School of Information Technology
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VOLTAGE REGULATION IN GENERATING NETWORKS.

LITERATURE REVIEW REPORT

Presented to the Graduate Program of Electrical and Power Engineering
of the School of Information Technology and Engineering
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INTRODUCTION

To keep the voltage level acceptable is the primary phenomenon of electrical power system and aiming to keep the voltage around acceptable level different load and generation conditions. Acceptable voltage regulation makes power quality, system reliability, and efficiency better [1].

During the long time, the tap changers have been used to regulate voltage in transformers, and capacitor banks are utilized for regulation of reactive power in electrical power systems.

Tap-changing transformers: To adjust voltage dynamically in transformer on-load tap changers regulate transformers turn ratios.

Shunt capacitor banks: For supporting local voltage and to make power factors better the capacitor banks are explicitly used.

Synchronous Condenser: generate reactive power supply and system consistency, crucial for huge- scale system.

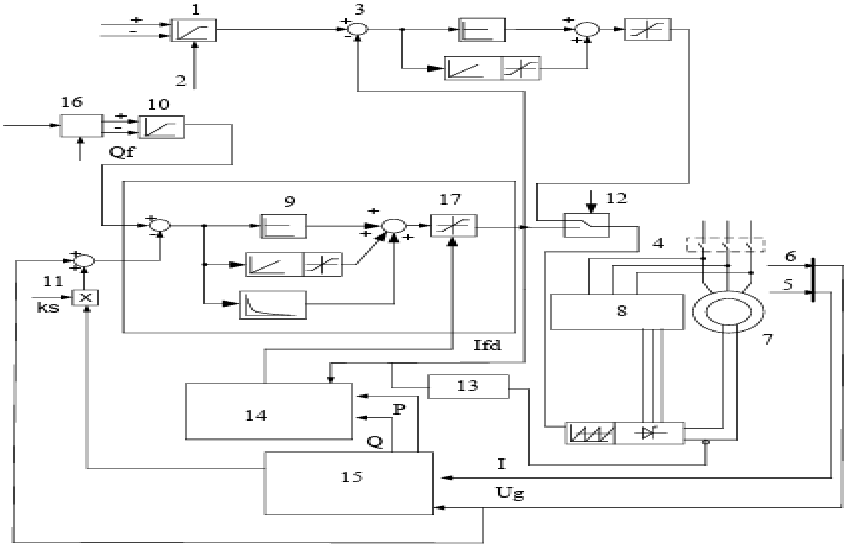
These ways, in cutting-edge power system, reliability, not including the speed and flexibility is mandatory.[4]

The including of distributed Energy sources and connection of them electrical system can cause some problems related with challenges in voltage regulation. At those times mentioned traditional regulation methods were insufficient for electrical grids and high integrated Distributed energy sources.

Literature Review

2.Regulation of excitement of synchronous Generator.

Due to the increasing complexity and expansion of distributed generation, especially in industrialized areas, traditional excitation systems are often unable to meet modern operational requirements. The one of the crucial elements of power plants is the generator that induced electrical energy, which is connected to high-capacity power grids. These grids transfer energy through parallel electrical lines (typically 110–500 kV) and are subject to non-static voltage pulsations, load alterations, and constraints in the thermal management system which are used to minimize temperature of generator. These factors are essential for advanced automatic excitation systems capable of regulating both voltage and ensuring dynamic and static stability [5,6]



Fifure1.1 Enhanced scheme of automatic adjust of the excitation system of the synchronous generator

1 - the depositor of the setting of the excitation current with the control key operator of the main control panel; 2 - tracking the actual excitation current; 3 - excitation current regulator (backup); 4 - generator switch; 5.6 - voltage and current winding of the generator stator; 7 - generator; 8 - transformer of the thyristor pathogen; 9 - voltage regulator; 10 - stator winding setting parameters; 11- reactive power; 12 - switch of generator voltage regulators; 13 - an excitation current sensor; 14 - a block of limitations; 15 - active and reactive power; UG, IQ - voltage and reactive current on the terminals of the stator winding; 16 - adjustment unit of the actual reactive power of the regulator; 17 - voltage limiter; QR, QF - a shown and actual parameters of the generator reactive power;

A new automatic excitation controlling system is depicted in Figure 1 below, customized depends on factory power plant circumstance. This system has characteristics added to constituents like correction of voltage units and tracking modules of reactive power. The main aim is to modify excitation dynamically to uphold desired performance, particularly during voltage decrease or spikes from the major grid [7].

This study underscores the importance of adapting excitation control systems for synchronous generators to meet the specific demands of industrial power plants. Unlike large regional stations, factory-based generators operate under tighter constraints, such as lower installed capacities, cooling limitations, and variable load conditions. Their integration with high-capacity transmission grids introduces additional challenges in maintaining voltage and stability [8].

The improved automatic excitation control system refers these problems by integrating real-time reactive power information, voltage level point rectification, and safeguards opposed to entering unsteady working region. Simulations utilizing MATLAB/Simulink validate that the system make better both static and dynamic steadiness, even during voltage interruption [9].

A key result is the clarification of acceptable operational regions for generators, eligible more trustworthy performance arranging and emergency aadministering. This approach is aligned by contemporary energy regulation strategies and assist huge system endurance and effectiveness [10,11].

The offered solution provides a practical and efficient advancement in excitation control technology, forcing the stability and dependability of industrial power supply system's operating in complex energy surroundings [12,13,14].

3. Voltage regulation in AC transmission systems.

Growing of power needs and transmission limitations, power systems are frequently faced by voltage changes and unsteadiness. The Sen Transformer (ST) is offered as an efficient solution through the FACTS, presenting autonomous govern of both active and reactive power in AC transmission lines.

The electrical transmission system is constructed utilizing a simple line with impedance and the regarding with phasor diagram.

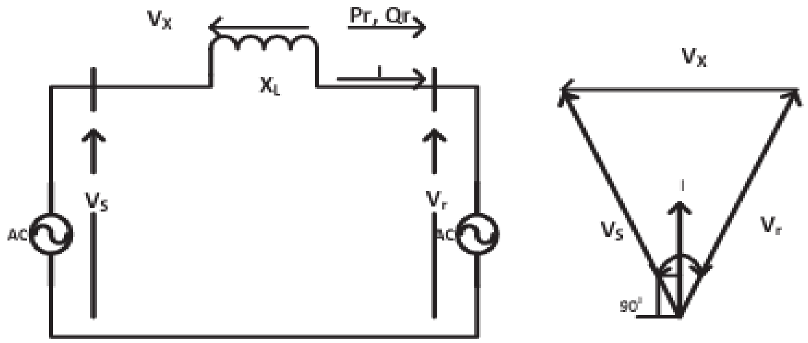


Figure 2.1 Basic diagram of transmission system.

$P_r = \frac{V_s V_r}{X_L} \sin\delta$ (1)

$Q_r = \frac{V_s V_r}{X_L} (\cos\delta - \frac{V_s}{V_r})$ (2)

Reactive and active power change is occurring at the compensation point for the transmission line. [15]

One excitation part and one compensation parts are including in SEN transformer that is kind of transformer. The excitation part consists of three windings, so they are connected star. These three windings are located on each limb of the three-limb. These three line to line transmission voltages (Vs A; Vs B; Vs C) provide exciter unit at the delivering point. For compensating voltage unit, the windings that are nine are constructed on secondary part of transformer. Through all windings, three windings of that are bound on each column of the transformer core. The set of the first components having a1-a2- a3, whereas the second components contain b1, b2, b3 and the third elements contain c1, c2, c3. All three windings, generate the voltage, which are bound on three different components. All couple of three windings have series connection. These neutralizing voltage groups supply power to the transmission line in series connection. For that the configuration are, a1-b1-c1; a2-b2-c2; a3-b3-c3 utilized to supply in phase A, B and C in corresponding order. The vital point is to be pointed that each configuration (a1-b2-c3); (b1-c2-a3) and (c1-a2-b3) are the inputs for same numbers of turns. Though, the amounts of turns in the group (a1-b2-c3); group (b1-c2-a3) and group (c1-a2-b3) may not be equal from reciprocally. With using of tap changer in the three windings. Because of this, the three 1200 phase changed generated voltages value is altered. In the end, the value and the phase angle of the adjusting voltage Vs's are varied spectrum is from 00 to 3600. The phasor adding of three generated voltages produce unit voltage Vs's [16].

As illustrated in Figure 2.2 in electrical system, at arbitrarily point, the voltage Vs is provided to three phase transformer's primary windings, that is parallel and transformer's nine other side windings.

