Nigerian Journal of Technology (NIJOTECH)
Vol. 37, No. 4, October 2018, pp. **1092 – 1098**
Copyright© Faculty of Engineering, University of Nigeria, Nsukka,
Print ISSN: 0331-8443, Electronic ISSN: 2467-8821
www.nijotech.com
http://dx.doi.org/10.4314/njt.v37i4.32

IMPROVING THE TRANSIENT STABILITY OF THE NIGERIA 330KV TRANSMISSION GRID USING THYRISTOR CONTROLLED SERIES COMPENSATOR

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ABSTRACT

This study reveals the transient stability improvement capability of Thyristor Controlled Series Compensation (TCSC) as an effective Flexible AC Transmission System (FACTS) device in damping low frequency oscillations on the Nigeria 330kV transmission system. The study was performed using commercially available MATLAB software. The analysis was carried out by simulating a 3-phase fault on the network in order to determine the Critical Clearing Time (CCT) of the system. In locating the TCSC, the most severely disturbed generator was considered. Simulation results on the Nigeria 330kV transmission system modelled in MATLAB environment reveals appreciable transient stability enhancement of the network.

Keywords: *transient stability, critical clearing time, thyristor-controlled series compensator, 3-phase fault, Nigerian 330kV transmission system*

1. INTRODUCTION

In the last few years, the power system interconnected network has become more complex and difficult to manage due to increase in load demand which has forced electric utilities to either operate the system beyond or close to their thermal stability limit [1]. This development of operating the system close to its limit will definitely have a negative effect on the system security [2]. Security of power system refers to its ability to withstand disturbances without losing synchronism. One of the measures to ascertain system security is the transient stability [3]. Transient stability of a power system is the ability of the power system to still maintain equilibrium after being subjected to disturbance [4]. The robustness of a power system is determined by its critical clearing time (CCT) value. CCT is the fault clearing time for the system to remain stable [5], a larger value of CCT denotes a better secured power system [6].

One of the ways to increase the CCT of a Power System is the use of Flexible AC Transmission Systems (FACTS), which has proven to be cost effective compared to construction of new transmission lines [7]. FACTS devices are power electronic based instruments that has the ability to control the network condition in a very fast manner and this unique ability can be utilized to improve transient stability of a power system [8]. The detailed explanation about FACTS devices can be found in the literature [9-10]. Different FACTS controllers have been proposed for enhancing power system stability which includes Static Var Compensator (SVC), Thyristor Controlled Series Compensator (TCSC), Static Synchronous Series Compensator (SSSC), Static Synchronous Compensator (STATCOM), Unified Power Flow Controller (UPFC), etc. Among all the FACTS families, TCSC is one of the most preferred series compensator in terms of improving transient of power system [11]. The TCSC ability to operate in different modes results in more power transfer, which invariably leads to improvement in system stability [12]. Furthermore, the extensive literature review projects TCSC as the most effective in terms of transient stability enhancement compared to other FACTS devices [13]. TCSC is a series compensator connected in series with the lines to be compensated [14]. It allows continuous and rapid changing of transmission line impedance, thereby improving system stability [15].

The Nigeria 330kV transmission network is be-deviled with series of challenges due to its long radial nature, weak transmission network and overloaded lines [16]. Various studies have been done on the Nigerian 330kV network by different indigenous researchers. In [17], the authors did a performance comparison on the effect

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of Power system stabilizer (PSS) and STATCOM in damping oscillations on the Nigeria 330kV North-Central network. The placement of STATCOM was optimally done using Genetic Algorithm (GA), whereas that of PSS was determined using eigenvalue analysis. The result reveals that STATCOM has a more pronounced positive effect in damping oscillation than PSS. In [18], the authors explored the use of TCSC in reducing real power losses of the Nigeria 330kV transmission grid. GA optimization technique was used to optimally locate the TCSC on the Nigeria 330kV grid. The result obtained shows a reduction of active power losses from the initial 2.1% to 1.5%. The authors in [19] considered the use of Interline Power Flow Controller (IPFC) in improving the voltage profile of weak buses in the Nigeria 330kV network. GA optimization technique was used for optimal placement of the IPFC. Their result reveals the importance of the use of FACTS devices in the Nigerian 330kV transmission grid. In [20], the authors compared the use of STATCOM and SSSC for voltage profile enhancement and loss reduction on the Nigeria 330kV transmission network. The result obtained from the incorporation of these devices shows that the voltage magnitude of the buses was improved to the satisfactory voltage magnitude (1.05pu-0.95pu), while the real and reactive power losses were reduced by 0.171% and 1.009% when STATCOM was incorporated, 1.078% and 10.33% with SSSC. Most of the studies carried out on the Nigeria 330kV transmission network were majorly focused on either voltage profile improvement or loss reduction. This paper is aimed at investigating the effect of TCSC on transient stability of the Nigerian 330kV transmission network using MATLAB/SIMULINK Software.

