FOREX Publication
Open Access | Rapid and quality publishing

International Journal of
Electrical and Electronics Research (IJEER)
Case Study | Volume 13, Issue 2 | Pages 337-345| e-ISSN: 2347-470X

Allocate Compatible Locations of TCSC in Baghdad City: A Case Study

Nadheer A. Shalash[1*], Yasar N. Lafta[2], and Aqeel S. Jaber[3]

*[*1]Department of Electrical Engineering, University of Technology, Baghdad, Iraq; 30256@uotechnology.edu.iq*
[2]Department of Mechatronics engineering, Al- Khwarizmi College of Engineering, University of Baghdad, Baghdad, Iraq; yasar@kecbu.uobaghdad.edu.iq
[3]Independent researcher, Halsinki, Finland; aqe77el@yahoo.com

*Correspondence: *30256@uotechnology.edu.iq*

ABSTRACT- Power systems are generally required to operate near their maximum capacity. Thus, there is an increased focus on improving real power system capacities through the installation of novel devices, including the Flexible AC Transmission Systems (FACTs). This paper discusses the optimal incorporation of thyristor-controlled series capacitor (TCSC) in the 400 kV Baghdad grid of the Iraqi network as a suggested method to control the power transfer of a transmission line (TL) and suppress Sub-Synchronous Resonance (SSR). The MATLAB 2019 simulation is executed utilizing the phase angle as an index to select an appropriate TCSC location. Nine places were chosen based on eigenvalues, and three suitable places were determined, where $0.5< X_c/X_l <2$. The Baghdad city 400 kV is examined by applying PSS/E 34 software with the series TCSC connected at each of the three selected locations, thus three distinct cases are studied. The results reveal that the TCSC connection between 16428 4BGE and 16419 4BGS, where the value of $(X_c/X_l) =1.46$, was the optimal place where the series TCSC connection is conducted. From the results, it can be concluded that the least X_c/X_l value indicates the better the control of frequency and voltage, as well as the power losses in TLs reduction are higher.

Keywords: FACTS, TCSC, SSR, TCR, series compensation.

ARTICLE INFORMATION
Author(s): Nadheer A. Shalash, Yasar N. Lafta, and Aqeel S. Jaber;
Received: 21/03/2025; **Accepted**: 22/06/2025; **Published**: 30/06/2025;
E- ISSN: 2347-470X;
Paper Id: IJEER 2103-07;
Citation: 10.37391/ijeer.130218
Webpage-link:
https://ijeer.forexjournal.co.in/archive/volume-13/ijeer-130218.html

crossref member
CROSSREF.ORG
THE CITATION LINKING BACKBONE

Publisher's Note: FOREX Publication stays neutral with regard to jurisdictional claims in Published maps and institutional affiliations.

1. INTRODUCTION

The huge AC Networks involve long power transmission lines (TLs). Thus, the Major anticipated technical issues are the heavily loaded system and stability problems. Uncontrolled power flow in the transmission lines and transformers can cause network failures, due to cascading outages or angular and voltage instability. Transmission system congestion is defined as the state in which additional power is supplied or flows through TLs and transformers, exceeding parallel or series capacitor units. Every unit is 17.5 kV, 405 kVAr, and at a frequency of 60 Hz.

Since 1993, in Kayenta, Arizona, United States, the TCSC has been utilized as suggested by the Siemens Company, each containing two standard Series Capacitor (SC) banks rated 165 MVAr. Furthermore, following its operation on the Slatt-Buckley in 1995, the different TCSC modules were integrated into the 500 kV line of the Northwestern Oregon system. It should be noted that the Slatt TCSC rate is 202 MV Ar. The 420

kV system extends between northern Sweden and the center of eight transmission lines, each integrated with 4800 MV Ar (SC) [1, 2].

High reactive power usage through a heavily loaded transmission line results in voltage drops in the system and restricts the production of real power. Voltage and reactive power (VAr) constraints impact system performance. Adding series capacitors injects reactive power, enhancing the real power transfer through a huge transmission system. In extra-high voltage lines, series capacitors are cost-effective approach for enhancing power flow transfer [1- 3].

The FACTS can significantly enhance system performance by regulating the network's load flow, not involving generation rescheduling or topological modifications [4, 5]. This can be achieved by controllable components such as an SC, connected in parallel to a Thyristor-Controlled Reactor (TCR). During the period 1980 - 1990, the TCSC scheme was developed as a technique to regulate power flow. TCSC has been utilized in projects and even in interconnected systems to enhance stability and quench oscillations regardless of system conditions or complexity [6, 7].

SSR suppression is considered a surplus benefit of FACTS that might be readily integrated into the power system to fulfill additional goals, such as improving the TL capability of transferring power. Generally, FACTS could offer an efficient

International Journal of
Electrical and Electronics Research (IJEER)
Case Study | Volume 13, Issue 2 | Pages 337-345| e-ISSN: 2347-470X

approach to improve SSR in which TCSC has been applied to achieve this goal [8- 11].

In online systems, the current important issue is voltage stability and enhancing the loadability of transmission lines, which affects power system performance. One of the methods used to solve these issues is the series connection of FACTs to the transmission line [12, 13].

In Southeast America, Hitachi Energy installed an SC at the Kanawha River in 1991 to implement the required compensation of a 345 kV main TL for ensuring an adequate, stable boundary throughout the 765 kV system during outages. Every segment is composed of several controls, resulting in a steady, effective, and consistent performance of the power system while enhancing the TLs network [14, 15].

The TCSC improves transient stability and dynamic performance, providing a positive damping effect. It can quickly and smoothly change its reactance by changing the ignition angle of its thyristor. However, the mitigation of SSR in previous studies was achieved using FACTs modules that are integrated with small signal stability; in this paper, it is used under the condition of $0.5 < X_c/X_l < 2$.

