Enhancement of Power Flow Control in Nigeria 330kv Transmission Network Using D-Facts Devices

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Abstract -Nigeria power transmission systems need to be continuously up-graded and expanded in order to cater for the need of ever growing power demand. This paper investigated the effect of D-FACTS devices in enhancing power flow control in Nigeria 330kV transmission network so as to relieve the network of congestion, limit loop flows and improve assets utilization more efficiently than centralized FACTS devices. Six selected 330kV transmission lines across six geo-political zones in Nigeria were simulated for line flow control and real power flow control without and with insertion of D-FACTS devices in Nigeria 41bus system under different scenarios. Newton Raphson load flow method was used for A.C. load flow analysis. The simulations were done in PowerWorld environment. At the end, it was found that installation of multiple D-FACTS devices on few Nigeria 330KV transmission lines for coupled control of line flow and real power flow on the network had improved the reliability, controllability and transfer capacity of the existing transmission lines economically. It also served as most cost-effective alternative to construction of new transmission lines. The end results showed satisfactorily achievement as the line flow and power flow on the network became efficiently controllable. The transmission grid also proved smart, more reliable, fault tolerance and self-recoverable.

Indexed Terms: Power flow, loop flow, congestion, line losses, Power world simulator, D-FACTS

I. INTRODUCTION

Rapid and ever increasing power demand are continuously stressing Nigeria 330kV transmission network. The transmission network is forced to operate at full or beyond its capacity due to heavy power demand which results in high and heavy power flow in the power transmission system network. This results in overloaded and congested transmission lines which leads to more losses and also threaten to decrease the stability and security of the system. Therefore, with power demand on the increase, Nigeria 330kV transmission grid is being operated under overloaded condition and hence, there is always an urgent need for strengthening of the Nigeria 330kV power transmission network. A conventional way of strengthening Nigeria 330kV transmission grid is by up-grading the infrastructure of the transmission system with addition of new transmission lines, substations and associated equipment. Construction of long transmission lines with large capability of power transfer is time consuming, uneconomical, controversial, causes political obstacle and requires several modification in existing urban landscape. Building more transmission lines in Nigeria has environmental impact and ill-effect on health due to electric and magnetic field associated with power transmission system. A more practical and useful way to utilize the existing Nigeria 330kV transmission system network maximally and at a minimum cost is by application of progressive power electronic technologies to enhance the utilization of the existing transmission system. Distributed Flexible Alternating Current Transmission System (D-FACTS) devices provide cost effective solutions for this new technical and operating challenges. It is in this context that the role of D-FACTS becomes significantly important [1] and its effect in enhancing power flow is investigated in this thesis. D-FACTS Technology is a new emerging smart technology which is playing crucial role in enhancing controllability and power transfer capability of the modern power systems which are operating close to their limit. D-FACTS controllers are power electronic based equipment and they offer cost effective solution for power transmission problem through increase in power transfer capacity of the transmission system. A.C. power parameters like line impedance, current, voltage and phase angle differences can be effectively controlled by D-FACTS controllers which in turn bring in necessary and desirable results in power system, indicating its performance improvement.

In the late 1980, the Electric Power Research Institute (EPRI) formulated the vision of Flexible A.C. Transmission System (FACTS) in which various power electronics based controllers regulate power flow and transmission voltages, and mitigate dynamic disturbances. It was an answer for more efficient use of already existing resources in then power system. [2] Proposed the concept of FACTS. These two authors highlighted the efficient controllability, reliability, transfer capability increase and congestion reduction capabilities of FACTS devices but were unable to discover obvious flaws of lumped solution instead of distributive solutions which was cost effective. [3] Proposed terms and definition for different FACTS devices. He noted that FACTS controllers can perform multiple functions in addition to power flow control and loss minimization along the existing transmission lines more than conventional devices such as capacitors and reactors. [4] initiated the idea of D-FACTS controllers as new emerging smart technology which offer distributive series compensation as well as efficient controllability and transfer capacity increment

II. ENHANCEMENT OF POWER FLOW CONTROL

Enhancement of power flow control simply implies the ability to improve regulation of transmission of an alternating current (A.C), increasing or diminishing the power flow in specific lines and responding instantaneously to the stability problems. It also entails the possibility of improving control of the routes of the power flow and the ability of connecting networks that are not adequately inter-connected.

