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# Performance Enhancement of Smart Grid Using an Optimal Placement of FACTS: Case of TCSC

***Abstract**. This paper proposes an optimal placement of FACTS to enhance smart grid performance. Indeed, this work analyzes the static and dynamic stability of voltage, angle, power and frequency of smart grid by testing some cases to explore the weakest regions. Currently, power grids, long power lines and rapidly increasing load demand make the system more demanding than ever. Random placement of FACTS cannot improve power grid performance. By studying unstable voltage regions using the line stability index method when placing FACTS methods predicts and prevents system failures. For this reason, a static and synchronous capacitors and Thyristor Controlled Series Compensator (TCSC) are used for effective voltage recovery and regulation. This device will be integrated in IEEE-14 bus. As results, the system can be managed efficiently and provide electricity to consumers in a reliable, safe and cost-effective manner. The PSAT SIMULINK environment is also used for performance analysis.*

***Streszczenie**. W artykule zaproponowano optymalne rozmieszczenie FACTS w celu zwiększenia wydajności inteligentnych sieci. Rzeczywiście, w tej pracy analizowano statyczną i dynamiczną stabilność napięcia, kąta, mocy i częstotliwości inteligentnej sieci, testując niektóre przypadki w celu zbadania najsłabszych regionów. Obecnie sieci energetyczne, długie linie energetyczne i szybko rosnące zapotrzebowanie na obciążenie sprawiają, że system jest bardziej wymagający niż kiedykolwiek. Losowe rozmieszczenie FACTS nie może poprawić wydajności sieci energetycznej. Badając niestabilne obszary napięcia za pomocą metody wskaźnika stabilności linii podczas umieszczania metod FACTS, przewiduje się i zapobiega awariom systemu. Z tego powodu do skutecznego odzyskiwania i regulacji napięcia stosowane są kondensatory statyczne i synchroniczne oraz kompensator szeregowy sterowany tyrystorowo (TCSC). Urządzenie to będzie zintegrowane z magistralą IEEE-14. Dzięki temu można efektywnie zarządzać systemem i dostarczać energię elektryczną odbiorcom w sposób niezawodny, bezpieczny i opłacalny. Do analizy wydajności wykorzystywane jest także środowisko PSAT SIMULINK. (**Zwiększanie wydajności inteligentnych sieci poprzez optymalne rozmieszczenie FAKTÓW: przypadek TCSC**)*

**Keywords:** Stability, TCSC, Grid's dynamic enhancement, FACTS
**Słowa kluczowe**: Stabilność, TCSC, dynamiczne wzmocnienie siatki, FACTSKTY

## Introduction

Researches and engineers are interested in the problem of voltage stability and voltage collapse that caused by the structural changes in the electricity. Indeed, sector and load fluctuations such as privatization and deregulation, changes in power supply topology, and both economic and environmental pressures provide instability in the electricity [1], [2] and [3].

In smart network interconnection, the flexible alternating current transmission system (FACTS) devices will boost the power transfer capacity between existing transmission lines without requiring the construction of a new line [1]. FACTS controller either reduces line impedance (by injecting voltage drop) or increases phase angle, improving active power transfer in power system. In addition, the FACTS device compensates for reactive power by injecting current into the existing system [4], [5], [6], [7], [8], [9], [10], [11] and [12].

Conventionally, controlled mechanical switches with long switching time were employed to link the compensators to the transmission line. During a fault, the power system requires rapid recovery, and fast acting power electronics base FACTS devices are employed in place of mechanical switches to provide this need. Aside from that, the following are some significant advantages of FACTS devices. The FACTS is created to enhancement of transmission lines' power transfer capacity, provide voltage assistance along the line, provide reactive power compensation at both the midpoint and the receiving end of the line, improve the dynamic and steady state stability of system interconnections and increase in power factor [10], [11] and [12].

Based on their coupling with transmission lines, FACTS controllers are classified into four categories. In fact, the first type of controller is a series controller, which injects voltage into the system. It also provides the system with variable impedance. In the line, these controllers absorb or transmit both active and reactive power. Thyristor controlled series capacitors (TCSC) and Static Synchronous Series Compensators (SSSC) are examples of series FACTS controllers [13].

The second type of controller is a shunt controller, which injects current into the system. If the phase angle between the injected current and the line voltage is 90 degrees, the device will only provide or absorb reactive power. This type of controller includes static VAR compensators (SVC) and static synchronous compensators (STATCOM) [14] and [15].

The third form of FACTS controller is a combined series-series controller, which is applied when more than one transmission line requires active and reactive power correction at the same time. It is a collection of series controllers linked by a DC link that offer compensation in various transmission lines, such as the interline power flow controller [16].

The fourth type includes a combined series-shunt controller, which is a mix of series and shunt FACTS devices coupled by a DC link. The DC link allows active power exchange between controllers. For example, the unified power flow controller (UPFC) is a combination of SSSC (series FACTS controller) and STATCOM (shunt FACTS controller) connected via a shared DC link [17], [18] and [19].

All these FACTS devices were randomly integrated in smart grid. However, this kind of placement cannot improve power grid performance. To overcome this problem, in this work, we propose an optimal placement of FACTS to enhance smart grid performance. The proposed line stability index is applied on IEEE 14 bus system.

This paper is organized as follows. In the next section, we will describe the problem statement. The proposed line stability index for voltage stability is presented in the third section. The fourth section shows the model of IEEE-14 bus system. Results and discussion are treated in the fifth section. Indeed, in this part, we will detail the influence of the integration of the TCSC in the used smart grid. The conclusions are given in the last section.

