Power flow improvement of 220 kv transmission line using static synchronous series compensator. A case of iringa- shinyanga transmission line

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Abstract
A reliable electrical power system plays a vital role in the economy of any society and its failure may seriously affect the economy. In order to achieve the reliable performance of power system different research are being carried out.Flexible AC Transmission Systems (FACTS) devices can control power flow in the transmission system to improve asset utilization, relieve congestion and limit loop flows. The Static Synchronous Series Compensator (SSSC) is a voltage source based series FACTS device that provides capacitive or inductive compensation independent of line current. The SSSC, a voltage source inverter connected in series with the transmission line injects the voltage in quadrature with the line current. In recent years, the demand for electrical power has increased and is expected to keep increasing in the northern part of Tanzania as a number of mining development projects have made progress in northwest regions (Geita, Musoma and Shinyanga) and the economic growth taking place in central region (Dodoma) and northeast regions of Tanzania (Arusha and Kilimanjaro). While power for the north comes mainly from hydroelectric source in the south, it is urgently needed to increase the capacity for transmitting power from the south to the north. The north grid is experiencing a power shortfall due to increase of load demand. This paper describes the active and reactive power flow into the line for purpose of compensation as well as enhancement of power transmission capability of transmission line using SSSC. Neutral point clamped (NPC) threephase, three level voltage source converter was designed using Insulated Gate Bipolar Transistor (IGBTs). The control circuit for voltage source converter was designed using Pulse Width Modulation (PWM) control technique. The peak demand for north regions has been studied. In this paper the load demand forecast for north regions of Tanzania has been performed to estimate the load for the next years. The single line diagram of the transmission line connected in series with SSSC using couplingtransformerwas modeled in MATLAB/Simulink. The simulation results showed that the SSSC performance was satisfactory in increasing power transfer capacity.

Keywords:-*SSSC, FACTS,Voltage Source Converter (VSC), Sinusoidal PWM, Load forecasting*.

I. INRODUCTION

Electrical energy is a backbone of development of every society in the world. This energy is used for commercial, hospitals, home, industrial and military applications. The growing of electrical energy demand is pushing transmission systems closer to their thermal and stability limits.The Tanzania Electric Supply Company (TANESCO) a state owned utility is responsible for generation, transmission and distribution of electricity in mainland Tanzania. The Iringa to Shinyanga line starts from Igumbilo in Iringa municipality and ends in Shinyanga urban. The transmission line consists of 670km in length at 220kV. The southern substations get power from hydro-electric power stations their capacities in brackets are as follows:Kidatu (200MW), Kihansi (180MW) and Mtera (80MW). This transmission line is very important as it links the existing and future power generation in the south of Tanzania to the load centres in central regions and northern regions of Tanzania.The demand of electrical energy has increased in the central and northen regions of Tanzania due to development of mining projects in northwest regions and economic growth taking place in central regions of Tanzania.

In a competitive electricity market, congestion happens when the transmission network is unable to accommodate all of the required transmissions because of a violation of system operational limits [1, 2]. Dynamic changes occurring in the transmission line are not compensated immediately as there is no device which can switch fast for this purpose. This in turn reduces the ability to load the transmission line close to its full operation capacity.Alternative method of increasing power transmission capacity is by constructing new generation power plants and building new transmission lines. But this method requires much time, huge amount of money and has impact to the environment. Figure 1 shows Tanzania grid System.

