Voltage Stability Improvement of Power Transmission System Using UPFC, a Case Study of 41-Bus Nigerian Power System Modelled In NEPLAN

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Abstract- This thesis deals with voltage stability improvement of power transmission system in Nigeria using UPFC (Unified Power Flow Controller). The UPFC model is an application of a power electronics device used to control the power flow and improve voltage stability of a system under static condition. Power flow solutions is developed in NEPLAN using Newton-Raphson iterative method and simulated on the existing 41-bus 330KV Nigerian composite power network. The simulated results were achieved without and with UPFC. The absence of UPFC is the normal state of the Network before intervention. At this state, voltage violations occurred at yola, new haven, makurdi, maiduguri, jos, gombe and damaturu bus stations with percentage bus voltage of 68.34%, 88.66%, 88.51%, 70.89%, 80.17%, 75.27%, 76.38% respectively. With the presence of UPFC in-between gombe and damaturu bus stations, the changes in voltage profile were very significant in yola, new haven, makurdi, maiduguri, jos, gombe and damaturu bus stations with percentage bus voltage of 104.44%, 93.68%, 93.59%, 93.73%, 91.61%, 100.00% and 98.47% respectively. The presence of UPFC in the network reveals a significant reduction in line losses. The active line loss on the network was significantly reduced (from 431.787MW to 278.406MW); about 21% reduction, while reactive line loss came down with 70% reduction (from 6035.725MVAR to 1827.334MVAR), thereby providing additional capacities for the consumers. In this way, the efficiency of the system is enhanced while the prolonged and frequent voltage collapses in the transmission network are minimized.

Indexed Terms- Unified Power Flow Controller (UPFC), Voltage Collapse, NEPLAN, Load Flow.

I. INTRODUCTION

Human population growth matched by industrialization is in league to push electrical energy demand, subjecting the electric power system network configuration and operation to excessive stress. Alleviating this stress for reliable system operation is an enormous challenge.

In meeting this challenge, innovations driven by economy, efficiency and chiefly, security for high level of operational and component reliability, have been made in the electric power sector with impacts that are both short and long termed.

Flexible Alternating Current Transmission Systems (FACTS) was developed and deployed as a sustainable short term measure to control system operation by ensuring voltage stability and increasing transmission line transfer capacity and it is currently incorporated in the implementation of Electric Power System Smart Grids. FACTS technology offers flexibility and utilization which have the capability of making transmission and distribution of electricity more reliable and controllable. The UPFC is a second generation FACTS controller. It is the most promising device in the FACTS concept. It has the ability to adjust the three control parameters, i.e. the bus voltage, transmission line reactance and phase angle between two buses, either simultaneously or independently at its series connected output while maintaining reactive power support at its shunt connected input to enhance the useable transmission capacities of line and control the power flow. UPFC is also the most versatile FACTS controller that can be used to improve steady state stability, dynamic stability and transient stability.

II. LITERATURE REVIEW

Flexible A.C transmission system is an evolving technology used to solve power system instability problems. Its first concept was introduced by Hingoram N.G and Gyugyi L. in 1988, since then different kinds of FACTS devices have been proposed. Among them, the UPFC, is the most versatile and effective device which was introduced in 1991. The UPFC consist of voltage source converters, one connected in series and other in shunt and both are connected back to back through a d.c capacitor. In order to investigate the impact of UPFC on power system effectiveness, it is essential to formulate their correct and appropriate model.

2.1 Review of Related Literatures

In many countries, problem due to voltage instability is one of the major concerns in power system planning, design and operation. Voltage instability may result in voltage collapse and sometimes lead to a complete blackout of the system. The basic precaution for preventing such severe system incident is the identification of voltage instability.

Several studies have shown that FACTS devices can be used to improve voltage stabilities for both steady state and transient stabilities. M. Mashayeki, A. Kazemi (2009), developed UPFC power frequency model with its capacitor dynamics neglected which might distort the real performances of UPFC and the global system dynamic behavior. However, S.M. Shirvani Boroujeni. (2011) proposed the UPFC frequency model with its capacitor dynamics included having the advantage of high efficiency and easily being interfaced to A.C network. Other models have problems such as difficult to include various control strategies or difficult to interface to A.C network.

