International Journal of Engineering and Environmental Sciences | *ISSN 1694-4372*
Published by ACADEMIC INK REVIEW | *https://airjournal.org/ijees*
12011 WestBrae Pkwy, Houston, TX 77031, United States
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Evaluation of Proper Placement of Thyristor Control Series Compensator in Transmission Line

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Publication Process	*Date*
Accepted	***December 20th, 2021***
Published	***December 31st, 2021***

ABSTRACT

Nigeria transmission lines are characterized with high line loss as a result of large distance of travel, breaking down of some generating plant since the Nigeria grid is interconnected system, which the sole aim of the design is to enable back feeding in case of uncertainties. The international standard for losses, that supposed to occur in transmission line range from 5% to 10%, because no matter how the line was design, losses must occur. Nigeria transmission line was characterized and it was observed that losses experienced in some lines exceeded the range of 5 % to 10%. Losses in some lines are 15%, 20% and 30% etc, it shows the terrible state of Nigeria transmission line and the losses runs in billions of naira. This results to huge economic loss to power investors. However, power consumers pay for what they did not consume. Secondly, the standard operating condition in transmission line ranges from 0.95 to 1.05 in per unit system. It was observed after characterization that Nigeria transmission line is marred with voltage violations. Therefore, there is need to mitigate the losses. Flexible Alternating Current Transmission System (FACTS) is a modem technology to control dynamic power flow and reduce line losses etc. THyristor Control Series Compensator (TCSC) which belongs to FACTS family was adopted to mitigate the technical loss in Transmission line. But the problem is the proper placement of TCSC in the transmission network in order to achieve maximum results. There are some many methods of placing TCSC in the transmission network which include Genetic Algorithm (GA), Particle Swarm Optimization (PSO), sensitivity method and multiple sensitivity method. These methods were examined but Multiple Sensitivity method performed better when compare with other methods

Keywords: *Proper Placement, Thyristor Control Series Compensator (TCSC), Transmission Line*

1. Introduction

Power is a complex system; it involves the transfer of buck power from generated centers to load centers. Due to its complexity, there is usually line loss, voltage violation across the buses due to technical losses, etc. Flexible Current Transmission Systems (FACTS) are normally in use to keep the voltage into standard operating conditions. FACTS devices are based on power electronics that are used for increasing transmission capacity in the power system network. It can control several parameters in the power system. There are various methods to connect the FACTS devices which include series, shunt, series-series, and series shunt. FACTS devices are environmentally friendly. This paper aims to review different methods of placing Thyristor Controlled Series Compensator (TCSC) which is a member of the FACTS family.

2. Model of Thyristor Controlled Series Compensator

Thyristor Controlled Series Capacitor (TCSC) is a FACTS device connected in series on the transmission lines to control the dynamic power flow and enhance the power quality. It consists of a thyristor, reactor, and capacitors in which the thyristor is connected with a reactor that is in parallel to the capacitor along the transmission line. TCSC control reactance due to reactors with shunt capacitor. This will increase the efficiency of the transmission line. The capacitive reactance of the controller can be varied by varying the firing angle of the Thyristor Controlled Reactor (TCR). The loadability of the system is increased by decreasing the line reactance (Shakil, 2014). TCSC has an LC circuit that carries a constant current.

