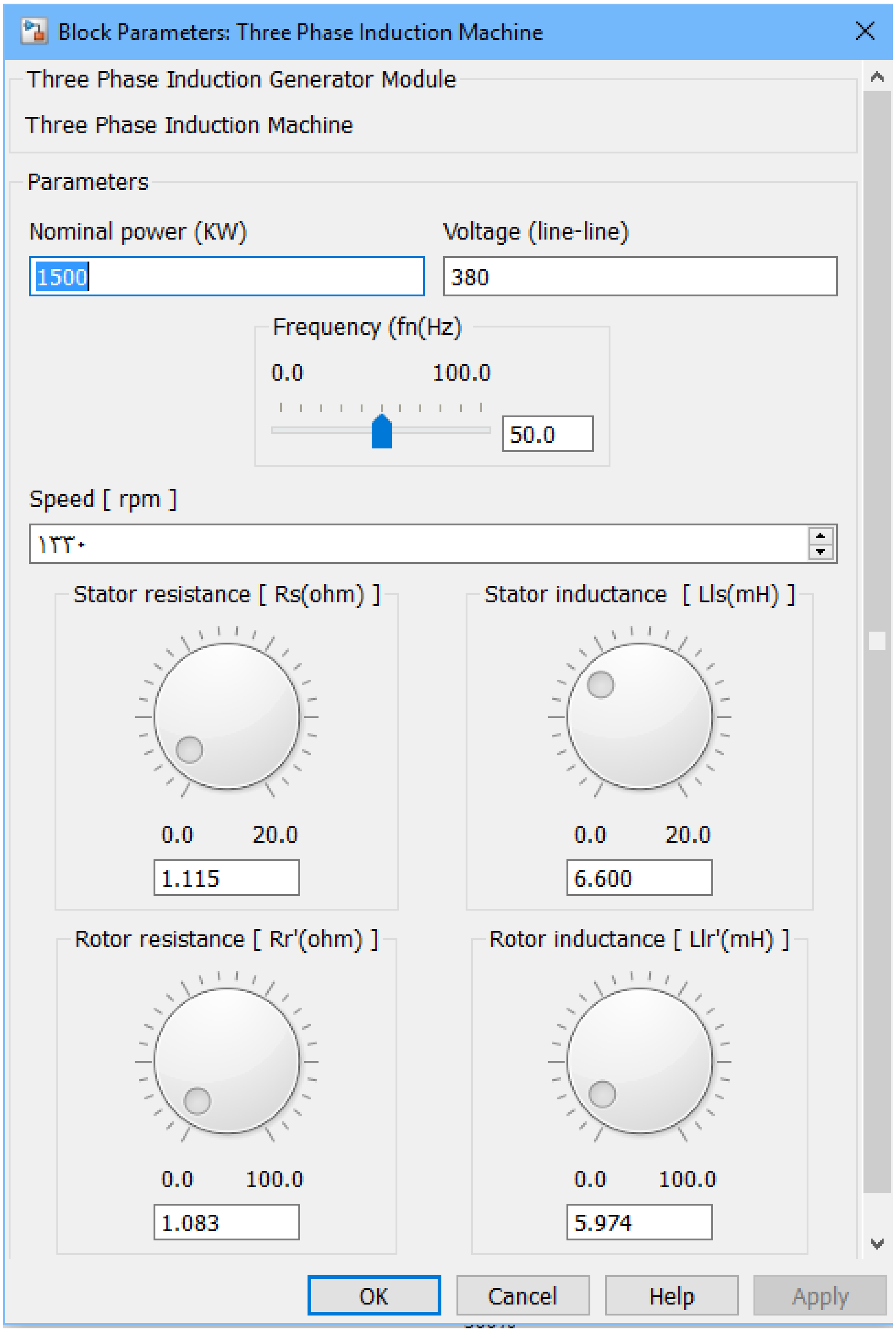


Figure 4.27: Three phase induction machine dialog box.

Figure 4.28 shows the final form (Inner content) of the induction machine, simulated using Matlab/Simulink to produce power around 1.5KW.

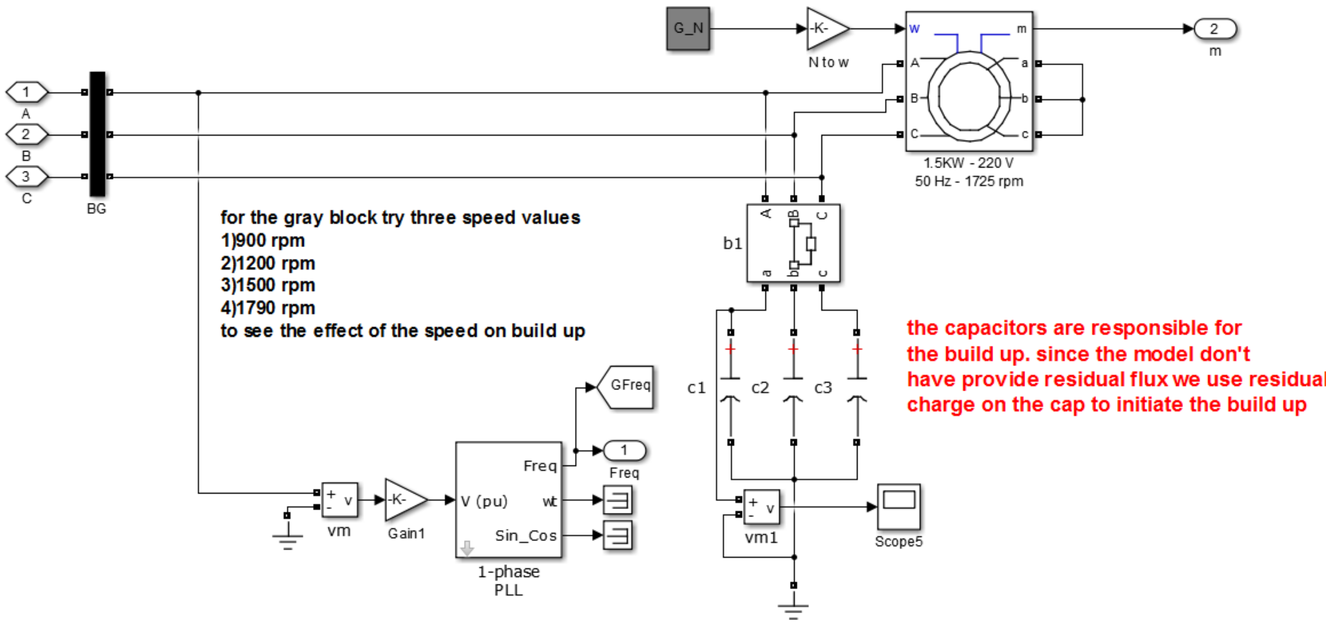
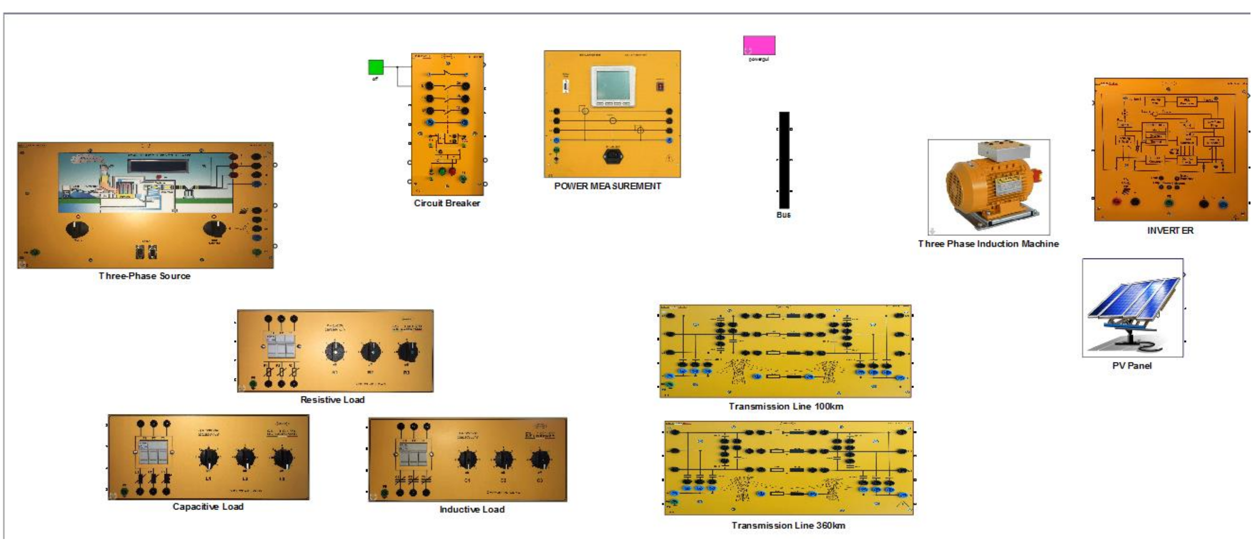


Figure 4.28: Inner content for three phase induction machine.

4.4 Final Form

After simulating most of the modules of renewable energy lab at Palestine Polytechnic University, the final form inside MATLAB is obtained as the following:



Several experiments on MATLAB and also practical are done and described later in chapter 5, and a comparison between the results is obtained.

5

Chapter Five Experiments

5.1 Loads

5.1.1 Introduction
5.1.2 R-Load
5.1.3 C-Load
5.1.4 L-Load

5.2 Transmission

5.2.1 Short
5.2.2 Medium
5.2.3 Long

5.3 Results Validation

5.3.1 Load results
5.3.2 Transmission results
5.3.3 Validation check

5.4 Combined Loads

5.5 Conclusion

5.1 Loads

5.1.1 Introduction

In this chapter several experiments on MATLAB and also practical are done, and a comparison between the results is obtained. After obtaining the comparison, a results validation is done later in section 5.3.

5.1.2 R-Load

The objective of this experiment is to connect the electrical source with R-Load, and obtain practical and experimental results. The connected electrical circuit will contain (Three phase source, circuit breaker, Power measurements module, and Three phase R-Load module), as shown in Figure 5.1.

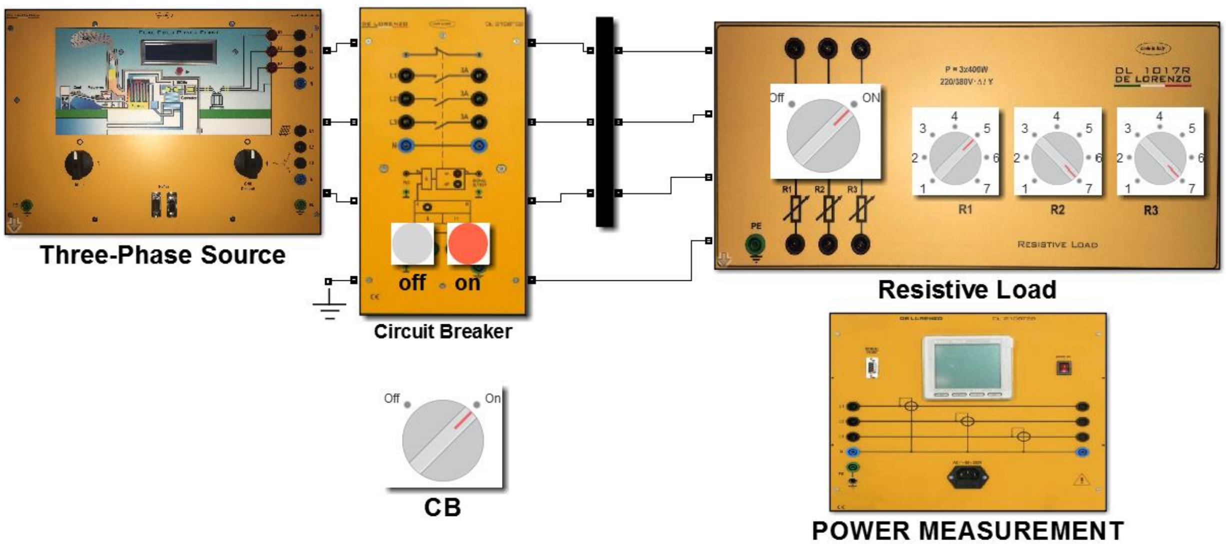


Figure 5.1: R-Load experiment.

Tables 5.1 and 5.2 show the results obtained.

RLOAD							
Resistance	Position	V	I	P	Q	S	PF
1050 Ohm	1	230.9	0.22	50.8	0	50.8	1
750 Ohm	2	230.9	0.308	71.11	0	71.11	1
435 Ohm	3	230.9	0.531	122.6	0	122.6	1
300 Ohm	4	230.9	0.77	177.8	0	177.8	1
213 Ohm	5	230.9	1.084	250.4	0	250.4	1
150 Ohm	6	230.9	1.54	355.5	0	355.5	1
123 Ohm	7	230.9	1.877	433.6	0	433.6	1

Table 5.1: R-Load Matlab results.

R-LOAD							
Resistance	Position	V	I	P	Q	S	PF
1050 Ohm	1	231	0.21	50	0	50	1
750 Ohm	2	229.5	0.3	70	0	70	1
435 Ohm	3	228.8	0.52	120	0	120	1
300 Ohm	4	228.5	0.77	180	0	180	1
213 Ohm	5	228	1.08	251	0	251	1
150 Ohm	6	228	1.5	355	0	355	1
123 Ohm	7	228	1.8	425	0	425	1

Table 5.2: R-Load Practical results.

5.1.3 C-Load

The connected electrical circuit will contain (Three phase source, circuit breaker, Power measurements module, and Three phase C-Load module), as shown in Figure 5.2.

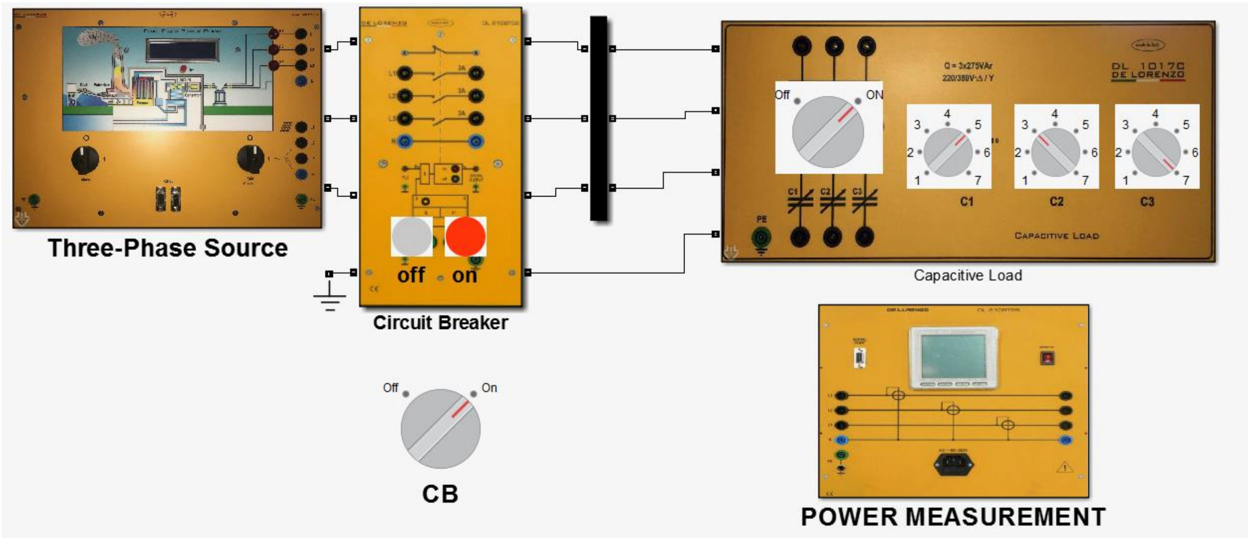


Figure 5.2: C-Load experiment.

Tables 5.3 and 5.4 show the results obtained.

C-LOAD							
Capacitance	Position	V	I	P	Q	S	PF
2 μF	1	230.9	0.145	0	-33.5	33.53	0
3 μF	2	230.9	0.217	0	-50.27	50.27	0
5 μF	3	230.9	0.363	0	-83.78	83.78	0
7 μF	4	230.9	0.508	0	-117.3	117.3	0
10 μF	5	230.9	0.725	0	-167.6	167.6	0
13 μF	6	230.9	0.943	0	-217.8	217.8	0
18 μF	7	230.9	1.306	0	-301.6	301.6	0

Table 5.3: C-Load Matlab results.

