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Evaluation of the Performance of a Loss Minimization Method using ANN Based UPFC

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Abstract:- Due to the shortcomings of conventional schemes, such as the tap changer and regulating transformer, and associated controller in the minimization of transmission system losses, this study 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. In the modeling of the neural network, controller for the UPFC carried out in this work, the input parameters of the neural controller includes power system variables that relates to the control of ohmic and corona losses on transmission lines. 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. 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 14.40% and an average reactive power loss reduction of 24.6%.

***Keyword:-** Power loss, Active Power, Reactive power, FACTS.*

I. INTRODUCTION

From the physical principles of electric power transmission, when a conductor is subjected to electric power, electric current flows in the medium. Resistance to the flow produces heat (thermal energy) which is dissipated to the surroundings. This power loss is referred to as Ohmic loss (Wang, C. and M.H. Nehrir, 2004). Ohmic loss otherwise known as line loss on power transmission occurs as a result of resistance of conductors against current flow. The effective resistance of the transmission line is a function of the current on the line. This is because of the heat produced in the conductor resulting from current flow, and this leads to a temperature rise in the conductor. This rise in temperature increases the resistance of the conductor and consequently the losses on the line . The power losses could take off a sizeable portion of the transmitted power since transmission lines usually span a long distance, sometimes several hundred kilometers (Wang, C. and M.H. Nehrir, 2004).

Losses can be minimized by reducing either the resistance or impedance of the transmission medium. This is possible by selecting a conductor with small resistivity. Another way of the reducing losses in a system is by decreasing the current and maximizing voltage (low power factor is highly undesirable as it causes an increase in current, resulting in additional losses of active power in all elements of power system). These can be achieved through the use of tap changer transformers and regulating transformers. Voltage control in transformers is required to compensate for varying voltage drops in the distribution system and to control reactive power flow over transmission lines. Tap changer control is the most popular because it is used for controlling voltage at all levels,(i.e. at both transmission distribution voltage levels).

The resistance R of a line conductor having resistivity ρ (Ω/m), length l (m) and an area of cross section (m^2) is given by:

$$R = \rho l / a \qquad (1.0)$$

One way to reduce power losses is to reduce the current in a transmission lines, but this way is limited due to the high cost of HV transformers. However, another way is by use of FACTS device to manipulate all the complex variables of the power flow base on the controller of parameters of current, resistance, and voltage to achieve loss minimization in transmission network.

II. REVIEW OF RELATED LITERATURE

Siti Amely Jumaat et.al. (2016) worked on optimal sizing of static var compensator (SVC) based on Particle Swarm Optimization for minimization of transmission losses considering cost function. Particle Swarm Optimization (PSO) is one of the artificial intelligent search approaches which has the potential to solve such a problem. For the study, static var compensator (SVC) was chosen as the compensation device. The worked was validated by implementing it on the IEEE 26-bus system. The IEEE 26-bus system was tested in order to find the optimal sizing of SVC. Result obtained showed that the SVC sizing achieved reduction of losses at several loading conditions in the power system. The analysis from simulations carried indicated 7.8% reduction in transmission losses. The work concluded that with the installation of SVC optimized using PSO, the transmission losses was reduced at all loading conditions. The limitation is that the authors did not model the control system for the SVC and the work did not consider the impact the placement of the SVC will have on power loss minimization.

Mohd nabil bin muhtazaruddin(2016), proposed a new hybrid optimization technique based on Artificial Bee Colony (ABC) and Artificial Immune System (AIS) algorithm for distributed generation (DG) coordination to minimize total power losses in power systems. The work was validated via simulations. Five case studies were conducted to test the performance of the proposed approach . The results obtained showed that determination of optimal DG location, output power and network reconfiguration simultaneously gave good results with 95.53% of power loss reduction, minimum voltage improvement by 8.95% .In addition, a comparison with other optimization technique showed promising results in decreasing the total loss reduction in the power system. However, it was found that the algorithm converged slowly and the authors did not validated the solution under load variations.

S. Salamat Sharif, James H. Taylor, Eugene F. Hill(2017) proposed the method of On-line optimal reactive power flow by energy loss minimization. The three objectives are included in this method: 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 concept of the proposed technique is on the basis the during the steady-state conditions total power loss can be minimized by finding the optimal reactive power dispatch for the system. In proposed method, the total system loss is minimized on the basis of on-line load conditions and the load forecast during the next hour. For minimizing the total loss, the method uses all the continuous and discrete variables. The voltage constraint violations are removed by running the optimal reactive power flow every 15 minutes. In the simulations carried out to validate the work, only continuous control variables are allowed to vary. The technique has the limitation that it is dependent on accurate load forecast for the next hour in order to achieve any substantial loss minimization and the work was not validated under different loading conditions.

III. METHODOLOGY

The key focus of the work in terms of methodology is the performance evaluation of transmission network loss minimization using ANN-based FACTS devices. The strategy is the placement and control of FACTS devices for the minimization of losses. The core strategy is the intelligent control of current and voltage in the power flow as carried out using the FACTS devices such that the ohmic and corona losses are minimized. The neural network that controls the UPFC has to control power flow in order to minimize losses in the transmission line. The key control concept is the modeling and training of the UPFC based NN or NN-based UPFC to control power flow such that power is transmitted at low current and at voltage that is very close to the critical disruptive voltage (in this case not exceeding it). This would ensure the minimization of ohmic and corona losses. The modeling and training of the neural network would ensure that the injection and adsorption of active and reactive power into the transmission system is such as to achieve the required voltage and current controls that minimizes the ohmic and corona losses. Minimizing the ohmic and losses due to corona effectively minimizes the total losses in the transmission system. Corona is accompanied by a loss of energy. This affects the transmission efficiency of the transmission line. To minimize losses due to corona, the neural network through the FACTS device has to control the transmission line voltage such that it does not exceed the value at which electro-static stresses start to develop at the surface of the transmission conductors. To minimize ohmic losses, the FACTS device under the control of the neural network has to effectively control power flow such that transmission is kept at low current. Current and voltage surge in the transmission network has to be effectively suppressed by the FACTS device under the control of the neural network in order to effectively minimize the overall transmission losses.3

IV. MATHEMATICAL MODEL FOR THE POWER LOSS

The main reason for losses in transmission and sub-transmission lines is the resistance of conductors against the flow of current. The production of heat in the conductor as a result of the flow of current increases its temperature. This rise in the conductor's temperature further increases the resistance of the conductor and this will consequently increase the losses. This implies that ohmic power loss is the main component of losses in transmission and sub-transmission lines, Mehta and Mehta (2008) and Gupta (2008). The expression for the ohmic power loss, Wadhwa (2009), is given as

$$L_{ohmic} = I^2 R \tag{1.1}$$

I denotes current along the conductor and

R represents resistance of the conductor.

The formation of corona on transmission line is associated with a loss of power, which will have some effect on the efficiency of the transmission line. The corona power loss for a fair weather condition, is given by Mehta and Mehta (2008), Wadhwa (2009), Gupta (2008) and James (2005).

$$L_{corona} = 242\,\frac{(f+25)}{\delta}.\sqrt{\left(\frac{r}{d}\right)}\,.(V-V_0)^2.\,10^{-5} \tag{1.2}$$

where
f represents the frequency of transmission,
δ denotes the air density factor,
r is radius of the conductor,
d represents the space between the transmission lines,
V is the operating voltage and
V_0 denotes the distruptive voltage.

Taking the total power loss on transmission lines to be the summation of ohmic and corona loss,

$$T_{loss} = L_{ohmic} + L_{corona} \qquad (1.3)$$

i.e

$$T_{loss} = I^2R + 242\,\frac{(f+25)}{\delta}.\sqrt{\left(\frac{r}{d}\right)} \quad .(V-V_0)^2.10^{-5} \qquad (1.4)$$

The general form of equation (1.4) is given by

$$T_{loss} = I^2\frac{\rho l}{A} + 242\,\frac{(f+25)}{\delta}.\sqrt{\left(\frac{r}{d}\right)} \quad .(V-V_0)^2.10^{-5} \qquad (1.5)$$

where
ρ is the resistivity of the conductor,
l denotes the length of the conductor and
A is the cross-sectional area of the conductor.

