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Voltage Stability Improvement in The NigerianSouthern 330kV Power System Network with UPFC FACTSDevice

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ABSTRACT : *The issue of voltage instability and abnormality occurs when the power generation equipment experience pertubations such as switching, increase in loads and or faults.As the fault becomes unstable and exceeds the expected excitation threshold, this leads to the transmission of power along the transmission line having either lower or higher voltage that is below or above the expected voltage rating of the power system network. The fault occurrence on the generation equipment has majorly been from the increase in load demand because the amount of power generated in Nigeria is lower than the load demand. In this paper, UPFC FACTS was utilized to improve the voltage stability of the Nigeria power system network located at the southern region with voltage rating of 330kV. The data utilized was a real time data of 32-bus network obtained from the National Control Center at Osogbo, Osun state, Nigeria. The power system network acquired was modeled with power system analysis toolbox in MatLab. The relationship between the real power and the distance of the transmission line was computed and particle swarm optimization (PSO) technique was deployed to obtain the optimal location for the placement of the UPFC FACTS and it optimal location with the least real power occurring along the transmission line connecting Jebba TS and Shiroro GS where the UPFC FACTS was incorporated. The level voltage stability improvement with the incorporation of UPFC was determined and the least voltage improvement percentage found was 5.7%.*

KEYWORDS:*FACTS, PSAT, PSO, UPFC, voltage instability*

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I. INTRODUCTION

The power system network comprises of generation equipment, transmission stations and substations and distribution systems[1-3]. In the power system network in Nigeria, the power system equipment have been stressed due to the constant increase in load demand, and reduction of power supply. This has led to voltage instability and ultimately resulting to the current epileptic level of power supply to the populace. The rate of power congestion in the Nigeria power system network has been alarming as this has also resulted in the voltage instability of the power system network [4-7].

This paper focused on the improvement of voltage instability of the Nigeria power system (located in the south southern region of the country) with the aid of UPFC FACTS. Many nations depend on the sale of its electricity tariffs as a form of increasing the gross domestic profits but that has not been possible in the Nigeria power system network. The rate of load demand increases on daily basis which cause a hold up in the transmission of power generated. When there is an occurrence of disturbance (grid collapse or fault occurrence on the transmission system), it is always difficult for the Nigerian power system network to return to its original level of power flow as a result of increase in instability of the power system network because the method of fault clearing in the Nigeria power system can be described as obscene (in most cases, faults would cascade to the power equipment before the implementation of protective measures [8-10]. Hence, this paper focused on the utilization of UPFC FACTS to improve the voltage instability of the Nigerian 330 kV network with emphasis on the power system network located at the southern region with some buses from Northern region which made up to a total of 32 real time buses. The process carried out was to model the acquired buses in PSAT application and determine the power flow with the aid of Newton-Raphson method.

II. REVIEW OF RELATED WORKS

In transient stability analysis, the authors in [11-13] employed the voltage stability sensitivity factor and continuation power flow to optimally placed STATCOM, SVC, TCSC, and SSSC in the Nigerian 330 kV, 48-bus power system network for system loadability enhancement and dynamic stability of the system through the responses of generator rotor angle, speed, Q-axis and D-axis voltage components behind transient reactance as well as the voltage magnitude profile under the influence of a three-phase fault and line outages. Results show that the FACTS controllers effectively improved the system stability by reducing the rotor angle and speed and by damping the post outage oscillations of the bus voltage and real power. In [14], the authors employed levenberg marquart based artificial neural network (ANN) technique to determine the level of voltage instability of the IEEE-33 bus network and also utilized voltage stability indicator to determine the level of voltage stability improvement after each training with the artificial intelligent model. the outcome gave an improved voltage stability. [15] utilized an ABC three phase calculator in the improvement of voltage stability of the power system network of lower voltage rating power system network. Power flow analysis obtained after utilizing the model showed that there was voltage improvement of the power system network.

