

TCSC Integration in National Transmission system of Pakistan to enhance transmission capability: A case study of Hub Jamshoro Section

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Abstract

TCSC employs fast switching ability of power electronic devices and is able to control power flow on transmission lines during various alarming stages. The aim of this work is to integrate TCSC into 500 KV Hubco-Jamshoro transmission line to investigate the operational benefits. A simulation model is developed under MATLAB/Simulink and many simulation studies are performed to verify the feasibility of the proposed model for transmission line. The core essence of this work is to improve the power transmission capabilities of 500kV transmission line by employing TCSC switching schemes, which helps to compensate the power flows when installed in transmission line and thereby increases the transmission line loadability.

Keywords

FACTS, PLL, Power flow control TCSC, Reactance Control

1. Introduction

Transmission networks play a key role in the structure of electrical power system of any country. Pakistan, in recent years, has faced not only an acute power crisis but its consumers also suffer from power quality issues particularly voltage and frequency instability (Rauf et al. 2015), (Nayyer et al. 2014), (Sahito et al. 2015) and (Rehman et al. 2016). Due to this power deficit, electricity remains off for 16-18 hours in rural areas while consumers in urban areas are facing 10–12 hours load shedding (Farooq and Shakoor 2013), (Rafique and Rehman 2017). The main power sources of Pakistan are located in north and south whereas the load centers are located in center. Due to

power shortages, Government of Pakistan (GoP) is looking for new power sources and also focusing on renewable options (Shakil et al. 2016), (Siddique and Wazir 2016). The countries' main renewable power projects are finding their way in District Jamshoro. Pakistan is also investing on its coal reserve in district Thar. With commissioning of these new sources of power, southern Sindh would become the main power center for the country. This extra generated power needs to be transported to the main power carries of National Transmission & Distribution Company NTDC transmission networks. One such network that would be under consideration for transporting extra power is the transmission network between Jamshoro and HUB. This section of transmission is used for power exchange from Jamshoro to Karachi. This research work focuses on enhancing the power carrying capacity of the existing section of the national transmission line. The work is primarily concerned with simulation of the existing line in MATLAB and proceeds further to implementing simulated TCSC on the same network.

2. Power scenario and administrative structure

Pakistan's total installed capacity is about 25,100 MW (NTDC, Pakistan 2015). Electricity production is mainly due to thermal power plants. These power plants are dependent on fossil fuels (gas, heating oil, coal). Due to the shortage of fossil fuels, Pakistan imports oil that overburdens its economy further. At the time of independence in 1947, Pakistan generation capacity was 60MW, which was rapidly increased to 9000MW in 1990. Due to rapid growth of population, the power demand is also, adequately increasing steadily at a rate of 10% annually while the generation addition of 7% (Rafique and Rehman 2017). Hence, it resulted insufficient addition of power in supply demand deficit of 4000-7000 MW (Qazi et al. 2017) so the load shading is inevitable. The administrative structure of electricity sector in Pakistan is given in Figure1(Qazi et al. 2017), (Perwez et al. 2015). The power generation bodies that contribute significantly in electricity production in Pakistan are WAPDA, generation authorities (GENCOS) and independent power producers (IPPS). The NTDC is responsible to manage transmission grids all over Pakistan except Karachi. K-electric Company controls the electricity in Karachi while Distribution companies (DISCOs) are responsible to distribute the power from power station to user and to rest of whole country (Zakaria and Noreen 2016). The DISCOs, NTDC and IPPs all are managed by Pakistan Electric Power Company PEPCO. One of the prime reasons of the establishment of NEPRA (National Energy and Power Regulatory Authority) was to protect the rights of its shareholders. NTDC regulates and manages fourteen 500 KV and thirty-eight 220 KV Grid Stations, the 500kV transmission line is spread over 5077km and 220KV to 7359km in Pakistan. The regional details of grid stations are shown in Table 1 (Kessides 2013).