To improve the energy quality in the distribution systems, many different solutions have been implemented like active filters, the Unified Power Flow Controller (UPFC) and the IPFC. The IPFC concept using a probabilistic approach to the distribution system decreases the power rating of the parallel active filters when it is a component of the IPFC as shown in the works of Ranjendra B. Sadaphale. Vicram, (2012).

Voltage profile improvement using UPFC approach on Artificial Immune System (AIS) optimization engine was developed by Mok T.K, and FF Wu (2000). The voltage profile improvement which utilized UPFCs as control variables is embedded into the system's data. Implementation on the IEEE reliability test system considering several variations in AIS properties indicated AIS potential in solving voltage control problems.

Seo. J.C., Moon, J.K. Park and J.W. Cheo (2011) presented an approach to optimally select and allocate flexible AC transmission (FACTS) devices in a distribution network in order to minimize the number of voltage sags at network buses. The method proposed was based on optimization of a preselected objective function using simple and niching Genetic Algorithms (GA). The objective of the optimization was to achieve the improvement in overall system sag performance of the network. Using proposed GA-based optimization, the location, the type and the rating of six (in total) FACTS devices are optimized simultaneously.

Y. Tamura, H. Mori and S. Iwamoto (2010) investigated a utility side solution for the problem of voltage sag. The end user solution suffers from small power and eliminates only the downstream effects. The use of proposed UPFC and compensator proved through the result its feasibility. The location of the compensator by the PIV method proved to be correct by multiple tests done on various buses. Different methods of harmonic elimination of multilevel converters are investigated

2.2 Summary of Review of Related Literatures

Several authors have used different approach to proffer solution to power system instability problems as reviewed in this literature but this research work proposed UPFC power injection model optimally located and interfaced to alternating current (A.C) network to improve the voltage profile/stability, reactive power compensation and power flow present in power system resulting from system overload. The UPFC power injection model regulates power flow through the line by controlling the voltage magnitude angle of the injected voltage. The shunt converter has the capability of independently supply or absorbing reactive power to stabilize the system.

2.3 The Nigeria Power System

In Nigeria, the power sector has been faced with lots of problems for many years which include: low generation, poor transmission and distribution and decaying facilities. The demand for electrical energy is continuously increasing from residential, commercial as well as industrial consumers, with the highest increase being in residential consumption [Sunny Orike, David W. Come, 2013].

The efficient and optimum operation of electric power systems has always been of great concern. It is necessary for utility companies to run their power systems with minimum cost while making profits, satisfying customers' demands at all times.

From inception, the electrical power sector was managed by the Electricity Corporation of Nigeria (ECN). it was later transformed into National Electric Power Authority (NEPA), and consequently into Power Holding Company of Nigeria (PHCN) that got liquidated in 2012. The system grid made use of in this work consists of a 41-bus, 330KV network which connects twelve thermal plants and five hydro plants to several load centers [Onyedikachi S.N., 2014]. Major reform milestones achieved by the sector according to the Director-General, Bureau of Public Enterprises include: creation of the Nigerian Electricity Regulatory Council as an independent regulator, creation of PHCN taking over from the defunct NEPA, unbundling of PHCN into eighteen (18) successor generation, transmission and marketing firms and privatization of these companies, creation of Nigerian Electricity Liability Management Company, creation of Nigerian Bulk Electricity Trading PLC. Table 2.1 shows the sector's reform targets for generation, transmission and distribution from 2014 to 2020. In line with the vision 2020-2020, the Federal Government aims a target generation of 40,000MW by 2020 [Nigerian Power sector review report, 2011].

