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Load Flow Simulation for Loss Minimization in Power Systems

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Abstract

Loss minimization is critical to a power system. Transmission line losses in a power system can be reduced by Var compensation. This paper investigates the transmission line losses using the 5-bus Ring segment of Nigeria National Grid and the improvement that a unified power flow controller (UPFC) can create by simultaneous or individual controls of basic system parameters like transmission voltage,impedance and phase angle. The network segment was analyzed using Newton-Raphson iterative method in Matlab/ Simulink environment. The network was modeled using Simulink block sets. The power losses in the transmission lines were calculated using differential power flow with and without the unified power flow controller (UPFC).The simulation results showed that all the bus voltage, V_b ***is within acceptable limit of*** $0.95p.u \geq V_b \leq 1.05p.u$***and incorporating the UPFC reduced real power losses from 491.79MW to -117MW and reactive power losses also decreased from -74.6 to -2548.8MVAr. This device has minimized losses and ensures a high efficient and reliable system due to power loss reduction. It was also shown that the power loss saved is 100-23.38% = 76.62% when UPFC are used. The high transmission and distribution losses of upto 45% currently associated with the Nigeria Power system will be greatly reduced if UPFC is deployed.***

1.0 Introduction

Today's power systems are highly complex and require careful design of new devices taking into consideration the already existing equipment, especially for transmission systems in new deregulated electricity markets like in Nigeria. This is not an easy task considering that power engineers are severely limited by economic and environmental issues. Thus, this requires a review of traditional methods and the creation of new concepts that emphasize a more efficient use of already existing power system resources without reduction in system stability and security [1].

Most of the large power system blackouts which occurred worldwide over the last twenty years are caused by heavily stressed system with large amount of real and reactive power demand and low voltage condition [2]. When the voltages at power system buses are low, the losses will also be increased [3].The comparative losses in each section of power system are presented in[4]. Application of Flexible Alternating Current Transmission System (FACTS) devices are currently pursued intensively to achieve better control over the transmission lines for manipulating power flows [2]. There are several kinds of FACTS devices. Thyristor-Controlled Series Capacitors (TCSC), Thyristor Controlled Phase Shifting Transformer (TCPST) and Static Var Compensator (SVC) which can exert a voltage in series with the line and, therefore, can control the active power through a transmission line [5]. On the other hand, Unified Power Flow Controller (UPFC) has a series voltage source and a shunt voltage source, allowing independent control of the voltage magnitude, and the real and reactive power flows along a given transmission line. The UPFC was proposed here for real-time control and dynamic compensation of the AC transmission system to provide the necessary functional flexibility required to solve many of the problems facing the utility industry [6].This opens up new opportunities for controlling the power, decreasing the losses and enhancing the usable capacity of existing transmission lines.

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1.1 The Operating Principle of UPFC

A simplified scheme of a UPFC connected to an infinite bus via a transmission line is shown in Figure 1.UPFC consists of parallel and series branches, each one containing a transformer, power-electric converter with turn-off capable semiconductor devices and DC circuit. Inverter 2 is connected in series with the transmission line by series transformer. The real and reactive power in the transmission line can be quickly regulated by changing the magnitude and phase angle of the injected voltage produced by inverter 2. The basic function of inverter 1 is to supply the real power demanded by inverter 2 through the common DC link. Inverter 1 can also generate or absorb controllable power.

