International Journal Of Engineering Research And Development
e- ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 20, Issue 3 (March. 2024), PP. 131-136

Power Flow Analysis of the Nigerian Power Grid with FACTS Devices

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ABSTRACT *This paper investigates the Nigerian power grid with Thyristor Controlled Series Capacitor (TCSC). Power flow analysis is carried out on the 28-bus 330kV transmission network without and with TCSC facts device in a MATLAB software environment. The simulation results show some weak buses in the network. However, with the incorporation of TCSC there is a considerable improvement in the voltage magnitude and a significant reduction in the system losses.*

Keywords: Power flow analysis, TCSC, FACTS, Nigerian power network, Bus Voltages

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Date of Submission: 10-03-2024 Date of Acceptance: 23-03-2024

I. INTRODUCTION

Nigeria electric power system is undergoing transformation as a result of growing electricity demand due to industrialization and economic development. This transformation will affect the power quality, reliability and voltage stability (Esaeosa and Odiase, 2012). Voltage stability is the ability of a power system to maintain steady acceptable voltage at all buses in the system at normal operation and after being subjected to a disturbance (Saadat H.,2012). The existing power systems are at dangers of voltage instability problems due to highly stressed operating conditions arising from increase in load demand, rapid industrializationand environmental constraints in the transmission lines (Adebayo *et al*, 2013), (Dafde R.A, 2017). The problem of voltage instability adversely affects the transmitted power and cause instability in the transmission system. For this reason, maintaining stability of such an interconnected power system has become a difficult task.

In order to solve voltage instability problems, flexible alternating current transmission system (FACTS) devices are used to control the parameter such as voltage magnitude and their angles, line impedance, active and reactive power flow (Rafee, S.M.; and Reddy A.S., 2021),(Acha *et al*, 1997), and (Adepojuand Komolafe, 2008). Various forms of FACTS are available such as static var compensator (SVC), static synchronous compensator (STATCOM), thyristor control series capacitor (TCSC), static synchronous series compensator (SSSC), interline power flow controller (IPFC), unified power flow controller (UPFC), super conducting magnetic energy storage (SMES). (Jammani and Kumar, 2019). Among the various FACTS devices, Thyristor controlled series capacitor (TCSC) is one of the most commonly utilized in practice due to their low costs, relatively simple control and effectiveness to provide series compensation, increase the power transfer capabilities, damp oscillations of transmission systems and reduce the sub-synchronous resonance (SSR) effect. (KundurP., 1984). In this paper, thyristor-controlled series capacitor will be considered for voltage stability improvement.

THYRISTOR CONTROLLED SERIES CAPACITOR

Flexible AC Transmission Systems (FACTS) devices was first introduced in 1970 and since then there are many FACTS devices which have been invented according to the need and their applications in industries and power systems (Higorani, 1988). TCSC is one of the most effective series Flexible AC Transmission System (FACTS) devices. It offers fast-acting reactive power compensation on high-voltage electricity transmission networks with much faster response compared to the traditional control devices (references). TCSC controllers use thyristor-controlled reactor (TCR) in parallel with capacitor segments of series capacitor bank as shown in Fig1. TCSC is an effective and economical means of solving problems of transient stability, dynamic stability, steady state stability and voltage stability in long transmission lines. TCSC is a series controlled capacitive reactance that can provide continuous control of power on the ac line over a wide range.

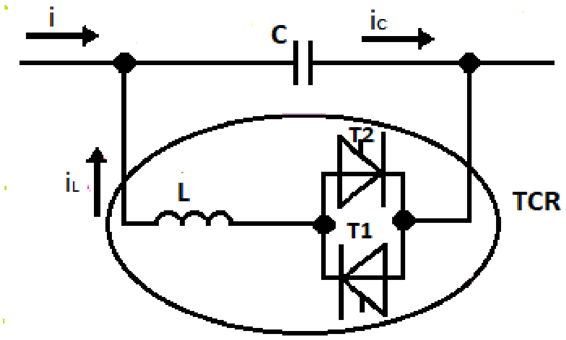

Fig 1. TCSC Controller (Meghwal and Mubeen, 2015).