**The problem statement**

For economic reasons, the integration of FACTS devices in all buses or branches of the electrical grid is difficult. The placement of FACTS in a network is a problem in itself. Up to now, there is no analytical method able of solving this kind of problem and giving it the overall optimum.

As a matter of fact, the exact methods that have the resolution times increasing exponentially with the dimension of power grids. Thus, for networks comprising several of buses and branches, we will move towards approximate methods, which do not guarantee the optimal solution in the global sense, allow to obtain good quality solutions in reasonable calculation times.

In this paper, we propose the approach adopted for the solution of the problem of optimal placement of FACTS by relying on the method of line stability index (LSI). Indeed, the equation which is applied in this work is divided in two parts; in the first part, it used for solving the problem of optimal line stability index value between power transmission lines from the static data of the network, and the second part is used for quick resolution of the optimal placement problem of the TCSC.

**The proposed line stability index for voltage stability**

To obtain the expression of the line stability index, the model of two-bus power system is given by the Figure 1.

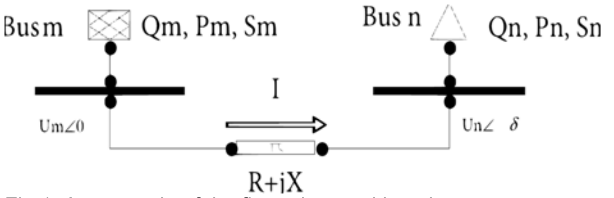


Fig.1. An example of the figure inserted into the text

Let's consider that bus $m$ is the sending bus and $n$ is the receiving bus. The sending bus is used as the reference.

(1) $\alpha_m = 0 \qquad \alpha_n = \alpha$

$\alpha$ represents the angle difference between the bus $m$ and bus $n$.

The power equation at bus n is as follows:

(2) $S_n = U_n I^* = P_n + jQ_n$

Where, $S_n$, $P_n$ and $Q_n$ are, respectively, the apparent power, the active power and the reactive power at the receiving bus.

$U_n$ is the voltage of the receiving bus and $I_n$ is the current of the line.

The quantity of the current $I_n$ of the line is given by the following expression:

(3) $$I = \frac{U_m\angle 0 - U_n\angle\delta}{R + jX}$$

(4) $$S = \left(\frac{R}{X}Q_n - \frac{U_nU_m}{X}\sin(\delta)\right) + j\left(\frac{U_nU_m}{X}\cos(\delta) - \frac{R}{X}P_n - \frac{U_n^2}{X}\right)$$

Where $R$ is the line's resistance, $X$ is the line's reactance, $U_m$ is the voltage of the sending bus and $U_n$ is the voltage of the receiving bus.

Equations (2) and (4) are connected to produce the following equations:

(5) $$U_mU_n\sin(\delta) - RQ_n + XP_n = 0$$

(6) $$U_n^2 - U_mU_n\cos(\delta) + RP_n + XQ_n = 0$$

The solution of the equation (6) is given by the following expression:

(7) $$U_n = \frac{U_m\cos(\delta) \pm \sqrt{U_m^2\cos^2(\delta) - 4(RP_n + XQ_n)}}{2}$$

To obtain real value of $U_n$, the discriminate of equation (6) must be superior or equal to 0. So we can write the following expression:

(8) $$\sqrt{U_m^2\cos^2(\delta) - 4(RP_n + XQ_n)} \geq 0$$

Then we can give this expression:

(9) $$U_m^2\cos^2(\delta) \geq 4(RP_n + XQ_n)$$

As a result we can derive the following expression:

(10) $$\frac{(RP_n + XQ_n)}{0.25U_m^2\cos^2(\delta)}$$

Because the angle difference between the sending bus and the receiving bus is very small, we can write:

(11) $$\cos(\delta) \simeq 1$$

Finally, the proposed line stability index $\gamma_{mn}$ can be expressed as:

(12) $$\gamma_{mn} = \frac{(R_{mn}P_n + X_{mn}Q_n)}{0.25U_m^2}$$

Where $R_{mn}$ and $X_{mn}$ are, respectively, the resistance and reactance between sending and receiving bus, $Q_n$ is the receiving bus's reactive power and $P_n$ is the receiving bus's active power. $U_m$ presents the voltage at sending bus.

Any line in the system that exhibits $\gamma_{mn}$ closed to unity indicates that the line is approaching its stability limit hence may lead to system violation. Therefore $\gamma_{mn}$ has to be maintained less than unity in order to maintain a stable system.

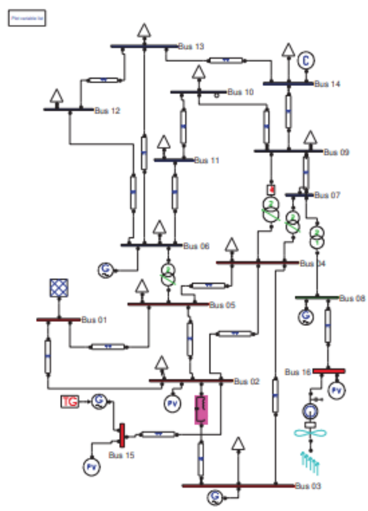

Fig. 2. The IEEE 14-bus system

**Presentation of the IEEE-14 bus system**

In this paper, an IEEE-14 bus system, given by Figure 2, is studied. Indeed, IEEE-14 bus system consists of 5 generators, 4 transformers, 11 loads and 14 buses. The bus numbered 01 is usually considered as slack bus. The simulation is done by Power System Analysis Toolbox (PSAT) MATLAB software tool. The PSAT software is used to create voltage profile and reactive power curves, power factor evolution curves, and eigenvalue investigations wich all used to study the IEEE-14 bus system.