The issue of SSR has restricted system planners from using greater routes for series compensation. The use of thyristor control is a promising method as it offers compensation methods utilizing series capacitors in long lines. In the Iraqi electric grid, FACTs are not used to solve the SSR issue and control transferred power. The current study aims to evaluate a technique that examines several sites of TCSC integrated into the Baghdad network. The evaluation is based on the load flow performance and the ratio of the TCSC's capacitor impedance to the inductive line. The effect of a series-connected TCSC in damping SSR is evaluated by varying its operating conditions, employing these cases on the Baghdad 400 kV ring in the Iraqi power grid.

Section 2 describes the methodology; *Section 3* describes the case study. *Section 4* presents the results, whereas *Section 5* discusses the obtained results, elaborating on the optimum TCSC position. Finally, *Section 6* concludes the study's findings and elaborates on potential approaches.

2. METHODOLOGY

The TCSC facilitates a variable series reactance that offers stable control of load flow on the TL across broader categories. TCSC properties provide fast and constant series compensation control of the TL; therefore, effectively regulate the load flow on it and thereby improve the ability of the transmission system to transfer power, besides other TCSC several roles [8, 16, 17].

Equations (1) & (2) clarify the relation of the real and imaginary power with the (δ) voltage phase angle between bus *a*, and bus *b* [11, 18, and 19]:

$$P_{ab} = \frac{V_a V_b}{X_{eq}} sin\delta \qquad (1)$$

$$Q_{ab} = \frac{V_a^2}{X_{eq}} - \frac{V_a V_b}{X_{eq}} cos\,\delta \qquad (2)$$

With
X_{eq} = TL inductive reactance X_l - TCSC controlled reactance X_{SC} *i.e.*

$$X_{eq} = X_l - X_{sc} \qquad (3)$$

Note that the X_{SC} value is affected by α. The reactance reduction enhances the transmitted active power.

Thus, to achieve the installation of TCSC amongst a, and b, the power flow *via* TCSC is supplemented to the nodal powers at bus a, as given in *equation (4)*;

$$P_a^{new} = P_a + P_{ab} \qquad (4)$$

The TCSC device at firing angle α acts as a parallel tuned LC circuit, and its reactance is depicted in *equation (5)*:

$$X_{Tcsc}(\alpha) = j\frac{X_{SC}X_L(\alpha)}{X_{SC} - X_L(\alpha)} \qquad (5)$$

Where in real circuits, $X_{L(\alpha)}$ as related to α, is the inductive reactance of the TCSC, is expressed in equation 6 [19, 20]:

$$X_L(\alpha) = X_L\frac{\pi}{\pi - 2\alpha - sin2\alpha} \qquad (6)$$

In the case of the TCSC controlled inductive reactance $X_{L(\alpha)}$ differs from the optimum value (infinite) to the lowest one (ωL), at that time TCSC rises its minimal capacitive impedance $X_{scmin} = 1/\omega C$ up to a value that achieves parallel resonance; i.e., $X_{sc} = X_{L(\alpha)}$; subsequently, $X_{sc} = \infty$.

When $X_{L(\alpha)}$ begins declining, the reactance $X_{TCSC(\alpha)}$ turns inductive achieving the minimal score for α= 0.

It is also evident that the TCSC function is in an inductive region that is accomplished by restricting the switching angle between 90° and 140°, in which a value less than 90° results in a decline of the value of the delivered power.

Sub-synchronous resonance develops in a power generator to transfer energy through the power system. The resonance frequency f_{ser} of the TCSC compensation in TL can be expressed as follows:

$$f_{ser} = f\sqrt{X_{CS}/X_t} \qquad (7)$$

Where f is the nominal frequency.

TCSC is applied when rapid impedance control of the transmission line is needed to mitigate power oscillations or regulate the power flow. Subsequently, when the compensated TL is oscillating, it remains within the sub-synchronous region, which under particular incidents leads to SSR states. The eigenvalues $\lambda_i = \sigma_i \pm w_i$ of the total system are determined, and then the degree of the impact of any state at any mode can be found, representing the participation factor. Furthermore, it is necessary to identify the boost factor K_B;

Open Access | Rapid and quality publishing

International Journal of
Electrical and Electronics Research (IJEER)
Case Study | Volume 13, Issue 2 | Pages 337-345 | e-ISSN: 2347-470X

$$K_B = \frac{X_{SC}}{X_C} \tag{8}$$

The function of SSR damping is combined *via* a stable current control, demonstrating that within the fundamental frequency, the TCSC reactance is purely capacitive, enhancing the transmission system's ability to transfer power. In addition, the parameter λ is expressed as the resonance frequency divided by the network frequency, as described below;

$$\lambda = \frac{W_r}{W_0} = \sqrt{-X_C/X_L} \tag{9}$$

The reactance X_{TCSC} could be patterned as follows:

$$X_{TCSC} = X_C\left[1 - \frac{K}{K^2-1}\cdot\frac{\sigma+\sin\sigma}{\pi} + \frac{4\cdot K^2\cdot\cos^2(\sigma/2)}{\pi(K^2-1)^2}\cdot \left(K\tan({}^{k\sigma}/_2) - \tan(\sigma/2)\right)\right] \tag{10}$$

As:

$\sigma = 2(\pi-\alpha)$, and $k = \sqrt{X_C/X_L}$

Where:

α: Firing angle
б: Conduction angle.
K: TCSC ratio

The TCSC can be constantly controlled by altering the ignition angle to act in a predetermined capacitive or inductive fashion. Consequently, this prevents resonance at steady state.