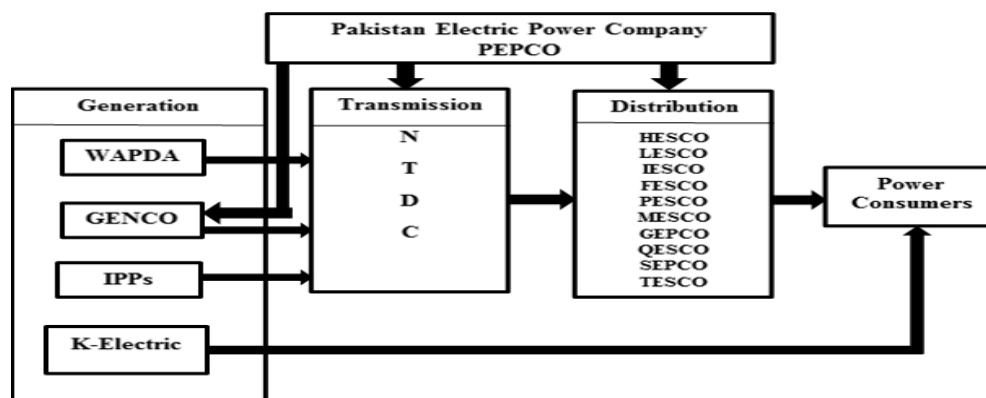


Figure.1 Administrative electric power sector of Pakistan

Table 1 . NTDC grid stations

Name of the region	500KV	220KV
Islamabad	2	7
Lahore	3	16
Multan	4	5
Hyderabad	4	9
Total	14	38

3. NKI 500kV grid station

HUBCO- JAMSHORO 500kV and 181 km transmission line connected with NKI grid station (GS) linked with Hub thermal power station and 500kV Jamshoro grid station. The 220kV system of K- electric that is KDA 220kV GS and Baldia 220kV GS is fed from 500kV NKI grid station. This GS is about 30km from Karachi city of Sindh province. The grid station is equipped with two 600MVA, 500/220kV auto-transformers. The NKI grid station is an interconnection station between K-Electric and NTDC which is shown in Figure 2 (Shah et al. 2011).

Hubco-Jamshoro transmission line consists of four wire (bundled conductor).The bundled conductors are used which reduces the transmission line impedance hence allowing to increase power transmission. The conductor used is coded as GREELAY; it is Aluminum Alloy Stranded Conductor (AASC). The geo-graphical location of transmission line under-consideration is given in Figure 3.



Figure 2. Block diagram of Hub-Jamshoro transmission network

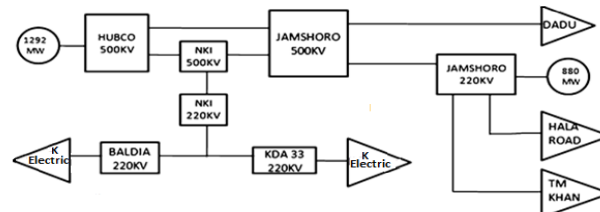


Figure 3. Geographical location Hub-Jamshoro transmission line

The parameters for the transmission section are collected form NTDC and are as tabulated in Table 2. Data on hourly basis of power transmission line under study is collected from NTDC in Figure 4 and power flow data is shown in Table 3.

Table 2. Parameters for transmission line

Typical Impedances of overhead Transmission lines Ω / Km				
kV	Size mm^2	$Z1=Z2$	$Z0$	$Z0m$
33	75	$0.36 + j0.4$	$0.56 + j1.02$	---
33	175	$0.15 + j0.37$	$0.35 + j0.97$	---
132	175	$0.177 + j0.402$	$0.345 + j1.022$	$0.178 + j0.509$
275	2*400	$0.038 + j0.32$	$0.147 + j0.839$	$0.109 + j0.6$
500	4*400	$0.19 + j0.277$	$0.105 + j0.79$	$0.086 + j0.425$

Table 3. Power flow data from ntde grid to hub

Sr. No	Parameters	Value/Unit
1	Frequency	49.82 Hz
2	Power Factor	0.9609 Lead
3	Active Power	0.118 GW
4	Apparent Power	0.1228 GVA
5	Reactive Power	-0.0340 GVAR
6	Voltage	289.9 kV
7	Current	00141A