C-LOAD							
Capacitance	Position	V	I	P	Q	S	PF
2 µF	1	231	0.15	0	-30	30	0
3 µF	2	229.5	0.22	0	-50	50	0
5 µF	3	228.8	0.36	0	-80	80	0
7 µF	4	228.5	0.59	0	-130	130	0
10 µF	5	228	0.74	0	-160	160	0
13 µF	6	228	0.97	0	-210	210	0
18 µF	7	228	1.33	0	-290	290	0

Table 5.4: C-Load Practical results.

5.1.4 L-Load

The connected electrical circuit will contain (Three phase source, circuit breaker, Power measurements module, and Three phase L-Load module), as shown in Figure 5.3.

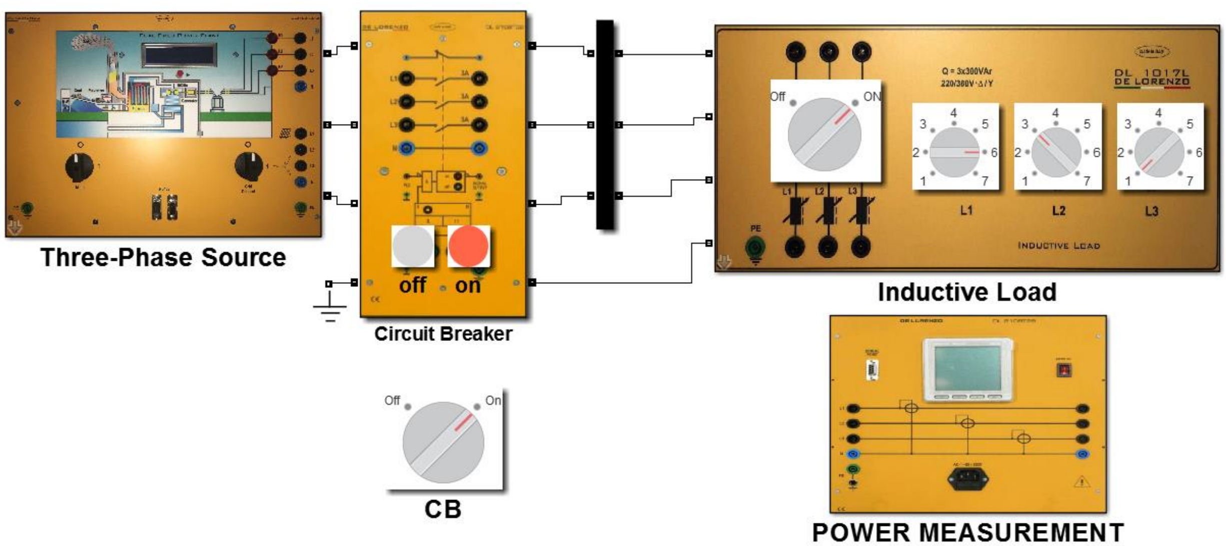


Figure 5.3: L-Load experiment.

Tables 5.5 and 5.6 show the results obtained.

L-LOAD							
Inductance	Position	V	I	P	Q	S	PF
4.46 H	1	230.9	0.165	0	38.06	38.06	0
3.19 H	2	230.9	0.23	0	53.22	53.22	0
1.84 H	3	230.9	0.399	0	92.26	92.26	0
1.27 H	4	230.9	0.578	0	133.7	133.7	0
0.90 H	5	230.9	0.817	0	188.6	188.6	0
0.64 H	6	230.9	1.149	0	265.2	265.2	0
0.52 H	7	230.9	1.414	0	326.5	326.5	0

Table 5.5: L-Load Matlab results.

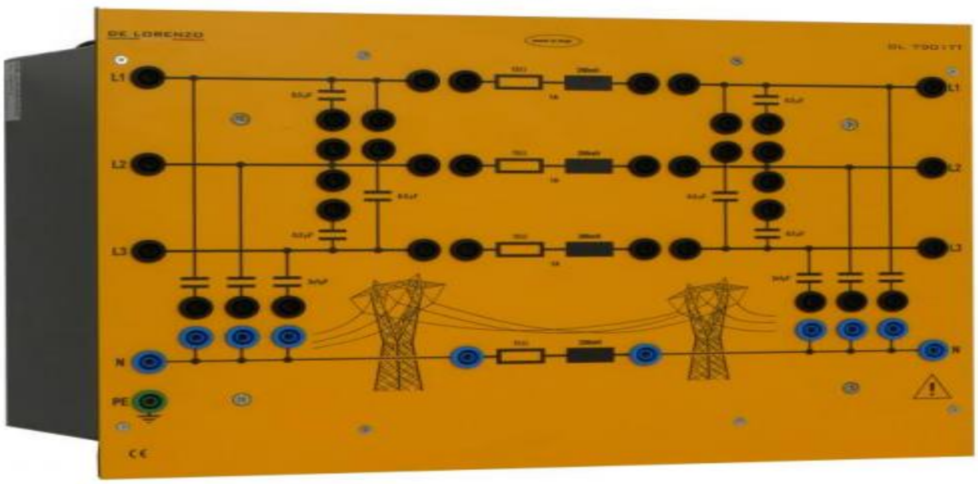
L-LOAD							
Inductance	Position	V	I	P	Q	S	PF
4.46 H	1	231	0.16	0	38	38	0
3.19 H	2	229.5	0.23	0	53	53	0
1.84 H	3	228.8	0.4	0	91	91	0
1.27 H	4	228.5	0.55	0	134	134	0
0.90 H	5	228	0.83	0	190	190	0
0.64 H	6	228	1.19	0	273	273	0
0.52 H	7	228	1.44	0	333	333	0

Table 5.6: L-Load Practical results.

5.2 Transmission

5.2.1 Short

To connect the transmission line module as short line → the capacitors between lines and neutral must be connected.



The connected electrical circuit will contain (Three phase source, circuit breaker, 2 Power measurement modules, 100Km Transmission line, and Three phase R-Load module), as shown in Figure 5.4.

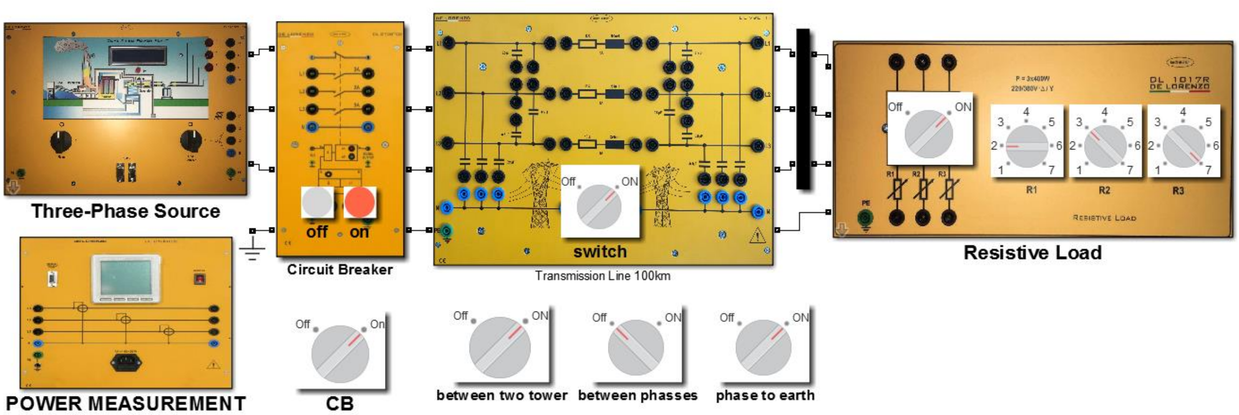


Figure 5.4: Transmission line connected as short experiment.

Tables 5.7 and 5.8 show the results obtained.

R-LOAD /Short							
Supply (Sending) Side							
Resistance	**Position**	**V**	**I**	**P**	**Q**	**S**	**PF**
1050 Ohm	1	230.9	0.222	51	-5.4	51.3	0.9944
750 Ohm	2	230.9	0.309	71.4	-4.3	71.5	0.9982
435 Ohm	3	230.9	0.528	122	0.3	122	1
300 Ohm	4	230.9	0.76	175.6	7.9	176	0.999
213 Ohm	5	230.9	1.062	244.3	21.8	245	0.996
150 Ohm	6	230.9	1.488	340	49.23	344	0.9897
123 Ohm	7	230.9	1.794	407.5	74.64	414	0.9836
Load (Receiving) Side							
Resistance	**Position**	**V**	**I**	**P**	**Q**	**S**	**PF**
1050 Ohm	1	230.5	0.219	50.6	0	50.6	1
750 Ohm	2	230.1	0.307	70.62	0	70.6	1
435 Ohm	3	229.2	0.527	120.7	0	121	1
300 Ohm	4	228	0.76	173.2	0	173	1
213 Ohm	5	226.2	1.062	240.2	0	240	1
150 Ohm	6	223.3	1.488	323.3	0	323	1
123 Ohm	7	220.8	1.795	396.4	0	396	1

Table 5.7: Short line MATLAB results.

R-LOAD /Short							
Supply (Sending) Side							
Resistance	**Position**	**V**	**I**	**P**	**Q**	**S**	**PF**
1050 Ohm	1	231	0.216	50	0	50	1
750 Ohm	2	231	0.302	70	0	70	1
435 Ohm	3	231	0.51	117	0	117	1
300 Ohm	4	230.2	0.746	171	7	171.14321	0.999
213 Ohm	5	229	1.016	234	20	234.85315	0.996
150 Ohm	6	230.7	1.438	324	43	326.84094	0.991
123 Ohm	7	230.2	1.694	383	62	387.98582	0.987
Load (receiving) Side							
Resistance	**Position**	**V**	**I**	**P**	**Q**	**S**	**PF**
1050 Ohm	1	229.1	0.214	49	0	49	1
750 Ohm	2	228.8	0.302	69	0	69	1
435 Ohm	3	226.5	0.51	115	0	115	1
300 Ohm	4	224.1	0.746	167	0	167	1
213 Ohm	5	220.2	1.022	226	0	226	1
150 Ohm	6	216	1.426	305	0	305	1
123 Ohm	7	214.2	1.686	356	0	356	1

Table 5.8: Short line Practical results.

5.2.2 Medium

To connect the transmission line module as medium line → the capacitors between lines must be connected. The connected electrical circuit will contain (Three phase source, circuit breaker, 2 Power measurement modules, 100Km Transmission line, and Three phase R-Load module), as shown in Figure 5.5.

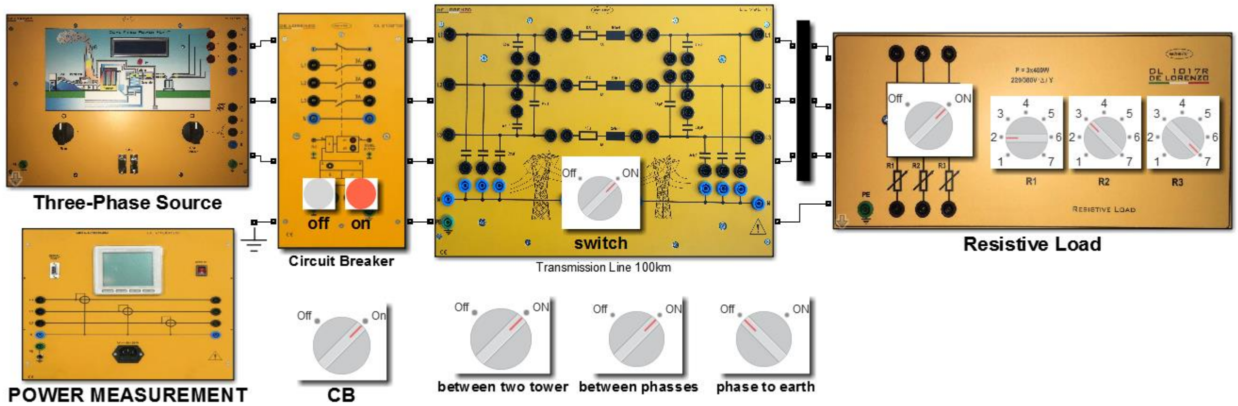


Figure 5.5: Transmission line connected as medium experiment.

Tables 5.9 and 5.10 show the results obtained.

R-LOAD /Medium							
Supply (Sending) Side							
Resistance	**Position**	**V**	**I**	**P**	**Q**	**S**	**PF**
1050 Ohm	**1**	**230.9**	**0.224**	**50.95**	**-8.816**	**51.7**	**0.9854**
750 Ohm	**2**	**230.9**	**0.31**	**71.16**	**-7.642**	**71.6**	**0.9943**
435 Ohm	**3**	**230.9**	**0.528**	**121.9**	**-2.98**	**122**	**0.9997**
300 Ohm	**4**	**230.9**	**0.76**	**175.5**	**4.62**	**176**	**0.9997**
213 Ohm	**5**	**230.9**	**1.062**	**244.4**	**18.55**	**245**	**0.9971**
150 Ohm	**6**	**230.9**	**1.487**	**340.3**	**46.05**	**343**	**0.991**
123 Ohm	**7**	**230.9**	**1.793**	**407.9**	**71.52**	**414**	**0.985**

Load (Receiving) Side							
Resistance	Position	V	I	P	Q	S	PF
1050 Ohm	1	230.7	0.219	50.68	0	50.7	1
750 Ohm	2	230.3	0.307	70.73	0	70.7	1
435 Ohm	3	229.3	0.527	120.9	0	121	1
300 Ohm	4	228.1	0.76	173.5	0	174	1
213 Ohm	5	226.4	1.063	240.6	0	241	1
150 Ohm	6	223.4	1.489	332.8	0	333	1
123 Ohm	7	221	1.797	397	0	397	1

Table 5.9: Medium line MATLAB results.

R-LOAD /Medium							
Supply (Sending) Side							
Resistance	Position	V	I	P	Q	S	PF
1050 Ohm	1	230	0.218	49	0	49	1
750 Ohm	2	229.2	0.306	69	0	69	1
435 Ohm	3	229.1	0.512	117	0	117	1
300 Ohm	4	228.8	0.742	171	4	171.04678	1
213 Ohm	5	229	1.022	234	16	234.54637	0.998
150 Ohm	6	228.5	1.424	320	40	322.49031	0.992
123 Ohm	7	228	1.682	380	58	384.40083	0.989

Load (Receiving) Side

Resistance	Position	V	I	P	Q	S	PF
1050 Ohm	1	228	0.212	48	0	48	1
750 Ohm	2	225.2	0.298	67	0	67	1
435 Ohm	3	222.8	0.502	112	0	112	1
300 Ohm	4	220	0.734	163	0	163	1
213 Ohm	5	218	1.018	223	0	223	1
150 Ohm	6	215	1.416	303	0	303	1
123 Ohm	7	214	1.676	354	0	354	1

Table 5.10: Medium line Practical results.

5.2.3 Long

To connect the transmission line module as long line → the upper and lower capacitors are connected. The connected electrical circuit will contain (Three phase source, circuit breaker, 2 Power measurement modules, 100Km Transmission line, and Three phase R-Load module), as shown in Figure 5.6.

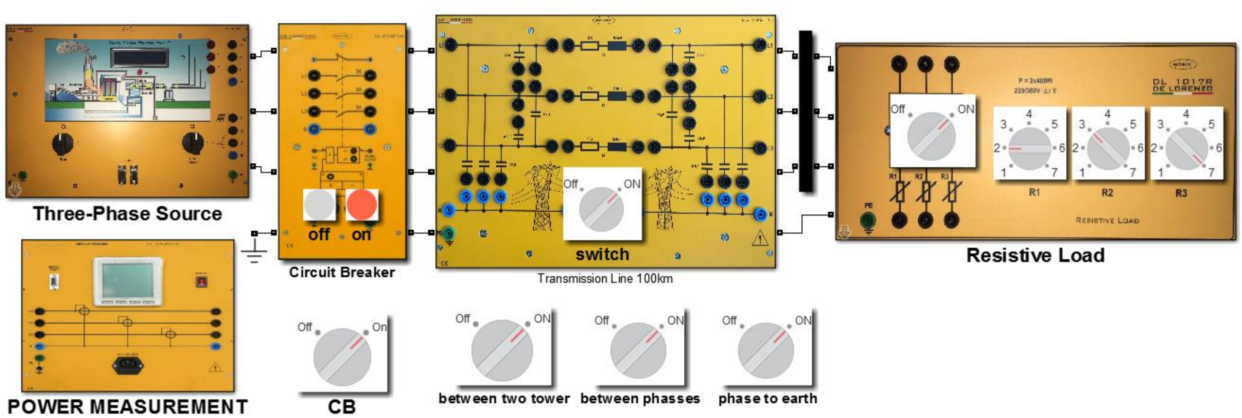


Figure 5.6: Transmission line connected as long experiment.