Power flow in alternating current (AC) system is unlike other flow problem such as in transportation or telecommunication. In transportation system, trucks can be routed along a desired path from a source to a destination. Similarly, in a communication system, packet can be routed such that they travel along a shortest path between a sender and a receiver.

However, electricity must follow Ohm's and physics law, so power flow is not routable and cannot be directly controlled [5]. Power flow control is also different from other types of flow problems since electricity must also be produced exactly when it is need. Generation must constantly track the load as the consumers demands change.

Controlling real and reactive power flow in Nigerian transmission network has been of interest for many years. Power flow control is highly applicable now as the structure of the electric power industry is changing and the power grid is becoming increasingly networked. Interconnecting parts of the systems which were previously independent has benefits such as allowing faulted areas to be quickly isolated which causes less service interruption to customers. It is noteworthy to mention that many interconnections - can restrict transmission capacity since the available transfer capacity (ATC) of an interface is limited by the first line to reach its transmission limits.

The ability to effectively control power flow in a network can allow better utilization of the existing network by routing power flow away from the over loaded lines in Nigeria. Also, studies indicate that transient stability and dynamic stability (damping) can be improved when reactive compensation is available and can be varied rapidly by electronic control [6].

Flexible alternating current transmission system (FACTS) is a system composed of static-equipment used for the A.C. transmission of electric energy. It is meant to enhance controllability and to increase power transfer capability of the network. It is generally a power electronic based system. FACTS is defined by IEE as "a power electronic based system and other static equipment that provides control of one or more of AC transmission system parameters to enhance controllability and increase power transfer capacity of a network" [2]. [7] Suggested a new concept of Distributed flexible alternating current transmission system controllers (D-FACTS) as an alternative solution which is cost-effective in controlling power flow along transmission lines. D-FACTS devices have more reliability, feasibility, and cost saving approach over traditional FACTS controllers. For robust, sensitive, optimum approach and operation, D-FACTS Controllers are better choice for improving power system transmission line performance. With relatively low investment compared to new transmission facilities, D-FACTS technology allows the industries to better utilize the existing transmission reserve while enhancing the power system performance.

Cascading disturbances, overloading of lines, power flow problem and equipment malfunctioning in transmission network account for majority of the faults that result to an interruption of power supply for the end-consumers [1]. The after effect of large interruption of power supply from our transmission grid to the larger society is considerably high. Essential amenities such as public water supply, telecommunication and heating industries are not regularly and efficiently functional due to interruption of power supply. Local back-up generators can be a close substitute temporally for some important occasions in the society, but this requires an organized distribution of fuel to the affected areas. The associated cost for the society due to power(1) interruption is significant [8].

Since congestion and loop flow can cause an outage event in our transmission lines, thereby paralyzing the society at large, the network has to been controlled to(2) meet high need of reliability, controllability and transfer capacity improvement using D-FACTS devices. As some people propose construction of new transmission lines in order to meet up with the Nigeria energy demand, it is important to access the security level of the existing transmission grid in order to devise a more defensive approach of operation. Transmission Company of Nigeria (TCN), projected to have the capacity to deliver about 12,500MW in 2013, but has the capacity of delivering 4800MW of electricity. Nigeria has a generating capacity of 5,228MW but with peak production of 4500MW against peak demand forecast 10,200MW. This shows that if the generation sector is to run at full production, the transmission grid will not have the capacity to handle the produced power reliably [9]. This is a proof that Nigeria 330kv transmission grid is not running effectively and efficiently as expected. Therefore, to ensure and maintain this delicate transmission grid, enhancement of power flow control cannot be over stressed. Uncontrolled loop flows result in overloading and possible cascading disturbances on existing transmission lines [10]. Active power flow control requires cost-effective series Var solution that can alter the impedance of the power lines, thus controlling power flow.

There is a general consensus that future power transmission grid will need to be smart, fault tolerant and self- healing, dynamically and statically controllable and energy efficient. To achieve this smartness, fault tolerant and self-healing on Nigeria 330kv transmission lines, D-FACTS devices have to come into play as a major remedial action of relieving our transmission grid of ugly trend of congestion and to limit loop flows. It is a well-known fact that, nowadays, electricity demand is rapidly increasing without any major reinforcement project to enhance power transmission networks.