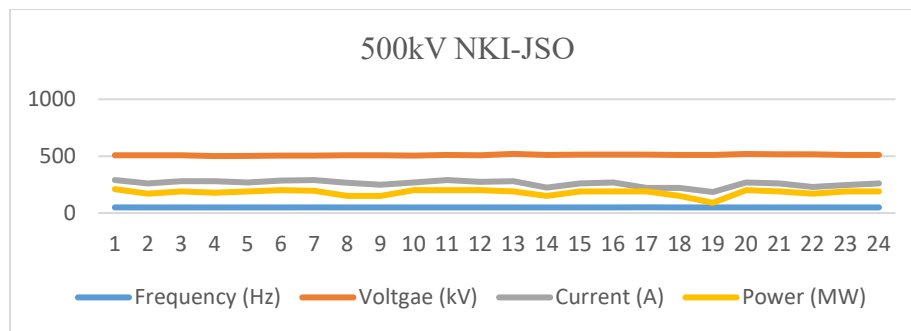


Figure 4. Hourly data on Hubco-Jamshoro transmission line

4. Thyristor controlled series capacitor

The TCSC controller is used to rapid adjustment of network impedance to solve the power flow problems. The basic TCSC unit as shown in Figure 5, proposed by Vithayathal in 1986 comprises of fixed valued capacitor in parallel with TCR (Shaikh et al. 2009). The TCSC reactance is controlled by adjusting the firing angles of anti-parallel thyristors. The prime use of series capacitor is to reduce the cost. The TCSC system comprises of cascade combination of many TCSC units. TCSC has three modes of operation, namely: thyristor blocked mode, thyristor fully conducting mode and thyristor phase controlled operating mode (Tenorio, Daconti 1998), (kumar

et al. 2017), (Deepak et al. 2015), (Tlijani et al. 2012), (Naik et al. 2010), (Canizares and Faur 1999), (Madhusudhana et al. 2010), (Besharat and Taher 2008), (Benabid et al. 2009). The TCSC equivalent model is given in Figure 6.

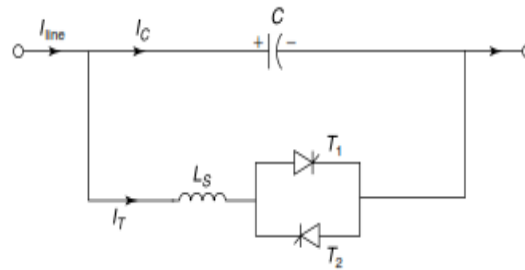


Figure 5. Basic structure of TCSC

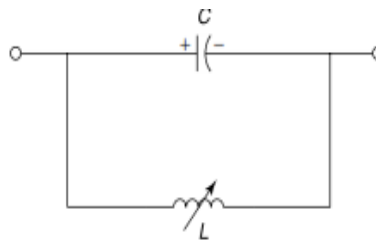


Figure 6. Equivalent circuit of TCSC

The very first TCSC developed by ABB in 1922, which later on installed at Kayenta substation in Arizona. This helped increased the line loadability up to 30% (Acharya et al. 2005). TCSC controller provides power flow enhancement in transmission line (Morsali et al. 2016) (Mathur et al. 2002). This is because; commutated solid-state devices like SCRs are used by TCSC while other series FACTs controllers like Static Synchronous Series Compensator SSSC consist of GTOs. The capacitors of TCSC are less expensive compared to GTOs (Morsali et al. 2016). The TCSC controller has an ability to prevent loop flow of power, damping of active power oscillation, suppressing sub-synchronous resonance, enhance the level of protection for series capacitors, limiting unsymmetrical components, reducing the short-circuit current and enhancing transient stability (Mathur et al. 2002), (Jowder and Ooi 2005), (Jiang and Chen 2006). Various authors have done the power transfer enhancement of transmission system using TCSC. Naik (Naik et al. 2010) implemented TCSC in power system network to enhance transmission capacity and voltage profile of lines by adding reactive power flow in available transfer capability ATC calculations. In (Arzani et al. 2008), optimized use of TCSC on ATC improvement in two-area interconnected power system is investigated. In (Madhusudhana et al. 2010), Power transfer capacity improvement of a power system network in normal and contingent cases using Static Var compensator SVC and TCSC were studied. For reducing network congestion and minimizing the generation, cost the appropriate location of TCSC in transmission line is necessary. Various studies have been discussed in literature (Singh and David 2001), (Besharat et al. 2008), (Siddiqui et al. 2017), for the investigation of optimal location of TCSC in power system networks.

The aim of this research is to improve the loading capacity of the transmission system using TCSC controller. The TCSC controller performance is assessed with the AC transmission line connected between Hub and Jamshoro grid stations in Sindh province of Pakistan.

5. Simulation model of Hubco-Jamshoro transmission line without TCSC

The Hubco-Jamshoro transmission line model is simulated in MATLAB considering the Simulink and SIM power libraries. This model exchange power between two areas. Initially, the transmission line under consideration is simulated without TCSC to validate the simulation data with collected data of NTDC. The Simulink model of Hubco-Jamshoro transmission line model is given in Figure 7.

