**Engineering and Technology Journal e-ISSN: 2456-3358**
**Volume 08 Issue 01 January-2023, Page No.-1863-1883**
**DOI: 10.47191/etj/v8i1.09, I.F. – 6.484**


# Development of ANN Controlled UPFC Based Protection Model for Nigerian 330kv Power Lines

**Chukwuagu M.I.[1], Ezechukwu O.A.[2], Aneke E.C.[3], Ogboh V.C.[4]**
[1,2,3,4]Nnamidi Azikiwe University, Awka, & Caritas University Amorji-Nike, Emene Nigerian

**ABSTRACT:** This paper, proposed the use of artificial neural network (ANN) based UPFC for transmission network loss minimization. The overall effect of power losses on the system is a reduction in the quantity of power available to the consumers. Power loss leads to high cost of power generation, transmission and distribution. Unlike exiting up change and regulating transformer techniques for loss reduction, FACTS devices have fast switching capability and can be subjected to very free control algorithms for more optimal performance in loss reduction application in power systems. The neural network was modeled to output the firing angle to enable the FACTS device effectively control the adsorption and injection of reactive power for transmission loss reduction. The Nigerian 330KV power grid was used as a case study for the evaluation of the proposed power loss reduction system A digital model of the case study power system with the proposed neural network controlled UPFC integrated was created in the MATLAB/SIMULINK programming environment. Genetic algorithm was used for the optimal placement of the FACTS device in the MATLAB/SIMULINK model of the Nigerian 330KV transmission system. Simulation carried out involved alteration of power flow in order to cause different levels and distribution of losses in the network. With each variation, load flows was carried out to evaluate the distribution of losses and the active and reactive loss reduction achieved by the proposed system. The simulation and evaluation were carried out under two scenarios: (i) with the UPFC installed and (ii) without the UPFC installed. With each variation of the load at the bus, load flow is run to determine total system loss either with the UPFC installed or without the UPFC installed. Results obtained showed that the proposed system achieved an average active power loss reduction of 12.8416% and an average reactive power loss reduction of 21.82%.

**KEYWORD:** comparison without UPFC and with UPFC, load variation, active and reactive power loss, UPFC, power flow, modeling

## I. INTRODUCTION

The importance of electric power in today's world cannot be overemphasized; it is the key energy source for industrial, commercial and domestic activities. Its availability in the right quantity is essential to advancement of civilization. Electrical energy is supplied to the consumers through the use of transmission lines run from one place to another. As a result of the physical properties of the transmission medium, some of the transmitted powers are lost to the surroundings. The overall effect of power losses on the system is a reduction in the quantity of power available to the consumers. As such, adequate measures must be put in place to reduce power losses to the minimum (Bamigbola, O et. Al, 2014).

Ideally, losses in an electric system should be around 3 to 6%. In developed countries, it is not greater than 10%, however, in developing countries, the percentage of active power losses is around 20%. Therefore, utilities in the electric sector are currently interested in reducing it in order to be more competitive, since the electricity prices in deregulated markets are related to the system losses (Magadum, M.R.B et. Al, 2016 )

Electricity that is been generated from the power station, needs to be transmitted to the end users, through transmission and distribution lines. This transmitted energy is not without losses, but the capacity to transmit at minimal losses is what this dissertation entails.

Transmission of electricity in Nigeria is through the nation grid, which could be in 330kV or 132kV. Transmission grid is a network that consists of conductors carried on steel towers in between transformer stations, which conveys generated power from power stations to major load centers, and interconnecting all power stations to form a solid network that is accessible to all load centers.

In electricity supply to final consumers, losses refer to the amounts of electricity injected into the transmission and distribution grids that are not paid for by users (Bayliss C.R, 2001). Energy losses arise due to technical and non technical losses as power flows through the network. These technical losses are inherent in the system and can be reduced to an optimum level.

Artificial Neural Network (ANN) initiates the biological nervous system to perform the tasks on the input data. To solve highly complex tasks such networks are widely used. It consists of input, one or two hidden and output layers (Mahammad A Hannan et al, 2018). ANN has a lot advantages that makes very suitable and of huge advantage in the design of controllers. In this regard its consideration as a universal approximations of functions for structured or unstructured multivariate datasets makes the its use in controllers very easy to realize (Haykin, S.S.,2009). Its massively parallel processing capability makes very much capable than conventional controller such as PI controller for real time control mission. ANN has found many applications in Power Systems (Vidya Sagaret.al, 1993).Once trained the neural network is able to provide sufficiently accurate recommendations in a very short time suitable for on-line applications in power system.

**Table 1.0 Summary Of Literature Review**

| Authors(s) | Title of Article | Work done | Research gaps |
|---|---|---|---|
| S. Salamat Sharif et. al., 2001 | On-line Optimal Reactive Power Flow for Loss Minimization‖ | The authors worked on a technique to minimize active power loss by finding the optimal reactive power dispatch for the system. In The method, three objectives are included : the first objective is to maintain the voltage profile of the network into acceptable range; second objective is to minimize the total system loss while satisfying the first objective and the third objective is to avoid the excessive adjustments of the system configurations. The variables for this case are VAR/voltages of the generators, transformer tap settings and amount of reactive power generation of reactive power sources. | The algorithm could not be shown to give results consistent with the topological configuration of the power system. |
| Numphetch et al. , , ,2011) | Loss Minimization Using Optimal Power Flow based on Swarm Intelligences | The authors worked on loss minimization using optimal power flow based on swarm intelligences. | The optimization was computation intensive and the algorithm converged slowly. |
| (T.S. Abdel-Salam et. Al, 2015) | A new technique for loss reduction using compensating capacitors applied to distribution systems with varying lad conditions | The authors proposed a heuristic method for reactive loss reduction by connecting a capacitor in that node in which losses due to reactive power is large. The work was validated using simulation. Result showed that the proposed technique reduced loss by 12.67% with reference to the base case of the power system. | It was found that the technique produced inconsistent result under wide variation of load. Further the scheme results in voltage violation due to addition of more capacitors. |
| (Griffin, T., et al, 2000) | Placement of dispersed generation systems for reduced losses. in System Sciences | The authors proposed an exact loss formula based analytical approach to calculate the optimal size and corresponding optimum location of DG in power system for active power loss minimization. Result obtained showed comparable values with loss minimization using similar algorithm in the placement of capacitors for loss minimization. | The DG placement required more complex control technique to enable synchronization with the main power system. Furthermore the work was not validated from the point of view of effect of load variation on performance. |
| F. Sheidei, M. Shadkam, M. Zarei,2008). | Optimal distributed generation allocation in sub-transmission systems employing ant colony to reduce | The authors worked on the use of ant colony optimization for the placement and sizing of distributed generators for loss reduction in sub-transmission systems. Simulations was used to validate the work. The impact on loss | The algorithm suffered from slow convergence, and the authors did no carry out comparative evaluation of the performance of the proposed |

| | | | |
|---|---|---|---|
| | losses | reduction on voltage profile was reported. Result evaluation showed that the proposed scheme achieved about 17.23% reduction in active loss , using the base power system as baseline. | method. |

**II. METHODOLOGY**

The Unified Power Flow Controller (UPFC) is the FACTS device used in this work for the proposed minimization of power loses in the Nigerian 330KV power system. The strategy adopted in this study is the placement and control of the UPFC device to optimally control current and voltage so as to reduce ohmic and corona losses in the power system. Neural network controller is used to control the injection and adsorption of active and reactive power by the UPFC so that current and voltage are dynamically controlled. This allows power to be transmitted at the lowest current possible (in order to reduce ohmic loss) and at an operating voltage level not exceeding the critical disruptive voltage (in order to reduce losses due to corona).

Genetic Algorithm will be used to compute the optimal locations for the installation of the FACTS devices.

The digital model of the Nigerian 330KV power system will be created in MATLAB/SIMULINK software for the evaluation of the performance of the neural network based UPFC. Simulation studies will be carried out to evaluate the ability of the UPFC to ensure that power is transmitted at minimal losses.

Transmission system faults and contingencies that cause rise in transmission current and voltages will be simulated. This will be done in order to determine the performance of the FACTS device in ensuring transmission loss minimization in the case study network.

**Power Flow UPFC Modeling**

Power flow UPFC model contains two voltage source converters (VSC), one has shunt connection and other has series connection. The converters have DC capacitors, which are connected in parallel as shown in Figure 1.0. When switches, 1 and 2 are open, the converters are STATCOM and SSSC, governing the injected reactive current and voltage in shunt and series of the line. When switches 1 and 2 are closed, it enables the two converters to transfer real power between the two converters. The series connected converter can draw or generate the active

Power

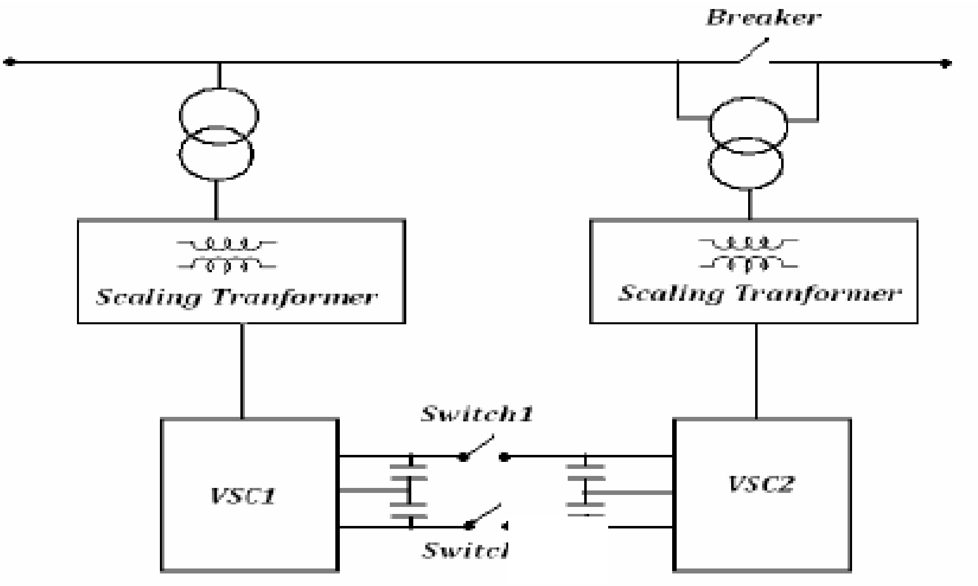


**Figure 1.0: A UPFC schematic.**

The general transfer admittance matrix is obtained by applying Kirchhoff current and voltage laws to the electric circuit shown in Figure 1.1.