The next sections go through the model's specifics. Each turbine is assigned a rated power of 2,5MW. A wind farm with 25 turbines is linked to bus numbered 08.

**Results and discussions**

In this section we will apply the proposed line stability index in the IEEE-14 bus system, in different cases of using or not the TCSC and the compensator devices.

**0.1 TCSC and compensator features**

The TCSC, given by the Figure 3, is a series reactance controlled by Thyristors in parallel on a fixed capacitor, all in series on the transmission line. If the Thyristors are blocked, the TCSC has fixed impedance, which is that of the capacitor. Generally, the impedance of the TCSC is still fixed and is equal to the equivalent impedance of the capacitor in parallel with the inductance [22], [23] and [24].

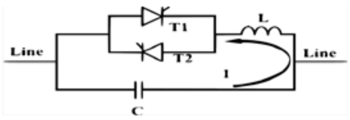


Fig. 3. The basic electrical model of TCSC

The compensator, which is reserved for bus 14, is sometimes installed and sometimes removed to note its role on the network. Its characteristics are presented in the following Table 1.

Table 1. The characteristics of the compensator

| Characteristics | Unit | Value |
|---|---|---|
| Power and voltage ratings | [MVA Kv] | [1 13.8] |
| Magnitude of voltage | [p.u.] | 1.01 |
| VMAX and VMIN | [p.u p.u] | [1.07 0.95] |
| Loss participation coefficient | - | 1 |

The Table 2 provides a description of the TCSC's properties. The TCSC's voltage rating is 69KV with a frequency of 60Hz and a power rating of 100MVA. The operating voltage value between the highest value of 1:07 p.u and the minimum value of 0:95 p.u.

Table 2. The characteristics of the TCSC

| Characteristics | Unit | Value |
|---|---|---|
| [V P F] | [kV MVA Hz] | [69 100 60] |
| Series comp's percent | % | 10 |
| Tr | [s] | [0.5] |
| XC and XL | [p.u. p.u.] | [0.2 0.1] |
| Kr: stab signal gain | [pu/pu] | [10] |

Table 3. The line characteristics

| Line | From Bus | To Bus | Line | From Bus | To Bus |
|---|---|---|---|---|---|
| 01 | 02 | 05 | 11 | 07 | 09 |
| 02 | 06 | 12 | 12 | 01 | 02 |
| 03 | 12 | 13 | 13 | 15 | 02 |
| 04 | 06 | 13 | 14 | 03 | 02 |
| 05 | 06 | 11 | 15 | 03 | 04 |
| 06 | 11 | 10 | 16 | 01 | 05 |
| 07 | 09 | 10 | 17 | 05 | 04 |
| 08 | 09 | 14 | 18 | 02 | 04 |
| 09 | 14 | 13 | 19 | 04 | 09 |
| 10 | 16 | 8 | 20 | 5 | 6 |

For each transmitter and receiver bus, Table 3 displays the voltage amplitude, active and reactive power flow rate, and line resistance and properties. As a result, line 14, which connects buses 2 and 3, is the most important line and has the highest stability index of all the lines, as shown by the bold text in the tables below. The line are given in the table 3. And the features of line are given in the table 4.

Table 4. The line characteristics

| Line | Vnpu | Pn | Qn | Rmn | Xmn |
|---|---|---|---|---|---|
| 1 | 1.045 | 0.106 | 0.022 | 0.056 | 0.173 |
| 2 | 0.949 | 0.085 | 0.022 | 0.122 | 0.255 |
| 3 | 0.949 | 0.189 | 0.081 | 0.220 | 0.199 |
| 4 | 0.949 | 0.189 | 0.081 | 0.066 | 0.130 |
| 5 | 0.949 | 0.049 | 0.025 | 0.094 | 0.198 |
| 6 | 0.933 | 0.126 | 0.081 | 0.082 | 0.192 |
| 7 | 0.937 | 0.126 | 0.081 | 0.031 | 0.084 |
| 8 | 0.937 | 0.208 | 0.070 | 0.127 | 0.270 |
| 9 | 0.900 | 0.189 | 0.081 | 0.170 | 0.348 |
| 11 | 0.970 | 0.413 | 0.232 | 0.005 | 0.110 |
| 12 | 1.060 | 0.096 | 1.218 | 0.019 | 0.059 |
| 13 | 1.045 | 0.096 | 1.218 | 0.046 | 0.197 |
| 14 | 0.929 | 0.096 | 1.218 | 0.046 | 0.197 |
| 15 | 0.929 | 0.669 | 0.056 | 0.067 | 0.171 |
| 16 | 1.060 | 0.106 | 0.022 | 0.054 | 0.223 |
| 17 | 0.967 | 0.669 | 0.056 | 0.013 | 0.042 |
| 18 | 0.958 | 0.669 | 0.056 | 0.058 | 0.176 |
| 19 | 0.967 | 0.413 | 0.232 | 0.005 | 0.556 |
| 20 | 1.045 | 0.156 | 0.105 | 0.005 | 0.252 |

**0.2 The obtained optimal placement**

In the Table 5, we present the rank and the different $\gamma_{mn}$ using the expression (12). The optimal placement of the TCSC is given by the highest index of $\gamma_{mn}$ as given by Table 5.

