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Improvement of Reactive Power and Voltage Control with D-Facts Devices in Nigeria Super Grid System

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Abstract ***Nigeria power transmission system requires continuous up-grading and expansion in order to cater for the need of ever growing power demand. This paper investigated the improvement of reactive power and voltage control using Distributed Flexible Alternating Current Transmission System (D-FACTS) devices in Nigeria 330kV transmission network so as to avoid deficiency of reactive power support, voltage violation/collapse, limit congestion and loop flows, improve assets utilization and to enhance the overall reliability of the network. Six selected 330kV transmission lines across the six geo-political zones in Nigeria were simulated for bus voltage improvement and reactive power support, without and with insertion of multiple D-FACTS devices in Nigeria 41bus system under different scenarios of geo-political zones. The simulations were done in Power World environment. Newton Raphson's Load flow method was used for A.C. load flow analysis. At the end, it was found that installation of multiple D-FACTS devices on Nigeria 330kV transmission lines for coupled control of reactive power and voltages at various buses/locations of the network had improved reactive power flow, improved voltage magnitude, improved the reliability, controllability, reduced losses and improved transfer capacity of the existing transmission lines as it would in any other physical electric network. In this thesis, D-FACTS devices had successfully overcome the limitations/barriers of lumped solutions of conventional FACTS devices. It also served as most cost-effective alternative to other sources of reactive power injection and absorption, including voltage control or modulation along the existing transmission lines. The end results were satisfactorily achieved as the reactive power and voltage profile of the network became efficiently, improved, stable and controllable as the transmission grid proved smart, more reliable, fault tolerant and self-recoverable.***

Indexed Terms: Voltage surge, Reliability, Fault tolerant, Self-recoverable, Off-peak period, Distributed solution, Transmission lines, and reactive compensation.

I. INTRODUCTION

Improvement of voltage control and reactive power support are difficult task because they are strongly influenced by random load fluctuations. Enhancement of reactive power support and voltage control application on Nigeria 330kV transmission system using D-FACT controllers are novel concepts and new emerging smart technologies .It can be regarded as a major reinforcement project and remedial action in the transmission network for averting several events of voltage collapse due to overloading and congestion in recent time [1].

Therefore, this paper proposes a distributed approach for realizing an improvement of reactive power and voltage control on existing Nigerian 330kV transmission grid through the use of D-FACTS controllers. This distributed implementation seems to overcome some of the most significant issues that have limited a wider application of traditional FACTS controller. D-FACTS controllers can realize significant change in power line impedance to improve the power transfer capacity and voltage profile of an inter-connected power system by using light-weight self- excited D-FACTS modules that float on the power lines. Such devices can operate with or without communications technique [2]. These small rated low-cost power devices, known as D-FACTS controllers can sustain the operation of the system even during contingency conditions, improving the reactive power, voltage profile and reliability of the overall network. Under fault conditions, the units can instantly revert back to their bypass mode, allowing protective relays to operate without change if so desired.

Similarly, capacitors banks and reactive power (Vars) produced by generators provide a means of keeping system voltage high. However, in some systems, it may also be desirable to lower voltage slightly if they become too high. During off-peak periods, large generators are producing high amount of reactive power which is not able to be absorbed, thus boosting voltages in the system. This may be a concern when a neighboring system has nearby generating units and no transformer or other regulating devices are in place between the two systems. The objective of interest is to determine if reactive power and voltage control can be provided by D-FACTS devices [3].

In particular, this application examines the use of D-FACTS devices as a means of increasing or decreasing voltage. Since D-FACTS devices behave like series connected voltage sources, they are a logical choice for consideration in voltage control applications and reactive power injection and absorption.

However, when reactive power and voltages are higher than a certain thresh-hold in a system containing D-FACTS devices, the system may benefit from changing the settings such that voltages and reactive power return to a normal level. Voltage and reactive power control may be done by determining the required line impendence settings in lines with D-FACTS devices to minimize the square of the difference between the voltage states in the system and the corresponding reference voltages.

Beneficial choices of lines for D-FACTS application may be determined from best transmission lines that have high sensitivities as better choices because changing the impedance on that line has a higher impact on the system voltages and reactive power. By producing a series compensating voltages which can effectively change transmission line impedance, D-FACTS devices may be applied to problems such as controlling system voltages and reactive power after they have become too high.