2. STRUCTURE OF THE NIGERIAN 330kV TRANSMISSION NETWORK

Figure 1 depicts the single line diagram of the Nigerian 330kV Transmission network used in this study. It consists of 11 generating stations, 21 load buses, 36 transmission lines and 32 buses [21]. The total installed capacity is approximately 5,000MW with 5,524km lines.

Table 1: Nigerian 330-kV Transmission Line Parameters

S/N	Transmission line		Length	Impedance		Shunt Admittance
	From	To	L(km)	Resistance (Rpu)	Inductance (Xpu)	1/2 Bpu (S)
1	Egbin G.S	Ikeja West	62	0.001122	0.008625	0.064345
2	Egbin G.S	Aja	14	0.000253	0.001948	0.014529
3	Benin	Ikeja West	280	0.005065	0.038953	0.290589
4	Benin	Omotosho G.S	51	0.001826	0.015501	0.096916
5	Benin	Oshogbo	251	0.008989	0.076291	0.476977
6	Benin	Ajaokuta	195	0.003492	0.029635	0.18528
7	Benin	Onitsha	137	0.002453	0.02082	0.130171
8	Benin	Sapele G.S	50	0.000904	0.006956	0.051891
9	Benin	Delta G.S	41	0.001468	0.012462	0.077913
10	Ikeja West	Akangba	17	0.000304	0.002584	0.016`53
11	Ikeja West	Sakete	70	0.002507	0.021276	0.133021
12	Ikeja West	Olorunshogo G.S	30	0.001074	0.009118	0.057009
13	Ikeja West	Omotosho G.S	200	0.007163	0.06079	0.380061
14	Ikeja West	Oshogbo	250	0.008953	0.075987	0.475077
15	Aiyede	Olorunshogo G.S	60	0.002149	0.018237	0.114018
16	Aiyede	Oshogbo	115	0.004118	0.034954	0.218535
17	Oshogbo	Ganmo	75	0.002686	0.022796	0.142523
18	Oshogbo	Jebba T.S	157	0.002811	0.02386	0.149174
19	Ganmo	Jebba T.S	80	0.002865	0.024316	0.152025
20	Shiroro	Jebba T.S	244	0.004369	0.037082	0.231837
21	Shiroro	Kaduna	96	0.001719	0.01459	0.091215
22	Shiroro	Katampe	218	0.003944	0.030328	0.226244
23	Jebba T.S	Jebba G.S	8	0.000145	0.001113	0.008303
24	Jebba T.S	Kainji G.S	81	0.00145	0.01231	0.076962
25	Birnin Kebbi	Kainji G.S	310	0.005551	0.047112	0.589095
26	Kano	Kaduna	230	0.004118	0.034954	0.43707

S/N	Transmission line		Length	Impedance		Shunt Admittance
	From	To	L(km)	Resistance (Rpu)	Inductance (Xpu)	1/2 Bpu (S)
27	Kaduna	Jos	196	0.00351	0.029787	0.37246
28	Jos	Gombe	264	0.004727	0.040121	0.501681
29	Gombe	Yola	240	0.004298	0.036474	0.456074
30	Ajaokuta	Geregu G.S	1	0.000018	0.000139	0.001038
31	Onitsha	Alaoji	138	0.004942	0.041945	0.262242
32	Onitsha	New Haven	96	0.003438	0.029179	0.182429
33	Onitsha	Okpai G.S	60	0.001085	0.008347	0.062269
34	Alaoji	Afam G.S	25	0.000452	0.003478	0.025945
35	Sapele G.S	Aladja	63	0.002256	0.019149	0.119719
36	Delta G.S	Aladja	32	0.001146	0.009726	0.06081