Table2.1 Nigerian Power System Reform Target

	2014	2016	2018	2020
Generation (MW)	9767	11879	14218	40000
Transmission (MW)	7488	8986	9885	10185
Distribution (MW)	7485	8061	9057	9843

Source [Nigerian Power sector review report, 2011]

III. METHODOLOGY

Static power flow method is adopted for this research work. This is basically a load flow problem which involves solving the set of non-linear algebraic equations. In carrying out this analysis, the Newton-Raphson iterative technique was adopted because of its fast convergence and accuracy with small number of iteration.

NEPLAN program was used to perform the load flow computation. The load flow result will identify buses with voltage magnitude less than 90%. Those are the buses termed as weak or deficient buses. Those deficient bus stations and lines are considered as the possible locations for placement of a FACTS device called UPFC, with a view of improving voltages in those buses to acceptable limits (i.e 100%).

3.1 Modeling of UPFC Power Injection Model

UPFC is the most recent FACTS device under development. Unified power flow controllers power injection model are capable of directing real and reactive power flows through a designated route and regulating the system voltage through reactive power compensation. UPFC can be viewed as combining static synchronous series compensator (SSSC) and STATCOM with a shared d,c bus (i.e common d.c storage capacitor). The UPFC consist of two ac/dc voltage supports for converter operation and functions as energy storage. The A.C side of the booster inserts a synchronous ac voltage of controllable magnitude and phase angle in series with the transmission line through a series booster transformer. The a.c side of the exciter is connected in parallel to the transmission line transformer where a current of a controllable magnitude and power factor is injected to or absorbed from the power. The block diagram of the UPFC is shown in fig 3.5

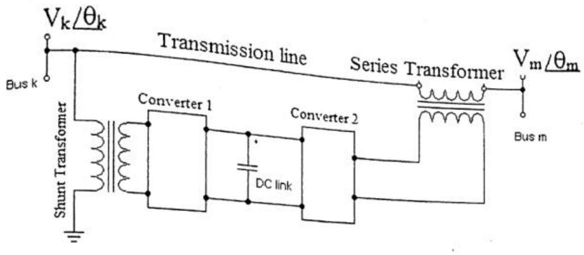

Figure 3.1 The block diagram of the UPFC.

The UPFC has several operating models. Two control modes are possible for shunt control by Adepoju G.A, Komolafe O.A (2011).

- VAR control mode: the reference input is an inductive or capacitive Var request.
- Automatic voltage control mode: the goal is to maintain the transmission line voltage at the connection point to a reference value.

The mathematical model for active and reactive power of the model as written by Hadi Saadat (2009) is shown to be:

At bus K,
Pk=Vk2Gkk+VkVm[Gkmcos(θk-θm)+Bkmsin(θk-θm)]+VkVcr[Gkmcos(θk-δcr)+Bkmsin(θk-δcr)]+VkVvr[Gvrcos(θk- δvr)+Bvrsin(θk-δvr)](3.1)
Qk=-Vk2Bkk-VkVm[Gkmsin(θk-θm)-Bkmcos(θk-θm)]+VkVcr[Gkmsin(θk-δcr)-Bkmcos(θk-δcr)]+VkVvr[Gvrsin(θk- δvr)+Bvrcos(θk-δvr)] (3.2)

At bus M,
Pm=Vm2Gmm+VmVk[Gmkcos(θm-θk)+Bmksin(θm-θk)]+ VmVcr[Gmmcos(θm-δvr)+Bmmsin(θm-δcr)] (3.3)
Qm=-Vm2Bmm-VmVk[Gmksin(θm-θk)-Bmkcos(θm-θk)]+ VmVcr[Gmmsin(θm- δvr)-Bmmcos(θm-δcr)] (3.4)

Series converter
Pcr=Vcr2Gmm+VcrVk[Gkmcos(δcr-θk)+Bmksin(δcr-θk)]+ VmVcr[Gmmcos(δcr - θm)+Bmmsin(δcr - θm)] (3.5)
Qcr=-Vcr2Bmm+VcrVk[Gkmsin(δcr-θk)-Bmkcos(δcr-θk)]+ VmVcr[Gmmsin(δcr - θm)-Bmmcos(δcr - θm)] (3.6)