Assume that TCSC can be linked in the middle of bus *a*, and bus *b* as illustrated in *fig. 1*, and it is anticipated that the controller is lossless. For long TLs, decreasing transmission angle is achieved by applying series compensation, therefore promoting improvement in the stability [31]. The following equations describe fundamental parameters of the series compensation device.

$$P_a = V_a V_b B_{aa}\sin(\theta_a - \theta_b) \tag{11}$$

$$Q_a = V_a^2 B_{aa} - V_a V_b B_{ab}\cos(\theta_a - \theta_b) \tag{12}$$

$$P_b = V_a V_b B_{bb}\, sin(\theta_b - \theta_a) \tag{13}$$

$$Q_b = V_b^2 B_{bb} - V_a V_b B_{ba}\, cos(\theta_b - \theta_a) \tag{14}$$

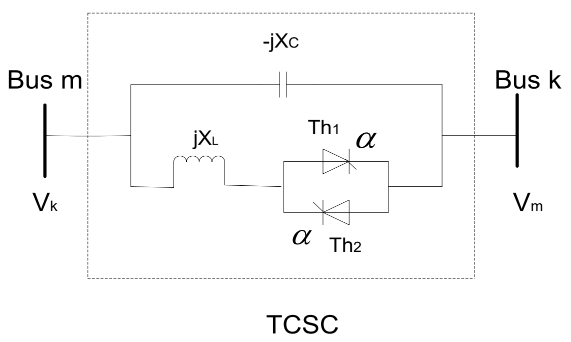

Figure 1. The assumed series compensation using TCSC

$$B_{TCSC} = -\frac{\pi(K^4-2K^2+1)\cos K(\pi-\alpha)}{H} \tag{15}$$

Where:

$H = X_C(\pi K^4\cos K(\pi-\alpha) - \pi\cos K(\pi-\alpha) - 2K^4\alpha\cos K(\pi-\alpha) + 2\alpha K^2\ \cos K(\pi-\alpha) - K^4\sin 2\alpha\cos K(\pi-\alpha) + K^2\sin 2\alpha\cos K(\pi-\alpha) - 4K^3\cos^2\alpha\sin K(\pi-\alpha) - 4K^2\cos\alpha\sin\alpha\cos K(\pi-\alpha))$

Equation (16) is retrieved from *equation (13)*. There are several methods to adjust the TCSC by controlling: power, current, transmission angle, and reactance. The current study applied the power control strategy.

$$\begin{bmatrix} I_a \\ I_b \end{bmatrix} = \begin{bmatrix} jB_{aa} & jB_{ab} \\ jB_{ba} & jB_{bb} \end{bmatrix}\begin{bmatrix} V_a \\ V_b \end{bmatrix} \tag{16}$$

Where:

$$B_{aa} = B_{bb} = -\frac{1}{X_{SC}}$$

$$B_{ab} = B_{ba} = \frac{1}{X_{SC}}$$

3. CASE STUDY

The Baghdad 400kV ring grid contains substations that supply the 132kV bulk supply points within the 400kV network. The high 132kV mesh connections reduce the impedance of that network. The Eigenvalues were calculated in three stages, based on the results of values of (xc/xl) for lines and bus locations with the TCSC controller. The proposed system has more than nine Eigenvalues for the base case. Only three of them were selected as the studied cases according to the largest participation factors, and when $0.5 < X_c/X_l < 2$, these are defined as swing modes. Voltage and power control via line impedance control is a vital method, which is applied by the series connection of TCSC to the 400kV grid, exploring 3 cases of connection to adopt the optimal TCSC position. *Fig. 2* shows the case study of the Baghdad 400kV ring grid.

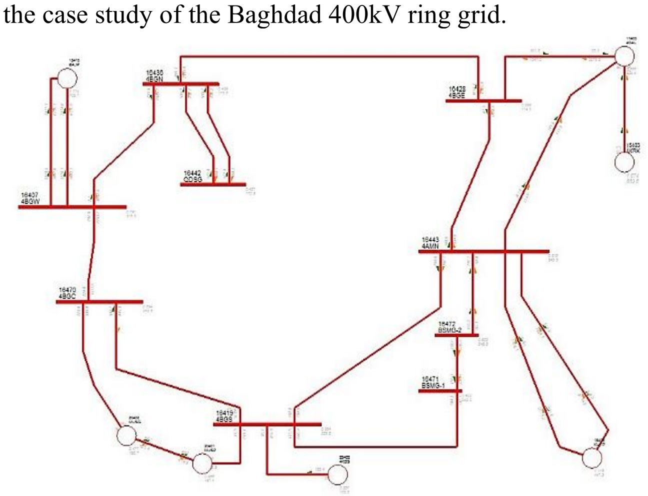

Figure 2. Baghdad 400kV ring grid [37]

The Eigenvalues, damping ratio, frequency, and time constant for the 3 studied places are depicted in *table 1*.

Table 1. Parameters between buses before adding TCSC

Place	Pole	Damping	Frequency	Time Constant
4BGW - AMN.	-5.16e-03 + 1.21e-02i	3.91e-01	1.32e-02	3.94e+02
4BGC - 4BGE.	-6.64e+00 + 5.55e+00i	2.83e-01	5.79e+00	6.11e-01
4BGE - 4BGS.	1.19e+01 + 2.16e+01i	4.83e-01	2.46e+01	8.40e-02

4. RESULTS

The incorporated TCSC is arranged according to the configurations of the TL and SSR problems, with a rated voltage of 400 kV, reactive power of 250 MVAr, a rated current of 1800 A, impedance of 150 ohms, and converter capacitor of 33 p.u. This article documents the mitigation of the SSR arising because of series compensation. The damping, frequency, time constant, and participation factors are observed for each case of the proposed model designed for Baghdad city, 400 kV in the Iraqi network. This analysis is done by applying PSS/E 34 and MATLAB 2019 software. To determine the optimal TCSC connection position, the highest damping value among the 3 cases is identified as the optimal case. However, participation factors were found for all cases.

4.1. Case 1

The TCSC is connected between the buses Al-Amine (AMN) and Baghdad west (4BGW) as shown in *fig. 3*.