TCSC is used to control the real power flow or the line current in transmission line by changing its series reactance employing thyristor (Meghwal and Mubeen, 2015). It has various roles in the operation and control of power systems such as scheduling power flow, decreasing unsymmetrical components, reducing net loss, providing voltage support, limiting short-circuit currents, damping power oscillations and enhancing transient stability. Thyristor Controlled Series Capacitor (TCSC) are installed in series with a transmission line, which means that all the equipment has to be installed on a fully insulated platform. Its properties can increase the power lines transmission capacity and power flow control. TCSC is a FACT device available for application in AC line of voltage up to 500kV. As the basic components of the voltage and the current are controlled, the TCSC becomes similar to controllable impedance, which is the result of the parallelization of the equivalent reactance of a component TCR and a capacity.
Let us note by: (De Souza et al,2003)

$$Z_{TCSC} = jX_{TCSC} \tag{1}$$

Equivalent impedance of TCSC

$$Z_{TCR} = jX_{TCR} = \frac{X_L \pi}{2(\pi - x) + sin2\alpha} \tag{2}$$

Equivalent impedance of the TCR

$$Z_C = -jX_C \tag{3}$$

Impedance of the capacity
Since

$$Z_{TCSC} = \frac{Z_C}{Z_{TCR}} = \frac{-jX_C . jX_{TCR}}{-jX_C + jX_{TCR}} \tag{4}$$

$$= j\frac{X_C X_L}{\frac{X_C}{\pi}(2(\pi - \alpha) + sin2\alpha) - X_L} \tag{5}$$

Where

$$X_{TCSC}(\alpha) = \frac{X_C . X_L}{\frac{X_C}{\pi}(2(\pi - \alpha) + sin2\alpha) - X_L} \tag{6}$$

The TCSC placed in series in transmission line makes it possible to control the flow of power and to raise the capacity of transfer of the lines while acting on the reactance X_{TCSC} which varies according to the angle of firing delay thyristor a given by equation (4)

NIGERIAN TRANSMISSION SYSTEM

Currently, the Nigerian transmission system consists of 5650km of 330kV transmission line with a radial system. The power system transmission capabilities inefficiency and its radial transmission nature are parts of the problems that affect the system reliability (Eseosa and Odiase,2012). The length of the transmission line is also another problem facing the system which result in high transmission line losses due to long distances between generating stations and load centre (Ibe et.al, 2013; Sule, 2010). The transmission network is characterized by irregular supply affecting the lives of its citizens (Onohaebi et al, 2007).

Nigeria has more than enough energy sources to meet the power demand. However, only a small percentage of the populance has constant access to power. According to Nigeria power sector review of 2010, only about 45% of the population is connected to the grid. On an average basis, approximately 45% of demand is met. This means that most homes have access to electricity only 60% of the time while some even have power only 30% of the time. Firms and companies also report outages and it is very common for homes and firms to have their own generating units. Aside from the economic implications of these current power problems, there are also environmental and health issues associated with (Ibe et.al,2015).

Currently, the Transmission Company of Nigeria (TCN), projected to have the capacity to deliver about 12,500MW in 2014, has the capacity of delivering 4475.87MW of electricity. Nigeria has a generating capacity of 5,228MW but with peak production of 4500MW against a peak demand forecast of 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 reliability. This goes a long way to tell that the 330Kv transmission systems are not running effectively as expected. Therefore, to maintain and ensure a secure operation of this delicate system, the need for power control cannot be over emphasized.

Reference recommended the incorporation of FACTS devices in the Nigeria power system so as to significantly minimize power losses that result in widespread blackouts. Based on literatures reviewed, little work has been done in incorporating these FACTS devices for improving power system operations of the Nigeria 330kV transmission system

II. MATERIAL AND METHODS

Newton Raphson iterative algorithm was adopted because of its fast convergence and accuracy with a small number of iterations. The load flow result will identify weak buses in the network. Thoseweak bus and lines are considered as possible locations for TCSC device with a view of improving voltages in those buses to acceptable limits.

THE NIGERIAN 330kV, 28-BUS SYSTEM

The Nigerian 330kV, 28-bus system is considered in this work. The single line diagram of the test system is shown in Fig 2. It consists of nine generating stations, fourteen loads' stations and thirty-one transmission lines. The north is connected to the south through one triple circuit lines between Jebba and Osogbo while the West is linked to the East through one transmission line from Osogbo to Benin and one double circuit line from Ikeja to Benin (Adebayo et.al, 2013; Onohaebiand Apeh, 2007).

