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SERIES COMPENSATION OF THE INTEGRATED NIGERIA'S 330KV TRANSMISSION GRID SYSTEM

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ABSTRACT

This study is on the Nigerian Power system which is complex and dynamic which is characterized by frequent faults and outages resulting to none steady supply of power to the teaming consumers. This scenario has great effect on the activities and mode of living of Nigerians. The work is aimed at bridging the gap of proposing further expansion of the grid system which is not only limited by huge sum of finance and difficulties in finding right –of- way for new lines but also which faces the challenges of fixed land and longtime of construction the data of the network was gotten and modeled into the network. The power flow Analysis was carried on the network comprising of 16 generators and 35 loads and 73 transmission lines using Power System Analysis Tool Box (PSAT) in MATLAB environment under the influence of Newton-Raphson Load Flow (NRLF) method. A base simulation of network was carried out and series compensation was carried out on the violated lines without contingencies. Series compensation using Thyristor Controlled series Compensator (TCSC) modeled with Newton-Raphson Load Flow (NRLF) method was adopted. The results obtained for base simulation revealed an MVA flow of 334.87 KVA and 212.73 MVA after compensation which showed a huge brought down of the MVA flow. The violated lines were Egbin – Ikeja West as 887MVA, Egbin –Benin 1514MVA

Ikeja West- Ikaro 4457 MVA, Ikaro- Egbin 1102 MVA, Benin- Onitsha-1026 MVA, Benin –Sapele 800MVA, Onitsha- Aloji 757 MVA, Ikotu Ekpene- Ugwuaji 768MVA. However, after compensation there were improvement in areas of violation on lower limit and reductions at higher limits as recorded again Egbin – Ikeja West as 289 MVA, Egbin –Benin 536 MVA,

Ikeja West- Ikaro 430 MVA, Ikaro- Egbin 375 MVA, Benin- Onitsha 629 MVA, Benin –Sapele 788MVA, Onitsha- Aloji 515 MVA, Ikotu Ekpene- Ugwuaji 431MVA.

KEYWORDS: Contingency, FACTS Controllers, Power flow study, Compensation,

1. INTRODUCTION

The Nigerian Power system is complex and dynamic, as a result of this it is characterized by frequent faults and outages resulting to none steady supply of power to the teaming consumers. This has great effect on the activities and mode of living of Nigerians (Obi, P.I and Offor, k. J, 2014).

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The Integrated power system presently being understudied is made up of existing 51 buses (comprising of 16 Generating stations and 35 loads) and 73 transmission lines, many still under construction.

One of the most important factors in the operation of a power system is the desire to maintain system security. System security involves practices designed to keep the system operating with its range and limits when components fail (Nonyelu & Madueme, 2013).

Contingency simply means future event, occurrence or situation that can possibly arise but cannot be predicted with certainty which usually cause problems.

Contingency Analysis of a power system is a major activity in power system planning and operation.

These controllers are used in order to alleviate the power system problems of voltage limit violations, and disproportionate power flows and high active power loss; a solution method of incorporation of FACTS controllers into the existing power system (Adepoju, G.A, et al, 2011).

As the Nigerian Government is finalizing the eventual deregulation of her power system it is important that the investing companies be availed with information of the technical benefit derivable from the incorporation of FACTS controllers within the system (Adepoju, G. A., et al 2011)

A power-flow study usually uses simplified notations such as a one-line diagram and per-unit system, and focuses on various aspects of AC power parameters, such as voltages, voltage angles, real power and reactive power. It analyzes the power systems in normal steady-state operation (Low, S.H, 2013)
Synchronous capacitor is a synchronous machine synchronized to the power grid and controlled to absorb or generate lagging VARs on the system. They are out door and are automatically controlled for startup, short down and on-line monitoring. When the machine is over excited, it acts as a shunt capacitor as it supplies lagging VARs to the system but when under-excited, it acts as a shunt coil (coil) as it absorbs reactive power to maintain terminal voltage.