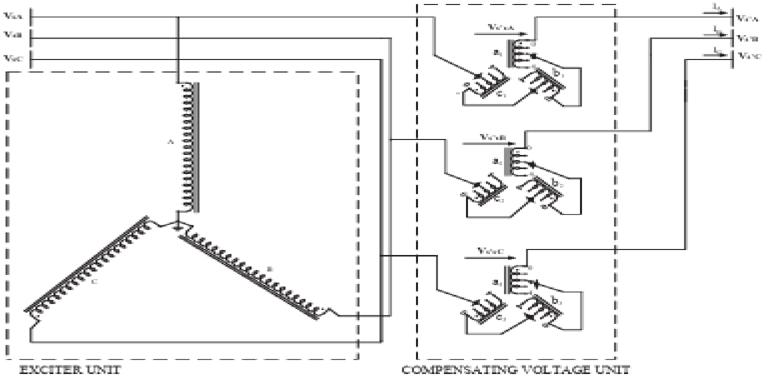


Figure 2.2 Simple model of SEN transformer.

By choosing the correct quantity of turns of the arbitrary winding (i.e. via load tap shifters) the modification of zero to top voltage is feasible in the compensating voltage level. Changing in any voltage depicted random phase, adjusting voltage in-phase element is induced in a winding which is bound on the connected phase of the transformer base that is depicted in figure 2.2 and phasor diagram is depicted in figure 2.4 [17].

The bidirectional compensating voltage Vs's is obtained from the phasor adding of the voltages generated in a three-phase winding group. For enhancing the voltage in any given phase, in phase element of the offsetting voltage is generated in a winding which is located on the related phase of the transformer base, as depicted in figure 2.2 and its equivalent phasor diagram is illustrated in figure 2.3.

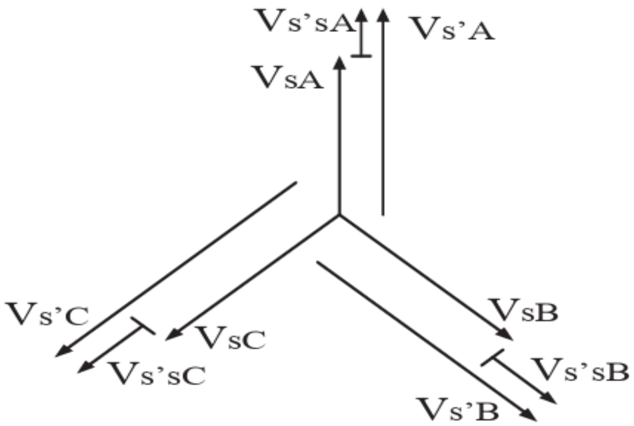


Figure 2.3 Phasor diagram of SEN transformer as voltage adjusting transformer to enhance line voltage.

For adjusting the voltage change in any given phase, the response regulation voltage out-of-phase element is generated from the phasor combining of the voltages induced in two parallel windings, which are constructed on the additional two phases of the transformer mounting platform. For instance, For the A-phase, the out-of-phase element of the adjusting voltage is acquiring from the phasor add of the voltages that are generation of phase-B and phase-C in two same windings and those are located on the base of primary winding of the same winding correspondingly. Correspondingly for first phase in-phase component of the regulated voltage is generated in a winding that is constructed on the base with the leading winding of the phase-A. Consequently, an adjusted voltage is gained at a special point of the transmission line.

The Sen Transformer is an affordable electrical equipment for adjusting power transfer in a transmission grid via voltage and phase angle run. The problem of voltage drops and rise, that is consistently, happens in transmission line, can be alleviate with the aid of ST. The pros of ST through other FACTS mechanisms are having basic control, lack of difficulty of switching of power electronics breakers and huge efficiency as minimal losses happens and main crucial character i.e. overall minimum cost. As an illustrated tackle to improve stability range of the power system, to show the causes of the Sen transformer on voltage drop and increase beneath little and huge disruptions ST was made and confirmed [18].

4. Voltage Adjusting with Reactor.

Southern California Edison has run the Big Creek Hydroelectric Program close to Shaver Lake, California—America's first huge-scale combined hydroelectric system. It contains 23 producing modules through nine powerplant, summing about 1,000 MW, and six reserves with through 560,000 acre-feet of supply. Location from north of the Rector Substation is approximately 70 miles in Visalia, Big Creek initially produces electric power for Los Angeles' Red Car trolley system. The Big Creek Corridor transfers that electric energy south and at that moment needs updates for maintaining system steady and dependability. Executing transmission improvements and a FACTS mechanism like the Reactor SVC enhances dynamic voltage supply and enlarges functional effectiveness [19].

The corridor attaches directly to a huge 230-kV grid at its southern end and divides into two freeways which region the northern hydro establishments. Power is transferred via three substations—one on the east point (Springville) and two on the west part (Vestal and Rector). Nevertheless, old facilities have established reliability problems, containing dropping conductors, old connections, and an absence of transposition structures, creating phase disturbance and restricted emergency capacity—especially beneath huge demand circumstances [20].

As a result, there is an important quantity of transmission declines in the corridor, especially beneath top level, massive summer demand circumstances of total hydro power production.

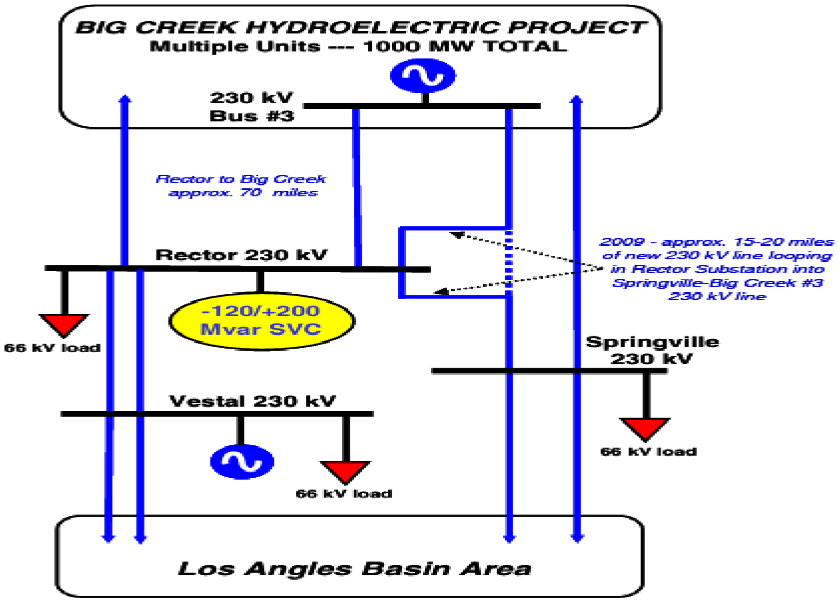


Figure 3.1 Example of voltage regulation with reactor.

As a result, the transmission corridor is quickly developing into a corridor which illustrated one directional power streams. Fundamentally, hydroelectric power produced in the north that was produced to the main 230-kV grid south part of the corridor. Power flow direction was firstly north-to-south and was vital equalized among the east and west points of the corridor. In recent contemporary, nevertheless, the occurrence of “urban expansion” demand increase has expanded into this transmission corridor. important demand increase has happened in the corridor to where the summer maximum demand in the corridor is at that moment in surplus of the hydro generation established capability. Consequently, beneath massive summer demand circumstance, the eequilibrium of local place demand not produced by the local hydro reserves is now produced by production resources outdoor of the corridor, i.e. south-to-north power transfer. Additionally, according to geographic restrictions, the huge most of this load increase has occurred at Substation which is including reactor positioned on the opposite of eastern point of the passage. This has occurred in running circumstance where the west part overburden correctly previously the east point (Springville) achieves maximum volume, mirroring an underemployment of the maximum transmission capability of the corridor [21].

Figure 3.2 illustrate the one-line scheme clarifying the main SVC device elements of the line reactor SVC and its interconnection to the 230 kV junction point at the substation that there is reactor. The SVC is a TCR/TSC/FC (thyristor-controlled reactor/thyristor-starting capacitor/stable capacitor) arrangement. The 200 MVA pairing transformer is consisting of three 66.7 MVA transformers that consist of on phase (with one single phase pare) that decreases the voltage from 230 kV system voltage to 9.5 kV low voltage for productive utilization and economic construction of the thyristor controls related with the TCR and TSC arms. The reactive power arms linked to the 9.5 kV bus are:

- three, 0 to -70 MVAr TCR armes
- three, +40 MVAr TSC armes
- two, +40 MVAr banks

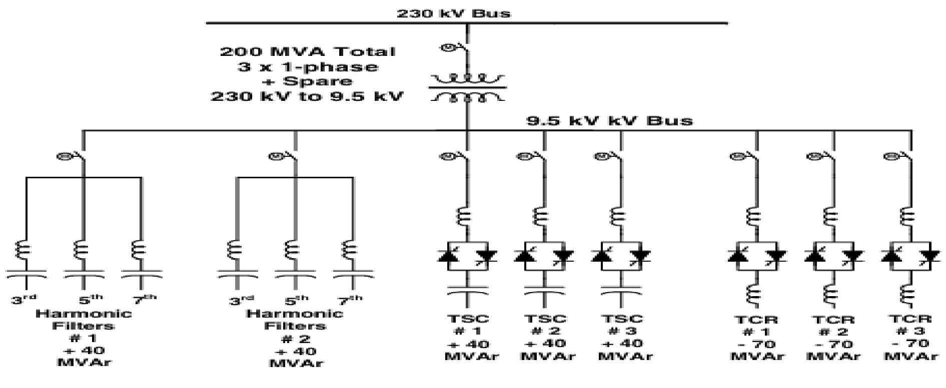


Figure 3.3 One-line scheme of the Reactor SVC.