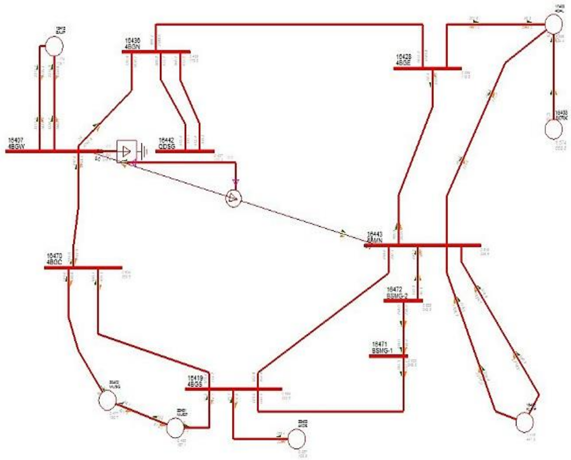

Figure 3. TCSC connection between 16407 4BGW and 164434AMN.

For this case, the value of (X_c/X_l) =1.67 between bus (16407 4BGW) and (164434AMN), and connecting TCSC leads to a significant improvement in results, as illustrated in *table 2*.

Table 2. Parameters influenced by the TCSC connected between 4BGW and AMN

Pole	Damping	Frequency	Time Constant	Participation Factors
-1.44e+00± 2.34e+00i	5.25e-01	2.75e+00	6.92e-01	0.9334
-5.11e+00+ 7.99e+00i	5.39e-01	9.48e+00	1.96e-01	0.5039
-4.51e+00+ 7.34e+00i	5.24e-01	8.62e+00	2.22e-01	0.4126
-2.62e+01+ 3.55e+01i	5.93e-01	4.41e+01	3.82e-02	0.2122
-5.25e+00+ 7.51e+00i	5.73e-01	9.16e+00	1.91e-01	0.1419
-6.28e+00+ 9.84e+00i	5.37e-01	1.18e+01	1.57e-01	0.0466
-3.62e+00+ 6.32e+00i	4.97e-01	7.28e+00	2.76e-01	0.0389
-1.28e+01+ 2.31e+01i	4.85e-01	2.65e+01	7.79e-02	0.0224
-2.53e+01+ 4.49e+01i	4.91e-01	5.16e+01	3.95e-02	0.0176

4.2. Case 2

The TCSC is connected between the buses Baghdad East (4BGE) and Baghdad Center (4BGC) as shown in *fig. 4*.

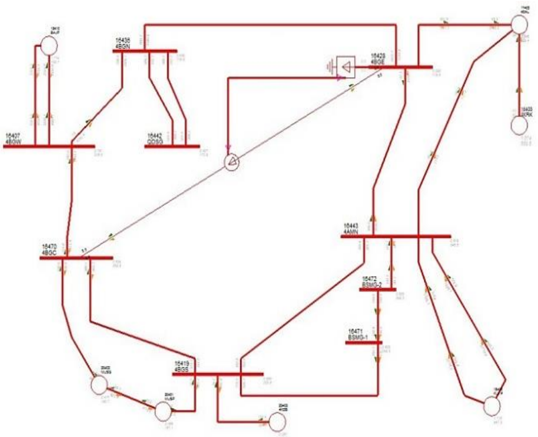

Figure 4. TCSC connection between 16470 4BGC and 16428 4BGE.

In this case, the value of (X_c/X_l) is 1.53 between the buses (16470 4BGC) and (16428 4BGE). The TCSC connection leads to significant improvements in results, as illustrated in *table 3.*

Table 3. Parameters influenced by the TCSC connected between 4BGC and 4BGE

Pole	Damping	Frequency	Time Constant	Participation Factors
-3.13e+00 + 7.23e+00i	3.98e-01	7.88e+00	3.19e-01	0.9293
-4.30e+00 - 7.77e+00i	4.84e-01	8.88e+00	2.32e-01	0.4924
-4.98e+00 + 1.30e+01i	3.58e-01	1.39e+01	2.01e-01	0.4212
-7.33e+00 + 1.88e+01i	3.62e-01	2.03e+01	1.38e-01	0.2115
-1.61e+01 + 3.07e+01i	4.63e-01	3.47e+01	6.23e-02	0.1403
-1.82e+01 + 3.67e+01i	4.43e-01	4.10e+01	5.51e-02	0.0486
-1.55e+01 + 3.58e+01i	3.98e-01	3.90e+01	6.43e-02	0.0371
-1.46e+01 + 3.49e+01i	3.85e-01	3.78e+01	6.86e-02	0.0210
-3.23e+00 + 6.72e+00i	4.33e-01	7.46e+00	3.10e-01	0.0132

4.3. Case 3

The TCSC is connected between the buses (4BGE) and Baghdad south (4BGS) as shown in *fig. 5*.

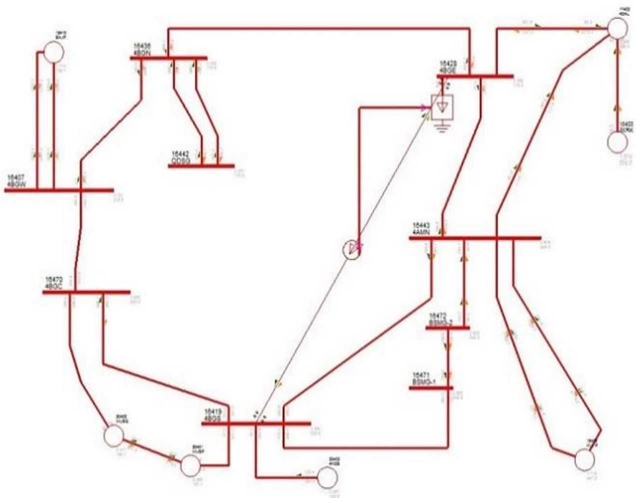

Figure 5. TCSC connection between 16428 4BGE and 16419 4BGS.

In this case, the value of (X_c/X_l) =1.46 between the buses (16428 4BGE) and (16419 4BGS). Connection of the TCSC led to significant system enhancement, as illustrated in *table 4*.