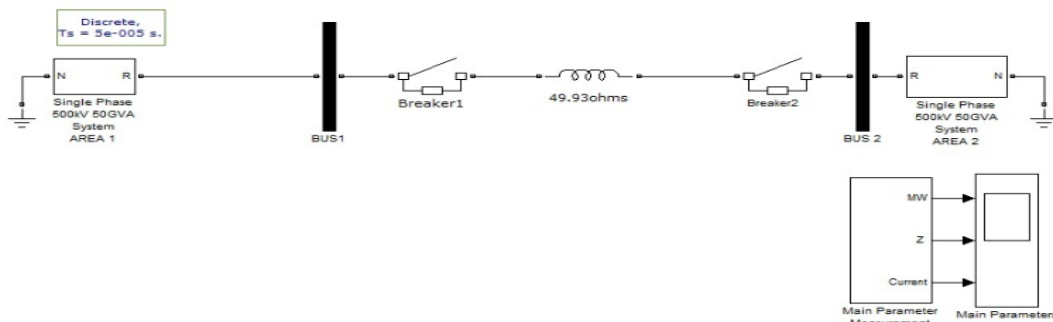


Figure 7. Simulation model of transmission line without TCSC

The power flow on transmission line without TCSC is illustrated in Figure 8. The line clearly handles 39.81 MW only which is a near match with the actual power flow. The line current is also measured and found to be within tolerance limit of 138.3 A. The results of line current are given in Figure 9.

6. Simulation model of Hubco-Jamshoro Transmission Line with TCSC

For simplicity, TCSC unit is installed on one phase of transmission line. As TCSC block is not available into the MATLAB therefore, a capacitor with fixed capacitance is inserted with fixed reactance in Simulink.

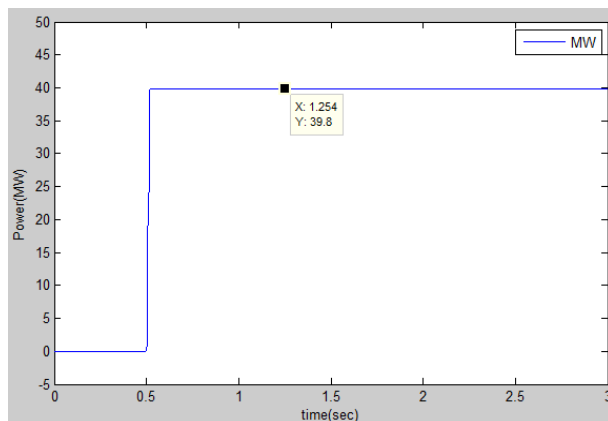


Figure 8. Power flow on transmission line without TCSC

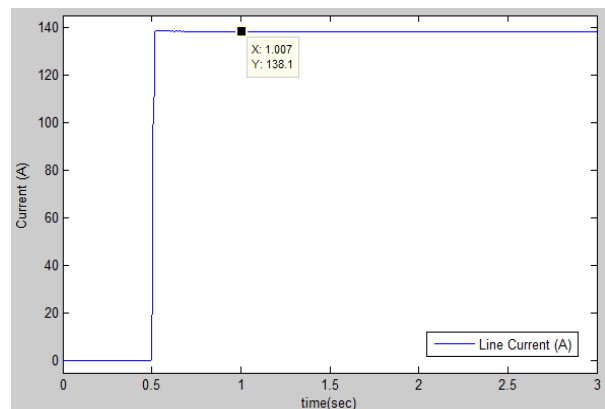


Figure 9. Line current on transmission line without TCSC

The reactor is connected with two back-to-back Silicon controlled rectifier SCR. After that, the resulted combination is connected in parallel with fixed series capacitor. This combination resulted a variable reactor that can act either capacitive or inductive by adjusting the firing angle of SCR. The resulting TCSC unit model is shown in Figure 10.