All capacitance-base arms are restricted to 40 MVAr to secure the voltage alteration (from starting capacitive armes) does not proceed 2% beneath lowest short circuit running circumstances. Every of the harmonic filter groups contain a 13 MVAr select aligned to the 3rd harmonic, a 14 MVAr selector adjusted to the 5th harmonic, and a 13 MVAr filter adjusted to the 7th harmonic. The third harmonic selector arm is applied to aid alleviate previously present triple harmonic voltage aberration. The SVC has three TCR arms, each having an ongoing capacity of 0 to -70 MVAr inductive, therefore decrease of one TCR arm does not decrease the SVC inductive MVAr outage by more than 50% (i.e., -60 MVAr), as compulsory by SCE's construction/configuration standard. For instance, if one of the TCR arms is out of order, the left two TCRs (2 x -70 MVAr) can produce 60 MVAr of inductive outage with two harmonic selector arms (2 x 40Mvar). In the happening of a malfunction in one of the reactive power arms, the SVC can operate in a diminished mode/decreased capacity (after a running shutdown) with the loss of single TSC branch, the vanishing of single TCR part, and the loss of one selected part. Figure 3.4 depicted the SVC's normal operating condition V-I characteristics as it is constructed to produce ongoing output via the indicated margin of –120 MVAr (inductive) to +200 MVAr [22].

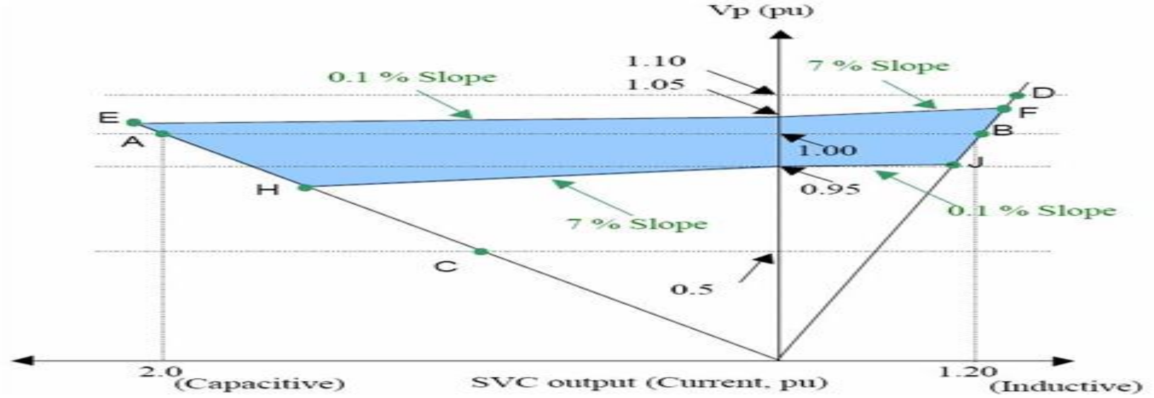


Figure 3.4 SVC stable condition volt-current (V-I) scheme.

The system issue and SVC tackle were presented, contain presentations on the pre-prodyucing changing efficincy traning and introduction of SVC working and nonworking circumstance is managed by running apparatus. The Reactor SVC was successfully conustructed, set up, checked, and commissioned in roughly 14 months through an in-service date of June 2007. The implimation of the Reactor SVC and stable condition orianted running produce enhanced short time voltage steadiness and active voltage supply in the Big Creek Corridor [23]

5. SVC and STATCOM for voltage regulation.

Static Var Compensator (SVC) installed in power systems is utilized for enhansing the system operation performance in different directions.

The SVC's are correspond to adjust system voltages, enhance steady-steat stability, improvement of transmission ability, minimise gradually overvoltages, make better dissipation of power oscillations, and diminsh non-synchronous resonances and rotational fluctations. The SVC as an intrumen to enhance power quantity is a sequences of the economic force on electrical energy systems via the world. So, a significiant understanding of running structure and dynamic treatment of SVC's is become vital so as to clarify the corresponding use of the compensator. This result could be attained by program simulation that also actss an essential role in the conustruction and deeply analysis of SVC's and other mechanisim.

The Static Var Compensator module is feathured by rapid response [24],

broad operational limit and increased reliability. From the numereous acceptable approaches to produce and run reactive power, currently thyristor controls are utilized as well as 54ICEEA'08 – International Conference on Electrical Engineering and its implementations. The important characteristic of the SVC is to adjust the voltage at a selected bus by governing the reactive power production at given places. Retaining the acceptable voltage point is crucial for correct working and use of burdens. Low voltage triggers decreasing in the operation of burdens such as induction motors, light bulbs.

Voltage increase affects magnetic saturation and outcome harmonic production, also maloperation of device according to insulation crashes. In its basic form,

the SVC is combination of a parallel connected TCR and bank of capacitors. From a working point of view, the SVC pretends itself like a parallel-connected changeable reactance, that either produce or compensate reactive power to regulatethe voltage level when at the junction point with the AC grid. It is utilized widely to produce peace reactive power and voltage adjust production. The svitching angle govern of the thyristor makes the SVC to have as well as sudden speed of reactions. The equivalent circuit of the structure of an SVC is depicted in Figure 4.1, which is similar with in parallel connected device that is composed of a number of in parallel device of single factor of a reactor with thyristor-switched.

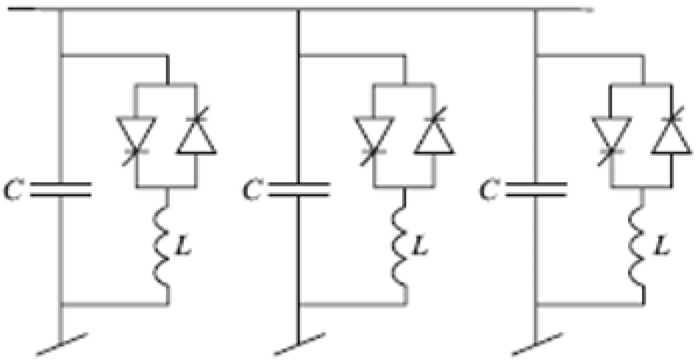


Figure 4.1 framework of Static Voltage Controller.

If we compare the response ttime The STATCOM is more attractive than SVC, demand of less space and through all its modern technology [25].

The STATCOMs can be used together with mechanically connected Reactors & Capacitors governed by STATCOM governer. The STATCOM could be mainly for dynamic regulation while the mechanically started reactors / capacitors could be for reactive regulation beneath stable condition. Beeyond that, research were proceeded for STATCOM as correlated to SVC. The elements of the researchs are written down:

The real-time regulation facilitates improved voltage steadiness by producing reactive power supply to the electric power system. Voltage steadiness is the ability of a system keeping voltage acceptable level at all the nodes in the system at all circumstance. The capability to transmit reactive power from producing resource to utilization areas while stable working circumstance is a main issue of voltage steadiness. A system primarily connects a circumstance of voltage nonstability while a fluctuation, growing in load requirement, or wariation in system circumstance cause a improwing and noncontrollable decrease in voltage.

A Static Synchronous Compensator (STATCOM) is a voltage resource changer (VSC)-main device, with the voltage resource back of a reactor. Voltage of STATCOM is formed by DC capacitor, so in practice the active power capability of STATCOM is limited. voltage (lower than that from AC voltage), it gives up reactive power. For instancee, if the point voltage of the VSC is greater than the AC voltage at the area of junction, the reactive current is produced by the STATCOM;

However, while the magnitude of the voltage supply is less than the AC voltage, it consumes reactive power. SVC has high response time compare with STATCOM, primarlly according to the quick starting times produced by the IGBTs of the voltage supply changer. The STATCOM compare with SVC produces high quality reactive power supply even in low AC woltages, so the reactive power from a STATCOM lowered linearly [26].