Tables 5.11 and 5.12 show the results obtained.

R-LOAD /Long							
Supply (Sending) Side							
Resistance	**Position**	**V**	**I**	**P**	**Q**	**S**	**PF**
1050 Ohm	1	230.9	0.231	51.05	-15.51	53.4	0.9568
750 Ohm	2	230.9	0.315	71.28	-14.33	72.7	0.9804
435 Ohm	3	230.9	0.531	122.2	-9.625	123	0.9969
300 Ohm	4	230.9	0.762	176	-1.968	176	0.9999
213 Ohm	5	230.9	1.063	245.1	12.05	245	0.9988
150 Ohm	6	230.9	1.487	341.2	39.71	344	0.9933
123 Ohm	7	230.9	1.793	409	65.31	414	0.9875
Load (Receiving) Side							
Resistance	**Position**	**V**	**I**	**P**	**Q**	**S**	**PF**
1050 Ohm	1	231	0.22	50.84	0	50.8	1
750 Ohm	2	230.7	0.307	70.96	0	71	1
435 Ohm	3	229.7	0.528	121.3	0	121	1
300 Ohm	4	228.5	0.762	174	0	174	1
213 Ohm	5	226.7	1.064	241.3	0	241	1
150 Ohm	6	223.8	1.492	333.8	0	334	1
123 Ohm	7	221.3	1.799	398.2	0	398	1

Table 5.11: Long line MATLAB results.

R-LOAD /Long							
Supply (Sending) Side							
Resistance	Position	V	I	P	Q	S	PF
1050 Ohm	1	231	0.23	51	-14	52.886671	0.964
750 Ohm	2	230	0.312	70	-12.44	71.09749	0.985
435 Ohm	3	230	0.52	119	-9.214	119.35618	0.997
300 Ohm	4	229	0.744	172	-15	172.65283	0.996
213 Ohm	5	228.6	1.024	234	10	234.21358	0.999
150 Ohm	6	228.2	1.436	327	34	328.76283	0.995
123 Ohm	7	228	1.694	386	52	389.48684	0.991
Load (Receiving) Side							
Resistance	Position	V	I	P	Q	S	PF
1050 Ohm	1	228	0.214	49	0	49	1
750 Ohm	2	227.6	0.3	68	0	68	1
435 Ohm	3	223.2	0.508	113	0	113	1
300 Ohm	4	222	0.738	164	0	164	1
213 Ohm	5	217.4	1.016	223	0	223	1
150 Ohm	6	213	1.424	305	0	305	1
123 Ohm	7	211.7	1.68	358	0	358	1

Table 5.12: Long line practical results.

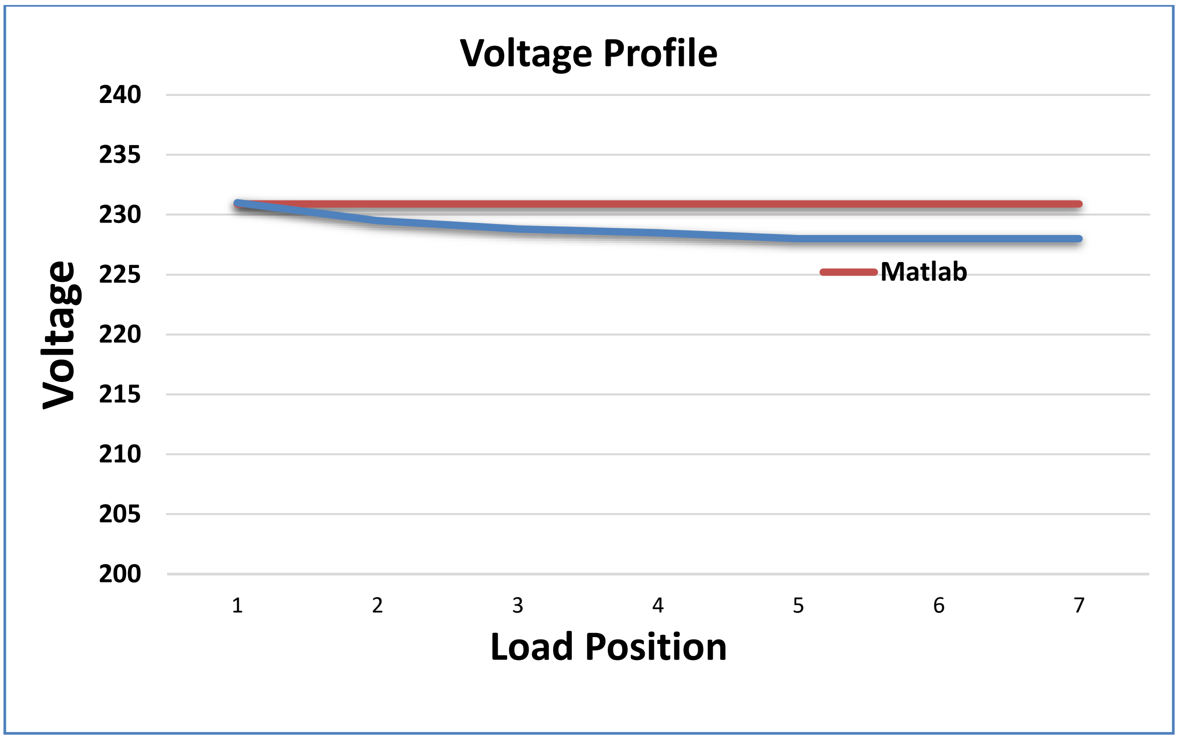
5.3 Results Validation

After obtaining the results of practical and MATLAB experiments, results validation check is needed to insure a valid simulation for the electrical lab modules by using curves.

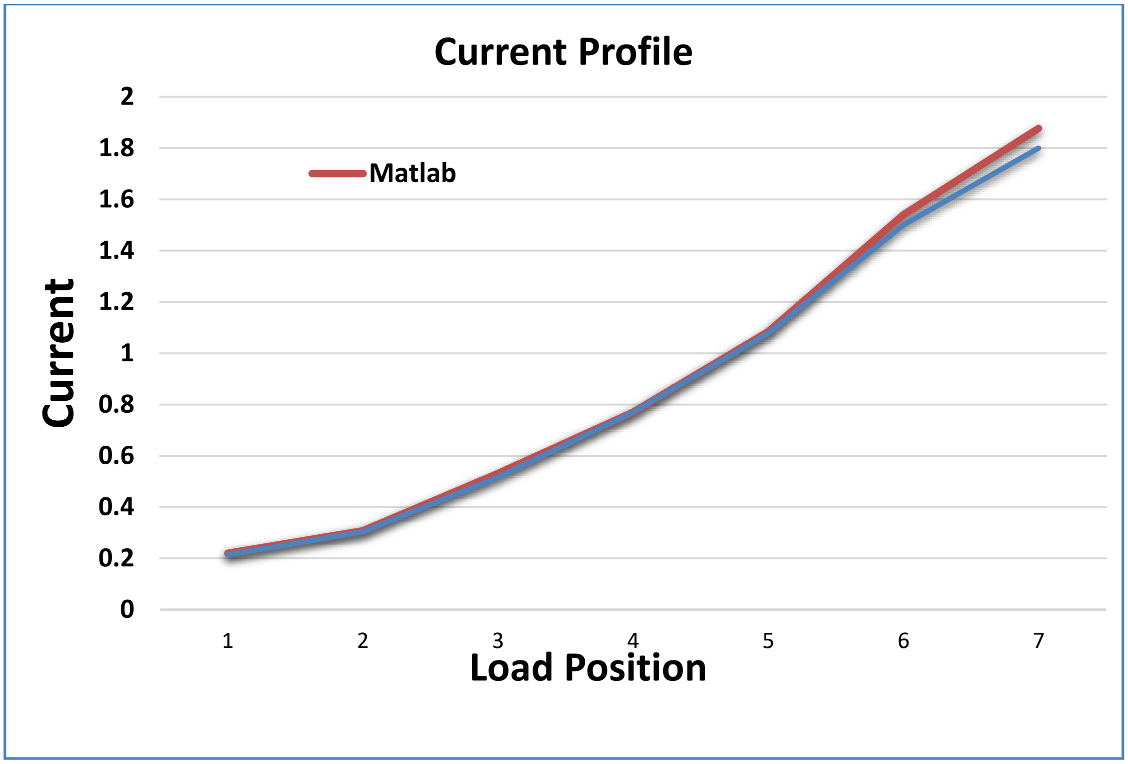
5.3.1 Load results

The following curves show a comparison between MATLAB and practical results.

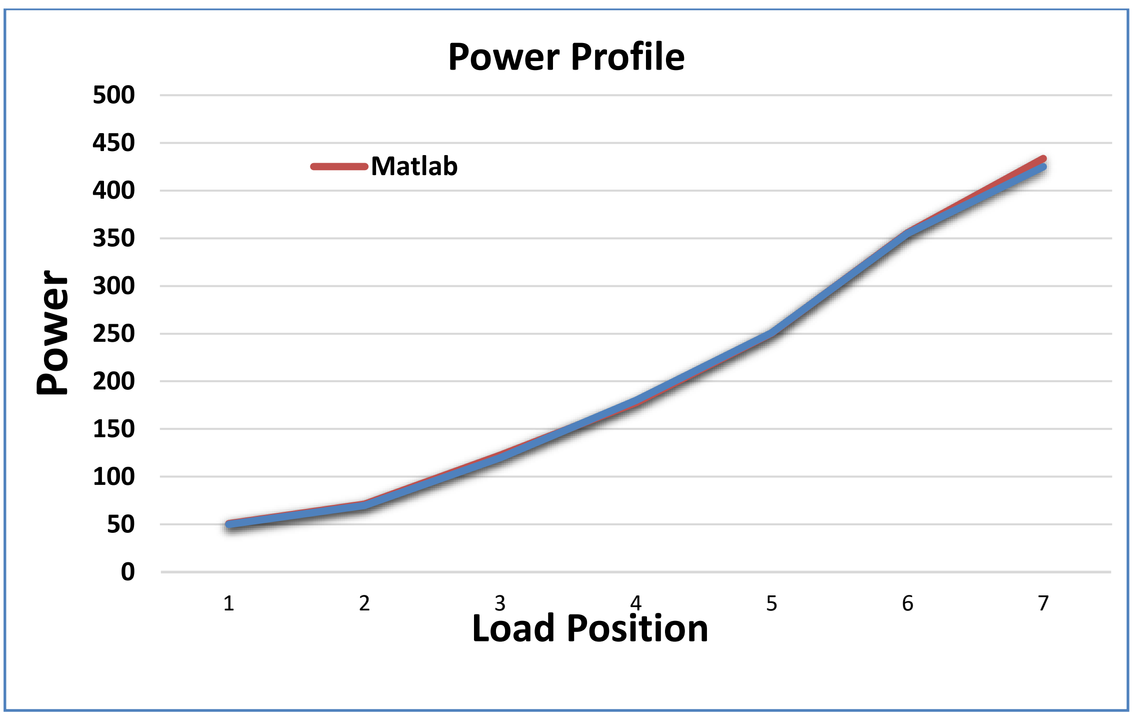
- R-LOAD (Voltage, Current, and Real power profiles)



- **Brown line**: Matlab results.
- **Blue line:** Practical results.

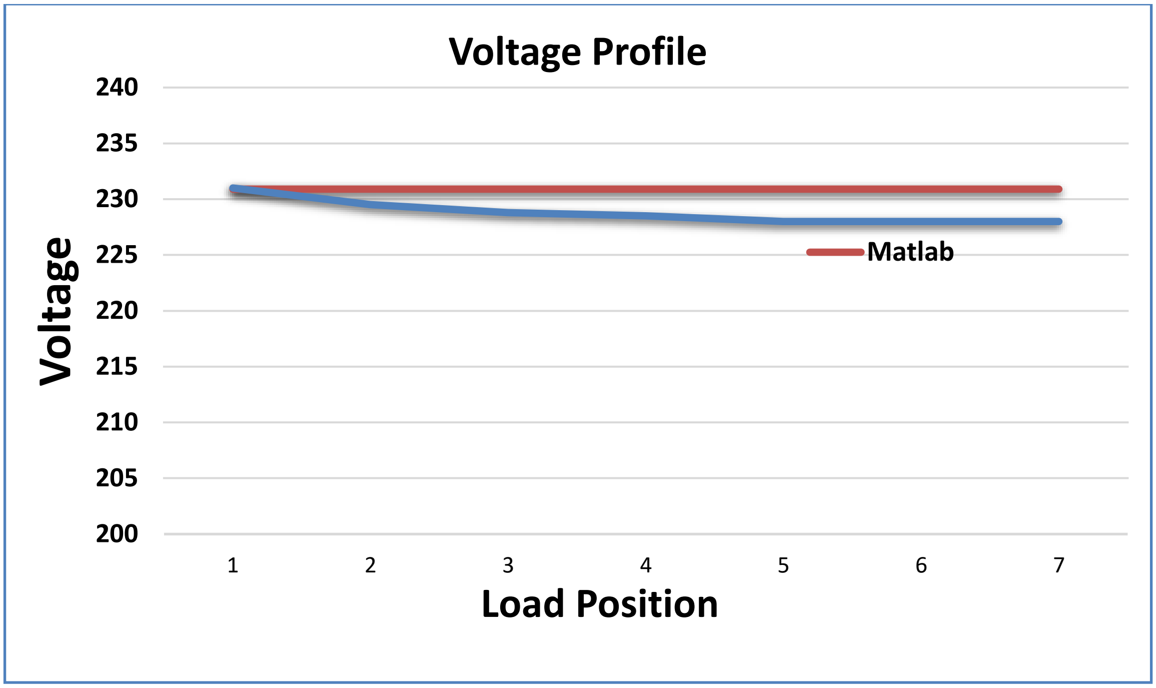


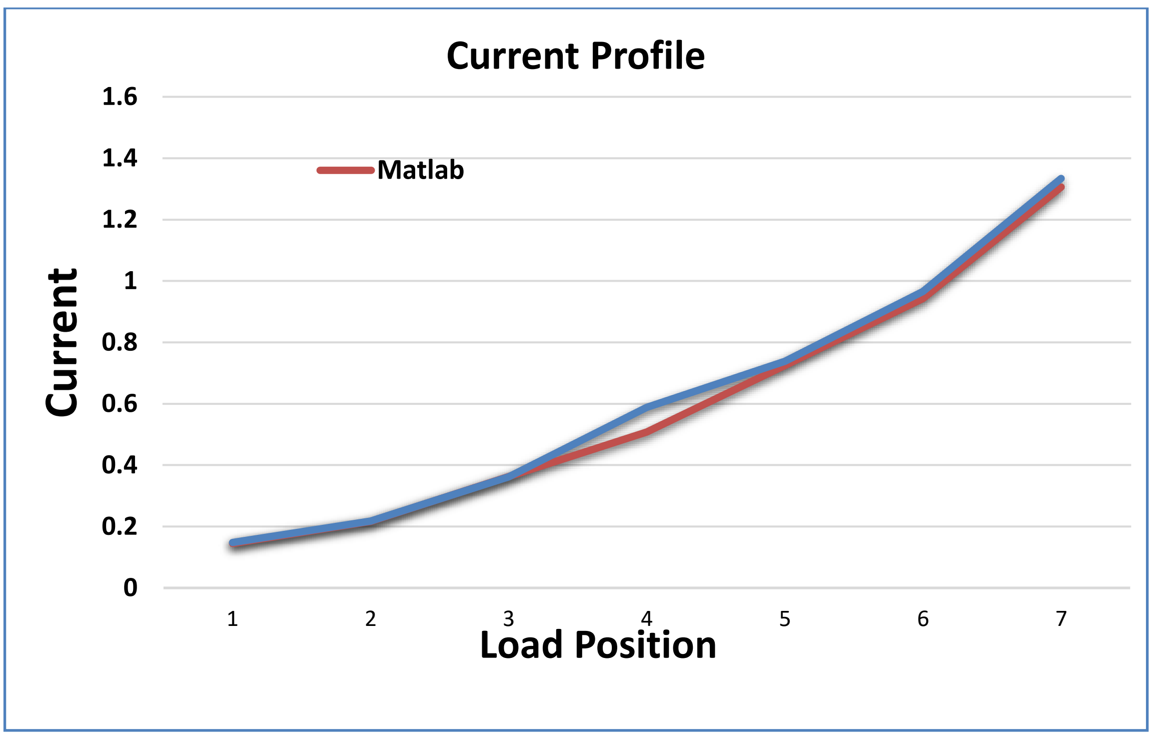
Current Profile
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Current
Matlab
1
2
3
4
5
6
7
Load Position

