University of Zawia

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Zawia - Libya

MSc thesis

Improvement of Power System Transfer Capabilities Using Thyristor Controlled Series Capacitor Compensation (TCSC)

A thesis submitted to the Faculty of engineering, University of Zawya in Fulfillment of the Requirements for Degree of Master of Science in the Department of Electrical and Electronic Engineering

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Fall 2020

جامعة الزاوية
كليـــــة الهندســـــــة
قسم الهندسة الكهربائية والإلكترونية

تحسين قدرات نظام نقل الطاقة باستخدام تعويض التوالي المحكوم بالثايرستور (TCSC)

اطروحة مقدمة لكلية الهندسة جامعة الزاوية لاستكمال متطلبات نيل درجة الاجازة العليا

(الماجستير) في مجال العلوم في قسم الهندسة الكهربائية والالكترونية

مقدمة البحث

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تحت اشراف

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خريف 2020

ABSTRACT

Electric power system faces many issues that limits their capability to work with max. Power transfer one of these issues are the faults that can occur on the inter connected power system which make some disturbance on the power system stability and control.

In order to increase the power system transfer capabilities, the Flexible Ac transmission, system (FACTS) can be a solution with its different categories. One of categories is called thyristors controlled series capacitor (TCSC) which is connected in series with the network and used to increase the power transfer capability by controlled the overall effective transmission line impedance. TCSC shows great ability to control the real and reactive power along with voltage magnitude. But there is a leak of in information about the operation of TCSC during faults conditions. In this thesis, the operation of TCSC during fault conditions is taken in consideration. To do that, two-test systems was modelled using two Matlab software and Neplan program, the simulation results shows a great effect of TCSC on the operation of test systems.

الملخص

تواجه منظومة القدرة الكهربائية العديد من الاشياء التي تقلل من قدرتها على العمل بأقصى قدرة ممكنة. واحد من تلك الاشياء هي الأخطاء التي تقع على المنظومة المتداخلة والتي تسبب بعض المشاكل على استقرارية والتحكم في منظومة القدرة.

كما نعرف جميعاً، لزيادة سعة نقل القدرة في المنظومة فإن منظومة نقل القدرة المرنة (FACTS) هي الأكثر فعالية في هذا المجال، ويمكن أن تكون الحل مع مختلف انواعها وتطبيقاتها. ومن بين هذه الأنواع المختلفة لمنظومة نقل القدرة المرنة يأتي (TCSC) في المقدمة. وحيث يوصل هذا الجهاز على التوالي مع الشبكة الكهربائية ويستخدم لزيادة نقل القدرة وذلك بالتحكم في القيمة النهائية للمفاعلة (Impedance) لخط النقل. هذا الجهاز أظهر قدرة عالية لتحكم في القدرة الحقيقية والقدرة المفاعلة وكذلك قيمة الجهد.

ولكن، هناك نقص في المعلومات حول عمل هذا الجهاز عند حدوث اي نوع من الأخطاء الشائعة.

وللوصول الى النتائج المرجوة تم استخدام برمجة الماتلاب وكذلك برنامج النيبلان. وقد اظهرت النتائج تأثير واضح لتعويض التوالي المحكوم بالثايرستور على عمل منظومة الاختبار.

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CHAPTER ONE
INTRODUCTION

Chapter One
Introduction

1.1- Background

The electricity supply industry is undergoing a profound transformation worldwide. Market forces, a shortage of natural resources and an increasing demand for electricity are some of the drivers of unprecedented change. In this rapidly evolving context, the expansion programs of many public utilities are thwarted by a variety of well-founded environmental, land-use and regulatory pressures that prevent licensing and the construction of new transmission lines. and electricity generating plants. An in-depth analysis of the options available to maximize existing transmission assets, with high levels of reliability and stability, has pointed in the direction of power electronics. There is general agreement that new power electronics equipment and techniques are possible substitutes for conventional solutions, which are typically based on electromechanical technologies that have slow response times and high maintenance costs.

An electric power system can be seen as the interconnection of generating sources and customer loads through a network of transmission lines, transformers and auxiliary equipment. Its structure has many variations that are the result of a legacy of economic, political, engineering and environmental decisions. Depending on their structure, energy systems can be broadly classified into mesh and longitudinal systems. Mesh systems can be found in regions with a high population density and where it is possible to build power plants near load demand centers. Longitudinal systems are found in regions where large amounts of energy must be transmitted over long distances from power plants to load demand centers.