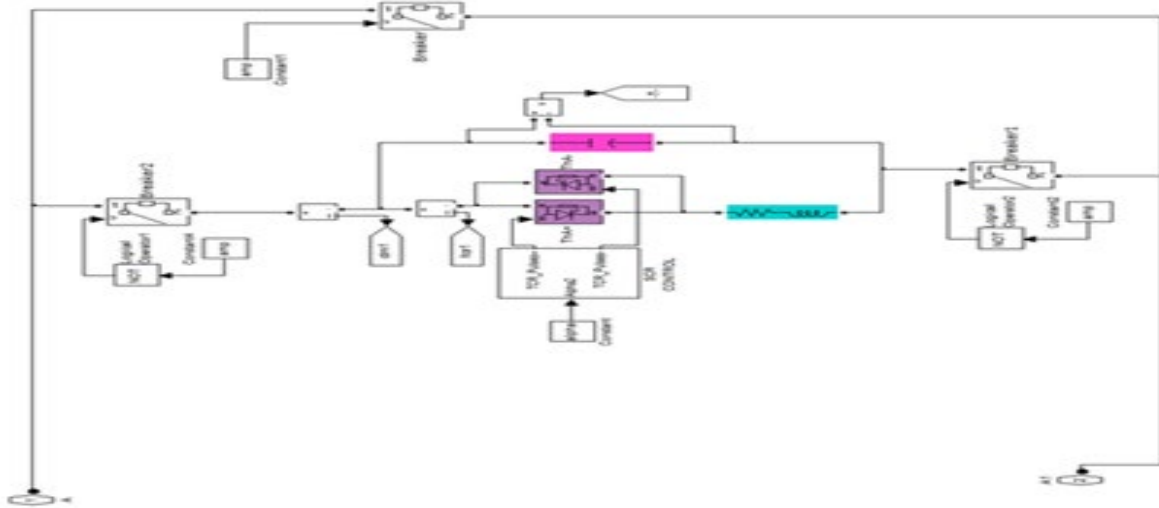


Figure 10. Simulation model of TCSC

6.1. TCSC Controller

The TCSC controller, as given in the Figure 11, is designed in Simulink library of MATLAB. For the measurement of current in transmission line, the measurement blocks (BUS1 and BUS2) as shown in Figure 9 send the signals to TCSC controller block; first, signal is converted into per unit (P.U.) Afterwards this P.U. is fed to the phase-locked loop (PLL) block. Output of this block is measured value of frequency and a sine wave synchronized with line current. The Phase-locked loop signal is converted into a square wave that alternates in synchronism with the current profile. Afterwards another square wave is generated that is exactly 180 out of phase to that of previous one by simply inverting first square wave. The earlier square wave assists in generating control signals for positive half cycle and the second square wave helps in generating control signals for negative half cycle. Afterwards the signals are sent to the logic switches that pass on the firing angle of the in accordance with the positive and negative pulse generators parts. By the multiplication of angle with sampling frequency, the firing angle is converted into time delay. In order to obtain a saw tooth wave so that alpha can be compared a discrete time integrator is used to integrate square wave. Firing angle are synchronized for positive and negative alternations by using certain logical blocks. This entire process is shown using a flow chart represented in Figure 12.

6.2 Transmission Line with TCSC implemented

The implementation of TCSC in Hubco-Jamshoro transmission line is made in three stages i.e unit 1, 2 and 3. The first stage represents 24% compensation, the second stage represents 48% compensation and final stage represents 72% compensation. All stages are similar to each other and are as depicted in Figure 10. All stages are inserted and tested at various firing angle of the SCRs. The simulation setup along with GUI to control angles is shown in Figure 13.

7. Result discussion after TCSC implementation

The power flow at 24% capacitive compensation is observed and found to be 59.4 MW with TCSC compared to just 39.8MW without TCSC. After this, the first stage (unit 1) of TCSC is fired in inductive mode and the results are measured to be 31.77MW. The line impedance at this inductive firing is measured at 64.19ohms.