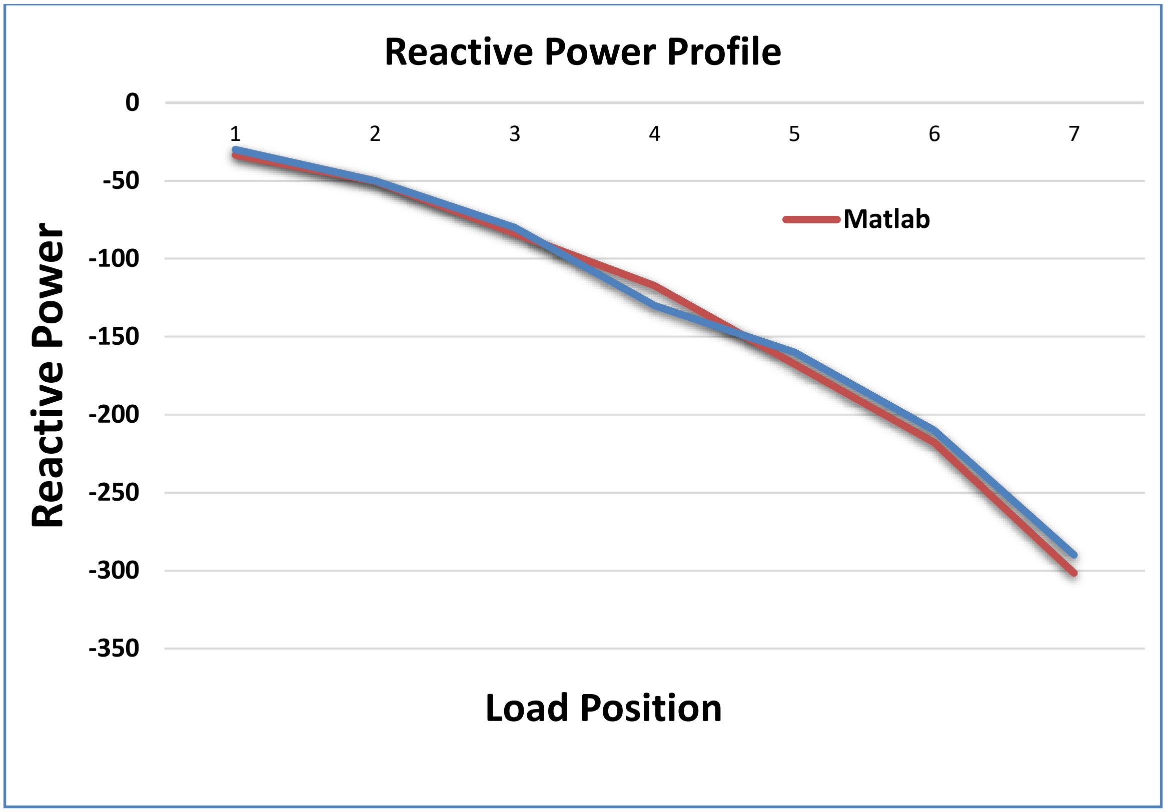


Power Profile
500
450
400
350
300
250
200
150
100
50
0
Power
Matlab
1
2
3
4
5
6
7
Load Position

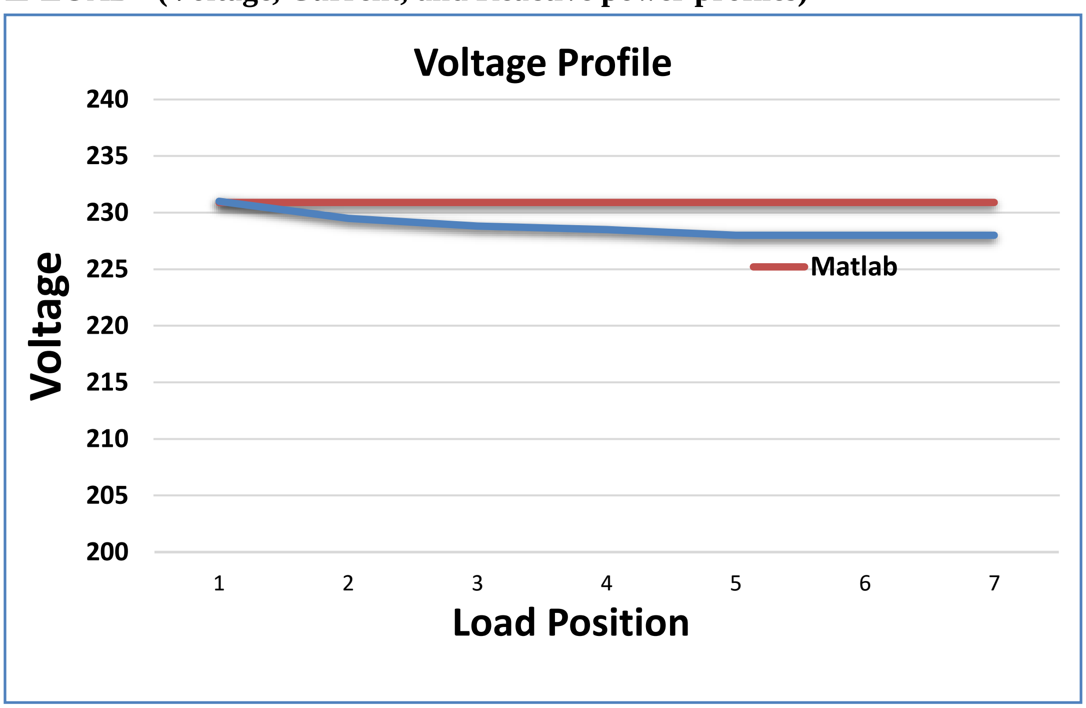
- C-LOAD (Voltage, Current, and Reactive power profiles)

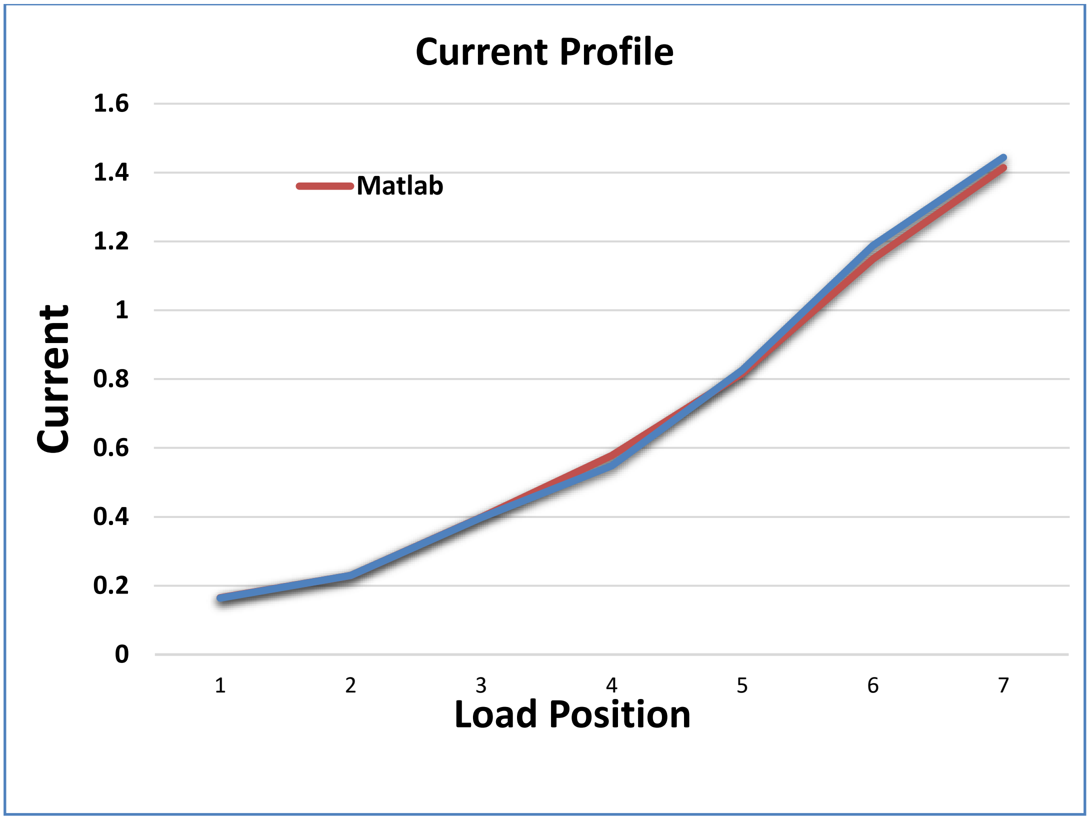


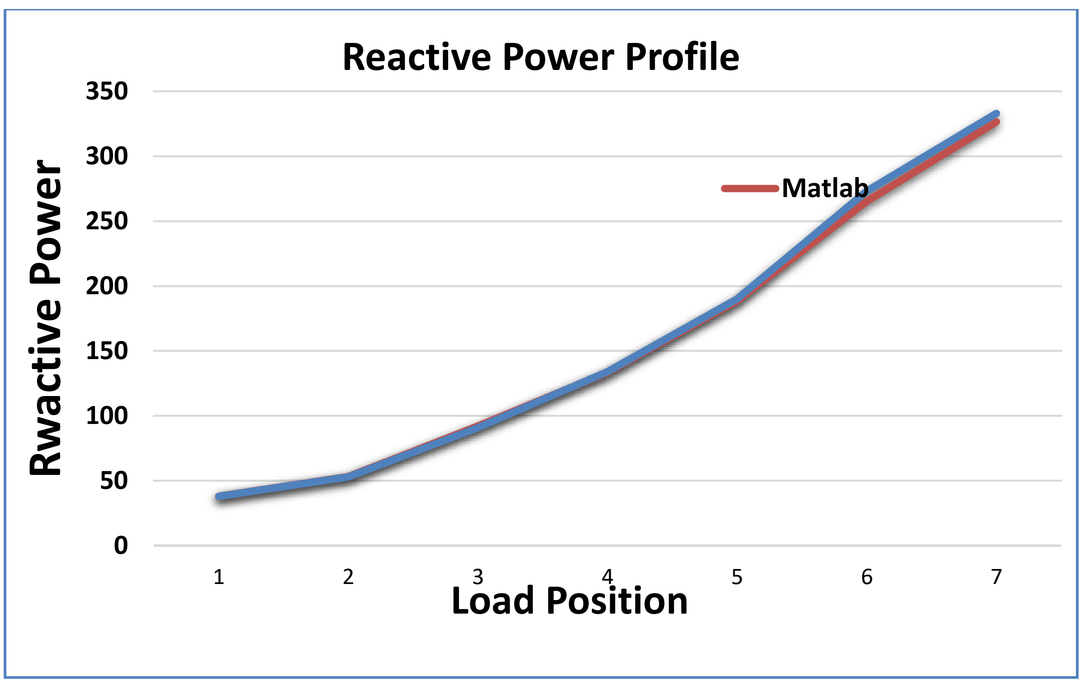




- **L-LOAD (Voltage, Current, and Reactive power profiles)**

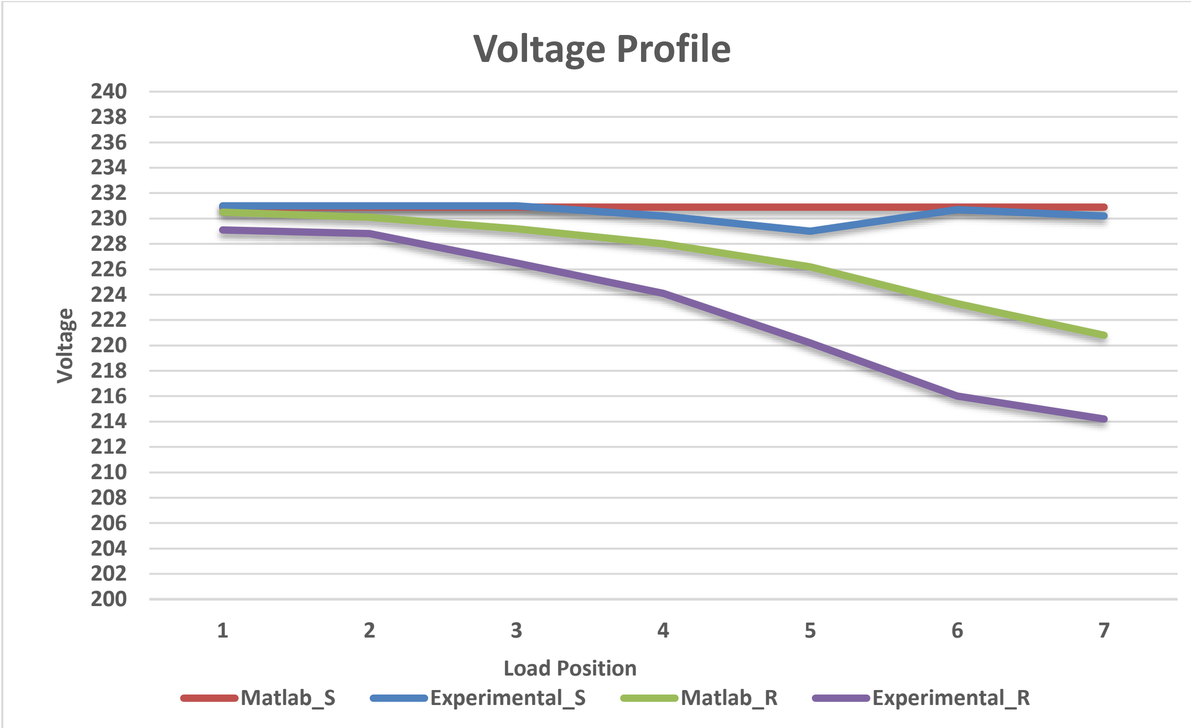


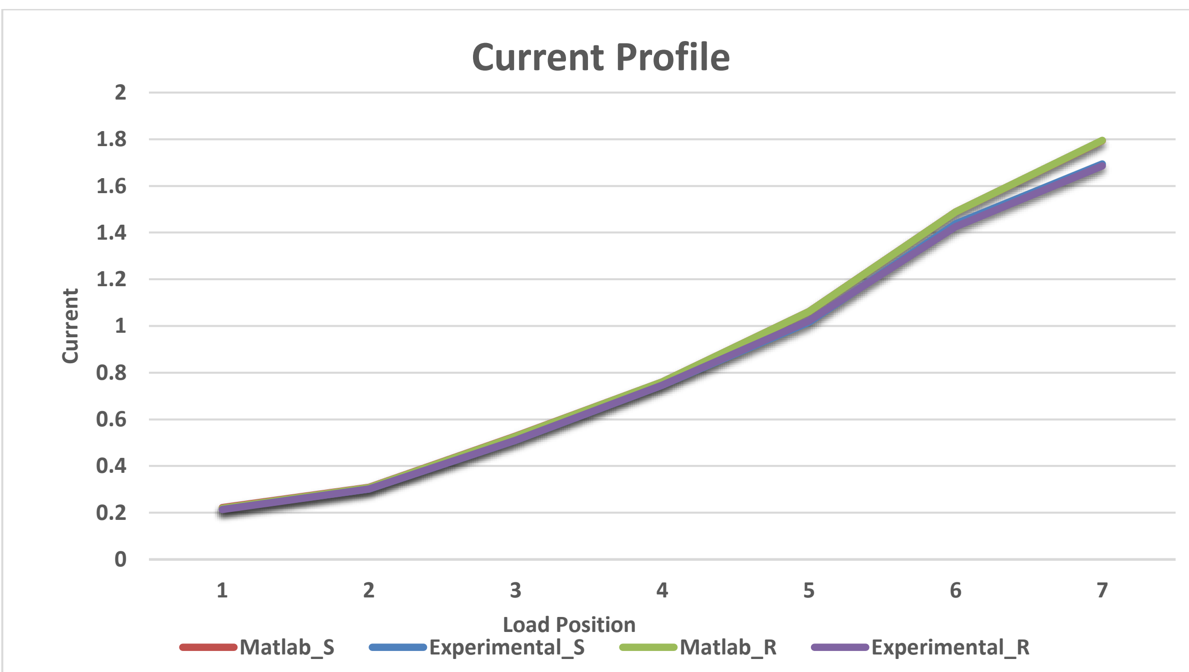

Current Profile
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Matlab
Current
1
2
3
4
5
6
7
Load Position