Shunt converter
Pvr=-Vvr2Gvr+VvrVk[Gvrcos(δvr-θk)+Bvrsin(δvr-θk)](3.7)
Qvr=-Vvr2Bvr+VvrVk[Gvrsin(δvr-θk)-Bmkcos(δvr-θk)] (3.8)

Where:
Pk = the real power at bus k
Pm = the real power at bus m
Vk = voltage magnitude at bus k
Vm = voltage magnitude at bus m
Qk = reactive power at bus k
Qm = reactive power at bus m
Pcr= series converter real power
Pvr= shunt converter real power
Bkm= element of susceptance between bus k and m
Gkm= element of conductance between bus k and m
Θ = voltage angle, δ = phase angle

The above model equations are the non-linear differential algebraic equations and its solution were obtained in the NEPLAN environment. In this work, Newton-Raphson load/power flow solver was selected for the simulation.

3.2 The Structure of 41-Bus 330KV Nigerian Transmission System

The Nigerian grid system was used as the case study in this work. The Nigeria grid system modeled in NEPLAN is a power network of 41-buses, 17 generating plants, 30 loads and 77AC π −transmission lines [Onyedikachi S.N., 2014]. It is interesting to note that this system by reason of the location of the generating plants is zoned into four areas; the four areas are interconnected with the lines during normal operating conditions.

