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1. abstract

Power engineering, also called power systems engineering, is a subfield of electrical engineering that deals with the generation, transmission, distribution, and utilization of electric power, and the electrical apparatus connected to such systems. Although much of the field is concerned with the problems of three-phase AC power – the standard for large-scale power transmission and distribution across the modern world – a significant fraction of the field is concerned with the conversion between AC and DC power and the development of specialized power systems such as those used in aircraft or for electric railway networks. The power system is a network which consists generation, distribution and transmission system. It uses the form of energy (like coal and diesel) and converts it into electrical energy. The power system includes the devices connected to the system like the synchronous generator, motor, transformer, circuit breaker, conductor, etc.

For economic and technological reasons, individual power systems are organized in the form of electrically connected areas or regional grids (also called power pools). Each area or regional grid operates technically and economically independently, but these are eventually interconnected to form a national grid (which may even form an international grid) so that each area is contractually tied to other areas in respect to certain generation and scheduling features. India is now heading for a national grid.

2. Introduction

Electricity is the most preferred used form of energy used in industry, homes, businesses and transportation. It can be easily and efficiently transported from the production centers to the point of use. In recent times, many important developments have come from extending innovations in the information and communications technology (ICT) field to the power engineering field. For example, the development of computers meant load flow studies could be run more efficiently allowing for much better planning of power systems. Advances in information technology and telecommunication also allowed for effective remote control of a power system's switchgear and generators. It is highly flexible in use as it can be converted to any desired form like mechanical, thermal, light, chemical etc. An electrical power system is made up of many components connected together to form a large, complex system that is capable of generating, transmitting and distributing electrical energy over large areas. From a general perspective, an electric power system is usually understood as a very large network that links power plants (large or small) to loads, by means of an electric grid that may span a whole continent, such as Europe or North America. A power system thus typically extends from a power plant right up to the sockets inside customers' premises. These are sometimes referred to as full power systems as they are autonomous. Power systems that are supplied by an external electricity source or that produce (by conversion from other sources) electricity and convey it to a larger grid are called partial power systems. The power systems that are of interest for our purposes are the large scale, full power systems that span large distances and have been deployed over decades by power companies.

3. problem definition

In this report we will try to discuss main topics in power system control, we want to make a program for calculating transmission line constants, also provide voltage control. system and power factor correction, considered that we are the main Power station and give this design parameters for substations. we will illustrate the main topics which help us doing this project we need to know more about transmission lines and voltage control methods

4. basic structure of a transmission line

The power system is a combination of central generating stations, electric power transmission system, Distribution and utilization system. This system generates electrical energy and transfers it to the places of use with the appropriate voltage. This system contains devices such as a synchronous generator, motor, transformer, etc.

The Power System Consists Mainly of Six Components:

1-The Power Plant
2-Transformer
3-Transmission Line
4-Substations
5-Distribution Line
6-Distribution Transformer

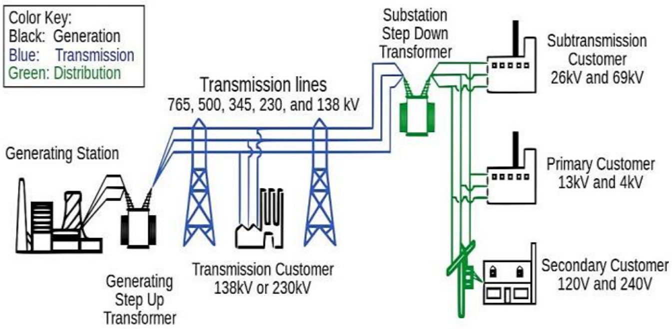

Figure 1. Electrical Power System

Because The Power System is a Complex System, It is subdivided into Subsystems. These Subsystems are Generating substation, Transmission Substation, Sub Transmission Substations and Distribution Substation.

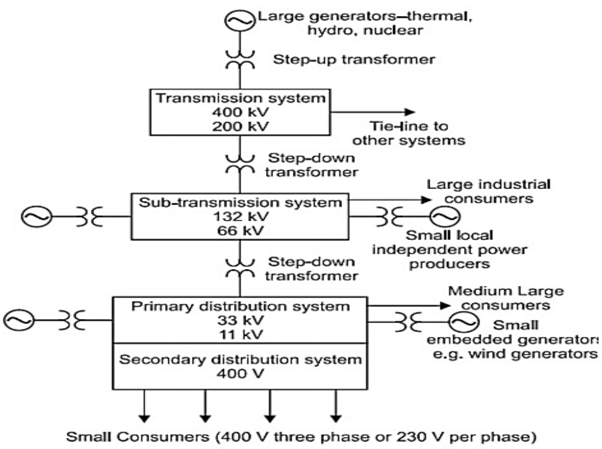

Figure 2 Power Supply System

4.1. Generating Substation

Generating stations are mainly classified into three types: thermal power plant, hydroelectric power plant and nuclear power plant.

Electricity is generated in the range of 11 kv to 25 kv from fuel (coal, water, nuclear power, etc.) to be transported by long-distance transmission lines.

Transformer and generator are the main components of a power plant.

Generator: It converts the mechanical energy resulting from burning coal, gas and nuclear fuel into electrical energy.

Ttransformer:it transfers the power with very high efficiency from one level to another. The power transfer from the secondary is approximately equal to the primary except for losses in the transformer. The step-up transformer will reduce losses in the line which makes the transmission of power over long distances.

4.2. Transmission Substation

This station contains the overhead lines that transmit the electric power that is generated in the generating stations to the distribution sub-stations and the big consumers.

- The transmission lines perform two main functions:

1- Transmission of energy from generating stations to receiving stations.
2- It connects two or more generating stations, as well as the adjacent substations.

- The transmission voltage is operating at more than 66kv and is standardised at 69kv, 115KV, 138KV, 161KV, 230KV, 345KV, 500KV, and 765KV, line-to-line. The transmission line above 230KV is usually referred to as extra high voltage (EHV).
- The high voltage line ends at stations called high voltage substations. In the next stage, the voltage is reduced to an appropriate value for using the loads in the high voltage substations.

4.3. Sub-transmission Substation

The subsystem is the part for connecting the high voltage substations to the distribution substations through the gradient transformer. The sub-transmission voltage level ranges from 90 to 138KV. The sub-transmission system directly serves some large industries. The capacitor and reactor are located in the substations for maintaining the transmission line voltage.

The transmission subsystem is similar in operation to the distribution system, but differs with it in:

1- The voltage of the subsystem is higher than the voltage of the distribution system.
2-The sub-system feeds only large loads.

