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# Modelling and Analysis using The Thyristors Controlled Series Compensators for Electrical Power Systems

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## ABSTRAK

*Untuk memastikan bahwa kebutuhan masyarakat yang berkembang terpenuhi dan tingkat ketergantungan sistem cukup, sangat penting untuk mengelola dan memelihara sistem distribusi daya yang andal. Karena jarak transmisi yang jauh, tidak mungkin untuk mencegah kerusakan instalasi pada sistem tenaga listrik. Hal ini berdampak signifikan pada transmisi tenaga listrik, yang mengakibatkan penurunan tegangan dan hilangnya energi listrik. Penggunaan Flexible Alternating Current Transmission System (FACTS) merupakan salah satu cara untuk mengurangi ketidakstabilan tegangan dan meningkatkan kehandalan jaringan tenaga listrik. Perangkat FACTS adalah Thyristor Controlled Series Compensator (TCSC). Kapasitas daya saluran transmisi ditingkatkan dengan menambahkan TCSC secara seri dengan saluran transmisi. Untuk meningkatkan aliran daya, reaktansi TCSC dapat disesuaikan untuk memodulasi reaktansi saluran transmisi.*

***Kata kunci**: sistem tenaga listrik, FACTS, kompensator seri, tiristor, TCSC*

## ABSTRACT

*In order to ensure that the expanding requirements of the community are met and that the system's level of dependability is sufficient, it is crucial to manage and maintain a reliable power distribution system. Due to the extensive transmission distance, it is impossible to prevent installation malfunctions in the electric power system. This has a significant impact on the transmission of electric power, resulting in a voltage decrease and a loss of electrical energy. Using a Flexible Alternating Current Transmission System (FACTS) is one way to reduce voltage instability and improve the dependability of the electrical power grid. A FACTS device is the Thyristor Controlled Series Compensator (TCSC). The power capacity of the transmission line is increased by adding the TCSC in series with the transmission line. In order to increase power flow, the TCSC's reactance can be adjusted to modulate the transmission line's reactance.*

***Keywords**: electrical power system, FACTS, series compensators, thyristors, TCSC*

## 1. INTRODUCTION

The electric power infrastructure is vital to human activities. Alongside the growth of society and technology, the demand for electricity continues to increase. However, the development of the electrical power system is insufficient to satisfy the demand for electrical energy. In order to satisfy the increasing demands of the community and maintain a sufficient supply, it is necessary to regulate and manage an effective electricity system.Installation failures in the electric power system are unavoidable because of the long transmission distance, covering a very large area, and the rapid growth of community needs compared to the improvement of the existing power transmission system **(Rui et al., 2016) (Zainuddin et al., 2018).** This has a major effect on the flow of power in the transmission of electric power, resulting in a decrease in voltage and loss of electrical power **(Tang et al., 2018)**. Based on the above problems, to overcome voltage stability and improve the reliability of the electric power system, one of them is to use Flexible Alternating Current Transmission Systems (FACTS) **(Zhang et al., 2019) (Shahbudin et al., 2019).** The FACTS device is a control device that is placed on a transmission network system that can increase the ability to transfer electrical power **(Eladany et al., 2018)**. FACTS devices can function optimally when placed at certain points of the network and adjust the given setting value, one of which is the installation of a Thyristor Controlled Series Compensator (TCSC) component **(Shafik et al., 2019)**. TCSC is a device that functions as an impedance controller of the transmission line. TCSC is a variable impedance type FACTS device that is easy to implement in power transmission networks to get better power flow results **(Jiang et al., 2019) (Taha et al., 2021).**The TCSC is installed in series with the transmission line in order to enhance the capacity of the transmission line. By controlling the reactance of the TCSC, it is possible to control the reactance of the transmission line, thereby increasing the power transfer or the transmission line's capacity **(Kulkarni & Ghawghawe, 2015)**. Installation of this TCSC can be done at one or several points to achieve the expected voltage and power loss values **(Eladany et al., 2018)**. The capacitance effect will cause the voltage on the receiving side to be smaller than the voltage on the sending side; this phenomenon is known as voltage drop. At light and medium loads, the voltage at the receiving end cannot exceed the permissible voltage according to the specifications of the power transformer used **(Deepak & Abraham, 2015)**. The problem of voltage drop will be more important if the transmission line is getting longer. For this problem, an effort is made by compensating the capacitive reactive power that occurs in the transmission line with inductive reactive power from other sources. Then it is used with the installation of shunt reactor compensation on the transmission line, especially on the load-receiving side **(Putra, 2021)**. The installation of SVC in the transmission system not only improves system voltage but also reduces power losses in the system by 14%. So, it can be concluded that the installation of SVC has proven to be influential in improving the voltage profile and power losses in the system **(Raj & Bhattacharyya, 2018) (Zhu, 2019).**