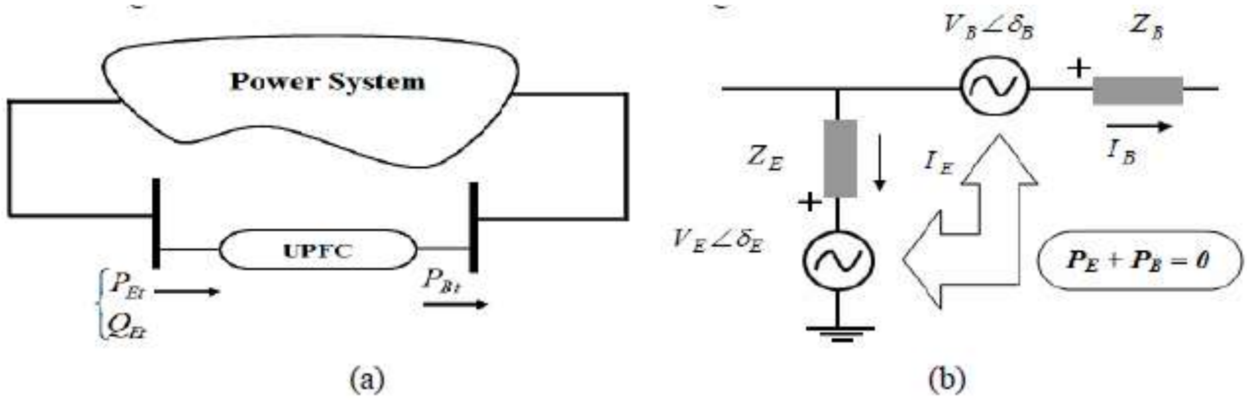


**Figure. 1.1: (a) UPFC Power Flow Model (b) UPFC Single Line Diagram.**

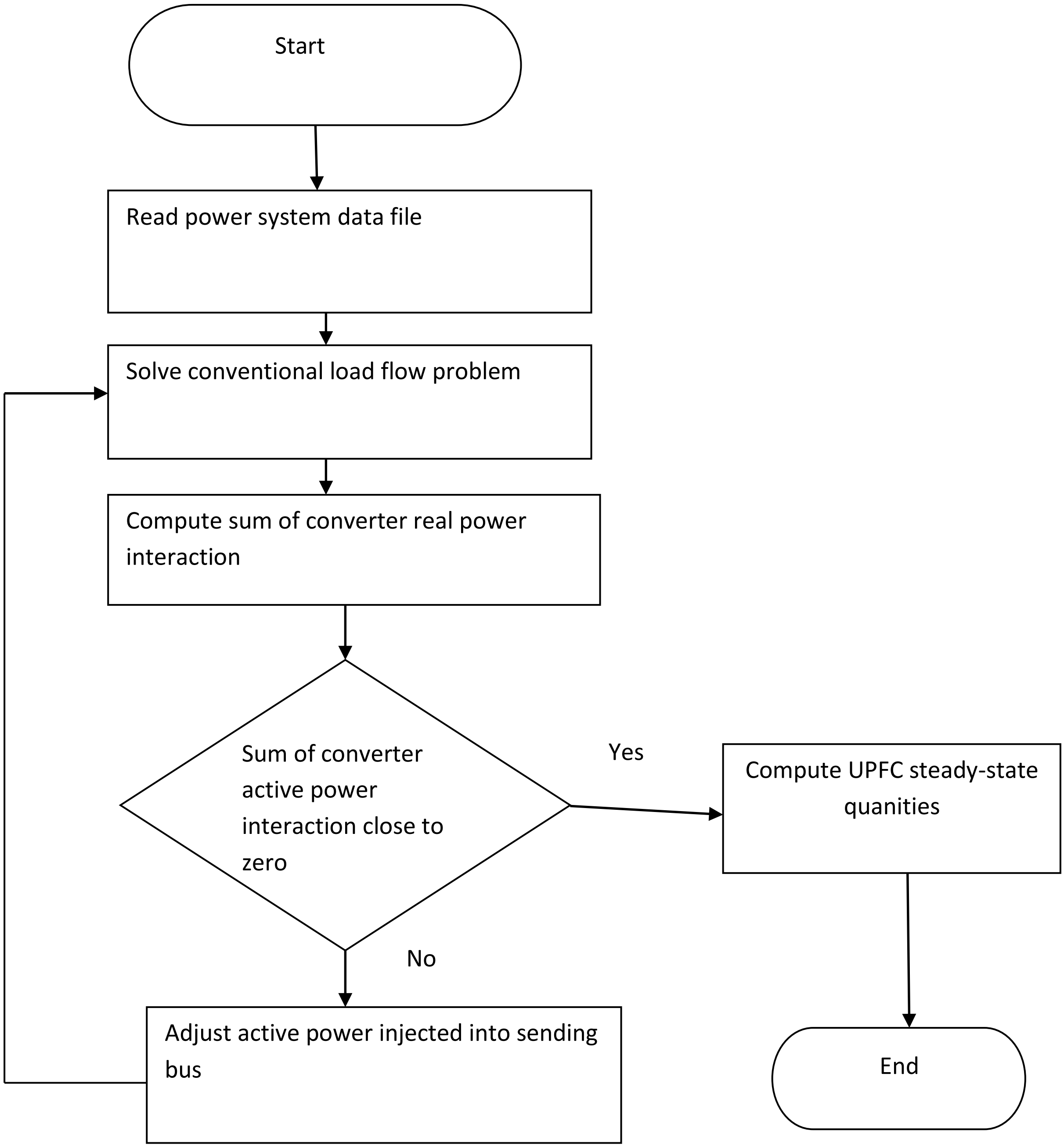


**Figure 1.2 : General Load flow Algorithm with UPFC**

Note: As indicated in the flowchart, reading the power system data file includes reading

- the UPFC parameters
- power flow at receiving bus
- initial power injected into sending bus

**III. TEST AND SIMULATIONS**

For the simulation, the single line diagram of the Nigerian 330kV power transmission network is used to create the SIMULINK digital model of the case study power system. The single line diagram of the case study network used is given on figure 1.0. The power system consists of 14 generators, 67 buses, 39 load points and 111 transmission lines. The generator data and line data of the case study power system is given on Table 1.1.

The case study power system is modeled in MATLAB/SIMULINK. Figure 1.1 shows the SIMULINK model of the power system without the neural network controlled UPFC installed.

**SINGLE LINE DIAGRAM OF THE NIGERIAN 330/132KV POWER SYSTEM**

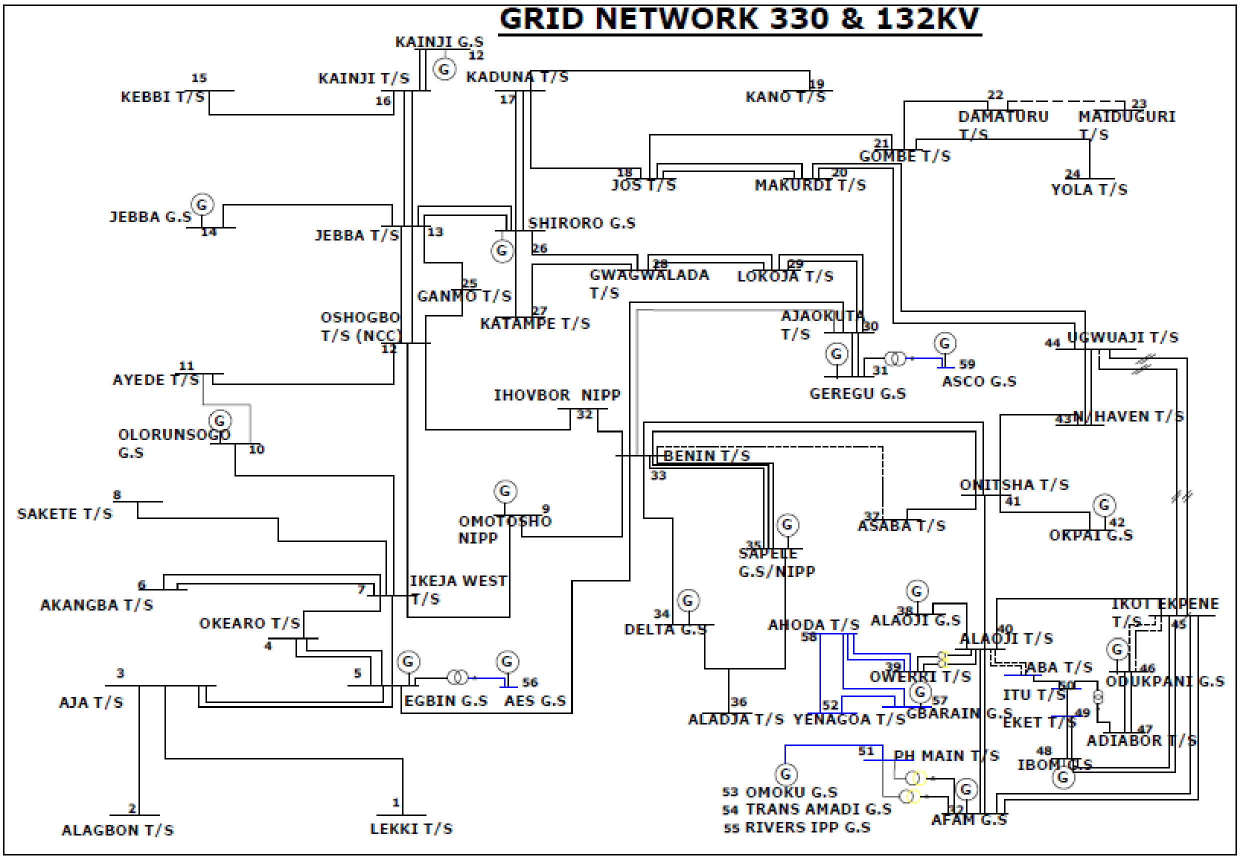


**Table 1.1 Generator Data**

There are 14 synchronous generations in the system. The base voltage is 330KV and 100MVA

| Generator Station | Generation | Rated Voltage | Voltage Pv |
|---|---|---|---|
| Kainji | 292mw | 332kv | 1.0060 |
| Jebba | 404mw | 312kv | 0.9455 |
| Shiroro | 450mw | 320kv | 0.9697 |
| Egbini | 611mw | 335kv | 1.0151 |
| Sapele | 68mw | 332kv | 1.0060 |
| Delta | 470mw | 318kv | 0.9636 |
| Geregu | 144mw | 319kv | 0.9677 |
| Omotosho | 187.5mw | 305kv | 0.9242 |
| Olominsogo gas | 163.6mw | 300kv | 0.9090 |
| Geregu NIpp | 150mw | 331kv | 1.0030 |

| | | | |
|---|---|---|---|
| Sapele NIpp | 113.1mw | 320kv | 0.9692 |
| Olorunsogo NIpp | 130.9mw | 316kv | 09576 |
| Omotosho NIpp | 228mw | 347kv | 1.05151 |
| Okapia | 363mw | 331kv | 1.0030 |

**The following table gives the generation inertia, resistance, leakage reactance, transient and sub-transient reactance, and time constant.**

| Generation Station | $X_1$ | $X_d$ | $X_q$ | $X_d^1$ | $X_q^1$ | $X_d^{11}$ | $X_q^{11}$ | $T_{d0}^1$ | $T_{q^D}^1$ | $T_{d0}^{11}$ | $T_{q0}^{11}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Kainji | 0.0030 | 0.2000 | 0.0190 | 0.0060 | 0.0006 | 0.0006 | 0.0006 | 7.000 | 0.7000 | 0.0330 | 0.0563 |
| Jebba | 0.0350 | 0.2950 | 0.2820 | 0.0697 | 0.0369 | 0.0369 | 0.0369 | 6.5600 | 1.5000 | 0.0660 | 0.0660 |
| Shiroro | 0.0304 | 0.2495 | 0.2370 | 0.0531 | 0.0320 | 0.0320 | 0.0320 | 5.7000 | 1.5000 | 0.0570 | 0.570 |
| Egbin | 0.0295 | 0.2620 | 0258 | 0.0436 | 0.0310 | 0.0310 | 0.0310 | 5.5900 | 1.5000 | 0.0570 | 0.0430 |
| Sapele | o.0540 | 0.6700 | 0.6200 | 0.1320 | 0.0568 | 0.0560 | 0.0562 | 5.400 | 0.4400 | 0.0540 | 0.0532 |
| Delta | 0.0224 | 0.2540 | 0.2410 | 0.0500 | 0.0236 | 0.0326 | 0.0326 | 7.3000 | 0.4272 | 0.0730 | 0.0624 |
| Geregu | 0.0322 | 0.2950 | 0.2920 | 0.0490 | 0.0340 | 0.0340 | 0.0340 | 5.6600 | 0.5300 | 0.0560 | 0.0731 |
| Omotosho | o.o280 | 0.2900 | 0.0800 | 0.0570 | 0.0300 | 0.0300 | 0.300 | 6.7000 | 1.540 | 0.0670 | 0.0832 |
| Olorunsogo | 0.0298 | 0.2160 | 0.2050 | 0.0587 | 0.0314 | 0.0314 | 0.0314 | 4.7900 | | 0.0470 | 0.0511 |
| Geregu NIpp | 0.0125 | 0.100 | 0.0690 | 0.0672 | 0.0132 | 0.0132 | 0.0132 | 10.200 | 1.9000 | 0.1000 | 0.0631 |
| Sapele NIpp | 0.0424 | 0.2543 | 0.0347 | 0.0570 | 0.0472 | 0.0123 | 0.0123 | 8.3102 | 0.9321 | 0.0830 | 0.0520 |
| OlorunsogNIpp | 0.0262 | 0.2216 | 0.0312 | 0.0310 | 0.0085 | 0.0226 | 0.0226 | 7.0769 | 1.6020 | 0.0082 | 0.0511 |
| OmotoshoNIpp | 0.0257 | 0.5571 | 0.0217 | 0.1168 | 0.0173 | 0.0533 | 0.0533 | 6.6234 | 0.6930 | 0.0032 | 0.0622 |
| Okapi | 0.0312 | 0.2862 | 0.5113 | 0.0227 | 0.0280 | 0.0571 | 0.0571 | 5.2700 | 1.2030 | 0.0070 | 0.0507 |