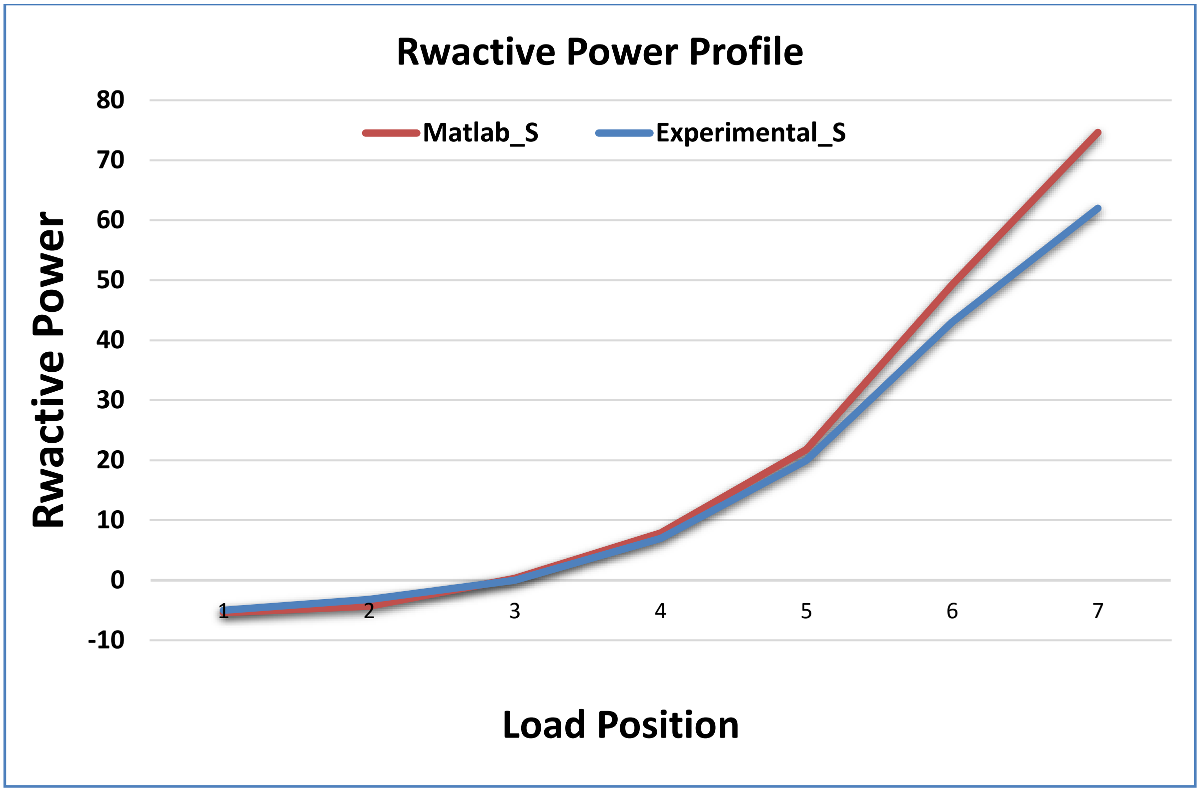

Reactive Power Profile
350
300
250
200
150
100
50
0
Matlab
Rwactive Power
1
2
3
4
5
6
7
Load Position

5.3.2 Transmission results

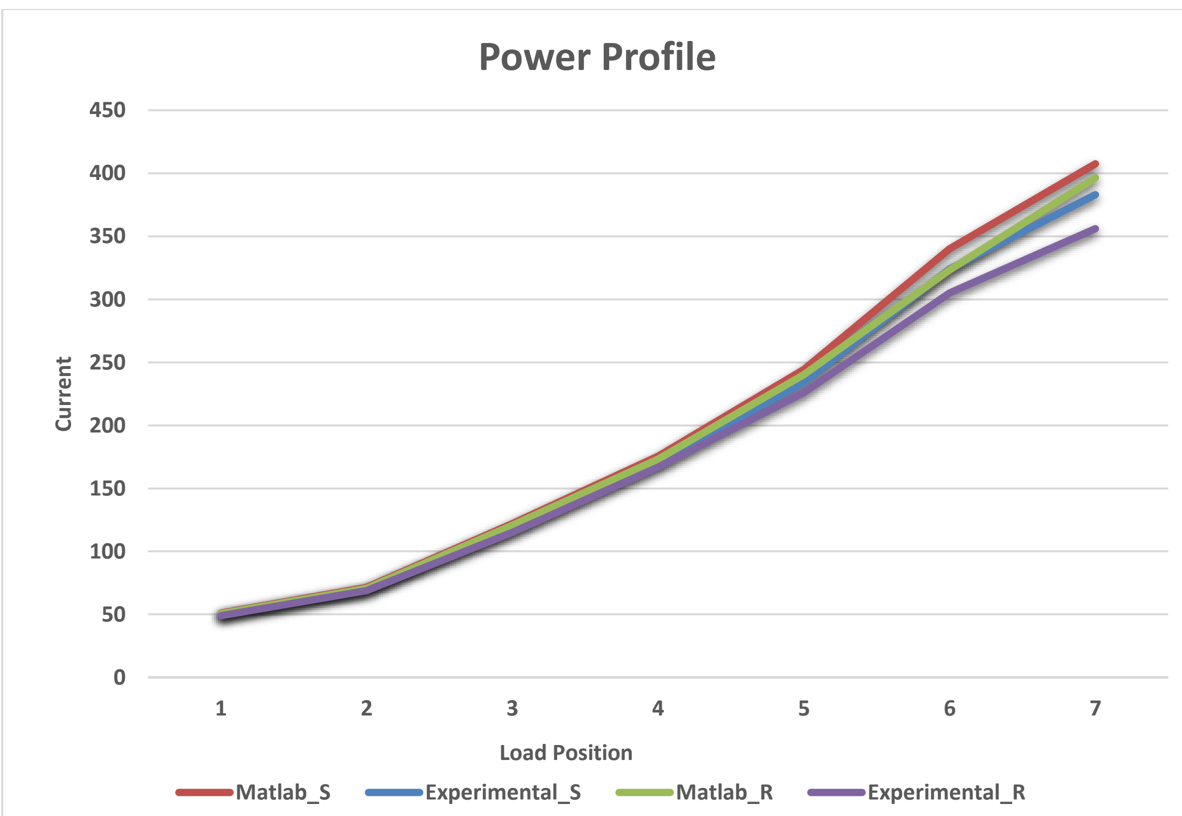
- Short Line (Voltage, Current, Real power, Reactive power, and Apparent power profiles)



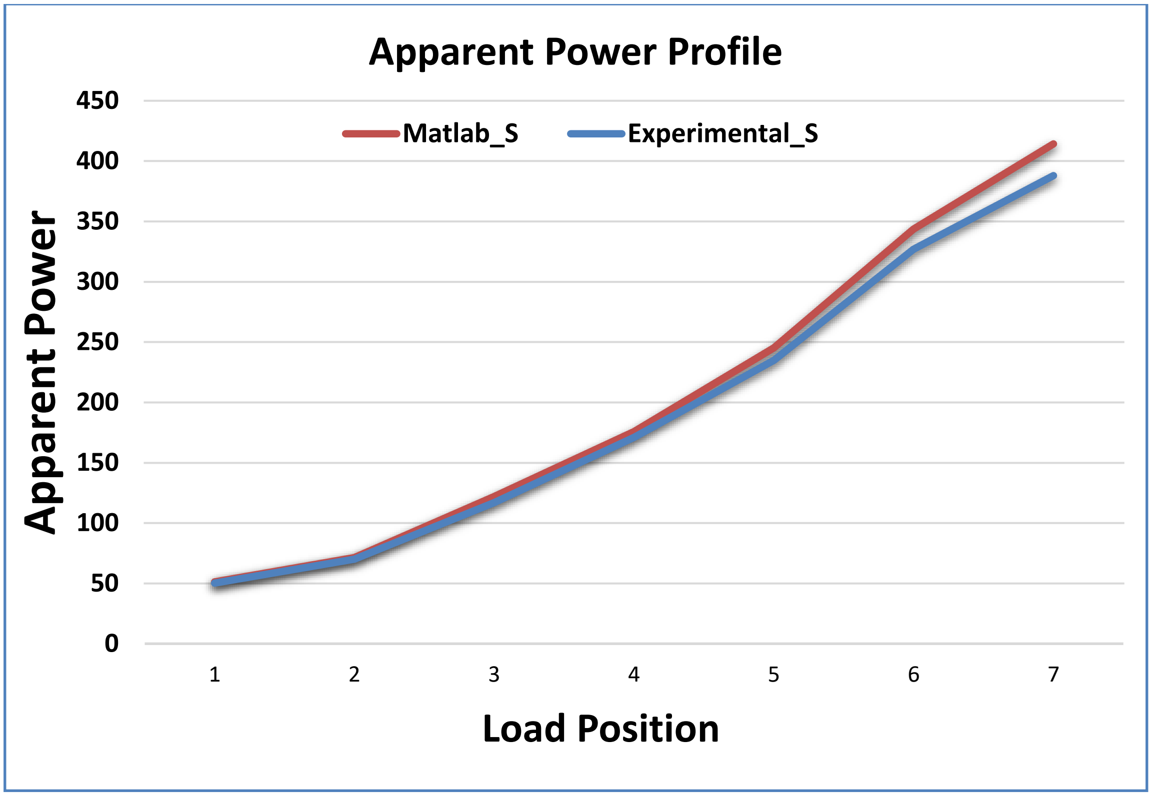




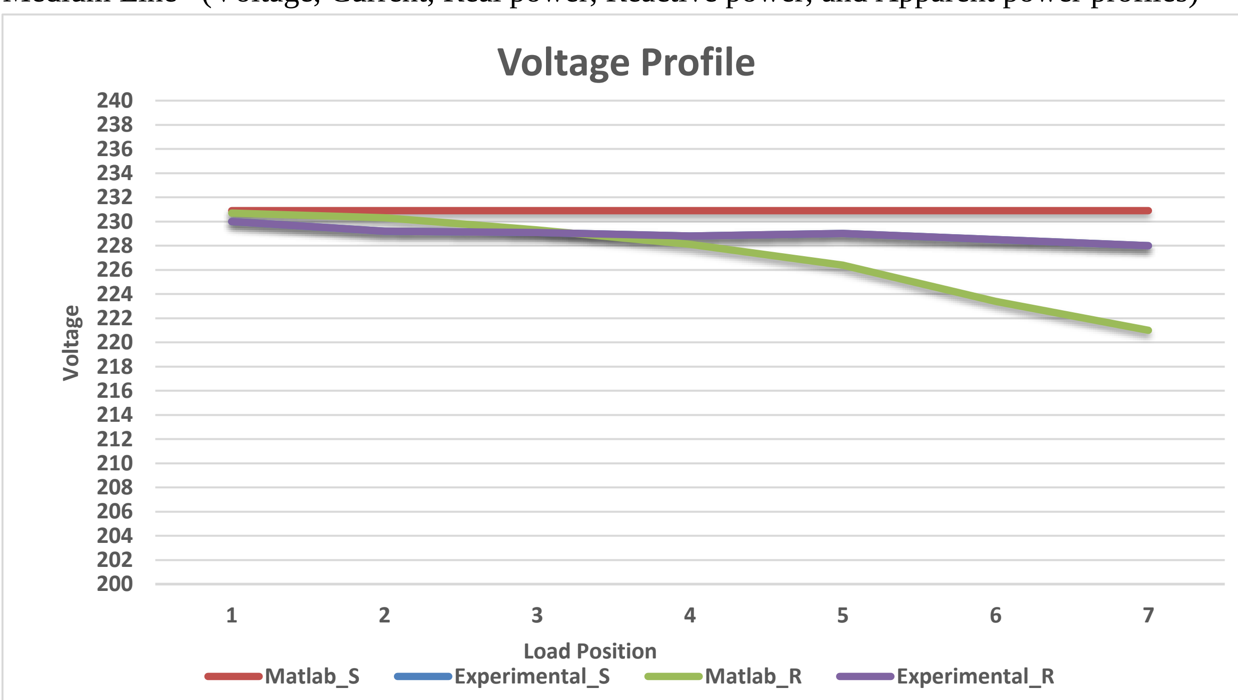
Rwactive Power Profile
Matlab_S
Experimental_S
Rwactive Power
80
70
60
50
40
30
20
10
0
-10
1
2
3
4
5
6
7
Load Position