Based on previous research related to FACTS on transmission lines, the researcher will propose to apply one of the FACTS equipment, namely TCSC which aims to increase reactive power compensation in the transmission system to improve power line efficiency **(Panda, 2009) (Nurohmah & Ali, 2013) (Ibrahim et al., 2020).** In this study, a thyristor will be used as a series compensator analysis for an electric power system.The advantage of this method is that it is more practical in larger power systems and requires less iteration. What distinguishes this research from previous research is the installation of TCSC to increase stability and calculate power flow from bus to bus. The data used is real load data installed on the 150 kV Riau transmission network in 2019 with peak load conditions. In general, the problem that arises from the study of power flow is when the load between one phase is not balanced with each other. Therefore, in completing the power flow study, the system is assumed to be in a stable state, the load is balanced between phases and does not experience disturbances so that the calculation is in one phase **(Saadat, 1999)**. For the needs of power flow studies, there are data from buses and data from transmission lines in an electric power system. The data contained in each bus include the magnitude of the voltage in p.u, the voltage angle (θ), the magnitude of the loading consisting of active power (P) and reactive power (Q), the magnitude of generation consisting of active power (P), reactive power (Q), Qmin, and Qmax **(Tleis, 2007)**. While the data contained in the transmission line includes transmission line resistance in pu., transmission line reactance in pu, transformer tap, and voltage rating in kV.

## 2. METHODS

The research method used this time is to use data from the electric power transmission system obtained from the GS Substation, then modeled the transmission line and designed a TCSC circuit to reduce power losses in the line and improve bus voltage stability. This study is data on single-line electricity from the KP bus to BP bus, introductory data, active and reactive loads, generators, transformers, and impedance. A simple description of a typical bus in a power system can be seen in Figure 1, describing the current flow process from the bus by passing the admittance on each bus and describing the bus voltage and voltage on each transmission line.

In general, the Newton-Raphson method is almost the same as the Gauss-Seidel, but the Newton-Raphson is more efficient and practical in solving power flow studies in large power systems **(Saadat, 1999) (Krzywonos & Krzysiak, 2017)**.The number of iterations required to complete the calculation is based on the size of the system. In the problem of power flow, the active power and voltage magnitude are specified for the generator bus while the power flow is formulated in polar **(Ferreira et al., 2023)**. Voltages, current, and power are oversized transmission lines that are observed to operate an electric power system. Based on this greatness, then steps are taken to regulate the operation so that the transmission line can be operated optimally **(Gonen, 2011)**. Operational regulation steps that are carried out are the regulation of active and reactive power sources **(Glover et al., 2012)**. The per-unit system is a way of simplifying a calculation value that is very useful in the analysis of electric power systems, which involve transmission lines, several transformers, and generators. The simplification of this calculation is to express a certain value such as power, voltage, current, impedance, and admittance into units per unit which later if desired to know the actual value can be referred to as the reference value **(Novriandi et al., 2019) (Zhang et al., 2021)**.