**LINE DATA**

| Line # | Buse Code p-q | Line positive sequence Resistance p.u | Line positive sequence Reactance p.u | Length km | Status |
|---|---|---|---|---|---|
| 1 | | 0.0612 | 0.0801 | 3.14 | |
| 2 | | 0.0312 | 0.0452 | 2.78 | |
| 3 | | 0.043 | 0.0713 | 1.98 | |
| 4 | | 0.0612 | 0.0801 | 3.14 | |
| 5 | | 0.0612 | 0.0801 | 3.14 | |
| 6 | | 0.0312 | 0.0452 | 2.78 | |
| 7 | | 0.0573 | 0.1013 | 5.0 | |
| 8 | | 0.0614 | 0.0994 | 4.50 | |
| 9 | | 0.0614 | 0.0994 | 4.50 | |
| 10 | | 0.03342 | 0.0784 | 4.80 | |
| 11 | | 0.043 | 0.0713 | 1.98 | |
| 12 | | 0.043 | 0.0713 | 1.98 | |
| 13 | | 0.0312 | 0.0452 | 2.78 | |
| 14 | | 0.0612 | 0.0801 | 3.14 | |
| 15 | | 0.0612 | 0.0801 | 3.14 | |
| 16 | | 0.0278 | 0.0407 | 1.20 | |
| 17 | | 0.0278 | 0.0407 | 1.20 | |
| 18 | | 0.0614 | 0.0994 | 4.50 | |
| 19 | | 0.0573 | 0.1013 | 5.0 | |
| 20 | | 0.0312 | 0.0452 | 2.78 | |
| 21 | | 0.043 | 0.0713 | 1.98 | |
| 22 | | 0.0278 | 0.0407 | 1.20 | |
| 23 | | 0.0603 | 0.1034 | 3.60 | |
| 24 | | 0.0389 | 0.0813 | 2.50 | |
| 25 | | 0.043 | 0.0713 | 1.98 | |

| | | | | | |
|---|---|---|---|---|---|
| 26 | | 0.03342 | 0.0784 | 4.80 | |
| 27 | | 0.0612 | 0.0801 | 3.14 | |
| 28 | | 0.0278 | 0.0407 | 1.20 | |
| 29 | | 0.043 | 0.0713 | 1.98 | |
| 30 | | 0.0278 | 0.0407 | 1.20 | |
| 31 | | 0.043 | 0.0713 | 1.98 | |
| 32 | | 0.0573 | 0.1013 | 5.0 | |
| 33 | | 0.0614 | 0.0994 | 4.50 | |
| 34 | | 0.03342 | 0.0784 | 4.80 | |
| 35 | | 0.0603 | 0.1034 | 3.60 | |
| 36 | | 0.0603 | 0.1034 | 3.60 | |
| 37 | | 0.0612 | 0.0801 | 3.14 | |
| 38 | | 0.0278 | 0.0407 | 1.20 | |
| 39 | | 0.043 | 0.0713 | 1.98 | |
| 40 | | 0.0603 | 0.1034 | 3.60 | |
| 41 | | 0.0389 | 0.0813 | 2.50 | |
| 42 | | 0.0603 | 0.1034 | 3.60 | |
| 43 | | 0.0389 | 0.0813 | 2.50 | |
| 44 | | 0.043 | 0.0713 | 1.98 | |
| 45 | | 0.0612 | 0.0801 | 3.14 | |
| 46 | | 0.03342 | 0.0784 | 4.80 | |
| 47 | | 0.0614 | 0.0994 | 4.50 | |
| 48 | | 0.0573 | 0.1013 | 5.0 | |
| 49 | | 0.043 | 0.0713 | 1.98 | |
| 50 | | 0.0278 | 0.0407 | 1.20 | |
| 51 | | 0.0278 | 0.0407 | 1.20 | |
| 52 | | 0.043 | 0.0713 | 1.98 | |
| 53 | | 0.0278 | 0.0407 | 1.20 | |
| 54 | | 0.0312 | 0.0452 | 2.78 | |
| 55 | | 0.0573 | 0.1013 | 5.0 | |
| 56 | | 0.0612 | 0.0801 | 3.14 | |
| 57 | | 0.0614 | 0.0994 | 4.50 | |
| 58 | | 0.0614 | 0.0994 | 4.50 | |
| 59 | | 0.0614 | 0.0994 | 4.50 | |
| 60 | | 0.0573 | 0.1013 | 5.0 | |
| 61 | | 0.03342 | 0.0784 | 4.80 | |
| 62 | | 0.0612 | 0.0801 | 3.14 | |
| 63 | | 0.043 | 0.0713 | 1.98 | |
| 64 | | 0.043 | 0.0713 | 1.98 | |
| 65 | | 0.0278 | 0.0407 | 1.20 | |
| 66 | | 0.0612 | 0.0801 | 3.14 | |
| 67 | | 0.0573 | 0.1013 | 5.0 | |
| 68 | | 0.03342 | 0.0784 | 4.80 | |
| 69 | | 0.043 | 0.0713 | 1.98 | |
| 70 | | 0.043 | 0.0713 | 1.98 | |
| 71 | | 0.0603 | 0.1034 | 3.60 | |
| 72 | | 0.043 | 0.0713 | 1.98 | |
| 73 | | 0.0603 | 0.1034 | 3.60 | |
| 74 | | 0.0278 | 0.0407 | 1.20 | |
| 75 | | 0.0278 | 0.0407 | 1.20 | |
| 76 | | 0.0612 | 0.0801 | 3.14 | |
| 77 | | 0.0573 | 0.1013 | 5.0 | |
| 78 | | 0.03342 | 0.0784 | 4.80 | |

| | | | | | |
|---|---|---|---|---|---|
| 79 | | 0.0612 | 0.0801 | 3.14 | |
| 80 | | 0.0389 | 0.0813 | 2.50 | |
| 81 | | 0.0278 | 0.0407 | 1.20 | |
| 82 | | 0.0614 | 0.0994 | 4.50 | |
| 83 | | 0.03342 | 0.0784 | 4.80 | |
| 84 | | 0.0312 | 0.0452 | 2.78 | |
| 85 | | 0.0389 | 0.0813 | 2.50 | |
| 86 | | 0.043 | 0.0713 | 1.98 | |
| 87 | | 0.0312 | 0.0452 | 2.78 | |
| 88 | | 0.0612 | 0.0801 | 3.14 | |
| 89 | | 0.03342 | 0.0784 | 4.80 | |
| 90 | | 0.0278 | 0.0407 | 1.20 | |
| 91 | | 0.0312 | 0.0452 | 2.78 | |
| 92 | | 0.0612 | 0.0801 | 3.14 | |
| 93 | | 0.0312 | 0.0452 | 2.78 | |
| 94 | | 0.0573 | 0.1013 | 5.0 | |
| 95 | | 0.043 | 0.0713 | 1.98 | |
| 96 | | 0.0603 | 0.1034 | 3.60 | |
| 97 | | 0.0573 | 0.1013 | 5.0 | |
| 98 | | 0.0612 | 0.0801 | 3.14 | |
| 99 | | 0.0312 | 0.0452 | 2.78 | |
| 100 | | 0.043 | 0.0713 | 1.98 | |
| 101 | | 0.0612 | 0.0801 | 3.14 | |
| 102 | | 0.0612 | 0.0801 | 3.14 | |
| 103 | | 0.0312 | 0.0452 | 2.78 | |
| 104 | | 0.0573 | 0.1013 | 5.0 | |
| 105 | | 0.0614 | 0.0994 | 4.50 | |
| 106 | | 0.0614 | 0.0994 | 4.50 | |
| 107 | | 0.03342 | 0.0784 | 4.80 | |
| 108 | | 0.043 | 0.0713 | 1.98 | |
| 109 | | 0.043 | 0.0713 | 1.98 | |
| 110 | | 0.0312 | 0.0452 | 2.78 | |
| 111 | | 0.0612 | 0.0801 | 3.14 | |

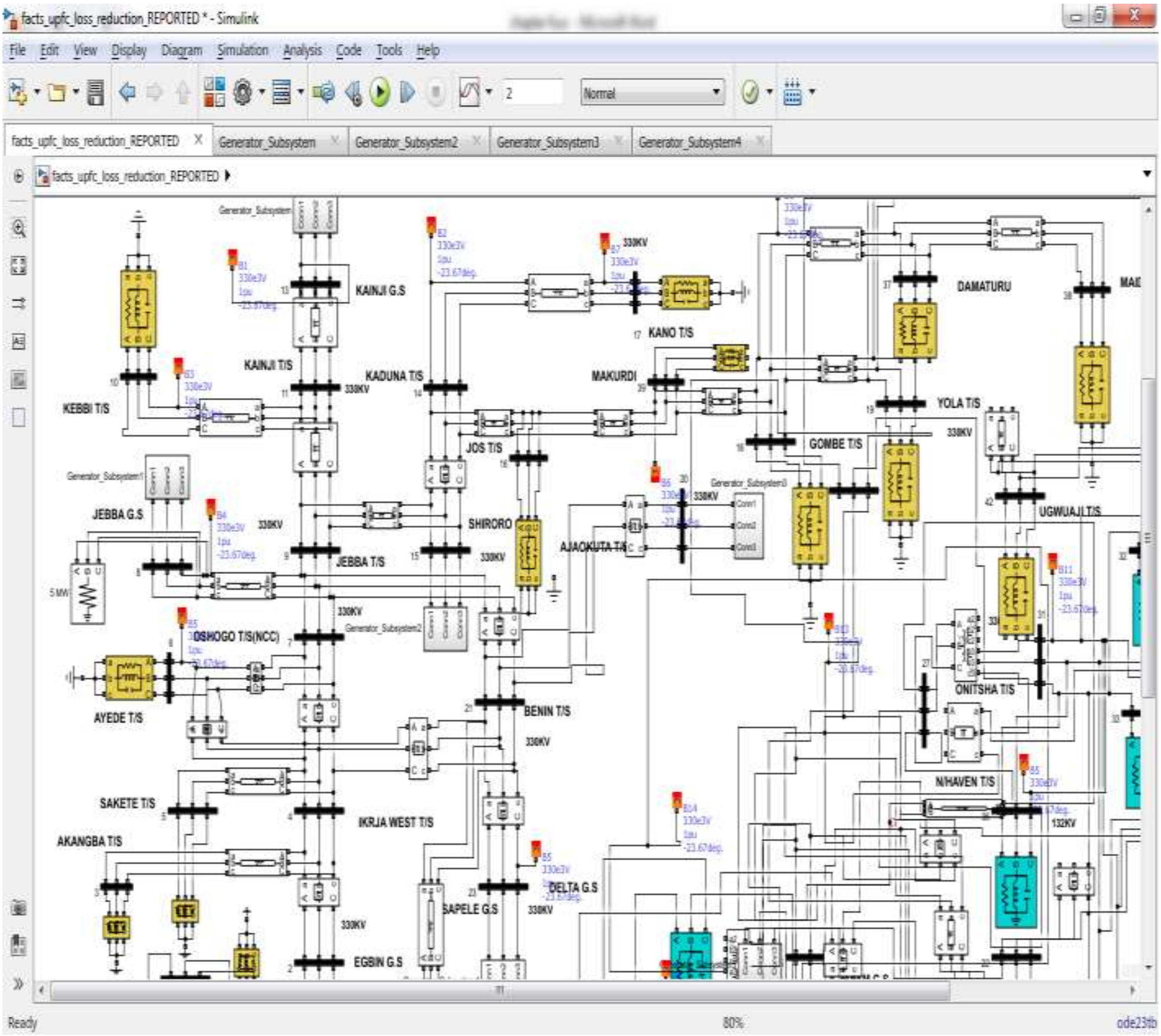


**Figure 1.1: SIMULIK model of the 330kV transmission network without the UPFC installed.**

## IV. TRANSMISSION LOSS REDUCTION FOR LOAD VARIATION AT BUS 49 WITHOUT UPFC INSTALLED

In the simulation carried out, load flows are carried out to evaluate the loss reduction for load variation at 49 (the most stable bus in the base case of the power system).The simulation and evaluations are carried out under two scenarios: (i) with the UPFC installed and (ii) without the UPFC installed.