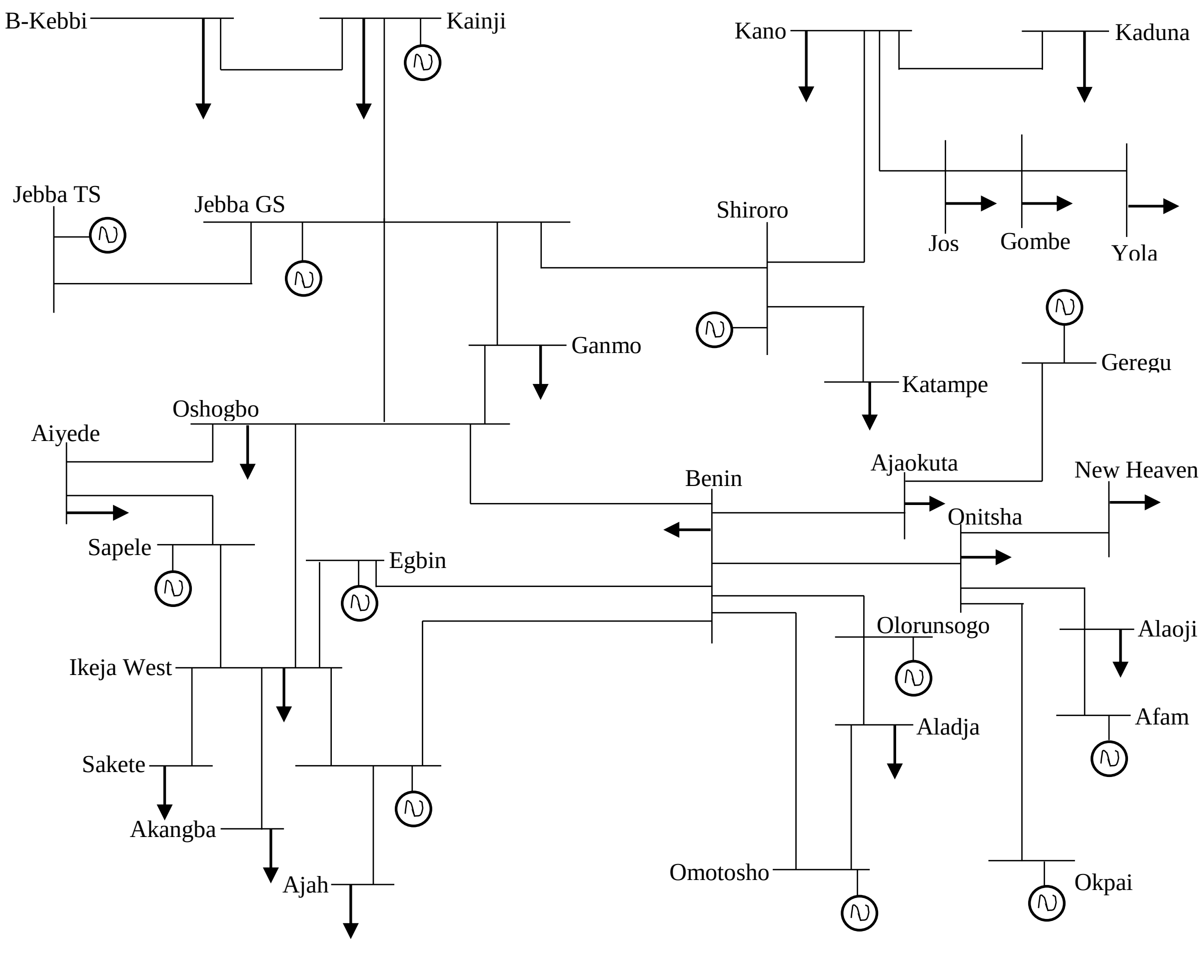

Fig 1: Single Line Diagram of the Nigeria 330-kV transmission [21]

3. MATHEMATICAL MODELLING

3.1 Multi-Machine Modelling of Power System

The rotor dynamics representing swing equation is given by equation (1) [22].

$$M_k \frac{d^2\delta_k}{dt^2} = P_{mi} - P_{ei} \qquad k = 1, \ldots n \qquad (1)$$

where, M = angular momentum (J-sec/rad); P_m= shaft power input (W); P_e= electrical power output (W); δ= angular displacement (rad). The electrical Power output of each generator is given by [23].

$$P_{ek} = E_k^2 Y_{kk} \cos\theta_{kk} + \sum_{k=1}^{m} |E_k||E_j||Y_{kj}| Cos(\theta_{kj} - \delta_k + \delta_j) \quad (2)$$