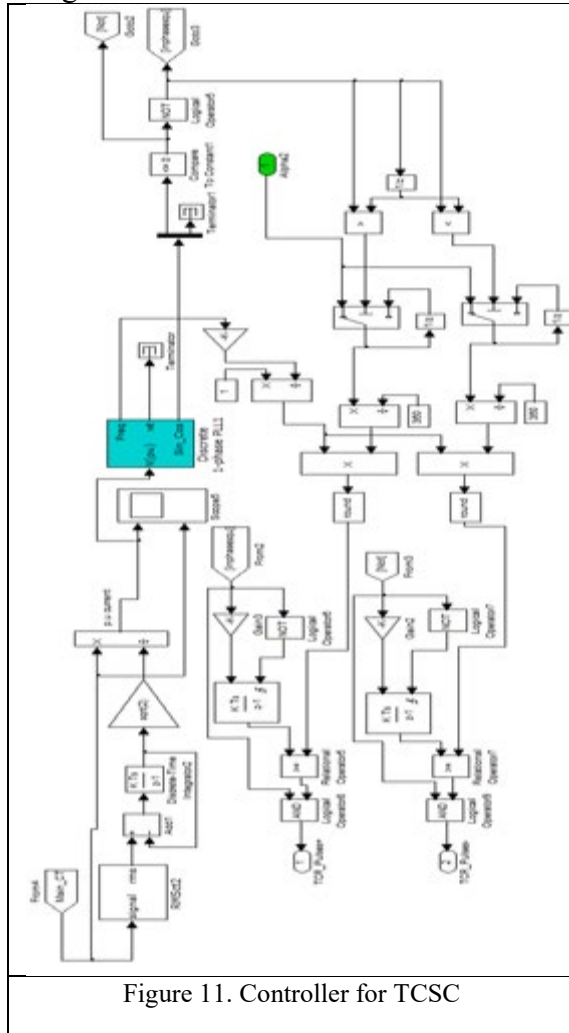


Figure 11. Controller for TCSC

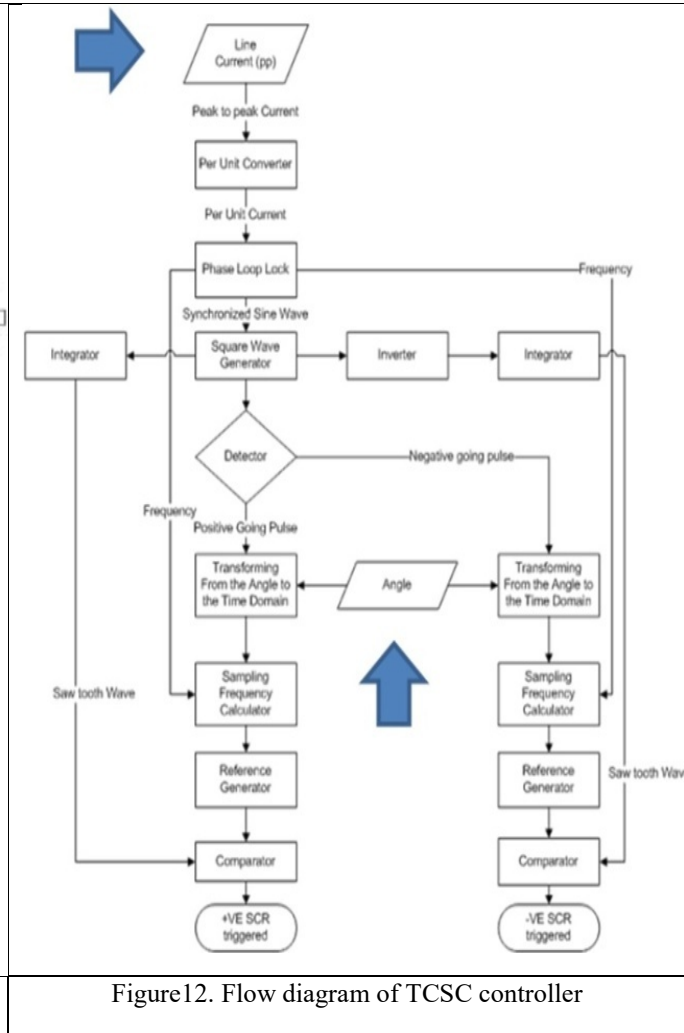


Figure12. Flow diagram of TCSC controller



Figure13. Model and its GUI command window for angle selection

At the last stage, all units of TCSC are fired up at 72% compensation and is switched between inductive and capacitive mode of firing. At first the capacitive mode is used to find the power enhancement, it is observed that at max firing angle of 160 degrees the power flow is observed to peak at 156.5 MW and line current is hovering at 930 A. This current flow marks the maximum allowable current through the conductor. This marks the upper most power carrying capacity of the line since beyond this the line would just fail. In actual the line would fail before this limit is even reached. The angle 160 degree was just used to show that in simulation environment the line can be hypothetically pushed to its limit. In actual, however, the angel must be limited below this value. The results for 24 % compensation are shown in Figure14.