According to [4], in a book titled "Distributed FACTS -A New Concept for Realizing Grid Power Flow" Distributed Flexible Alternating Current Transmission System (D-FACTS) devices promises to be simpler and cost effective solution to the power flow problem. Traditional FACTS devices offer lumped solutions and can only be applied at one or two locations in a network. D-FACTS devices on the other hand can be applied to a large number of locations in the same network. Traditional solutions to upgrade the electrical transmission system infrastructure have been primarily in the form of new transmission lines. Substations and other associated equipment. However, as experience have proven over the past decade or more, the process to permit, site and construct new transmission lines has become extremely difficult, expensive, time-consuming and controversial. FACTS and D-FACTS Technologies provide advanced solutions as cost-effective alternative to new transmission line constructions.

[5] 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.

As highlighted above, one cannot but agree that an electric power transmission network is vulnerable to problems of overload, system failure, power losses, voltage variation, power flow problem and cascading disturbances. More so, power transmission systems are being pushed closer to their thermal and stability limit while the focus on quality of power delivered is greater than ever. Therefore, maintenance of reliable secure, inexpensive and quality power supply is a very important issue in power transmission system design and operation. The function of an electric power transmission system is to satisfy the systems' load requirement with a reasonable assurance of continuity and quality. The concept of enhancing reactive power control and voltage profile/voltage control in Nigeria 330kv transmission network is very broad and covers the ability of the system to satisfy customers' load requirement. A P-I (Power-current) curve process analysis is applied to determine D-FACTS setting such that the system voltages will be controlled to 1.00per unit. It is important to note that these results depend heavily on operating conditions. The voltages at each bus in the system are shown in Figure 1. Before and after the D-FACTS algorithm was applied.

II. MATERIALS AND METHODS

The methods adopted in this paper are as follows:

(1) Newton Raphson technique was used for A.C. load flow analysis.

(2) Powerword Simulator was used for simulation of Nigeria 41-Bus system incorporated with multiple D-FACTS devices

(3) Power-Current (P-I) curve analysis was used to determine the settings of D-FACTS devices.

.(4) Microsoft Excell was used for ploting of the graphs of base case and compensated/Improved voltage.against transmission lines.

2.2 Application of Power Electronics for System Control

The basic equation for power transmission explains the solutions for system enhancement in a more detailed way (Bertsekas 1999). The power transmitted between two subsystems depends on voltages at both ends of the connecting line, the lines impedance and the phase angle difference between the connecting points. Power electronics can actively influence one or more of these parameters and control or direct the power flow through the interconnection.

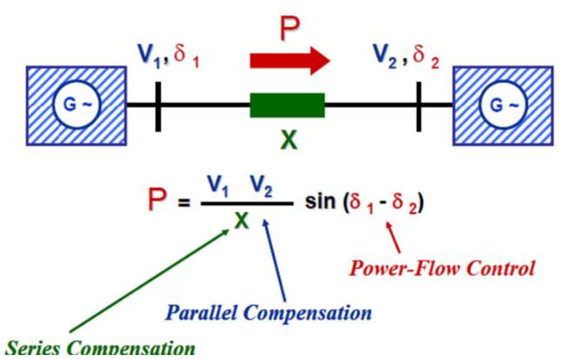

Fig 1: Simple Power Transmission Line (Becks & Breuer, 2006)

Each of these parameters can be used for Load-Flow Control and Power Oscillation Damping

By using FACTS for reactive power compensation (Overbye ., 1994), the impedances and voltage of the system can be influenced, by adding series compensation (fixed or controlled) into the line, its reactance X can be reduced or modulated (for power oscillation damping, ref. to the equation), with FACTS parallel compensation, eg SVC (static var compensator), the voltage can be stabilized (at constant values or modulated for damping of oscillation) The transmission angle can be influenced by using HVDC for power-flow control.

Deregulation and privatization is posing new challenges on high voltage transmission systems. System elements are going to be loaded up to their thermal limits, and wide-area power trading with fast varying bad patterns will contribute to an increasing congestion. To keep the power supply reliable and safe, system enhancement will be essential (Olson ., 2006).

High voltage power electronics (D-FACTS) provide the necessary features to avoid technical problem in the power systems, they increase the transmission capacity and system stability very efficiently and they assist in prevention of cascading disturbances (i.e total black out).