3-It supplies only a few substations as compared to a distribution system which supplies some loads.

4.4. Distribution Substation

The distribution system is one of the components of electrical power systems and connects all consumers and loads with bulk energy sources. Power is distributed to consumers through substations.

5. components of a transmission line

Transmission lines are one of the components of the electrical power system and its main function is to transfer electricity from generation sources to load places with a power of 275 kv, 132 kv and 66 kv. Transmission lines consist of: conductors, cables, insulators, network structures and grounding systems.

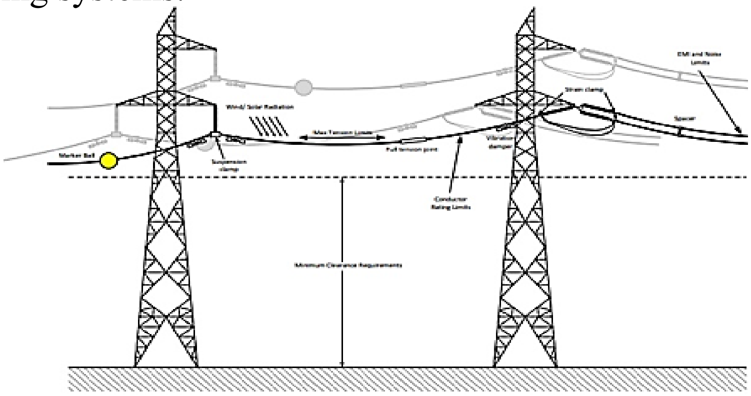

Figure 3 Typical transmission line

5.1. Transmission Line Structure

The primary function of transmission line structures is to maintain mechanical integrity and keep the geometry of the structure from permanent deformation under final loading conditions.

- Other functions of transmission lines Structure:
  - Preserving the safety of people and the environment.
  - Reduce the cost.
  - Providing an electrical path to the ground for fault currents.

- Structure types include free-standing:
  - Lattice towers, masts
  - Steel tubular poles.
  - Stobie poles
  - Concrete poles.

5.2. Transmission Line Conductors

The main function of transmission line conductor systems is to transfer electrical power between designated locations, within prescribed performance, operating and environmental conditions.
Other functions of transmission line conductors:

1- Maintain electrical safety and minimize adverse effects on the environment.
2- Provide a whole-of-life cost-effective service

5.3. Transmission Line Insulators

The insulation of the transmission line is made of porcelain, and it performs two main functions:

1. Transferring mechanical loads to the structure and supporting the conductor system.
2. Isolation of active components from grounded structures

5.4. Transmission Line Earthing

The main functions of the grounding system are:

1. Protecting people and the environment by providing an electric path inside the ground for fault currents and lightning strikes.
2. Ensure that faults are removed within the NER time limits.
3. Dissipate leaking currents.

5.5. Transmission High Voltage Cables

The high voltage transmission cable consists of:

1- Cables, Connectors and Discharge Detection Equipment
2- Support structures and expansion rooms.
3- Monitoring system and temperature sensor.

and the high voltage transmission cables perform two main functions:

1- Transmission of power electricity between different sites.
2- Maintain electrical and environmental safety.

6. Parameters of transmission line

The efficiency of the transmission line depends on some parameters. The transmission line contains 4 basic parameters: resistance, inductance, capacitance, and conduction transformation, and these parameters are distributed equally along the line.

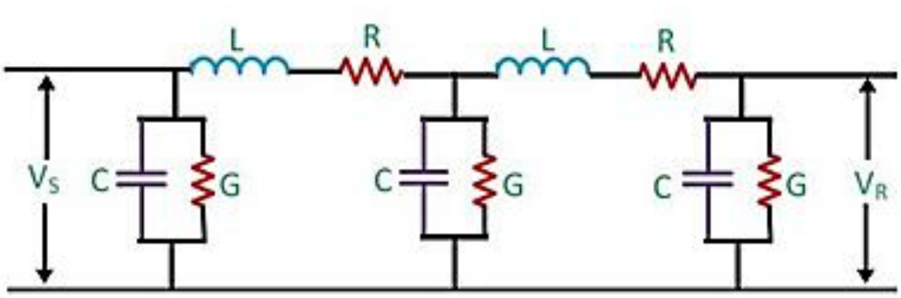

Figure 4 Transmission line model

6.1. Line Resistance (R)

This parameter relies on the cross-sectional area of the conducting material. It is represented by R and its unit is ohms per unit length of the conductor.

6.2. Line Inductance (L)

The change of current in the transmission line leads to the generation of emf in the circuit, as a result of changing the magnetic flux. This emf resists the flow of current. The magnitude of emf depends on the rate of flux change.

6.3. Line Capacitance (C)

Air acts as and dielectric medium in transmission lines. This dielectric medium acts as a capacitor between the conductors. This capacitor stores electrical energy or increases the capacitance of the line.Capacitance is negligible in short transmission lines but in long transmission, it is the most important parameter. As it affects the efficiency, voltage regulation, power factor and stability of the system.

6.4. Line Conductance (G)

Air acts as and dielectric medium between the conductors, and some current flows in this dielectric medium due to dielectric defects when alternating voltage is applied. The leakage of this current depends on pollution and the condition of the atmosphere.

7. TL types

There are two types of transmission, either by overhead transmission lines or by underground transmission lines, but in order to decide which type we choose, the comparison between the advantages and drawbacks of each type may be useful as following:

TL type	Overhead transmission lines	Underground transmission
advantages	➢ Easy to maintain and repair ➢ Cheaper to setup compare to underground transmission	➢ Less transmission losses ➢ Not affected by weather conditions ➢ These lines have reduced EMFs
Drawbacks (disadvantages)	➢ They pollute the area visually where they are installed ➢ Some problems can appear like lightening	➢ Cost of underground cables (e.g. HVDC) are three times higher compare to overhead lines ➢ It is difficult to maintain underground system compare to overhead due to underground cabling ➢ underground lines can not be uprated to increase the capacity.