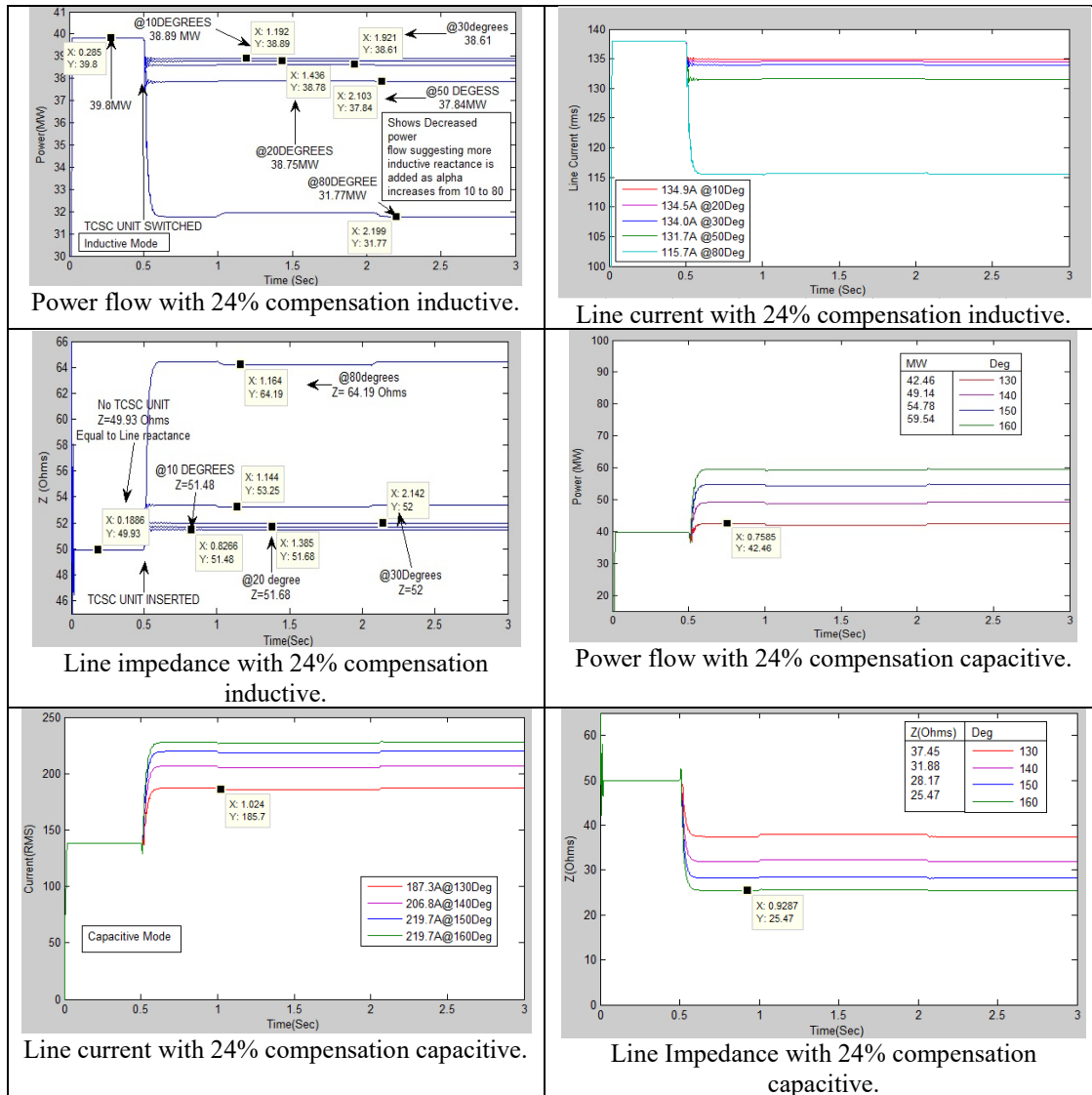


Figure 14. The results for 24 % compensation of transmission line with TCSC

The results for 72% compensation in inductive as well as capacitive mode are shown in Figure 15. During this simulation, the firing angles were chosen to be from 130 to 160 degrees with increment of 10 degree in each step for capacitive mode.