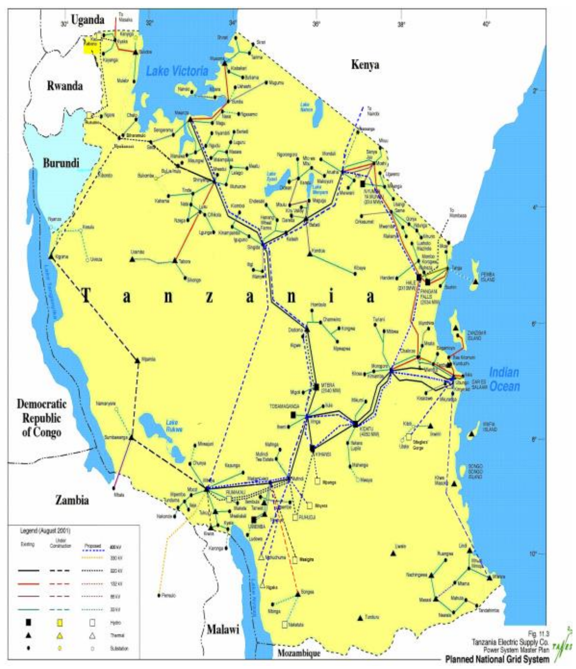

Fig .1. Tanzania Grid System

II. LITERATURE REVIEW

A power system is a large interconnected network with components converting nonelectrical energy into the electrical form to meet the demanded high quality power supply to the end users. A power system is an electrical network divided into three sub-systems. The three sub-systems are the generation stations, the transmission systems and the distributed systems. Electric power produced by a generating unit transmitted from generators to loads by transmission system. The transmission systems are the connecting link between generating stations and the distributed systems that leads to other power system over interconnections

A. Power Flow Over Transmission Line

The transmission systems are the connecting link between the generating station and distribution system. The power flow over transmission line can be controlled through effective control of voltage, line impedance and phase angle [3]. One of the most important problems in the control of energy transmission system is the reactive power compensation. Reactive power causes the increase in transmission system losses, decrease in power capacity carried in transmission lines and the changes in the voltage amplitude at the end of lines. It is necessary to provide reactive power compensation in order to increase transmittable power, decrease losses and provide voltage amplitude stability [4]. The power flow in transmission line is as indicated in figure 2.

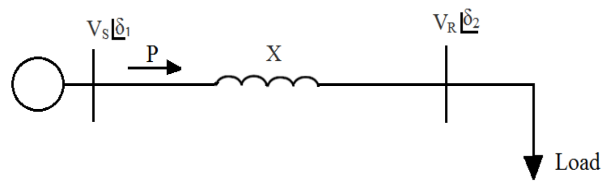

Fig. 2.Power Flow in Single line diagram of transmission line

B. Limits to Power Flow in Transmission System

It is desired to utilize the transmission capacity to its best use taking into account loading capability and contingency conditions, but there is a limit to the loading of transmission lines. The capacity of transmission systems to transmit power is subjected to some limitations, like thermal limits, voltage magnitude, angular stability, dynamic stability and transient stability [5]. These factors determine maximum transmitted power without permanent damage to transmission system.Thermal limit of transmission line is a function of the temperature, environmental conditions,physical structure of the conductor and ground clearance. Line losses convert electrical energy to heat and heat weakens the power lines conductor.For the equipment to operate properly, the voltage should not be allowed to fall below a specified value. Generally, for the transmission lines, the maximum allowable in voltage is limited to between 5% and 10% of the sending end bus voltage [6].Stability phenomena limits the transfer capability of the system, there is a need to ensure stability and reliability of power system due to economic reasons. Different types of power system stability have been classified as follows;

- Dynamic Stability
- Transient Stability
- Voltage Sag
- Sub-synchronous Resonance

The limitation on power transfer can be relieved by addition of new transmission and generation facilities. Alternatively, FACTS Controller can enable the same objectives to be met with no major alterations to system layout. The potential benefit brought by FACTS Controllers include reduction of operation and transmission investment cost, increased system security and reliability, increased power transfer capabilities and an overall enhancement of quality of the electric energy delivered to consumer[7].

C. Flexible Alternating Current Transmission Systems (FACTS)

The Flexibility Alternating Current Transmission System (FACTS) is a new technology based on power electronics devices which offers an opportunity to enhance controllability, stability and power transfer capability of AC Transmission Systems. FACTS are used for generating or absorbing reactive power in transmission system.The employment of FACTS devices in transmission lines becomes necessary owing to reasons like over loaded transmission lines, power flow in unwanted paths, and non-optimal operation of line capacity [9].The objective of FACTS devices is to bring a system under control and transmit power as ordered by the control centers; it also allows increasing the usable transmission capacity to its thermal limits.
FACTS controllers are classified as series controllers, shunt controllers, combined series - series controllers and combined series - shunt controllers.