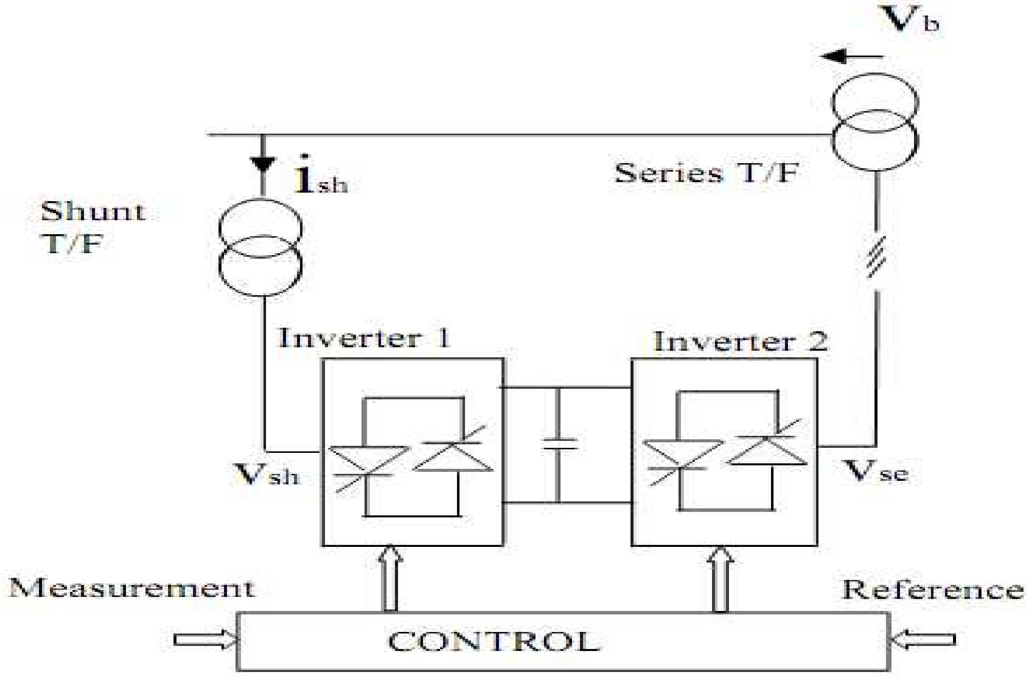

Figure 1 UPFC installed in a Transmission Line [3,7,8].

1.2 Mathematical Representation of UPFC

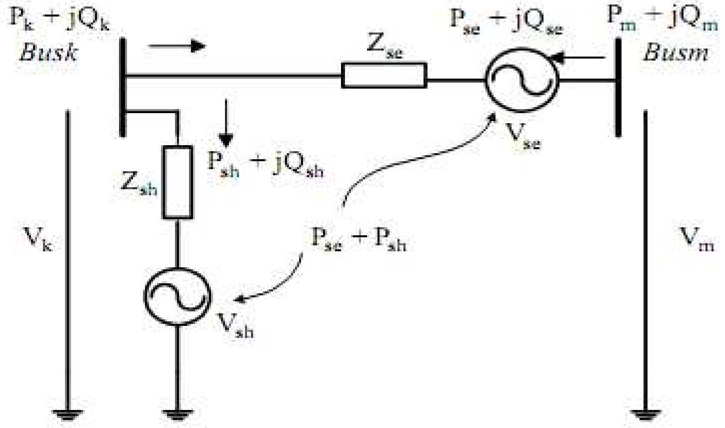

Figure 2 Voltage source model of UPFC [3, 7,8].

The two ideal voltage sources of the UPFC can be mathematically represented as [3,7,8]:

$$V_{se} = V_{se}(\cos\theta_{se} + j\sin\theta_{se}) \quad \text{……………………………………………} (1)$$

$$V_{sh} = V_{sh}(\cos\theta_{sh} + j\sin\theta_{sh}) \quad \text{……………………………………………} (2)$$

UPFC is connected between two buses *k* and *m* in the power system. Applying the Kirchhoff's current and voltage laws for the network in Fig. 2 gives:

$$\begin{bmatrix} I_k \\ I_m \end{bmatrix} = \begin{bmatrix} y_{se}+y_{sh} & -y_{se} & -y_{se} & -y_{sh} \\ -y_{se} & y_{se} & y_{se} & 0 \end{bmatrix} \begin{bmatrix} V_k \\ V_m \\ V_{se} \\ V_{sh} \end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (3)$$

