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ENHANCING THE STABILITY OF THE NIGERIAN 132/33KV TRANSMISSION SYSTEM USING UNIFIED POWER FLOW CONTROLLER

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ABSTRACT

This research presents enhancing the stability of the Nigerian 132/33KV transmission system unified using power flow controller. The work was embarked on with the aim of improving the stability and control of power flow fluctuation during transmission. The methods used were characterization of the New Haven 132/33KV transmission station to read the unstable bus via Newton Raphson load flow analysis. Unified Power Flow Controller (UPFC) was developed to stabilize the unstable bus characterized with load flow problem through series and shunt compensation processes. The controller was implemented with Simulink and then evaluated. The result showed that the voltage profile satisfy the Nigerian Electricity Regulatory Commission (NERC) standard for transmission network.

Keywords: Transmission, Power, Controller, Shunt compensator, Shunt, Simulink, UPFC

I. INTRODUCTION

In the present scenario, most of the power systems in the developing countries with large interconnected networks share the generation reserves to increase the reliability of the power system. However, the increasing complexities of large interconnected networks had fluctuations in reliability of power supply, which resulted in system instability, difficult to control the power flow and security problems that resulted large number blackouts in different parts of the world. The reasons behind the above fault sequences may be due to the systematically errors in planning and operation, weak interconnection of the power system, lack of maintenance or due to overload of the network (Jinfu et al., 2016).

In order to overcome these consequences and to provide the desired power flow along with system stability and reliability, installations of new transmission lines are required. However, installation of new transmission lines with the large interconnected power system are limited to some of the factors like economic cost, environment related issues (Marouni et al., 2016). These complexities in installing new transmission lines in a power system challenges the power engineers to research on the ways to increase the power flow with the existing transmission line without reduction in system stability and security (Zhang, 2016).

In the late 1980's the Electric Power Research Institute (EPRI) introduced a concept of technology to improve the power flow, improve the system stability and reliability with the existing power systems. This technology of power electronic devices is termed as Flexible Alternating Current Transmission Systems (FACTS) technology. It provides the ability to increase the controllability and to improve the transmission system operation in terms of power flow, stability limits with advanced control technologies in the existing power systems (Tara and Tulasiram, 2018)

Unified Power Flow Controller (UPFC) is one among the different FACTS controllers introduced to improve the power flow control with stability and reliability. It is the most versatile device introduced in early 1990s designed based on the concept of combined series-shunt FACTS Controller. It has the ability to simultaneously control all the transmission parameters affecting the power flow of a transmission line i.e. voltage, line impedance and phase angle (Jinfu et al., 2016). Hence this work adopted this specially designed FACTS type controller to enhance voltage stability in the Nigerian 33KV transmission line.

TABLE 1: Systematic Literature Review

Author	**Title**	**Work done**	**Research gap/ limitations**
Tara and Tulasiram (2018)	Simulation Of Real and Reactive Power Flow Control with UPFC Connected to Transmission Line	The study used UPFC to control load flow instability on 132kv transmission system and achieved steady state	The study was able to achieve load flow stability and will be adopted for the case study 33KV transmission system for stability of load flow
Padiyar and Kulkarni (2017)	Flexible AC Transmission System; A Review	The study reviewed the various FACTS devices and identified their pros and cons	The review identified UPFC as a reliable device for the control and regulation of load flow instability
Rajiv et al. (2018)	Benefits of SVC and STATCOM for Electric Utility	The study used the two FACTS devices to regulate and control load	The application of the two FACTS devices involves high cost

	Application	flow dynamics in the power transmission system	
Mark (2019)	Voltage Stability Improvement Using Static Var Compensator in Power System	The research developed an SVC and deployed for the control of load flow dynamics in power system	The result achieved can be improved using UPFC which is more reliable and affordable
Laszlo et al. (2017)	Static Synchronous Series Compensator for Power Transmission Lines	The study used SVC to control active and reactive power flow in transmission lines	The result achieved can be improved using UPFC which is more reliable and affordable
Samina et al. (2018)	Power Flow Control with UPFC in Transmission System	The study used UPFC to control and regulate active and reactive load flow in power systems	The result achieved high stability index in the load flow and will be used for the new study on 33KV transmission system

II. METHODOLOGY

This paper employs the Power System Computer Aided Engineering method (PSCASE) to develop the new system. The approach used load flow analysis to characterized the New Haven 132/33kv injection feeder and determine the voltage stability performance of the bus. The unstable bus was identified and UPFC was configured and place on them using sum of square minimization approach in (Kowsalya et al., 2009) to improve the performance. This was implemented with Simulink and the results evaluated based on the NERC standard which stated 0.5% $\pm$ (1.00000).