III. RESULTS AND DISCUSSION

Owing to rampant overloading of some transmission lines, step-up transformers and generators, due to transfer of chap power from generator bus to load bus, as a result of faults and other disturbance, distributed series reactance modules and Distributed Series Capacitances modules were mainly used to relieve our transmission equipment of overloaded power. While controlling or regulating real power flowing through some targeted lines across the six-geo-graphical zone of this country, distributed series reactance and distributed series capacitor were incrementally deployed in the ratio of 2:1. This is justifiable because distributed series reactance module operates by injecting reactive impedance in the over loaded lines thereby pushing away real power from the over loaded elements to the under loaded lines whereas Distributed series Capacitance pulls power to lines that are not overloaded or are under-utilized by way of injecting vars in the system.

Therefore, distributed series capacitors operate by injecting capacitance on the lines that are not over loaded thereby increasing its reactive power, real power and voltage magnitude. It is mainly useful in under-loaded lines.

It should be noted that the two varieties of D-FACTS modules used are of the same rated value of 47µF and

47μH respectively. The MVA limit set of the D-FACTS module is 777 MVA with equivalent current limit of 750 amps. 47μF is the value of injected impedance per module.

It shall be clearly observed that D-FACTS devices have much positive effect on regulating/controlling real power flowing through 330KV Nigerian transmission grid as will be verified. This method proved to be the most reliable, fast, efficient and cost effective solution to Nigerian transmission system control. The under mentioned selected and regulated transmission lines across the six geo-graphical zone using D-FACTS devices are verifiable cases in point.

3.1 Control of System's High Voltage to Normal Voltage Using D-Facts Devices

The voltage profile in a power system is often kept at a sufficiently high level with Vars produced by capacitor banks and generators. During off-peak periods when the lines are loaded below their surge impedance loading, they start acting capacitive instead of reactive. At such times, there is often too much reactive power in the system and the voltage become elevated. There is often no suitable means to lower the system voltages and absorb reactive power. The generator in the system may be able to absorb some reactive power, but generators do not have much capability to operate at a leading power factor without causing instability. In fact, some operators will not run their units at leading power factor. Here we examine the use of D-FACTS devices as a means to lower voltage in Nigeria 41 bus system. However, D-FACTS devices can act inductive as well as capacitive, so both raising and lowering system voltages are important potential applications.

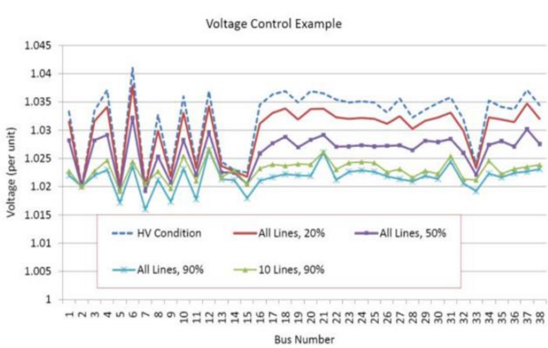

Fig.5: Study System Voltage Control (Katherine Rogers,2010)

The initial high voltages (HV) condition caused by low load level is shown above. Several control scenarios illustrates the results of the optimization procedures. In the first three scenarios, D-FACTS devices are allowed to change xy (line impedance) by 20%, 50% and 90%. The result indicates that voltages are only significantly affected when D-FACTS devices are allowed to cause a large percentage change in effective line impedance. However, during these low load conditions, it could be acceptable for D-FACTS devices to change effective line impedance by more than + 20% because the corresponding current flows will be lower for the same voltage drop.

To illustrate the importance of device placement in the fourth scenario, D-FACTS devices are placed on the six best lines determined by SIV across the six geo-graphical zones of the country.

Line impedances are allowed to change by + 90% to correspond with the previous scenario which allowed the most control. An interesting conclusion is that the result of placing D-FACTS devices on all lines and the results of placing D-FACTS devices on only 6 (six) best lines are very similar. Thus, these 6 lines are good choices for use in voltage control. Conversely, there is little benefit to be gained by placing devices on ineffective lines.

The final voltage in the Figure 5 above illustrates that in all cases, the use of D-FACTS devices (DSI) will lower system voltages, but the amount of the change depends strongly on the range over which D-FACTS devices are allowed to change. Thus, it is important to determine what amount of voltage reduction is sufficient for the situation of interest and more exactly what the devices limitations are.