D. Shunt FACTS controllers

Shunt controllers inject current into the system at the point of connection. The reactive power injected can be varied by varying phase of current. Example of shunt FACTS controllers is Static VAR Compensator (SVC) and Static Synchronous Compensator (STATCOM). SVC is based on thyristor controlled reactors (TCR), thyristor switched capacitors (TSC), or Fixed Capacitors (FC) tuned to Filters.

E. Series FACTS Controllers

These devices are connected in series with the lines to control the reactive and capacitive impedance there by controlling or damping various oscillations in a power system.The effect of these controllers is equivalent to injecting voltage phasor in series with the line to produce or absorb reactive power.Series controllers work in two modes of operation. They control real power when injected voltage is in quadrature with feeder current, otherwise they can control real and reactive power [5, 8]. Example of series FACTS controllers are Static Synchronous Series Compensator (SSSC), Thyristor controlled Series Capacitor (TCSC) and Thyristor - Controlled Series Reactor (TCSR). They can be effectively used to control current and power flow in the system and to damp system's oscillations.

F. SSSC

SSSC is a FACTS device connected in series with the transmission line. The addition of dielectric capacitors to lower the cost of series compensation by SSSC has been reported [10]. It is normally connected in series with transmission line as shown in Figure 3. The device has a voltage source converter serially connected to a transmission line through a transformer. Other components of SSSC are energy storage and control system. A simplified model of a transmission line with series compensation is shown in Figure 3. The voltage magnitudes of the two buses were assumed equal, and phase angle between them is δ. The transmission line was assumed lossless and represented with a line reactance X.

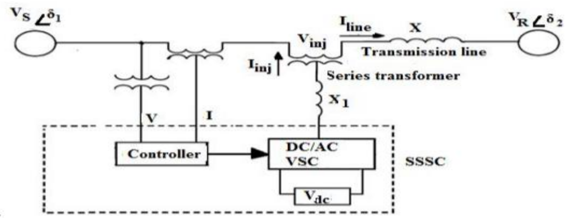

Figure 3. Block diagram of SSSC

G. Working Principle of SSSC

Basically, a SSSC generates on its output terminal a sinusoidal voltage, with controllable amplitude, in quadrature with the transmission line currents. Consider simple representation of equivalent circuit where SSSC is used to compensate between sending and receiving buses as shown figure.4.

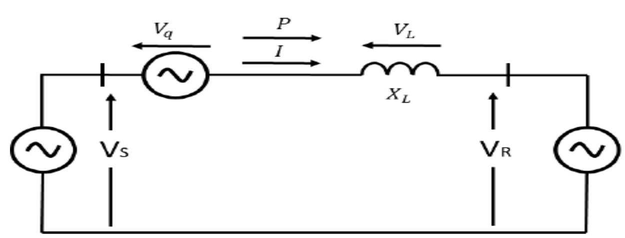

Figure 4: Equivalent circuit of SSSC

SSSC injects a voltage in quadrature with the line current to emulate a series capacitive or inductive reactance into the transmission line as indicated in figure 5

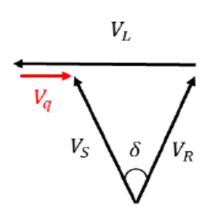

Figure 5 Phasor diagram of SSSC compensation

$$V_S = V_R = V$$

$$P = \frac{|V_S| \times |V_R|}{X_L - \frac{V_q}{I}} sin\delta \quad (1)$$

The real power transfer through the transmission line is expressed by following formula [11]

$$P = \frac{|V_S| \times |V_R|}{X_L} sin\delta + \frac{V}{X_L} V_q \cos(\delta/2) \quad (2)$$

V_S, V_R =Active power source voltages

V_q =SSSC injected voltage

δ =Power angle

The injection of voltage in transmission line lead power flow in transmission line to change. Hence, the SSSC is a powerful device to control transmission line impedance, and therefore the power flow is independent of the line current. Also, the reactive power exchange is controlled by the magnitude of the injected voltage to the transmission line, and angle control is used to regulate the active power exchange. The inductive or capacitive mode of operation is set by the injected voltage phase angle with respect to the transmission line current. When the injected voltage is leading the line current the reactive power is absorbed and the SSSC operates in inductive mode; in capacitive mode, injected voltage is lagging the line current and injects reactive power into the transmission line. The SSSC is one of the most important FACTS devices for power transmission line series compensation [12].