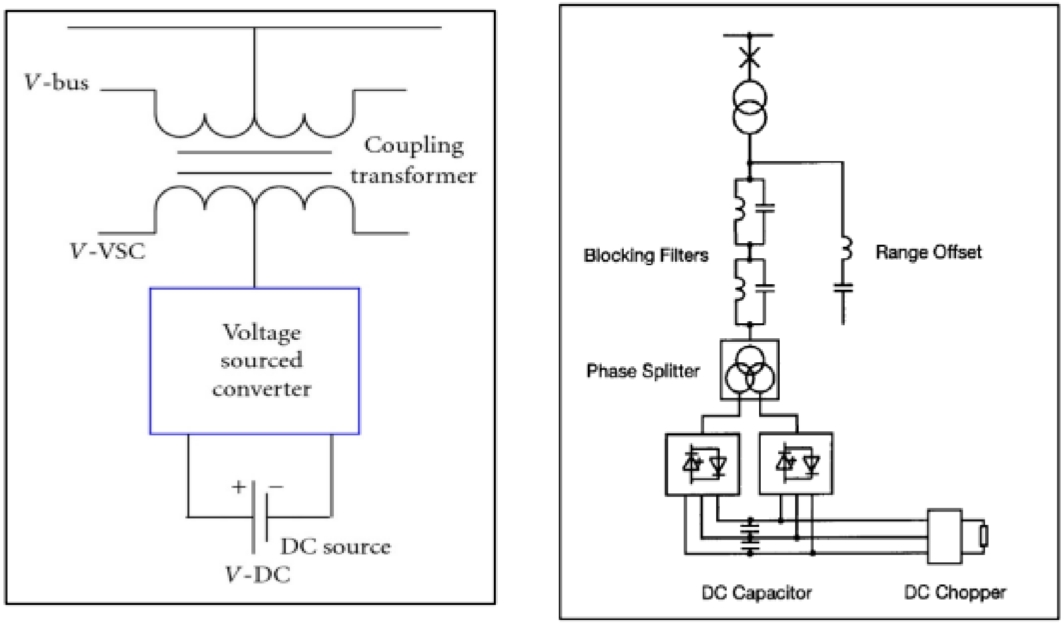


Figure 4.2 Principisl disgram and line diagram of STATCOM accordingly.

6. Vltage regulation in decentralized networks.

It is accordingly observed like the voltage imbalance, voltage oscillation, harmonics, steady state, short term changes, and long term changes are the characteristic voltage quantity problems includ in the electrical power system. The two of these charaecteristic problems are under-voltage circumstance and over-voltage circumstance may be shown beneath the longest voltage changes[27]. Lower voltage environment is where the network voltage is diminished than 90% of the acceptable voltage and the circumstance carry on more than 60 seconds . The canditions for lower voltage circumstances are highly chaged lines and extremely linked devices to the electrical system. Distributed generation (DG) is a result of over-voltage chaharcteristic. The voltage supply or the reactive power adjusting is the circumstance to The power electronic-based apparatus such as High Voltage Direct Current (HVDC) connections, For improving qualitiy and making more reliable the system Flexible Alternating Current transmission system and other devices have been applied [28]. Nowadays , the voltage regulation phenomen, that arises in alternating energy systems according to the high implementation of PV energy producers, has grabbed the focus of many investigations [29]. Conventional and highly improved techniques are utlized to tackle the voltage infringement issue and maintain the voltage through the acceptable levels. There are some techniques for exmaple running of grouped capacitors, adjustment of the transformer’s turns ratio while beneath load circumstance (OLTC), and voltage regulators of transformer (SVR) in that is the nonelectrical management systems are used. The quick workings of these nonelectrical equipments to quickly enhance the voltage infraction issues according to producing occasionally can trigger a crucial decrease in the lifespan of these equipments. The next techniques contain the management of reactive power supplied/consumed into/from the decentralized system via the PV energy converter and the D-STATCOM [30]. Additionally, the reduction of the actual power production of the PV generating system to enhance the voltage infringement which proceed the hihg acceptable limit [31]. In [32], the realization of a PV producing apparatus such as STATCOM at the nocturnal and diurnal the day in a decentralized systems has been offered.

Conclusion.

This literature review illustrate the ceratain importance of voltage control in maintaining the stability, reliability, and effectivness of advanced electrical power systems. Conventional ways such as regulation with tap- changer of transformer, parallel connected capacitor banks, and rotating VAR generator have been long time server as foundational element controllingof voltage. On the other hand, the improving chellenges of power systems, integration of alternative energy sources and distributed utilizers, have emerged the limitations of these conventional ways.

In industrial infrastructure at in present days having enhanced system that controls magnetic field of generator plays crucilal role in producing electrical power, where working cicumstances requires quick reaction and correct voltage control. These operating systems, supplied by immediate information and active control programs, have validated successfull in ensuering both static and active voltage stediness, especially beneath complex situations such as voltage decrease and abrupt burden changes.

In electrical transferin systems, the Sen Transformer (ST) providing a creative tackle for controlling voltage and phase location angle without the challenge of power electronic devices. Its basic conustruction and capability to transmit one directional voltage regulation make it a affordable device for alleviate voltage disturbance and improving power transfer abilities.

Versatile Alternative Current Transmission Systems (FACTS) devices such as Static Var Compensators (SVCs) and Static Synchronous Compensators (STATCOMs) produce active voltage supply via reactive power regulation. At the same time SVCs provide quick responce adjustment utlizing thyristor-based switching, STATCOMs surpluses them in in minimum reaction time, working beneath decreasing voltage circumstances, segmentability, and decreased positional demands. Research by POWERGRID and the Central Electricity Authority (CEA) validate STATCOMs' enhanced efficiency in real-life network conditions, making themfundemental for next-generation power systems.

As result, a combined solution combining conventional and advanced voltage control ways are crucial for paying the requirements of today’s growing.

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Metodology.

Basic Theory of AC Circuits.

Reactive power is produced while the current wave is not in the same phase with the voltage wave on account of inductive reactance or capacitive reactance components. Only in one case does the form of current in the same phase with voltage produces actual power that does the real time work. Imaginary power is needed for generating the magnetic fields and electric fields in capacitors and inductors. The lines that is used for transmitting electrical energy have both capacitive and inductive characters. A conventional transmission line can be depicted by a PI corresponding model as indicated in Fig. 3.1.

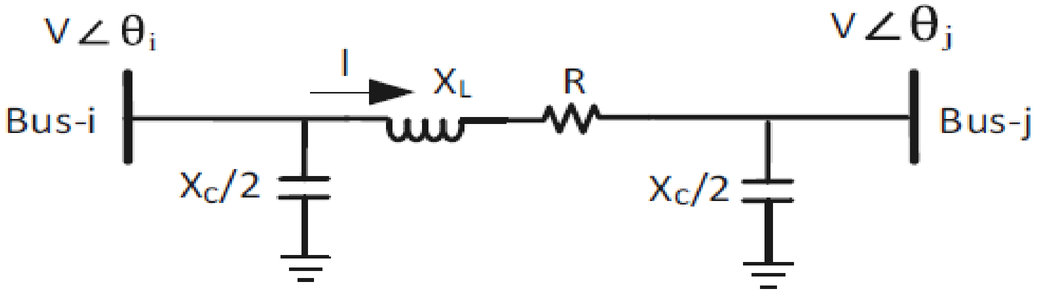


Fig. 3.1. Two buses line is used for transmission of electrical power and is depicted as corresponding PI scheme.