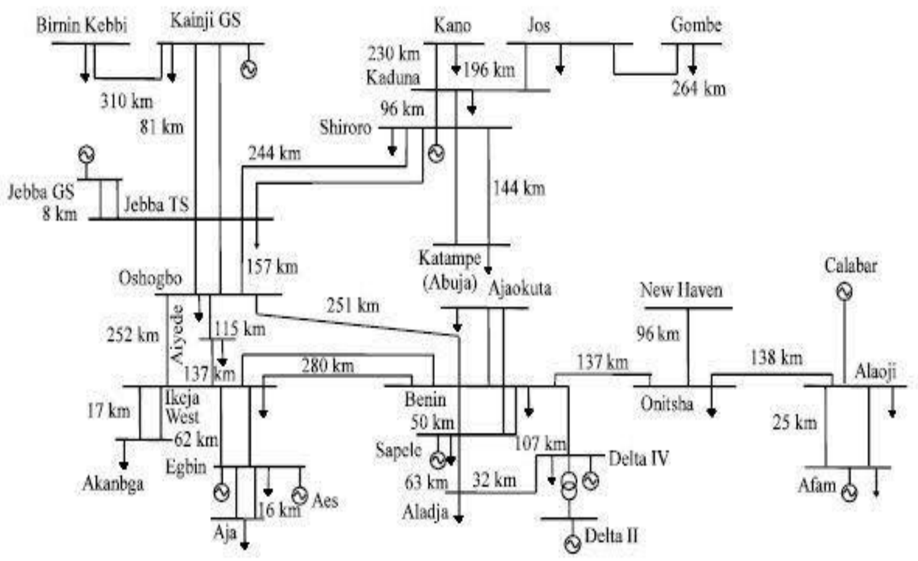

Figure 2: Single line diagram of the Nigeria 28 bus, 330kV transmission grid (Fasina et al, 2020)

III. POWER FLOW ANALYSIS

Power flow analysis is a mathematical approach for determination of various bus voltages, their phase angle, active and reactive power flow through different branches, generators and loads under steady state condition. The power flow analysis is a tool used in power system planning and control and growth planning studies of power system. The objective of power flow analysis is to find; ratings of equipment's, losses in system, voltage profile and angles at bus, loading of electrical equipment.

3.1 Data Collection

The data used for this study were obtained from Power Holding Company of Nigeria (PHCN) and are presented in **Table 1**

Table 1: Line Data of Nigerian 330KV, 28- Bus transmission system (Fasina et al, 2020)

FROM BUS	TO BUS	RESISTANCE (R)PU	REACTANCE (X)PU
3	1	0.0006	0.0044
3	1	0.0006	0.0044
4	5	0.0007	0.0050
4	5	0.0007	0.0050
1	5	0.0023	0.0176
1	5	0.0023	0.0176
5	8	0.0110	0.0828
5	8	0.0110	0.0828
5	9	0.0054	0.0405
5	10	0.0099	0.0745
6	8	0.0077	0.0576
6	8	0.0077	0.0576
2	8	0.0043	0.0317
2	7	0.0012	0.0089
7	24	0.0025	0.0186
8	14	0.0054	0.0405
8	10	0.0098	0.0742
8	24	0.0020	0.0148
8	24	0.0020	0.0148
9	10	0.0045	0.0340
15	21	0.0122	0.0916
15	21	0.0122	0.0916
10	17	0.0061	0.0461
10	17	0.0061	0.0461
10	17	0.0061	0.0461
11	12	0.0010	0.0074
11	12	0.0010	0.0074
12	14	0.0060	0.0455
13	14	0.0036	0.0272
13	14	0.0036	0.0272
16	19	0.0118	0.0887
17	18	0.0002	0.0020
17	18	0.0002	0.0020
17	23	0.0096	0.0721
17	23	0.0096	0.0271
17	21	0.0032	0.0239
17	21	0.0032	0.0239
19	20	0.0081	0.0609
20	22	0.0090	0.0680
20	22	0.0090	0.0680
20	23	0.0038	0.0284
20	23	0.0038	0.0284
23	26	0.0038	0.0284
23	26	0.0038	0.0284
12	25	0.0071	0.0532
12	25	0.0071	0.0532
19	25	0.0059	0.0443
19	25	0.0059	0.0443
25	27	0.0079	0.0591
25	27	0.0079	0.0591
5	28	0.0016	0.0118
5	28	0.0016	0.0118