In this work FACTS device (UPFC) under the control of neural network is used for the minimization of power losses. Referring to equation (1.4), if the current I is kept low and the operating voltage V is kept very close to the critical disruptive voltage V_0(so that the difference $V - V_0$ is low) , then T_{loss} will be minimized. Hence, the transmission current I, the operating voltage V and the critical disruptive voltage V_0 are used as part of the inputs to the neural network for the control of the FACTS device.

V. THE MODEL OF THE UPFC NEURAL NETWORK CONTROLLER

The strategy for the loss minimization is the intelligent control of the FACTS device in order to put under control the rise in current (to reduce ohmic losses) and voltage beyond the level that causes corona. The shunt and series controllers of the UPFC is for the control of reactive power injection into or absorption from the power system in the events of irregular rise in transmission current or rise in voltage above the critical disruptive voltage. The neural network control is to generate the right levels of amplitude modulation ratios (*mE*, *mB)* and phase angles (i.e firing angles δE, δB,) of the control signal of each VSC in the UPFC. Figure 1 shows the functional model of the UPFC with the neural network controller.

For the control of the UPFC for the injection of the right active and reactive power in order to adapt the transmission system power flow for loss minimization, two neural network controllers are used: One for the control of the series VSC and the other for the control of the shunt VSC.

The proposed neuro-controller is a multi-layer feed forward network trained with Modified Recursive Prediction Error Algorithm (MRPE). Although the gradient descent algorithm can also be used train neural network models, it does not converge as quickly as the (MRPE) algorithm.

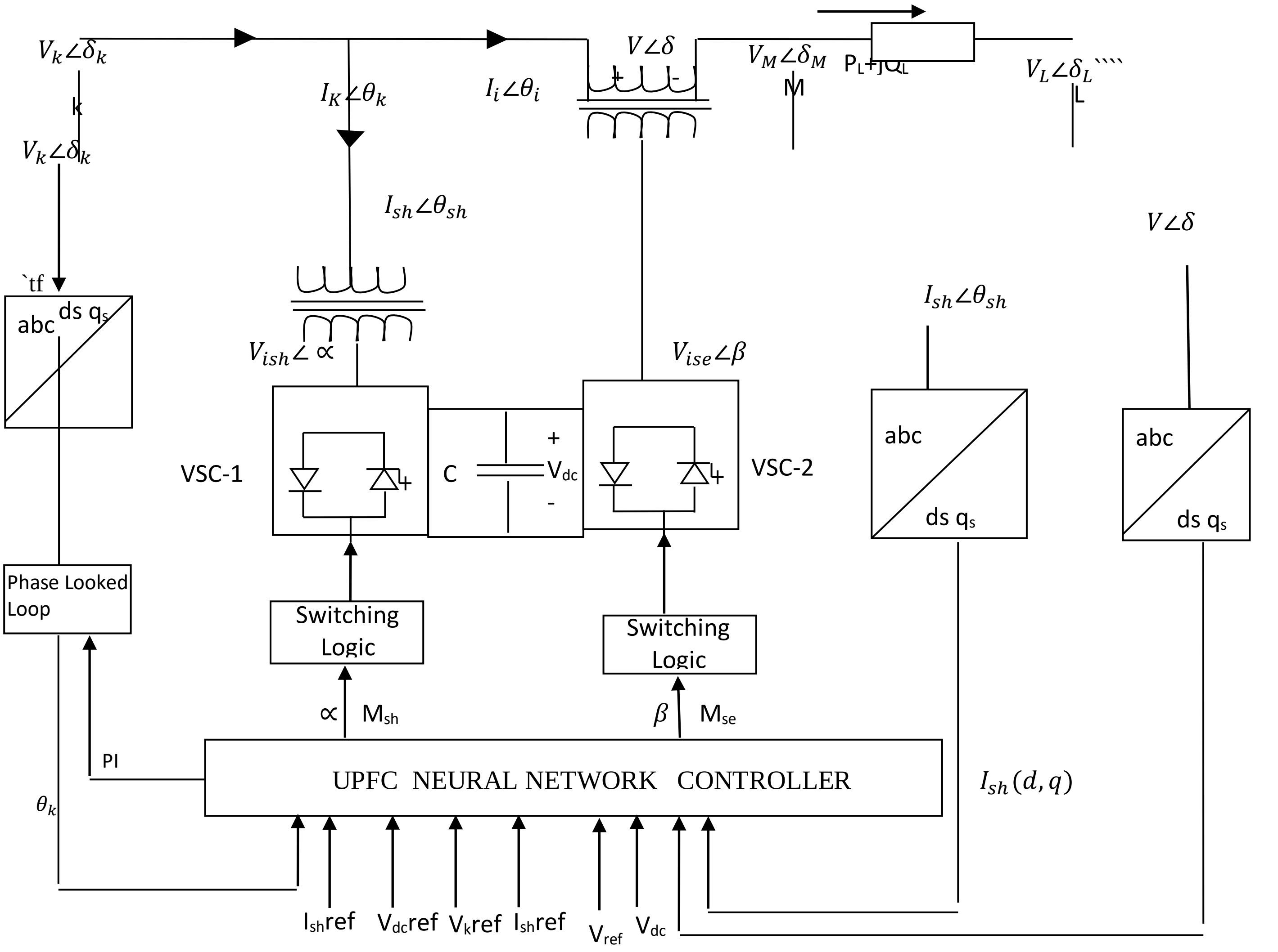

Fig. 1: The UPFC Functional model

The neural network controls the injection of real and reactive power by the UPFC into the transmission line such that the current and voltage is put under control, so that ohmic and corona losses are minimized. The main objective of the series converter is to produce an ac voltage of controllable magnitude and phase angle, and inject this voltage at fundamental frequency into the transmission line, exchanging real and reactive power at its ac terminals through the series connected transformer. The shunt converter provides the required real power at the dc terminals; thus, real power flows between the controller shunt and series ac terminals through the common dc link.

- Inputs to the UPFC series Neural network controller:
  - Shunt converter(i.e. shunt VSC) reference current: $I_{sh_{ref}}$
  - Link capacitor reference voltage: $V_{dc_{ref}}$
  - Critical disruptive voltage: V_0
  - Operating voltage reference: V_{ref}
  - Active power injected at node j: P_j
  - Reactive power injected at node j: Q_j
  - Active loss at the i^{th} and $(i+1)th$ bus: $P_{loss\ i,i+1}$
  - Power balance deviation: P_{dev}
  - Minimum voltage constraint deviation: $V_{min_{dev}}$
  - Maximum voltage constraint deviation: $V_{max_{dev}}$

- Output of the UPFC series neural network controller:
  - amplitude modulation ratio : mE
  - firing angle: δE