The three phase SIMULINK R-L-C load blocks installed at the load buses are configurable. The load values in the blocks can be reconfigured in MATLAB.

With each variation of load at the bus, load flow is run to determine total system loss either with the UPFC installed or without the UPFC installed.

The variation of load on the bus starts at 198MW (which is about 2% of the total Nigerian load demand of 9895MW, not including export demand) . Then an increment of 50% (i.e. 99MW) of the initial load is added to obtain further load variations at the bus. Hence, the variations of loading conditions at the bus are: 198MW, 297MW, 396MW, 495MW, and 594MW.

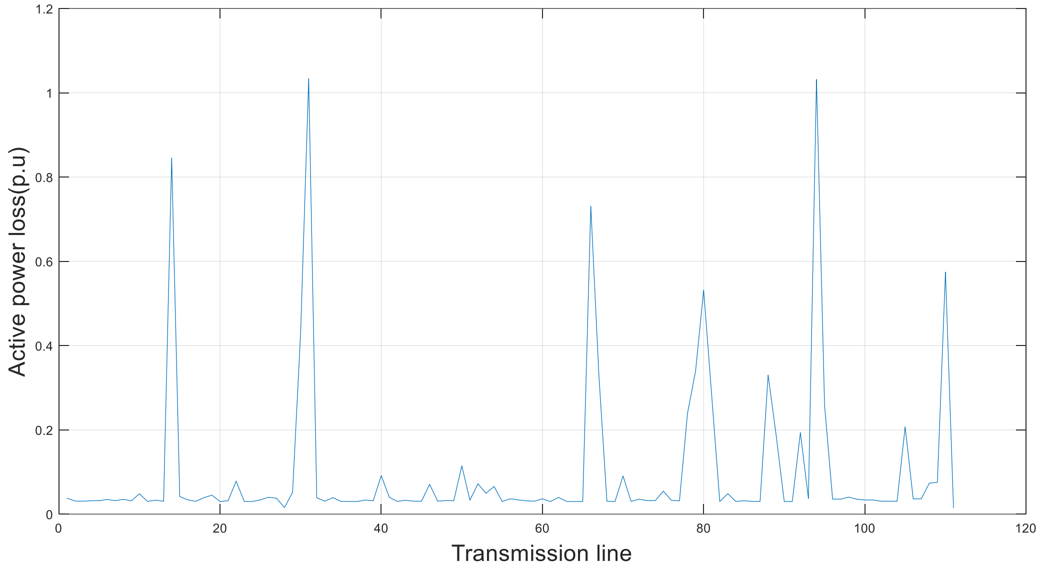


**Figure.4.2: Active power loss distribution in the power system without UPFC installed for 198MW load drawn at bus 49.**

**Table1.2: Variation of power losses with load in the power system without UPFC installed**

| **Load variation(MW)** | **Total active power loss(p.u)** | **Total Reactive power loss(p.u)** |
|---|---|---|
| 198 | 11.1730 | 60.7648 |
| 297 | 12.1387 | 68.4904 |
| 396 | 13.1044 | 84.1944 |
| 495 | 13.8587 | 97.1322 |
| 594 | 14.7901 | 113.3895 |
| **Total** | **65.0645** | **423.9713** |

The trend that can be observed from Table 1.2 is that as the load increases, the active and reactive losses increase. To observe this trend visually, the variations of active power loss with load and the variations of reactive power losses with load are plotted as shown in Figure 1.2 and Figure1.3 respectively.

From Figures 1.2 and 1.3, it can be observed that despite the nonlinearity of the power system generally, the total systems active and reactive power losses increase almost linearly with increase in load variation at a bus. This power loss with load variations without UPFC installed will be used as baseline to evaluate the power loss reduction due to the installation of UPFC.

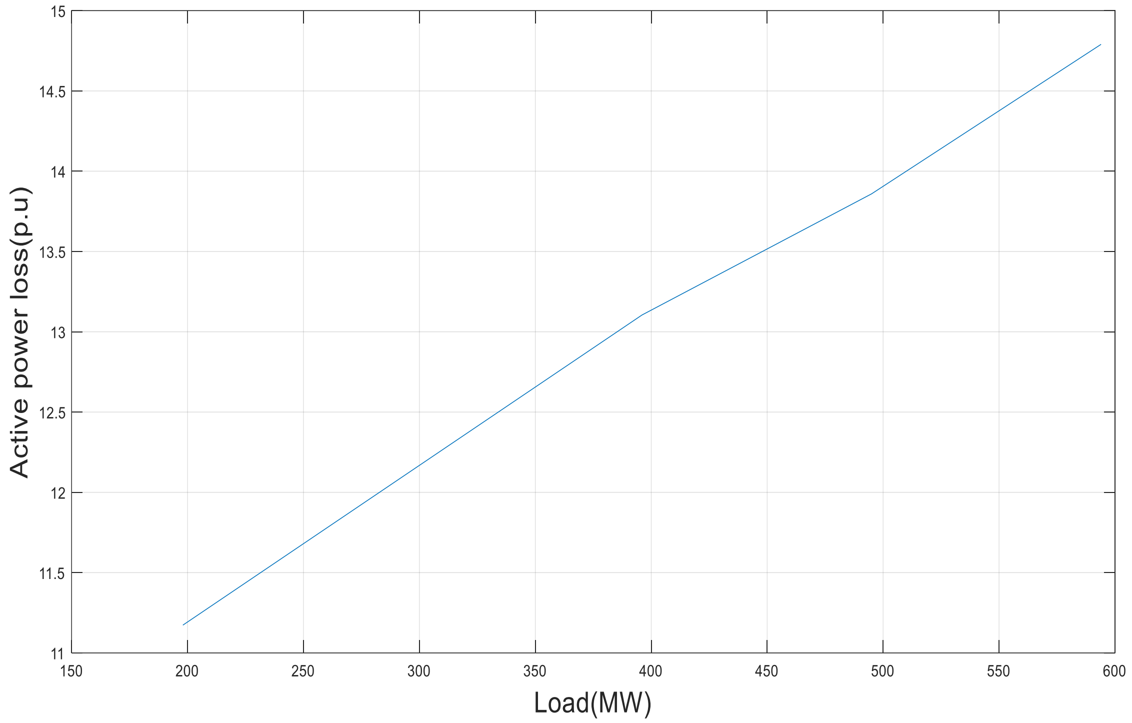


**Figure 1.2: Active power with load variation without UPFC installed in the power system**

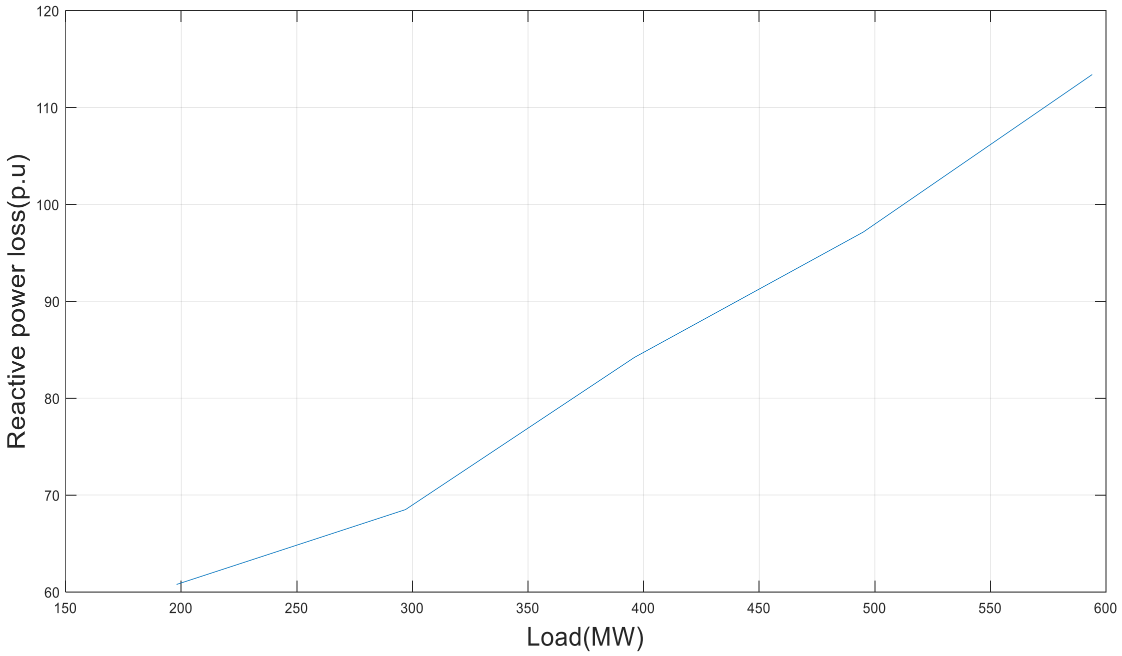


**Figure 1.3: Reactive power with load variation without UPFC installed in the power system**

**VI. TRANSMISSION LOSS REDUCTION FOR LOAD VARIATION WITH UPFC INSTALLED IN THE POWER SYSTEM.**

Simulations are carried to compute the location for placement of the FACTS devices ( i.e. UPFC and the TCSC.) . In the simulation carried out, the FACTS device placement genetic algorithm was coded in MATLAB m-file program. The source code of the genetic algorithm program used to compute the location of placement of the FACTS device is given on appendix U. The algorithm computes the optimal location for the placement of the FACTS device. When loaded into memory, it communicates with the load flow program via the MATLAB program workspace, from where it reads the values of load flow variable. The genetic algorithm program outputs the bus locations for the optimal placement of the UPFC device. Running the genetic algorithm program a number of iterations would give the optimal location for placement of corresponding number of FACTS devices.

However one iteration for placement of one UPFC device was executed in the simulation carried out. From simulation out put, the UPFC was placed between bus 16 (at Jos T/S) and bus 39(at Markurdi). The SIMULINLK(the digital model) of the Nigerian 330KV network given in Figure 1.4.