Regardless of the structure of an energy system, energy flows through the network are largely distributed based on the impedance of the transmission line. A transmission line with low impedance allows a greater flow of energy through it than a transmission line with high impedance. This is not always the most desirable result because it often leads to a myriad of operational problems; The system operator's job is to step in to try to achieve redistribution of energy flow, but with limited success. Examples of operational problems that can be caused by unregulated active and reactive power flows are: loss of system stability, power flow loops, high transmission losses, voltage limit violations, inability to utilize capacity from the transmission line to the thermal limit and cascade tripping.

In the long term, these problems have traditionally been resolved through the construction of new power plants and transmission lines, a solution that is costly to implement and that involves long construction times and opposition from lobbyists. A new solution to such operational problems is expected to hinge on the improvement of existing transmission corridors through the use of the latest electronic power equipment and methods, a new technological thinking that comes under the generic title of FACTS, an acronym for transmission. AC flexible systems.

FACTS technology has to do with the ability to adaptively control the path of energy flows through the grid, where before the advent of FACTS, high-speed control was very restricted. The ability to control line impedance and nodal voltage magnitudes and phase angles at the send and receive ends of key transmission lines, almost without delay, has significantly increased network transmission capabilities while Greatly improves system security. In this context, power flow computer programs with FACTS controller modeling capabilities have been very useful tools for planners and system operators to assess the technical and economic benefits of a wide range of alternative solutions offered by FACTS technology, including TCSC [1]. These programs include MATLAB and NIPLAN.

1.2- Literature Review

Several references can be found in the technical literature on the development of stable, dynamic and linearized models of TCSC.

"NY Power & Light" used for the first time in the United States (1928) a more economical technique, such as "Fixed Series Compensation (FSC)", which uses fixed capacitors (FC) to increase the power transfer Capability. The FSC had been successful for many years to improve the stability and load capacity of transmission lines. The FSC had been successful for many years to improve the stability and load capability of transmission lines. The power oscillation damping problem as experienced by the Mojave generator station in southern Nevada in the 1970s and 71s, where two axes of the turbine generator failed has limited the use of FSC [2]. Vithayathil. (1986) proposed a method of "rapid adjustment of the impedance of the network" consisting of the series compensating capacitor derived by a thyristor controlled reactor. In a practical implementation of TCSC, several of these basic compensators can be connected in series to obtain the desired voltage rating and operating characteristics [3].The TCSC test (first single phase) began in 1991 by American Electric Power Co., based in Columbus, Ohio [4].

In [5], a recently the thyristor for Thyristor Controlled Series Compensation (TCSC) was developed. Mathematical models based on semiconductor physics and a comprehensive series of high current tests for unusually severe requirements were made.

The world's first TCSC facility (the manufacturer named it as Advanced Series Capacitor) is in the Kayenta substation between Glen Canyon and Shiprock, Arizona, USA. UU. In the 1990s. The Western Area Energy Administration (WAPA) in collaboration with Siemens completed the Kayenta advanced series capacitor project [6]. Whereas [7] analyzed the impact of installing FACTS devices by studying the linear sensitivities of power system quantities such as voltage magnitude, bus power injections, line power flow, and power losses with respect to line impedance.

In [8], presented a comprehensive review of research and developments in improving power system stability using FACTS controllers. Several technical issues related to FACTS installations have been highlighted and the performance comparison of different FACTS controllers has been discussed. Furthermore [9], Analyzed the optimal location of Flexible AC Transmission Systems (FACTS) in the power system of various machines using a genetic algorithm. The goal is to get the system bus voltages within healthy limits. TCSC is the FACTS device chosen for the proposed algorithm.

But [10], presented dealted with the used of the thyristor controlled series capacitor (TCSC) in the power system and show the possibilities of using TCSC to control the energy flow, given the current rate of increase in electricity transmission and growth requirements for transit is to increase the safety, capacity and control capacity and flexibility of systems for electricity transmission, needed the implementation of certain specialized measures and equipment. In [11] Provides a comprehensive review and evaluation of FACTS controllers, where the Flexible AC Power Transmission System (FACTS), a new technology based on power electronics, offers the opportunity to improve controllability, stability and power transfer capacity of alternating current transmission systems.

The benefits of utilizing FACTS devices with the purpose of improving the operation of an electrical power system and different FACTS controllers has been discussed. In addition, some of the utility experience and semiconductor technology development have been reviewed and summarized [12]. Reviewed of the comparison of different

FACTS controllers in the power system to improve stability and benefits of FACTS controllers for powering the system are also discussed [13]. A comprehensive review and evaluation of FACTS controllers was given in [14].

In this project, through the above, that most of the studies did not address all the problems suffered by the network, and the most important are the fault types. Therefore, it is necessary to investigate and analyze the effect of these types of faults on the network and the TCSC reaction.