IV. RESULTS

The result of the power flow analysis carried out in MATLAB software environment is presented in this section. The analysis was based on 28-bus 330kV Nigerian power transmission line used as a case study. The line data for the Nigerian 330kV grid is given in Table 1.The result of the power flow solution for the system under consideration is as presented in Table 2.

Table 2: Power flow solution without TCSC

Bus no	**Bus name**	**Voltage mag**	**Angle degree**
1	Egbin GS	1.040	0.000
2	Delta PS	1.040	11.923
3	Aja	1.035	-0.284
4	Akangba	1.012	0.650
5	Ikeja – west	1.019	1.079
6	Ajaokuta	1.036	6.181
7	Aladja	1.035	10.354
8	Benin	1.028	6.459
9	Ayede	1.010	2.003
10	Oshogbo	1.014	7.760
11	Afam	1.038	10.394
12	Alaoji	1.030	9.787
13	New heaven	0.846	2.513
14	Onitsha	0.856	3.896
15	Birnin Kebbi	1.033	13.853
16	Gombe	0.897	3.376
17	Jebba	1.037	13.397
18	Jebba GS	1.039	13.649
19	Jos	0.895	10.265
20	Kaduna	0.863	6.010
21	Kainji	1.040	16.557
22	Kano	0.863	1.862
23	Shiroro	1.038	8.075
24	Sapele	1.039	7.931
25	Calabar	1.015	14.257
26	Kantape	1.027	6.011
27	Okpai	1.030	26.044
28	AES-GS	1.037	3.253

4.1. POWER FLOW SOLUTION WITH TCSC

The voltage profile for the system shows buses 13 (new heaven), 14 (onitsha), 16 (gombe), 19 (jos), 20 (kaduna) and 22 (kano) to be having low voltages (i.e. below 0.99pu the allowable voltage limit) and thus as to be improved in other to maintain the bus voltage magnitudes at 1.04pu. This was done by incorporating TCSC into the system. The updated voltages are presented in Table 3. It was observed that the voltage of the deficient buses i.e., buses 13 (new heaven), 14 (Onitsha), 16 (Gombe), 19 (Jos), 20 (Kaduna) and 22 (kano) were improved sufficiently enough to maintain the voltage at 1pu.

Table 3: Power flow solution with TCSC

Bus no	**Bus name**	**Voltage mag**	**Angle degree**
1	Egbin GS	1.040	0.000
2	Delta PS	1.040	17.299
3	Aja	1.035	-0.284
4	Akangba	1.012	2.093
5	Ikeja – west	1.019	2.622
6	Ajaokuta	1.036	10.444
7	Aladja	1.035	14.862
8	Benin	1.028	10.720
9	Ayede	1.010	5.978
10	Oshogbo	1.014	11.900
11	Afam	1.038	17.455
12	Alaoji	1.030	16.830
13	New heaven	1.000	9.877

14	Onitsha	1.000	10.972
15	Birnin kebbi	1.033	18.560
16	Gombe	1.000	14.732
17	Jebba	1.037	18.103
18	Jebba GS	1.039	18.357
19	Jos	1.000	17.231
20	Kaduna	1.000	13.685
21	Kainji	1.040	21.265
22	Kano	1.000	9.561
23	Shiroro	1.038	14.162
24	Sapele	1.039	12.213
25	Calabar	1.015	21.239
26	Kantape	1.027	12.098
27	Okpai	1.030	33.014
28	AES-GS	1.037	4.704

V. CONCLUSION

As observed in the results, incorporation of TCSC has helped to improved voltage stability in the system. The power flow analysis of the Nigeria 330kV grid system was done with the incorporation of TCSC into the power flow analysis.The simulations results showed that TCSC provide improvement to the voltage magnitude in the network.Based on the result in this paper, it is strongly recommended that power utilities in Nigeria should consider the integration of TCSC to the power system for voltage improvement and reduction of voltage losses in the network.

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