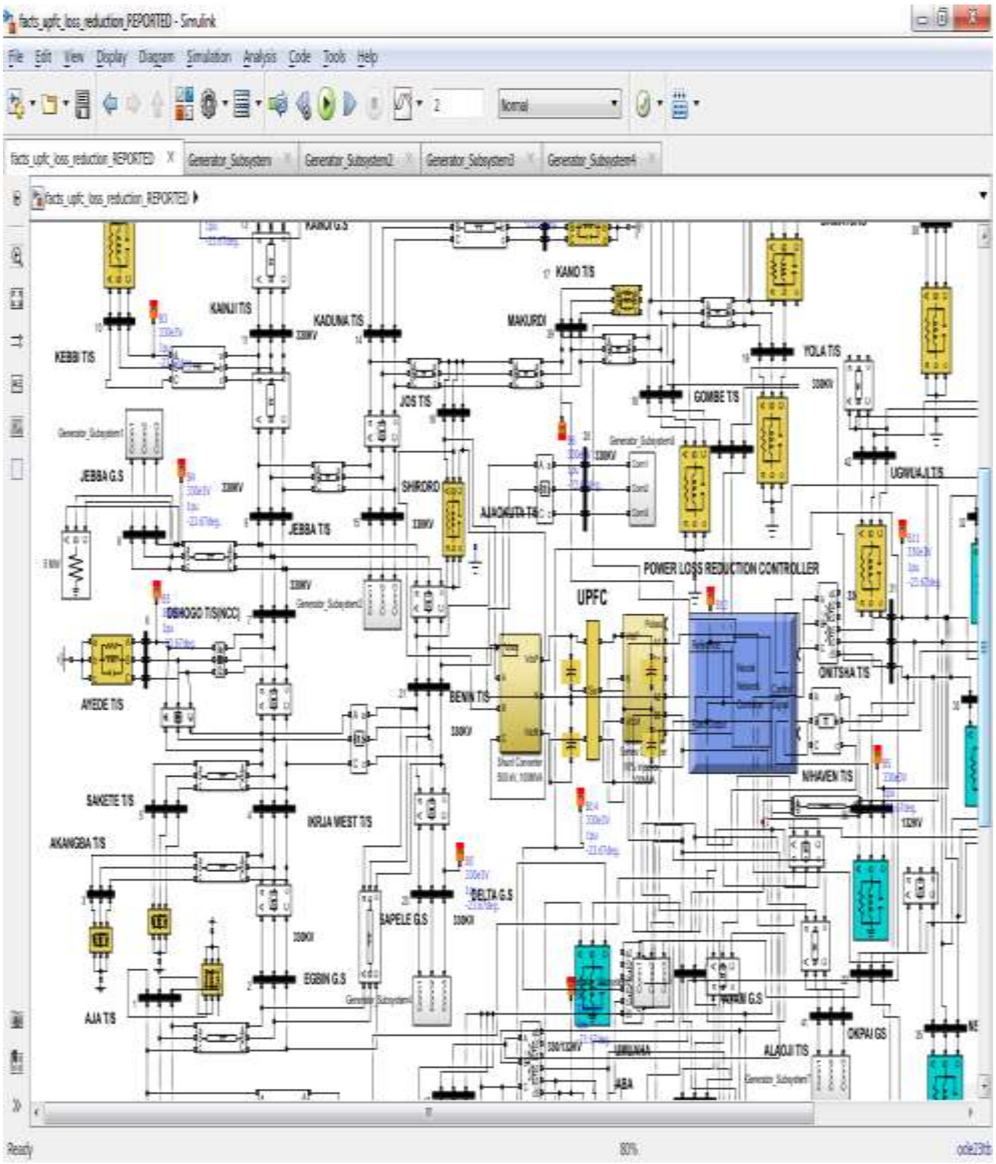


**Figure 1.4: SIMULINK model of the power system with UPFC installed at the optimal location determined using genetic algorithm.**

The simulation model of the power system is shown in figure 1.4 with the UPFC placed at the selected location. With the placement of the UPFC in the power system, load variation simulation is carried out to evaluate the impact of the UPFC on loss reduction in the power system.

With the placement of the UPFC and installation of the NN power loss reduction controller, variations of load at bus 49 is carried out as done in the previous scenarios (i.e. in the case of the power system without the UPFC installed) to evaluate the reduction of active and reactive losses in the system due to the installation of the UPFC.

With the UPFC installed in the power system, similar evaluation is carried out as in the case of the power system without the installation of the UPFC.

Variation of the load are 198MW, 297MW, 396MW, 495MW and 594MW loads drawn at bus 49 respectively with UPFC installed. The base value of 100MVA was used.

**Table1.3: Variation of power losses with load in the power system with UPFC installed.**

| Load variation(MW) | Total active power loss(p.u) | Total Reactive power loss(p.u) |
|---|---|---|
| 198 | 8.0838 | 56.0455 |
| 297 | 10.9512 | 59.988 |

| | | |
|---|---|---|
| 396 | 11.7169 | 64.9305 |
| 495 | 12.6826 | 66.873 |
| 594 | 13.6483 | 73.8155 |
| **Total** | **57.0828** | **321.6525** |

The trend that can be observed from Table 1.3 is that as the load increases, the active and reactive losses increase. From Table 1.3, to observe this trend visually, the variations of active power loss with load and the variations of reactive power losses with load are plotted as shown in Figure 1.5 and Figure 1.6respectively.

The total active and reactive losses of the power system after the installation of the UPFC are 57.0828 **p.u** and **321.6525 p.u** respectively. These values are lower than the case of the power system without the proposed neural network controlled UPFC installed. This shows that the UPFC reduced both the active and reactive powers in the system.

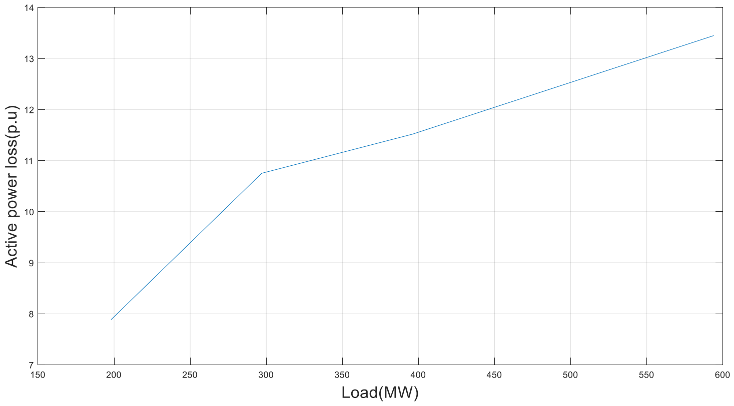


**Figure 1.5: Variation of active power loss with load variation with UPFC installe**

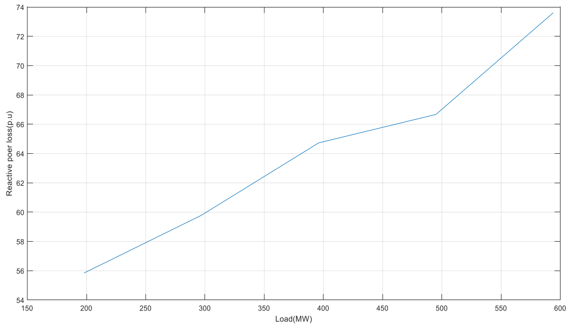


**Figure 1.6: Variation of active power loss with load variation with UPFC installed**

Figure 1.5 and 1.6 show relationship between active and reactive power losses with load variations in the power system. It can be noticed that the trend in the relationships have similarities with the case of the power system without the UPFC installed. However there are differences in the trajectories of the graphs. A close comparison will show the quantitative difference existing between the trend of the active and reactive losses with and without the UPFC installed. To carry out the comparison, the values of losses with load variation for the power system with and without the UPFC will be tabulated together in order to closely examine the loss reduction as a result of the installation of the UPFC. For visual comparison the variation of the active and reactive losses without load will be plotted together.

## VII. COMPARISON OF ACTIVE AND REACTIVE LOSSES WITH AND WITHOUT UPFC INSTALLED IN THE POWER SYSTEM.

The distribution of losses in the transmission lines in the power system due to load variations for the cases of the power system with and without the UPFC installed is plotted together for close comparison. The transmission lines losses for the 198MW, 297MW, 396MW, 495MW and 594MW variations in loads in the system with and without the UPFC installed are plotted together.

Figures 1.7, 1.9, 2.1, 2.3 and 2.5 shows the combined plot of active power losses in the transmission lines for the power system with and without the UPFC installed for the 198MW, 297MW, 396MW, 495MW and 594MW loads respectively.

Figures 1.8, 2.0, 2.2, 2.4 and 2.6 shows the combined plot of reactive power losses in the transmission lines for the power system with and without the UPFC installed for the 198MW, 297MW, 396MW, 495MW and 594MW loads respectively.

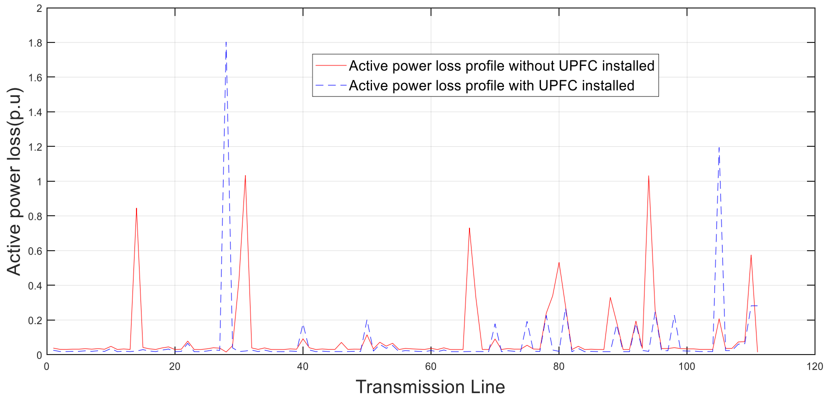


**Figure 1.7: Comparison of active power loss distribution in the power system with UPFC installed for the 198MW load drawn at bus 49.**

Figure 1.7 shows the comparison of the active loss power loss profiles of the power system with and without the UPFC installed. Form the combined plot, in the overall; it can be observed that the active loss without the UPFC installed is higher than with the UPFC installed. However the distribution of the levels of losses for the two situations is not even. In few locations like at lines 28, 105, the loss in the system with the UPFC installed are higher than without the UPFC installed. This is definitely as a result of the complexities and nonlinearity of the power system generally. The UPFC in order to reduce losses inject and absorb active and reactive powers under the control of the neural networks. This has the effect of counteracting the effects of turbulence in the power system in order to compensate for the abnormal power flows that give rise to the increase in losses. However, this may lead to some increases in losses in some other locations in order to rebalance the power flows. Nevertheless the overall impact of the effect of the FACTS device is to reduce the total power loss in the power system.