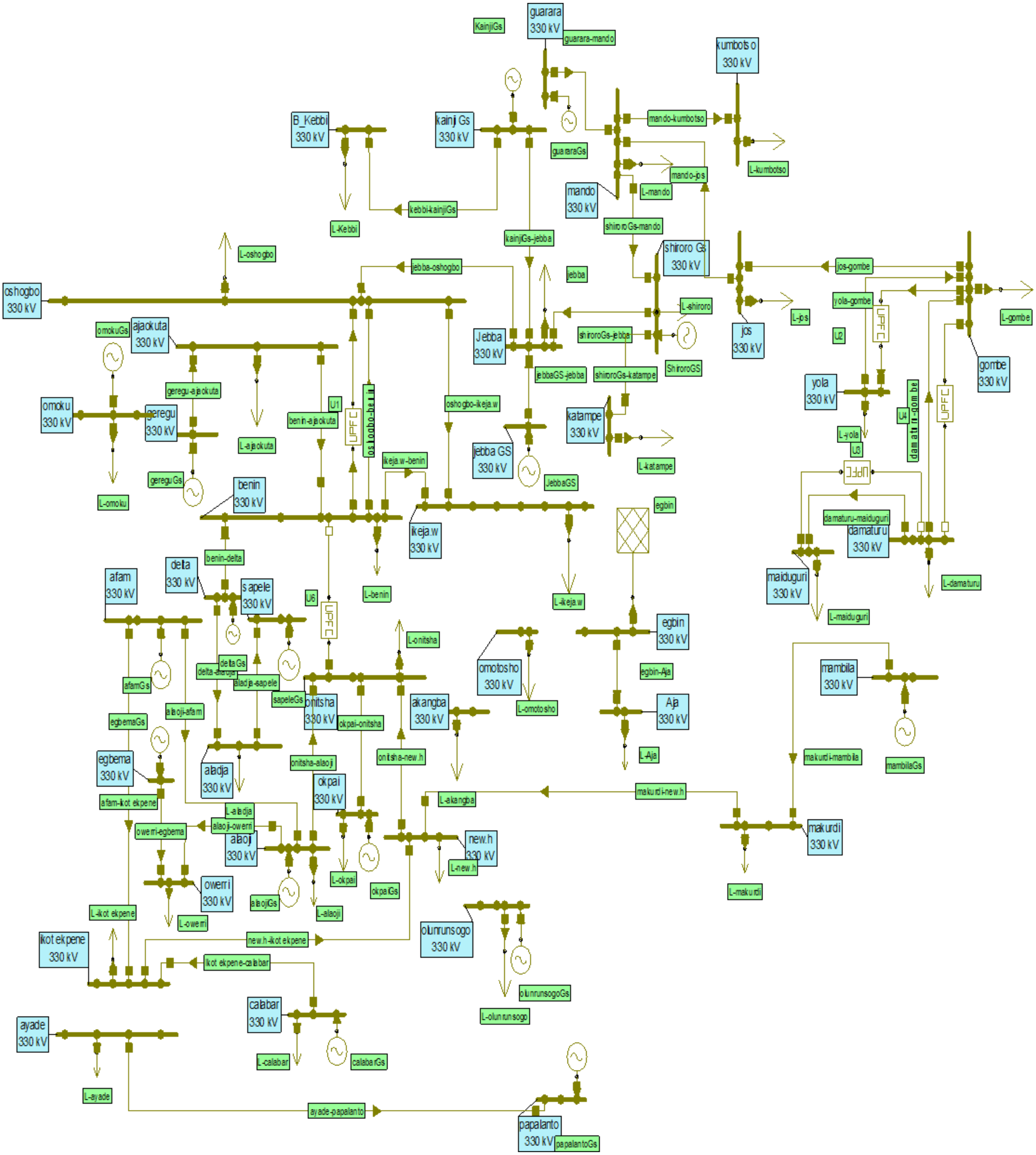

Figure 3.2: One-line diagram of NIPS 41 Bus Nigerian Grid in NEPLAN

IV. RESULTS AND DISCUSSION

This chapter presents the result of load flow analysis using Newton-Raphson iterative method with the NEPLAN software. The analysis was based on the 41-Bus 330KV power transmission line in Nigeria used as a case study, taking into consideration IEEE standard acceptable limits of ±10% tolerance.

4.1 Result of Load Flow Analysis on NIP Network with and without UPFC

Table 4.1 shows the percentage voltage profile of the network with and without UPFC.

Name	Without UPFC		With UPFC	
	V(kV)	V(%)	V(kV)	v(%)
Aja	327.585	99.27	327.20	99.15
ajaokuta	329.141	99.74	329.78	99.93
akangba	325.967	98.78	325.74	98.71
aladja	329.407	99.82	329.32	99.79
ayade	319.93	96.95	324.81	98.43
B_Kebbi	316.599	95.94	314.21	95.22
Benin	303.516	91.97	330.00	100.00
damaturu	252.045	76.38	324.95	98.47
gombe	248.392	75.27	330.00	100.00
ikeja.w	329.108	99.73	329.38	99.81
ikot ekpene	326.46	98.93	327.58	99.27
Jebba	326.997	99.09	328.19	99.45
Jos	264.573	80.17	302.32	91.61
katampe	308.234	93.4	304.27	92.20
kumbotso	297.072	90.02	302.70	91.73
maiduguri	233.948	70.89	309.32	93.73
makurdi	292.092	88.51	308.86	93.59
mando	307.056	93.05	314.05	95.17
new.h	292.565	88.66	309.13	93.68
omotosho	309.113	93.67	305.81	92.67
onitsha	302.117	91.55	317.04	96.07
oshogbo	298.293	90.39	319.37	96.78
owerri	322.764	97.81	321.58	97.45
Yola	225.519	68.34	344.65	104.44