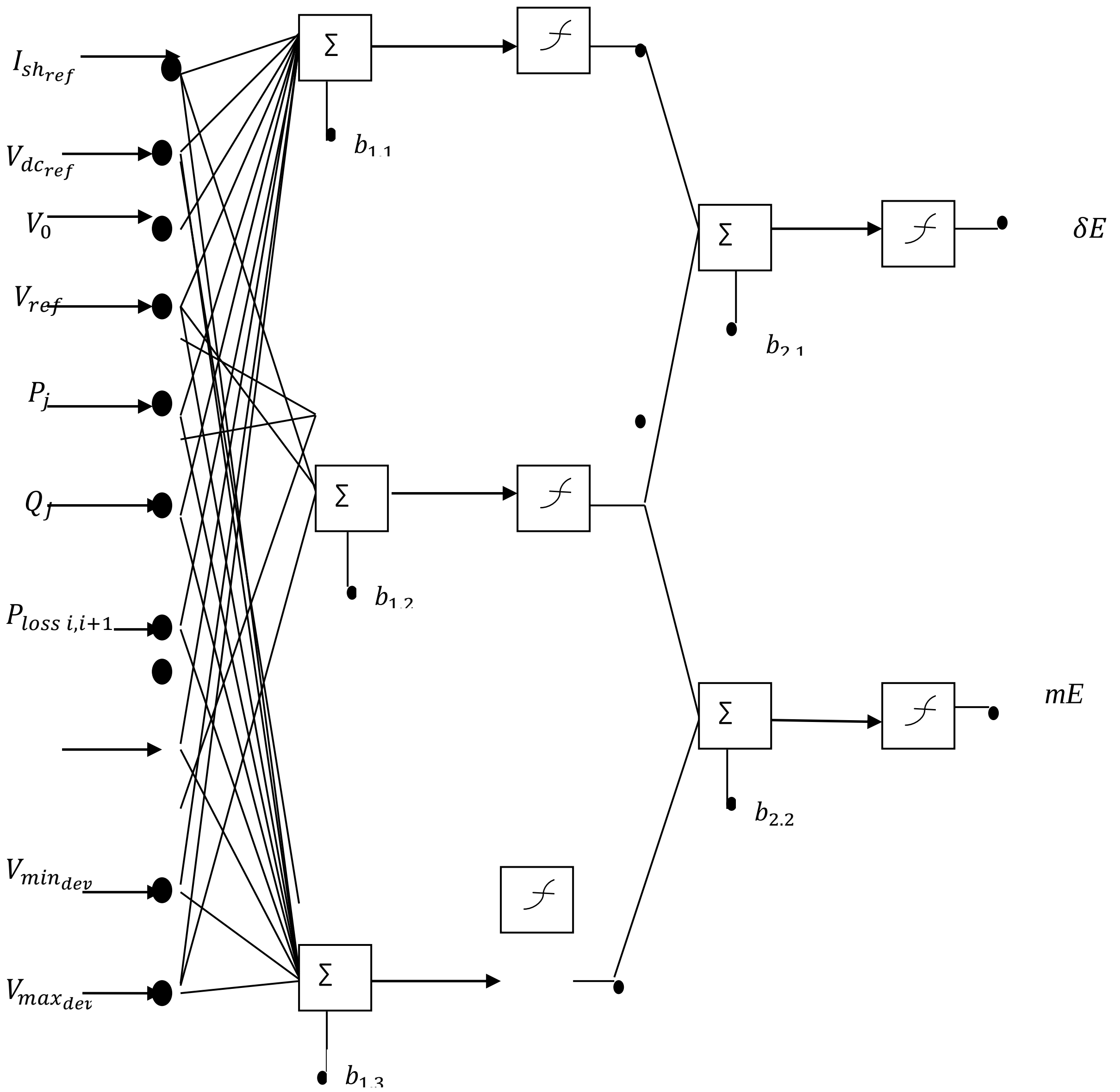

Fig. 2: The model of the Neural network for the control of the UPFC

VI. 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 3. 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 2.

VII. SIMULATING THE EFFECT OF LOADING PATTERN IN SYSTEM LOSS

Loss in the power system results from power flow. The nature of the power flow is primarily due to the load conditions the power system is subjected to at various buses in the system. Hence, in this work, load variations will be used to evaluate the transmission loss reduction due to the installations of the neural network controlled FACTS devices. The simulations is carried out in MATLAB and a particular selected bus is subjected to load variations in order to effectively determine the effect of the neural network controlled FACTS devices on active and reactive power loss reduction.

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In order to keep the effect of system instability to a minimum as much as possible, the buses subjected to load variation are buses that are stable. To ensure this, the bus selected is a bus having eigen value that lie on the left side of the S-plane and having a high value of damping ratio.

The eigen value program is loaded into the MATLAB workspace to carry out eigen value analysis on the digital model of the power system. The output from the eigen value analysis is extracted and tabulated on table 1.0.

Bus Name	Eigen value	Damping ratio(G)	Participation factor(%}
AFAM GS		0.4762	0.0102
ALAOJI 330KV	-2.325±j8.0321	0.2781	2.0018
EGBIN GS		0.4810	0.2146
SAPELLE		0.2233	10.1575
AKANGBA	-0.4087±j0.8293	0.4421	0.0625
ALAGBON	0.8922±j3.013	0.2842	3.1174
LEKKI	-5.3063±j10.3295	0.4569	0.0625
OMOTOSO TS	-5.1617±j11.2755	0.4162	12.4678
SAKETE	-0.4759±j0.5616	0.6465	0.0933
AJA	-04164±j0.6618	0.5325	0.0536
GBARAIN		0.2562	2.0341
JEBBA TS	-1.1731±j4.1051	0.2751	4.3210
KADUNA	-0.8042±j2.9632	0.2623	0.7326
OKEARO TS	-1.1843±j3.845	0.2942	3.0072
OMOKU		0.3283	0.4136
OWERRI	-0.9499±j3.5917	0.2552	2.0018
RIVERS 132KV		0.5716	1.4172
YENEGOA	5.5160±j5.22030	0.7108	8.3066
ABA 132KV	-3.7688±j6.0058	0.5315	3.4172
ADIABOR	-3.2505±j82795	0.36543	0.9847
AFAM	-2.8394±j7.8648	0.3396	2.6731
AFAM 132KV	2.6431±j8.0318	0.3126	0.9874
AHOADA	-2.9202±j7.7275	0.3536	0.0378
AJAOKUTA	3.5157±j6.3330	0.4762	0.0102
ALADJA	-2.325±j8.0321	0.3781	1.0018
ALAOJI GS		0.2810	0.2146
ALAOJI 132KV	-2.4892±j10.8650	0.2233	10.1575
ASABA	-2.4087±j0.8293	0.5421	0.0625
AYEDE	-0.8922±j3.013	0.2842	5.1174
BENIN	3.3063±j12.3295	0.3569	0.0625
DAMATURU	-5.1617±j11.2755	0.4162	12.4678
DELTA		0.3465	2.0933
EGBIN TS	-04164±j0.6618	0.5325	0.0536
EKET 132KV	-2.0922±j7.914	0.2562	2.0341
GANMO	-1.1731±j4.1051	0.2751	4.3210
GERGU GS		0.2623	0.7326
GOMBE	1.1343±j3.345	0.2942	1.0072
GWAGWA	-1.1012±j3.1752	0.3283	0.4136
IBOM 132KV		0.2552	2.0018
IHOVBOR TS	-3.0428±j5.80451	0.5716	1.4172
IKEJA WEST	5.5160±j5.22030	0.3108	5.3066
IKORODU	-3.7688±j6.0058	0.5315	3.4172
IKOT EKPENE	-2.2505±j82795	0.36543	1.9847
ITU 132KV	-2.8394±j7.8648	0.3396	2.6731
JEBBA GS		0.3126	2.9874
JOS	-2.9202±j7.7275	0.2536	1.0378
KAINJI GS		0.3762	0.0102
KANO	-2.325±j8.0321	0.2781	3.0018
KATAMPE	-5.6837±j10.3601	0.8810	2.2146
KEBBI	-2.4892±j10.8650	0.2233	4.1575
LOKOJA	-3.4087±j0.8293	0.4421	0.0625
MAIDUGURI	-0.8922±j3.013	0.2842	3.1174

MAKURDI	-5.3063±j4.3295	0.4569	0.0625
NHAVEN	-3.1617±j1.2755	0.4162	6.4678
ODUKPANI G.S		0.6465	0.0933
OKPAI GS		0.5325	0.0536
OLORUNSOGO GS		0.2562	2.0341
OLORUNSOGO TS	-6.1731±j4.1051	0.2751	4.3210
OMOTOSO GS		0.2623	0.7326
ONITSHA	-8.1843±j3.845	0.2942	3.0072
OSHOBO	-1.1012±j3.1752	0.3283	0.4136
PH MAINS		0.2552	2.0018
SAGAMU		0.5716	7.4172
SHIRORO	-3.5160±j5.22030	0.7108	8.3066
SHIRORO GS		0.5315	3.4172
UGWUAJI	-3.2505±j82795	0.36543	0.9847
YOLA	-2.8394±j7.8648	0.3396	2.6731