With close examination of the combined plot of Figure 1.7, it can be observed that the losses without the UPFC in all lines are generally higher than in the case of the power system with the UPFC, except for the few locations in which the losses with the UPFC installed are higher. For a more quantitative comparison the total losses with and without the UPFC installed for the case of the 198MW load drawn is used to determine the loss reduction as a result of the installation of the neural network controlled UPFC. From table 1.2, the total active loss in the case of the 198MW load drawn at bus 49 without the UPFC installed is **11.1730 p.u**. From table 1.3, the total active loss in the case of the 198MW load drawn with the UPFC installed is **8.0838 p.u** . This shows that the installation of the UPFC reduced the total system active loss in the case of the 198MW load variation at bus 49 from **11.1730 p.u** to **8.0838 p.u.** This means that for the case of the 198MW load varied at bus 49, the installation of the UPFC reduced the active loss by **27.64%.**

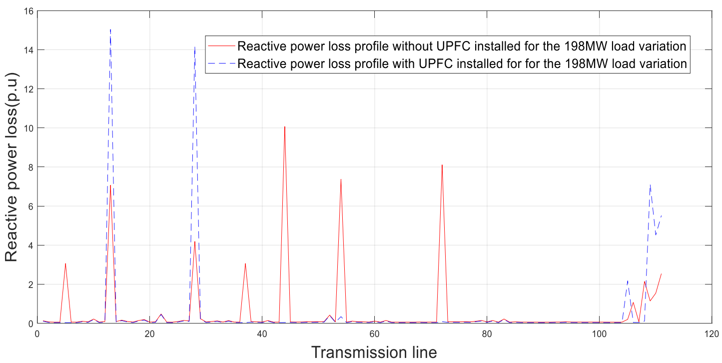


**Figure 1.8: Comparison of reactive power loss distribution in the power system with UPFC installed for the 198MW load drawn at bus 49.**

Figure 1.8 shows the comparison of the reactive power loss profiles of the power system with and without the UPFC installed for the 198MW load variation at the selected bus. With close examination of the combined plot of Figure 1.8, it can be observed that the reactive losses without the UPFC in all lines are generally higher than in the case of the power system with the UPFC. However, like in the case of the active loss for the 198MW load variation, lines 13, 28, 104, 109 and 111 are the few places where the reactive power loss with the UPFC installed are higher than the reactive power losses without the UPFC installed. From table 1.2, the total reactive losses in the case of the 198MW load drawn at bus 49 without the UPFC installed is **60.7648p.u.** From table 1.3, the total reactive loss in the case of the 198MW load drawn with the UPFC installed is **56.0455 p.u** . This shows that the installation of the UPFC reduced the total system reactive loss in the case of the 198MW load variation at the selected bus from **60.7648p.u** to **56.0455 p.u.** These values represent **7.76%** reduction of reactive power loss due to the 198MW load variation at the selected bus.

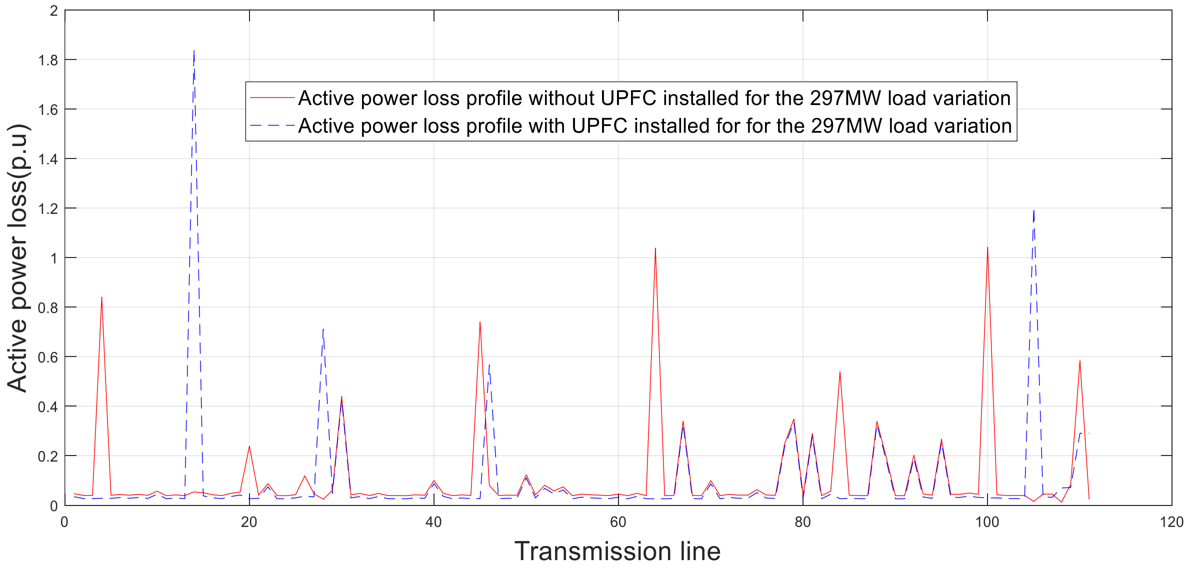


**Figure 1.9: Comparison of active power loss distribution in the power system with UPFC installed for the 297MW load drawn at bus 49.**

Figure 1.9 shows the comparison of the active loss power loss profiles of the power system with and without the UPFC installed for the 297MW load variation at the selected bus.

With close examination of the combined plot of Figure 1.9, it can be observed that the active losses without the UPFC in all lines are generally higher than in the case of the power system with the UPFC. However like in the case of the previous comparisons, lines 14, 28, 46 and 105 are the few transmission lines where the active loss with the UPFC installed is higher than without the UPFC installed. At all other locations the active losses without the UPFC installed are higher than the active losses with the UPFC installed. From table 1.2, the total active losses in the case of the 297MW load drawn at the selected bus without the UPFC installed is **12.1387 p.u**. From table 1.2, the total active loss with the UPFC installed is **10.9512p.u** . This shows that the installation of the UPFC reduced the total system active loss in the case of the 297MW load variation at the selected bus from **12.1387 p.u** to **10.9512 p.u .** These values represent **9.78%** reduction of active power loss due to the 297MW load variation at the selected bus.

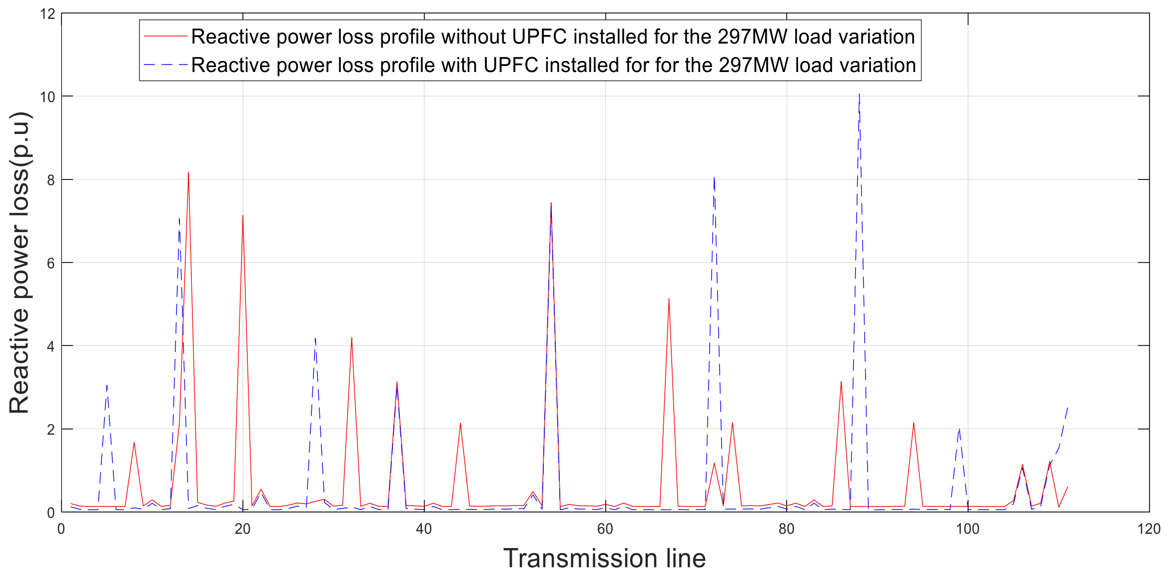


**Figure 2.0: Comparison of reactive power loss distribution in the power system with UPFC installed for the 297MW load drawn at bus 49.**

Figure 2.0 shows the comparison of the reactive loss power loss profiles of the power system with and without the UPFC installed for the 297MW load variation at the selected bus.

With close examination of the combined plot of Figure 2.0, it can be observed that the reactive losses without the UPFC in all lines are generally higher than in the case of the power system with the UPFC. However, like in the case of the previous comparisons, lines 5, 13, 28, 72,88, 99 and 111 the transmission lines where the reactive loss with the UPFC installed are higher than without the UPFC installed . At all other locations the reactive losses without the UPFC installed are higher than the reactive losses with the UPFC installed. From table 1.2, the total reactive losses in the case of the 297MW load drawn at the selected bus without the UPFC installed is **68.4904 p.u**. From table 1.3, the total reactive loss with the UPFC installed is **59.988 p.u**. This shows that the installation of the UPFC reduced the total system reactive loss in the case of the 297MW load variation at the selected bus from **68.4904 p.u** to **59.988 p.u.** These values represent **12.76%** reduction of reactive power loss due to the 297MW load variation at the selected bus.

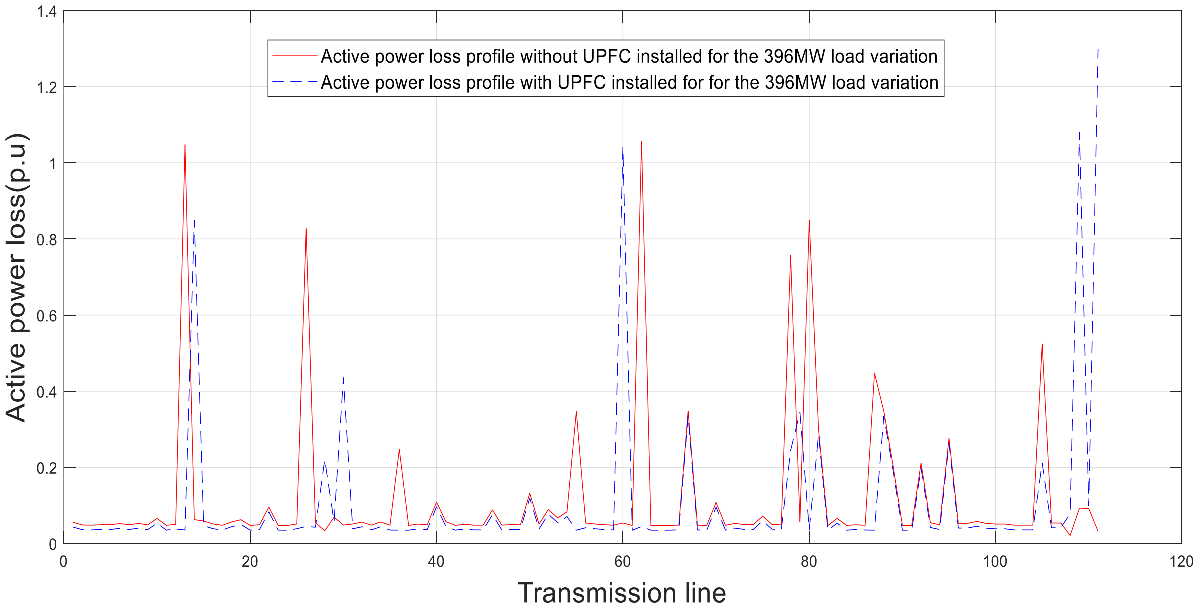


**Figure 2.1: Comparison of active power loss distribution in the power system with UPFC installed for the 396MW load drawn at bus 49.**

Figure 2.1 shows the comparison of the active loss power loss profiles of the power system with and without the UPFC installed for the 396MW load variation at the selected bus.

With close examination of the combined plot of Figure 2.1, it can be observed that the active losses without the UPFC in all lines are generally higher than in the case of the power system with the UPFC. However like in the case of the previous comparisons, lines 14, 28, 30, 60, 79, 109 and 111 are the transmissions lines where the active loss with the UPFC installed are higher than without the UPFC installed. At all other transmission lines, the active losses without the UPFC installed are higher than the active losses with the UPFC installed. From Table 1.2, the total active losses in the case of the 396MW load drawn at the selected bus without the UPFC installed are **13.1044 p.u**. From Table 1.3, the total active loss with the UPFC installed is **11.7169p.u.** This shows that the installation of the UPFC reduced the total system active loss in the case of the 396MW load variation at the selected bus from **13.1044 p.u** to **11.7169 p.u.** These values represent **10.588%** reduction of active power loss due to the 396MW load variation at the selected bus.