III. MATERIAL AND METHODS

The methods adopted in this thesis are listed below**:** Application of Newton-Raphson technique for A.C. load flow studies. Simulation of Nigeria 41-Bus system without and with incorporation of D-FACTS devices using PowerWorld Software tool. Microsoft Excel was used for plotting of graphs.

2.1 Formulation Of Power Flow Equations

The apparent power injected into any *i* named bus is given as

$$Sj=Pj+jQi \qquad (1)$$

In terms of bus voltage and conjugate of bus current, the apparent power injected into bus *j* is given as

$$Sj=VjIj^* \qquad (2)$$

where;

P_j is the real power component of the power in bus *j*

Q_j is the reactive power component of the power in bus *j*

V_j is the voltage at bus *j*

I_j is the current at bus *j* while,

I_j^* is the conjugate of current at bus *j*

Combining equations (1) and (2) produces

$$Pj+jQj=VjIj^* \qquad (3)$$

Usually, of the four parameters (real power, reactive power, bus voltage magnitude and voltage phase angle) only two are specified to identify the bus which predefines the type of bus in use. The current, I*j* injected in or out of a bus is not specified and is initially unknown, so its conjugate I_j^* cannot be determined ab initio. This constraint limits the use of equation (3). Since V_j is often specified for some buses, its conjugate can be found. Hence equation (3) can be replaced with its mathematical equivalent as

$$Pj-jQj=Vj*Ij \quad (4)$$

The application of Kirchoff's Current Law (KCL) to an interconnection of n buses, the expression for the current I_j injected into any j bus is given as

$$Ij=knYjkVk \quad (5)$$

For $_{j, k}$ = 1, 2, 3, …, n
Where, Y_{jk} is the admittance for the transmission line between buses j and k. The substitution of equation (5) into (4) gives

$$Pj-jQi=Vj*knYjkVk \quad (6)$$

Comparing terms;
P_i represents the real part while Q_j represents the negative imaginary part of the RHS of equation (6). Mathematically this becomes

$$Pj=\text{real part of } Vj*knYjkVk \quad 7$$

$$Qj=\text{imaginary part of } Vj*knYjkVk \quad (8)$$

With $Y_{jk} = G_{jk} + jB_{jk}$ recall that in their polar forms Y_{jk}, V_j^* and V_k are given as

$$Yjk=Yjkej\theta jk=Yjk<jk \quad (9)$$

$$Vj*=Vje-j\delta j=Vj<-\delta j \quad 10$$

$$Vk=Vkej\delta j=Vj<k \quad (11)$$

where, □$_{ik}$ and □$_i$ are the phase angle of the admittance and the bus voltage respectively.
Substituting for Y_{jk}, , V_j^* in equation (6) gives

$$Pj-jQi=Vje-j\delta j\ knYjkej\theta jkVk\ ej\delta k$$

$$Pj-jQi=VjknYjkVk\ ejjk+k-j$$

This implies that

$$Pj-jQi=Vj\ knYjkVk\ ejjk-j-k \quad (12)$$

For $_{j, k}$ = 1,2,3,…,n
But noting that $Aeix=A<x=Acosx+jAsinx$

Then equation (12) becomes;

$$Pj=Vj\ knYikVk\ cosjk-j-k \quad (13a)$$

$$Qj=-Vj\ knYjkVksinjk-j-k \quad (13b)$$

For $_{j, k}$ = 1, 2,3,…,n
Equation (13a) and (13b) are called the power flow equations (Gupta, 2008).
In setting up the Newton-Raphson numerical method, the power-flow expressions of equations (13a) and (13b) are employed because these equations are more flexible and convenient to work with in developing and computing the elements of Jacobian matrix than the use of equation (12).