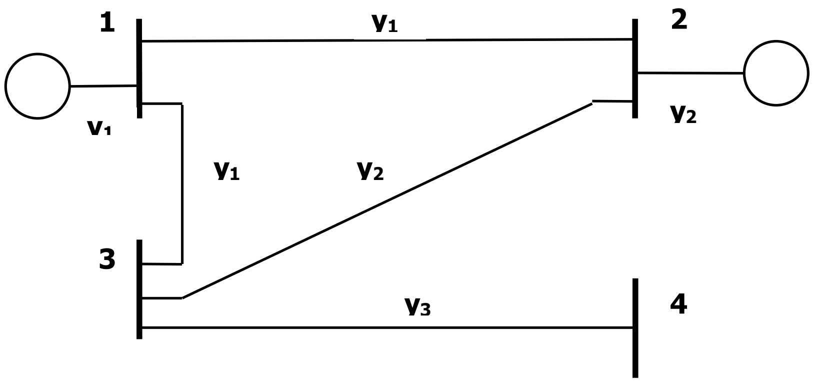


**Figure 1. Typical Bus of a Power System**

For power flow calculations, it is assumed that power flow occurs between two buses (i and j) as shown in Figure 2.

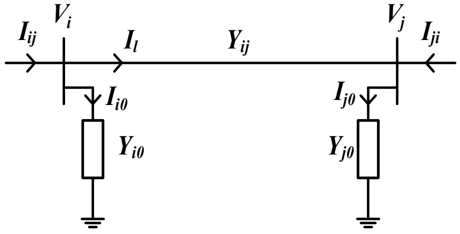
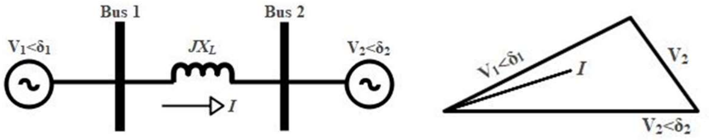


**Figure 2. Transmission Line Modeling for Power Flow**

Resistance, inductance, conductance, and capacitance are the four parameters that affect a transmission line's ability to function as a component of a power system. In addition to voltage drop, transmission lines also experience power losses. Power losses occur when the power received is less than the power sent by the transmitting side **(Gonen, 2011)**. In general, the load on the power system line is resistive-inductive. The load will absorb the active power (P) and reactive power (Q) generated by the inductive component which will cause a voltage drop at the voltage supplied by the sending bus. As a result, the value of the voltage on the receiving side will be different from the value of the voltage on the sending side **(Raoofat et al., 2015) (Eladany et al., 2018)**.

The flow of active power and reactive power in the electric power transmission network is not directly related to each other because each is influenced and regulated by different quantities. Although the effect of series compensation will increase both **(Agrawal et al., 2019)**. Active power regulation is closely related to frequency regulation, and reactive power can be adjusted through voltage regulation. Frequency and voltage are important quantities in determining the quality of the power supply in a power system so the regulation of active power and reactive power is important to show the appearance of the electric power system. The voltage and frequency at each load point are expected to be constant and free from harmonics and the power factor is one. The ability of the power system to approach the above ideal conditions is a measure of the quality of a power delivery **(Gonen, 2011)**.Compensation means the process of compensating for losses or ways to compensate for losses. In simple terms, it can also be interpreted as a balancing process. Compensation on the electric power transmission line is basically the insertion or insertion of reactive power generating or absorbing equipment in the electric power system. This is intended to improve the appearance of the line, including stabilizing the working voltage between the sending and receiving sides, and reducing the electrical length of the line so as to increase its power delivery. Compensation devices on the transmission line include shunt reactors, shunt capacitors, series capacitors, or a combination of themas shown in Figure 3. Shunt reactor compensation is usually used on medium-distance transmission lines (80–250 Km), compensation with series capacitors or a combination of shunt reactors with series capacitors is used on long-distance transmission lines (>250 Km) **(Iešmantas & Alzbutas, 2019) (Brinkmann, 2020).**