Where

$$y_{se} = \frac{1}{z_{se}} \quad \text{and} \quad y_{sh} = \frac{1}{z_{sh}}$$

The element of transfer admittance matrix can be put as

$$\begin{aligned} Y_{kk} &= G_{kk} + jB_{kk} = y_{se} + y_{sh} \\ Y_{mm} &= G_{mm} + jB_{mm} = y_{se} \\ Y_{km} &= Y_{mk} = G_{km} + jB_{km} = -y_{se} \\ Y_{sh} &= G_{sh} + jB_{sh} = -y_{sh} \end{aligned} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (4)$$

The UPFC converters are assumed lossless in this voltage sources model. This implies that there is no absorption or generation of active power by the two converters for its losses and the active power demanded by the series converter at its output is supplied from the AC Power system by the shunt converters via the common D.C link. The DC link capacitor voltage V_{dc} remains constant. Hence the active power supplied to the shunt converter P_{sh} must be equal to the active power demanded by the series converter P_{se} at the DC link. Then the following equality constraint has to be guaranteed [3].

$$P_{se} + P_{sh} = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (5)$$

From Figure 2 and by equation (1), (2), (3) for the series and shunt sources the power equations of UPFC can be written as[3].

$$\begin{aligned} P_{se} = {} & V_{se}^2 G_{mm} + V_{se}V_k(G_{km}\cos(\theta_{se} - \theta_k) + B_{km}\sin(\theta_{se} - \theta_k)) \\ & + V_{se}V_m(G_{mm}\cos(\theta_{se} - \theta_k) + B_{mm}\sin(\theta_{se} - \theta_m)) \end{aligned} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (6)$$

$$P_{sh} = -V_{sh}^2 G_{sh} + V_{sh}V_k(G_{sh}\cos(\theta_{sh} - \theta_k) + B_{sh}\sin(\theta_{sh} - \theta_k)) \quad \ldots\ldots\ldots\ldots \; (7)$$

Where:

V_{se}, P_{se}, Q_{se}, Z_{se}, θ_{se} are the series UPFC voltage,active power,reactive power,impedance and power angle respectively.

V_{sh}, P_{sh}, Q_{sh}, Z_{sh}, θ_{sh} are the shunt UPFC voltage, active power, reactive power, impedance and power angle respectively.

V_k, P_k,Q_k,θ_k are the UPFC voltage,active power, reactive power and power angle respectively at bus **k**.

V_m, P_m, Q_m,θ_m are the voltage, active power, reactive power and power angle respectively at bus **m**.

I_k and $I_m$are the currents in bus **k** and bus **m** respectively.

G_{kk} and G_{mm} are the self-conductance of bus **k** and bus **m** respectively while G_{km} is the mutual conductance between bus **k** and bus **m**.

B_{kk} and B_{mm} are the self-susceptance of bus k and bus m respectively while B_{km} is the mutual- susceptance between bus **k** and bus **m**.

2.0 Methodology

Power flow analysis was carried out using Newton-Raphson method in Matlab environment[9, 10, 11, 12] to determine voltages and power angles, real and reactive power at various buses and the power losses on the lines.Simulation of the results using graphic user interface(GUI) method in Matlab/Simulink environment (Version 7.5) [13] to ascertain the various flow configurations among various possibilities and effects on the networks with flexible AC transmission system (FACTs) devices[6]. Figure 3 shows the 330kV ring network of the Nigeria Transmission network [14] and Figure4 shows the Matlab/Simulink model of the test system with UPFCincorporated between the buses 1 and 2 in 5 bus system.