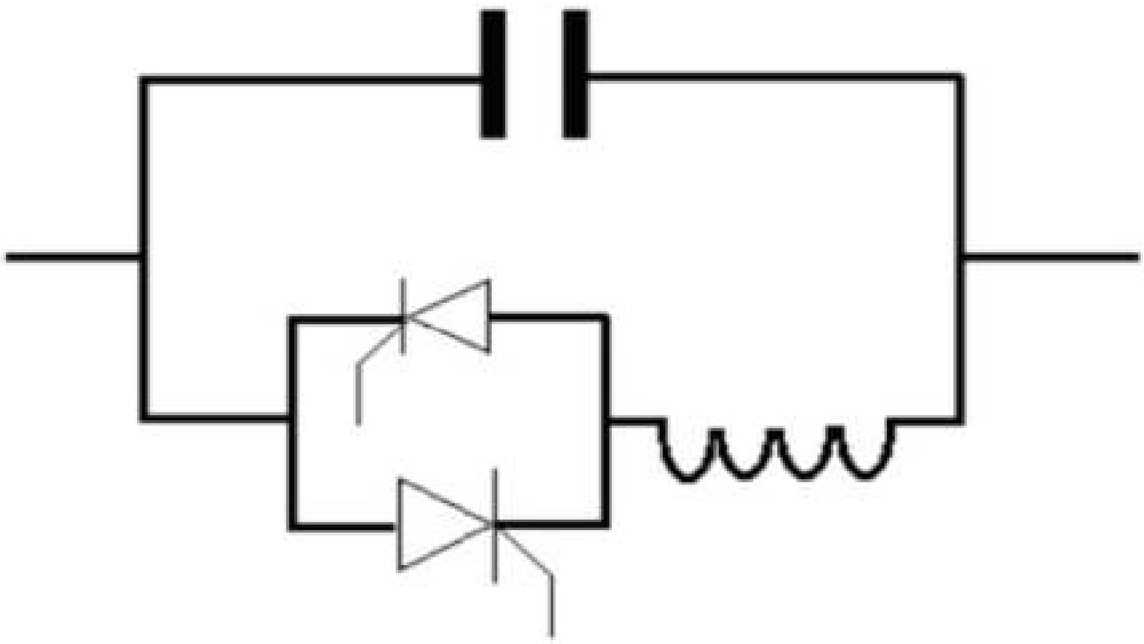

Figure 1: Thyristor Controlled Series Capacitor (TCSC) (Shakil, 2014).

TCSC was made of capacitors, reactors, and bidirectional thyristors. The action of the thyristors was to control the line reactance. This was achieved by switching thyristors either to the capacitive mode or to the inductive mode. When the line was heavily loaded, the thyristors switch to inductive mode thereby releasing more reactors into the line and compensating the line. But when the line was lightly loaded, the thyristor switch to capacitive mode thereby withdrawing more reactors out of the line and compensating line as well reduces the line losses. The switching of the thyristors to the capacitive mode or inductive mode was achieved by the firing angle of the thyristors

Figure 1.2Characteristics of TCSC

International Journal of Engineering and Environmental Sciences | IJEES
Vol. 4. No. 3 | December, 2021 | pp. 1-10
https://airjournal.org/ijees