Table 1: Extracted output from eigen value analysis

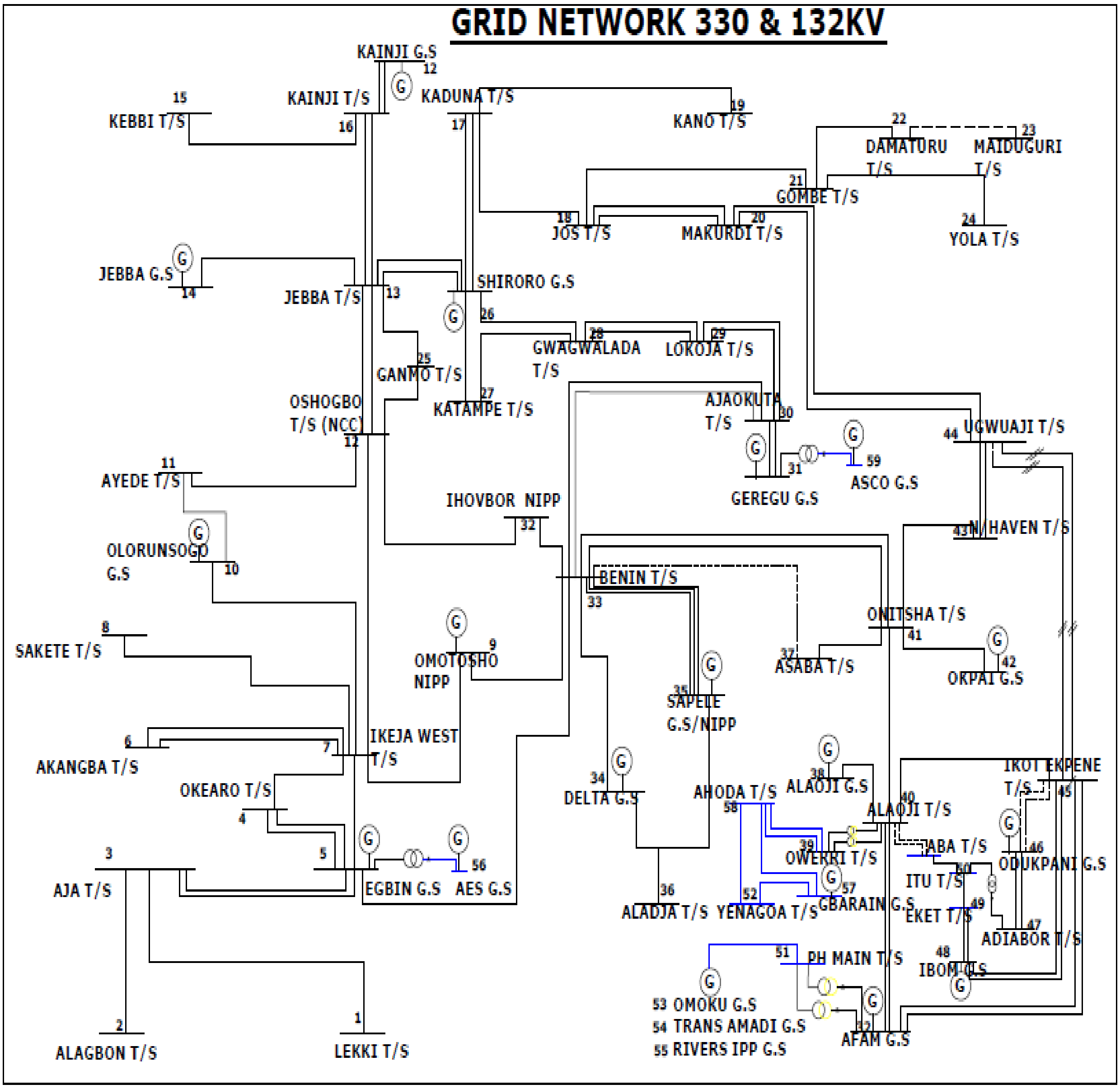

Fig. 3: SINGLE LINE DIAGRAM OF THE NIGERIAN 330/132KV POWER SYSTEM

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

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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

Table 2: GENERATOR DATA

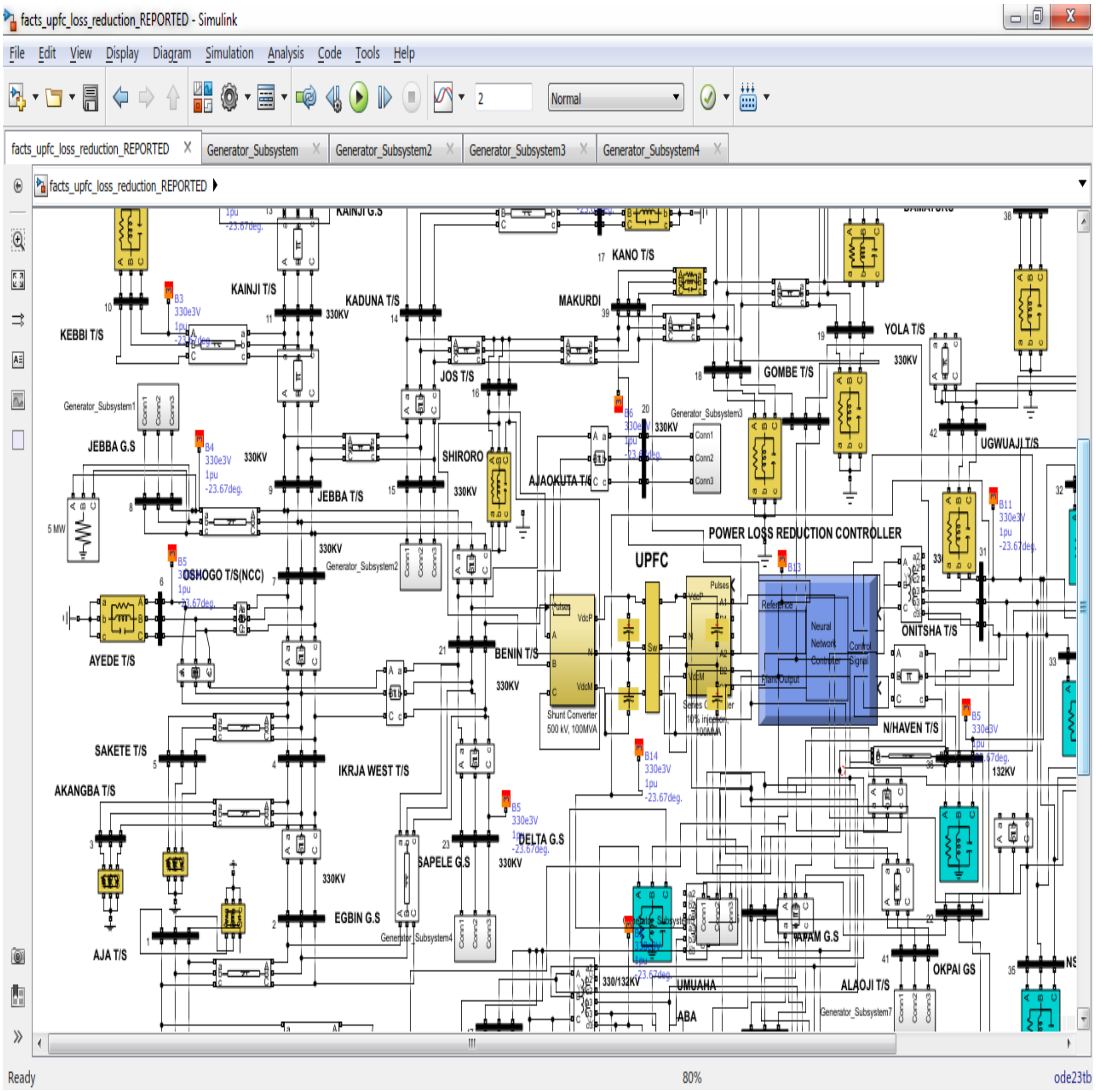

Fig. 4: SIMULINK model of the power system with UPFC installed

The simulation model of the power system is shown in figure 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.

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

Figures 5, 7, 9, 13 and 14 give the graphs of the distribution of active power losses for the 198MW, 297MW, 396MW, 495MW and 594MW loads drawn at bus 49 with UPFC installed.