2.0 MATERIALS AND METHOD

2.1 SERIES COMPENSATION (CAPACITIVE COMPENSATION)

This is the use of series capacitors which results into increase in maximum transmittable power, reduction in transmission angle and increase in virtual surge impedance loading. The thyristor controlled series compensator is used for the series compensation. It is made up of thyristor, reactor, and capacitor. The capacitive reactance of the controller is varied by varying the firing angle of the thyristor controlled reactor

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(TCR) (Babar Noor, Mahammed Aamur Aman, MaURAD Ali, Sanaullah Ahmed and Fazal Wahab Kasam, 2018).

The Thyristor Control Series Conpensator (TCSC) is a capacitive reactance compensator consisting of a series capacitor bank shunted by a Thyristor-Controlled Reactor (TCR) in order to provide a continuously variable series capacitive reactance. It can play various roles in the operation and control of power systems, such as scheduling power flow, damping of power oscillations, decreasing unsymmetrical components, providing voltage support, limiting short-circuit currents, mitigating sub-synchronous resonance (SSR) and enhancing transient stability, (Zhou, X and Liang, J., 1999). The figure below shows the basic TCSC connection.

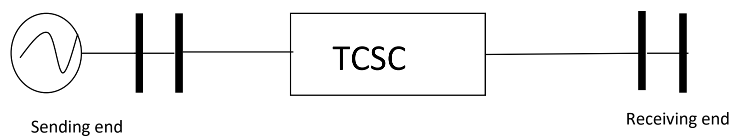

Figure1 Basic TCSC connection.

The load ability of the system is increased by decreasing the line effective reactance due to the capacitive reactance connected in series with the line reactance.

The thyristor is connected with a reactor that is in parallel to the capacitor along with transmission line. The figure below shows the individual components of the TCSC.

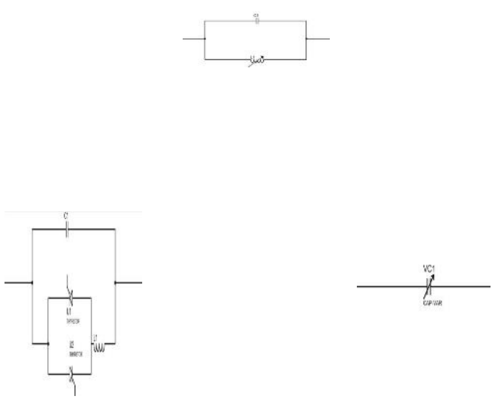

Figure 2: The figure below shows the individual components of the TCSC.

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The lagging reactive power (inductive reactive power) and TCR current amplitude can be controlled continuously by varying the thyristor firing angle between 900 and 1800. The TCR firing angle can be fully changed within one cycle of the fundamental frequency, thus providing smooth and fast control of reactive power supplied to the system (Sankarbabu, P and Subrahmanyam, J.B.U, 2010)

The leading vars (capacitive reactive power) are usually provided by a different number of capacitor bank units. By combining these two components, fixed capacitor and continuously controlled reactor, as smooth variation in reactive power over the entire range can be achieved and the sum of the reactive power becomes linear. (Oltean, S.E, Dulau, M and Duka, A.V, 2012)

2.2 TSCS Power Flow Model

The TCSC power flow model presented in figure below is based on the simple concept of a variable series reactance, the value of which is adjusted automatically to set the power flow through the line to the specified value. The reactance value is determined efficiently by means of Newton's method. The changing reactance *TCSC*, shown in (a) and (b), represents the equivalent reactance of all the series-connected modules making up the TCSC, when operating in either the inductive or the capacitive regions (S. J. Helbing and G. G. Karady,1994) and (E. Acha, C. R. Fuerte-Esquivel, H. Ambriz-Pérez, C. Angeles-Camacho, 2004)