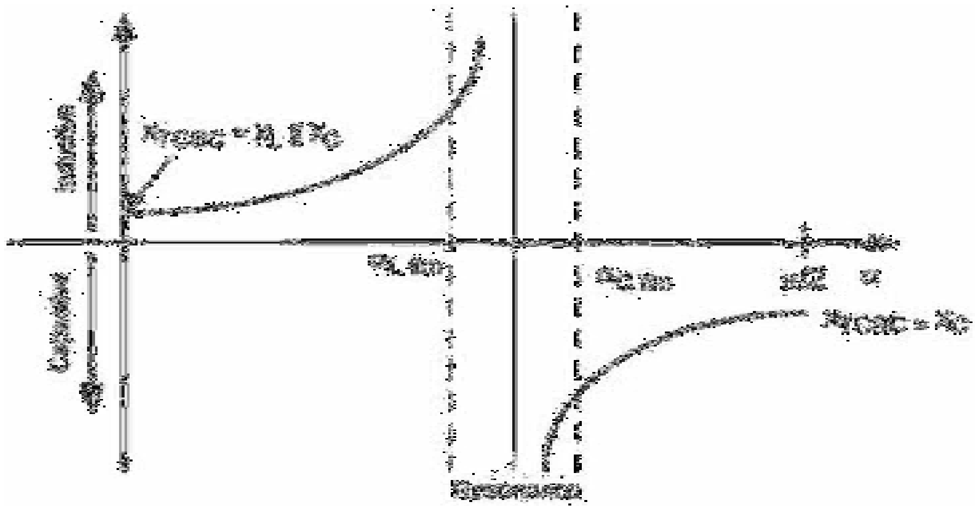

Figure 2: Characteristics of TCSC

Figure 2 showed the characteristics of TCSC. α was the delay angle measured from the crest of the capacitor voltage or equivalently, the zero crossing of the line current. Therefore, with the usual TCSC arrangement in which the impedance of the TCR reactor X_L was smaller than that of the capacitor, X_C, the TCSC has two operating ranges around its internal circuit resonance, capacitive mode or inductive mode.

From the system viewpoint, the principle of variable-series compensation is simply to increase the fundamental-frequency voltage across a Fixed Capacitor (FC) in a series compensated line through appropriate variation of the firing angle, α. This enhanced voltage changes the effective value of the series capacitive reactance. A simple understanding of TCSC functioning can be obtained by analyzing the behavior of a variable inductor connected in parallel with an FC. The maximum voltage and current limits are design values for which the thyristor valve, the reactor, and capacitor banks are rated to meet specific application requirements.

By analyzing the behavior of a variable inductor connected in parallel with an FC. The equivalent impedance, Z_{eq}, of this LC combination is expressed as

I. The impedance of the FC alone, however, is given by -j(l/ωC).

II. If ωC - (l/ωL) > 0 or, in other words, ωL> (1/ωC), the reactance of the FC is less than that of the parallel-connected variable reactor and that this combination provides a variable-capacitive reactance are both implied.

III. If ωC - (1/ωL) = 0, a resonance develops that results in an infinite-capacitive impedance-an unacceptable condition.

IV. If, however, ωC – (1/ωL) < 0, the LC combination provides inductance above the value of the fixed inductor.

The mathematical equation of TCSC is given in equation 1.1.

$$TCSC = X_L \alpha \qquad (1.1)$$

where the $X_L$was the reactors

α was the firing angle of the thyristor

The power moving from sending end to receiving end was given by

$$P = \frac{V_S V_R}{X_L} \cos\theta \qquad (1.2)$$

V_S was the sending voltage

V_R was the receiving end voltage

Cos θ was the power factor

X_L was the impedance of the line

When TCSC was connected in series with the line, equ. (1.2) become

$$P = \frac{V_S V_R}{X_{L\alpha}} \cos\theta \quad (1.3)$$

The thyristors control the capacitor and the reactors. TCSC switches either to the capacitive mode or to the inductive mode using the firing angle. At a firing angle of 180^0, TCSC switches to inductive mode, but it can be varied to get the desired compensation. Also, at firing angle 90^0, TCSC switch to capacitive mode but it can be varied to get the desired compensation.

The TCSC was modeled as follows. Thyristors have three modes of operation, thyristor block, thyristor bypass, and venier mode. Thyristor block occurred when it does not allow any current to pass through the gate of the thyristors, it was called thyristor block. When it allowed current to pass through the gate of the thyristors and latch the thyristors, it was called thyristor bypass. But venier mode was a control mode that allows current to pass through the gate of the thyristors, but in a control mode, a predetermined current setting will either not latch the thyristor or latch the thyristor in capacitive or inductive mode. Venier mode was used in modeling TCSC. The reactors were connected in series; the TCSC drew a certain amount of reactive power that was needed to compensate the line depending on the compensation percentage, whether it was capacitive mode or inductive mode. The reactive power to be injected or withdrawn was controlled by 75% compensation because if 100% compensation was used, there will be noise, distortion, harmonics, and interference. It was modeled in such a way that the current rating of 6A to 10A represents a voltage range of 0.950 to 1.045 per unit system and in Kilovolt, it ranges from 313.5 kV to 346.5 kV. When the voltage was within this range, the thyristor was in block mode. The current does not latch the thyristors. Current rating of 1A to 5A represented voltage below 0.950 in the per-unit system, and below 313.5 kV in kilovolt, when the voltage was below 0.950 in per unit or 313.5 kV in kilovolt, the current will latch the thyristors, and in bypass mode but capacitive mode, that is to say, it will withdraw reactive power from the line and reduce line loss with 75% compensation. But the current rating of 11A to 15A represents voltage above 1.045 in the per-unit system and 346.5 kV in kilovolt, that is to say, when the voltage was above 1.045 in the per-unit system or above 346.5 kV in kilovolt, the current will latch the thyristors but in inductive mode, that is, it injected reactive power into the network and compensate the line using 75% compensation.