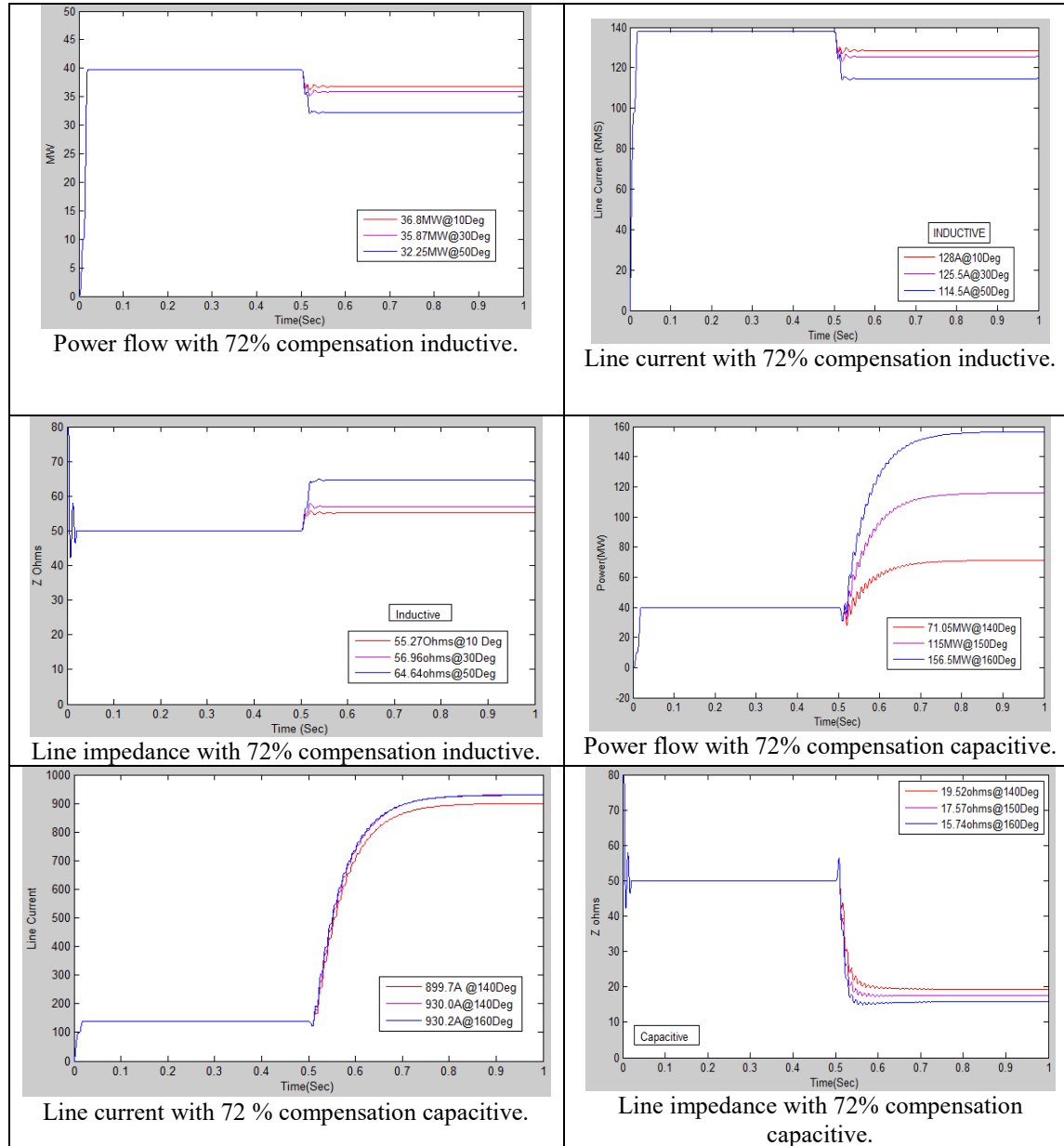


Figure 15. The results for 72 % compensation of transmission line with TCSC

8. Conclusion

This research discusses the power transfer from Hub to Jamshoro through Jamshoro to Hub transmission line. The data collected from NTDC is compared with the simulation model and it varies in accordance to collected data. After that the transmission line is simulated with TCSC installed, the resulting outcome of transmission line shows that it transfers power in a range of 35

to 42 MW per phase. This power transmission capacity can be raised to 54MW by providing 24% compensation as shown by the simulated model. That results in an overall improvement of 49% The model is then simulated to achieve compensation of 72% when the transmission line is driven to upper thermal limit. The results of this simulation represent that the line could transfer power up to 156 MW with an overall improvement of 298%. This much improvement might undergo stability issues so it can be assumed as hypothetical value it can be achieved if it is allowed by system constraints.

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