Figures 6, 8, 10, 13 and 15 give the graphs of the distribution of reactive power losses for the 198MW, 297MW, 396MW, 495MW and 594MW loads drawn at bus 49 respectively with UPFC installed.

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

In the simulation carried out, load flows is 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 evaluation are carried out with 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 the load at the bus, load flow is run to determine total system total system loss with 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 variation of loading conditions at the are: 198MW, 297MW,396MW, 495MW, 594MW. With 198MW drawn at bus1, the values output from the load flow is given in the active and reactive power loss profiles are plotted as shown in figure 5 and 6 respectively.

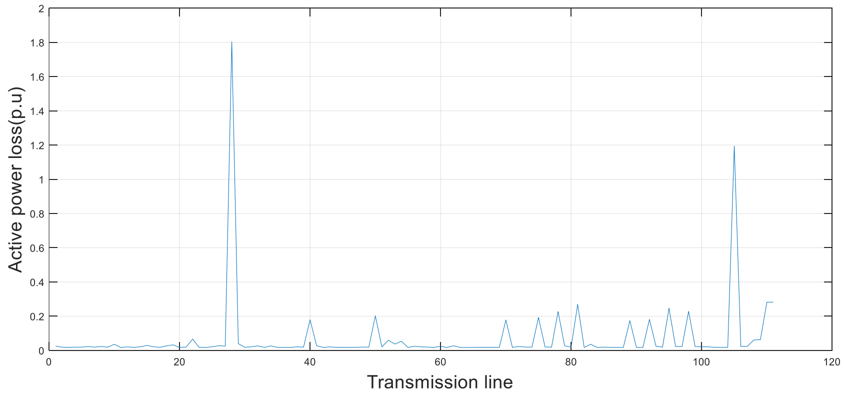

Fig. 5: Active power loss distribution in the power system with UPFC installed for the 198MW load drawn at bus 49

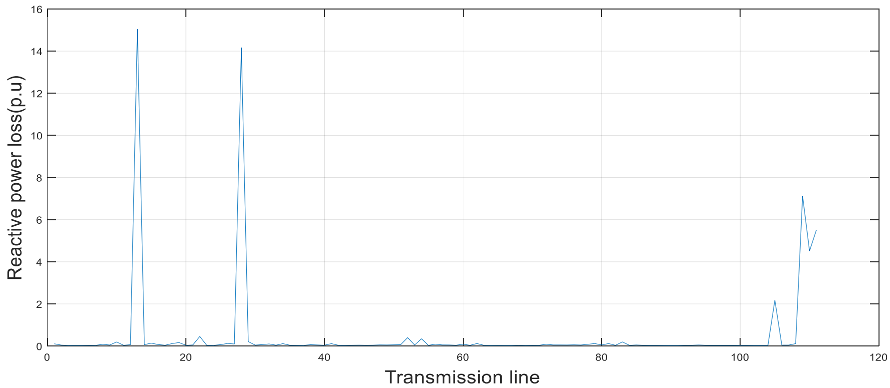

Fig. 6: Reactive power loss distribution in the power system with UPFC installed for the 198MW load drawn at bus 49.

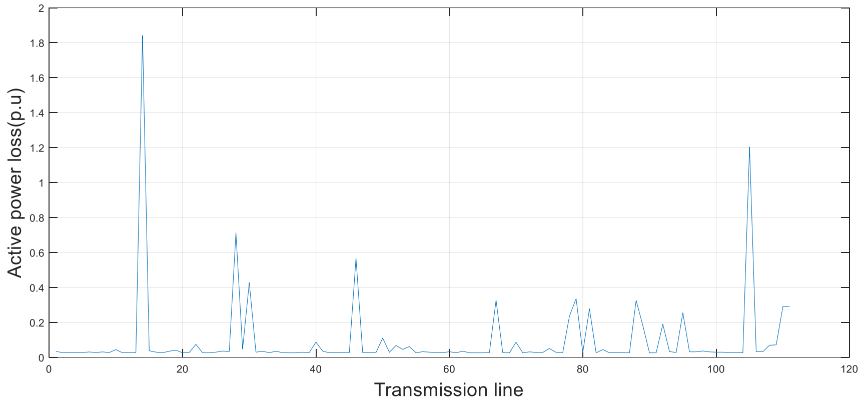

Fig. 7: Active power loss distribution in the power system with UPFC installed for the 297MW load drawn at bus 49.

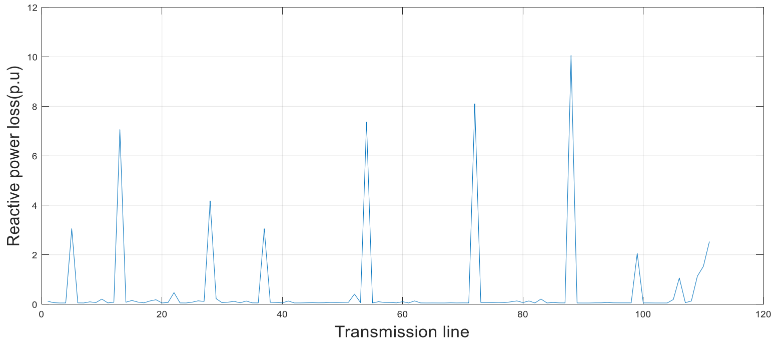

Fig. 8: Reactive power loss distribution in the power system with UPFC installed for the 297MW load drawn at bus 49.

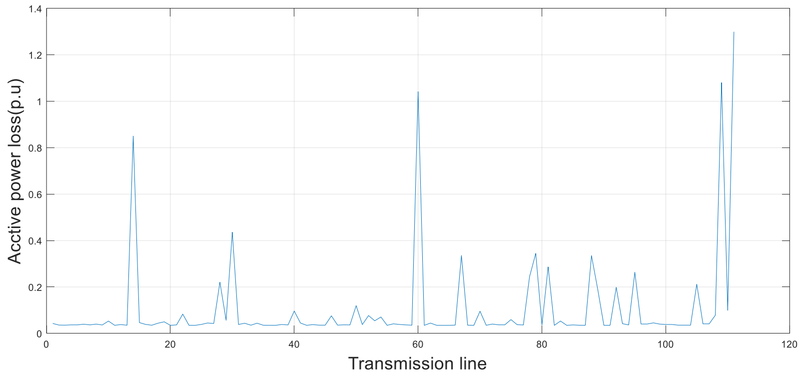

Fig. 9: Active power loss distribution in the power system with UPFC installed for the 396MW load drawn at bus 49.

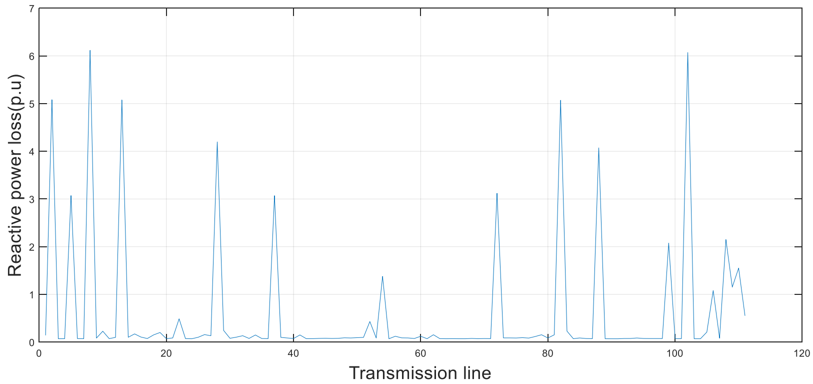

Fig. 10: Reactive power loss distribution in the power system with UPFC installed for the 396MW load drawn at bus 49.