TCSC was modeled using the MATLAB/SIMULINK library. The TCSC block consists of a fixed value capacitor and parallel thyristor-controlled reactor (TCR).

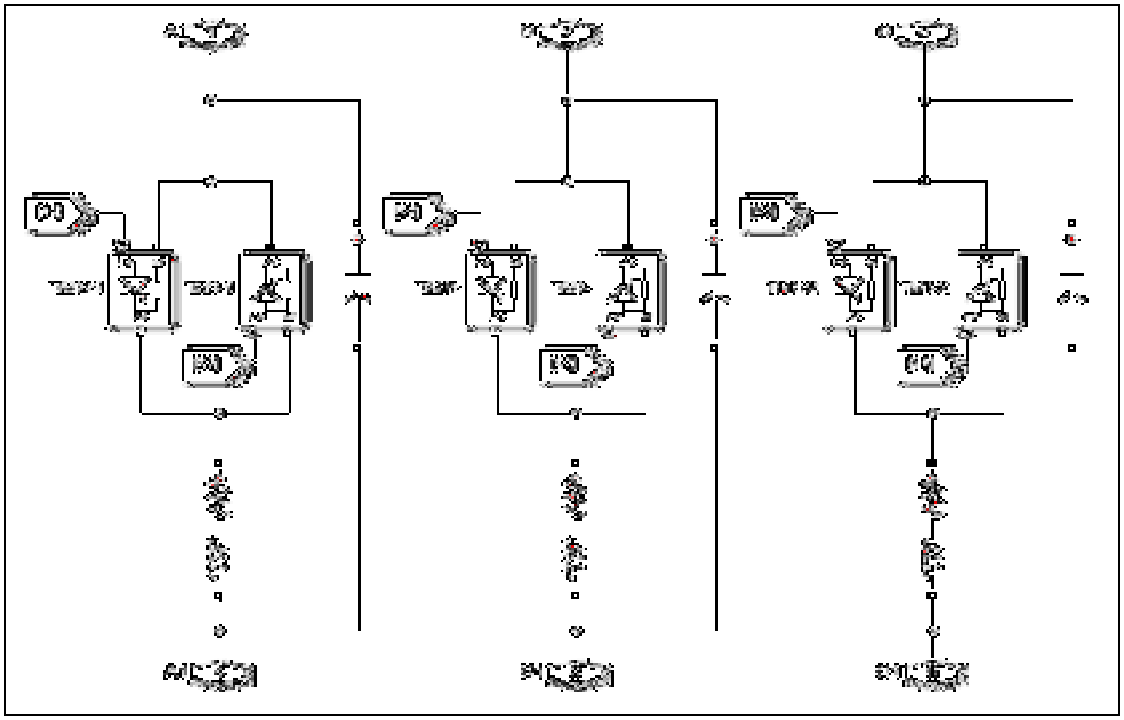

Fig 3: Simulink model of TCSC (for three-phase network model)

The Simulink model of Figure 1.3 was developed in MATLAB. The above-named components blocks were sourced from the Simscape library of Simulink. First, a new model space was opened in Simulink, the components were then copied to the new model space. TCSC was connected using the circuit diagram as shown in Figure 1.3. After connection, thyristors, capacitors, and reactors were modeled by right-clicking on each block, their parameters were queued in the dialog box. TCSC Simulink model was simulated by clicking the simulate button. Successful simulation without errors showed a successful development of the TCSC Simulink model.