The studies in [16-18] focused on steady state stability utilizing STATCOM, TCSC, UPFC, IPFC, and SVC for the improvement of voltage magnitude profile and power transfer capabilities of the power systems. These FACTS devices were optimally placed using Newton Raphson iteration, continuation power flow, and voltage stability sensitivity factor. Simulations of the systems modeled using PSS/E, NEPLAN, and PSAT software indicated huge improvement in the voltage stability, power loss reduction, and available power transfer capabilities of the power systems.The authors in [19,20] proposed a fuzzy based approach and Coot bird behavior-based optimization algorithm (COOTBA), for optimal placement of TCSC and SVC devices in an IEEE 30-node transmission power network. Fuzzy rule base was made to fix the rating of FACTS devices using the membership functions under overloaded conditions. Line loading Index was employed to rank the lines under varied loading conditions. The ranking of the lines based on line loading shows the order of severity of the lines that wants further supporting devices.This provides the optimal placement of FACTS devices. This proposed technique based on Fuzzy logic yielded an efficient solution which considerably reduced load voltage deviations and relieved the lines off their over loads under various loading conditions. In [21,22], the authors optimized the simultaneous implementation of photovoltaic distributed generation and distribution static synchronous compensator units in a standard IEEE 33-bus radial distribution system with the objective of reducing active power losses and enhancing the voltage profile and also proposed an enhanced nonlinear control strategy based on synergetic control theory for PSSs. the study demonstrated that the optimization of photovoltaic distributed generation and distribution static synchronous compensator installation using the adaptive accelerated coefficients for particle swarm optimization algorithm could significantly reduce active power losses and enhancement of voltage profile in the distribution system.

The authors in [23-25] provided a comprehensive review of the existing proposals for the enhancement of power system performance adopting FACTS devices, presented a procedure for placing static var compensators (SVC) in an EPS using the fuzzy c-means clustering technique, and developed a linearized optimal power flow (OPF)–based algorithm to minimize the real power flow of vulnerable lines, considering the thermal limits of lines to prevent infeasible solutions. The performance of the proposed optimization problem was tested on IEEE 14-, 30-, and 118-bus systems for several scenarios. The results were validated with the AC power flow results from MATPOWER and the proposed technique proved to be effective for the creation of VCAs and for the optimal placement of SVC equipment.The author in [26] focused on dynamic security assessment as a necessity in enabling voltage stability of the power system network and convolution neural network (CNN) in the improvement of the power system voltage stability in an IEEE 14 and 39-bus network. By utilizing artificial neural networks as the primary model of reducing the impact of unstable voltage and also improving the voltage stability of the power system network. Hence, the ANN and CNN models were found to solved the issue of general imbalance, transient stability of the power system, and improved the voltage stability of the power system network. In [27],the authors utilized a hybrid of Grad-CAM and convolution neural network in the improvement of voltage stability in an IEEE 14-bus network. The Grad-CAM algorithm was used to identify the key parameters in the power system network and the intelligent model was utilized in improving the parameters so as to improve the voltage stability of the power system network. The authors in [28] utilized an alternating iterative pattern of differential algebraic models to evaluate the voltage stability of the power system network in a IEEE 24-bus network. The outcome of the proposed method on the power system network gave an improved voltage stability majorly based on the analytical conversion from the differential algebraic method to an algebraic differential method before iterating.

III. MATERIALS AND METHOD

There have been fluctuations in the voltage profile of the Nigerian 330kV transmission network mainly due to increase in demand and various fault occurrence in the power system network. Hence, this study aims at normalizing and improving the voltage profile stability with UPFC FACTS controllers. The region of the Nigerian 330kV network modeled in power system analysis toolbox (PSAT) is the southern region. Steady-state power flow analysis isanalysed for the system without and with FACTS controllers. The result enabled the determination of the efficiency of the FACTS utilized for optimum voltage stability. Particle swarm optimization technique is deployed for the optimal placement of the FACTS. This is done by creating an empirical relationship between the distance of the transmission lines and the total active power transmitted. The snapshot of the power system network obtained from the national control center in Osogbo Osun state Nigeria is shown in fig.1.