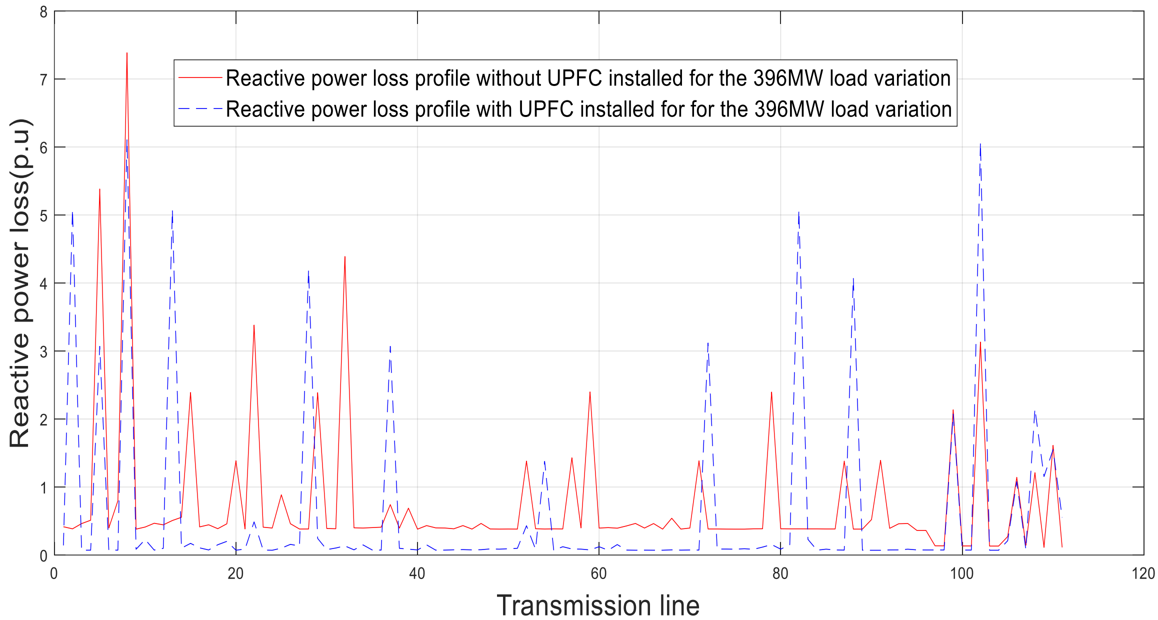


**Figure 2.2: Comparison of reactive power loss distribution in the power system with UPFC installed for the 396MW load drawn at bus 49.**

Figure 2.2shows the comparison of the reactive loss power loss profiles of the power system with and without the UPFC installed for the 396MW load variation at the selected bus.With close examination of the combined plot of Figure 2.2, it can be observed that the reactive losses without the UPFC in all lines are generally higher than in the case of the power system with the UPFC. However, like in the case of the previous comparisons, lines 2, 13, 28, 37, 54,72 , 82,102 and 108 are the transmission lines where the reactive loss with the UPFC installed are higher than without the UPFC installed . At all other transmission lines the reactive losses without the UPFC installed are higher than the reactive losses with the UPFC installed. From Table 1.2, the total reactive losses in the case of the 396MW load drawn at the selected bus without the UPFC installed are **84.1944 p.u**. From Table 1.3, the total reactive losswith the UPFC installed is **64.9305 p.u**. This shows that the installation of the UPFC reduced the total system reactive loss in the case of the396MW load variation at the selected bus from **84.1944 p.u** to **64.9305 p.u** These values represent **22.88%** reduction of reactive power loss due to the 396MW load variation at the selected bus.

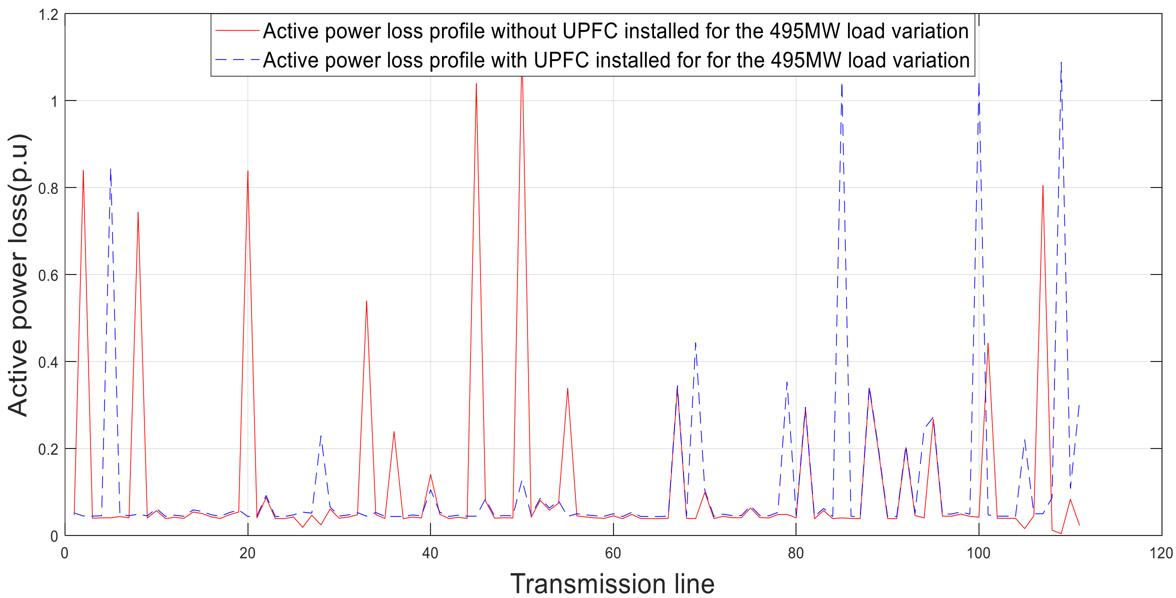


**Figure 2.3: Comparison of active power loss distribution in the power system with UPFC installed for the 495MW load drawn at bus 49.**

Figure 2.3 shows the comparison of the active loss power loss profiles of the power system with and without the UPFC installed for the 495MW load variation at the selected bus.With close examination of the combined plot of Figure 2.3, it can be observed that the active losses without the UPFC in all lines are generally higher than in the case of the power system with the UPFC. However like in the case of the previous comparisons, lines 5, 28, 69,79, 85, 100,109 and 110 are some of transmission lines where the active loss with the UPFC installed are higher than without the UPFC installed . At all other transmission lines the active losses without the UPFC installed are higher than the active losses with the UPFC installed. From Table 1.2, the total active losses in the case of the 495MW load drawn at the selected bus without the UPFC installed are **13.8587 p.u**. From Table 1.3, the total active loss with the UPFC installed is **12.6826 p.u**. This shows that the installation of the UPFC reduced the total system active loss in the case of the 495 MW load variation at the selected bus from**13.8587 p.u** to **12.6826 p.u.** These values represent **8.48%** reduction of active power loss due to the 396MW load variation at the selected bus.

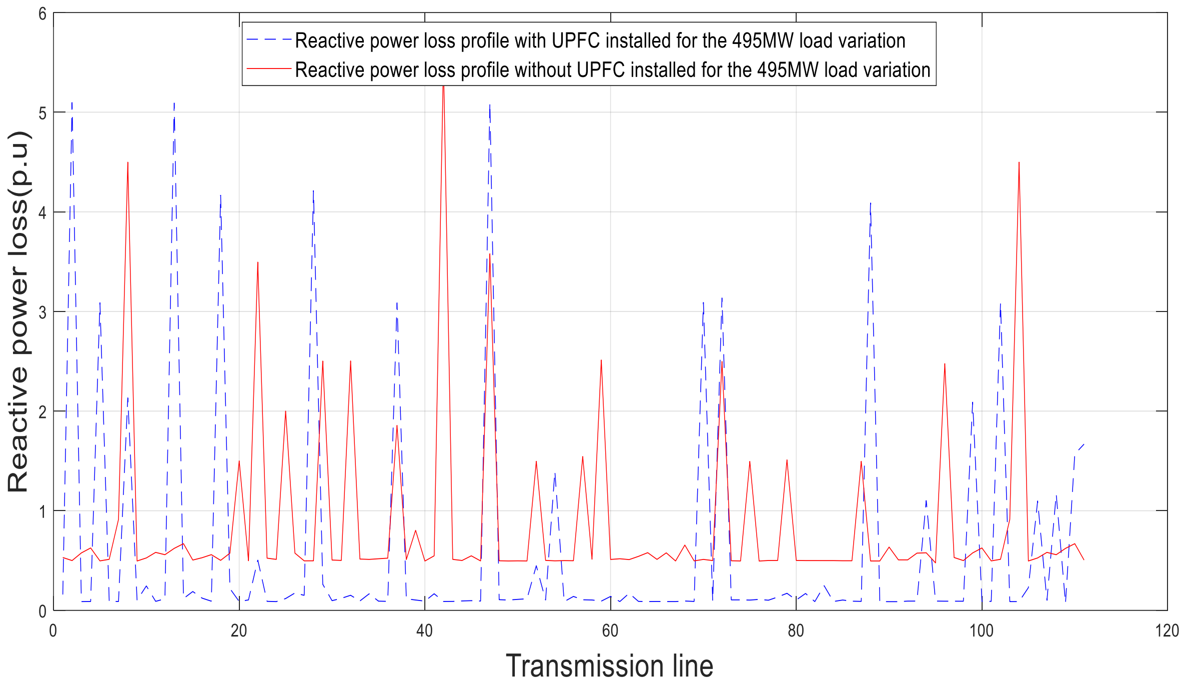


**Figure 2.4: Comparison of reactive power loss distribution in the power system with UPFC installed for the 495MW load drawn at bus 49.**

Figure 2.4 shows the comparison of the reactive loss power loss profiles of the power system with and without the UPFC installed for the 495MW load variation at the selected bus.

With close examination of the combined plot of figure 2.4, like as in the previous cases, it can be observed that the reactive losses without the UPFC in all lines are generally higher than in the case of the power system with the UPFC. From Table 1.2, the total reactive losses in the case of the 495MW load drawn at the selected bus without the UPFC installed is**97.1322 p.u**. From Table 1.3, the total reactive loss with the UPFC installed is **66.873 p.u.** This shows that the installation of the UPFC reduced the total system reactive loss in the case of the 495MW load variation at the selected bus from **97.1322 p.u** to **66.873 p.u**These values represent **31.15%** reduction of reactive power loss due to the 495MW load variation at the selected bus.