**(a)** **(b)**

**Figure 3. Power Transmission Model (a) System Circuit (b) System Vector**

TCSC is a controlled series capacitive reactance that can indefinitely regulate power flow over a wider spectrum. Variable series compensation is based on the concept of increasing the fundamental frequency of the voltage on a fixed capacitor in a series compensated line by altering the ignition angle. This change in voltage determines the effective value of the capacitive reactance. By analyzing a circuit consisting of a variable inductor connected in parallel with a fixed capacitor, the TCSC's operating principle can be better comprehended **(Nurohmah, 2013) (Shahbudin et al., 2019)**. In operation, TCSC has several kinds of operating image modes, and the form of the operation is: by-passed thyristor mode; blocked thyristor mode; capacitive Vernie mode. This circulating current will increase the voltage across the capacitor, thereby effectively increasing the capacitive equivalent reactance and series compensation level on the line. In other words, the vernier capacitive TCSC mode is capacitive **(Eladany et al., 2018)**. To limit the possibility of resonance, the TCSC is operated with an ignition angle period between min $<\alpha<180°$. If the loop current will increase then the ignition angle will be smaller from 180° to min. The maximum reactance of TCSC is obtained when $\alpha=\alpha$ min, which is usually the magnitude of the TCSC reactance, is greater than the value of capacitive reactance at the fundamental frequency **(Shafik et al., 2019) (Peng et al., 2021)**.

## 3. RESULTS AND DISCUSSION

This chapter discusses the design of the TCSC circuit modeling on the GS bus transmission line to improve voltage stability on the 150 kV transmission line. The modeling of the electric power system from the KP bus, BG bus, GS bus, and BP bus became the object of research. In this modeling, the TCSC circuit model will be designed and simulated. Then the simulation results are matched with the data taken, whether the voltage stability has been reached or above the data under study. In this study, the simulation was carried out using data, namely the real data of the Riau 150 kV electric power system as validation. On loading, several tests will be carried out on the system, the system without TCSC installation, and the TCSC placement used on GS bus. In regulating the electric power system, it must meet the rules of reliability and efficiency, both economically and operationally. One of the efforts to improve the reliability of the electric power system is to make several studies that are applied to the system to anticipate the condition of the system lacking power supply, both active power and reactive power.

One of the tasks of the dispatcher is to maintain the quality of the system voltage at the normal voltage limit of 150 kV. Voltage regulation can be done by operating the TCSC generator or installation. If the system is experiencing power factor problems due to a shortage of active power supply, to contain the rate of power factor decline, an operating strategy is adopted with load shedding, which is a release using an Under Voltage Load Shedding (UVLS) relay. Factors that cause voltage problems include the absence of generators to support Mvar because they are currently under maintenance, interruption, or expiration of the leased power plant contract, while the load growth is very significant. The contributing factor is the summer which resulted in hydropower plants with a capacity of 3x38 MW not operating optimally, resulting in several substations experiencing a decrease in voltage quality. In the current condition of the electricity system, the largest generating power is found in the subsystem of 1,823 MW with a peak load of 1,695 MW. Meanwhile, the subsystem has a generating power of 1,315 MW with a peak load of 781 MW. The other subsystem is 209 MW with a peak load of 303 MW. 236 MW is distributed to the West Sumatera, then from the West Sumatera system goes to the Riau system of 214 MW. The Riau system is currently capable of generating 443 MW of electrical energy and a peak load of 657 MW. Then, the Riau system is fulfilled, and the remainder is distributed to the North Sumatera system of 54 MW. The Power plants operating on the Riau system on the object of research are as follows; water turbine of KP 3x38 MW, and gas turbine BP 29 MW. The largest power plant operating is the generator at the KP which can produce electrical energy of 144 MW. The KP is the most important generator bus, so it greatly affects the voltage stability in the system in the event of a disturbance. In this case, the problem that often occurs in the KP is the water crisis due to the dry weather that has occurred in Riau for a long time. Due to the long dry weather, the KP hydropower plant was disrupted due to a decrease in water flow so the water turbine did not operate, and the generator did not work. Under these conditions, the supply of active and reactive power at substations in the Riau region experiences a voltage drop and the distribution of the load becomes uneven. The condition of the electricity load in Riau which is served is divided into several sectors, namely, household, industrial, commercial, and business. The characteristics of each sector are different because in this case, it is related to the pattern of electricity consumption by consumers. The largest sector in energy use is the household sector, so the peak load of the Riau transmission system occurs at night.