Table 5. The rank of line by value of $\gamma_{mn}$

| Line | $\gamma_{mn}$ | Rank | Line | $\gamma_{mn}$ | Rank |
|---|---|---|---|---|---|
| **14** | **1.120** | **01** | 06 | 0.081 | 11 |
| 13 | 0.887 | 02 | 18 | 0.075 | 12 |
| 19 | 0.565 | 03 | 04 | 0.059 | 13 |
| 12 | 0.258 | 04 | 02 | 0.035 | 14 |
| 09 | 0.171 | 05 | 07 | 0.035 | 15 |
| 03 | 0.113 | 06 | 05 | 0.026 | 16 |
| 20 | 0.113 | 07 | 16 | 0.023 | 17 |
| 08 | 0.112 | 08 | 01 | 0.020 | 18 |
| 11 | 0.108 | 09 | 17 | 0.019 | 19 |
| 15 | 0.089 | 10 | 10 | -- | 20 |

Four buses: 03, 04, 05, and 14 are taken into consideration in order to analyse the impact of increased reactive power on the factor and to identify the crucial line. Indeed, the coefficient for each system line is obtained as a function of the load increase. The critical line is defined as the line having the highest index. After using TCSC, we have a voltage level change.

The voltage evolution of each bus, with and without TCSC, is shown by figure 4 to figure 8. The most important line is shown by being higher. For instance, line 14 between buses 02 and 03 is a crucial line. According to the table 5, we can see that the highest value of $\gamma_{mn}$ is noted on line 14, here the $\gamma_{mn}$ value is equal to 1:1206. For this reason, the TCSC will be placed in this line.

Depending on the horizontal axes of the curves, we can deduce that the voltage of the buses 03, 04 and 05, without TCSC, are, respectively, 0:93 p.u, 0:96 p.u and 0:965 p.u whereas by integration of the TCSC they are, respectively, 0:96 p.u, 0:97 p.u, 0:98 p.u.

### 0.3 Eigenvalue system

In order to study the stability of the system using the eigenvalue method we should recall that the model of the IEEE-14 bus system could be presented by a differential algebraic equation as given by the following expression.

(13) $$\dot{x} = f(x, y, u)$$

(14) $$0 = g(x, y, u)$$

Where x and y are the state and algebraic variables respectively, and u is the input vector. The system given by equations (13) and (14) may be represented in a descriptor form as:

(15) $$E\dot{x} = Ax(t) + Bu(t)$$

where $E, A$ and $B \in \mathbb{R}^{n*p}$ and possibly refer to a singular matrix, state matrix and input matrix respectively. $x$ is the vector of state variables, and $u$ is an input matrix. The generalized eigenvalues of IEEE-14 bus system are plotted and shown in Figure 4. According to this figure, the system is stable because the found eigenvalue of the system have all negative real part.

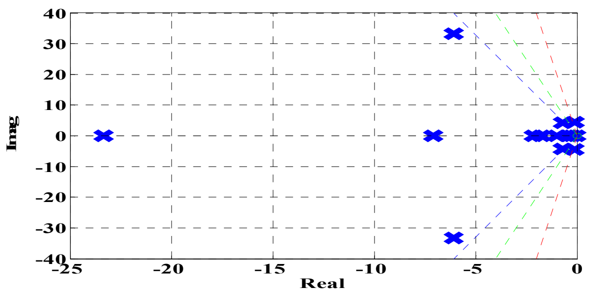

Fig. 4. The IEEE 14-bus Eigenvalue with TCSC and compensator

Our system has 25 different dynamic orders. The eigenvalues are summarized in Table 6. In reality, there are 23 values with a negative real part, 19 of which are purely negative, along with 3 complex pairs and two zeros.

Table 6. Eigenvalue IEEE-14 bus system with TCSC

| Eigenvalue | Number |
|---|---|
| Dynamic order | 25 |
| Eigenvalue with negative real part | 23 |
| Eigenvalue with positive real part | 0 |
| Eigenvalue with real part | 19 |
| Eigenvalue with pair complexes | 3 |
| Zero eigenvalues | 2 |

Table 7. Comparison of losses with and without FACTS

| Power | Total generation | Total load | Total losses |
|---|---|---|---|
| Real power case without Facts [p.u.] | 3.8363 | 3.626 | 0.21025 |
| Reactive power case without Facts [p.u.] | 1.6043 | 1.1396 | 0.4647 |
| Real power case with TCSC & C [p.u.] | 3.7660 | 3.626 | 0.13995 |
| Reactive power case with TCSC & C [p.u.] | 1.5227 | 1.1396 | 0.3831 |
| Active power rise [p.u] | 0.0703 | - | 0.0703 |
| Reactive power rise [p.u] | 0.0816 | - | 0.0816 |

### 0.4 Line losses

According to the Table 7 below, total loads are 3.626 perunit, total active power generated is 3.8363 per unit and total reactive power generated is 1.6043 per unit. However, online losses of active and reactive power are 0.21025 per unit and 0.4647 per unit, respectively, when FACTS are not used. Additionally, when we employed the TCSC and the compensator, together, for bus 14, total generated active power and reactive power were, respectively, 3.7660 per unit and 1.5227 per unit, total loads were 3.626 per unit, and on-line losses for active and reactive power were 0.13995 p.u. and 0.3831 p.u. Finally, we obtained a gain in active power of 0.0703 p.u. and a gain in reactive power of 0.0816 p.u. at the loss value in the lines.

### Critical bus analysis study

In this section, we are focusing on the critical bus analysis study. Indeed, the critical buses studies are shown in the following subsection.

### 0.5 Voltage study

In figure 5, we present the voltage evolution for four buses (03, 04, 05 and 14) for four cases.