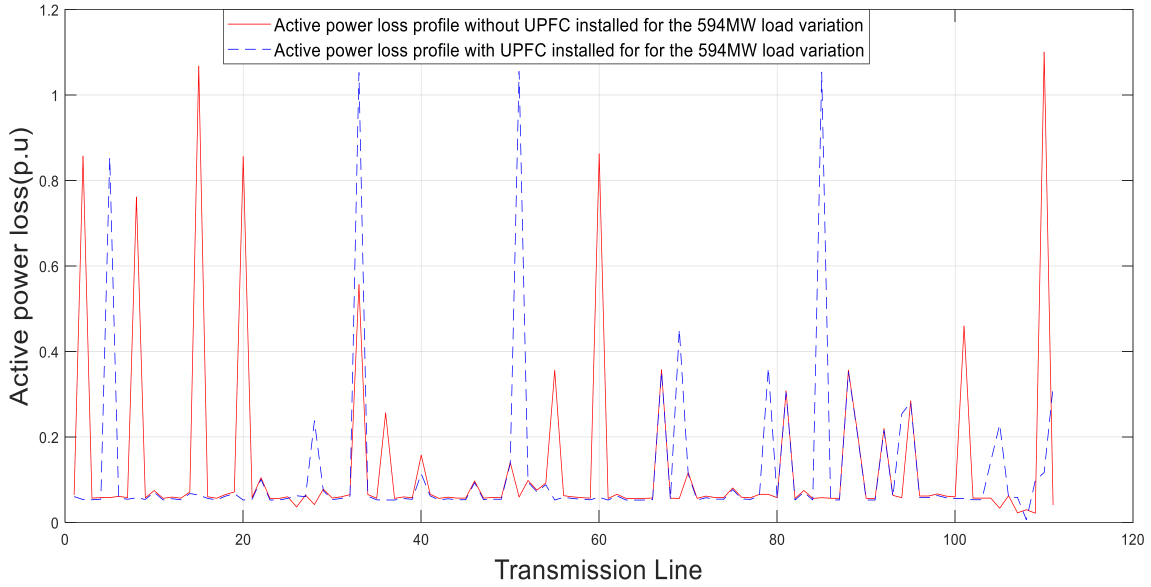


**Figure 2.5: Comparison of active power loss distribution in the power system with UPFC installed for the 594MW load drawn at bus 49.**

Figure 2.5 shows the comparison of the active loss power loss profiles of the power system with and without the UPFC installed for the 594MW load variation at the selected bus. With close examination of the combined plot of Figure 2.5, it can be observed that the active losses without the UPFC in all lines are generally higher than in the case of the power system with the UPFC. However like in the case of the previous comparisons, lines 5, 28, 33,51,69,79,84,105 are the transmission lines where the active loss with the UPFC installed are higher than without the UPFC installed . At all other transmission lines the active losses without the UPFC installed are higher than the active losses with the UPFC installed. From table 1.2, the total active losses in the case of the 594MW load drawn at the selected bus without the UPFC installed is **14.7901p.u**. From Table 1.3, the total active loss with the UPFC installed is **13.6483 p.u**. This shows that the installation of the UPFC reduced the total system active loss in the case of the 594 MW load variation at the selected bus from **14.7901p.u** to **13.6483 p.u .**These values represent **7.72%** reduction of active power loss due to the 594MW load variation at the selected bus.

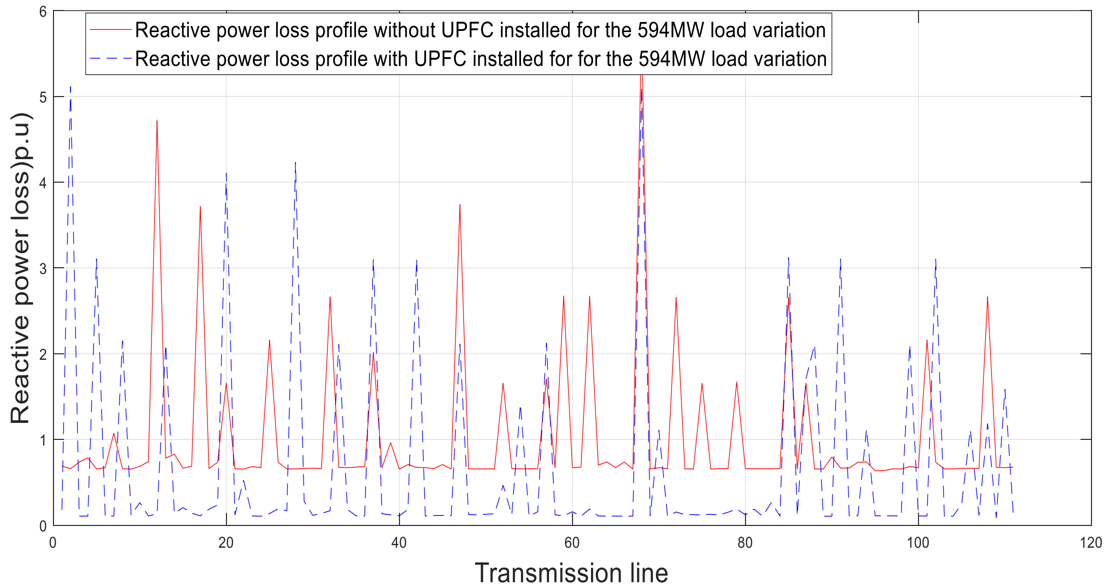


**Figure 2.6: Comparison of reactive power loss distribution in the power system with UPFC installed for the 594MW load drawn at bus 49.**

Figure 2.6 shows the comparison of the reactive loss power loss profiles of the power system with and without the UPFC installed for the 594MW load variation at the selected bus. With close examination of the combined plot of Figure 2.6, it can be observed that the reactive losses without the UPFC in all lines are generally higher than in the case of the power system with the

UPFC. However like in the case of the previous comparisons , lines 2, 5, 8 , 13,20, 28 , 33, 37,41,47,54,57,70,85,88,91,94,99,102 and 110 are the transmission lines where the reactive loss with the UPFC installed are higher than without the UPFC installed . At all other transmission lines the reactive losses without the UPFC installed are higher than the reactive losses with the UPFC installed. From Table 1.2, the total reactive losses in the case of the 594MW load drawn at the selected bus without the UPFC installed is**113.3895 p.u**. From Table 1.3, the total reactive loss with the UPFC installed is **73.8155 p.u**. This shows that the installation of the UPFC reduced the total system reactive loss in the case of the 594MW load variation at the selected bus from **113.3895 p.u** to **73.8155 p.u** .These values represent **34.90%** reduction of reactive power loss due to the 594MW load variation at the selected bus.

## VIII. SUMMARY OF RESULT FOR COMPARISONS OF LOSSES WITH AND WITHOUT THE PROPOSED NEURAL NETWORK CONTROLLED UPFC INSTALLED IN THE POWER SYSTEM.

The results obtained so far for the comparison of systems losses with and without the UPFC installed are given in Table 4.4

**Table 1.4: Active and reactive loss reduction for load variations with UPFC installed in the power system**

| Load variation (MW) | Active power loss(P.U) | | Reactive power loss(P.U) | | Active power loss reduction with UPFC installed(%) | Reactive power loss reduction with UPFC installed(%) |
|---|---|---|---|---|---|---|
| | Without UPFC | With UPFC | Without UPFC | With UPFC | | |
| 198 | 11.1730 | 8.0838 | 60.7648 | 56.0455 | 27.64 | 7.76 |
| 297 | 12.1387 | 10.9512 | 68.4904 | 59.988 | 9.78 | 12.41 |
| 396 | 13.1044 | 11.7169 | 84.1944 | 64.9305 | 10.588 | 22.88 |
| 495 | 13.8587 | 12.6826 | 97.1322 | 66.873 | 8.48 | 31.15 |
| 594 | 14.7901 | 13.6483 | 113.3895 | 73.8155 | 7.72 | 34.90 |
| **Average** | **13.01298** | **11.41656** | **84.79426** | **64.3305** | **12.8416** | **21.82** |

The Table shows that the neural network controlled UPFC reduced both the active and reactive power losses in the power system. The UPFC achieved an average active power loss reduction of **12.8416%** and an average reactive power loss reduction of **21.82%.**

## CONCLUSION

The Nigerian 330KV power grid was used as case study for the evaluation of the proposed power loss reduction system. The digital model of the case study power system with the proposed neural network controlled UPFC integrated was created in the MATLAB/SIMULINK programming environment.

Simulation carried out involved alteration of power flow in order to cause different levels and distribution of losses in the network. With each variation, load flows were carried out to evaluate the distribution of losses and the active and reactive loss reduction achieved by the proposed system. The simulation and evaluations are carried out fewer than two scenarios: (i) with the UPFC installed and (ii) without the UPFC installed. With each variation of load at the bus, load flow is run to determine total system loss either with the UPFC installed or without the UPFC installed.

## CONTRIBUTION TO KNOWLEDGE

This paper contributed an intelligent approach that uses neural network for the control of the adsorption and injection of active and reactive power via power electronics (FACTS devices) for the minimization of losses in transmission systems.

## REFERENCES


1. Bamigbola, O., M. Ali, and M. Oke(2014), Mathematical modeling of electric power flow and the minimization of power losses on transmission lines. Applied Mathematics and Computation, p. 214-221.
2. Magadum, M.R.B. and M.T.M. Timsani(2016), Minimization of Power Loss in Distribution Networks by Different Techniques, pp. 13-45
3. Bayliss C.R(2001), Transmission and Distribution Electrical Engineering, London: Newness, 2nd ed , pp. 11-23.
4. Lukman D & Blackburn T.R (2004), Modified algorithm of load flow simulation for loss minimization in power systems, Proceedings of the Australian Universities Power Engineering Conference (AUPEC 94) pp.34,37
5. Engr. H. S. Labo(2010), Current status and future outlook of the transmission network, pp.12-22
6. M S Bhalla(2013),**Transmission and Distribution Losses (Power)**
7. M. Vilathgamuwa, X. Zhu, and S. S. Choi(2000), A robust control method to improve the performance of a unified power flow controller, Electrical Power System Research, vol. 55, pp. 103-111.

8. B. C. Pal(2002) , Robust damping of interarea oscillations with unified power flow controller, IEE Proceedings on Generation, Transmission, Distribution, vol. 149, no. 6, pp. 733-738.
9. H. M. A. Rahim, and S. A. Al-Baiyat(2004), A robust damping controller design for a unified power flow controller, in Proc. 39th IEEE Universities Power Engineering Conference, (UPEC), IEEE, Bristol, pp. 265-269.
10. A.H M.A. Rahim, J. M. Bakhashwain, and S. A. Al-Baiyat(2006), Robust damping controls for a unified power flow controller, International Journal of Emerging Electric Power Systems, vol. 6, no. 2, pp. 1-21.
11. S. A. Taher, S. Akbari, A. Abdolalipour, and R. Hematti(2010), Robust decentralized controller design for UPFC using μ-synthesis, Communications in Nonlinear Science and Numerical Simulation, vol. 15, pp. 2149-2161.
12. Numphetch, S., Uthen, L., Umaporn, K., Dusit, U. & Thanatchai, K. (2011), Loss Minimization Using Optimal Power Flow based on Swarm Intelligences , ECTI Transactions on Electrical, Electronic and Communication Engineering, 9 (1), pp 212-222.
13. T.S. Abdel-Salam, A.Y. Chikhani, R. Hackam(2015). A new technique for loss reduction using compensating capacitors applied to distribution systems with varying lad conditions. IEEE Transactions on Power Delivery, Vol.9, No. 2, pp. 819-827
14. N. Acharya, P. Mahat, N. Mithulananthan(2006), An analytical approach for DG allocation in distribution network., International Journal of Electric Power and Energy System, Vol.28, No. 10, pp.669-678
15. F. Sheidei, M. Shadkam, M. Zarei(2008). Optimal distributed generation allocation in sub-transmission systems employing ant colony to reduce losses, In: proceedings of 43 rd International universities Power Engineering conference UPEC; pp.44-67
16. Y.M. Atwa, E.F. EI-Saadany, M.M.A. Salama, R. Seethapathy(2016),Optimal renewable resources mix for active loss minimization, IEEE Transaction on Power System, Vol.25, No.1, pp. 360-370
17. R.S. AI Abri, E.F. EI-Saadany, Y.M. Atwa, (2014), Optimal placement and sizing method to improve active power loss reduction in sub-transmission systems, IEEE Transactions on Power System, Vol. 28, No. 1, pp. 326-334
18. Julluri Namratha Manohar, Amarnath Jinka, Vemuri Poornachandra Rao(2012 ), Optimization of Loss Minimization Using FACTS in Deregulated Power Systems, Innovative Systems Design and Engineering ISSN 2222-1727 (Paper) ISSN 2222-2871 (Online) Vol 3, No 3 pp.231-239