The capacitive need of the line is generated the generative reactive power (Produced), and the other component of line is inductance utilizes the reactive power (Qconsumed), which can be computed in a model line (R = 0) as:

$$P_{roduced} = \frac{V^2}{X_C} \qquad (3.1)$$

$$Q_{consumed} = I^2 X_L \qquad (3.2)$$

where V, XC, XL, and I are the bus voltage, the line's capacitive reactance, the line's inductive reactance and the line current, respectively. Therefore, the amount of reactive power consumed by a line is related to the current flow in the line; the amount of reactive power supplied by a line is related to the phase-to-phase voltage. At a Surge Impedance Loading (SIL), the produced reactive power is the same as the utilized imaginary power.

$$Q_{produced} = Q_{consumrd} \qquad (3.2)$$

By exchanging (3.1) and (3.2) in (3.3), the surge impedance (Z0) can be resulted:

$$Z_0 = \frac{V}{I} = \sqrt{\frac{X_L}{X_C}} \qquad (3.3)$$

The surge impedance loading (SIL) is same as the voltage multiplier voltage divided by the surge reactance:

$$\mathrm{SIL} = \frac{V^2}{Z_0} \qquad (3.4)$$

The expression depicts that a suitable line (with zero resistance) packed at its surge impedance packing does not generate or utilize imaginary power, so it will have the identical voltage at two ends. When a transmission line is loaded above its SIL, it acts like a shunt reactor which absorbs the reactive power from the system, and when a line is packed through its SIL, it plays like a parallel capacitor which provides imaginary power to the electrical system. Balance of this two utilization and generation of three imaginary power role and its manageability in AC electrical power … 119 imaginary powers at a special stacking level ends into a constant voltage profile through the line. The utilization of imaginary power by electrical transmission lines proceeds with the square of current. Thus, imaginary power is challenging to transfer through no short lines. In an electrical power system, the aim is to boost the consumption of the propulsion system, but some components restrict the load-carrying capacity of the electrical transmission systems. Equation (3.4) illustrates that the transferred power along a long electrical transmission line can be proceeded by growing the quantity of the line voltage (V) or by decreasing the surge impedance (Z0). This depiction shows that there are two main changeable quantities that can be immediately governed for maximizing the accomplishment of the electrical power system. These are:

- Voltage
- Impedance

Maximizing the phase-to-phase voltage is the most suitable case for proceeding with the power restriction beneath heavy packing circumstances. But there are some economic and practical restrictions. The surge reactance can be lowered by either proceeding with the capacitance of the transmission line or by lowering the inductance of the transmission line. With the establishment of "which" parameters can be governed in an electrical power system, the next question is "how" these parameters should be and can be governed. The a result is imaginary power production devices, which is mentioned below for example, series connected capacitors, or parallel connected capacitors may be utilized to decrease the quantity of the surge impedance.

3.2 Basic Principles of Power Transmission Operation

A transmission system is a complicated network of transmission lines which connect all power substations to the loads. The AC systems can be connected by the transmission lines to create a large power system for exchanging electrical energy. In a power system, the goal is to use the transmission lines with the least possible power losses and to maximize its loading capability by considering emergency conditions all the time. But some factors limit the loading capability of transmission systems, which are as follows

3.2.1 **Thermal Limit**

The thermal level of an overhead transmission line is attained while the current flow through the line that heats the conductor material up to a higher temperature that the current carrier material incrementally decreases mechanical endurance. It is fact, the thermal capacity of an overhead transmission line is a role of surroundings temperature, wind circumstance, conductor circumstance and its space from the earth. proceeding temperature reasons that the electrical transmission lines decrease their mechanical endurance and decrease its anticipated needed lifespan. Streaming current over the heat capacity is accepted only for a long and restricted time. Because of definition, normal and nominal current carrying capability of an electrical transmission line is a current that may be streamed over the line for an unrestricted time delay.

The line which currents (I in Fig. 3.1) can be separated into two constituents:

$$I = I \cos \theta + I \sin \theta \quad (3.6)$$

where h is the phase factor between voltage and current two components of transmission line. So, the line deficits can be attained as below:

$$P = R\,(I \cos \theta + I \sin \theta\,)^2 = R\,(I \cos \theta)^2 + R\,(I \sin \theta)^2 = P + P' \quad (3.7)$$

where $P' = R\,(I \sin \theta)^2$ is the imaginary power dissipation. Therefore, by decreasing imaginary power, the line deductions are reduced and accordingly the loading capability is maximized. The subsequent ways can possibly help maximize the loading capability of an electrical conductor line:

– Phase changing transformers

– Series connected capacitors or series connected reactors to align the reactance of the transmission lines

– FACTS components to govern the imaginary power streams utilizing power electronics.

– The phase changing transformers and series connected capacitors or series connected reactors are usually chipper options while FACTS are very flexible and more costly as well.

3.2.2 **Voltage Limit**

Voltage restrictions normally demand that the voltage value through the electrical transmission network be preserved within a suitable range, for example ±5% of the rated voltage. The voltage in the electrical transferring line can be shifted by the shift of the burden or happening of the threshold in electrical transmission and carrier lines or other devices. In these circumstances, it should be written that the dynamic and transient volt ages should be maintained through a depicted interval. If the line voltage proceeds more than the top nominal quantity, it can end in no longer circuit and may cause harm to transformers and other devices in the substations. The voltage in AC transmission system is almost linked to the value of imaginary part of current of the conductor as well as line's impedance. Capacitors and reactors can be established on the lines to govern the voltage shifts through the line.

3.2.3 Stability Limit

Because of explanation, power system ability to be stable is the capability of the power network to maintain in an equilibrium circumstance while normal working condition of the network and to deliver back equilibrium circumstance through the minimum potential time after the happening of interruption. In general, in the literature, four distinguished types required to be handled constant operating point, controlled motion stability, none steady stead stability and voltage stability.

3.2.3.1 Steady State Stability

Steady state stability directed to system power system ability to be stable in reaction to tiny deviations and ongoing shifts in the burden. Balanced state stability can be enhanced by

– Proceeding the voltage value of the system

– Putting in new electrical lines to the electrical transmission systems

– Decreasing the series impedance of the conductor with bundling the tying, with mounting of series connected capacitors through the line.

3.2.3.2 Transient Stability In a power system

No balanced state stability is the capability of the system in moderating the fluctuations according to extreme disorders, for example, the response of the voltage to malfunction in the electrical transmission network produced by happenings such as flash. Transient stability of the electrical network may be enhanced by boosting the system voltage and booming the X/R ratio of the electrical power system. A growing in the system voltage outline and X/R ratio suggests an enhance in the electrical power transmit capability. So, it aids to enhance the ability of being stable.

3.2.3.3 Dynamic Stability

The capability of an electrical power system to keep stability beneath immediate tiny deviations is researched below the designation of dynamic stability (also recognized as small-signal stability). For example, power fluctuations happen from separation of huge quantity of production or burden or energizing of some of the transmission lines.

3.2.3.4 Voltage Stability

Voltage Stability is the ability of the system to maintain steady state voltages at all the system buses when subjected to a disturbance. The system voltage might be unstable, if the load demand suddenly increases, or a disturbance occurs. One of the important factors that plays a significant role in voltage instability is the inability of the system to provide the required reactive power. Voltage instability causes voltage collapse in which the buses' voltage begins to drop progressively and uncontrollably. Placement of series and shunt capacitors and reactive power controllers can prevent voltage instability. Such compensation has the purpose of injecting reactive power to maintain the voltage magnitude in the buses close to the nominal values, as well as to reduce the line currents and therefore the total system losses. In brief, reactive power generation technologies can provide remedies for all of the above voltage and stability issues and create the possibilities to run the transmission system closer to its thermal limit by controlling two main variables of the power system: Voltage and impedance.

3.3 Equipment for Reactive Power Generation in Power System

Reactive power can be produced by power stations, capacitors, static reactive power generators and synchronous condensers. Imaginary power production by power stations has two issues: first and foremost, the imaginary power production ability of a power station is restricted and secondly, this enormous power consumes the capability of electrical transmission line, transformers, and enforces some shortfalls in the electrical network. The possibilities of imaginary power origins close to the utilization not only minimize the expenses but also maximize the capability of the electrical transmission line.

3.3.1 Parallel Capacitor

Situated on the quantity of voltage decrease, some shunt connected capacitor batteries are joined to the system and produce the needed imaginary power. It proceeds with the burden power component and ultimately the real power capability of transformers.

3.3.2 Series Capacitor

Series connected capacitors at the system are utilized to minimize the reactance of the transmission lines that proceed with the power transfer capability and minimize the voltage fall. Recently, it was also been utilized for dynamic balance capability and restriction of

Sub-Synchronous Resonance (SSR). That is to say, the series connected capacitors is consumed to neutralize the series connected to inductive causes of conductor by producing a negative impedance. Capacitive inductance could always be lower than inductive impedance, and this circumstance is deliberated to ascertain the capability of the series connected capacitor. Not paying attention to this circumstance can result in over-compensation at the end of the line, which is not acceptable.

3.3.3 Reactor

Reactors are imaginary power utilizers that are mainly facilitated in substations and at the end of prolonged transmission current carrier in shunt. Fundamentally, a circuit breaker is implemented with reactors to join them in the system, when it is required. Normally, the reactor is powered on when the system burden is minimal, and it is powered off when burden is great.