Indeed, the first case is without FACTS and without compensator, thus the result is shown in the red color. But the second case, with the blue color, only the compensator at bus 14 is used. In the third case, only the TCSC is used between buses 02 and 03, this case is presented with the blue color. Finally, the black once, is when we integrate the TCSC between buses 02 and 03 also the compensator is linked to bus 14.

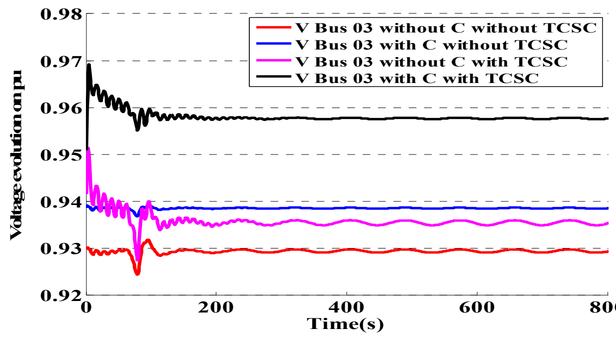

Fig. 5. Voltage evolution with and without TCSC and Compensator bus 03

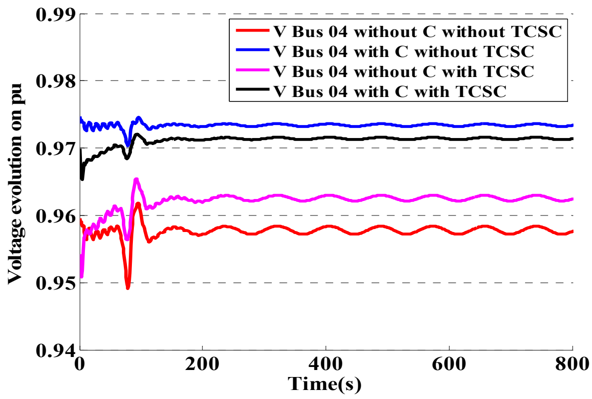

Fig. 6. Voltage evolution with and without TCSC and Compensator bus 04

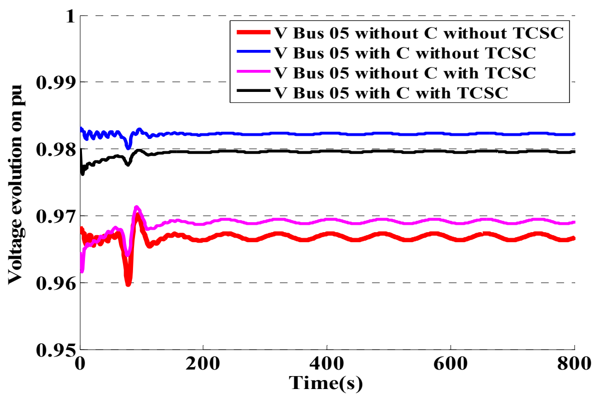

Fig. 7. Voltage evolution with and without TCSC and Compensator bus 05

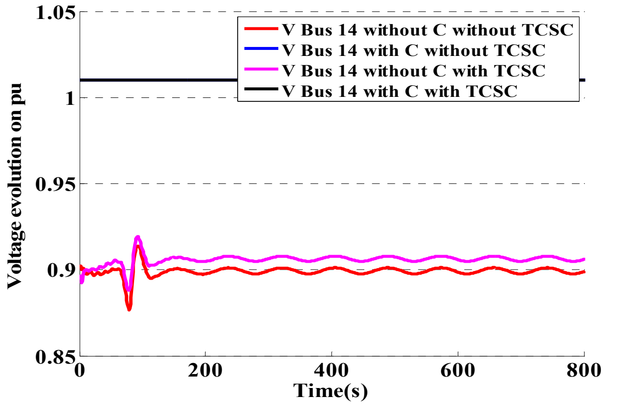


Fig. 8. Voltage evolution with and without TCSC and Compensator bus 14

It appears in these voltage curves at buses 03, 04, 05 and 14, respectively, the TCSC greatly improves the stability of the network. For instance, the voltage value, in Figure 5, was increased from 0:96 p.u to 0:985 p.u. Also, figures 5, 6 and 7 show the positive impact of this device on the voltage value and the stability rate. The case of figure 8 shows very effective performances especially the case when we integrate a static compensator with the TCSC which is integrated between buses 02 and 03. In fact, the voltage happens to slightly exceed the unit in p.u. This is the objective of integration of this device.

## 0.6 Power factor

This part shows the evolution of the power factor in all critical buses and therefore the impact of the TCSC and compensator as given in figure 9 to figure 12.