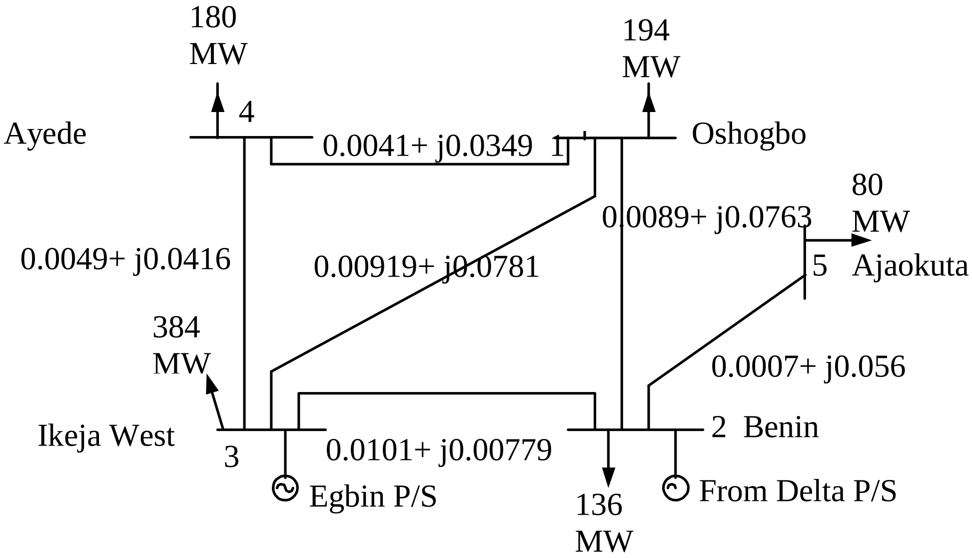

Figure 3 330kV ring network of the Nigeria Transmission network [8].

2.1 Optimal Power Flow Simulation with UPFC

A UPFC is used to control the power flow in the 330 kV transmission systems. The UPFC is connected between Ikeja West and Benin buses, it consists essentially of five buses (B1 to B5) interconnected through the transmission lines and two 132 kV/330kV transformer banks situated at the power station. Two power plants located on the 330-kV system generate a total of 1406MW which is transmitted to the 330-kV network and to loads connected at the buses. The plant models include a speed regulator, an excitation system as well as a power system stabilizer (PSS). In normal operation, most of the generation capacities of power plants are exported to the 330-kV network through 6x220-MVA 132/330kV and 6x140 MVA, 4x71.25 MVA, 6x140 MVA and 2x168.5MVA transformers located at the Egbin and Delta Power plants [9]. For this investigation we are considering a contingency case where the Egbin power plant is generating 80% capacity and Delta power plants are generating 35% capacity. Matlab/simulink model of the test system is shown in Figure 4.The block set in Simulink user guide [15] were used to develop the Matlab/Simulink model of the test system. A base voltage of 330kV and base power of 100MVA was used in this analysis.