Table 4. Parameters influenced by the TCSC connected between 4BGE and 4BGS

Pole	Damping	Frequency	Time Constant	Participation Factors
-6.36e+00 + 7.56e+00i	6.44e-01	9.88e+00	1.57e-01	0.9477
-7.50e+00 - 7.88e+00i	6.89e-01	1.09e+01	1.33e-01	0.5841
-9.33e+00 + 8.26e+00i	7.49e-01	1.24e+01	1.06e-01	0.4131
-6.25e+00 + 7.43e+00i	6.44e-01	9.71e+00	1.60e-01	0.2341
-6.84e+00 + 7.19e+00i	6.89e-01	9.92e+00	1.46e-01	0.1502
-5.91e+00 + 5.54e+00i	7.30e-01	8.10e+00	1.69e-01	0.0520
-7.40e+00 + 8.49e+00i	6.56e-01	1.14e+01	1.34e-01	0.0393
-6.37e+00 + 7.82e+00i	6.32e-01	1.01e+01	1.57e-01	0.0256
-4.24e+01 - 3.76e+01i	7.49e-01	5.67e+01	2.36e-02	0.0188

5. DISCUSSION

The above results can be compared using various parameters to determine the optimal design for improving network performance.

Using a base voltage of 400 kV, optimal power flow is converged within 100 iterations. With a total absolute system mismatch of 0.0298 MVA, for TCSC firing-angle ranges 148 - 163 degrees.

From *tables 2-4*, it is obvious that case 3 is the best, as the damping ratio and the participation factor are the highest values. Comparing the damping of 6.44e-01 in case 3 with the 4.83e-01 between 4BGE and 4BGS without TCSC, it is evident that the participation factor is increased. This increment validates the proposed method, and implementing TCSC connection in the real Iraqi power system requires a feasibility study.

The TCSC optimizes real and reactive load flow levels in TL to 25% and 15%, respectively. As can be concluded, maximum loadability points are 1.25 times greater than a normal load. The system responds to a 3-phase fault occurring in the middle of one of the TLs at t = 1.15 sec, which is cleared after a duration of 5 cycles. This is applied to compare active power transmission between the Baghdad buses, the system power response is depicted in *fig. 6*. The first case indicates a clear improvement in settling time and keeping line power as high as possible, followed by case 3 in keeping high line power but case 2 settling time is better than case 3.

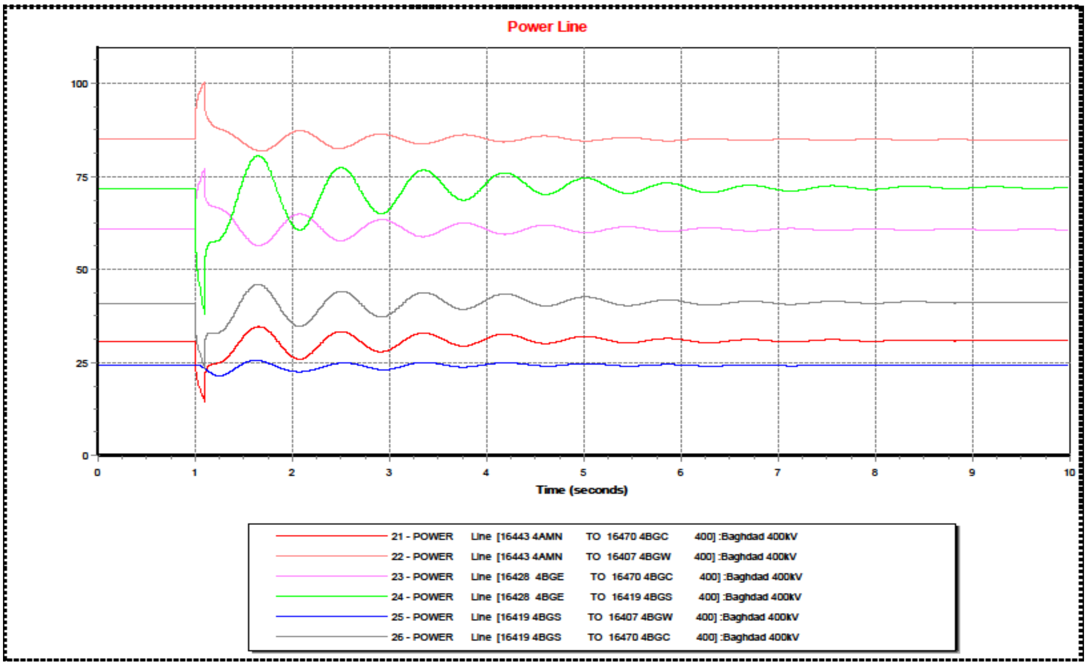

Figure 6. Power line comparison

The VAr line parameter depicted in *fig. 7* can verify that the least VAr value is established in case 3 (4BGE- 4BGS), proving the best location of the TCSC.

Open Access | Rapid and quality publishing

International Journal of
Electrical and Electronics Research (IJEER)
Case Study | Volume 13, Issue 2 | Pages 337-345| e-ISSN: 2347-470X