TCSC Modeling Parameters
Thyristors parameters
I. Generator rated power = 6000MVA

II. Line Voltage = 330KV

III. Compensation percentage = 75%

IV. Frequency = 50Hz

V. Maximum firing angle and Minimum firing angle = 180^0 and 90^0

VI. Latching current: 1A to 15A

Capacitors Parameters
Capacitor = 2000F

Reactors parameters
A: Resistors
Resistor = 1000Ʊ

B: inductors
Inductor = 1000H

Rated Parameters Factors

a. **Generated rated power:** The operating generating capacity in Nigeria vary from 4000MW to 6000MW that was why generator rated power capacity was chosen as 6000MVA
b. **Line Voltage:** The line Voltage rating was chosen because the highest operating high voltage in Nigeria was 330 kV
c. **Compensation percentage:** 75% compensation percentage was chosen because 100% compensation will produce noise, distortion, and interference, to improve performance and avoid noise and interference, 75% compensation was chosen.
d. **Frequency:** The operating frequency in Nigeria transmission line was 50Hz, therefore, 50Hz frequency was adopted
e. **Maximum and Minimum Firing Angle of Thyristors**: The maximum limit for firing angle of thyristors ranges from 160^0 to 180^0 while the Minimum limit of thyristors ranges from 60^0 to 90^0, 180^0 was adopted for maximum and 90^0 was adopted for the minimum to avoid excessive reactive power in the network.
f. **Capacitor, Resistor, and Inductor:** In an ideal situation, reactive power is supposed to be lower than the active power at the load bus, to avoid excess reactive power in the network, 2000F was chosen for capacitor, 1000Ʊ was chosen for resistor and 1000H was chosen for the inductor.

3. Method of Placing Thyristor Controlled Series Compensator (TCSC)

There is a different method of optimal placement of TCSC in the transmission line, which we are going to look at them holistically and select the best method.

a. Sensitivity Method
It employs placing TCSC at the weakest bus after optimization or continuation load flow. The most sensitive bus or most sensitive line is chosen for optimal placement of TCSC in the network.

b. Genetic Algorithm (GA)
It is a biological approach borrowed to solve power problems and mitigate technical losses in transmission but the limitation of the approach is, it does not work in a real-time format which limits the smart grid operation.

c. Particles Swarm Optimization (PSO)
This technique employs the principle of optimization to mitigate technical losses. Although the technique is slightly better than a genetic algorithm due to its dual characteristics it is limited to a real-time grid system. That is to say that it performed poorly in the smart grid system.

d. Multiple Sensitivity method
This method employs placing TCSC at the weakest bus and most sensitive line which mitigates both the bus voltage and the line losses simultaneously. The method performed better than the sensitivity method, Genetic Algorithm, and particle Swarm Optimization. It was chosen for the proper location of TCSC in the network for optimum results.

Integration of TCSC in the Network
Sensitivity method, Genetic Algorithm and particles Swarm Optimization employ placing TCSC at the weakest bus, what differs is the speed of arriving at the weakest bus. On the other hand, the multiple sensitivity method employed placing TCSC at the weakest bus and the most sensitive line. A simulation was run with multiple sensitivity methods and other methods (sensitivity method, GA and PSO).

Optimal Location of TCSC in the network
There are many methods of placing TCSC in transmission network, but the multiple sensitivity method was very reliable and achieve reasonable efficiency when compared with the sensitivity method, Genetic algorithm, and Particle Swarm optimization, as shown by the simulation result. The sensitivity method, Particle Swarm Optimization, and Genetic Algorithm employed similar end point of placing TCSC at the weakest bus or the line with highest number of losses, what differs was the approach route to arrive at the weakest bus and the speed. Particle Swarm Optimization was faster than the genetic algorithm and genetic algorithm was faster than the sensitivity method but their endpoint was the weakest bus or line with the highest number of losses. Multiple Sensitivity Method was