For the variation of α from 0 to 90°, XL (α) varies from actual reactance (XL) to infinity. This controlled reactor is connected across the series capacitor, so that the variable capacitive reactance, as fig.3.6 is possible across the TCSC which modify the transmission line impedance. Effective TCSC reactance Xtcsc with respect to alpha (α) can be given the equations below. Kadia, J. V and Jamnani, J. G, 2012)

$$X_L(\alpha) = X_L \frac{\pi}{\pi - 2\alpha - Sin2\alpha} \quad (1)$$

$$X_C = \frac{1}{2\pi FC} \quad (2)$$

$$X_{TCSC}(\alpha) = -X_C + C_1\left(2(\pi-\alpha) + \mathrm{Sin}\left(2(\pi-\alpha)\right)\right) - C_{2COS}{}^2(\pi-\alpha) w \tan(w(\pi-\alpha)) - \tan(\pi\alpha)) \quad (3)$$

$$C_1 = \frac{X_C + X_{LC}}{\Pi} \quad (4)$$

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$$C_2 = \frac{4x^2LC}{XL\pi} \quad (5)$$

$$X_{LC} = \frac{X_CX_L}{X_C-X_L} \quad (6)$$

$$W = \sqrt{\frac{Xc}{Xl}} \quad (7)$$

Table 1: showing various Regions of compensation

Range of firing angle (α)	Region
$90^0 \leq \alpha \leq \alpha_{Lim}$	Inductive Region
$\alpha_{Lim} \leq \alpha \leq \alpha C_{im}$	Resonance Region
$\alpha C_{im} \leq \alpha \leq 180^0$	Capacitive Region

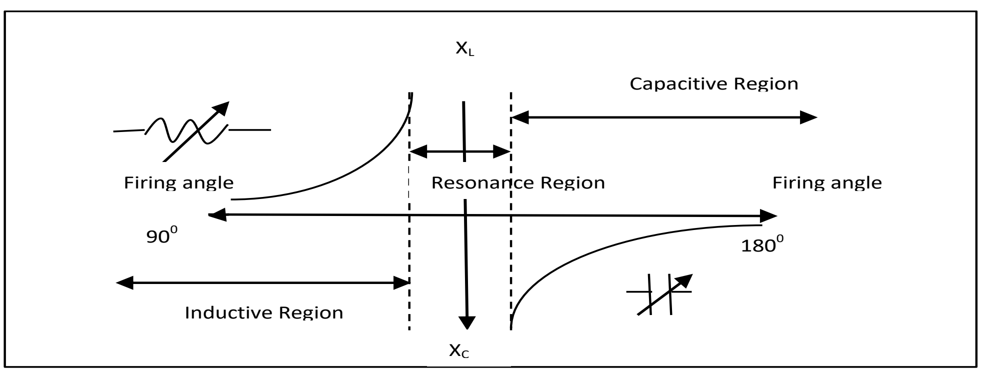

Figure 3: Resonance Condition of TCSC

Figure below shows the series compensation technique for both inductive and capacitive regions.

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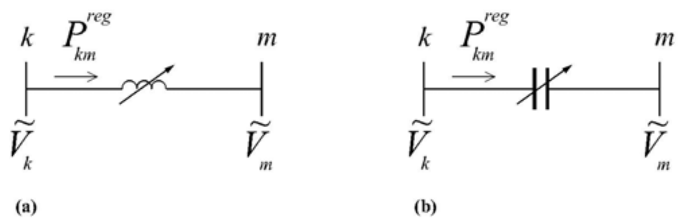

Figure 4: Thyristor-controlled series compensator equivalent circuits: (a) inductive and (b) capacitive regions

2.3 Transfer Admittance of the Variable Series Compensator

$$\begin{bmatrix} I_k \\ I_m \end{bmatrix} = \begin{bmatrix} jB_{kk} & jB_{km} \\ jB_{mk} & jB_{mm} \end{bmatrix} \begin{bmatrix} V_k \\ V_m \end{bmatrix} \quad \text{--- (1)}$$

For inductive operation, then it is

$$\left. \begin{aligned} B_{kk} &= B_{mm} = -\frac{1}{X_{TCSC}} \\ B_{kk} &= B_{mm} = -\frac{1}{X_{TCSC}} \end{aligned} \right\} \quad \text{--- (2)}$$