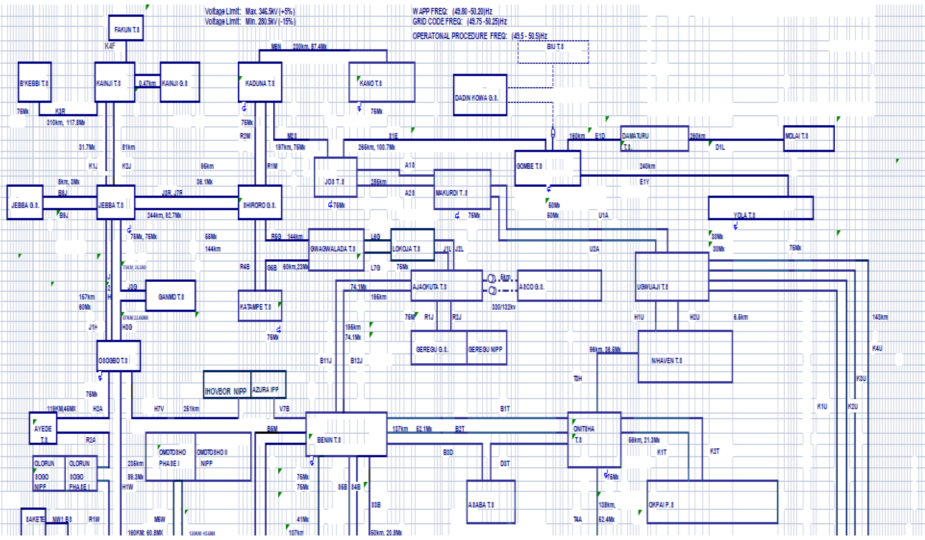

Fig.1. Power system network data

The diagram in fig.1 was majorly the southern network with little of northern stations to achieve a 32 bus system network of which 26 of them are load buses while 6 are generator buses.The network consists of 36 transmission lines with all the parameters modeled using PSAT and simulated using Newton Raphson iteration algorithm.The transmission lines data aregiven in Table 1.

Table 1. Transmission line data

Lines	From	To	Distance (km)
1	Kainji GS (1)	Kainji TS(2)	0.47
2	Kainji TS(2)	Fakun TS (3)	5.2
3	Kainji TS(2)	Benin Kebbi TS(4)	310
4	Kainji TS(2)	Jebba TS (6)	81
5	Jebba GS (5)	Jebba TS (6)	8
6	Jebba TS (6)	Shiroro GS(11)	244
7	Jebba TS (6)	Ganmo TS (7)	70
8	Jebba TS (6)	Osogbo TS (8)	157
9	Ganmo TS (7)	Osogbo TS (8)	33
10	Osogbo TS (8)	Ayede TS (25)	119
11	Ayede TS (25)	Olorunsogo GS (31)	81
12	Olorunsogo GS (31)	Ikeja West TS(32)	102
13	Osogbo TS (8)	Ihovbor TS (26)	251
14	Ihovbor TS (26)	Benin TS(27)	76
15	Benin TS(27)	Asaba TS (28)	64
16	Asaba TS (28)	Onitsha TS (29)	21
17	Onitsha TS (29)	Okpai GS (30)	56
18	Shiroro GS(11)	Kaduna TS (9)	219
19	Shiroro GS(11)	Katampe TS(13)	182
20	Shiroro GS(11)	Gwagwalada TS (14)	144
21	Katampe TS(13)	Gwagwalada TS (14)	60
22	Kaduna TS (9)	Kano TS (10)	230
23	Kaduna TS (9)	Jos TS (12)	197
24	Jos TS (12)	Makurdi TS (17)	285
25	Jos TS (12)	Gombe TS(19)	265
26	Gombe TS(19)	Damaturu TS (20)	160

27	Gombe TS(19)	Yola TS (22)	240
28	Damaturu TS (20)	Molai TS (21)	260
29	Makurdi TS (17)	Ugwuaji TS (23)	304
30	Ugwuaji TS (23)	NewHeaven TS (24)	54
31	NewHeaven TS (24)	Onitsha TS (29)	96
32	Gwagwalada TS (14)	Lokoja TS (15)	67
33	Lokoja TS (15)	Ajaokuta TS (16)	61
34	Ajaokuta TS (16)	Geregu GS (18)	82
35	Ajaokuta TS (16)	Benin TS (27)	195
36	Benin TS (27)	Onitsha TS (29)	137

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IV. OPTIMAL PLACEMENT OF FACTS WITH PSO

The power analysis of the power system model in fig.2is determined to obtain the locations for the implementation of UPFC FACTS device for voltage stability improvement. The power values at each locations is used to generate a polynomial relationship between the power and the distance with the schematic of the model presented in Equation 1.

$$P = a_0 + a_1 d + a_2 d^2 + \dots + a_n d^n \quad (1)$$

where P is the active power, a represents the coefficient of the model, d is the distance in km, and n, the order of the polynomial.The order of the polynomial model was increased until an R-squared valued greater than 95% was achieved. Then the model was subjected to particle swarm optimization to determine the optimal location for the placement of UPFC FACTS as shown in fig.2. The optimal location for the placement of FACTS is on the transmission line connecting Jebba TS and Shiroro GS.