1.3 - Problem Statement

At nowadays is an increase in electricity demand and dramatically, causing the biggest problem is the requirement to increase the transmission of capacity to the system than originally designed.

The main lines of electricity transmission are long distances and the concentration of the load requires more transmission lines to be interconnected. These characteristics of the energy systems cause many problems in system stability and problems related to currents.

Based on that, this thesis will investigate the behavior of TCSC in presence some kinds of fault types and how will affect the overall power system operation and control.

1.4 - Methodology

In order to study the previous presented problem the following steps will be conducted.

- A test system consists of a programmable voltage source of sending and receiving ends of the transmission line (TL). Single diagram is used in this system is shown in Figure (1.1), a 500kV transmission line, but due to losses in the lines, the final reception voltages were reduced to 477kV. The transmission line has an impedance of

(6.0852+j 162.97) Ω. Will be used model in Matlab software in order to study the performance of TCSC.

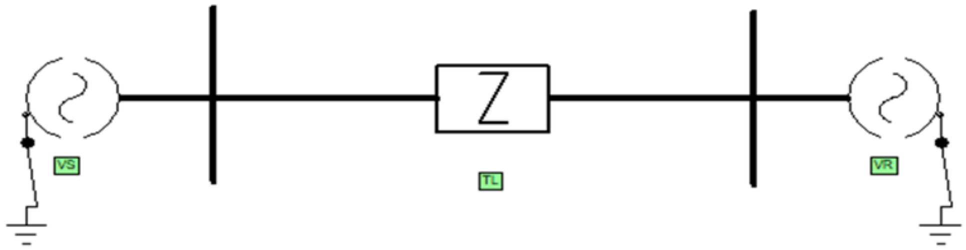

Fig (1.1) single line diagram of the model of electrical network

- Study the effect behavior of TCSC connected to the test system steady state analysis & the effect of fault type on the test system without and with TCSC.
- Also, for deeply investigater of TCSC capability in improving transfer capability, A IEEE 14 bus test system is used in Neplan software program, the details for IEEE-14 bus test system is given in (Appendix I).

1.5- Objectives

The main objectives of this thesis are:

- To analysis the effect of steady state without and with the TCSC.
- To analysis the effect of the fault types in power system without and with the TCSC.
- To discuss the behavior of TCSC on the power oscillation damping**.**
- To analysis, the capabilities of TCSC on power transfer.

1.6- Outline of Thesis

This thesis consists of five chapters as follows:

Chapter One:

This chapter presents general introduction, objective and the research structure.

Chapter Two:-

- This chapter introduces the main relations related to power transfer problems.

Chapter Three:-

Chapter Three describes Specifications of TCSC Composition and operation methods.

Chapter Four:-

Deals with the simulation of the effects of TCSC when used to improve Power System Transfer Capabilities by using MATLAB & NEPLAN, under normal and abnormal continues.

Chapter Five:-

Introduces the Conclusion of this thesis and provide some recommendations for future works.

Chapter Five

Conclusion and Recommendation

5.1- Conclusions

In this thesis, two types of computer programs were used to investigate the operation of TCSC under different operation conditions. Two models of 500 KV test system in Matlab software and IEEE-14 bus test system in Neplan software were used.

The simulation results shows that, the TCSC has a great influence on the test system under different operation conditions as follows:

- Increases power transfer capabilities.
- Quick response to the changes of operation conditions.
- Minimize power system losses.
- Has great effect on power system oscillations.
- Has great effect on voltage-bus stability.
- Better results can be achieved by using more than one TCSC.
- Can be used for bigger networks.

Based on that, TCSC is very effective tools on the power system operation and control, and it can be a suitable solution to the general electric company of Libya (GECOL) in order to enhance their system networks.

5.2- Recommendations for Future Works.

The following steps can be taken as recommendations for future works:

1- The work done can be extended by installing TCSC to a Real networks in reality.

2- More researches can be conceded by Installing TCSC at multiple sites in the system.
3- Installing more number of TCSC in the system requires more Investigation.
4- The operation of TCSC in presence of other FACTS type controllers can be considered.
5- The suitable solution to the networks is to meet the requirements for smart grid with more researches and investigation.

REFERENCES

References

[1] Acha, Enrique, et al. FACTS: modelling and simulation in power networks. John Wiley & Sons, 2004.

[2] Meikandasivam, S., Rajesh Kumar Nema, and Shailendra Kumar Jain. "Performance of installed TCSC projects." India International Conference on Power Electronics 2010 (IICPE2010). IEEE, 2011.

[3] Larsen, E. V., et al. "Characteristics and rating considerations of thyristor controlled series compensation." IEEE Transactions on power delivery 9.2 (1994): 992-1000.