3.3.4 Synchronous Condenser

No synchronous condenser is a synchronous work principal motor, that works at no burden and may be controlled as an inductor or a capacitor by adjusting its excitation current. The electrical device has three working conditions, that are relying on the power aspect. Lower-excited condition, normal-excited condition, and over-excited condition. A lower-excited synchronous electrical motor consumes both real and imaginary power from the system. A high-excited synchronous motor consumes real power from the system, producing imaginary power at the same time. A balanced-excited motor consumes only real power. Due to the energy warehousing ability, synchronous compensator with automatic run have quick and smoother reaction to imaginary power utilizers. Accordingly, they are highly beneficial than the shunt connected capacitor battery. Those imaginary power producers enhance the voltage and frequency balance, and both may produce electrical energy in short-term resulted by short-circuit failures. Automatic excitations adjust of synchronous compensator can enhance the system balance by producing phase-delayed kVar at less burdens and phase-advanced kVar at high loads. Also, they can retrain over-voltage occurrences at less demands, that is named the Ferranti law. Comparatively huge shortfalls are the crucial weak ways of this electrical device.

3.3.5 Reactive Power Control Transformer

Reactive power adjusts transformers regulate secondary voltage by tap changer and at the end, maintains the imaginary power through the indicated scope.

3.3.6 Static Reactive Power Generators with Variable Impedance

No dynamic imaginary power producer with changeable reactance modifies the imaginary power quantity by powering the capacitor banks and reactors. The goal of the method is to produce changeable reactance for regulating the transferring system.

3.3.6.1 Thyristor-Controlled Reactor (TCR)

A one phase Thyristor- controlled Reactor (TCR) is depicted on the Fig. 3.2a. The equipment is made of a stable reactor through the inductance L and a based on thyristor AC controller. The main impedance of the inductor can be modified uninterruptedly by adjusting the switching angle of the semiconductor device.

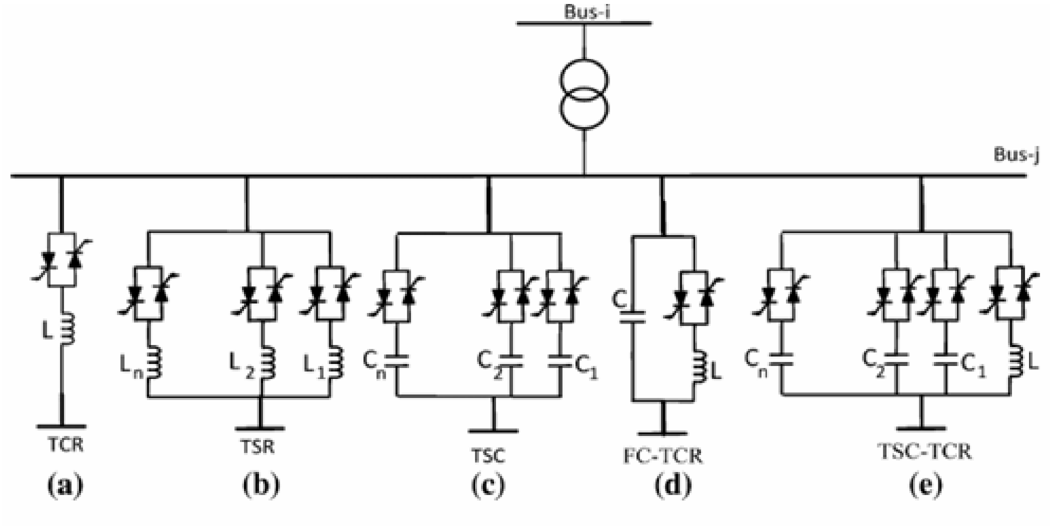


Fig. 3.2 Shunt adjuster for imaginary power adjusting, a Thyristor-Controlled Reactors, b Thyristor-Powered Reactor, c Thyristor-Switched Capacitor, d Fixed Capacitor Thyristor-Controlled Reactor, e Thyristor-Switched Capacitor-Thyristor-Controlled Reactor.

3.3.6.2 Thyristor-Switched Reactor (TSR)

A Thyristor-Switched Reactor (TSR) is made of numerous shunt inductors and breakers that are without firing angle adjustment and is illustrated in Fig. 3.2b. Utilizing the switches without switching angle adjust causes less shortfalls, but the adjust of imaginary power is not uninterrupted.

3.3.6.3 Thyristor-Switched Capacitor (TSC)

In a Thyristor-Switched Capacitor (TSC), the switches based on thryistor (there is no adjusting of switching angle) are consumed to power on or off the shunt capacitor modules that produce the demand imaginary power of the user (Fig. 3.2c). Contrary to the shunt reactive power consumer, which is reactor, the shunt capacitors may not be powered established on the switching angle to adjust the imaginary power uninterruptedly.

3.3.6.4 Fixed Capacitor Thyristor-Controlled Reactor (FC-TCR).

One of the crucial facilities to produce imaginary power is to consume a Fixed Capacitor and a Thyristor-Controlled Reactor (FC-TCR), That is depicted in Fig. 3.2d. The capacitive stable imaginary power together with changeable imaginary power of the TCR produce an output imaginary power

3.3.6.5 Thyristor-Switched Capacitor-Thyristor-Controlled Reactor (TSC-TCR).

A simple construction of one phase Thyristor-Switched Capacitor-Thyristor Controlled Reactor (TSC-TCR) is illustrated in Fig. 3.2e. For a depicted scope of the power output signal, the facility is made of n TSC sections and a TCR. The result signal of capacitive imaginary power is modified by the TSCs in process and a correspondingly low output of the inductive imaginary power is consumed to minimize the not used imaginary power for producing the demand imaginary power.

3.3.6.6 Thyristor-Switched Series Capacitor (TSSC)

The core component of a Thyristor-Switched Series Capacitor (TSSC) is a capacitor that is joined in shunt to a thyristor established ac breaker as depicted in Fig. 3.3a. A TSSC may only act as a role of a non continuous capacitor for adjusting and there is discrete adjust over it.

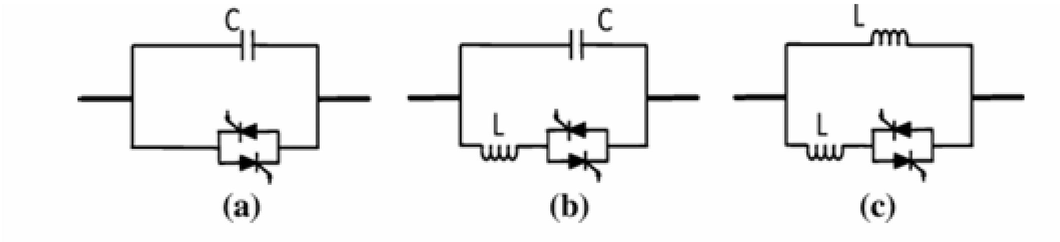


Fig. 3.3 Series compensators for reactive power control, a Thyristor-Switched Series Capacitor (TSSC), b Thyristor-Controlled Series Capacitor (TCSC), c Thyristor-Controlled Series Reactor (TCSR)

3.3.6.7 Thyristor-Controlled Series Capacitor (TCSC)

Thyristor-Controlled Series connected Capacitor (TCSC) is made of a capacitor unit in shunt with a thyristor-controlled reactor to produce the series connected capacitive impedance with the slightly modifies (Fig. 3.3b). The reactance of reactors is configured to be much less than the reactance of the series connected capacitors. At the switching angle of 90°, the TCSC aids to restrict the short circuit current. The TCSC may be made of numerous little capacitors with various dimensions for attaining super efficiency.

3.3.6.8 Thyristor-Controlled Series Reactor (TCSR)

A Thyristor-Controlled Series connected Reactor (TCSR) is an inductive reactance adjuster that is made of a series connected reactor through with an adjusted -reactor as illustrated in Fig. 3.3c.

3.3.7 Static Reactive Power Generators Based on the Power Electronic Converters

Nowadays, discrete (self-commutated) thyristors and other power electronics devices semiconductors are consumed to produce and to consume imaginary power, without the consume of alternative current capacitors or reactors, in which the output voltage signal is adjusted for producing the demand imaginary power. So, a stable imaginary power adjuster with a power electronic device converter is a system, which can produce adjusted imaginary part of current from an AC power supply.

3.3.7.1 STATic Synchronous COMpensator (STATCOM)

A STATic synchronous COMpensator (STATCOM) is a stable synchronous producer, that works as a shunt imaginary power adjuster and can adjust the output signal of capacitive or inductive current as illustrated in Fig. 3.4

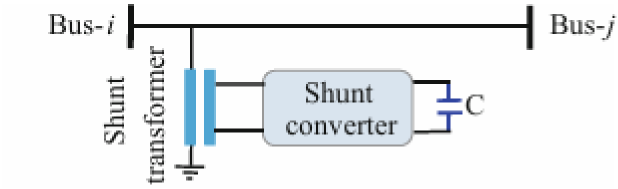


Fig. 3.4 STATic synchronous COMpensator (STATCOM)

3.3.7.2 Static Synchronous Series Compensator (SSSC)

Capacitor Bus-j Static Synchronous Series Compensator (SSSC) is a stable synchronous producer built on power electronics devices without an external energy supply, and runs as a series connected neutralizer (Fig. 3.5). It is consumed to improve or to minimize the imaginary part of voltage drop through the transmission line and accordingly regulate the transmitted electrical power.