Characterization of the New Haven 132/33kv feeder Network

This work characterizes the New Haven 132/33KV transmission substation using Newton Raphson load flow analysis. The station is made up of 4 power transformers (TR) and 9 load feeders. The TR1 rated 30MVA supplies power to feeder Kingsway line 1, TR2 rated 30MVA supplied feeder Kingsway line 2, TR3 rated 60MVA supplies feeders' thinkers'corner, Ituku-ozalla and trans-Ekulu and TR4 rated 60MVA supplies government house, independence layout, Emene industrial and New NNPC regions respectively. The single line diagram is presented below as;

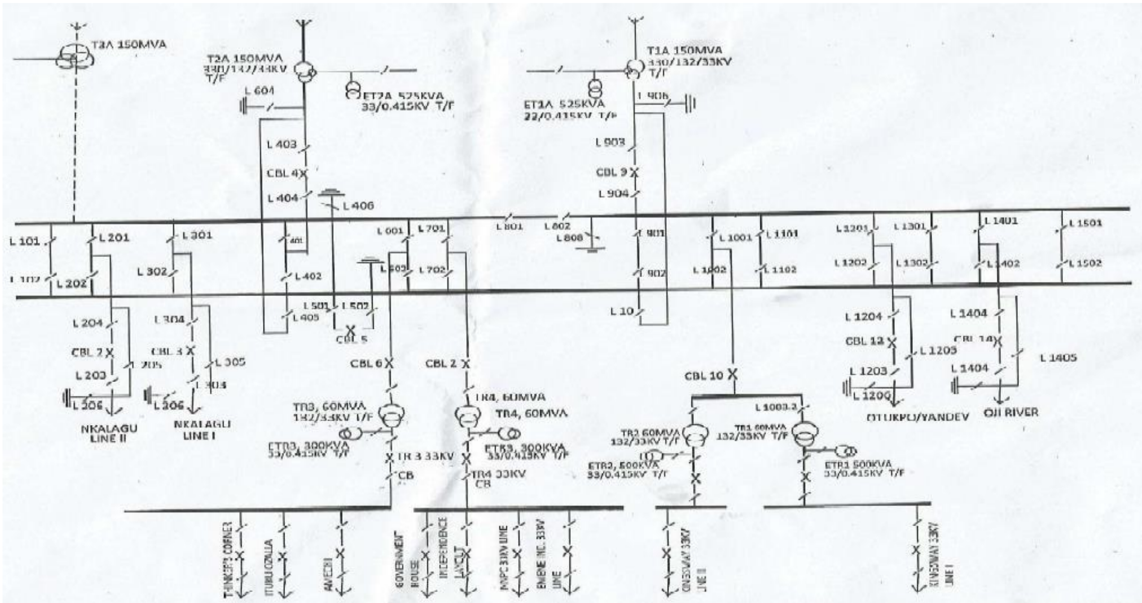

Figure 1: single line diagram of the New Haven 33/132/33KV station (Mark, 2019)

The diagram in figure 1 presents the single line diagram of the New Haven 33kv transmission station, showing the substation, 33/11/415KV distributive feeders respectively. The load shading to the respective 11KV feeders is presented in table 2 with the various sub feeders, load ratings and voltage profile.