The rotor dynamics representing the swing equation of generator k is given by

$$\frac{H_k}{\pi f_o} \frac{d^2\delta_k}{dt^2} = P_{mk} - P_{ek} \qquad (3)$$

Therefore, the swing equation for during-fault and post-fault are expressed by equations (4) and (5) respectively.

$$\frac{H_k}{\pi f_o}\frac{d^2\delta_k}{dt^2} = P_{mk} - P_{ek(during-fault)} \tag{4}$$

$$\frac{H_k}{\pi f_o}\frac{d^2\delta_k}{dt^2} = P_{mk} - P_{ek(post-fault)} \tag{5}$$

Table 1: Impedance characteristics of TCSC

Range of firing angle	Operating region
$90^o \le \alpha \le \alpha_{Llim}$	Inductive region
$\alpha_{Llim} \le \alpha \le \alpha_{c\ lim}$	Resonance region
$\alpha_{clim} \le \alpha \le 180^o$	Capacitive region

Table 2: Bus nomenclature

Bus No	*Bus Name*	*Bus No*	*Bus Name*
1	Egbin G.S	17	Kaduna
2	Benin	18	Jos
3	Ikeja West	19	Gombe
4	Akangba	20	Yola
5	Sakete	21	Katampe
6	Aiyede	22	Ajaokuta
7	Olorunshogo G.S	23	Geregu G.S
8	Omotosho G.S	24	Onitsha
9	Oshogbo	25	Alaoji
10	Ganmo	26	New Haven
11	Shiroro G.S	27	Sapele G.s
12	Jebba T.S	28	Delta G.S
13	Jebba G.S	29	Okpai G.S
14	Birnin Kebbi	30	Afam G.S
15	Kainji G.S	31	Aja
16	Kano	32	Aladja

3.2 Modelling TCSC

The TCSC is a series type reactive power compensator, which consists of a series capacitor bank, shunted by a thyristor-controlled reactor. It is connected in series with the transmission line where it is located [24]. Figure 2 depicts the single line diagram of a TCSC.

TCSC can be controlled by changing the firing angle (α) of the thyristor which modifies the frequency of the capacitor [26]. Equation (6) shows the relationship between the firing angle of the thyristor (α) and the reactance (X_{TCSC}):

$$X_{TCSC}^{(\alpha)} = X_c - \frac{X_c^2}{(X_c - X_p)} \times \frac{\sigma + Sin\sigma}{\pi} + \frac{4X_c^2}{(X_c - X_p)} \times \frac{Cos^2(\sigma/2)}{(K^2-1)} \times \frac{(K\cdot\tan(K\sigma/2) - \tan(\sigma/2)}{\pi} \tag{6}$$

where, X_C = Capacitance of the capacitor; X_P = Inductive reactance of the reactor; σ = 2(π-α) = Conduction angle of TCSC controller; K= $\sqrt{\frac{X_c}{X_p}}$ = Compensation ratio.

The TCSC is operated here in the capacitive mode for transient stability enhancement [27]. Figure 3 and Table 1 shows the impedance characteristics of TCSC.

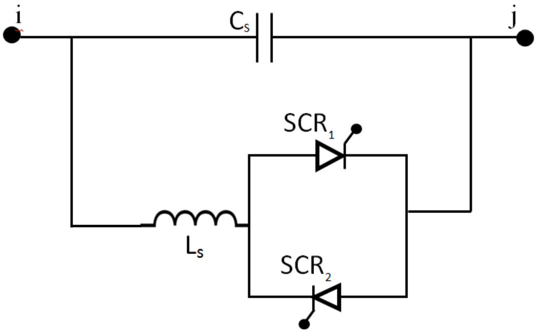

Fig 2: Basic Circuit diagram of TCSC [25]

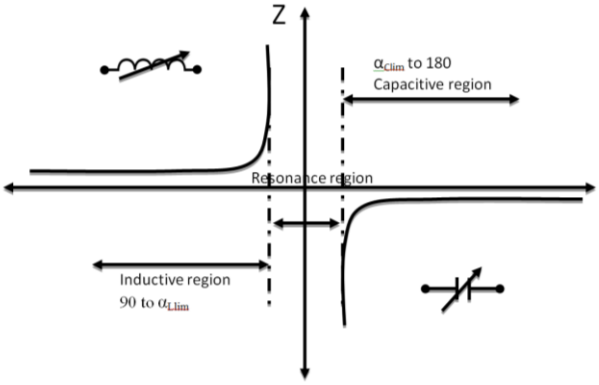

Fig 3: Impedance characteristic of TCSC [27]