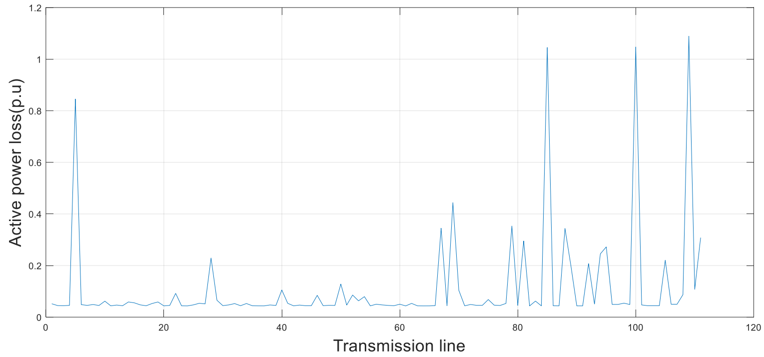

Fig. 11: Active power loss distribution in the power system with UPFC installed for the 495MW load drawn at bus 49.

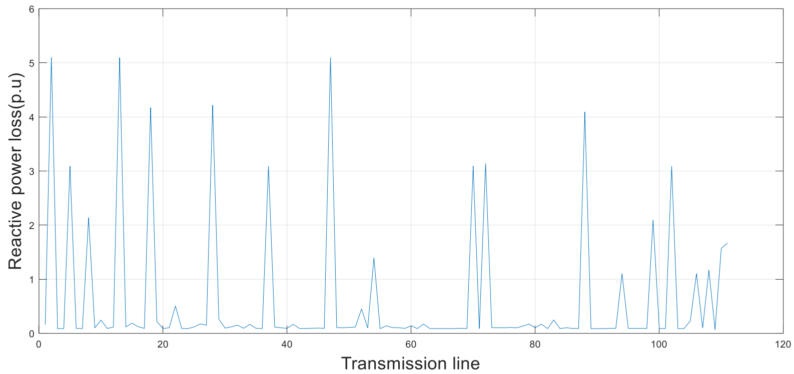

Fig. 12: Reactive power loss distribution in the power system with UPFC installed for the 495MW load drawn at bus 49.

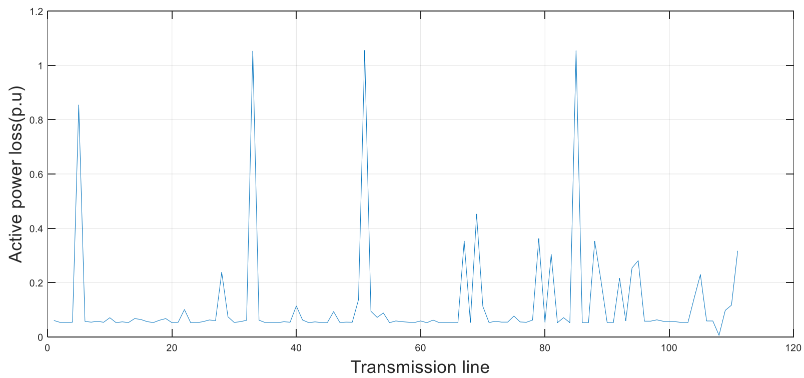

Fig. 13: Active power loss distribution in the power system with UPFC installed for the 594MW load drawn at bus 49.

Load variation(MW)	Total active power loss(p.u)	Total Reactive power loss(p.u)
198	7.8838	55.8455
297	10.7512	59.7880
396	11.5169	64.7305
495	12.4826	66.6730
594	13.4483	73.6155
Total	**56.0828**	**320.6525**

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

The trend that can be observed from Table 3 is that as the load increases, the active and reactive losses increase. From Table 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 14 and Figure 15 respectively.

The total active and reactive losses of the power system after the installation of the UPFC are **56.0828 p.u** and **320.6525 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.

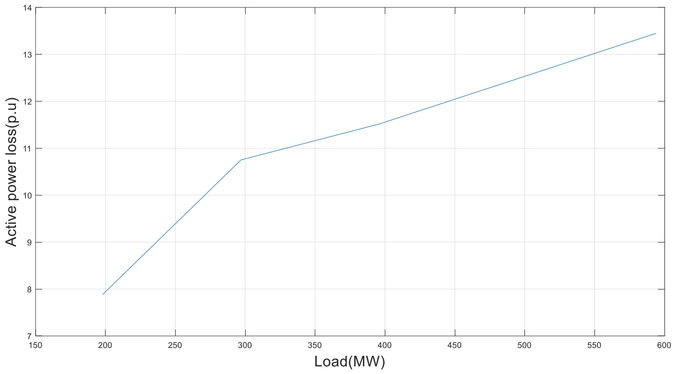

Fig. 14: Variation of active power loss with load variation with UPFC installed

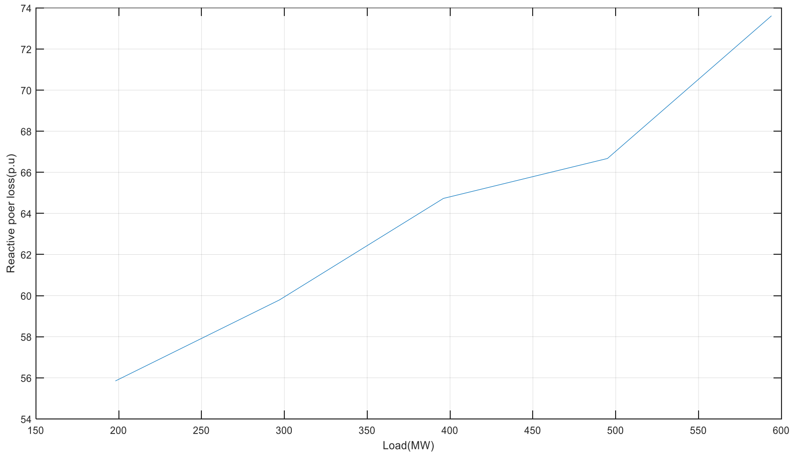

Fig. 15: Variation of active power loss with load variation with UPFC installed

Figures 14 and 15 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 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.

IX. 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 16, 18, 20, 23 and 25 show 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 17, 19, 21, 24 and 25 show 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.

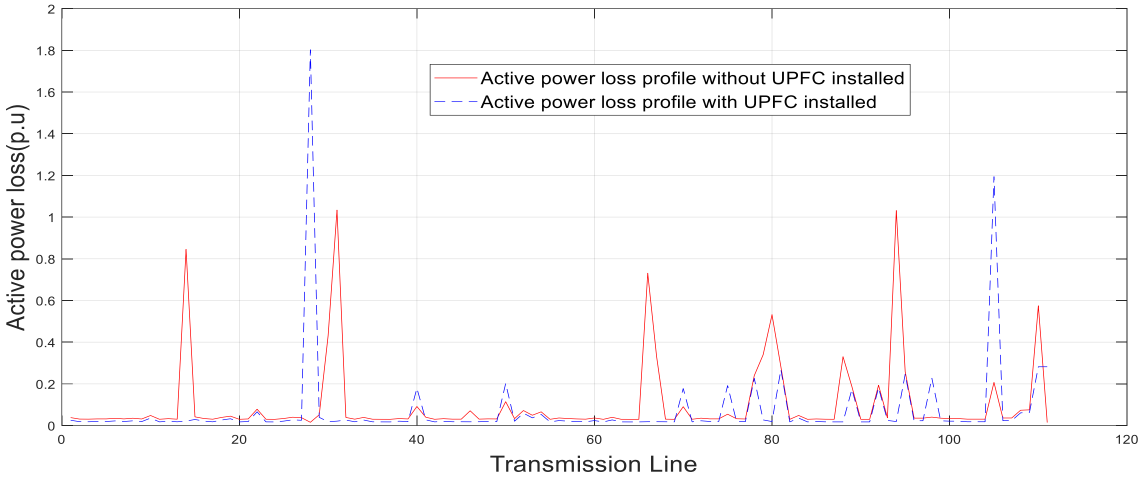

Fig. 16: Comparison of active power loss distribution in the power system with UPFC installed for the 198MW load drawn at bus 49.