2.3 Nigeria 330kv Transmission Network Visualization/Line Flow Controls

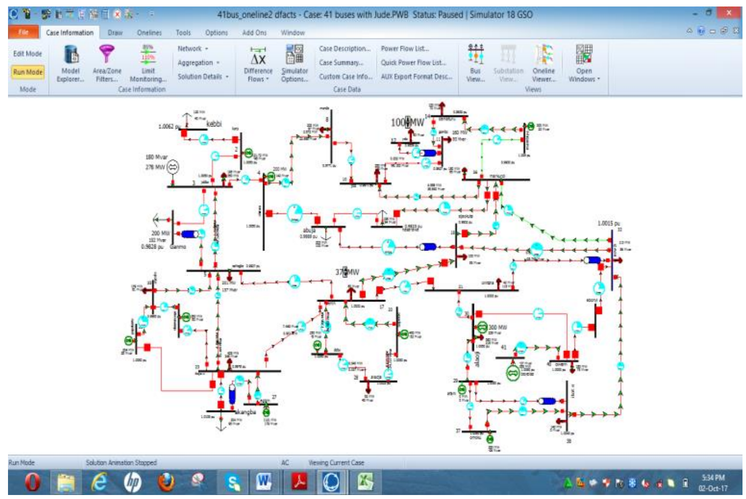

Fig.1. Single Line Diagram of Nigeria 41 Bus System With multiple D-Facts modules (series compensated case).

IV. RESULTS AND DISCUSSION

To buttress the fact that quality, adequacy and controllability of an electric power transmission network are significantly improved by the use of D-FACTS devices, the Nigeria 330kV transmission grid is simulated under six different scenarios. The characteristics of these scenarios are presented below. Here the interest is on enhancing control of current and real power flow in Nigeria 330kV transmission network. In each scenario, the network in its conventional state (without D-FACT) is simulated and compared with the simulation result obtained from the network when D-FACTS modules are installed on it for compensation. The result of each respective case are compared with the base scenario and the positive difference between them represents the improvement in the system controllability and transfer capacity increment. In this work, two varieties of D-FACTS devices are jointly applied for effective and efficient controllability and transfer capacity increase. These varieties are; Distributed Series Reactance modules which were applied for inductive injection and Distributed Series Capacitance modules for capacitive injection.

The overloaded base case current and line parameters used for modeling Nigeria 41 bus network were compared with the compensated and simulated cases as shown in the table below.

Table 1: Line Flow Control (Current)

FROM BUS	TO BUS	AMP WITHOUT DSR & DSC	AMP WITH DSR & DSC
Kanji	Jebba	827.8	122.1
Shiroro	Mando	276	276
Abuja	Shiroro	1132.3	215.4
Oshogbo	Benin	435.7	435.7
Jos	Markurdi	224	224
Yola	Gombe	1107.7	385.6
Damaturu	Gombe	222.9	222.9
Damaturu	Mambiya	358.9	358.9
Ajaokuta	Benin	1188.4	568.4
Benin	Sapelle	371.9	371.9
Onitsha	Alaoji	161	161
Onitsha	new.h	1560.6	637.4
Delta	Aladja	559.2	559.2
Ayede	Papalanto	263	263
Egbin	Akangba	1246.6	521.9

The above table of value illustrates clearly the efficient and positive improvement of D-FACTS modules in relieving some critical overloaded transmission lines of overload. Critically overloaded transmission lines such as Kanji-Jebba transmission line with an overload current of 827.8A but was reduced to 122.1A by joint application of DSC and DSR modules. A positive current difference of 705.7A was diverted to other coupled under-utilized transmission lines. Abuja-Shiroro transmission lines with an excess current of 1132.3A was reduced to 215.4A by joint application of these devices. Similarly, other notable overloaded transmission lines like Yola-Gombe transmission lines, Ajeokuta-Benin transmission lines, Onitsha-Newhaven transmission lines and Egbin-Akangba transmission line are all proof of the controlling effect of D-FACTS modules.

It is worthy of note to mention that the state and nature of the line loading determines the switching in of either DSC or DSR on the transmission lines. This is because under loaded lines requires DSC module for modulation of line power flow on under loaded lines whereas DSR modules are required in over loaded lines for modulation of the line flow. Therefore, switching in either of the two varieties of D-FACTS gives an excellent result as shown graphically below. Further still, switching in either of the variety of the D-FACTS controller depends mainly on the nature, sensitivity and topology of the network. This is a clear proof of the cost effectiveness of D-FACTS controllers as an alternative to new transmission line construction. As observed from the result so far recorded, this new method of line flow control is entirely devoid of huge capital requirement ,environmental impact, land use restriction , social controversy and Time consuming which are prevalence in new transmission lines' construction including barriers/limitations associated with conventional FACTS devise which includes non-reliability, lumped solution, high cost and low return on investment.