TABLE 2: LOAD SHADING DATA AT THE SWITCH YARD

Feeder	**Priority**	**Sub-Feeders**	**Load (MW)**	**V (pu)**
Kingsway I	High	6	17.50	0.818
Kingsway II	Low	5	19.50	0.846
Amechi road	Low	1	13.60	0.825
Ituku-Ozala	High	3	15.10	0.919
Government house	High	1	08.00	0.990
Independence layout	High	4	10.60	0.987
New NNPC	Low	2	19.00	0.801
Thinkers corner	Low	4	19.50	0.840
Emene	Low	1	08.00	0.910

From the characterized data presented in table 2 the performance of the voltage stability in the substation is analyzed and presented using the graph in figure 2 which shows the respective voltage profile for each of the major feeder within the characterized network without a universal power flow controller;

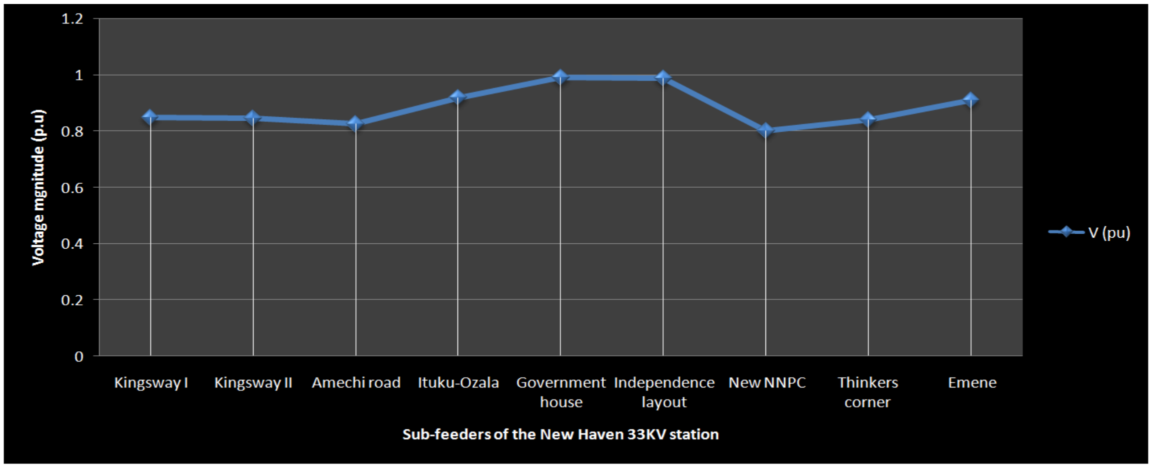

Figure 2: voltage profile performance at the New Haven 33KV station

From the graphical analysis, it was observed that Kingsway I, Kingsway II, New NNPC and Thinkers corner bus were all unstable and need to be corrected as they fall below the NERC standard for power flow stability bus. This problem was addressed in this research using a UPFC system and then used to improved the performance of the various bus characterized as unstable.

III. Model of the 132/33kv Feeder Transformer

The model of the feeder transformer which is the main distribution system in the grid distributive network is presented using the equivalent schematics in figure 3;

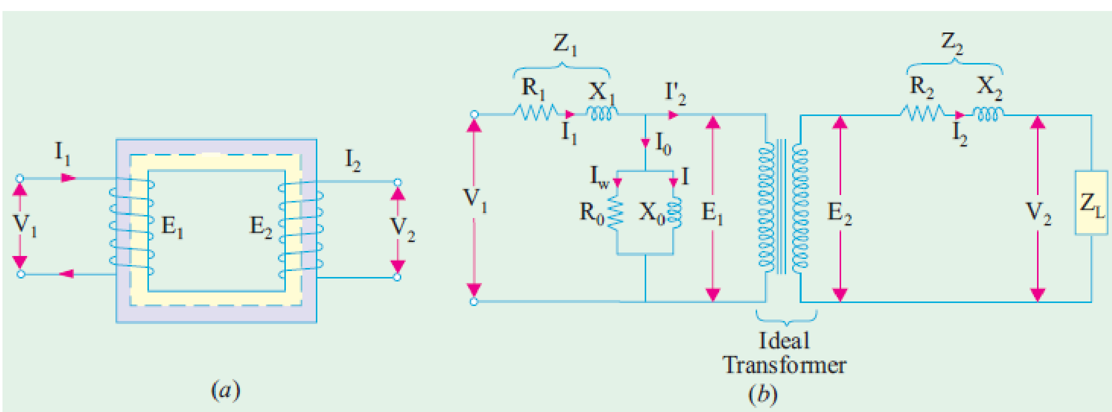

Figure 3: equivalent representation of the feeder transformer (Bulac et al., 2013)