3.2 Voltage Improvement in 41 Bus System of Nigeria Transmission Grid Using D-Facts Controllers

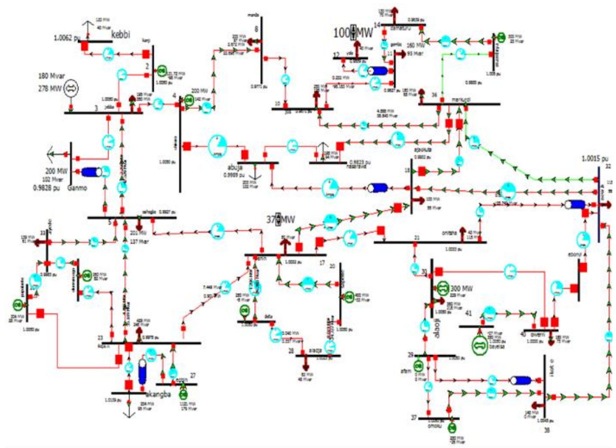

Figure 6 Single Line Diagram Of Nigeria 41-Bus System With Multiple D-Facts Devices.

Table 1 Voltage Control (Improvement)

Bus Records		Base Case	D-FACTS inserted
Number	Name	PU Volt	PU Volt
2	Kanji	1	1.005
3	Jebba	1	1.005
4	Shiroro	1	1.005
5	Gombe	0.94274	0.96274
8	Yola	0.91592	1.005
10	Onitsha	1.001	1.00331
11	Ikeja.w	0.99171	0.99779
12	Papalanto	1	1.005
13	Egbin	1	1.013
14	New.h	1	1.0015
17	Kebbi	1.0024	1.00624
18	Abuja	0.98914	0.99894

To illustrate the use of D-FACTS in a voltage control application, several scenarios are examined on Nigeria 41 bus grid as a system study. The above schematic diagram is an illustration of an implemented and simulated 41-Bus system in a Power world environment using D-FACTS devices. D-FACTS devices were installed on the best line in each of the six geo-political zone purposely to improve the reactive power and voltage profile of the system.

3.3 Voltage Improvement at Various Buses across the Six Geo-Political Zones

In the north-east geopolitical zone of Nigeria, it is significant to mention that the low voltage magnitude experienced in Yola (Adamawa State) had been improved from 0.91592 P.U. to 1.005PU by the placement of Distributed series capacitor modules on that bus as show in the table below. It is commonly known that Distributed Series Capacitance modules mostly generate reactive power that boosts or increases voltage profile of a transmission grid. Similarly, D-FACTS modules are installed in each of the six geographical zone as indicated in the above table for critical observation and comparism of the simulated and base results at critical locations of all the six geo-political zones as shown below

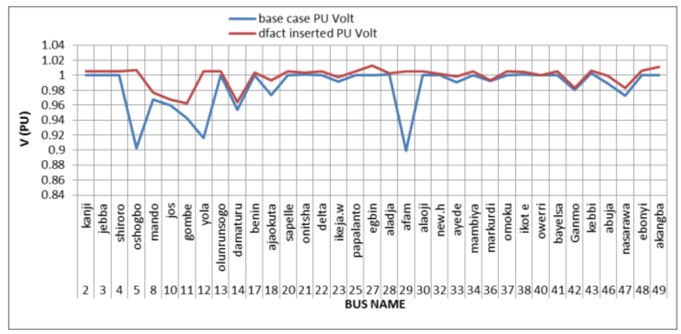

Figure 6 Graph of Improved Voltage Profile

The above graph illustrates the result or improvement achieved in using D-FACTS modules to control voltage at some critical locations in the network.. As indicated in the graph, blue line represents result of the base case, while red line represent the result of the simulated and controlled case using D-FACTS modules.

3.4 Enhancement of Reactive Power

It is very imperative to remind us that reactive power injection or absorption gives rise to elevation or depression of voltage profile. Therefore, it simply implies that voltage magnitude of any bus is dependent on the degree of reactive power injected into the bus or reactive power absorbed from the network. The above graph illustrates excellent improvement of voltage profile using D-FACTS modules. For moderate reactive power modulation, control, injection or absorption, multiples Distributed Series Capacitance and Distributed Series Reactive modules type of D-FACTS devices are essential.

Scenario B: Reactive Power Improvement on Damaturu-Gombe Transmission Line (North- East Zone)

From the simulation scenario, it is evident that before clamping of D-FACTS module on the transmission line connecting Damaturu in Yobe State and Gombe, the value of reactive power (uncompensated) was 15.0 MVAR but after clamping of D-FACTS modules on the line, the Distributed Series Capacitor injected reactive power on the line and the Distributed value of compensated reactive power becomes 21.5 Mvar, hence distributed series reactive support are provided in all the location of the under loaded lines in that zone by DSC Modules. Alternatively, Distributed Series Capacitive Modules either inject reactive power into the under loaded lines or pulls power from over loaded lines to the under loaded lines. As mentioned earlier the lines are directly coupled for ease of control and to avoid controlling the lines independently. Also, high sensitive lines are equally considered. Upgrading the reactive power of any network is very essential in order to avoid critical voltage collapse which could cause cascading or blackout in the entire nation.