III. METHODOLOGY

In order to improve the power handling capability of a 220kV transmission line, transmission line model has been simulated in MATLAB Simulink environment to analyze the performance of transmission line before andafter simulating the SSSC in the model. The technical data of a 220kV transmission line has been collected from TANESCO. The performance of a transmission line with and without SSSC in the system has been analyzed. The data of 220kV transmission line has been shown in Table 1.

A. Peak demand for Central and North Regions of Tanzania

Electricity demand in Tanzania has been increasing. The rapidly increasing population, the increase in number of customer's connections, the expansion in industrialization and development of mining projects, and extending electricity to remote village are all factors playing a substantial role in the increased power demand.

North part of Tanzania is experiencing electricity demand growth due to increased economic activity, particularly in the mining sector. The Table 1 shows the annual peak demand increase in the North Regions that were connected to Iringa –Shinyanga transmission line from 2014 to 2018. Figure 4 shows trends of the increase in electricity demand for north regions from 2014 to 2018.

Table 1 shows Peak demand for Central and North Regions of Tanzania connected to Iringa – Dodoma transmission line

Table 1: Peak demand for Seven Regions Connected to Iringa–Dodoma Transmission Line

No	REGION	PEAK LOAD (MW)				
		YEAR				
		2014	2015	2016	2017	2018
1	Dodoma	17.70	18.00	18.70	19.20	19.80
2	Singida	6.00	6.00	6.20	7.00	7.10
3	Shinyanga	65.53	73.70	74.30	74.30	78.00
4	Mwanza	41.00	41.43	42.00	43.60	45.80
5	Arusha	53.20	53.00	53.83	54.74	54.21
6	Tabora	7.00	7.00	7.70	8.00	9.72
7	Musoma	17.30	18.00	20.20	22.00	23.00
	Total	208.73	217.13	222.93	228.64	237.63

B. Power demand forecast

Forecasting is the estimation of value of variable at some future point in time. A forecasting exercise is usually carried out in order to provide an aid to decision making and planning the future. In this study, power demand forecasting was carried out using trend method. A raw data regarding peak demand covering a period of five years was used for this study. Peak loads for seven (7) regions were used, spreading from year 2014 through the year 2018. Data for each region was tabulated as shown in Table 1

Based on the time period load forecast can be divided into three categories.

- **Short term forecast**
  Short term forecast is usually from one hour to one week. It provides basis for planning start up and shutdown schedule of generator units, reserve planning and study of transmission constraints.
- **Medium term forecast**
  Medium term forecast is usually from a week to one year. Used mainly for scheduling fuel supplies, maintenance programmes, financial planning and tariff formulation.

- **Long term forecast**
  Long term forecast is usually for longer than one year. It facilitates economic planning of new generating capacity and transmission networks. Methods used for short, medium- and long-term load forecasting are Trend, End-use and Econometric approach. In this paper trend method wasused.Trend lineanalysis was used to identify the trends of increase of actual peak demand.

The consistency of demand growth for five years has led to numerous attempts to fit mathematical curves to this trend. One of the simplest curves is

$P = P_0 e^{a(t-t_0)}$

(3)

Where a =Average per unit growth rate,

$P =$ Peak demand in yeart,

t_0 =Base year

P_0 =Peak demand at year t_0.

In this study the yearly peak demand for seven regions were obtained from TANESCO. The average per unit growth rate is calculated from 2014 to 2018 as shown in figure 6.

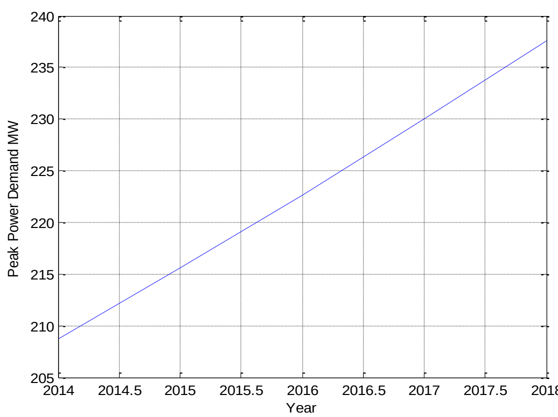

Figure 6Trend Line analysis for peak demand

Data for each region is tabulated and Matlab script is drafted to compute peak demand in the years to come (From 2018 to 2023). Matlab made the realization of the power forecasting with exponential equation. The equation is very simple since it gives the researcher the freedom to determine the growth of power demand over a range of years using the peak power demand.