From the equivalent circuit the following transmission parameters are defined;

V_i = primary voltage of the transformer, R_i = the primary circuit resistance, X_i = the primary circuit impedance, I_2 = secondary current, I_1 = primary current, R^o = excitation resistance, X_o = excitation reactance, I_w = loss component of excited current, I = magnetizing component of excited current, E_1= primary EMF induced, E_2= secondary EMF induced, R_2 =secondary circuit resistance, X_2 = secondary circuit reactance

V_2 = terminal voltage, I_2 = secondary current

V_2 = terminal voltage and Z_L = load impedance

Algorithm of Newton Raphson technique for power flow (Ikule et al., 2019);

1. Start
2. Load the phasor parameters data values of the busses
3. Load the self admittance data for each bus
4. Load mutual admittance data between busses
5. Initialize the Y-Bus matrix
6. Compute the driving point admittance using series and shunt admittance
7. Compute the transfer admittance using negative admittance between two uses i and j
8. Check for end bus count
9. Formulate the Y- Bus admittance matrix of the network
10. Assume the initial value of bus magnitude $|V_i|$ and the phase angle Θ equal to slack quantities.
11. Initialize $|V_i|$ = 1.00pu and Θ = 0rad.
12. Initialize count for iteration t =0
13. Compute the real and reactive power for each bus
14. Compute the bus error
15. If
16. Reactive power is within limit = true
17. Then
18. Compute change in real power only.
19. Else if
20. Equate the violated limit as reactive power and treat as PQ Bus.
21. Compute the Jacobian matrix elements using estimated $|V_i|$ and Θ in step 2
22. Obtain the change of $\Delta|V_i|$ and ΔΘ with changes in real and reactive power components of the bus voltage
23. Update $\Delta|V_i|$ and ΔΘ at all loads
24. Next iteration with updated $\Delta|V_i|$ and ΔΘ values
25. Do
26. Until (scheduled error for all busses are within the specified error tolerance
27. $\Delta P_i^{(r)} < \varepsilon, \Delta Q_i^{(r)} < \varepsilon$ (Where ε is the tolerance level for the load bus) compute the line flows and power at the slack bus
28. End

Development of the UPFC controller

The Unified Power Flow Controller (UPFC) is the most versatile member of the Flexible AC Transmission Systems (FACTS) family using power electronics to control power flow on power grids. The UPFC uses a combination of a shunt controller and a series controller interconnected through a common bus. Both controllers use voltage sourced converters connected on the secondary side of a coupling transformer. The converters use forced commutated power electronics which in this case is a thyristor to synthesize voltage from the DC source generated from the common connected capacitor. The shunt converter controls voltage the AC voltages at its terminals and the bus voltage using a voltage regulation loop as shown in figure 4.

The series converter can operate either in power flow control (automatic mode) or in manual voltage injection mode. In power control mode, the measured active power and reactive power are compared with reference values to produce P and Q errors.