Figure 16 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 are 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 16, 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 3, 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 4, the total active loss in the case of the 198MW load drawn with the UPFC installed is **7.8838 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 **7.8838 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 **29.44%.**

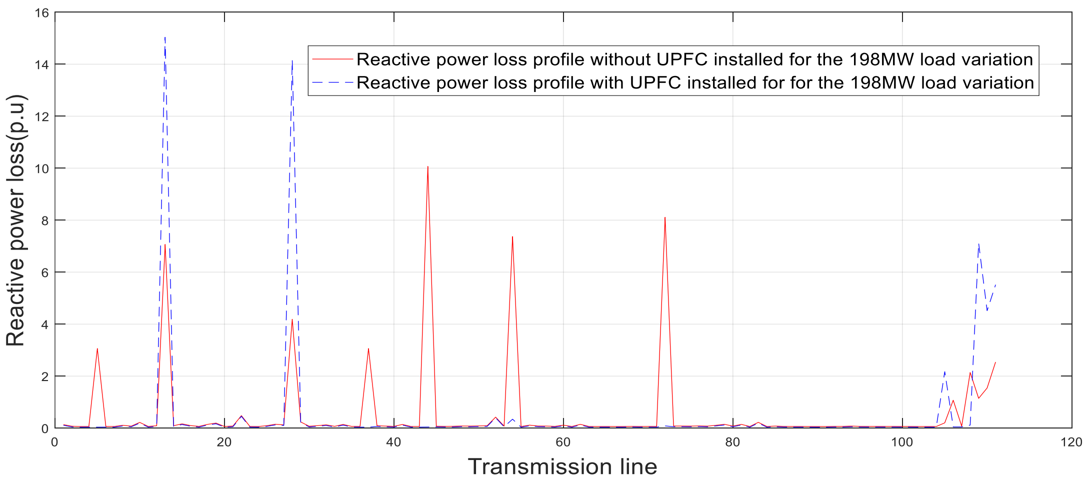

Fig. 17: Comparison of reactive power loss distribution in the power system with UPFC installed for the 198MW load drawn at bus 49.

Figure 17 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 2.5, 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 1.2, the total reactive loss in the case of the 198MW load drawn with the UPFC installed is **55.8455 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 **55.8455 p.u.** These values represent **8.10%** reduction of reactive power loss due to the 198MW load variation at the selected bus.

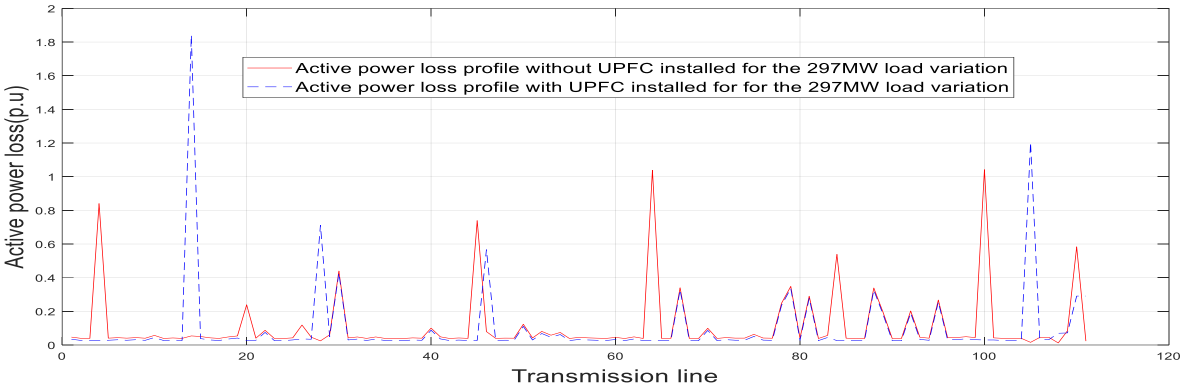

Fig. 18: Comparison of active power loss distribution in the power system with UPFC installed for the 297MW load drawn at bus 49.

Figure 18 shows the comparison of the active loss power loss profiles of the power system with and without the UPFC installed for 297MW load variation at the selected bus.

With close examination of the combined plot of Figure 18, 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 **10.7512p.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 **10.7512 p.u .** These values represent **11.43%** reduction of active power loss due to the 297MW load variation at the selected bus.

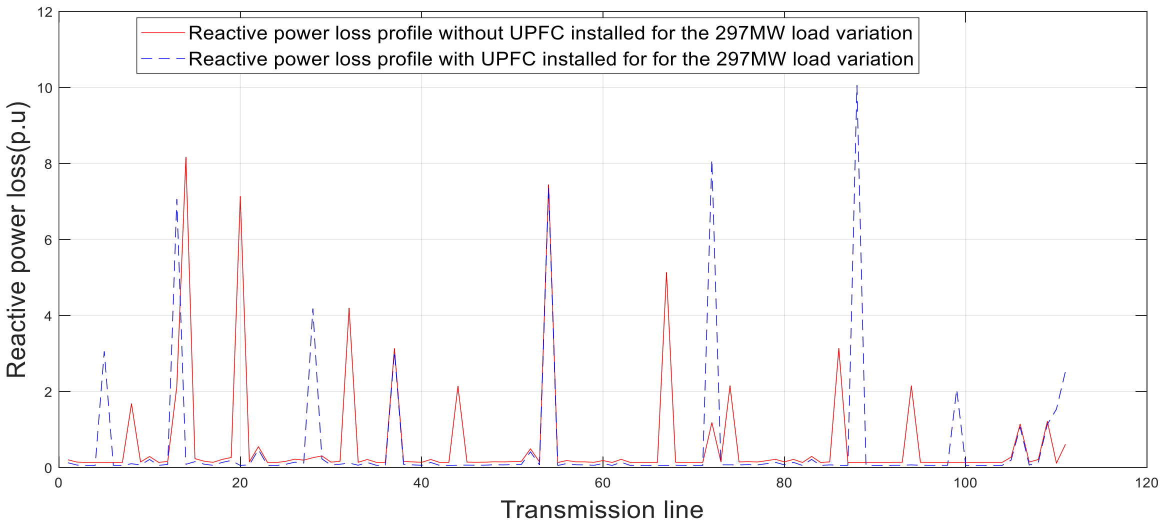

Fig. 19: Comparison of reactive power loss distribution in the power system with UPFC installed for the 297MW load drawn at bus 49.

Figure 19 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 19, 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 3, 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 4.3, the total reactive loss with the UPFC installed is **59.7880 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 **59.7880 p.u.** These values represent **12.71%** reduction of reactive power loss due to the 297MW load variation at the selected bus.

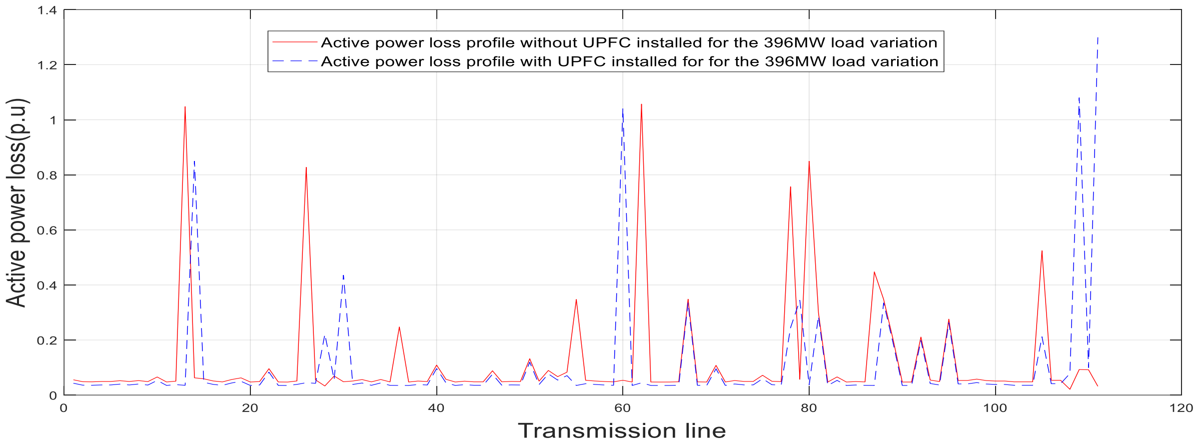

Fig. 20: Comparison of active power loss distribution in the power system with UPFC installed for the 396MW load drawn at bus 49.