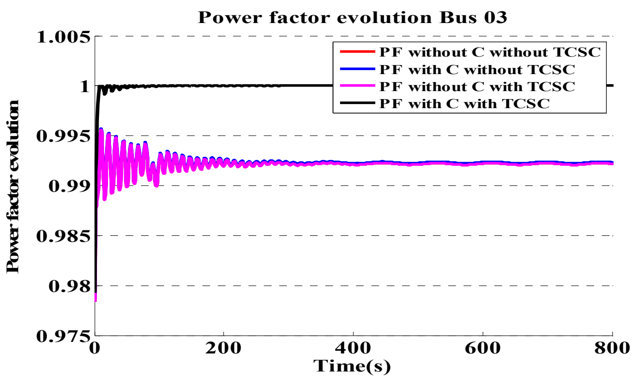


Fig. 9. Power factor evolution with and without TCSC and Compensator bus 03

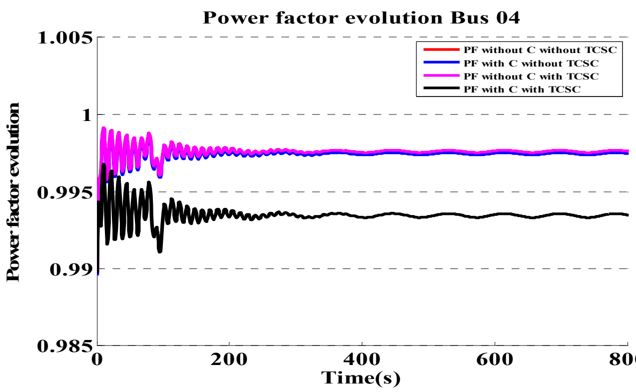


Fig. 10. Power factor evolution with and without TCSC and Compensator bus 04

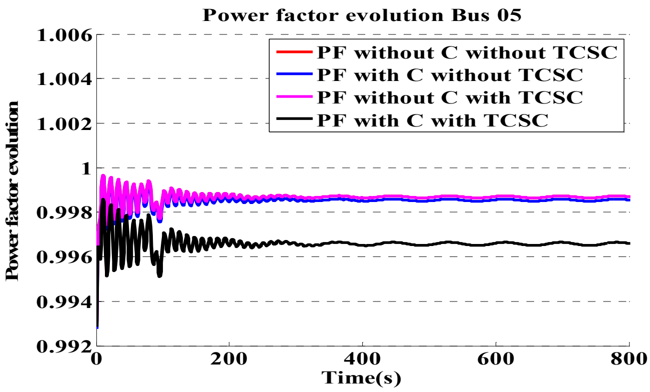


Fig. 11. Power factor evolution with and without TCSC and Compensator bus 05

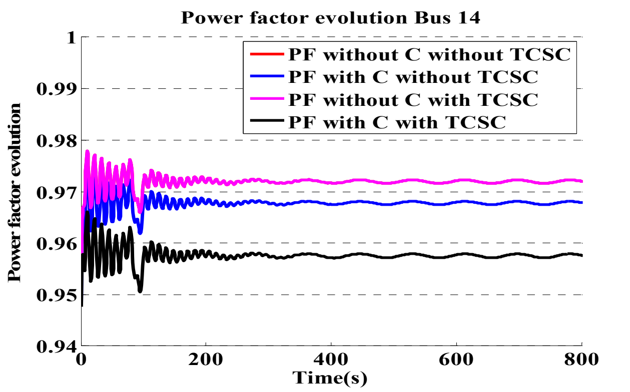


Fig. 12. Power factor evolution with and without TCSC and Compensator bus 14

From the above, we notice that the evolution of the angle at bus 03 passes from -0.13 rad to a zero phase shift and consequently a power factor tending towards one. This evolution, also, appears when one looks at the evolution of the angle in the bus 04 in fact the value goes from -0.12 rad to -0.06 rad which is not the case for the bus 14. The power angle between the sending end and receiving end voltages are kept in the range of 300 to 400 from the viewpoint of stability.

## 0.7 Voltage magnitude and reactive power

From figure 13 to figure 20, we present the voltage profile and reactive power in the absence of FACTS and the case of TCSC and compensator.

The TCSC is used to provide variable continuous capacity. It is a fast device of adjusting the impedance of the electrical grid. It changes apparent power smoothly and can improve transient stability and dynamic performance. The TCSC is beneficial in preventing sub-synchronous oscillations and reducing short circuit current. The basic type of TCSC is the open loop impedance control and it is used for power flow control.