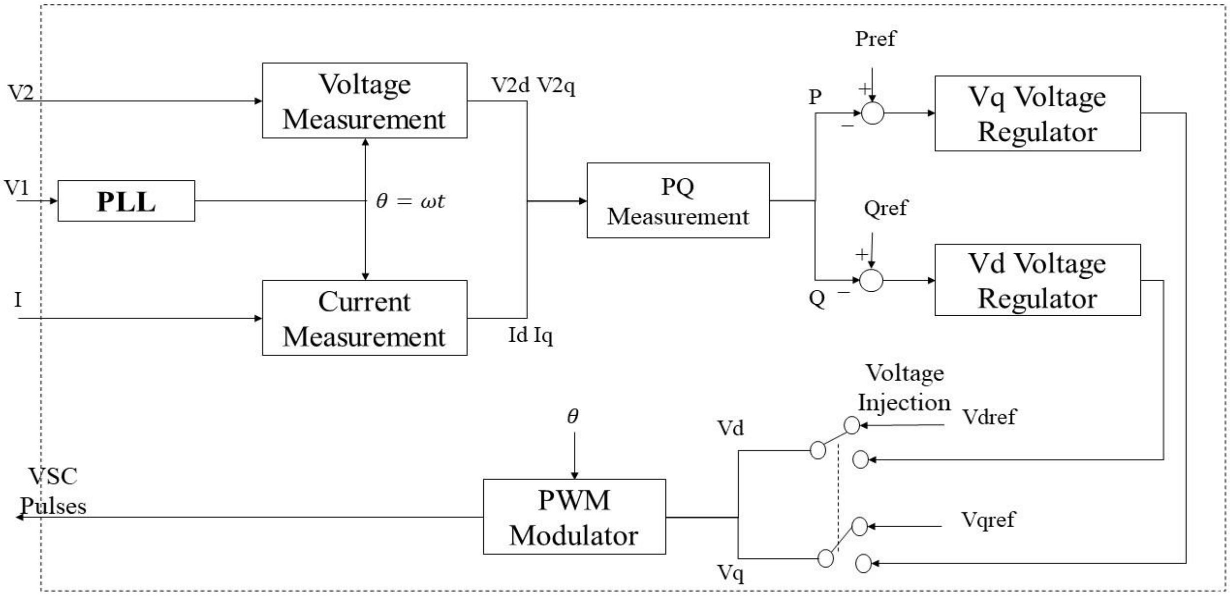

Figure 4: Block diagram of the UPFC

The P error and the Q error are used by two PI regulators to compute respectively the Vq and Vd components of voltage to be synthesized by the VSC. (Vq in quadrature with V1controls active power and Vd in phase with V1 controls reactive power). In manual voltage injection mode, regulators are not used. The reference values of injected voltage Vdref and Vqref are used to synthesize the converter voltage.

According to Billinton (2017), If the coupling transformers are assumed to contain no resistance, then the active power at bus k matches the active power at bus m; that is,

$$P_s + P_{se} = P_k + P_m = 0 \qquad (1)$$

For the cases when the UPFC controls the following parameters:

1) Voltage magnitude at the shunt converter terminal
2) Active power flow (P_s) from bus P_m to bus P_k and
3) Reactive power injected (P_{se}) at bus P_m,

IV. IMPLEMENTATION SIMULATION

The system was implemented using the UPFC model and the sum of square minimization approach adopted to implement the UPFC into the 132/33KV feeder transformer for the correction of the 6 identified unstable bus as shown in the figure 6 using Simulink platform.