For capacitive operation, there is reversal of sign

The active and reactive power flow equation at bus k are as follows

$$P_{km} = V_k V_m B_{km} \text{Sin}(\theta_k - \theta_m) \quad \text{- (3)}$$

$$Q_{km} = -V_k^2 B_{kk} - V_k V_m \text{Cos}(\theta_k - \theta_m) \quad \text{-- (4)}$$

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$\tilde{V}_K = V_K < \theta_K$ and $\tilde{V}_m = V_m < \theta_m$

Using Newton- Raphson solution and linearizing the equations with respect to the series reactance and by solving iteratively

For the solution in the amount of active power flowing from bus k to bus m at a value Pkm reg then set of linearized power flow equations is

$$\begin{bmatrix} \Delta P_K \\ \Delta P_M \\ \Delta Q_K \\ \Delta Q_M \\ \Delta P_{KM} \end{bmatrix} = \begin{bmatrix} \frac{\partial P_K}{\partial Q_K} & \frac{\partial P_K}{\partial Q_M} & \frac{\partial P_K V_K}{\partial V_K} & \frac{\partial P_K V_M}{\partial V_M} & \frac{\partial P_K{}^{xtcsc}}{\partial X_{TCSC}} \\ \frac{\partial P_M}{\partial Q_K} & \frac{\partial P_M}{\partial Q_M} & \frac{\partial P_M V_K}{\partial V_K} & \frac{\partial P_M V_M}{\partial V_M} & \frac{\partial P_M{}^{xtcsc}}{\partial X_{TCSC}} \\ \frac{\partial Q_K}{\partial Q_K} & \frac{\partial Q_K}{\partial Q_M} & \frac{\partial Q_K V_K}{\partial V_K} & \frac{\partial Q_K V_M}{\partial V_M} & \frac{\partial Q_K{}^{xtcsc}}{\partial X_{TCSC}} \\ \frac{\partial Q_M}{\partial Q_K} & \frac{\partial Q_M}{\partial Q_M} & \frac{\partial Q_M V_K}{\partial V_K} & \frac{\partial Q_M V_M}{\partial V_M} & \frac{\partial Q_M{}^{xtcsc}}{\partial X_{TCSC}} \\ \frac{\partial P_{KM}{}^{xtcsc}}{\partial Q_K} & \frac{\partial P_{KM}{}^{xtcsc}}{\partial Q_M} & \frac{\partial P_{KM}{}^{xtcsc}}{\partial V_K} & \frac{\partial P_{KM}{}^{xtcsc}}{\partial V_M} & \frac{\partial P_{KM}{}^{xtcsc}}{\partial Q X_{TCSC}} \end{bmatrix} \begin{bmatrix} \Delta Q_K \\ \Delta Q_M \\ \frac{\Delta V_K}{V_K} \\ \frac{\Delta V_m}{V_M} \\ \frac{\Delta X_{TCSC}}{X_{TCSC}} \end{bmatrix}$$

Where $\Delta P_{km}{}^{XTCSC} = P_{km}{}^{reg} - \Delta P_{km}{}^{XTCSC\ cal}$

is the active power flow mismatch for the series reactance

ΔX_{TCSC} , is given by

$\Delta X_{TCSC} = X^{(i)}{}_{TCSC} = X^{(i-1)}{}_{TCSC}$

The incremental change in series reactance and $P_{km}{}^{XTCSC\ cal}$ the calculated power is given by eg. (3). The state viable X_{TCSC} of the series controller is updated at the end of each iterative step according to (Echa E, fuerte, C.R, Ambriz – perez, H and Angeles –camacho, C, 2004)

$$\text{Thus } X^{(i)}{}_{TCSC} = X^{(i-1)}{}_{TCSC} + X_{TCSC}\left(\frac{X^{(i-1)}{}_{TCSC}}{\Delta}\right)$$