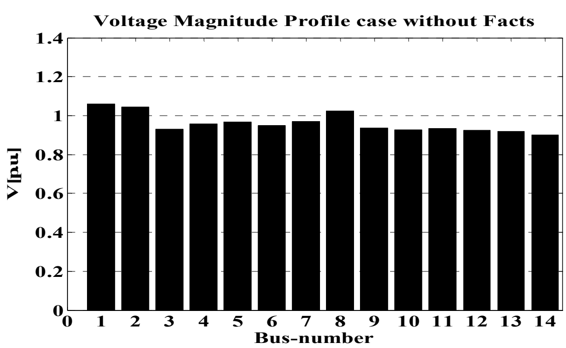


Fig. 13. Voltage magnitude profile case without FACTS

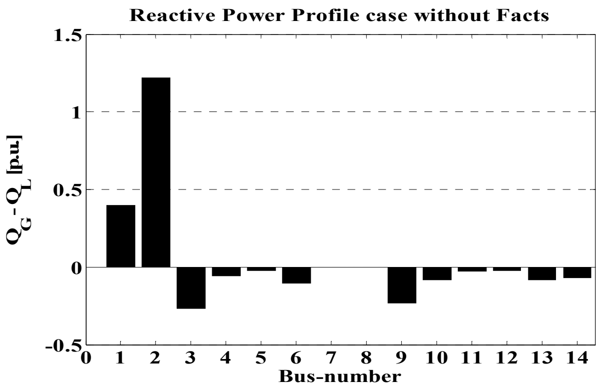


Fig. 14. Reactive power profile case without FACTS

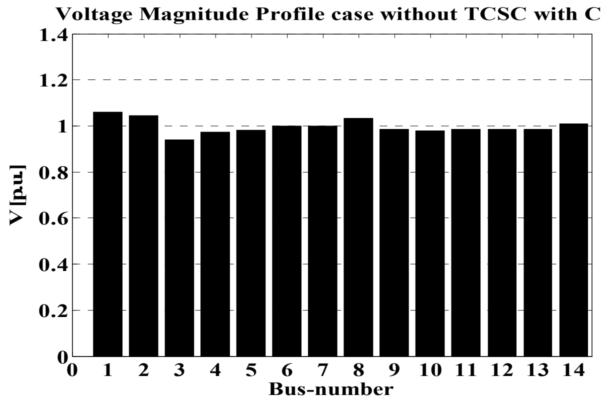


Fig. 15. Voltage magnitude profile case with Compensator and without TCSC

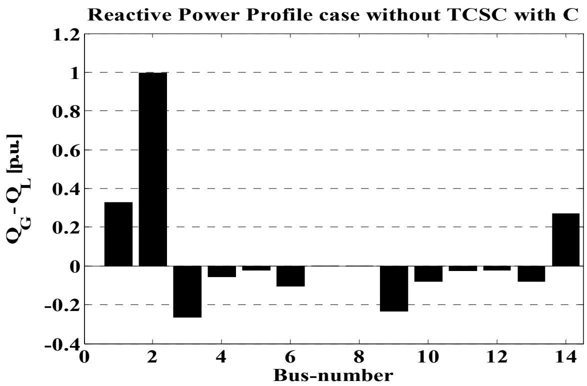


Fig. 16. Reactive power profile case with Compensator and without TCSC

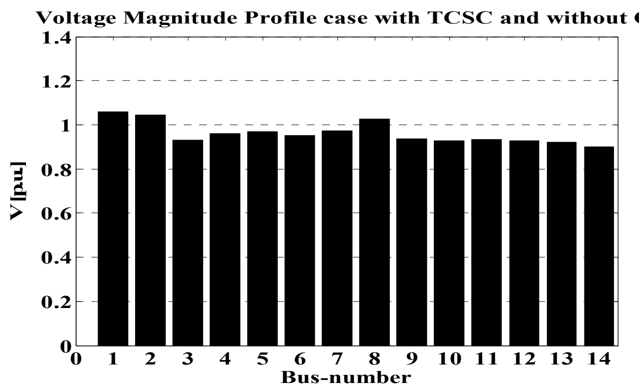


Fig. 17. Voltage magnitude profile case with TCSC and without Compensator

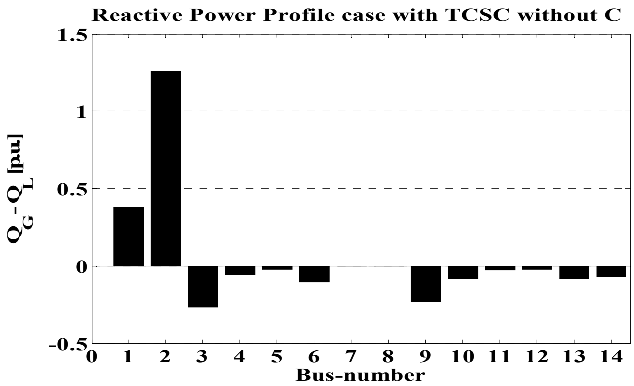


Fig. 18. Reactive power profile case with TCSC and without Compensator

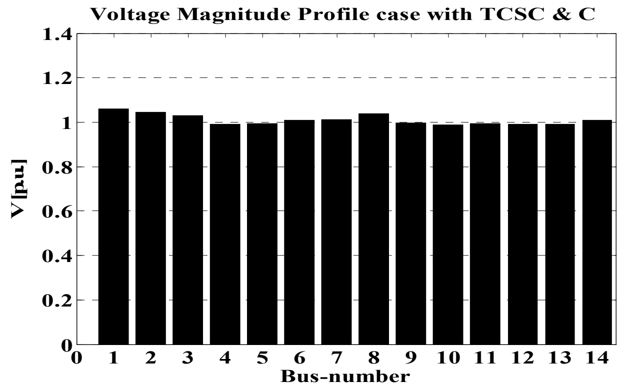


Fig. 19. Voltage magnitude profile case with TCSC and with Compensator

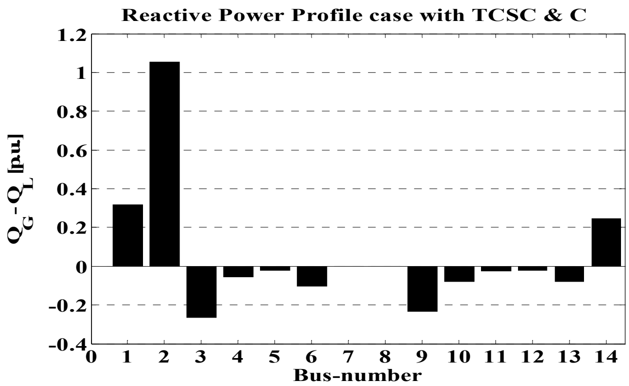


Fig. 20. Reactive power profile case with TCSC and with Compensator.

## Conclusion

In this paper, we proposed an optimal line stability index to integrate a TCSC in the smart grid. Indeed, the applied TCSC is used to avoid any fluctuations caused a load deviation. Therefore, the dynamic performance of the TCSC on the voltage control with linear loads is analyzed. By using the IEEE-14 bus system, the simulation results show the voltage and reactive power variation at the critical buses. It was observed that using the TCSC, the voltage and reactive power were significantly improved.