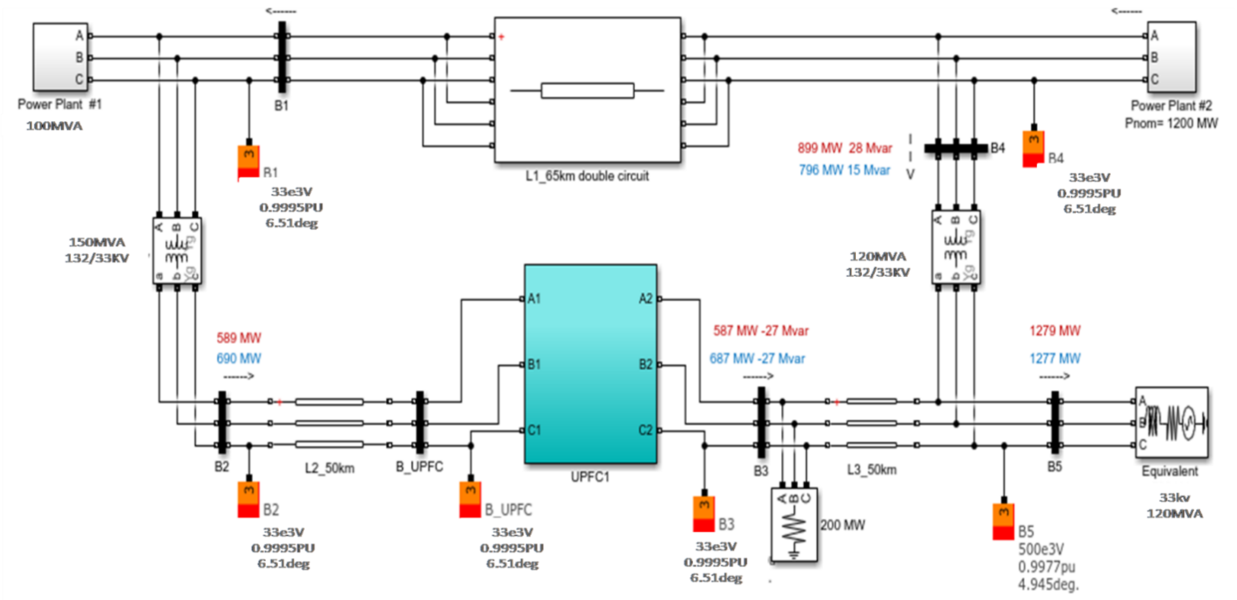

Figure 6: simulation model of transmission lines interconnected with UPFC

From the model in figure 6, the UPFC was strategically mounted between Bus 1 and Bus 2. The UPFC series converter can inject nominal line to ground voltage of 10% maximum (28.87KV) in series with the line 2 to control power low in the bus. The Simulink model was simulated and the load flow was presented in the figure 7;

	Block type	Bus type	Bus ID	Vbase (kV)	Vref (pu)	Vangle (deg)	P (MW)	Q (Mv...	Qmin (Mvar)	Qmax (Mvar)	V_LF (pu)	Vangle_LF (deg)	P_LF (MW)	Q_LF (Mvar)	Block Name
1	Bus	-	BUS_9	230.00	1	0.00	0.00	0.00	0.00	0.00	1.0201	0.33	0.00	0.00	
2	RLC load	Z	BUS_4	230.00	1	0.00	15.00	35.00	-Inf	Inf	0.9648	-3.35	13.96	32.58	
3	RLC load	PQ	BUS_8	230.00	1	0.00	100.00	35.00	-Inf	Inf	1.0027	-0.90	100.00	35.00	
4	Bus	-	BUS_7	230.00	1	0.00	0.00	0.00	0.00	0.00	1.0125	2.18	0.00	0.00	
5	Vsrc	PV	BUS_2	18.00	1.0250	0.00	163.00	0.00	-Inf	Inf	1.0250	7.81	163.00	28.71	
6	RLC load	PQ	BUS_5	230.00	1	0.00	125.00	50.00	-Inf	Inf	0.9488	-5.49	125.00	50.00	
7	RLC load	PQ	BUS_6	230.00	1	0.00	90.00	30.00	-Inf	Inf	0.9671	-5.16	90.00	30.00	
8	Vsrc	PV	BUS_3	13.80	1.0250	0.00	85.00	0.00	-Inf	Inf	1.0250	3.06	85.00	10.84	
9	Vsrc	swing	BUS_1	16.50	1.0250	0.00	0.00	0.00	-Inf	Inf	1.0250	0.00	100.69	110.31	
10	RLC load	Z	*1*	230.00	1	0.00	15.00	80.00	-Inf	Inf	0.9648	-3.35	13.96	74.46	

Figure 7: Result of simulation

From the figure 7, the performance of the transmission network with the UPFC was simulated and presented. The result showed that all the unstable were corrected to the NERC standard except the bus with serial number 6. The implication of the result showed that the UPFC placement algorithm adopted was not able to identify the bus 6 for the placement of UPFC, however recommendation for better placement algorithms based was recommended for further studies.