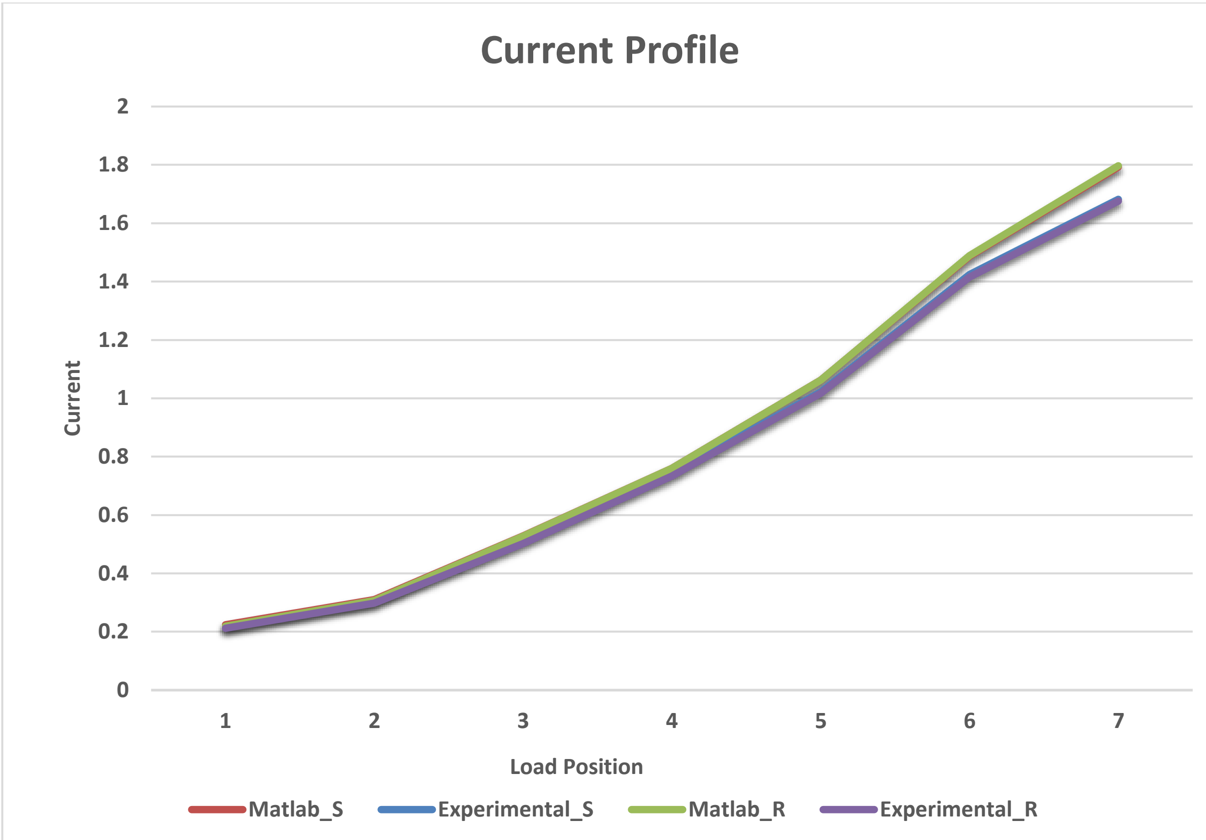


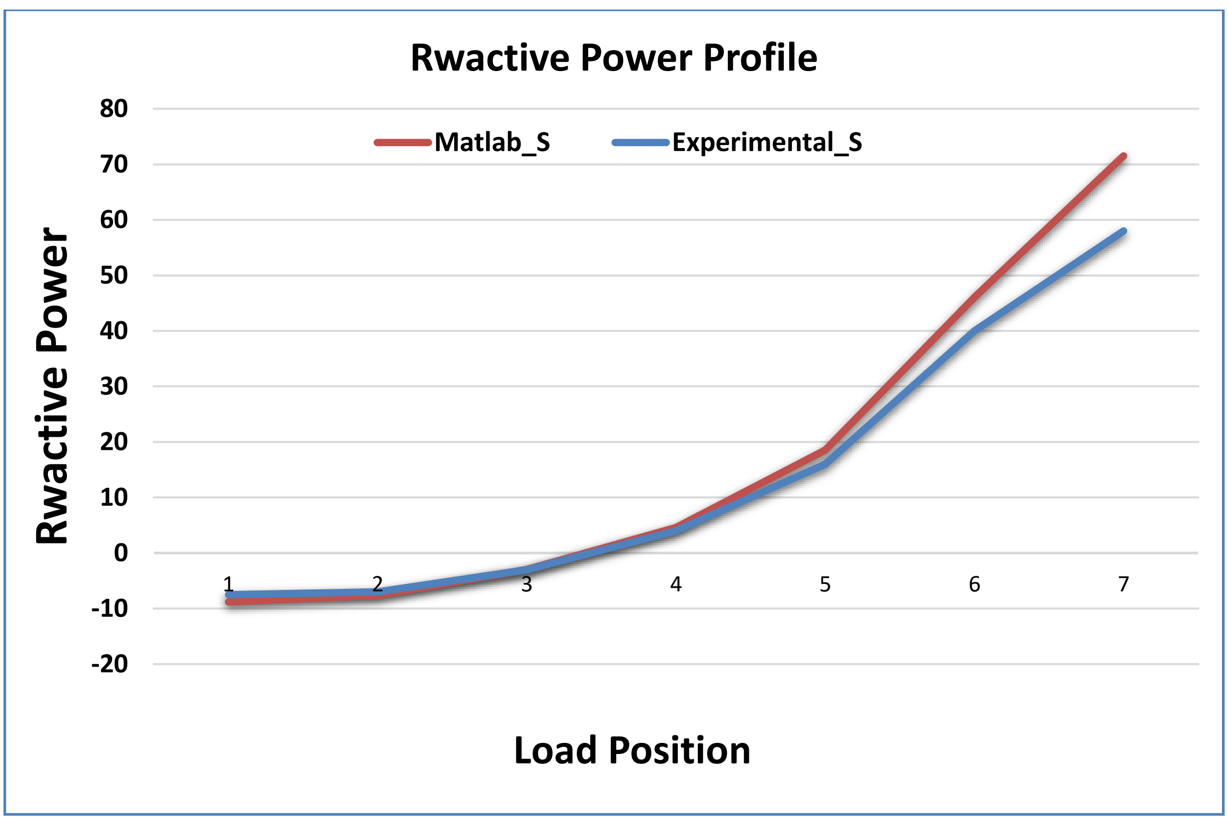
Power Profile
Current
450
400
350
300
250
200
150
100
50
0
1
2
3
4
5
6
7
Load Position
Matlab_S
Experimental_S
Matlab_R
Experimental_R

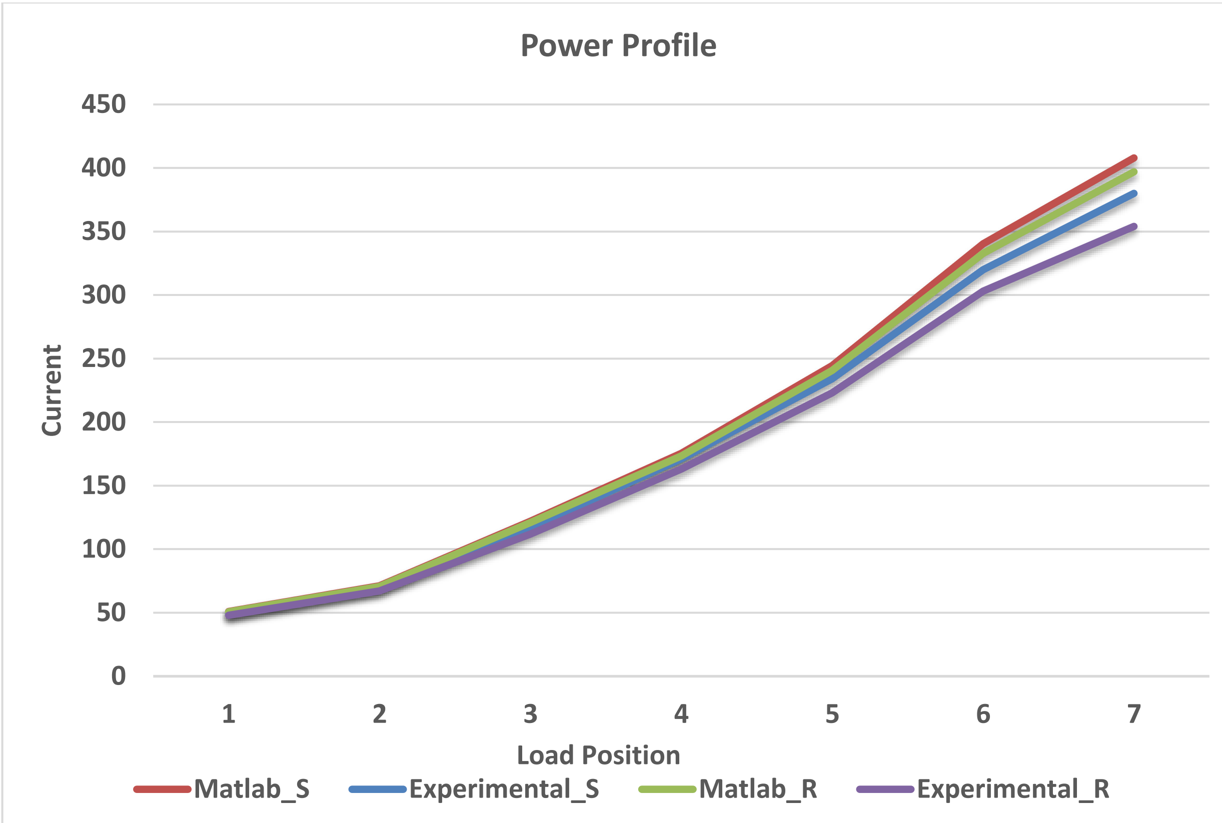


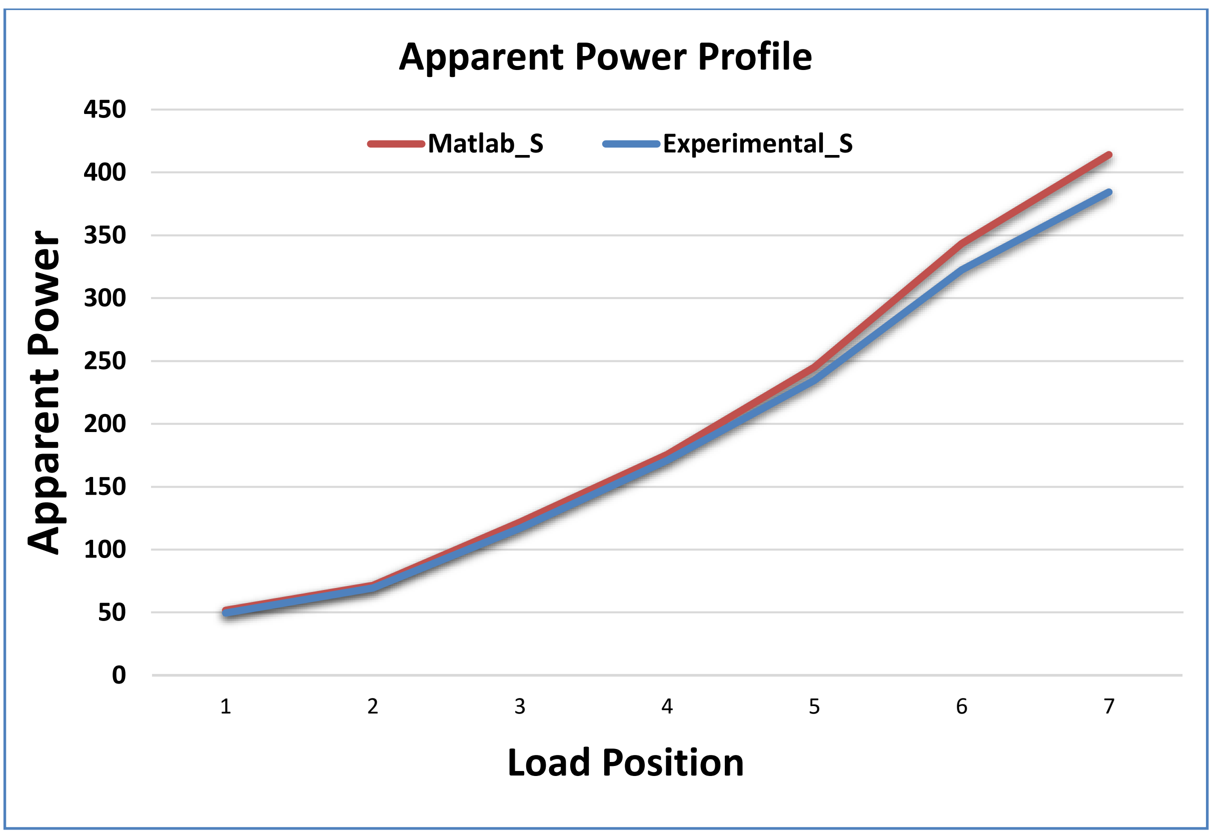
- Medium Line (Voltage, Current, Real power, Reactive power, and Apparent power profiles)



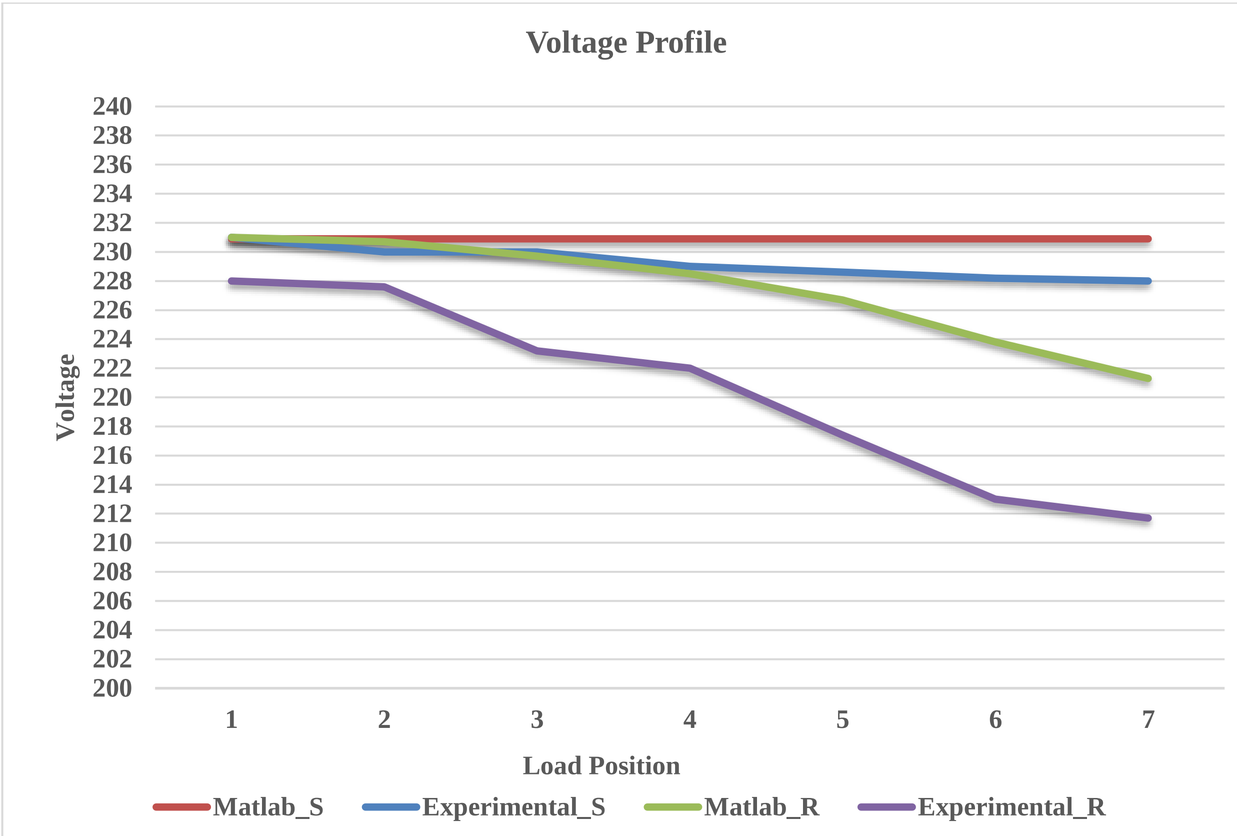

Current Profile
Current
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
2
3
4
5
6
7
Load Position
Matlab_S
Experimental_S
Matlab_R
Experimental_R

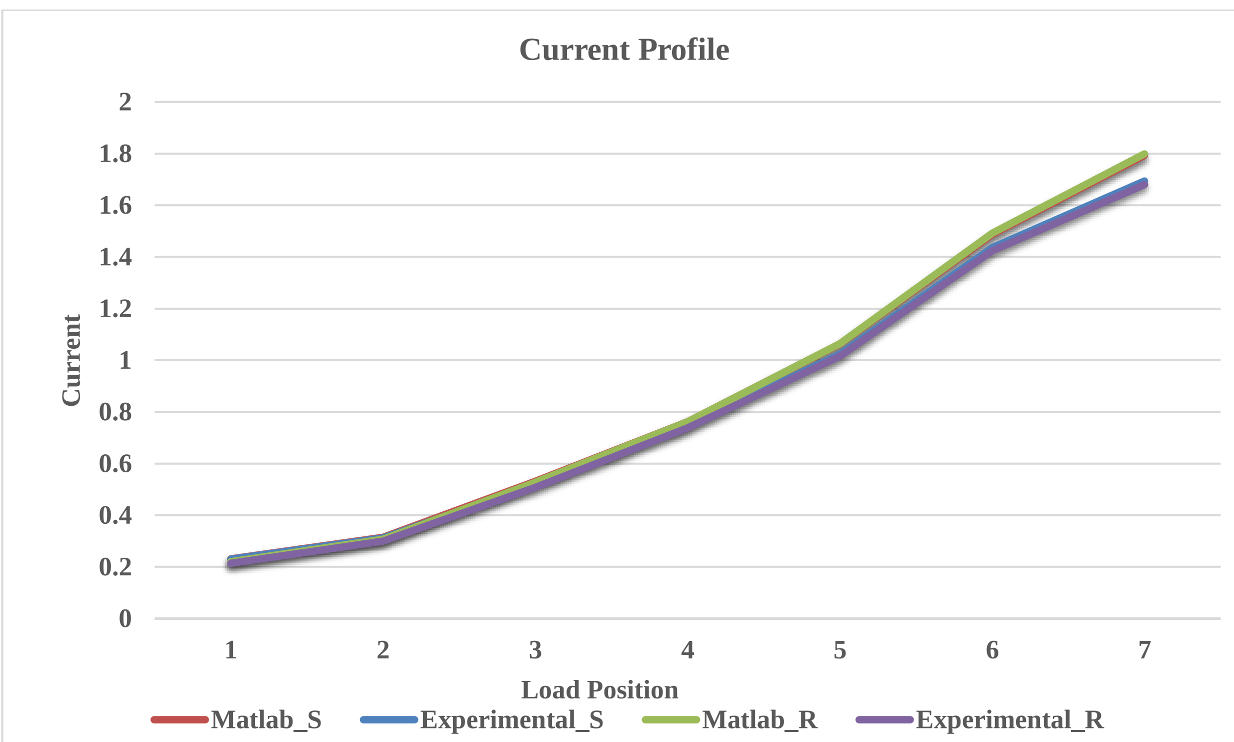

Rwactive Power Profile
Rwactive Power
80
70
60
50
40
30
20
10
0
-10
-20
Matlab_S
Experimental_S
1
2
3
4
5
6
7
Load Position