Consequently, to avoid over compensation of transmission line, the working range of X_{TCSC} is chosen from -70% X_{line} to 20% X_{line} [28].

$$X_{TCSC} = r_{TCSC} \times X_{line} \tag{7}$$

$$X_{line(new)} = X_{line(old)} + X_{TCSC} \tag{8}$$

With -70% compensation of line ($X_{line(old)}$)), i.e. r_{TCSC} = 0.0024346pu; $X_{line(old)}$ = 0.003478pu and $X_{line(new)}$ = 0.0010434pu; where, r_{TCSC} = Compensation Factor; $X_{line(old)}$ = line reactance before compensation; $X_{line(new)}$ = line reactance after compensation.

In this work, the location of TCSC was chosen such that it will improve the transient stability of the most severely disturbed generator with the line (Aiyede-Olorunshogo) close to the fault removed to quickly clear the fault. Details of location of TCSC and severely disturbed generator can be found in [21, 29].

3. RESULTS AND DISCUSSION

To assess the effectiveness of the TCSC, simulation was done using the most severe fault (3-phase fault) and the most severely disturbed generator (Afam generating station) for transient stability enhancement. The dynamic responses of the generator are shown in Figures 4 – 9 when a 3-phase fault is applied at Aiyede bus.

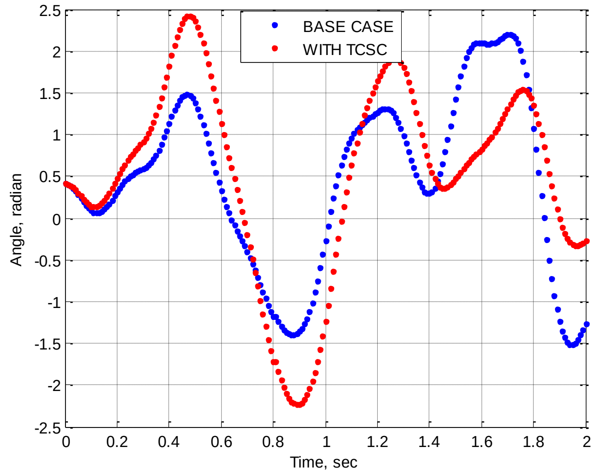

Fig 4 : Swing curve of generator at Afam with Line 6-7 removed (CCT = 800ms)

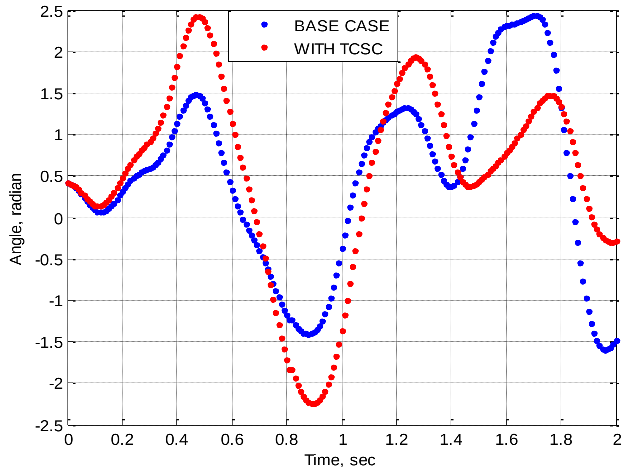

Fig 5 : Swing curve of generator at Afam with Line 6-7 removed (CCT = 810ms)

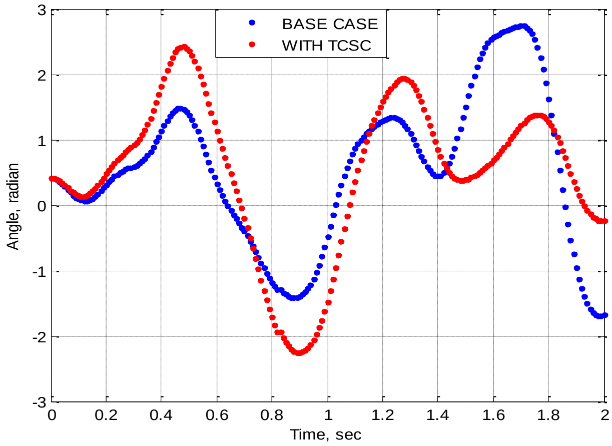

Fig 6 : Swing curve of generator at Afam with Line 6-7 removed (CCT = 820ms)