Source: NEPLAN Load Flow

4.1.1 The Impact of UPFC on the Transmission Network with respect to Voltage Profile

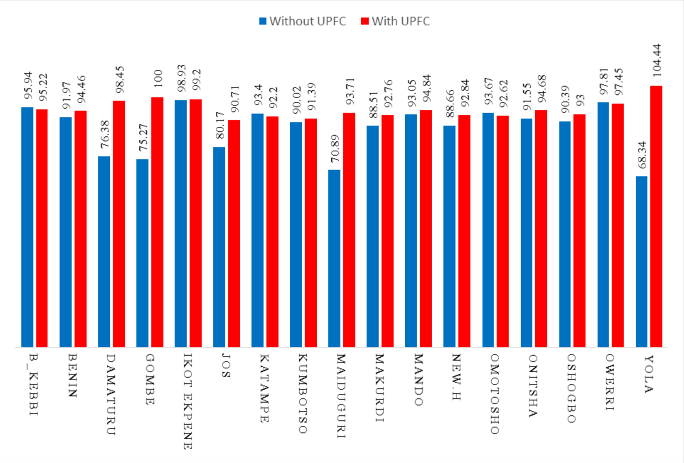

Figure 4.1: Bus percentage voltage profile before and after Intervention

From the result of the nodal analysis in table 4.1 and Fig. 4.1, the absence of UPFC is the normal/base state of the Network before intervention. At this state, voltage violations occurred at yola, new haven, makurdi, maiduguri, jos, gombe and damaturu bus stations with percentage bus voltage of 68.34%, 88.66%, 88.51%, 70.89%, 80.17%, 75.27%, 76.38% respectively. With the presence of UPFC in-between Oshogbo-Benin and Yola-gombe bus stations, the changes in voltage profile were very significant with yola, new haven, makurdi, maiduguri, jos, gombe and damaturu bus stations having percentage bus voltage of 104.44%, 93.68%, 95.17%, 93.73%, 91.61%, 100.00% and 98.47% respectively.

Table 4.2: Summary of Load flow analysis on the Network with and without UPFC

	P Loss (MW)	Q Loss (Mvar)	P Imp (MW)	Q Imp (Mvar)	P Gen (MW)	Q Gen (Mvar)	P Load (MW)	Q Load (Mvar)
Without UPFC	431.787	6035.725	0	0	11407.40	8654.644	10675.61	2598.919
With	278.406	1827.	936.	499.177	1140	4682.	1082	2855.07

UPFC	334	254		7.40	399	8.99

4.1.2 The Impact of UPFC on the Transmission Network with respect to Transmission Line Losses

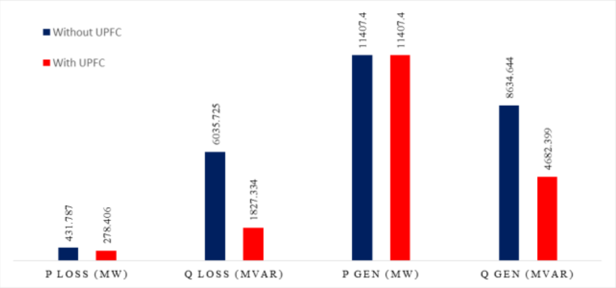

Figure 4.2: Transmission line losses, power generated and load before and after intervention.

Figure 4.2 is a chart of load flow analysis on the network before and after intervention with respect to network line loss and the power generated (reactive and active).

The presence of UPFC in the network reveals a significant reduction in line losses. The active line loss on the network was significantly reduced (from 431.787MW to 278.406MW); about 21% reduction, while reactive line loss came down with 70% reduction as shown (from 6035.725MVAR to 1827.334MVAR). The improvement in voltage and active power transmission of the system was due to injection of reactive power by UPFC to compensate for the drop in voltage in the affected buses thereby, providing additional capacities for the consumers. In this way, the efficiency of the system is enhanced while the prolonged and frequent voltage collapses in the transmission network are minimized.

CONCLUSION

The problem of voltage instability and insecurity of power systems network especially in my country Nigeria led to this work in order to ameliorate the situation of the voltage profile in power systems. The use of FACTS devices particularly UPFC was used to improve voltage stability and power flow.

The power systems without optimally tuned UPFC exhibits lower voltage violations (the system was overloaded at Yola, New haven, Gombe, Jos, Maiduguri, Makurdi, and Damaturu bus stations). There were very significant improvements in the voltage profile, power transfer capacity (loadability) of the transmission lines but significant reduction in active and reactive power line losses with optimized UPFC.

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