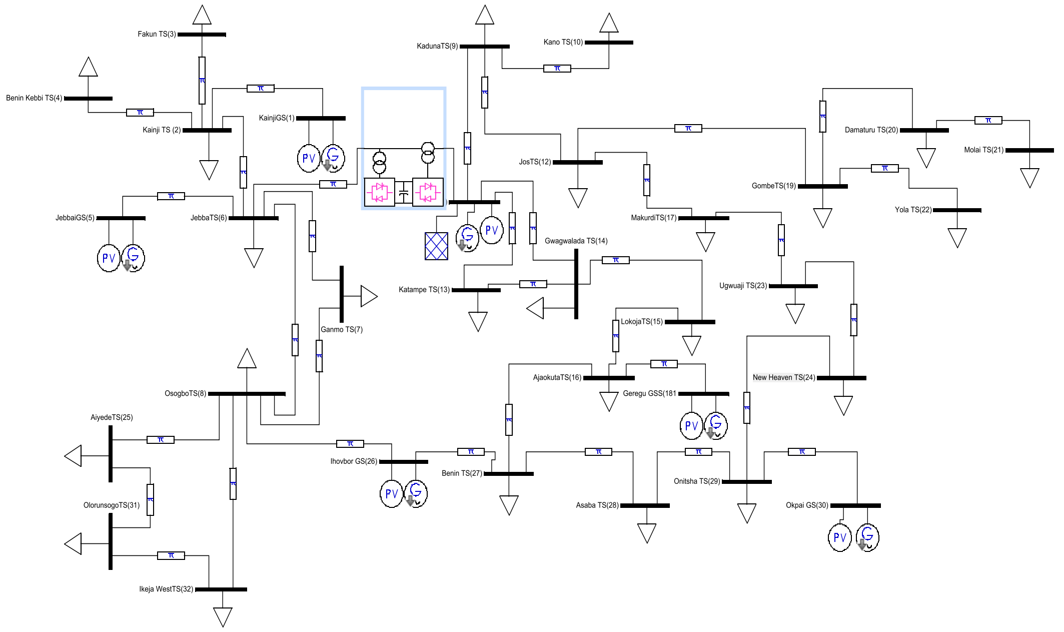

Fig.2. Implementation of UPFC FACTS

V. RESULTS AND DISCUSSION

The outcome of the power flow analysis utilized for the determination of optimal location of the UPFC in the Nigerian Power system network is shown in Table 2.

Table 2. Parameters for optimal location of the UPFC FACTS device

Cumulative distance (kM)	Voltage (kV)
0.47	320.07
5.67	320.53
315.67	316.63
396.67	320.57
404.67	319.16
648.67	316.49
718.67	317.39

875.67	318.73
908.67	320.79
1027.7	320.82
1108.7	316.79
1210.7	320.85
1461.7	320.79
1537.7	318.43
1601.7	320
1622.7	316.71
1678.7	318.11
1897.7	320.58
2079.7	319.96
2223.7	320.8
2283.7	319.28
2513.7	316.18
2710.7	320.25
2995.7	320.67
3260.7	319.39
3420.7	319.79
3660.7	319.72
3920.7	317.96
4224.7	319.28
4278.7	316.86
4374.7	319.53
4441.7	316.16
4502.7	317.38
4584.7	316.23
4779.7	316.49
4916.7	320.12

The snapshot of the environment in MatLab utilized for the determination of the order of the polynomial is shown in fig.3.

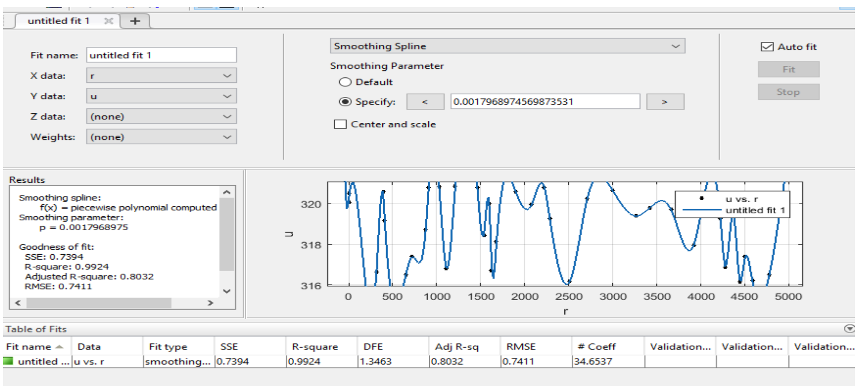

Fig.3. Polynomial order

From the snapshot, the polynomial order utilized at the R-squared value of 99.24% was the fifth polynomial. The PSO outcome on the model showed the optimal location to be between Jebba TS and Shiroro GS. Hence the UPFC device was implemented on the transmission line connecting Jebba TS and Shiroro GS. The voltage profile of the power system without FACTS deviceis shown in fig.4. Here, it is observed that load buses 3(Fakun), 6(Jebba), 16(Ajaokuta), 22(Yola), 30(Okpai), and 32(Ikeja West) have very low voltage profile well below 317 kV. It is also worthy to note that the highest voltage profile without the FACTS controller is even less than 321 kV.