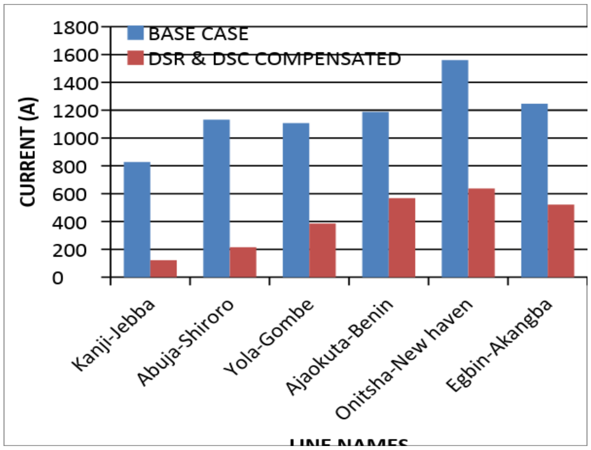

Figure 2; Transmission Line Current Flow Control

Figure 2; illustrates the relationship between different transmission lines and the values of uncompensated and compensated current due to joint application of DSC and DSR modules for line flow control. Blue bars indicate the value of the uncompensated state of current against transmission lines while red bars represented the value of controlled and compensated current.

4.1 Enhancement of Real Power Flow Across Six Geo-Political Zones In Nigeria

Figure Snapshot of Nigeria 41-Bus System with D-Facts Modules for Real Power Control in Powerword Simulators

As shown in the Table 2, results of uncompensated and compensated real power flow as enhanced using D-FACTS modules had been simulated thus: Scenario B; In North East Zone, the transmission line connecting Yola and Gombe is chosen and targeted for control using D-FACTS controllers. The results of the real power enhanced by the use of D-FACTS devices are sampled thus. As in Fig.2, Installation of D-FACTS module on the transmission line linking Yola and Gombe showed that the value of real power was decreased from 200.6MW to 187.6MW indicating energy saving of 23.0MW which was diverted to underutilized lines.

North Central Zone: Simulation result of Installed D-FACTS module on the transmission line linking Abuja and Ajaokuta indicated that the real power flowing through the line before compensation by the D-FACTS module was 67MW and was decreased to 61MW after compensation, resulting in an energy saving of 6MW which was pulled into underutilized lines.

North-West Zone: The power flowing along the line linking Ganmo-Jebba Transmission Network was 370MW before compensation and was reduced to 351MW after compensation with D-FACTS module resulting in an energy saving of 19MW.

South-East Zone:The real power flowing along the transmission line linking Onitsha and New-Haven was 34.7MW before the application of D-FACTS modules for series compensation and 27.1MW after series compensation, resulting in energy saving of 3.6MW.

South-West Zone: The real power flowing along the transmission line linking Egbin and Akangba was 59.4MW before compensation and was reduced to 53.8MW after series compensation by D-FACTS modules, resulting in energy saving of 5.6MW.

South-South Zone: The real power flowing along the transmission line linking Ikote-Ekpene and Afam was 109.6MW before been compensated and was reduced to 100.8MW after compensation resulting in energy saving of 8.8MW.

Table 2: Real Power Flow Control

		UNCOMPENSATED (WITHOUT DFACT)	COMPENSATED (WITH DFACTS)
FROM BUS	TO BUS	P(MW)	P(MW)
Kainji	Jebba	467.8	410
Abuja	Shiroro	336.1	316.6
Yola	Gombe	200.6	187.6
Ajaokuta	Benin	148	139.9
Onitsha	N. Haven	34.7	27.1
Egbin	Akamgba	58.1	51.7