chosen after simulation was run and compared the results with multiple sensitivity method and other methods (Sensitivity method, Genetic algorithm, and Particle Swarm Optimization). The result showed that the multiple sensitivity method reduced line losses and improved voltage profile when compared with other methods. Multiple sensitivity methods employed placing the TCSC on the weakest bus and the line with the highest number of line losses. In this work, continuation load flow was used to determine the weakest bus and the line with the highest number of line losses. To determine the proper and optimal location of TCSC, load flow was rerun by increasing the generator capacity, and the most sensitive bus and the line were chosen which are bus 37, line 16, and line 19 respectively (Ugwu, 2019). So, TCSC was optimally placed at bus 37, lines 16 and 19 as shown below. For other methods (PSO, GA, and Sensitivity method), TCSC was placed at bus 37 only. The simulation was run and the result showed that the multiple sensitivity method performed better than other methods.

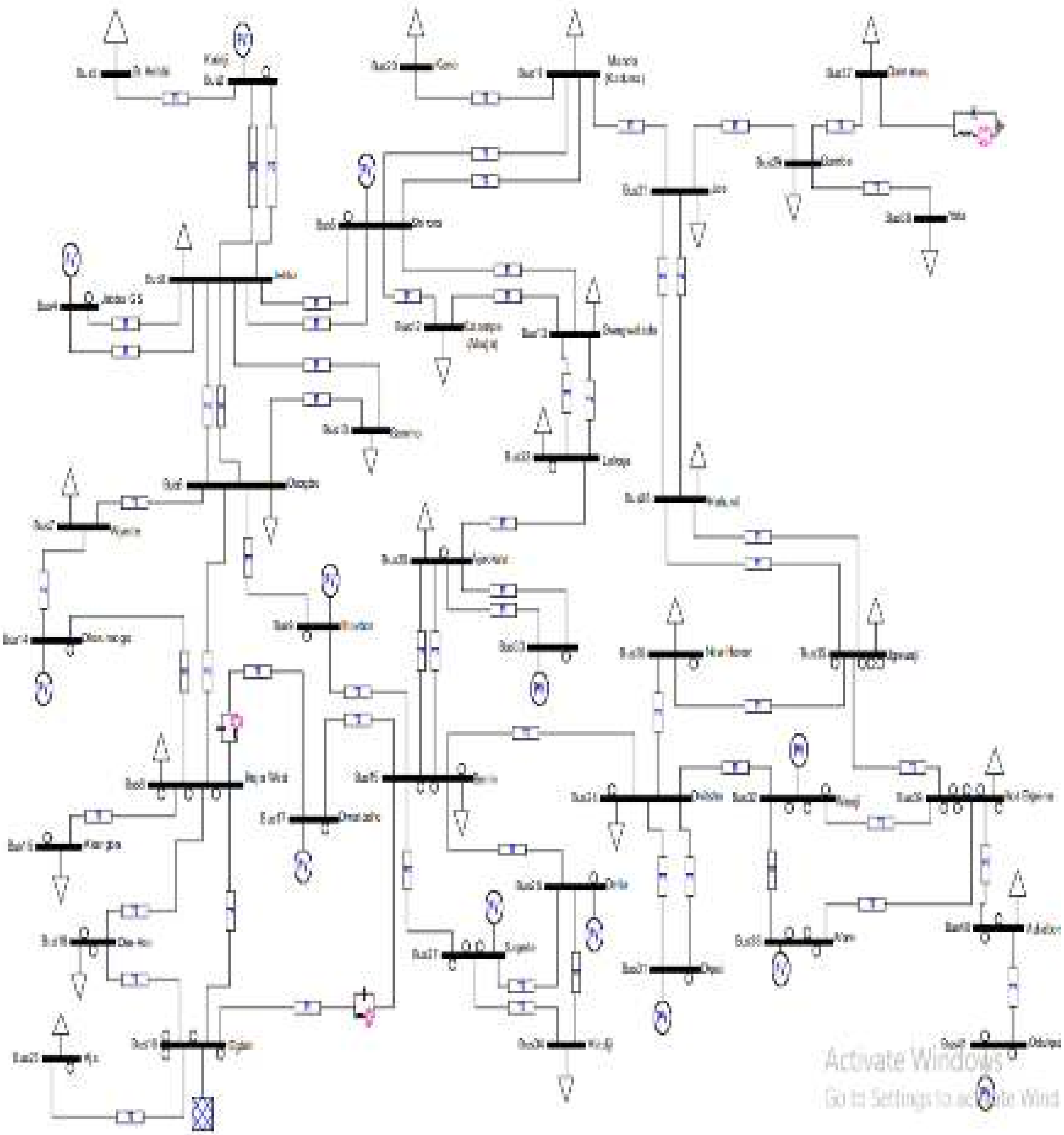

Figure 4: Multiple Sensitivity Model

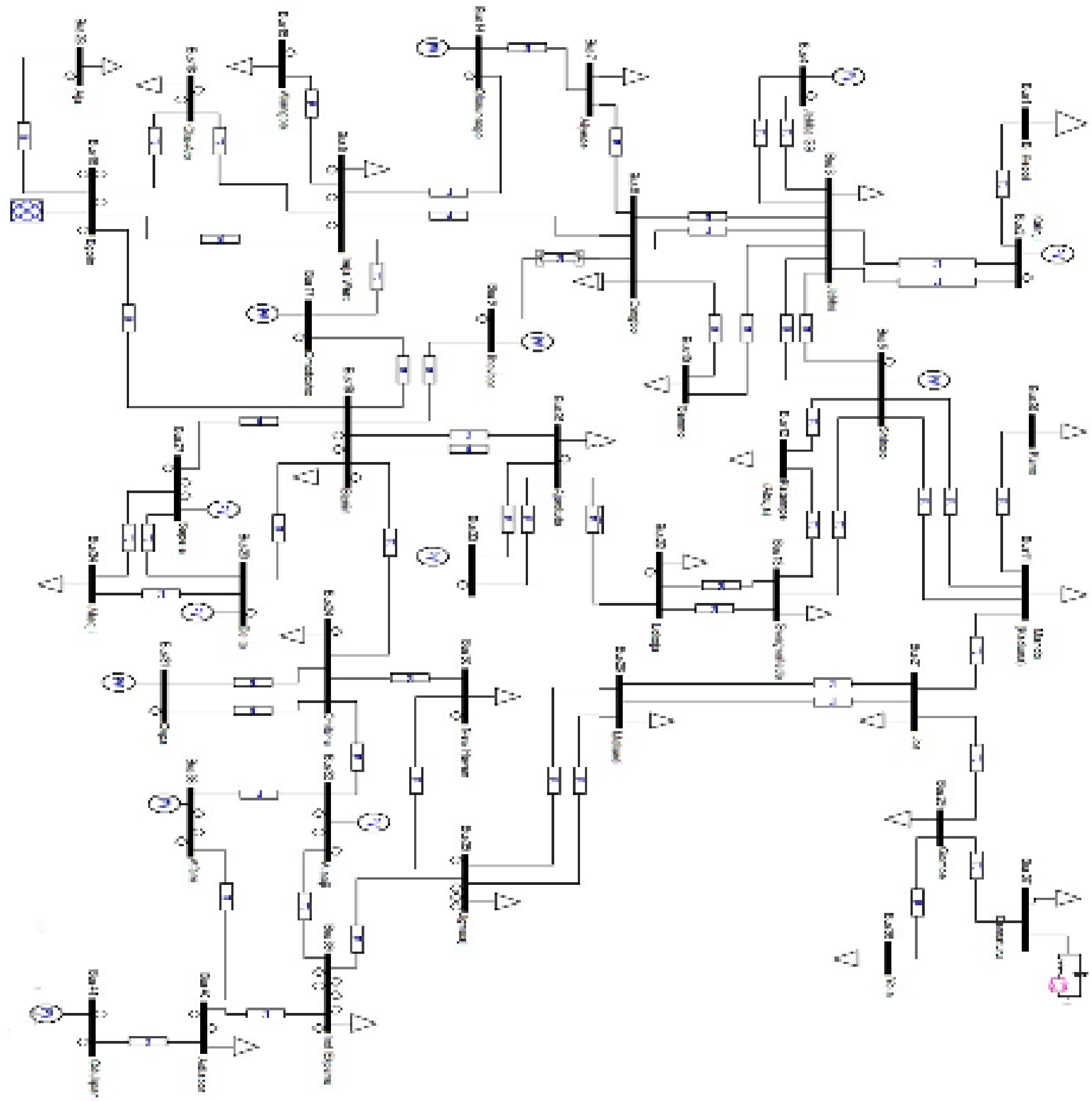

Figure 5: Sensitivity Method Model