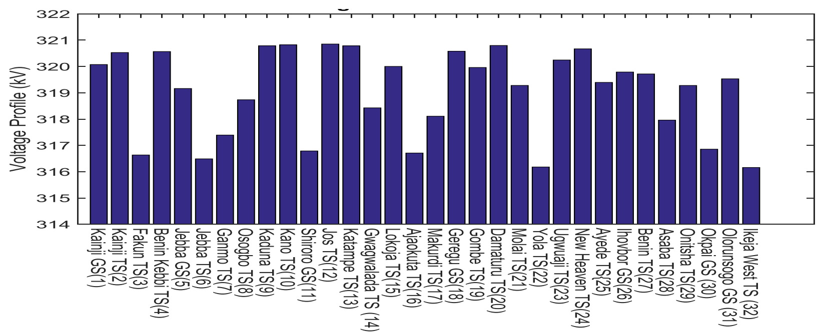

Fig.4. Voltage profile of the system without FACTS

The voltage profile of the system with UPFC FACTS deviceis shown in fig.5. It can be seen from this graphical representation that all the buses characterized by low voltage profile without FACTS have been compensated and all the voltage levels improved to more than 326 kV with some of the buses having improved voltage profile almost up to 330 kV indicating the stability of the voltage profile of the system.

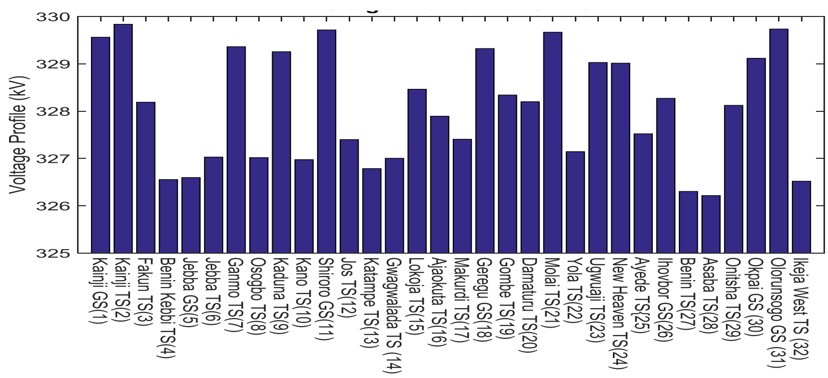

Fig.5. Voltage profile of the power system network with UPFC FACTS.

The comparative barchart of the power system without and with FACTS deviceis depicted in fig.6.It can be seen from the figure that there is a remarkable improvement in voltage stability of the system with the implementation of the UPFC FACTS device.

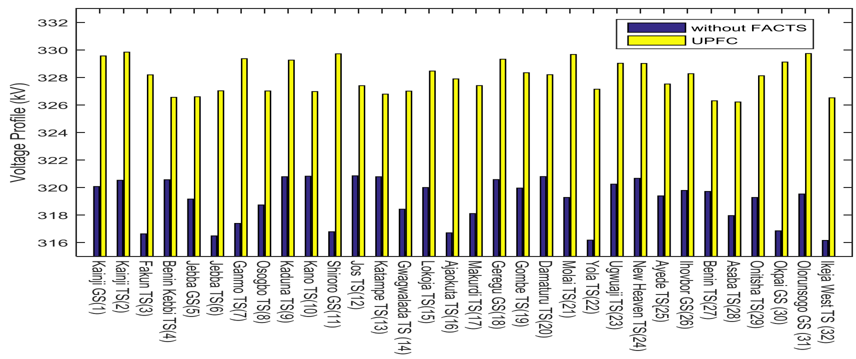

Fig.6. Comparative barchart of the system without and with UPFC FACTS device

VI. CONCLUSION

Increase in load demand affects the voltage stability of the power system network. Nigerian power system has been stressed due to constant increase in load demand. This paper utilized UPFC FACTS device to improve the voltage stability of the network. Particle swarm optimization (PSO) techniquewas employed for optimal placement of the FACTS controller on the transmission line between Jebba TS and Shiroro GS. The outcome showed a high level of voltage stability improvement in the Nigeria power system network.

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