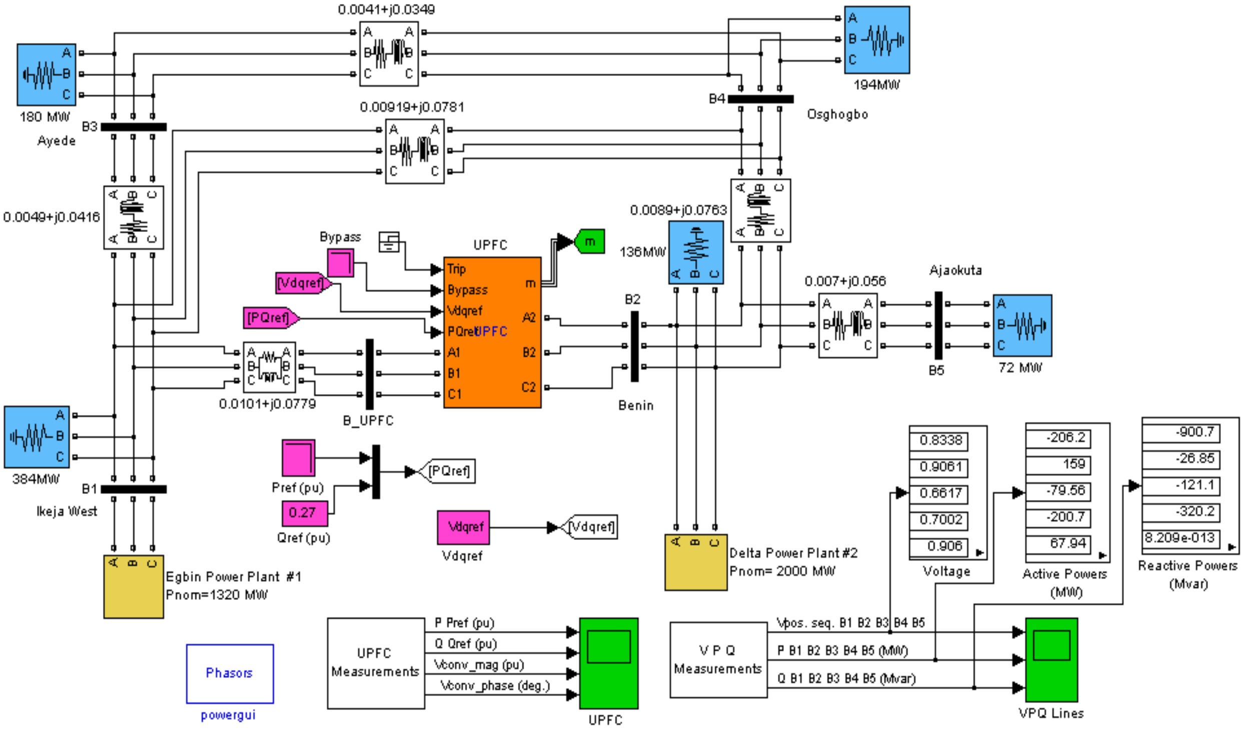

Figure 4 The Matlab/Simulink model of the test system

3.0 Results and Discussion

Table 1 shows the lines power flows, losses and Table 2 gives the summary of bus voltages profile. The result shows that the losses were higher in Oshogbo – Benin (0.002MW) line and Oshogbo - Ikeja West (0.0017WM) line.

Table 1Simulation Result of 330kV Ring Network (Bus Voltages)

Bus No	Name	P.u (Volt)	U (kV)	Angle (Deg)
1	Oshogbo	0.9999	330	-0.0039
2	Benin	0.9999	330	-0.0013
3	Ikeja West	1.0000	330	0.0000
4	Ayede	0.9999	330	-0.0038
5	Ajaokuta	0.9999	330	-0.0036

Table 2 Simulation Result of 330kV Ring Network (Line flow and losses)

From Bus	To Bus	From MW	From MVar	To MW	To MVar	MW Loss	MVar Loss
3	2	44.92	109.71	-44.92	-109.70	0.00	0.01
1	2	-68.92	19.32	68.9221	-19.32	0.002	0.00
4	1	9.72	35.32	-9.72	-35.32	0.00	0.00
3	4	189.72	145.34	-189.7201	-145.32	-0.0001	0.02
3	1	115.36	102.02	-115.3583	-102.00	0.0017	0.02
2	5	80.00	45.00	-80.00	-45.00	0.00	0.00

3.1 Simulation Result with UPFC

Using the load flow option of the powergui block, the resulting power flow obtained at buses B1 to B5 is shown in Table 3.

Table3 Bus Voltages and Power With and Without UPFC

Bus No.	**Bus Voltage Without UPFC**	**Bus Voltage With UPFC**	**Bus Power Without UPFC**		**Bus Power With UPFC**	
	Voltages(pu)	**Voltages(pu)**	**P (MW)**	**Q (MVar)**	**P (MW)**	**Q (MVar)**
1	0.8748	0.8331	-212.60	-589.80	-203.60	-898.80
2	0.8749	0.9053	351.40	492.90	160.70	-26.80
3	0.6912	0.6612	-140.30	-216.10	-79.33	-120.80
4	0.7045	0.6997	-153.10	-257.00	-200.50	-319.40
5	0.8748	0.9053	64.91	9.298E-13	67.83	8.327E-13