X_{TCSC}

2.4 Modeling of the power system

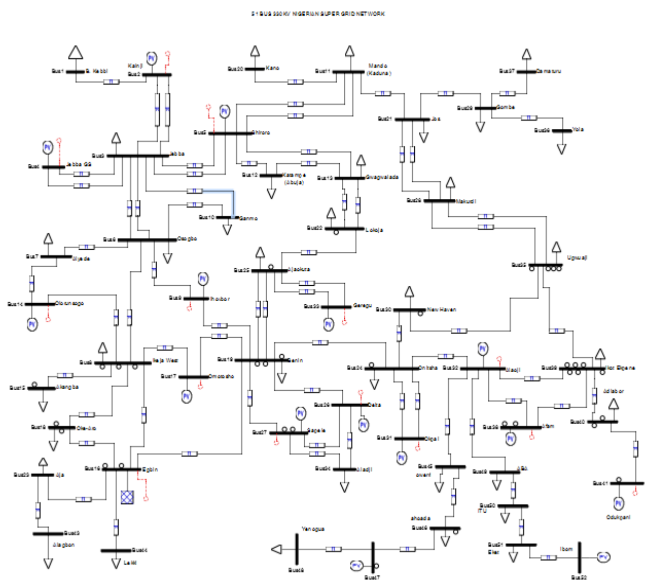

Figure 5: The Modelled power system

3.0 RESULTS OF SIMULATION

3.1 Table of MVA flow with and without compensation against Lines

Line Name	MVA flow without compensation	MVA Flow with compensation
Kainji-Jebba	191.1177676	201.6087829
B. Kebbi-kainji	138.9244399	138.9244399
Shiroro-katampe	59.08613173	123.3008066
oshogbo-Ganmo	255.0833954	75.3531326
Jebba-oshogbo	308.44411	121.40419
Jebba-	308.44411	121.40419

oshogbo		
Ikeja West-oshogbo	711.8944074	257.2481437
oshogbo-Ayede	491.4705616	116.0854575
Ganmo - Jebba	370.3126698	182.4674403
ikeja West-olorunsango	783.3950017	453.2031702
oshogbo-olorunsango	431.7063632	77.06083234
Jos-Mando	305.6352763	112.5482843
Ikeja West-Akangba	28.96616861	28.86920291
Egbin-Ikeja West	887.4068586	289.0269124
Aja - Egbin	218.2671245	218.2671245
Egbin-Benin	1514.454932	536.1736731
Ikeja West - Oke Aro	1157.016472	430.5190459
Oke Aro - Egbin	1102.238618	375.3991545
Ikeja West - Omotosho	707.7020493	239.2402424
Omotosho - Benin	456.9917562	84.68026934
Jebba GS - Jebba	428.2396156	306.3452285
Ajaokuta - Benin	60.02271202	90.09351158
Benin - Onitcha	1026.831279	629.5373796
Ajaokuta - Benin	61.12165503	91.46470839
Geregu-Ajaokuta	209.3447002	200.7566867

Geregu-Ajaokuta	209.3447002	200.7566867
Benin-sapele	800.8706103	708.7550022
sapele-Delta	136.2900401	134.1732413
Kainji-Jebba	191.1177676	201.6087829
Benin - Delta	428.6457165	397.175757
Onitcha-New Haven	42.23569173	121.7239159
Okpai - Onitcha	284.5368663	219.1252758
Okpai - Onitcha	288.4557359	221.5013897
Onitcha-Alaoji	757.1046328	515.5969456
Alaoji-Afam	393.3626576	517.0425284
New heaven - Ugwuaji	54.24194973	99.96985972
Ajaokuta - Lokoja	396.4702369	173.3614639
Jebba GS - Jebba	428.2396156	306.3452285
Ihovbor-Benin	126.2043172	222.7825526
aladji-Sapele	74.93780423	74.09671156
aladji-Delta	260.767858	259.4512722
Yola-Gombe	74.41377561	74.41377561
Mando-Kano	106.9164445	107.7558938
Gombe-Jos	183.7362874	199.7824925
Gombe-Damaturu	78.60615939	89.34837391
Gwagwalada-lokoja	136.0804444	43.53730942
Jebba-Shiroro	219.3334711	53.44878725
Gwagwalada-lokoja	136.0804444	43.53730942