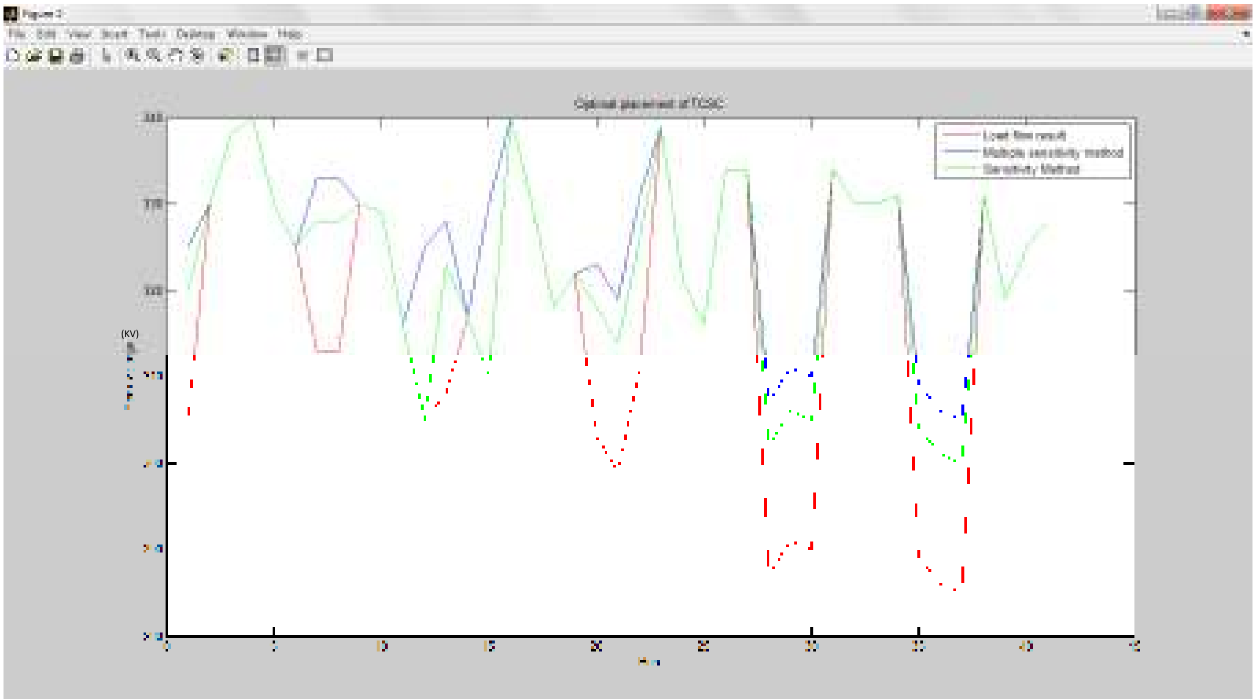

Figure 6: Optimal Placement of TCSC

4. Conclusion

The summary showed that before TCSC was introduced, there is 15 voltage violations, when the TCSC was introduced using multiple sensitivity method, the violation was reduced to 6, then, using the Sensitivity method, the violation was reduced to 7, from the results, it showed that multiple sensitivity method performed better than Sensitivity method and that is why multiple sensitivity method was adopted for optimal placement of TCSC in the network.

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