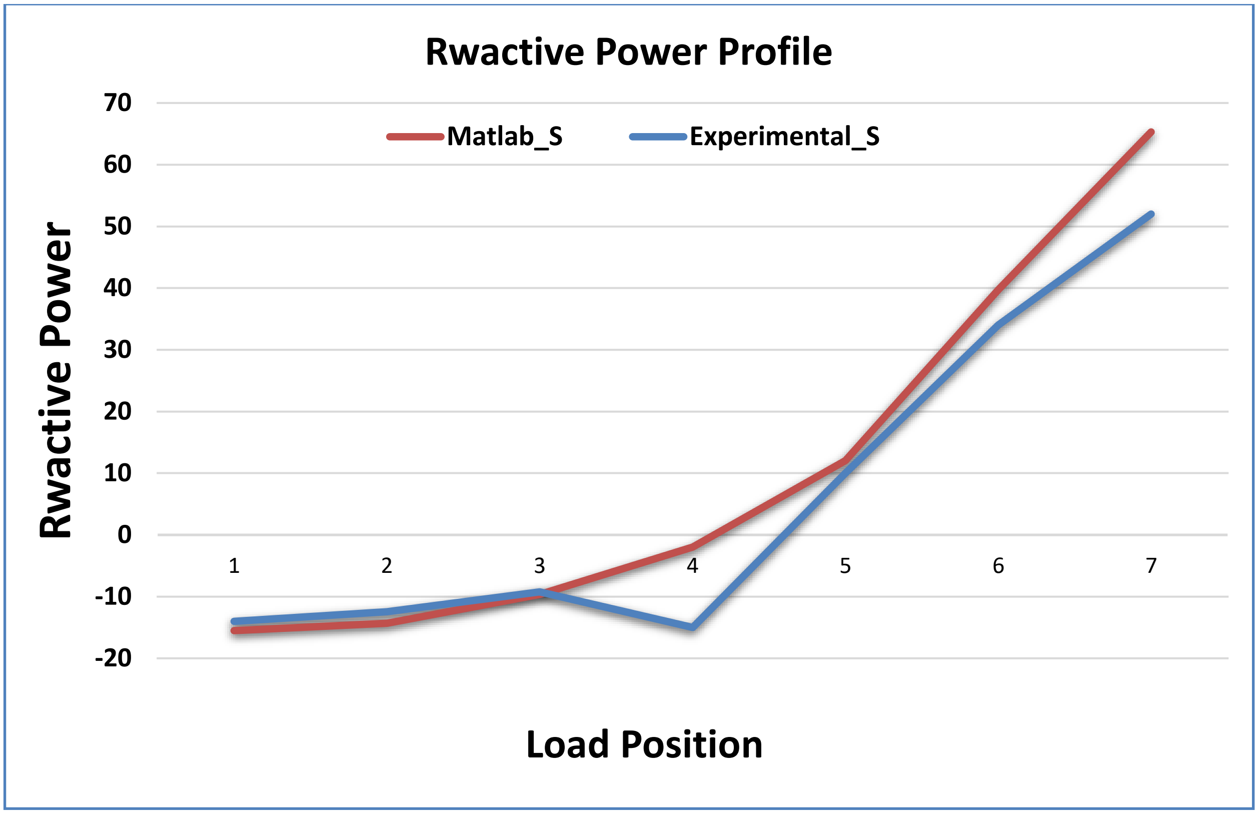

Power Profile
450
400
350
300
250
200
150
100
50
0
Current
1
2
3
4
5
6
7
Load Position
Matlab_S
Experimental_S
Matlab_R
Experimental_R

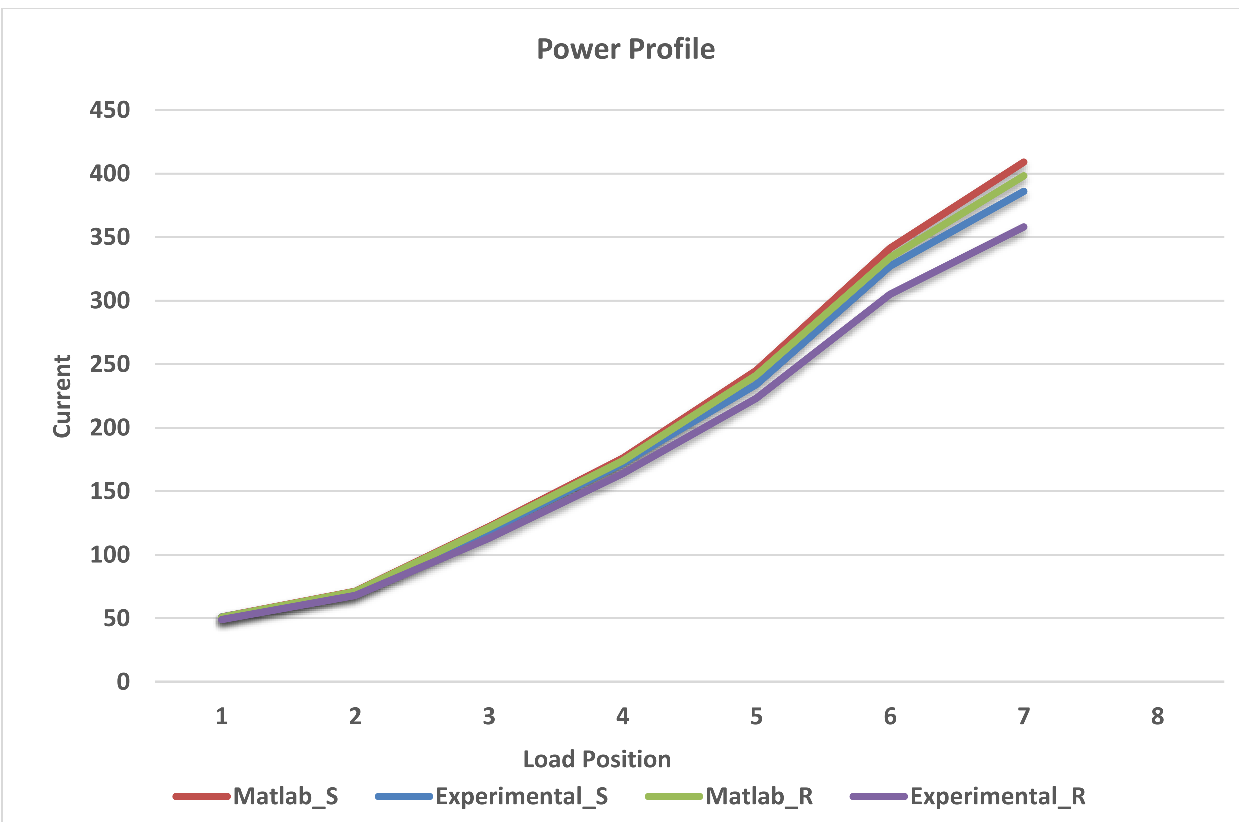

Apparent Power Profile
Matlab_S
Experimental_S
450
400
350
300
250
200
150
100
50
0
Apparent Power
1
2
3
4
5
6
7
Load Position

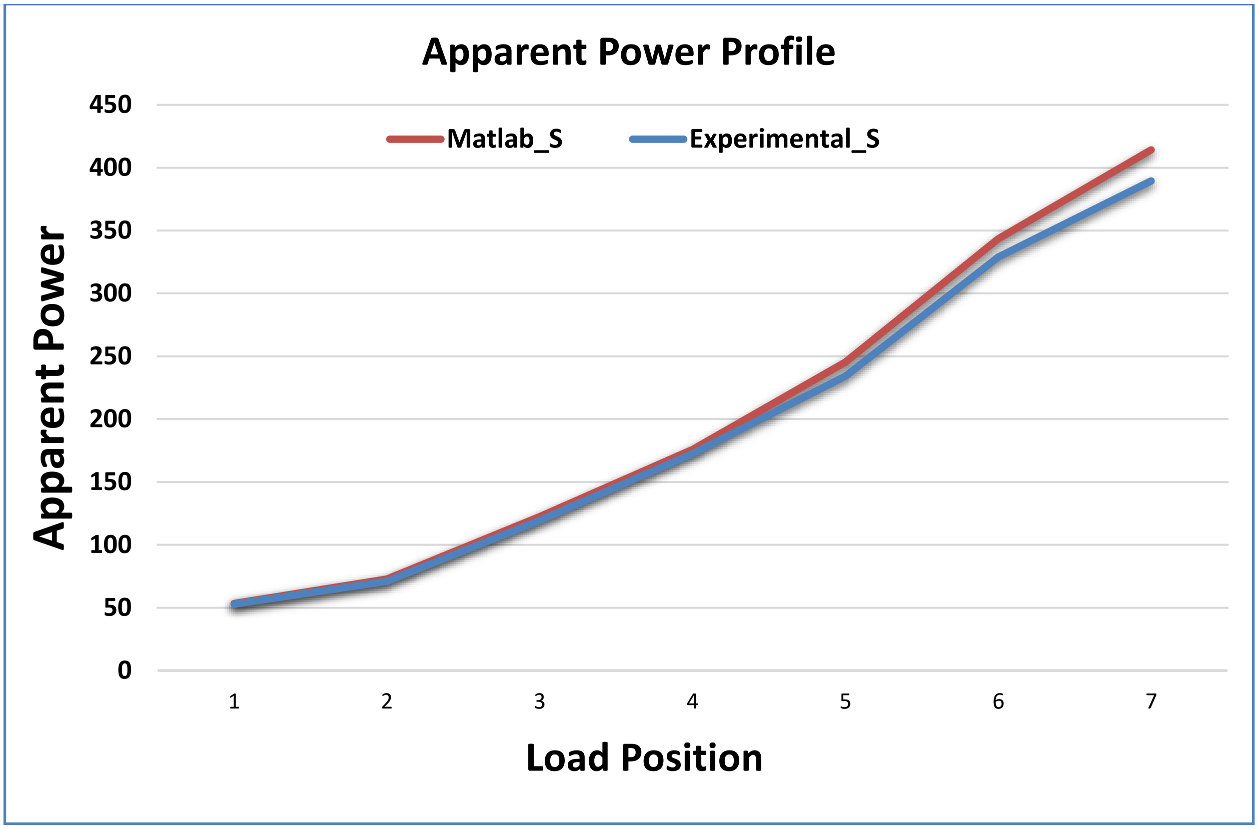
- Long Line (Voltage, Current, Real power, Reactive power, and Apparent power profiles)






Rwactive Power Profile
Matlab_S
Experimental_S
Rwactive Power
70
60
50
40
30
20
10
0
-10
-20
1
2
3
4
5
6
7
Load Position


Power Profile
Current
450
400
350
300
250
200
150
100
50
0
1
2
3
4
5
6
7
8
Load Position
Matlab_S
Experimental_S
Matlab_R
Experimental_R



5.3.3 Validation Check

- Validation check is done by finding the maximum deviation between Practical and MATLAB results, and also by finding the max error.

➔ MAX value = $Absolute\ value\ of\ (Practical - MATLAB)$.

➔ MAX error = $\frac{MAX\ Deviation}{MAX\ value} * 100\%$.

➔ Accuracy % = 100- MAX error.

So, by using the up-mentioned three methods, a validation accuracy is obtained.

➢ **Loads**:

- Validation Accuracy for R-Load:

R	V	I	P	Q	S	pf
1	0.1	0.006	0.8	0	0.8	0
2	1.4	0.004	1.11	0	1.11	0
3	2.1	0.015	2.6	0	2.6	0
4	2.4	0	2.2	0	2.2	0
5	2.9	0.006	0.6	0	0.6	0
6	2.9	0.04	0.5	0	0.5	0
7	2.9	0.077	8.6	0	8.6	0
MAX deviation	2.9	0.077	8.6	0	8.6	0
MAX error	1.25595	4.102	1.983	0	1.983	0
Accuracy %	98.744	95.9	98.02	-	98.02	-

- Validation Accuracy for C-Load:

C	V	I	P	Q	S	pf
1	0.1	0.003	0	3.5	3.53	0
2	1.4	0.001	0	0.27	0.27	0
3	2.1	0.001	0	3.78	3.78	0
4	2.4	0.08	0	12.7	12.7	0
5	2.9	0.013	0	7.6	7.6	0
6	2.9	0.023	0	7.8	7.8	0
7	2.9	0.028	0	11.6	11.6	0
MAX deviation	2.9	0.08	0	12.7	12.7	0
MAX error	1.25595	6.126	0	4.211	4.211	0
Accuracy %	98.744	93.87	-	95.79	95.79	-

- Validation Accuracy for L-Load:

L	V	I	P	Q	S	pf
1	0.1	0.001	0	0.06	0.06	0
2	1.4	0	0	0.22	0.22	0
3	2.1	0.001	0	1.26	1.26	0
4	2.4	0.03	0	0.3	0.3	0
5	2.9	0.009	0	1.4	1.4	0
6	2.9	0.039	0	7.8	7.8	0
7	2.9	0.03	0	6.5	6.5	0
MAX deviation	2.9	0.039	0	7.8	7.8	0
MAX error	1.25595	2.758	0	2.389	2.389	0
Accuracy %	98.744	97.24	-	97.61	97.61	-

➢ **Transmission**:

- Validation Accuracy for R-Load at Sending side:

R	V	I	P	Q	S
1	0.1	0.006	1	0.4	1.036
2	0.1	0.007	1.4	1.1	1.456
3	0.1	0.018	5	0.3	5
4	0.7	0.014	4.6	0.9	4.634
5	1.9	0.046	10.3	1.8	10.42
6	0.2	0.05	16	6.23	16.7
7	0.7	0.1	24.5	12.64	26.29
MAX deviation	1.9	0.1	24.5	12.64	26.29
MAX error	0.823	5.574	6.012	16.93	6.347
Accuracy %	99.18	94.43	93.99	83.07	93.65

- Validation Accuracy for R-Load at Receiving side:

R	V	I	P	Q	S
1	**1.4**	**0.005**	**1.6**	**0**	**1.6**
2	**1.3**	**0.005**	**1.62**	**0**	**1.62**
3	**2.7**	**0.017**	**5.7**	**0**	**5.7**
4	**3.9**	**0.014**	**6.2**	**0**	**6.2**
5	**6**	**0.04**	**14.2**	**0**	**14.2**
6	**7.3**	**0.062**	**18.3**	**0**	**18.3**
7	**6.6**	**0.109**	**40.4**	**0**	**40.4**
MAX deviation	**7.3**	**0.109**	**40.4**	**0**	**40.4**
MAX error	**3.167**	**6.072**	**10.19**	**0**	**10.19**
Accuracy %	**96.83**	**93.93**	**89.81**	**-**	**89.81**

- Validation Accuracy for C-Load at Sending side:

C	V	I	P	Q	S
1	**0.9**	**0.006**	**1.95**	**1.316**	**2.136**
2	**1.7**	**0.004**	**2.16**	**0.622**	**2.213**
3	**1.8**	**0.016**	**4.9**	**0.02**	**4.898**
4	**2.1**	**0.018**	**4.5**	**0.62**	**4.514**
5	**1.9**	**0.04**	**10.4**	**2.55**	**10.56**
6	**2.4**	**0.063**	**20.3**	**6.05**	**20.91**
7	**2.9**	**0.111**	**27.9**	**13.52**	**29.72**
MAX deviation	**2.9**	**0.111**	**27.9**	**13.52**	**29.72**
MAX error	**1.256**	**6.191**	**6.84**	**18.9**	**7.177**
Accuracy %	**98.74**	**93.81**	**93.16**	**81.1**	**92.82**

- Validation Accuracy for C-Load at Receiving side:

C	V	I	P	Q	S
1	2.7	0.007	2.68	0	2.68
2	5.1	0.009	3.73	0	3.73
3	6.5	0.025	8.9	0	8.9
4	8.1	0.026	10.5	0	10.5
5	8.4	0.045	17.6	0	17.6
6	8.4	0.073	29.8	0	29.8
7	7	0.121	43	0	43
MAX deviation	8.4	0.121	43	0	43
MAX error	3.7	13.75	21.71	0	21.71
Accuracy %	96.3	86.25	78.29	-	78.29

- Validation Accuracy for L-Load at Sending side:

L	V	I	P	Q	S
1	0.1	0.001	0.05	1.51	0.467
2	0.9	0.003	1.28	1.886	1.609
3	0.9	0.011	3.2	0.411	3.222
4	1.9	0.018	4	13.03	3.358
5	2.3	0.039	11.1	2.05	11.18
6	2.7	0.051	14.2	5.71	14.74
7	2.9	0.099	23	13.31	24.69
MAX deviation	2.9	0.099	23	13.31	24.69
MAX error	1.256	5.521	5.623	20.38	5.962
Accuracy %	98.74	94.48	94.38	79.62	94.04

- Validation Accuracy for L-Load at Receiving side:

L	V	I	P	Q	S
1	3	0.006	1.84	0	1.84
2	3.1	0.007	2.96	0	2.96
3	6.5	0.02	8.3	0	8.3
4	6.5	0.024	10	0	10
5	9.3	0.048	18.3	0	18.3
6	10.8	0.068	28.8	0	28.8
7	9.6	0.119	40.2	0	40.2
MAX deviation	10.8	0.119	40.2	0	40.2
MAX error	4.675325	6.614786	10.09543	0	10.09543
Accuracy %	95.32	93.39	89.9	-	89.9

For the Accuracy% results obtained by loads and Transmission experiments indicate to good results, and therefore the Simulation for renewable energy lab at PPU has succeeded.