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REFERENCES

[1] Mahmud K., Town GE., Morsalin S., Hossain MJ.S.: Integration of electric vehicles and management in the internet of energy, Renewable and Sustainable Energy Reviews, 82(4), pp. 4179–839, 2018.
[2] Kamarposhti, Mehrdad A., H. Lesani.: Effects of STATCOM, TCSC, SSSC and UPFC on static voltage stability, Electrical Engineering, 93(1), pp. 33–42, 2011.
[3] Tostado V., Marcos, Salah K., Francisco J.: Development and Comparison of Efficient Newton-Like Methods for Voltage Stability Assessment, Electric Power Components and Systems, 48(16), pp. 1798–1813, 2021.
[4] Abdelaziz, Almoataz Y., Metwally A. El-Sharkawy, Mahmoud A. Attia: Optimal location of thyristor-controlled series compensation and static VAR compensator to enhance steadystate performance of power system with wind penetration, Electric Power Components and Systems, 43(18), pp. 1999– 2009, 2015.
[5] Makarov, Yuri V., al.: Blackout prevention in the united states, europe, and russia., Proceedings of the IEEE, 93(11), pp. 1942–1955, 2005.
[6] Musa, Mohammed HH., Abusabah Ahmed IA.: Faulted-Phase Identification in TCSC-Compensated Transmission Lines using Concordance Correlation Coefficient-Based Method, Electric Power Components and Systems, 49(8), pp. 782–791, 2021.
[7] Alhmoud, Lina, Al-Zoubi H.: IoT applications in wind energy conversion systems, Open Engineering, 9(1), pp. 490–499, 2019.
[8] Taha R., Yahia S.,Ines M. , Florin I. , Ayachi E.: The impact of integration wind turbine on the stability of the electricity Grid, International Conference on Information Technology and Smart Industrial Systems Paris, July 15 – 17 2022.
[9] Taha R., Yahia S.,Ines M. , Florin I. , Ayachi E.: Influence of increasing order of AVR machine on electrical grid stability, 3rd International Conference on Applied Engineering and Natural Sciences July 20-23, Konya, 2022.
[10] Sreejith, S., Sishaj P., Simon, Selvan .M. P.: Power flow analysis incorporating firing angle model based TCSC, 5th International Conference on Industrial and Information Systems, 19(3), IEEE, 2010.
[11] Patel, Ramnarayan, Vasundhara M., Vinay P.: Modelling of TCSC controller for transient stability enhancement, International Journal of Emerging Electric Power Systems, 7(1), IEEE, 2006.
[12] El-Hawary, Mohamed E.: The smart grid state of the art and future trends, Electric Power Components and Systems, 70(3), pp. 239–250, 2014.
[13] Panda, Sidhartha,Narayana P.P. : MATLAB/SIMULINK based model of single-machine infinite-bus with TCSC for stability studies and tuning employing GA, International Journal of Energy and Power Engineering, 1(3), pp. 560–569, 2007.
[14] Chaudhuri, Balarko, Bikash C. Pal.: Robust damping of multiple swing modes employing global stabilizing signals with a TCSC, IEEE Transactions on power systems, 19(1), pp. 499–506, 2004.
[15] Vijayakumar, K.: Optimal location of FACTS devices for congestion management in deregulated power systems, International Journal of Computer Applications, 16(6), pp. 29–37, 2011.
[16] Yazdanpanah G., A., Asghari R.: A novel line stability index (NLSI) for voltage stability assessment of power systems, Proceedings 7th WSEAS Int. Conf. on Power Systems, 2007.
[17] Mathur, Mohan R., Rajiv K. Varma. : Thyristor-based FACTS controllers for electrical transmission systems, John Wiley Sons, 2002.
[18] Li, B. H., al.: Modelling of TCSC dynamics for control and analysis of power system stability, International Journal of Electrical Power Energy Systems, 22(1), pp. 43–49, 2000.
[19] Juncheng, Geng, al.: Mathematical model for describing characteristics of TCSC., Proceedings. International Conference on Power System Technology, 2002.
[20] Marian NOGA, Andrzej O˙ZADOWICZ, Jakub GRELA, Grzegorz HAYDUK, Active Consumers in Smart Grid Systems - Applications of the Building Automation Technologies, PRZEGLA˛D ELEKTROTECHNICZNY, ISSN 0033-2097, R. 89 NR 6/2013
[21] Sabrije OSMANAJ, Bukurie HOXHA, Rexhep SELIMAJ,An experimental study of Wind Data of a Wind Farm in Kosovo, PRZEGLA˛D ELEKTROTECHNICZNY, ISSN 0033-2097, R. 94 NR 7/2018
[22] Josip PAVLEKA, Srete NIKOLOVSKI, Marinko STOJKOV, Finding Optimal Location of FACTS device for dynamic Reactive Power compensation using Genetic Algorithm and Particle Swarm Optimisation (PSO), PRZEGLA˛D ELEKTROTECHNICZNY, R. 95 NR 8/2019.
[23] M. Eslami, H. Shareef, A. Mohamed, M. Khajehzadeh, A Survey on Flexible AC Transmission Systems (FACTS), Przegla˛d Elektrotechniczny, 2012, 88, 1-11. Fatiha LAKDJA, F.Z GHERBI, S.A ZIDI, OPF including TCSC devices using FACTS program software, PRZEGLA˛D ELEKTROTECHNICZNY (Electrical Review), R. 88 NR 11a/2012.
[24] Roshanak REZAEIPO, Ahad KAZEMI, Milad TAYEBI, Operational comparison of a new FACTS controller RHFC) with other FACTS devices considering modified steady-state model, PRZEGLA˛D ELEKTROTECHNICZNY (Electrical Review), R. 88 NR 7a/2012