Shiroro-Gwagwalada	89.75949646	163.5133015
katampe-Gwagwalada	80.39912569	17.98856176
Ugwuaji-Markurdi	333.1656428	215.8978878
Jos-Markurdi	275.3659151	123.2834555
Jos-Markurdi	275.3659151	123.2834555
Ugwuaji-Markurdi	333.1656428	215.8978878
Ikot Ekpene-Ugwuaji	768.2425931	431.024755
Jebba-Shiroro	219.3334711	53.44878725
Ikot Ekpene-Adiabor	463.6331998	470.7219485
oshogbo-Ihovbor	502.3383532	184.4530935
Ikot Ekpene-Alaoji	222.898708	70.72155674
Ikot Ekpene-Afam	297.9249363	164.8824299
Mando-Shiroro	64.59225869	189.7897228
Adiabor-Odukpani	562.1125131	558.1737662
Egbin-Lekki	91.63646282	91.63646282
aja-Alagbon	78.02324196	78.02324196
Alaoji-Owerri	17.25337644	17.25337644
Owerri-Ahoada	89.0958636	89.0958636
Bus 47 - Ahoada	162.7686541	162.7686541
Yenogua-Bus 47	132.4122351	132.4122351
Alaoji-Aba	176.2350766	176.2350766

Aba-ITU	298.9747867	298.9747867
Mando-Shiroro	64.59225869	189.7897228
ITU-Eket	365.0672303	365.0672303
Eket-Ibom	458.7842354	458.7842354

3.2 Graphs of MVA flow against the Lines on Base Simulation

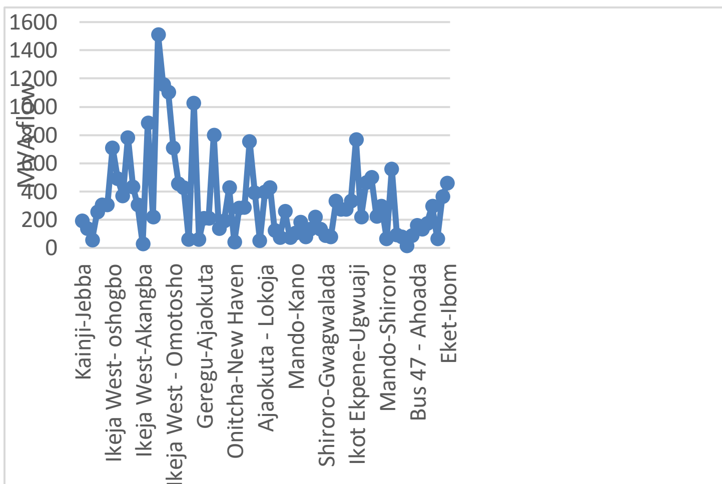

Figure 6: Graphs of MVA flow against the Lines on Base Simulation

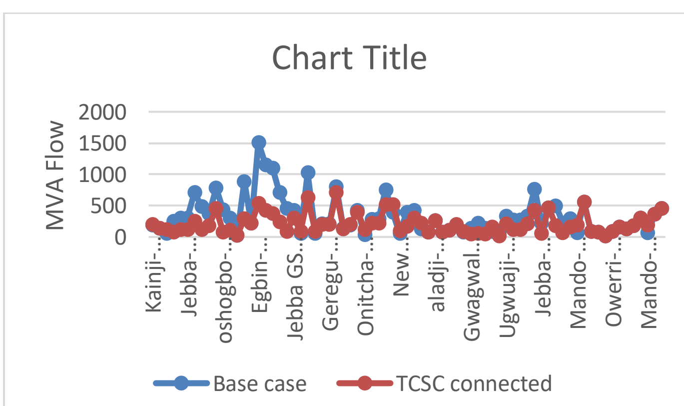

Figure 7: Graphs of MVA flow against the Lines on Base Simulation after compensation

3.3 Discussion of Results/ Summary

The results obtained for base simulation revealed an MVA flow of 334.87 KVA and 212.73 MVA after compensation which showed a huge brought down of the MVA flow. The violated lines were Egbin – Ikeja West as 887MVA, Egbin –Benin 1514,

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The series compensation using TCSC improved the system voltage and power transfer capability of the lines

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