[4] Meikandasivam, S., and Shailendra Kumar Jain. "Behavioral Study of TCSC Device–A MATLAB/Simulink Implementation 1." (2008).

[5] McDonald, D. J., J. Urbanek, and B. L. Damsky. "Modeling and testing of a thyristor for thyristor controlled series compensation (TCSC)." IEEE transactions on power delivery 9.1 (1994): 352-359.

[6] Shea, J. J. "Understanding FACTS-concepts and technology of flexible AC transmission systems [Book Review]." IEEE Electrical Insulation Magazine 18.1 (2002): 46-46.

[7] Rogers, K. M., and Thomas J. Overbye. "Some applications of distributed flexible AC transmission system (D-FACTS) devices in power systems." 2008 40th North American Power Symposium. IEEE, 2008.

[8] Abido, M. A. "Power system stability enhancement using FACTS controllers: A review." The arabian journal for science and engineering 34.1B (2009): 153-172.

[9] Bansal, H. O., et al. "Optimal location of FACT devices to control reactive power." International Journal of Engineering Science and Technology 2.6 (2010): 1556-1560.

[10] German-Sobek, Martin, Ľubomír Beňa, and Roman Cimbala. "Using of the thyristor controlled series capacitor in electric power system." Elektroenergetika 4.4 (2011).

[11] Georgilakis, Pavlos S., and Peter G. Vernados. "Flexible AC transmission system controllers: An evaluation." Materials Science Forum. Vol. 670. Trans Tech Publications Ltd, 2011.

[12] Mohanty, Alok Kumar, and Amar Kumar Barik. "Power system stability improvement using FACTS devices." International Journal of Modern Engineering Research (IJMER) 1.2 (2011): 666-672.

[13] Mathad, Vireshkumar G., Basangouda F. Ronad, and Suresh H. Jangamshetti. "Review on comparison of FACTS controllers for power system stability enhancement." International Journal of Scientific and Research Publications 3.3 (2013): 2250-315.

[14] Singh, Ravi Pratap, S. K. Bharadwaj, and R. K. Singh. "Flexible AC transmission system controllers: A state of art." International Journal of Electronic and Electrical Engineering 7.8 (2014): 843-850.

[15] Sahadat, Md Nazmus, et al. "Real power transfer capability enhancement of transmission lines using SVC." 2011 Asia-Pacific Power and Energy Engineering Conference. IEEE, 2011.

[16] Srikanth, P., et al. "Load flow analysis of ieee14 bus system using matlab." International Journal of Engineering Research and Technology 2.5 (2013): 149-155.

[17] Das, Debapriya. Electrical power systems. New Age International, 2007.

[18] Reddy, M. Venkateswara, Bishnu Prasad Muni, and A. V. R. S. Sarma. "Enhancement of voltage profile for IEEE 14 bus system with inter line power flow controller." 2016 Biennial International Conference on Power and Energy Systems: Towards Sustainable Energy (PESTSE). IEEE, 2016.

[19] Boudreaux, John Albert. "Design, Simulation, and Construction of an IEEE 14-Bus Power System." (2018).

[20] Jovcic, Dragan, and G. N. Pillai. "Analytical modeling of TCSC dynamics." IEEE Transactions on Power Delivery 20.2 (2005): 1097-1104.

[21] Hingorani, Narain G., Laszlo Gyugyi, and Mohamed El-Hawary. Understanding FACTS: concepts and technology of flexible AC transmission systems. Vol. 1. New York: IEEE press, 2000.

[22] Kundur, Prabha, et al. "Definition and classification of power system stability IEEE/CIGRE joint task force on stability terms and

definitions." IEEE transactions on Power Systems 19.3 (2004): 1387-1401.

[23] Zhang, Xiao-Ping, Christian Rehtanz, and Bikash Pal. Flexible AC transmission systems: modelling and control. Springer Science & Business Media, 2006.

[24] Mathur, R. Mohan, and Rajiv K. Varma. Thyristor-based FACTS controllers for electrical transmission systems. John Wiley & Sons, 2002.

[25] Hassan, H. T., et al. "Stability improvement of power system using Thyristor Controlled Series Capacitor (TCSC)." International Journal of Engineering and Computer Science 13 (2013): 30-34.

[26] Meikandasivam, S., Rajesh Kumar Nema, and Shailendra Kumar Jain. "Selection of TCSC parameters: Capacitor and inductor." India International Conference on Power Electronics 2010 (IICPE2010). IEEE, 2011.

[27] Mathur, R. Mohan, and Rajiv K. Varma. Thyristor-based FACTS controllers for electrical transmission systems. John Wiley & Sons, 2002.