3.3.7.3 Unified Power Flow Controller (UPFC)

A Unified Power Flow Controller (UPFC) is made of STATCOM and SSSC, that are joined via a dc access, to neutralize active and reactive component of power at the same moment without outward power supply (Fig. 3.6). It is an conclude neutralizer for adjusting the active and reactive component of power as well as the system voltage.

3.3.8 Interline Power Flow Controller (IPFC)

An Interline Power Flow Controller (IPFC), as illustrated in Fig. 3.7, can consume the active component of power from one end of a transmission line and produce to the other end of the transmission line. Consequently, contrary to the SSSC, this neutralizer is able to regulate both the phase and amplitude of the produced voltage into the transmission line.

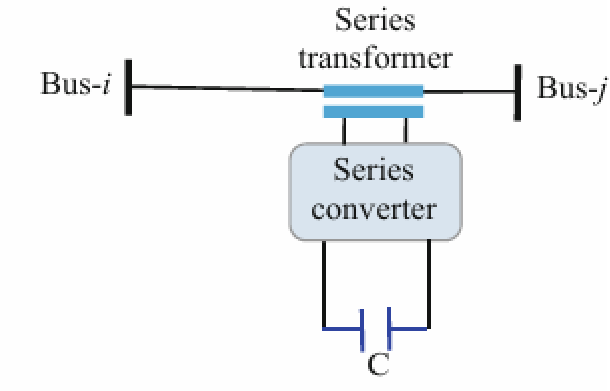


Fig. 3.5 Static Synchronous Series Compensator (SSSC)

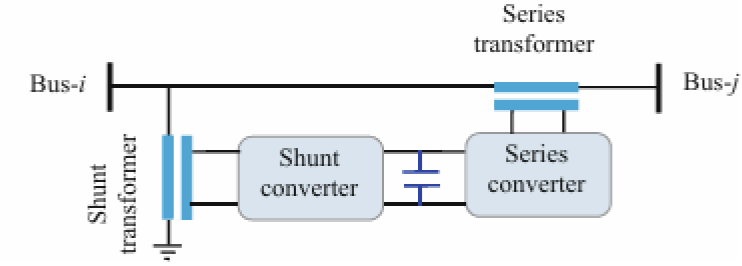


Fig. 3.6 Unified Power Flow Controller (UPFC)

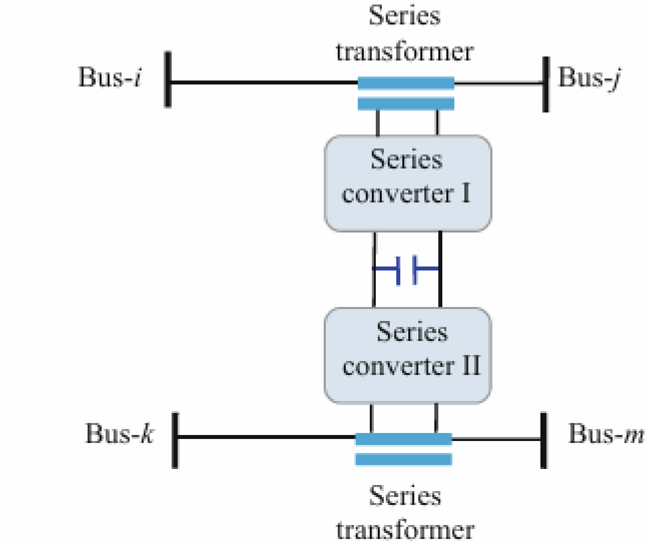
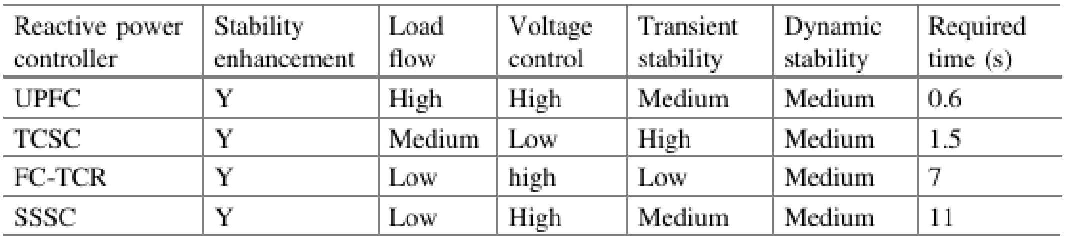


Fig. 3.7 Interline Power Flow Controller (IPFC)

Table 3.1 Comparison between reactive power sources for power system stability enhancement



Reactive power controller	Stability enhancement	Load flow	Voltage control	Transient stability	Dynamic stability	Required time (s)
UPFC	Y	High	High	Medium	Medium	0.6
TCSC	Y	Medium	Low	High	Medium	1.5
FC-TCR	Y	Low	high	Low	Medium	7
SSSC	Y	Low	High	Medium	Medium	11

Table 3.1 Illustrates a collation between different imaginary power supplies for power network being stable improvement. It is clarified that UPFC is a more efficient apparatus for power flow, voltage regulation and being stable improvement of the electrical power network, but it is as well as a highly expensive tackle.

3.4 Control of Reactive Power in a Power Transmission System

Figure 3.8 illustrated a streamlined model of a power transferring system, where XL is the impedance of the current carrier, Vi ∠ θi and Vj ∠ θj are phasors of the voltage of the grid nodes. The main idea of the reactive power regulation in power transferring network are to (a) transfer as much power as achievable on a current carrier of the special voltage and (b) regulate the voltage through the line through the frontiers. The active and reactive power at nodes i and j can be calculated by Equations. (3.8) and (3.9), correspondingly:

$$P_i = \frac{V_i V_j}{X_L} \sin(\theta_i - \theta_J), \quad Q_i = \frac{V_i(V_i - V_J \cos(\theta_i - \theta_J)}{X_L} \qquad (3.8)$$

$$P_J = \frac{V_i V_j}{X_L} \sin(\theta_i - \theta_J), \quad Q_J = \frac{V_i(V_J - V_i \cos(\theta_i - \theta_J)}{X_L} \qquad (3.8)$$

According to (3.8) and (3.9) the active and reactive power may be regulated by the voltages, phase angles and line reactance of the transferring network. Imaginary power regulation can be done by imaginary power producers, that are joined to the current carrier line in shunt or in series connected. The working procedure of parallel and series connected imaginary power regulators are depicted below.

3.4.1 Shunt Compensation.

Parallel reactive regulation is consumed in transmission networks to regulate the voltage magnitude, enhance the voltage quality and the being stable ability of the system. Parallel-joined reactors minimize the current carrier over-voltages by utilizing the imaginary power, at the same time parallel-joined capacitors preserve the voltage levels by regulating the imaginary power. Instead of inductors or capacitors, there are imaginary power regulators built on power electronic converters are made of semiconductor devices, that can produce the imaginary power free of the voltage at the node of junction.

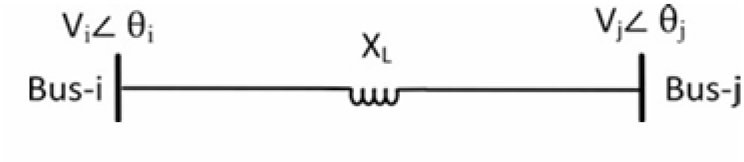


Fig. 3.8 Model of a shortfalls power transmission network

3.4.1.1 Parallel-linked Capacitors

Figure 3.9 depicts a streamlined model of a regulated transmission current carrier, in which the voltage quantity of the nodes is considered as $V \angle \theta_i$ and $V \angle 0$. An ideal regulated parallel-linked capacitor C is anticipated to adjust the voltage at the junction node as $V \angle \theta_i /2$. By consuming the on top of supposition, (3.8) and (3.9), the imaginary powers at node i and j can be acquired as Qi = Qj = $\frac{2V^2}{X_L}(1 - \cos\frac{\theta_i}{2})$ (3.10) Therefore, the produced imaginary power by the capacitor to regulate the mid-point voltage can be compute as:

$$Q_C = -(Q_i - Q_J) = -4\frac{V^2}{X_L}(1 - \cos\frac{\theta_i}{2}) \quad (3.11)$$

3.4.1.2 Shunt Compensation Built on the Power Electronic Converters.

Figure 3.10 depicts an equivalent circuit of the system, which is regulated by a parallel connected power electronic device. There are various configurations including for the parallel regulator such as modular numerous-level inverter, six-pulse three phase