Alongside the growth of the residential, industrial, commercial, and business sectors, the carrying capacity is increasing. The rapid growth of community needs relative to the expansion of the existing electricity transmission system has a substantial effect on the flow of power in electric power transmission, resulting in a decrease in voltage and power loss.TCSC is a controlled series capacitive reactance that can control the power flow continuously over a wider range. The principle of this variable series compensation is actually very simple increasing the fundamental frequency of the voltage on a Fixed Capacitor (FC) in a series-compensated line by changing the ignition angle. This change in voltage determines the effective value of the capacitive reactance. In variable mode, the inductive reactance will increase while the capacitive reactance will decrease. The minimum equivalent capacitive reactance is obtained when the reactance value is very large or when the variable inductor is in an open circuit state so that in this condition the value is the same as the reactance of the FC itself. The characteristics of the TCSC itself are almost the same as the combination of parallel LC circuits. The difference is that in this LC circuit, the current and voltage waveforms are pure sinusoidal so that harmonics analysis is not carried out, whereas in TCSC the current and voltage forms are not purely sinusoidal. This is due to the effect of switching on the thyristor which results in distorted current and voltage waveforms.

In capacitive mode, the current flowing through the inductor is smaller than the current flowing through the capacitor. Where the inductor current is opposite to the capacitor current, causing the circulation of current to flow in the TCSC. This circulating current will increase the voltage across the capacitor, thereby effectively increasing the capacitive equivalent reactance and series compensation level on the line. In other words, the TCSC capacitive mode is capacitive. To limit the possibility of resonance, the TCSC is operated with an ignition angle period between $\alpha_{min} < \alpha < 180°$. If the loop current will increase then the ignition angle will be smaller from $180^{o}$ to α min. The maximum reactance of TCSC is obtained when α =α min, which is usually the magnitude of the TCSC reactance, is greater than the value of capacitive reactance (FC) at the fundamental frequency. The power flow simulation was carried out in 2020 on the Riau electricity system. Capacity Factor (CF) of generators that operate normally at peak loads and according to system requirements in the software simulation. The power flow of the Riau system under normal conditions in 2020, the voltage on the BG bus is 0.9868 p.u and the GS bus has a voltage of 0.9637 p.u, it can be concluded that the electricity system has uneven capabilities. Buses at the end have low stability because they are far from the generating center. BG and GS buses have a long distance from the KP which results in higher line reactance. The peak load occurs at night, and the voltage value on the bus which is far from the generating center occurs voltage drops. The voltage drop occurs because the BG bus and GS bus are far from the power source. As a result of the voltage drop, damage occurs to electrical equipment, both equipment and consumer equipment. More detailed simulation results can be seen in the static report of the power flow study.

**Table 1. The Voltage before TCSC was Installed on 150 kV**

| **Bus** | **Voltage** |
|---|---|
| BP | 1 |
| BG | 0.9868 |
| GS | 0.637 |
| KP | 1 |

Table 1 describes the simulation results of the initial state of the electrical system before installing TCSC on the channel using the static report command in the software. Power Flow Calculation before TCSC Installation; to simplify the calculation of the power flow on the 150 kV transmission line, the author assumes the KP bus as p and the BG bus as q, so the power flow Equation (1) until (9) from bus p to q is as follows **(Gonen, 2011) (Glover et al., 2012)**:

$$P_{pq} + jQ_{pq} = V_p I_{pq} = V_p \left[ \left( V_p - V_q \right) y_{pq} + V_p \frac{y'_{pq}}{2} \right] \tag{1}$$

The power flow from bus q to p is as follows:

$$P_{qp} + jQ_{qp} = V_q I_{qp} = V_q \left[ \left( V_q - V_p \right) y_{pq} + V_q \frac{y'_{pq}}{2} \right] \tag{2}$$