The load flow shows that most of the power generated by the plants is transmitted through the transformers along bus 2 path on the 330kV network transmission network. The study illustrates how the UPFC can relieve this power congestion through optimal power flow. The P and Q measured at bus B2 follow the reference values set on the UPFC. At t=5s, when the Bypass breaker is opened the natural power is diverted from the Bypass breaker to the UPFC series branch without noticeable transient. The power decreases at a rate of 2pu/s. It takes two seconds for the power to decrease to 160 MW as seen in the result of Table 3. This 200 MW decrease of active power at bus B2 is achieved by injecting a series voltage of 0.1pu with an angle of 94 degrees thus relieving the congested branch elements of bus 2.

Tables 4 and 5 shows power flow results of a 5-bus system without and with UPFC. Table 3 shows the comparative results of system. From the tables it is concluded that the system power transfer was optimized and the losses are reduced when UPFC is installed.

Table 4 Power Flows without UPFC

Branch	**From**	**To**	**From bus injection**		**To bus injection**		**Loss**	
			P(MW)	**Q(MVar)**	**P(MW)**	**Q(MVar)**	**P(MW)**	**(QMVar)**
1	1	2	-212.60	-589.80	351.40	492.90	138.8	-96.9
2	1	3	-212.60	-589.80	-140.30	-216.10	-72.3	-373.7
3	1	4	-212.60	-589.80	-153.10	-257.00	-59.3	-332.8
4	2	4	351.40	492.90	-153.10	-257.00	198.3	235.9
5	2	5	351.40	492.90	64.91	9.298E-13	286.49	492.9
Total							49	-74.6

Table 5 Power Flows with UPFC

Branch	**From**	**To**	**From bus injection**	**To bus injection**	**Loss**			
			P(MW)	**Q(MVar)**	**P(MW)**	**Q(MVar)**	**P(MW)**	**Q(MVar)**
1	1	2	-203.60	-898.80	160.70	-26.80	-42.9	-872
2	1	3	-203.60	-898.80	-79.33	-120.80	-124.27	-778
3	1	4	-203.60	-898.80	-200.50	-319.40	-3.1	-579.4
4	2	4	160.70	-26.80	-200.50	-319.40	-39.8	-292.6
5	2	5	160.70	-26.80	67.83	8.327E-13	92.87	-26.8
Total					-117.2	-2548.8		

Table 6 Comparative Result

Power Loss	**P(MW)**	**Q (MVar)**
Without UPFC($UPFC_{WO}$)	491.79	-74.6
With UPFC($UPFC_W$)	-117.2	-2548.8

From the comparative results presented in Table 6, the percentage drop in the magnitude of active power loss is given as

$(UPFC_W/UPFC_{WO})X100 = (117.2/491.79)x100 = 23.38\%$

Hence the power loss saved is 100-23.38%=76.62% when UPFC are used. The high transmission and distribution losses of upto 45%[16] currently associated with the Nigeria Power system will be greatly reduced.

4.0 Conclusion

The paper presents the application of UPFC in loss minimization in power system. The unified power flow controller provides simultaneous or individual controls of basic system parameters like transmission voltage, impedance and phase angle, there by controlling the transmitted power. The model was implemented in MATLAB and SIMULINK environment to compute power flow. The power loss occurring in the various branches and state variables of 5 bus system was evaluated.The Numerical result for the 5 bus network has been presented with and without UPFC and compared in Tables 4, 5 and 6. From the results it is concluded that the system performs better when the UPFC is connected .i.e. the state variables are improved and the total losses are minimized.The results obtained showed that all the bus voltages, Vb is within acceptable limit of 0.95p.u≥V_b≤1.05p.u and incorporating the UPFC reduced real power losses from 491.79MW to -117MW and reactive power losses also decreased from -74.6 to -2548.8MVAr. It was also shown that the power loss saved is 100-23.38% = 76.62% when UPFC are used. The high transmission and distribution losses of upto 45% [16] currently associated with the Nigeria Power system will be greatly reduced.

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