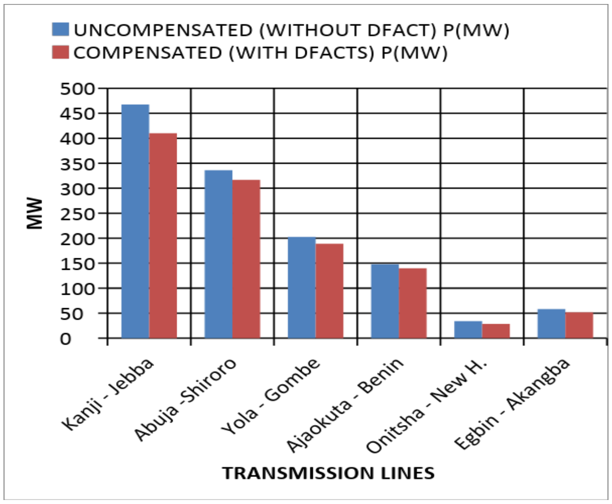

Fig. 3: Real Power flow control without & with D-FACTS compensation

From the graph above, blue bar represent the real power flow without installation of D-FACTS devices, while the red bars represent the value the compensated real power flow with D-FACTS modules in place on the network.

V. CONCLUSION

This paper has presented a novel concept and distributed approach for realizing line flow control, and real power flow control on existing Nigeria 330kV transmission grid using D-FACTS modules. D-FACTS devices have the unique ability to be installed in multiple form at different locations per conductor per mile along various transmission lines to provide distributed solutions. It had been demonstrated here that D-FACTS modules can provide widespread and versatile control of current and real power flow at various locations of the network whenever needed. These controlled Nigeria 330kV transmission lines implemented with multiple D-FACTS modules could realize significant benefits such as enhanced assets utilization, reduced system losses, reduced system congestion and increased controllability and transfer capacity of the transmission grids.

REFERENCES

[1] Divan, D. and Johal (2007). H. Distributed FACTS—A New Concept for Realizing Grid Power Flow Control," IEEE Trans. Power Electronics, vol. 22, issue 6, pp.2253-2260.

[2] Abido, M. A. (2007). Multiobjective particle swarm for environmental/economic dispatch problem. Proc. of International Power Engineering Conference (IPEC 2007), pp. 1385-1390.

[3] Edris, A., Adapa, R., Baker, M.H, Bohmann, L., Clark, K., Habashi, K., Gyugyi, L., Lemay, J., Mehraban, A., Myers, A.K., Reeve, J., Sener, F., Torgerson, D.R. and Wood, R.R. (1997). Proposed Terms and Definitions for Flexible AC Transmission System (FACTS), IEEE Transactions on Power Delivery, Vol. 12, No. 4, October. doi: 10.1109/61.634216 http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=00634216

[4] Divan, D. M., Brumsickle, W. E., Schneider, R. S., Kranz, B., Gascoigne, R. W., Bradshaw, D. T., Ingram, M. R. and Grant, I. S. (2007). A Distributed Static Series Compensator System for Realizing Active Power Flow Control on Existing Power Lines. IEEE Transactions on Power Delivery, Vol. 22, No. 1, pp. 642-649.

[5] Divan, D., Brumsickle, W., Schneider, R., Kranz, B., Gascoigne, R., Bradshaw, D., Ingram, M. and Grant, I. (2004). A distributed static series compensator system for realizing active power flow control on existing power lines. in IEEE PSCE Conf. Records, Oct. 2004.

[6] Alsac O, J., Bright, J., Prais, M. and Stott, B. (1990). "Further developments in LP-based optimal power flow," IEEE Transactions on Power Systems, vol. 5, no. 3, pp. 697-711, Aug.

[7] Azzam-ul-Asar, S. R. ul Hassnain and Khan, A. (2007). Short Term Load Forecasting Using Particle Swarm Optimization Based ANN Approach. Proc. of International Joint Conference on Neural Networks, pp. 1476-1481.

[8] Baker, D. H., Boukarim, G. E., Aquila, R. D., and Piwko, R. J. (2005). Subsynchronous resonance studies and mitigation methods for series capacitor applications," Proc. Of IEEE Power Engineering Society Inaugural Conference and Exposition, pp. 386-392.

[9] Cai, L.J., Erlich, I. and Stamtsis, G. (2004). "Optimal choice and allocation of FACTS devices in deregulated electricity market using genetic algorithms," Proc. of the IEEE PES Power Systems Conference and Exposition, vol. 1, pp.201-207.

[10] Chen, X. R., Pahalawaththa, N. C., Annakkage, U. D. and Kumble, C. S. (1997). Output feedback TCSC controllers to improve damping of meshed multi-machine power systems," IEE Proceedings: Generation, Transmission and Distribution, vol. 144, no. 3, pp. 243-248, May.