The power losses in the transmission line between bus p and bus q are given by:

$$S_{loss,pq} + jQ_{loss,pq} = \left( P_{pq} + jQ_{pq} \right) + \left( P_{qp} + jQ_{qp} \right) \tag{3}$$

BG to GS;

$$P_{pq} + jQ_{pq} = V_p I_{pq} = V_p \left[ \left( V_p - V_q \right) y_{pq} + V_p \frac{y'_{pq}}{2} \right] \tag{4}$$

The power flow from bus q to p is as follows:

$$P_{qp} + jQ_{qp} = V_q I_{qp} = V_q \left[ (V_q - V_p) y_{pq} + V_q \frac{y'_{pq}}{2} \right] \tag{5}$$

The power losses in the transmission line between bus p and bus q are given by:

$$S_{loss,pq} + jQ_{loss,pq} = \left( P_{pq} + jQ_{pq} \right) + \left( P_{qp} + jQ_{qp} \right) \tag{6}$$

GS to BP;

$$P_{pq} + jQ_{pq} = V_p I_{pq} = V_p \left[ (V_p - V_q) y_{pq} + V_p \frac{y'_{pq}}{2} \right] \tag{7}$$

The power flow from bus q to p is as follows:

$$P_{qp} + jQ_{qp} = V_q I_{qp} = V_q \left[ (V_q - V_p) y_{pq} + V_q \frac{y'_{pq}}{2} \right] \tag{8}$$

The power losses in the transmission line between bus p and bus q are given by:

$$S_{loss,pq} + jQ_{loss,pq} = \left( P_{pq} + jQ_{pq} \right) + \left( P_{qp} + jQ_{qp} \right) \tag{9}$$

**Table 2. Power Flow before TCSC is Installed**

| Bus to Bus | Power Flow | | Power Loss |
|---|---|---|---|
| p - q | p to q | q to p | |
| KP to BG | $0.045 - j0.557$ | $0.008 + j0.016$ | $0.053 - j0.541$ |
| BG to GS | $0.0236 - j0.038$ | $0.0206 + j0.035$ | $0.0442 - j0.0021$ |
| GS to BP | $0.0335 + j0.0643$ | $0.064 - j0.194$ | $0.0975 - j0.1297$ |
| | losses | | $0.1947 - j0.6728$ |

Calculation of power flow before installation of TCSC in normal operating conditions. The calculation results can be seen in Table 2 where the total power losses are 0.1947-j0.6728 p.u. The line reactance causes power losses to increase, so the voltage on the receiving bus falls. The power losses increase with the length of the transmission line. The solution to this problem is to install TCSC to increase reactive power. The power flow prior to the installation of TCSC on the transmission line there is an uneven loading on the BG bus and the GS bus, namely, 0.9868 p.u and 0.9637 p.u. The GS bus has a very long distance so it has a larger line reactance. At the time of peak load that occurs at night, the voltage value on the bus which is far from the generating center occurs a voltage drop. The voltage drop occurs because the GS bus is far from the electrical power supply. The problem that arises from this voltage drop is damage to electrical equipment, both equipment and consumer equipment, so TCSC is installed on the GS bus line. Then after the installation of the TCSC circuit on the transmission line the voltage value on the uneven load bus increased. On the BG bus it increased to 0.99008 and on the GS bus it increased to 0.97693. More detailed simulation results can be seen in the static report of the power flow study in Table 3.