5.4 Combined Loads

In this section, several combined loads experiments have been made on MATLAB/Simulink environment.

- **Experiment# 1:**

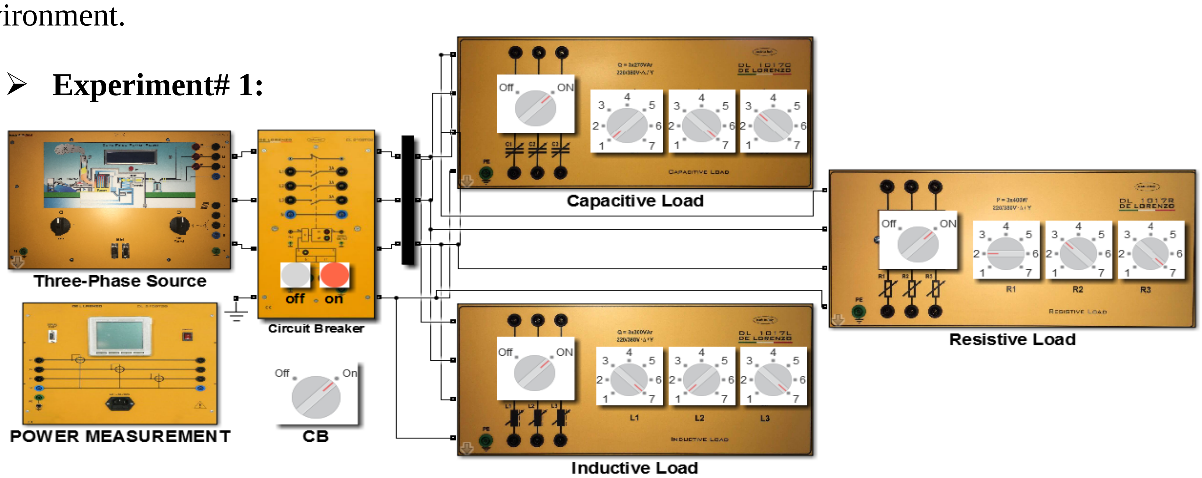


Figure 5.7: RLC combined load experiment.

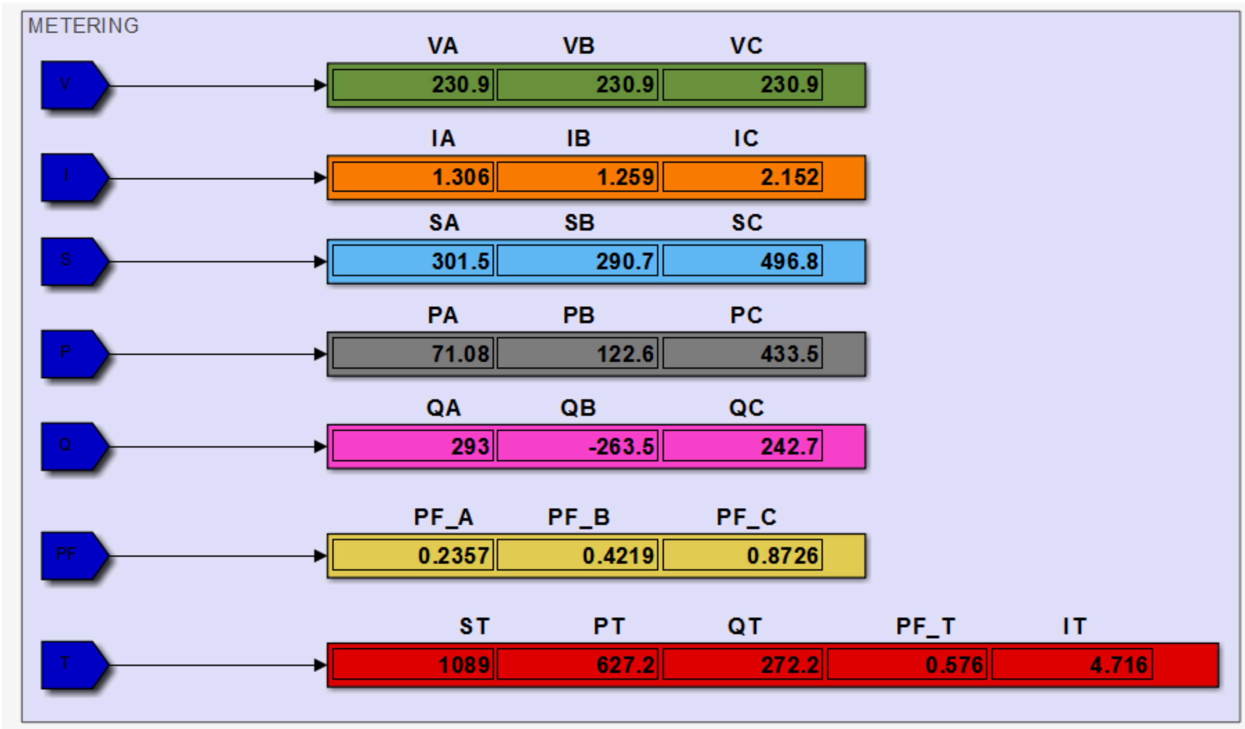


Figure 5.8: RLC combined load experiment metering results.

➢ **Experiment# 2**:

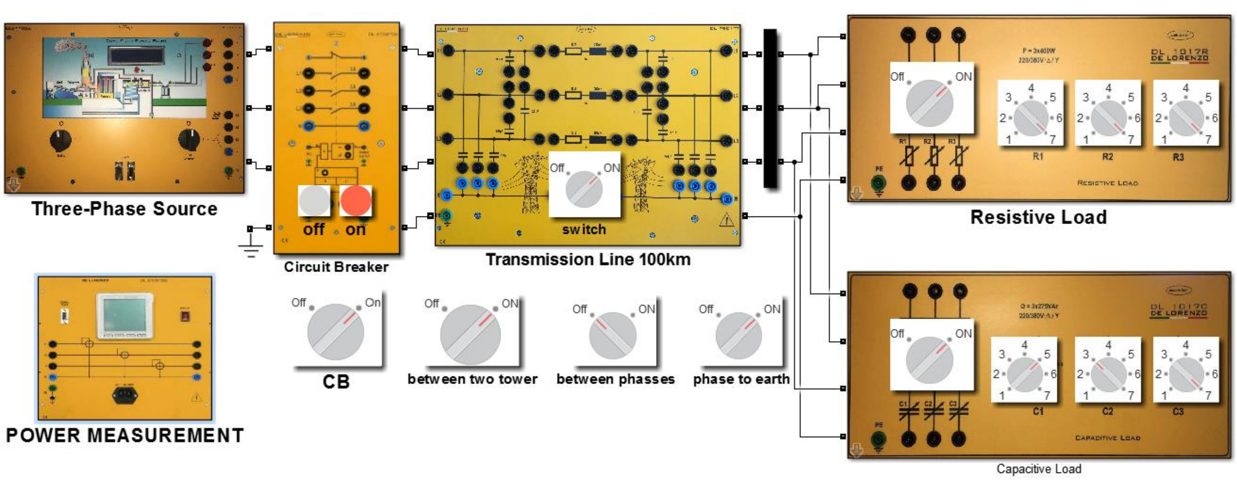


Figure 5.9: RC combined load with transmission experiment.

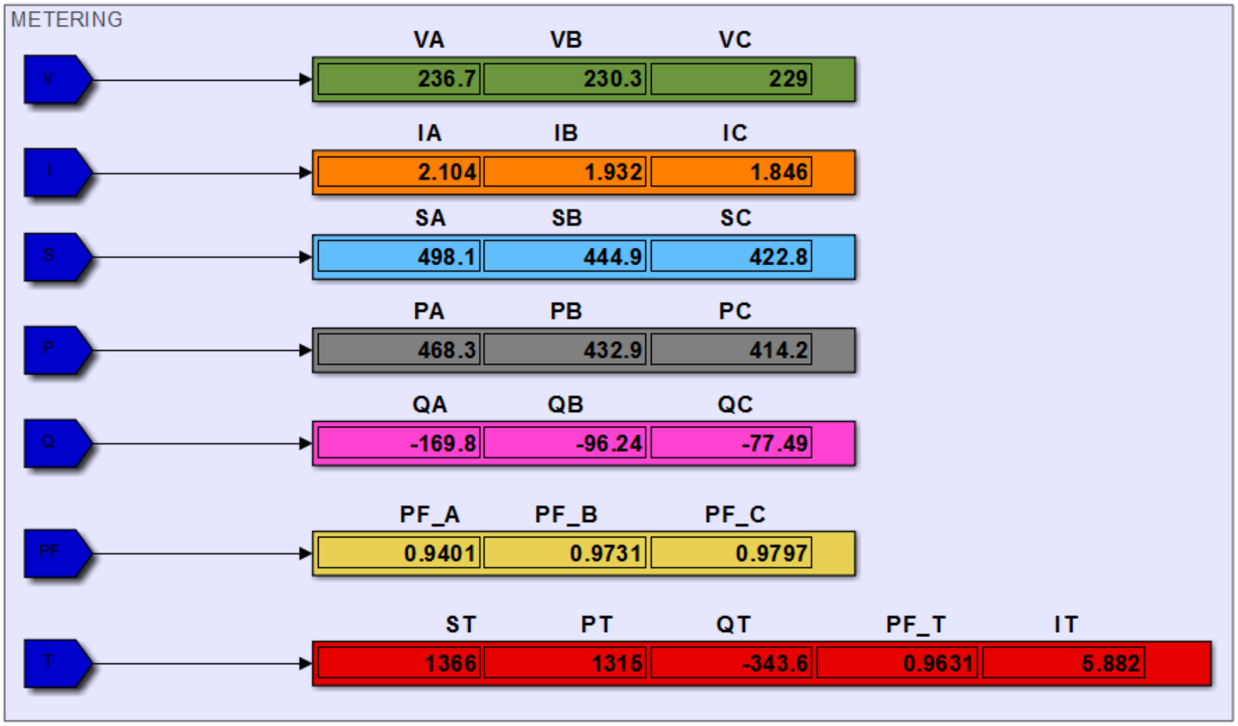


Figure 5.10: RC combined load with transmission experiment results.

- **Experiment# 3**:

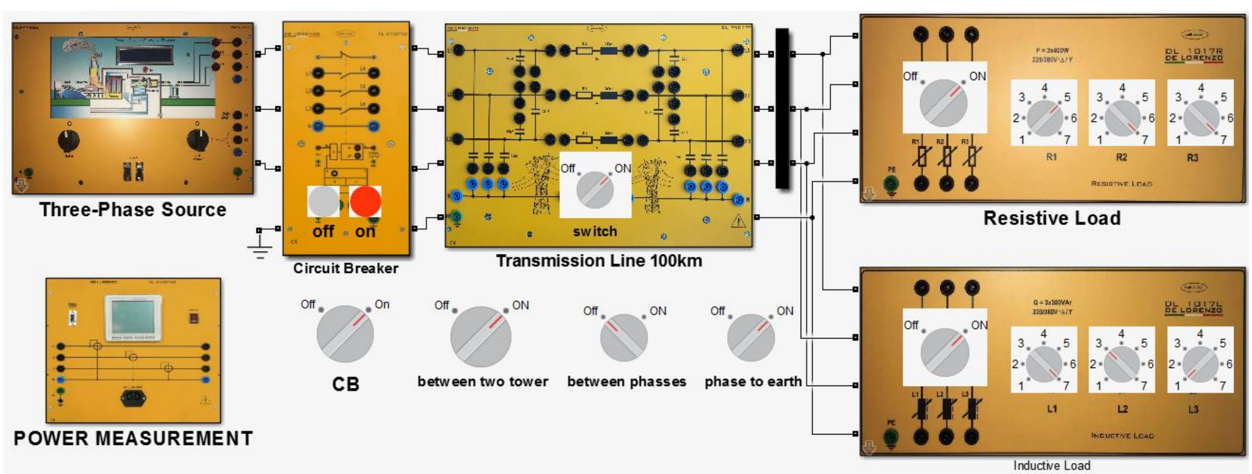


Figure 5.11: RL combined load with transmission experiment.

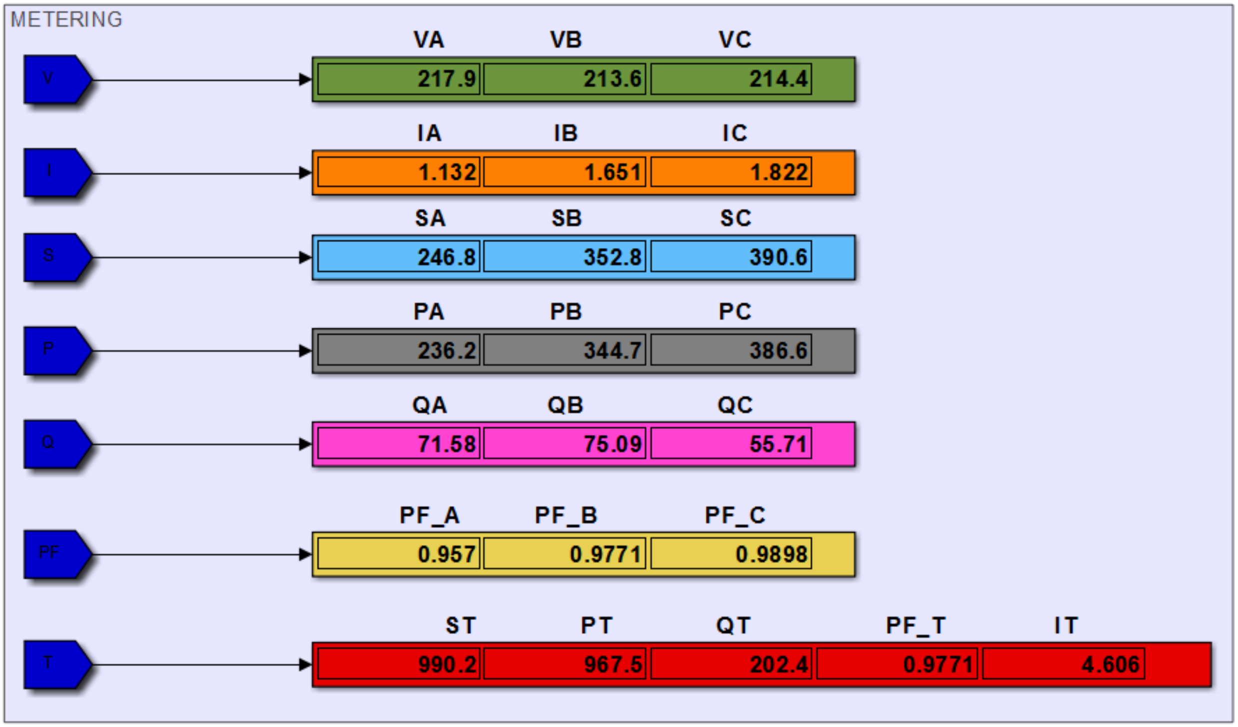


Figure 5.12: RL combined load with transmission experiment results.

5.5 Conclusion

The objective was mainly about deriving the equations of the components to be simulated using MATLAB/Simulink, in order to create modules/Blocks in Simulink to study the behavior of the system components under different operating conditions. The modules used for the simulation were (Power circuit breaker, Maximum demand meter, PV module, three phase induction generator, Loads, Transmission lines, and Inverter module).

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