V. RESULTS OF SYSTEM INTEGRATION

Having tested the performance of the simulation model, the UPFC was deployed at the Newhaven 132/33KV transmission feeder station and tested using the ETAP software. The results collected from the system were presented in the table 3;

TABLE 3: New Haven 132/33KV Feeder Result with UPFC

Feeder	**V(p.u) with UPFC**
Kingsway I	1.001

Kingsway II	0.922
Amechi road	0.977
Ituku-Ozala	1.001
Government house	1.001
Independence layout	0.992
New NNPC	0.931
Thinkers corner	0.942
Emene	0.917

From the result, it was observed that the UPFC was able to correctly balance the unstable bus and ensure that they all satisfy the NERC standard for voltage stability.

Comparative Bus performance

The comparative result showed when the characterized and new feeder transformer was compared as presented in table 4

TABLE 4: COMPARATIVE ANALYSIS

Feeder	V(p.u) with UPFC	V (pu) without UPFC
Kingsway I	1.001	0.648
Kingsway II	0.922	0.846
Amechi road	0.977	0.825
Ituku-Ozala	1.001	1.001
Government house	1.001	0.990
Independence layout	0.992	0.987
New NNPC	0.931	0.901
Thinkers corner	0.942	0.640
Emene	0.917	0.910
Average	1.004	0.830

The result in the table 4 presented the performance of the new and characterized transformers and it was observed that the average voltage profile in the new transformer is 1.004pu and the characterized is 0.830. ETAP software was used to analyze the load flow stability voltage margin and the result is presented a shown in figure 7;

The result showed the comparative bus voltage in the case study system when tested with UPFC and without UPFC. The result showed that the UPFC was able to achieved better voltage stability with a percentage increase of 21% in average increase bus voltage performance.

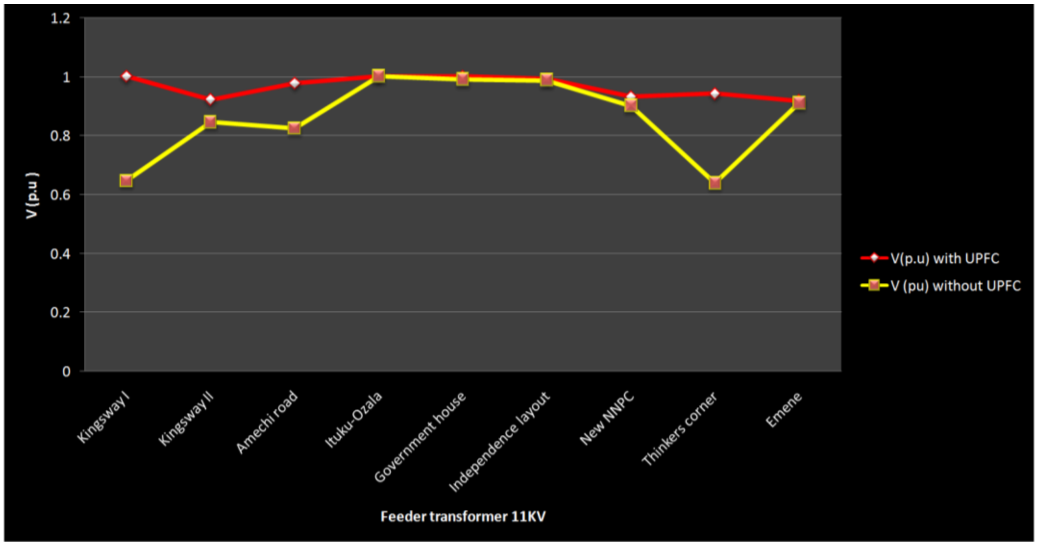

Figure 7: comparative analysis

VI. CONCLUSION

The problem of power system instability has been reviewed in this research work, identifying various techniques employed in the previous researches to combat the problem. Among this technique, recent works have adopted the use of various flexible AC transmission systems like STATCOM, Static Var compensator among other, however the problem with this technique is that that were able to control active and reactive power flow but at the same time injects current and voltage harmonics into the system. This becomes a major problem adopting the technique. This work has been able to solve the problem of power flow control using a UPFC which is a member of the FACTS family, but this time more of a hybrid system composed of STATCOM AND STATIC var compensator devices. This system was able to control the power flow in the specified connected Bus by injecting a nominal line to ground voltage of about 21% into the Bus to compensate for loss and improved power flow and voltage stability performance

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