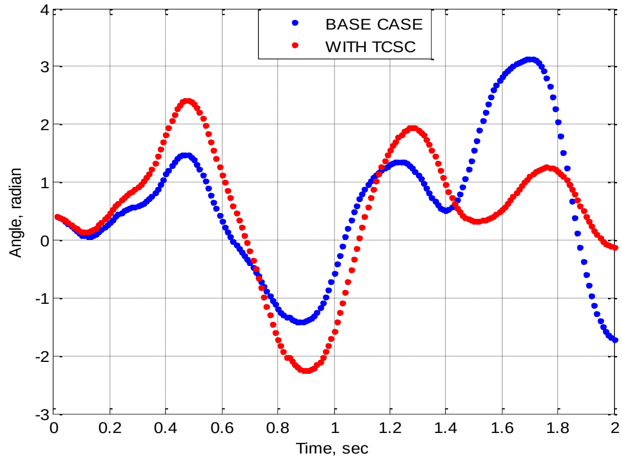

Fig 7 : Swing curve of generator at Afam with Line 6-7 removed (CCT = 830ms)

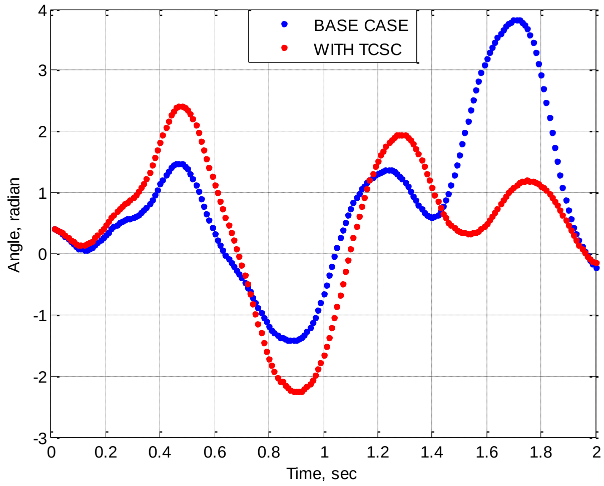

Fig 8 : Swing curve of generator at Afam with Line 6-7 removed (CCT = 840ms)

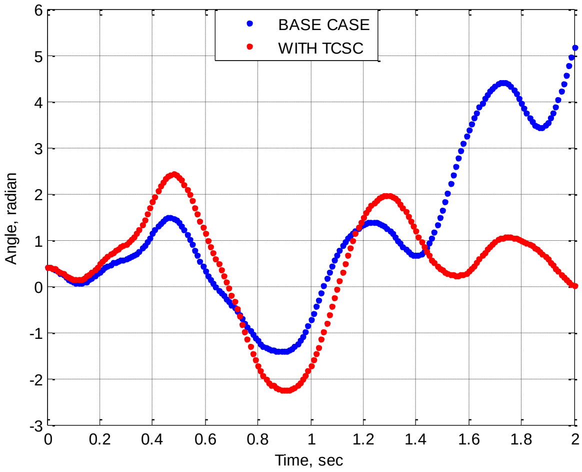

Fig 9 : Swing curve of generator at Afam with Line 6-7 removed (CCT = 850ms)

At a CCT of 800ms to 840ms (Figures 4 to 8), the dynamic responses of the generator with and without TCSC were stable, i.e. without losing synchronism. When the CCT was increased to 850ms, the swing curve without TCSC loses synchronism, while the one with TCSC still remained stable. Hence, the dynamic response of the generator at a CCT of 850ms clearly depicts that the proposed TCSC controller can damp power system oscillations better than a system without TCSC.

4. CONCLUSION

In this paper, investigation on the use of TCSC in enhancing transient stability of the Nigeria 330kV transmission network was carried out. The swing curve for the network was obtained, from which the transient stability analysis was done. The result shows that with a 3-phase fault on Aiyede bus, the generating station at Afam loses synchronism at a CCT of 850ms. Hence, for the system to remain stable, the fault must be cleared at a CCT of 840ms. But with the incorporation of TCSC into the network, the system was able to withstand a 3-phase fault even beyond a CCT of 850ms. The result therefore signifies the effectiveness of TCSC controller in improving the CCT of the System without losing synchronism when a 3-phase fault occurs.

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