**Table 3. Voltage after TCSC**

| Bus | Voltage (pu) |
|---|---|
| BP | 1 |
| BG | 0.99008 |
| GS | 0.97693 |
| KP | 1 |

**Table 4. Power Flow after TCSC Installed**

| Bus to Bus | Power Flow | | Power Loss |
|---|---|---|---|
| p-q | p to q | q to p | |
| KP to BG | $0.0434 - j0.435$ | $-0.042 - j0.426$ | $0.0008 - j0.0086$ |
| BG to GS | $0.0273 - j0.208$ | $-0.026 + j0.206$ | $0.0004 - j0.00028$ |
| GS to BP | $-0.0421 - j0.163$ | $0.043 - j0.09$ | $0.0011 - j0.2622$ |
| | Total Power Loss | | $0.0023 - j3.7567$ |

Power losses on the transmission line between bus p and bus q of all research object buses after the installation of TCSC system conditions operate normally. The calculation results can be seen in Table 4 where the total power losses are 0.0023–j3.7567 pu. These data indicate that the total power losses during TCSC installation are smaller than before TCSC installation, where the total power losses before TCSC installation are 0.1947–j0.6728. After calculating the line power losses on BG bus and GS bus, the power losses on BG bus and GS bus before TCSC installation were 0.0442–j0.0021 and 0.0975–j0.1297. Power losses after TCSC installation decreased on BG bus and GS bus to 0.0004–j0.00028 and 0.0011–j0.2622. The power flow calculation uses the formula in equation (1) to (9), that the voltage range on the bus in the electricity system is getting better, which is at the permitted interval, which is 0.97693-1.00 pu. This proves that TCSC is a tool that can improve the voltage profile and by comparing the power losses before and after TCSC installation, the power losses become smaller, namely, the total power losses of 0.0023-j3.7567, where before the TCSC installation the total power losses are 0.1947–j0.6728. It can be seen graphically that the reactive power compensation carried out by TCSC can improve the system voltage profile. Reactive power compensation analysis, where reactive power is power that results in power losses or power that results in a decrease in power factor value. The calculation of power flow before and after TCSC installation shows that the reactive power in the line has decreased by 6.79%, a decrease in reactive power will result in an increase in the value of the power factor so that the active power will increase. The comparison of the increase in voltage from before using TCSC with after using TCSC can be seen in the curve shown in Figure 4.

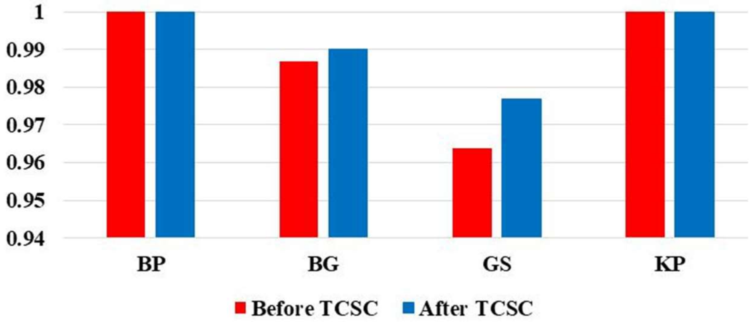


**Figure 4. Comparison Before and After TCSC is Installed**

Figure 4 illustrates the comparison of power flow that before the installation of TCSC the lowest loading was on the BG bus 0.9868 p.u and the GS bus 0.9637 p.u. After the installation of TCSC on the 150 kV transmission system, the installed TCSC rating is 25 MVar. TCSC is installed on the GS-BP line, where the GS bus has a low voltage due to high reactive power. The purpose of this installation is to reduce reactive power that causes voltage drops. Therefore, TCSC is installed to improve voltage quality to maintain the stability of the electric power system, especially on the GS bus. Parameter values alpha $0.2 - j0.8$. After installing the TCSC, the voltage stability changed on the BG bus and the GS bus, increasing to 0.99008 p.u (148.512 kV) and 0.97693 p.u (146.535 kV). The length of the transmission line between the bus GS to the bus BP, 77.10 Km increases the line power losses which causes the voltage drop to increase. However, with the installation of TCSC, the voltage stability increases, and the power losses in the line decrease, in accordance with the TCSC function which can regulate the amount of reactive load on the transmission line. Under the normal system, the RMS voltage recorded on bus KP in 2019 when peak load conditions had a value of 0.978092 p.u (146.7138 kV). Figure 8 is a model of the Riau system using the DIgSILENT software. The sub-system modeling includes the hydropower plant in KP with a capacity of 3x38 MW, the bus KP with a load of 19.63 MW, the bus BG with a load of 52.5 MW, the bus GS with a load of 75 MW, the bus BP with a load of 14.63 MW, and a gas engine power plant at BP with a generated capacity of 29 MW. Figure 5 shows the model used; the parameter data used in the software is in accordance with real data in the field. Modeling Figure 5 system under normal conditions where all power plants are operating or not under fault and during maintenance. By running a simulation, the simulation results were obtained for the magnitude of the voltage on each bus. Table 5 describes the voltage on the research object bus under normal conditions where the generator has no fault and the maintenance period.