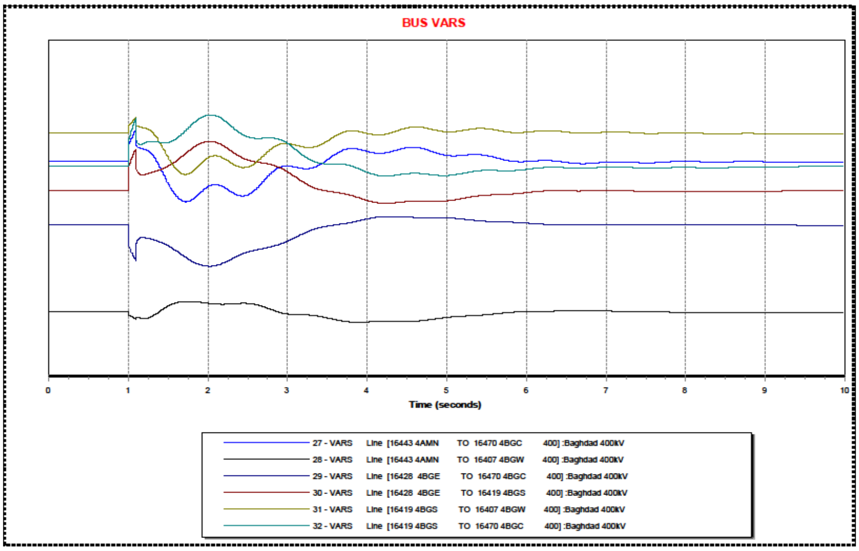

Figure 7. VAr line comparison

The speed deviations of bus generators for all cases are depicted in *fig. 8* which, shows that bus 4BGE has the least fluctuation, followed by the AMN bus.

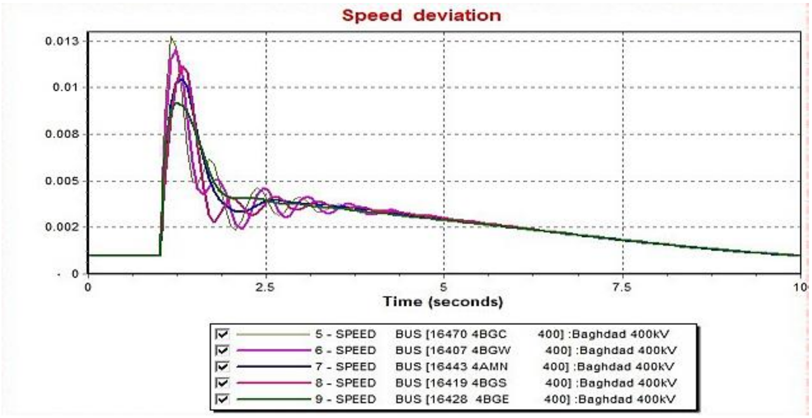

Figure 8. Buses' speed deviation.

Final gain parameters are determined by executing a step-response test on the system and ensuring that the system's settling time and overshoot speed for the buses are low. Furthermore, the response oscillations in frequency and voltage magnitude in *pu* for all buses at the base case are shown in *figures 9 and 10*, respectively.

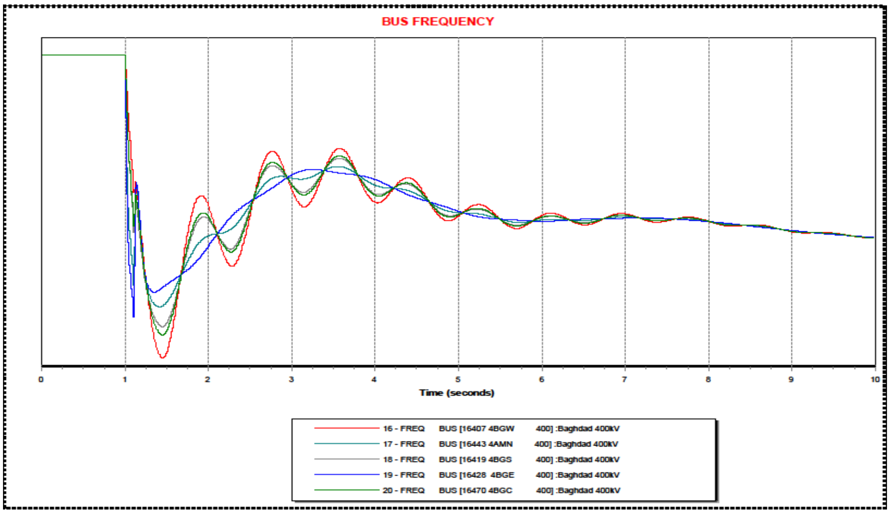

Figure 9. buses frequency

International Journal of
Electrical and Electronics Research (IJEER)
Case Study | Volume 13, Issue 2 | Pages 337-345 | e-ISSN: 2347-470X

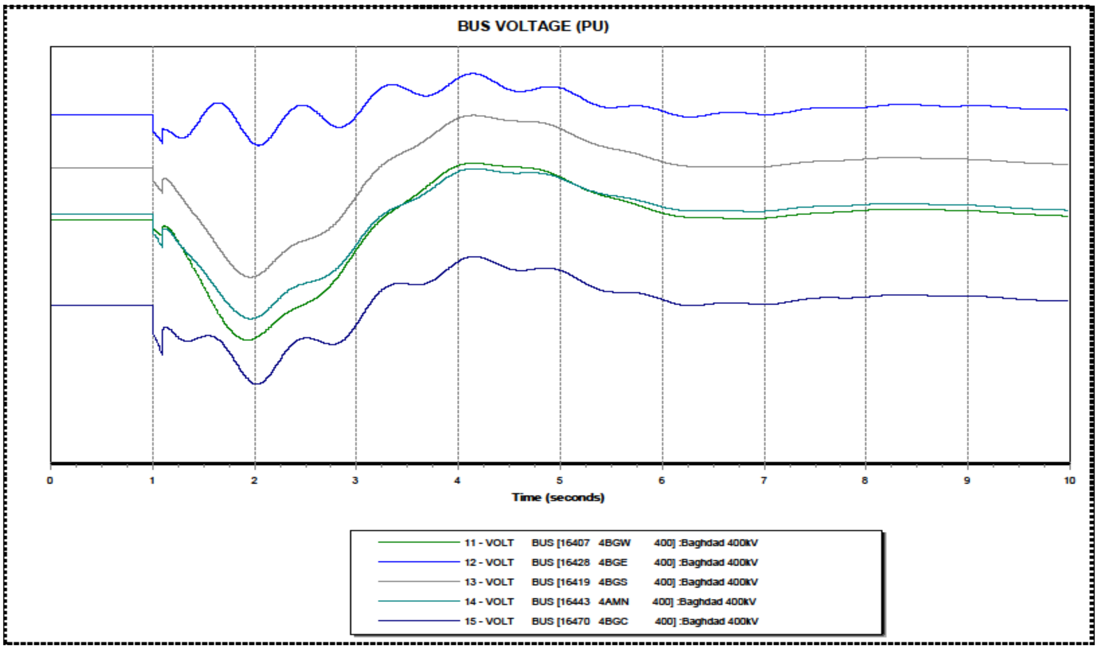

Figure 10. buses voltage

Finally, the results indicate that the TCSC connection between 4BGE and 4BGS improves the damping ratio by 66% and the time constant by 30 %.