The transmission line has many models and classifying the model of a transmission line depends on the length if it. So, we can classify it as follows:

- Short TL: is that whose length is less than 80 km
- Medium TL: for the transmission lines whose length is between 80 km and 240 km
- Long TL: whose length is longer than 240 km

7.1. short transmission line

The equivalent circuit of a short transmission line can be represented by the following circuit:

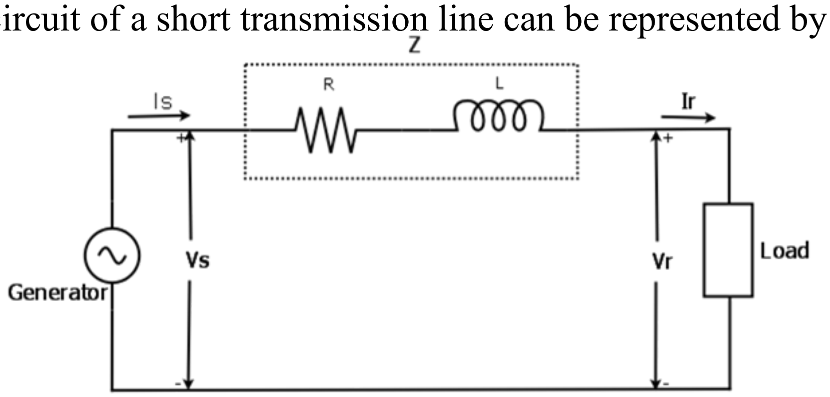

Figure 5 equivalent circuit of a short transmission line

any model of the transmission line can be presented by a Generalised Circuit Constants of TL (ABCD Constants). The general equations of the lines are as below [1]:

$$V_s = A\,V_r + BI_r$$

$$I_s = C\,V_r + DI_r$$

And for the short transmission line,

$$V_s = V_r + ZI_r \rightarrow A = 1 \text{ and } B = Z$$

$$I_s = I_r \rightarrow C = 0 \text{ and } D = 1$$

7.2. medium transmission line

The parameters (Resistance, Inductance, and Capacitance) are distributed uniformly along the line. We can represent it by two models:

7.2.1. T model

In this model, the shunt admittance is concentrated at the centre of the line. This can be shown as below [2]:

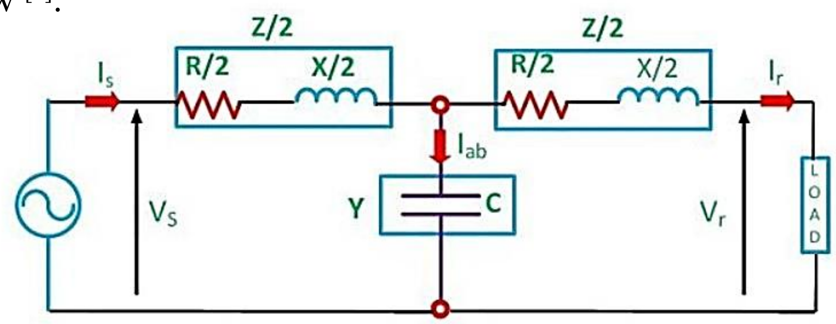

Figure 6 T model for a medium TL

$V_{ab} = V_r + \frac{Z}{2} I_r$ (From KVL) $\qquad$ $I_s = I_r + I_{ab}$ (From KCL)

$I_{ab} = \frac{V_{ab}}{Z_{ab}} = YV_{ab}$ $\qquad$ $I_s = I_r + YV_{ab}$

$$\text{Hence, } I_s = I_r + Y(V_r + \tfrac{Z}{2} I_r) \ldots (1)$$

$$V_s = V_{ab} + \frac{Z}{2} I_s$$

$$\text{Hence, } V_s = V_r + \frac{Z}{2} I_r + \frac{Z}{2}\left[YV_r + (1 + \tfrac{ZY}{2}) I_r\right] \ldots (2)$$

From equation (1) and (2), we can deduce the constants:

$$A = D = 1 + \frac{ZY}{2}$$

$$B = Z(1 + \tfrac{ZY}{4})$$

$$C = Y$$

7.2.2. pi model of a TL.

This is another model of a TL to deal with. In the nominal pi model of a medium transmission line, the series impedance of the line is concentrated at the centre and half of each capacitance is placed at the centre of the line. The model is as shown below [3]:

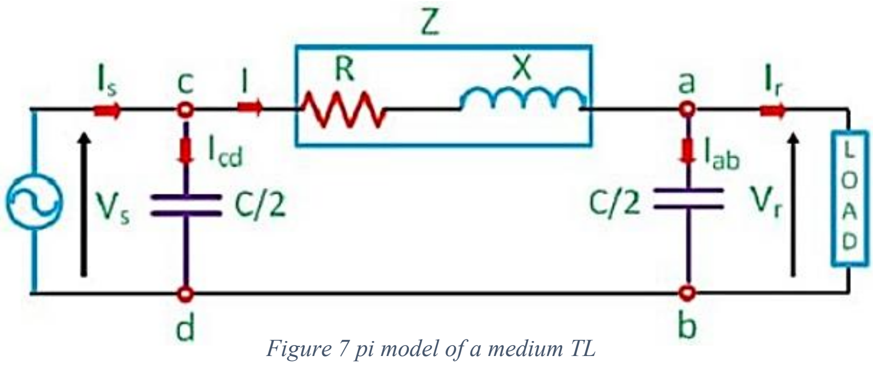

Figure 7 pi model of a medium TL

$V_{ab} = V_r \ , \ Z_{ab} = \frac{1}{Y_{ab}} \rightarrow I_{ab} = \frac{Y}{2} V_r$

$I = I_r + I_{ab} = I_r + \frac{Y}{2} V_r$

$V_s = V_{cd} = V_{ab} + IZ = V_r + Z\left(I_r + \frac{Y}{2} V_r\right)$

$V_s = \left(1 + \frac{ZY}{2}\right) V_r + Z I_r \ \ldots(3)$

$I_s = I + I_{cd} \rightarrow I_s = Y\left(1 + \frac{ZY}{4}\right) V_r + \left(1 + \frac{ZY}{2}\right) I_r \ \ldots(4)$

From equations (3), (4) we can deduce the ABCD constants:

$$A = D = 1 + \frac{ZY}{2}$$

$$B = Z$$

$$C = Y(1 + \frac{ZY}{4})$$

7.3 long TL

The equivalent circuit can be represented as following:

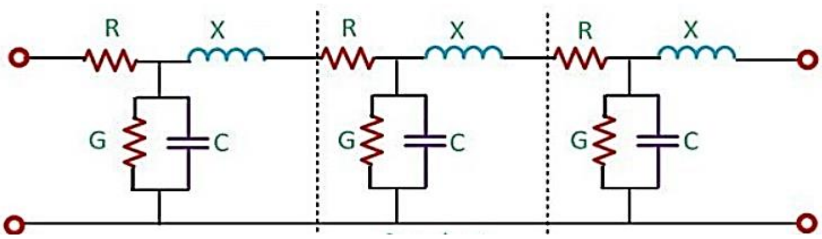

Figure 8 long TL equivalent circuit

Let's consider a bit smaller part of a long transmission line having length 'ds' situated at a distance 's' from the receiving end [4]