Scenario C: North Central Zone: Improvement of Reactive Power on Kanji-Jebba Transmission Lines

In the North Central geo-political zone of Nigeria, transmission lines connecting Kainji and Jebba both in Niger state is chosen and targeted for reactive power control. Before clamping of D-FACTS modules on the line, the value of un-compensated reactive power was 44 Mvar whereas after clamping of D-FACTS modules on the line, the value of compensated reactive power becomes 53Mvar. Therefore, the compensated reactive power becomes 53Mvar - 44Mvar = 9Mvar, which is the total reactive power that is injected into the network.

sures 26.7Mvar. The improvement of reactive power from 20.6Mvar to 26.7 Mvar is very important in improving the voltage profile of the network. It is still crucial to always note that it is only the Distributed Series Capacitance

Scenario D: North West Zone: Improvement of Reactive Power on Kebbi - Kainji Transmission Line

In the North West geo-political zone, a transmission line linking Kebbi and Kainji is chosen and targeted for control of reactive power on the network. Prior to the clamping of D-FACTS module (DSC) for reactive power control, the value of the uncompensated reactive power flowing on the line was 20.6 Mvar. After clamping of D-FACTS module on the same line, the value of compensated reactive power flow, mea Modules that are useful in reactive power control. These controllers have good advantage of not causing sub-synchronous resonant in the network quite unlike series capacitors

Scenario E: South East Zone; Improvement of Reactive Power on Onitsha - Alaoji Line

In controlling reactive power flowing in the South East geo-political zone of Nigeria, a transmission line between Onitsha and Alaoji was chosen and targeted for control. The value of the uncompensated reactive power pre to clamping of D-FACTS modules on the line was 92-4Mvar, whereas after the clamping of D-FACTS module on the line, the value of compensated reactive power remains 120.3 Mvar. This has given rise to a revamped and compensated network capable of being smart, fault tolerance and quick self-healing.

Table 2

	BASE CASE	D FACTS Compensated
From – To	Mvar Loss	Mvar Loss
kanji – jebba	33.6	35.56
kebbi – kanji	33.53	39.23
shiroro – jebba	23.12	27.43
yola – gombe	6.56	47.59
damaturu – gombe	2.84	3.24
olunrunsogo - ikeja. W	32.84	47.43
ayede –olunrunsogo	16.47	17.52
damaturu – mambiya	3.42	3.82
ajaokuta – benin	12.92	14.1
benin –sapelle	1.04	1.21
aladja – sapelle	24.13	24.73
onitsha – alaoji	10.31	13.76
onitsha - new. H	22.98	25.74
ikeja.w – egbin	8.32	8.96
ikeja.w – akangba	3.82	4.48
ayede – papalanto	10.32	11

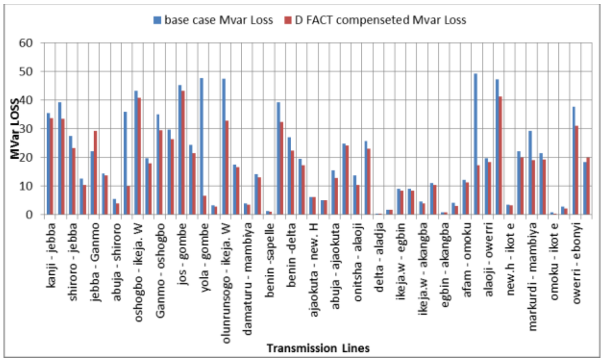

Figure 4 Graph of Reactive Power Against Transmission Lines

From the graph above, blue line represents the bar case while red line represents the compensated case.

IV. CONCLUSION

Installation of multiple D-FACTS devices in suitable locations of Nigeria 330kV transmission network can lead to control of reactive power flow and to maintain bus voltages in desired level so as to improve voltage stability margin. Nigeria 41 bus system had been simulated for reactive power improvement and voltage control in a POWERWORD environment and the results obtained were presented in this article. In this paper, a novel approach for reactive power and voltage control using D-FACTS devices like DSR & DSC modules was presented. The overall end results satisfactorily proved efficient controllability of both reactive power and voltage profile including reduced losses and enhanced assets utilization. Multiple applications of D-FACTS modules served as most cost effective alternative to construction of new transmission lines,

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