6. CONCLUSION

The current study presents an adequate model and associated equations for demonstrating TCSCs in steady-state studies, specifically the voltage-drop. Concerning voltage regulation, procedures for appropriately positioning and modeling the TCSCs are suggested in the Baghdad system.

The findings indicate that TCSCs are promising for enhancing system loadability in real-world applications, as the improvement of the damping ratio is 66% and the time constant by 30% when the TCSC is connected between 4BGE and 4BGS. Feasibility studies conducted by the utility generally indicate that similar improvements in transfer capabilities can be accomplished through series compensation. Subsequently, this understanding could lead to a thorough exploration of integrating TCSC into electric networks, particularly in series compensation applications. Thus, appropriate modeling of these controllers in transient stability programs could evaluate their potential benefits for voltage stability convergence. However, finding Xc/Xl and the appropriate Eigenvalue, and the firing angle consumes time; thus, it is better to use optimization algorithms to find them. Presently, the study investigators are designing suitable dimensions for other controller types, analyzing steady-state stability, evaluating findings relevant to previous theoretical studies, and establishing a working tool for future research. The proposed future study is connecting the system to a static synchronous series compensator integrated with a unified power flow controller.

Conflicts of Interest: The authors declare no conflicts of interest.

REFERENCES

[1] Cadini F, Lomazzi L, Zio E., "Vulnerability Analysis of power transmission grids subject to cascading failures", *Electronics*. 2024; 13(5):943. https://doi.org/10.3390/electronics13050943.

[2] Samson Ademola Adegoke & Yanxia Sun., "Power system optimization approach to mitigate voltage instability issues: A review", *Cogent Engineering*, 10:1, 2153416, DOI: 10.1080/23311916.2022.2153416,2023.

[3] Hoq, M. T., Wang, J., & Taylor, N., "Review of recent developments in distance protection of series capacitor compensated lines", *Electric Power Systems Research*, 190, 106831. 2021. doi:10.1016/j.epsr.2020.106831.

[4] M. Aybar-Mejía, J. Batista, K. Díaz, W. Fernandez, F. Reyes-Romero, E. De Leon-Concepci ´ on´, D. Mariano-Hernandez., "Reduction of operational restrictions of the transmission system in electrical systems through facts implementation", *e-Prime - Advances in Electrical Engineering, Electronics and Energy*, 2,100047. 2022. doi.org/10.1016/j.prime.2022.100047.

[5] Jan Machowski, Zbigniew Lubosny, Janusz W. Bialek, and James R. Bumby, *Power System Dynamics Stability and Control*, Third Edition, Wiley, 2020.

[6] Stig Nilsson, Antonio Ricardo de Mattos Tenório, Subir Sen, Andrew Taylor, Shukai Xu, Gang Zhao, Qiang Song & Bo Lei. *Technical Description of Thyristor Controlled Series Capacitors (TCSC)*, CIGRE Green Books, Springer 2019.

[7] Chethan, M., Kuppan, R., "A review of FACTS device implementation in power systems using optimization techniques", *Journal of Engineering and Applied Science* 71, 18, (2024). https://doi.org/10.1186/s44147-023-00312-7.

[8] Taha, I. B. M., ELGebaly, A. E., Ahmed, E. S., & Abd el -Ghany, H. A., "Generalized voltage estimation of TCSC-compensated EHVs for adaptive distance protection", *International Journal of Electrical Power & Energy Systems*, 130, 107018, 2021. doi:10.1016/j.ijepes.

[9] Sarma (NDR) Nuthalapati, *Power System Grid Operation Using Synchrophasor Technology*, Springer, 2019, https://doi.org/10.1007/978-3-319-89378-5.

[10] Ngo Minh Khoa, Doan Duc Tung, "Modeling for Development of Simulation Tool: Impact of TCSC on Apparent Impedance Seen by Distance Relay", *Engineering, Technology & Applied Science Research*, Vol.8, No.5, pp. *3332-3337,* 2018.

[11] Debasish Mondal, Abhijit Chakrabarti, Aparajita Sengupta. *Power system small signal stability analysis and control*, Elsevier, Academic Press, 2020.

[12] Rachakonda Raghavendra, N. C. Kotaia, and K. Radha Rani, "Artificial Neural Network based FACTS in a Contingency Situation", *International Journal of Electrical and Electronics Research, Vol.12, No. 1,* p.p. 8-11, 2024.

[13] Srinu Bhukya, T. Murali Krishna, G. Mallesham, & Ch. Anilbharadwaja, "Enhanced Performance of E-STATCOM Using Fuzzy Logic Controller for Grid-Connected Wind Systems Under Dynamic Fault Conditions", *International Journal of Electrical and Electronics Research, Vol.13, No. 1,* p.p. 1-9, 2025.

[14] Yasar N. Lafta, Nadheer A. Shalash, Y. N. Abd, & Ali. A. Al- Lami, "IEC 60909 and ANSI standards comparison with ASCC based fault calculations of Iraqi power system", *Journal of Cogent Engineering*, vol.6, 2019.

[15] Youssif K. Hamad, Yasar N. Lafta, Ali N. Hussain, "Enhancing Efficiency in Distribution Power Networks by Power Factor Controlling of Renewable Energy Generators: a Case Study of Iraqi Wasit Network", *International Review of Electrical Engineering (IREE)*, vol. 19, no.2, 2024, pp. 132–140.