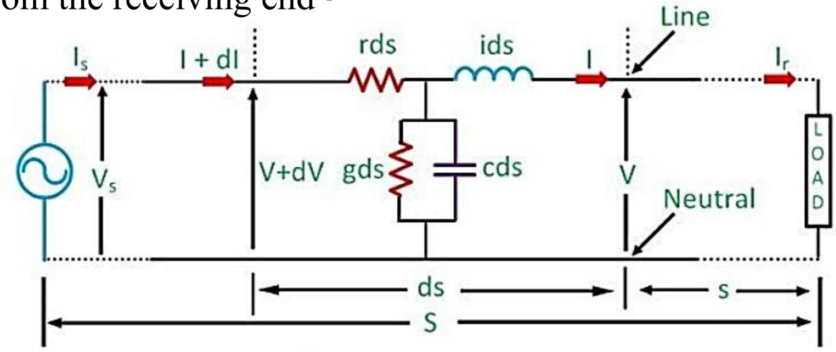

Figure 9 incremental length of a long TL

Where:

r : resistance per unit length, per phase
l : inductance per unit length, per phase
c : capacitance per unit length, per phase
x : inductive reactance per unit length, per phase
z : series impedance per unit length, per phase
g : shunt leakage conductance, per phase to neutral per unit length
b : shunt leakage susceptance, per phase to neutral per unit length
y : shunt admittance per unit length, per phase to neutral

for constant supply voltage:

V : voltage at a distance 's' from the load end
V + dV : voltage at a distance (s+ds) from the load end
I : current at a distance 's' from the load end
I + dI : current at a distance (s+ds) from the load end.

γ : the square root of (zy)

After some basic analysis of the circuit, the governing equations for the sending end voltage and current:

$$V_s = V_r \cosh \gamma s + Z_0 I_r \sinh \gamma s$$

$$I_s = I_r \cosh \gamma s + \frac{V_r}{Z_0} \sinh \gamma s$$

$$A = \cosh \gamma s$$

$$B = Z_0 \sinh \gamma s$$

$$C = \frac{1}{Z_0} \sinh \gamma s$$

$$D = \cosh \gamma s$$

8. power system control by reactive compensation

It's an essential component in any power system. It's the process of adding or removing VARs in such systems to provide voltage control and compensating the reactive power [5]. Inductors and capacitors are used on medium-length and long transmission lines to increase line load ability and to maintain voltages near rated values. Shunt capacitors are used in order to control the voltage with a required level [6]. The following sketch explains the types of compensation:

- rotating synch. Compensator
- static var compensation, which consists of:
    - controllable facts
    - fixed shunt reactor, fixed shunt capacitor and fixed series capacitor.

8.1. rotating synch. Compensator

When the synchronous machine runs on no-load, such as, on a freely rotating shaft, with controlled excitation, it is called a synchronous condenser or compensator. Using it in this configuration we can add reactive power unto the grid by over-excitation and consume reactive power from the grid by under-excitation of its field windings [7]

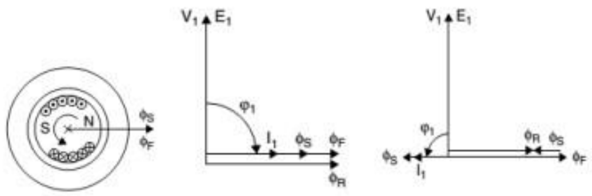

Figure 10 Phasor Diagram of the Cylindrical Rotor of an ideal Synchronous compensator

If the field excitation is increased over the value required to produce E1, the stator currents generate a flux that counteracts the field-generated flux. Under this condition, the machine is said to be over-excited. The machine thus behaves as a leading condenser; that is, it is delivering reactive power to the network [8]

8.2. static var compensation (SVC)

8.2.1 controllable FACTS:

we can control the reactive power by using FACTS. It consists of basic types of control as following:

- thyristor switched capacitors (TSC_s)
- thyristor controlled reactor (TCR_s)
- combined TSC_S and TCR_s

8.2.1.1. thyristor switched capacitors (TSCs)

It's used in EHV (extra high voltage) lines to provide leading reactive power or leading VARS. The following circuit represents TSC.

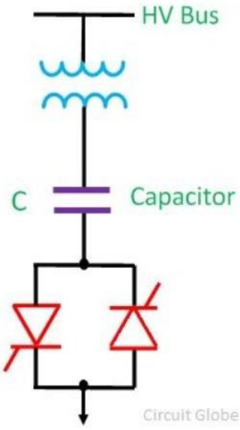

Figure 11 thyristor switched capacitors

we can control the capacitor current by controlling the back-to-back thyristor connected in series with the capacitor so if the voltages is reduced below reference value, capacitive VA_s is injected by the static var compensator by using TSC. When the voltage raises the reference value, inductive VARS is injected by TCR [8].

8.2.1.2. thyristor controlled reactor (TCRs)

It consists of reactor in series with the thyristor valve. This reactor is the controlled element of the TCR. It is used for providing lagging VARS by controlling the duration of the current, which can be controlled by the firing angle [9].

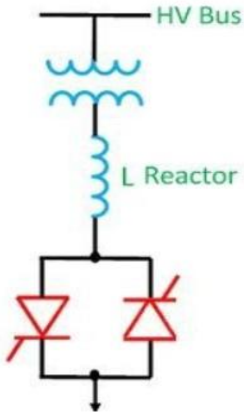

Figure 12 thyristor-controlled reactor

8.2.1.3 combined TCRs and TSC_s

It is used to provide continuous variable reactive power by using combination of TSC and TCR. A continuous change from a fully lagging to fully leading can be achieved by this combination [10]

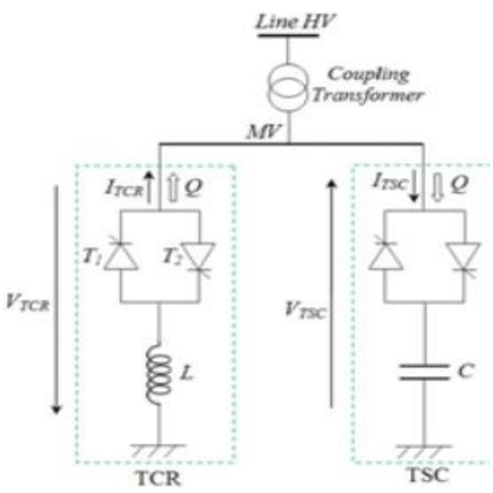

Figure 13 TCR and TSC combined

8.2.2. fixed compensation

There is three methods in fixed compensation type, each method has a specific use and analysis that we will discuss it

- **Shunt capacitor:**

Shunt capacitors bank supply reactive power and boost local voltages. they are used throughout the system and are applied in a wide range of sizes.