The plot of the predicated demand is shown in Figure 7.

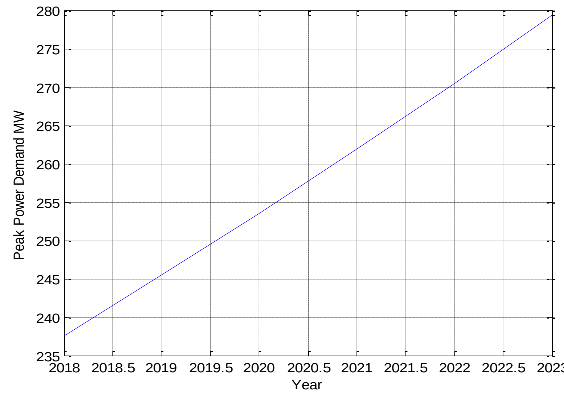

Figure 7:Peak Demand from 2018 to 2023

IV. DATA PRESENTATION, ANALYSIS AND DISSCUSSION OF THE RESULTS

In order to improve the power handling capability of a220kV transmission line, transmission line model hasbeen simulated in MATLAB Simulink environment toanalyze the performance of transmission line before and after simulating the SSSC in the model. The technicaldata of a 220kV transmission line has been collected from TANESCO. The data of20kV transmission line has been shown in Table 2.

Table 2: Technical data of 220kV Transmission Line

Type of conductor	BOIDE
Length of transmission line	670KM
Transmission line rating	343MVA
Current rating	900A
Voltage rating	220kV
Frequency	50HZ
Resistance per KM	0.02116p.u
Inductive reactance per KM	0.1175p.u

A. Development of Iringa-Shinyanga 220kV Transmission Line Model without SSSC

Two cases were considered, the first case was the simulation without SSSC and the second case was modeled by incorporating with SSSC as shown in figures 8 and 8respectively.

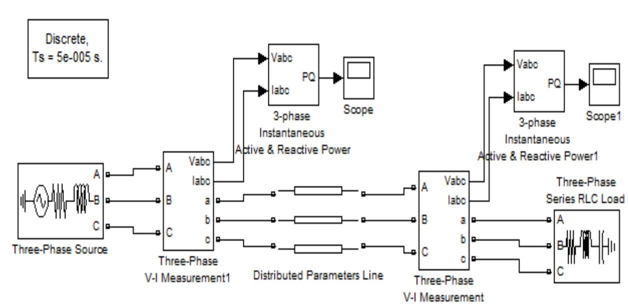

Figure 8: The 220kV Transmission Line Model without SSSC.

The graphs mentioned in Figure 9 show the waveforms of Active power and reactive power before implementing SSSC in the simulation model. In Fig. 9 the green color waveform is reactive power flow through the transmission line. The reactive power varies from 0.8MVAR to 1.2kVAR for 0.87 second. At 1.2 kVAR the variations were minor throughout the simulation period. The blue color waveform is active power flow through the transmission line. The active power changes from 1.3kW to 1.75kW for 0.87 second. At 1.75kW as observed in reactive power there were minor changes of the power throughout the period.

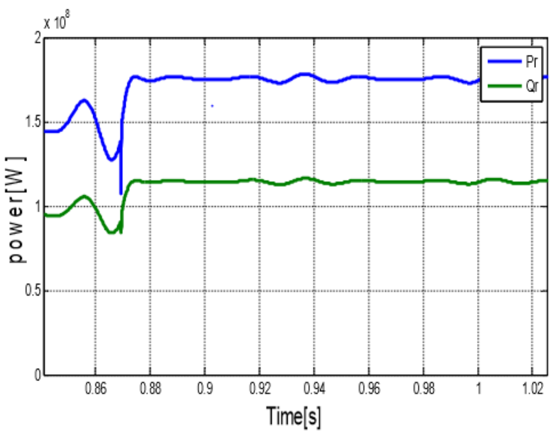

Figure 9: Simulation Results of 220kV Transmission line without SSSC

B. Development of 220kV Iringa-Sinyanga Transmission Line Model with SSSC

The Simulation model of 220kV transmission line along with unified power flow controller is shown in figure10