[16] Nigam Bam Malla, Vision Parajuli, Dev Kumar Kalwar, Prabhat Lal Karn, Shishir Aryal, "Enhancement of power transfer capability of transmission line using thyristor-controlled series capacitor (TCSC)", *Journal of Electronics, Computer Networking and Applied Mathematics*, Vol: 04, No. 01, Dec 2023-Jan 2024. https://doi.org/10.55529/jecnam.41.26.37.

[17] Syed Abdullah-Al-Nahid, TafsirAhmed Khan, Md. Abu Taseen, Silvia Tasnim, Tareq Aziz, Taskin Jamal, "Maximizing power transfer in transmission networks with TCPS: A non-linear programming-genetic algorithm approach", Elsiveir, Energy *Reports*, Vol. 11, p.p.2608- 2622, 2024.

[18] Bjarne R. Andersen, Stig L. Nilsson. *Flexible AC Transmission Systems FACTS, CIGRE Green Books* (CIGREGB), Springer, 2020.

[19] Xiao-Ping Zhang, Christian Rehtanz, and Bikash Pal. *Flexible AC transmission systems: modelling and control*, Springer-Verlag Berlin Heidelberg, 2012.

[20] Nwozor O. E. and Olumoko O. E., "A review of the functional and analytical characteristics of thyristor-controlled series capacitor (TCSC) in electric power system", *Futo Journal Series (FUTOJNLS)*, Vol.6, Issue - 2,2020, pp- 109 – 125.

[21] Barry W Williams, *Principles and Element of Power Electronics*, Barry W Williams, ISBN 978-0-9553384-0-3, 2006.

[22] Manasi Prashant Deore, "Examining the Thyristor-Controlled Reactor's (TCR) Performance to minimize Self-Generated Harmonics", *Journal of Electrical Systems*, Vol. 20, No. 2s, 2024

[23] Doan Duc Tung, Le Van Dai, and Le Cao Quyen, "Subsynchronous resonance and FACTS-novel control strategy for its mitigation", *Journal of Engineering*, Vol 2019, Hindawi, 2019, https://doi.org/10.1155/2019/2163908.

[24] Robin Noel Damas;Yongju Son;Myungseok Yoon;Sung-Yul Kim;Sungyun Choi, "Subsynchronous Oscillation and Advanced Analysis: A Review", *IEEE Access,* 2020. doi:10.1109/access.2020.3044634.

[25] *Reader's guide to subsynchronous resonance*. (1992), *7(1), – 157.* doi:10.1109/59.141698.

[26] Nadheer A. Shalash, Yasar N. Lafta, M. N. Lafta, "C. B interrupt duty reduction based controlling TRV and symmetrical breaking current", *Journal of Cogent Engineering,* vol.10, 2023.

[27] Bjarne R. Andersen and Stig L. Nilsson, *DC Systems and power electronics Flexible AC Transmission Systems*, *study* committee *B4:* (CIGRE), Springer Nature Switzerland AG 2020.

[28] Salah Kamel, Mohamed Abokrisha, Ali Selim, and Francisco Jurado, "Power flow control of power systems based on a simple TCSC model", *Ain Shams Engineering Journal*, Vol. 12, Issue 3 , 2021. doi:10.1016/j.asej.2020.11.023.

[29] Gautam A, Ibraheem, Sharma G, Bokoro PN, Ahmer MF., "Available Transfer Capability Enhancement in Deregulated Power System through TLBO Optimised TCSC", *Energies*, Vol. 15, No. 12, 4448. 2022. https://doi.org/10.3390/en15124448

[30] Bizzarri, Federico; Brambilla, Angelo; Milano, Federico, "Analytic and Numerical Study of TCSC Devices: Unveiling the Crucial Role of Phase-Locked Loops", *IEEE Transactions on Circuits and Systems*, Vol. 65, Issue 6, p.p. 1–10, 2017. doi:10.1109/TCSI.2017.2768220.

[31] Muddu Chethan and Ravi Kuppan, "A review of FACTS device implementation in power systems using optimization techniques", Springer, *Journal of Engineering and Applied Science*, 71, 18. 2024. https://doi.org/10.1186/s44147-023-00312-7.

[32] Arcia-Garibaldi, G., Cruz-Romero, P., & Gómez-Expósito, "Future power transmission: Visions, technologies and challenges", *Renewable and Sustainable Energy Reviews*, 94, p.p. 285–301. 2018. doi:10.1016/j.rser.2018.06.004.

[33] Sadovskaia, K., Bogdanov, D., Honkapuro, S., & Breyer, "Power transmission and distribution losses – A model based on available empirical data and future trends for all countries globally", *International Journal of Electrical Power & Energy Systems*, 107, p.p 98–109. 2019. doi:10.1016/j.ijepes.2018.11.012.

[34] Yasar N. Lafta, Nadheer A. shalash, "Voltage profile modification of distribution grid-based spike/ REGs - a case study: the province of Mosul in Iraq", *International Review of Electrical Engineering (IREE),* vol. 18, no.5, 2023.

[35] Muhammad, Y., Khan, R., Raja, M. A. Z., Ullah, F., Chaudhary, N. I., & He, Y., "Solution of optimal reactive power dispatch with FACTS devices: A survey", *Energy Reports*, 6, 2211–2229, 2020. doi:10.1016/j.egyr.2020.07.030.

[36] Ku, H.-K., Kwon, H.-I., Song, J.-Y., Oh, S.-C.; Shin, J.-H., "Analysis of the System Impact upon Thyristor Controlled Series Capacitor Relocation Due to Changes in the Power System Environment", *Energies*, 16, No. 2, 722, 2023. https://doi.org/10.3390/en16020722.

[37] Republic of Iraq, Ministry of Electricity, Planning and Studies Office, 2024.