Figure 20 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 20, 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 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 3, the total active losses in the case of the 396MW load drawn at the selected bus without the UPFC installed is **13.1044 p.u**. From Table 3, the total active loss with the UPFC installed is **11.5169p.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 **11.5169 p.u.** These values represent **12.15%** reduction of active power loss due to the 396MW load variation at the selected bus.

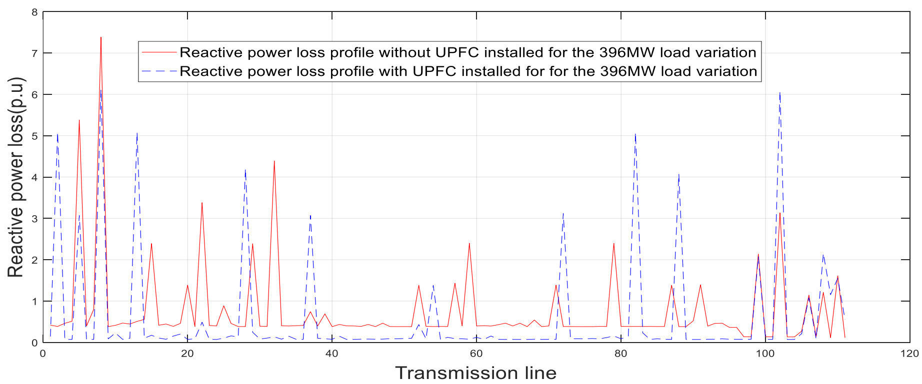

Fig. 21: Comparison of reactive power loss distribution in the power system with UPFC installed for the 396MW load drawn at bus 49.

Figure 21 shows 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 21, 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 is **84.1944 p.u**. From Table 1.2, the total reactive loss with the UPFC installed is **64.7305 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 **64.7305 p.u** These values represent **23.12%** reduction of reactive power loss due to the 396MW load variation at the selected bus.

Fig. 22: Comparison of active power loss distribution in the power system with UPFC installed for the 495MW load drawn at bus 49.

Figure 22 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 4.33, 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 3, the total active losses in the case of the 495MW load drawn at the selected bus without the UPFC installed is **13.8587 p.u**. From Table 3, the total active loss with the UPFC installed is **12.4826 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 **12.4826 p.u.** These values represent **9.93%** reduction of active power loss due to the 396MW load variation at the selected bus.

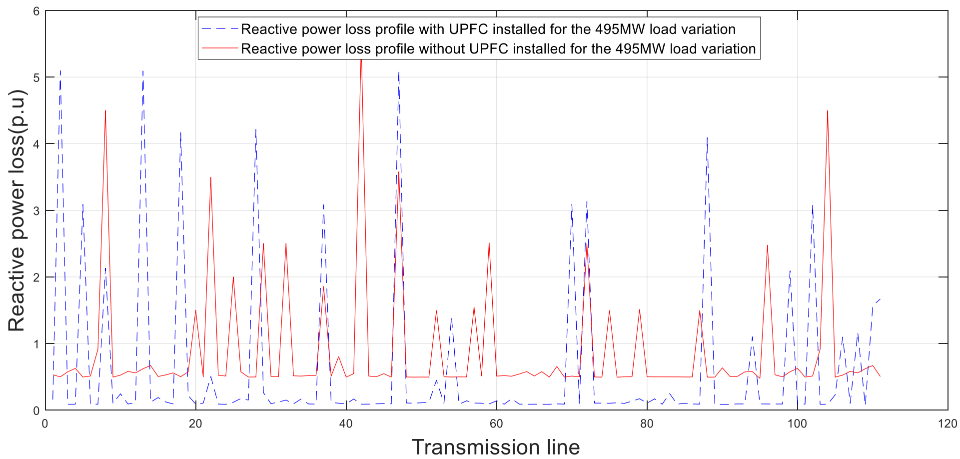

Fig. 23: Comparison of reactive power loss distribution in the power system with UPFC installed for the 495MW load drawn at bus 49.

Figure 23 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 23, 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 3, 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 3, the total reactive loss with the UPFC installed is 66.6730 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 66.6730 p.u These values represent 31.36% reduction of reactive power loss due to the 495MW load variation at the selected bus.

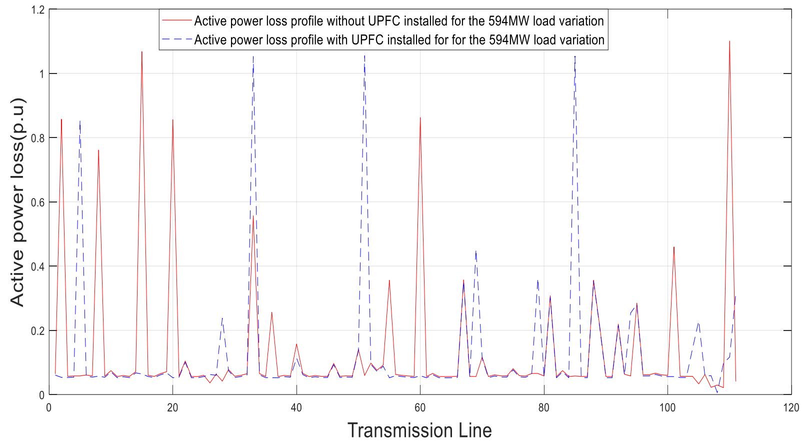

Fig. 24: Comparison of active power loss distribution in the power system with UPFC installed for the 594MW load drawn at bus 49.

Figure 24 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 24, 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 3, 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 3, the total active loss with the UPFC installed is **13.4483 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 **13.4483 p.u .** These values represent **9.07%** reduction of active power loss due to the 594MW load variation at the selected bus.

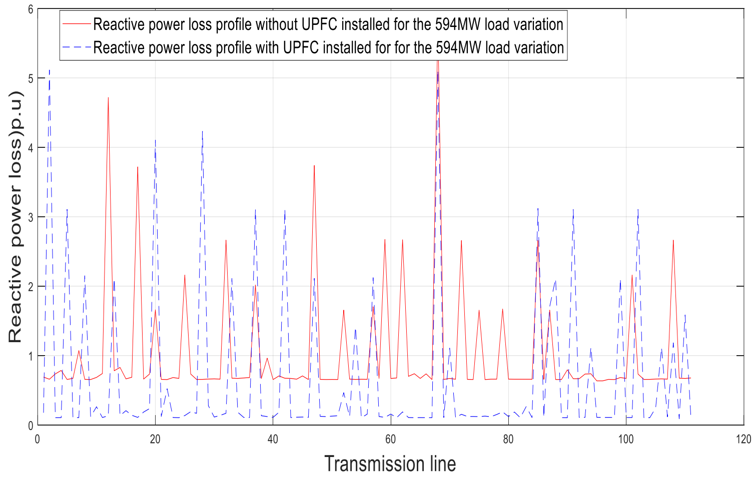

Fig. 25: Comparison of reactive power loss distribution in the power system with UPFC installed for the 594MW load drawn at bus 49.

Figure 25 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 25, 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 3, 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 3, the total reactive loss with the UPFC installed is **73.6155 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 **73.6155 p.u.** These values represent **33.08%** reduction of reactive power loss due to the 594MW load variation at the selected bus.

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.

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	7.8838	60.7648	55.8455	29.44	8.10
297	12.1387	10.7512	68.4904	59.7880	11.43	27.71
396	13.1044	11.5169	84.1944	64.7305	12.15	23.12
495	13.8587	12.4826	97.1322	66.6730	9.93	31.36
594	14.7901	13.4483	113.3895	73.6155	9.07	33.08
Average	**13.01298**	**11.21656**	**84.79426**	**64.1305**	**14.404**	**24.674**

Table 4: Active and reactive loss reduction for load variations with UPFC installed in the power system,

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 **14.404%** and an average reactive power loss reduction of **24.674%.**

X. CONCLUSION

In this paper, the neural network controlled UPFC was used for the reduction of losses in power transmission network. In the modeling of the neural network controller for the UPFC , the input parameters of the neural controller includes power system variables that relates to the control of ohmic and corona losses on transmission lines.

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 was carried out to evaluate the distribution of losses and the active and reactive loss reduction achieved by the proposed system.

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