Shunt capacitors were first used in the mid -1910s for power factor correction.

- **Application to transmission systems**

>> shunt capacitors are used to compensate for XI^2 losses in transmission systems and to ensure satisfactory voltage levels during heavy loading conditions.

>> they are normally distributed through the transmission system so as to minimize losses and voltage drops.

>> detailed power-flow studies are performed to determine the size and location of capacitor banks to meet the system design criteria which specify maximum allowable voltage drop following specified contingencies.

- **Advantages of shunt capacitor compensation**

The principal advantages of shunt capacitors are their low cost and flexibility of installation and operation. they are readily applied a various point in the system. thereby contributing to efficiency of power transmission and distribution.

- **disadvantages of shunt capacitor compensation**

The principal disadvantages of shunt capacitors are that their reactive power output is proportional to the square of the voltage. consequently, the reactive power output is reduced at low voltage when it is likely to be needed most.

- **shunt capacitor analysis**

without compensation, assuming lossless line:

$Z_C = \sqrt{LC} = \sqrt{Xl/Bc}$ $\theta = \beta * 1$

$\beta = \omega \sqrt{LC}$

β is the phase constant

shunt analysis:

$b`_C = b_C - b_{Sh} = b_C\ (1 - k_{Sh})$

K_{sh} is the degree of compensation

$K_{Sh} = b_{Sh} / b_C$

$Z'_C = Z_C / \sqrt{1 - Ksh}$ $\beta' = \beta \sqrt{1 - Ksh}$

Z'_C is the characteristic impedance after compensation

θ Is the line angle

L is the series inductance per unit length

C is the shunt capacitance per unit length

β' is the phase constant afrer compensation

B_C is the total shunt susceptance , (is the real-valued susceptance, measured in siemens.)
b_C is the shunt susceptance per unit length

b'_C is the shunt susceptance per unit length after compensation

l is the line length

- **series capacitors:**

series capacitors are connected in series with the line conductor to compensate for the inductive reactance of the line.

this reduce the transfer reactance between the buses to which the line is connected, increases the maximum power that can be transmitted, and reduces the effective reactive power (XI^2) losses.

- **Application to transmission systems**

A through series capacitors is not usually installed for voltage control as they do contribute to improved voltage control and reactive power balance. the reactive power produced by a series capacitor increases with increasing power transfer. a series capacitor is self – re **For analysis without compensation , assuming a lossless line :**

$Z_C = \sqrt{LC} = \sqrt{Xl/Bc}$ $\theta = \beta * l$

$\beta = \omega \sqrt{LC}$ β is the phase constant

series capacitor analysis

$Xl' = Xl (1 - K_{se})$

K_{se} is the degree of series compensation >>> $K_{se} = X_{cse} / Xl$ (+ve)

$Z'_C = Z_C \sqrt{1 - Kse}$ $\beta' = \beta \sqrt{1 - Kse}$

Z_C the characteristic impedance

θ Is the line angle

L is the series inductance per unit length

C is the shunt capacitance per unit length

X_l' is the line impedence after compensation

β' is the phase constant afrer compensation

B_C is the total shunt susceptance , (is the real-valued susceptance, measured in siemens.)
b_C is the shunt susceptance per unit length

b'_C is the shunt susceptance per unit length after compensation

l is the line length

gulating in this regard.

➢ shunt reactor

they are usually required for Extra high voltage (EHV) overhead lines longer than 200 km. shunt reactors are used to compensate for the effects of line capacitance particularly to limit voltage rise on open circuit or light load (Ferranti effect), these are connected at both ends of all TL.

Application to transmission systems

- A shunt reactor of sufficient size must be permanently connected to the line to limit fundamental – frequency temporary over voltages to about 1.5 pu for a duration of less than 1 s.

- such line-connected reactors also servo to limit energization over voltages

(Switching transient).

- additional shunt reactors required to maintain normal voltage under light-load conditions may be connected to the EHV bus.

- during heavy loading conditions some of the reactors may have to be disconnected.

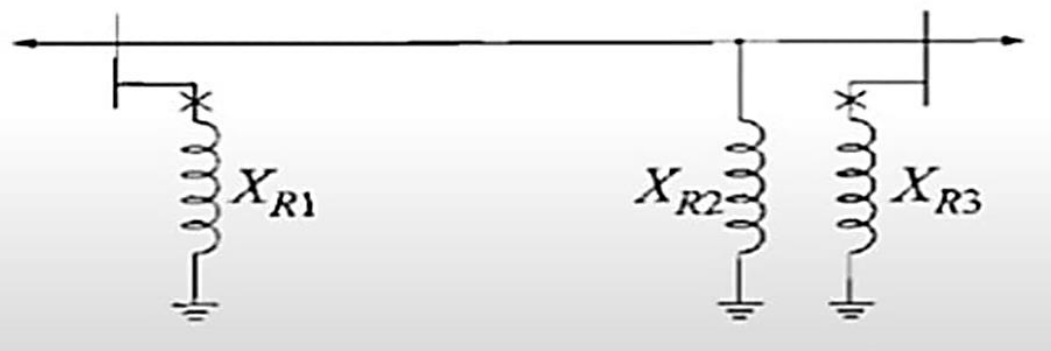

Figure 14 pi model of TL with shunt reactor

9. Results and simulations

We made a simulation program using GUI. The program inputs are resistance per unit length, inductance per unit length, capacitance per unit length, frequency, length, the voltage at the sending end, the power at sending end, the given power factor and the required power factor. which can compute multiple parameters. The program interface is shown below:

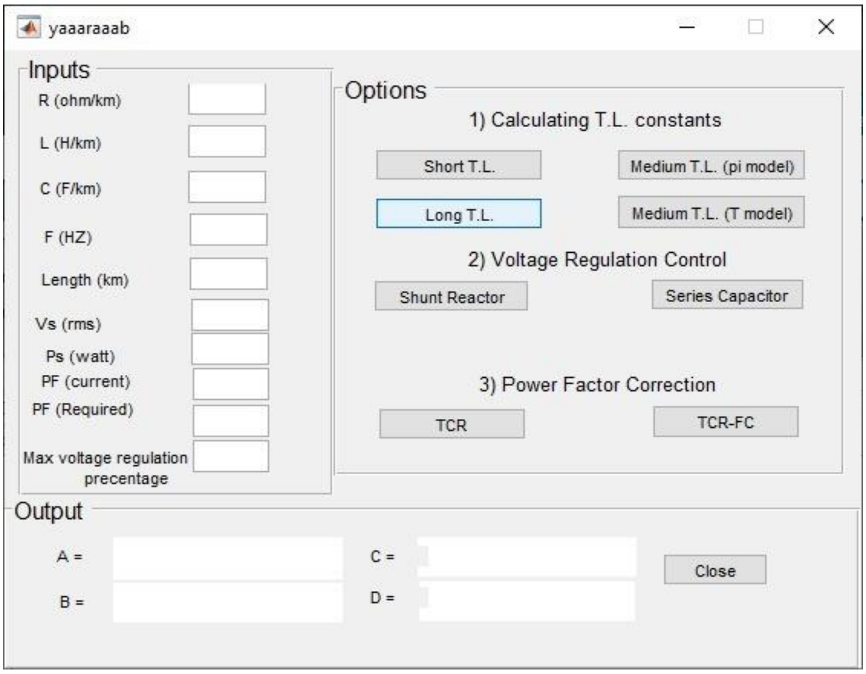

Figure 15 program interface

We can calculate the ABCD constants for any type of lines. For example, for the short model the ABCD constants are:

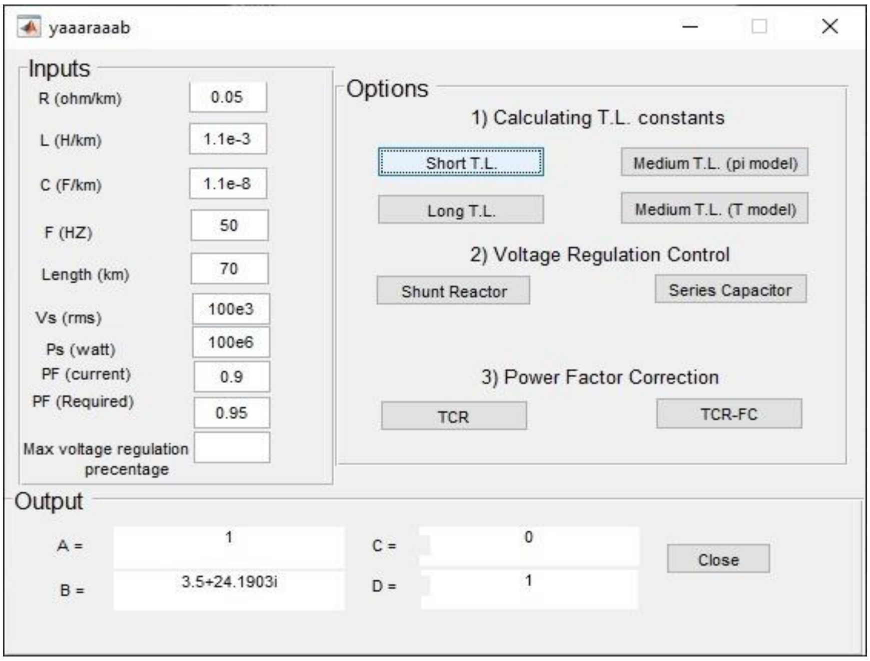

Figure 16 an example for calculating short TL constants

For a medium pi model, the program computes constants as following:

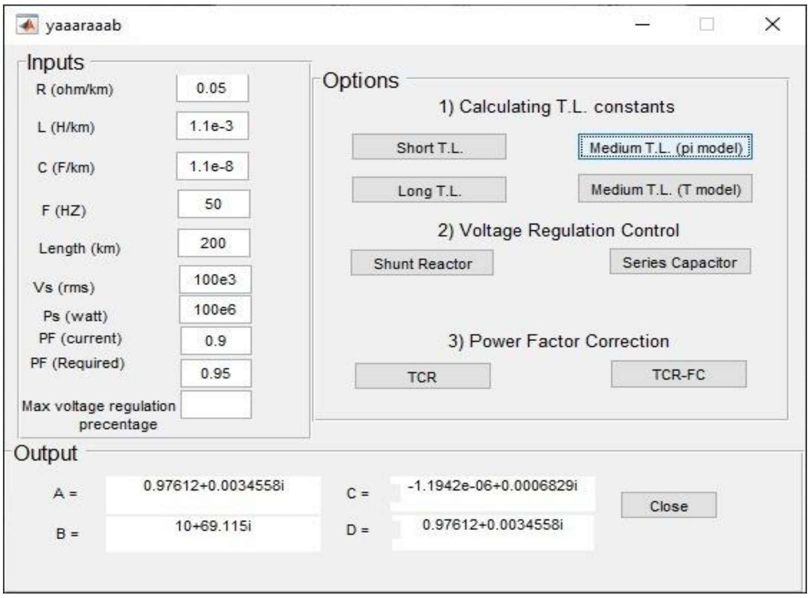

Figure 17 an example for calculating medium TL constants (pi model)

For a medium T model and long TL:

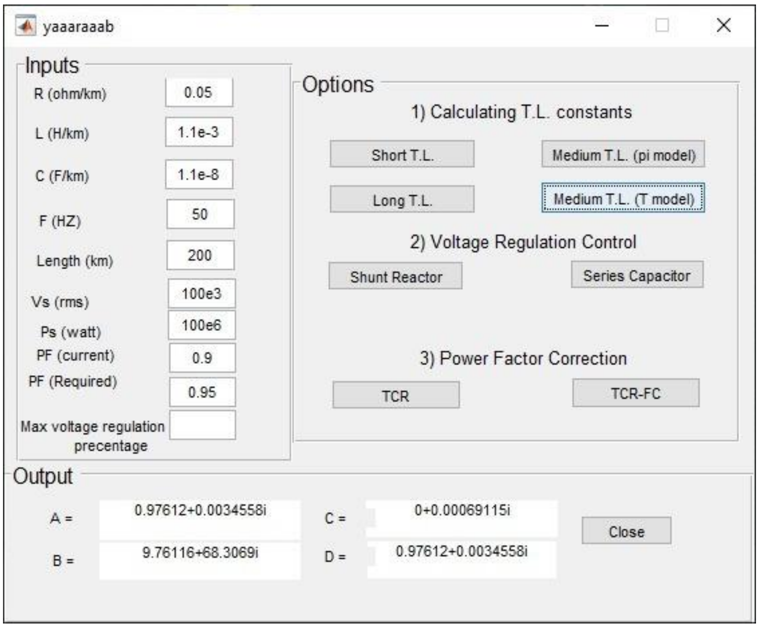

Figure 18 an example for calculating medium TL constants

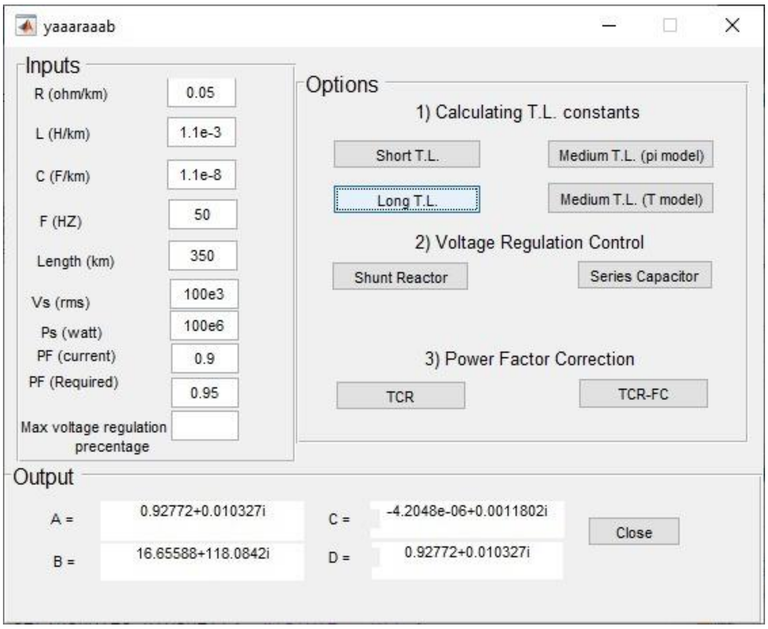

Figure 18 an example for calculating long TL constants (T model)

As we said, our program can also make more calculations like power factor correction and voltage regulation. The following figures will show our results about both of them.

For the voltage regulation using series capacitor:

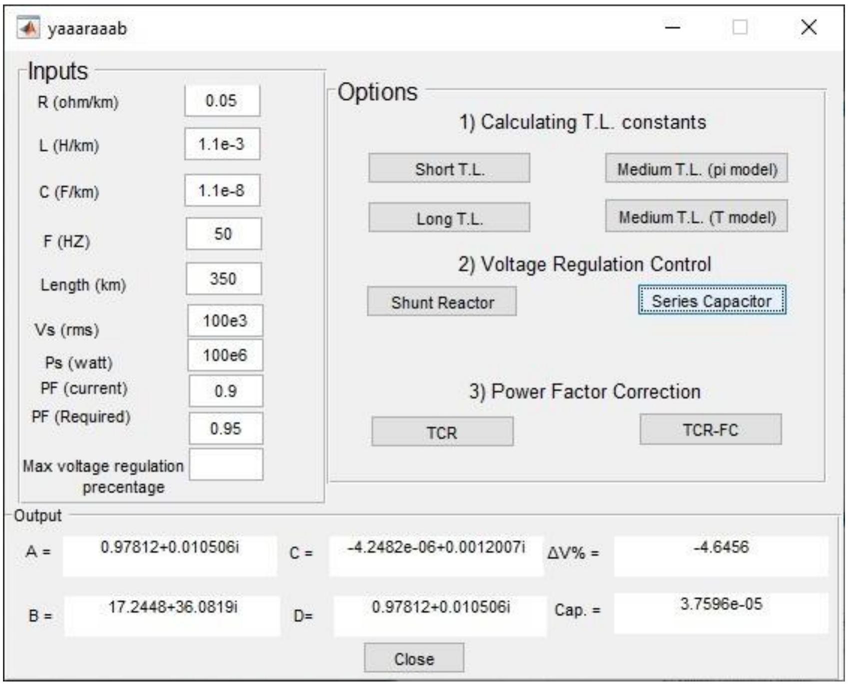

Figure 19 voltage regulation control by series capacitor

Voltage regulation control by shunt reactor:

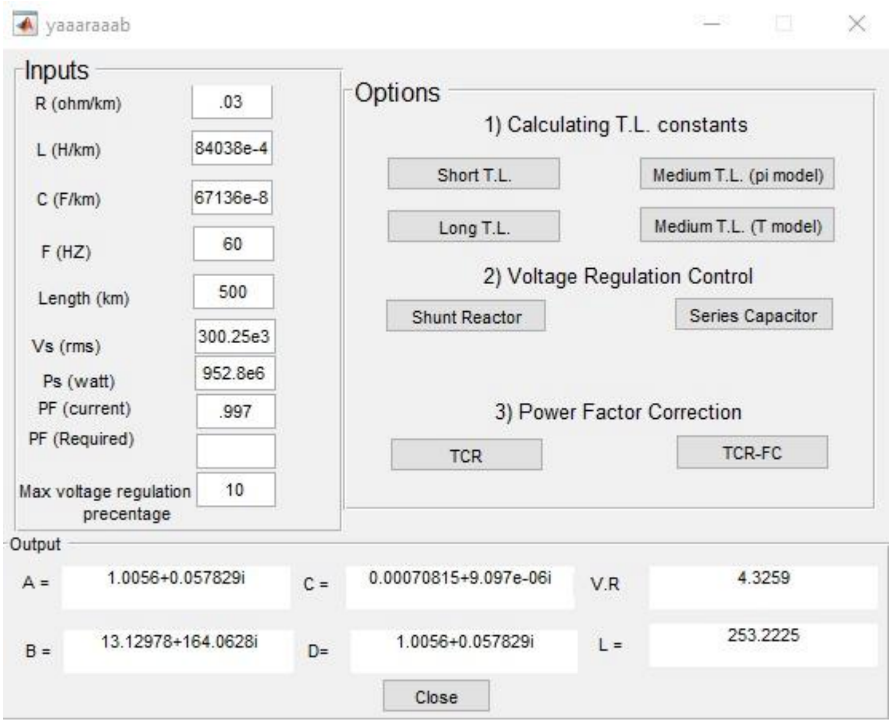

Figure 20 Voltage regulation control by shunt reactor

For the power factor correction, using TCR:

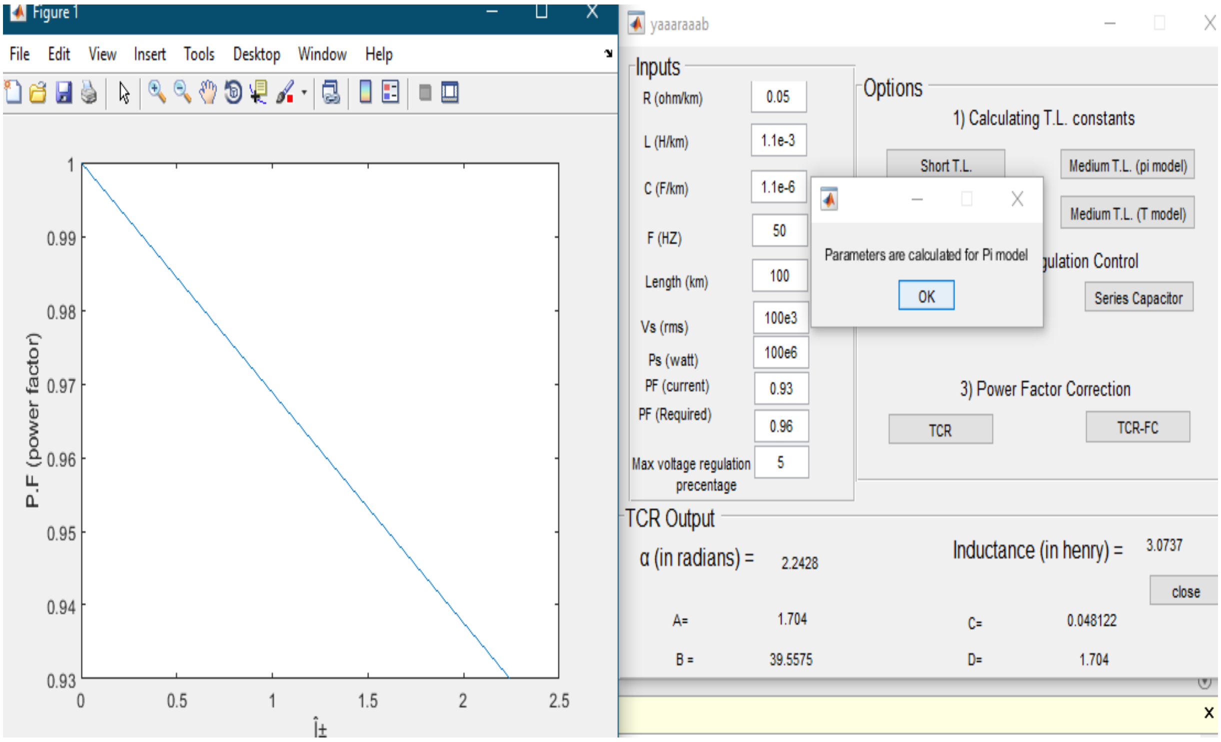

Figure 21 power factor correction by TCR

For the power factor correction, using TCR-fc

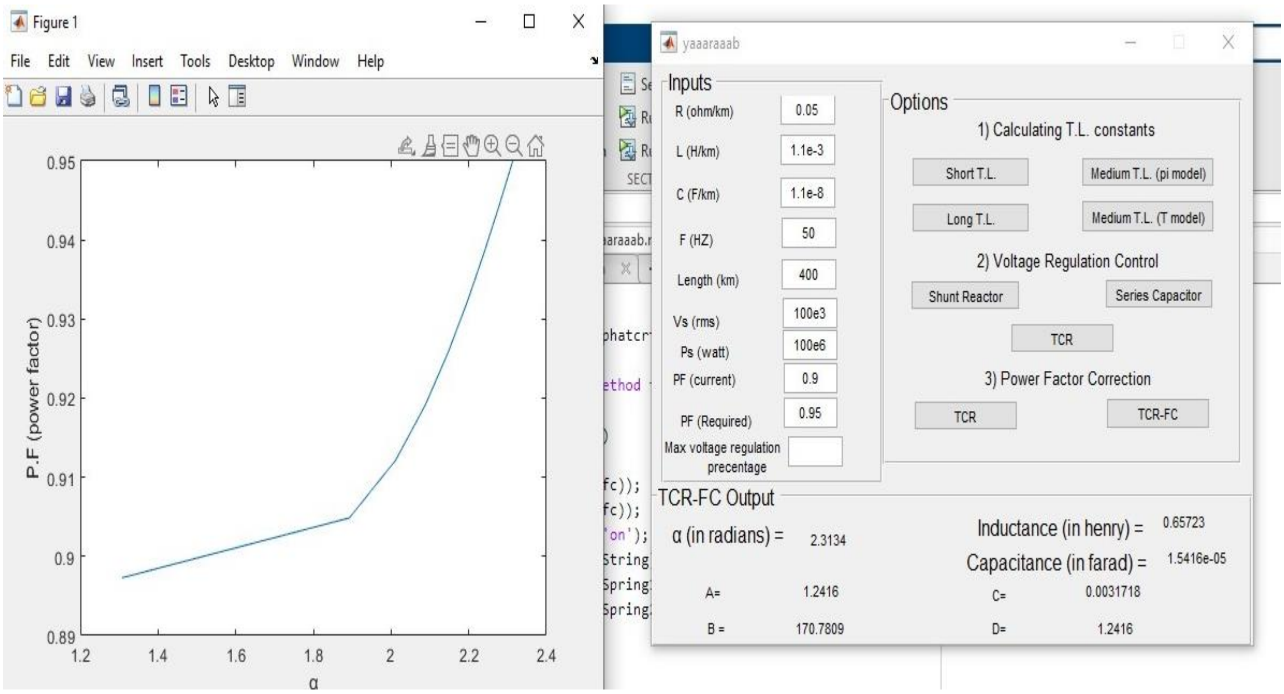

Figure 22 power factor correction by TCR-FC

10. summary

In this report we talked generally about transmission line system, so we talked about the basic structure of transmission line and discussed the Generating, transmission, distribution substation. then the report discussed the components of transmission line system, its parameters such as resistance, inductance and capacitance, and its conductors, insulators and earthing system.

After introducing the TL components and its parameters we had to talk about the TL types (short, medium and long) and it models (Pi & T), finally we discussed and introduced the power system control by reactive compensation such as SVC and rotating synch compensation

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