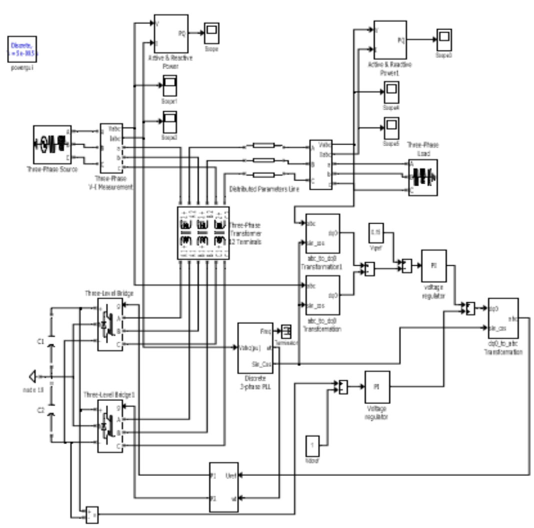

Figure 10: The 220kV Transmission Line Model with SSSC.

In Figure11 the green color waveform represents reactive powerflowing through the transmission line while the blue color waveform is active power flowing through the transmission line after incorporating the SSSC in the simulation. There is no variation of active power as maintained at 2.75kW as well as the reactive power is kept at 1.4 kVAR throughout the simulation as shown in figure 11

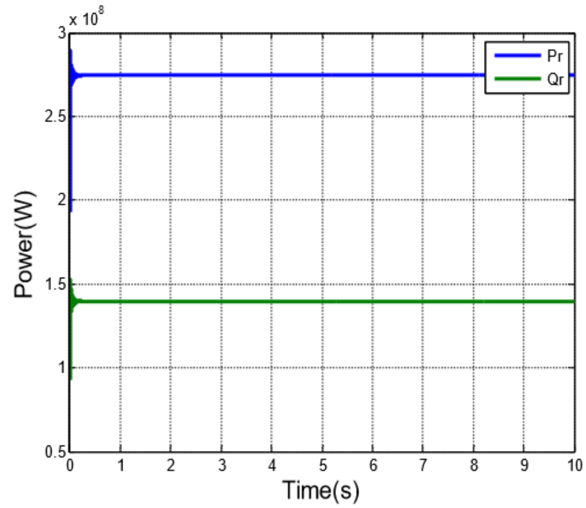

Figure 11: Simulation Results of 220kV Transmission line with SSSC

C. Comparison of Results

The results depicted in Table 2 shows that the active and reactive power of 220kV transmission line is improved after implementation of SSSC based controller. The results for the active and reactive power flow of transmission line are calculated in terms of actual values as well as in p.u quantity. This proves the applicability and suitability of SSSC based controller for the transmission line.

V. CONCLUSION

After simulating the SSSC, the load flow through the 220kV transmission has been improved. Active power through the system has been enhanced. As power flow is enhanced so the per unit cost will also be reduced. Existing transmission lines can be used at an extending capacity thereby reduced the economic burden of newly erected transmission lines. Technical losses through the transmission line are reduced. Therefore, the overall performance of a transmission line is improved

ACKNOWLEDGEMENT

The authors desire to thank TANESCO administration for providing us with guidance and encouragement and all necessary information required for this study.

LIST OF ABBREVIATIONS AND ACRONYMS

FACTS	Flexible Alternating Current Transmission
FC	Fixed Capacitors
NPC	Neutral Point Clamped
SSSC	Static Synchronous Series Compensator
STATCOM	Static Compensator
SVC	Static VAR Compensator Systems
TANESCO	Tanzania Electric Supply Company
TCR	Thyristor Controlled Reactors
TCSC	Thyristor Controlled Series Capacitor
TCSR	Thyristor - Controlled Series Reactor
TSC	Thyristor Switched Capacitors
UPFC	Unified Power Flow Conditioner

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