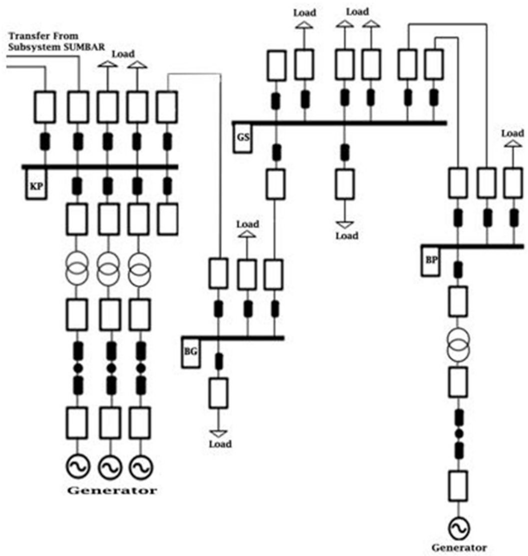


**Figure 5. Transmission Line Model System**

**Table 5. Results of System Modeling**

| Bus | Voltage (pu) |
|---|---|
| KP | 0.9780 |
| BG | 0.9735 |
| GS | 0.9758 |
| BP | 0.9942 |

**Table 6. Validation between Matlab & DIgSILENT**

| Bus | Matlab (p.u) | DIgSILENT (p.u) |
|---|---|---|
| KP | 1 | 0.9780 |
| BG | 0.99008 | 0.9735 |
| GS | 0.97693 | 0.9758 |
| BP | 1 | 0.9942 |

Table 6 describes the comparison of the voltages on each bus on the research object between the results of the DIgSILENT software simulation using real data from the normal condition with the simulation results of the Matlab toolbox PSAT 2.1.11 software after installing TCSC on the bus GS to BP. After the installation of TCSC at the 150 kV GS substation on the GS line to BP with a distance of 77.10 Km, the voltage for each bus has increased, especially on the bus closest to the installation location because the installation of TCSC can affect the voltage on the buses adjacent to it installation location. The increase in voltage on the bus KP from 0.9780 p.u to 1 p.u, the bus BG from 0.9735 p.u to 0.99008 p.u, the bus GS from 0.9758 p.u to 0.97693 p.u, and the bus BP from 0.9942 p.u becomes 1 p.u it can be concluded that the average voltage on the research object has increased from 0.9803 p.u (147.056 kV) to 0.9917 p.u (148.762 kV). This proves that TCSC is a tool that is able to improve the voltage profile and reduce power losses according to the calculations referred to in Table 3 and Table 4, according to the TCSC function which is able to regulate the amount of reactive load on the transmission line.

## 4. CONCLUSIONS

Based on the results of the design and modeling of the series compensator circuit using a thyristor on the 150 kV GS line, several conclusions can be drawn, that is; Firstly, the installation of TCSC on the GS line to BP caused an increase in voltage stability on the BG bus 0.4 % (148,512 kV) and on the GS bus 1.4 % (146,535 kV), the average stress on the research object has increased 1.15 %. Secondly, the installation of TCSC can reduce the total power losses on the line by 6.79 %. Thirdly, the installation of TCSC can affect the voltage on adjacent buses. If TCSC works in the capacitive region, it means that Xtcsc has a negative value which can cause the voltage to rise around the GS line, otherwise if TCSC works in the inductive region

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