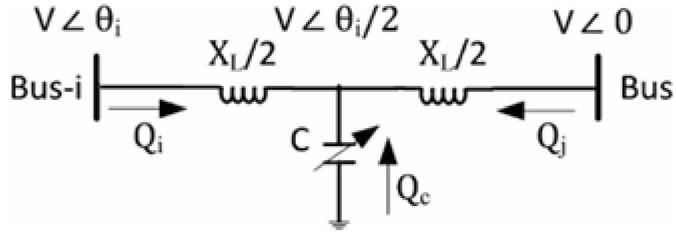


Fig. 3.9 Basic scheme of a regulated transmission current carrier by a parallel-connected capacitor

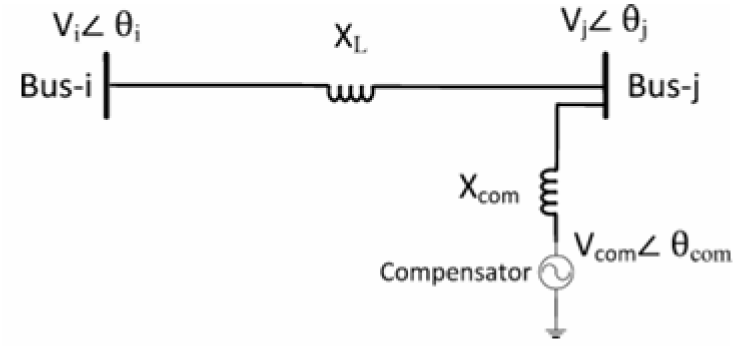


Fig. 3.10 Parallel regulation built on the power electronic devices

inverter, cascaded H-bridge converter, Neutral Point Clamped (NPC) inverter etc. So, the phase variation between the converter voltage and grid bus-j voltage (θcom–θj) is minimum during ordinary working condition, then sin (θcom–θj) (θcom–θj) and cos (θcom–θj). Accordingly, built on (3.8) and (3.9), the active power Pcom and imaginary power Qcom transferring out of the shunt connected converter are

$$P_{com} = \frac{V_i V_{com}}{X_{com}} = \sin(\theta_{com} - \theta_J) = \frac{V_i V_{com}}{X_{com}} (\theta_{com} - \theta_J) \quad (3.12)$$

$$Q_{com} = \frac{V_i V_{com}}{X_{com}} = \cos(\theta_{com} - \theta_J) - \frac{V_i^2}{X_{com}} = \frac{V_i}{X_{com}} (V_{com} - V_J) \quad (3.13)$$

From (3.13), the imaginary power Qcom can be regulated by modifying the voltage variation between the converter and grid nodes (Vcom–Vj). While the imaginary power Qcom is modified, the voltage Vj modifies less as well. This may be consumed to adjust the voltage at the PCC. Therefore, a parallel imaginary power regulator primarily has two distinguished working modes: one is named the direct Q adjust regime, that produces the admired quantity of imaginary power, and the other is named the voltage adjust regime, that adjusts the PCC voltage. Equation (3.12) depicts the correlation between the active power Pcom and the phase variation of the converter voltage and node voltage. The real power transferring in or outside powers the DC- junction voltage to maximize or minimize. At the end, it can be adjusted by regulating the phase angle of the voltage produced by the changer. When the shunt connected regulator is carried out in voltage adjusting regime, it performs the following V I characteristic. Figure 3.11 depicts as far as the imaginary current stands through the minimum and maximum current values (–Imax, Imax) mandated by the changer parameters, the voltage is adjusted at the citation voltage Vref.

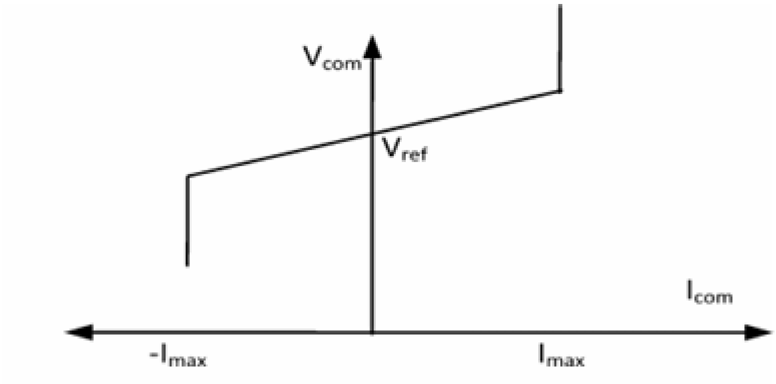


Fig. 3.11 V-I relation of the shunt connected compensator

3.4.2 Series Compensation Series compensation controls

the sequence reactance of the transferring current carrier. Built on Eqs. (3.8) and (3.9), the AC power transferring is simply restricted by the sequence imaginary reactance of the transmission current carrier. Series regulation with capacitors is the most corresponding phenomenon way to eliminate the impedance part of the current carrier. Like shunt connected compensation, sequence regulation can also be executed with power electronic changer.

3.4.2.1 Series Capacitors

A basic scheme of a sequence-regulated transmission current carrier is depicted in Fig. 3.12. The transmission current carrier is anticipated as ideal, and it is illustrated by the impedance X_L. A sequence regulated capacitor is linked in the transmission current carrier. The result sequence inductance of the regulated transmission current carrier is:

$$X_{total} = X_L - X \qquad (3.14)$$

Therefore, a sequence connected capacitor can eliminate the impedance section of the current carrier. This maximizes the maximum power, minimizes the transmission angle at an establishing level of power transmission, and maximizes the surge reactance demanding. Based on Eq. (3.8), the transmitted active power in the regulated current carrier is calculated as:

$$P = \frac{V_i V_J}{X_l - X} \sin(\theta_i - \theta_J) \qquad (3:15)$$

Similar to parallel connected regulation, sequence regulation can also be executed with voltage supplement changer. During compensation circumstances, the changer produces a voltage vector between two nodes in sequence. The result circuit, that is equivalent circuit to show the produced voltage vector by the changer is depicted in Fig. 3.13. As it may be understood, bus-j voltage vector can be illustrated as below:

(3.16)

Fig. 3.12 Basic scheme of a series regulated transmission line

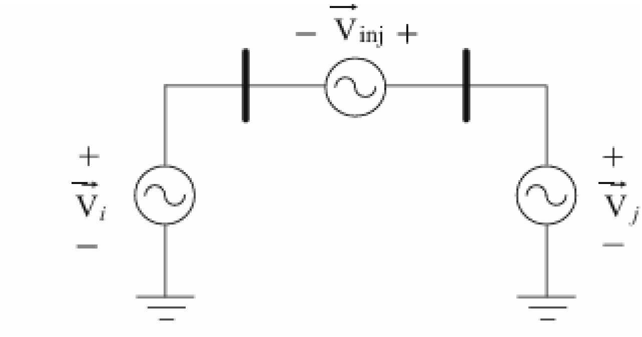


Fig. 3.13 Series compensation based on the power electronic converter

Where V_i V_{inj} and V_i are node -I voltage vector, produced voltage vector by the sequence changer and node-j voltage vector, accordingly. By producing a corresponding voltage vector by the changer, the voltage may be adjusted. The regulation model is one of the crucial section of the sequence regulator and has four simple duties:– First, the network nodes voltages must be assessed– After assassin, consuming a corresponding regulation way, the regulation model produces the voltage citation.– After generation the voltage source, the sending tasks are produced by the corresponding modulation way.– When the current magnitude exceeds the rated converter range, the control scheme will generate the corresponding inquiry to the protection apparatus. The two following ways have been normally consumed in literature for regulation and voltage control: 1. After transformation of the three-phase voltages to the synchronous documentation frame, dq-components of the voltages are adjusted consuming PI regulators as depicted in Fig. 3.14

2. By consuming a phasor assessment way such as Kalman filter, Discrete Fourier Transform, or Least Error Squares, phasor values of the sensed voltages and currents are assessed separately for every phase. Then the regulate model provides the voltage source for each phase. Figure 3.15a shows the vector scheme of the voltages and current during

the regulation and Fig. 3.15b depicts the regulation scheme built on phasor assessment technique. Here

$\vec{V_i} = V_i \ < \theta_i$, $\vec{V_j} = V_j \ < \theta_j$, $\overrightarrow{V_{inj}} = V_{inj} \ < \theta_{inj}$, $\vec{I} = I \ < \theta$, are the vectors of bus-i voltage, bus-j voltage, produced voltage by the changer and the line transferring current, accordingly. Vnom is the regulated voltage value. / is the phase variation between the current and voltage of the bus-j. c is phase variation between the produced voltage and bus-i voltage. due to Fig. 3.15, the produced power is computed as

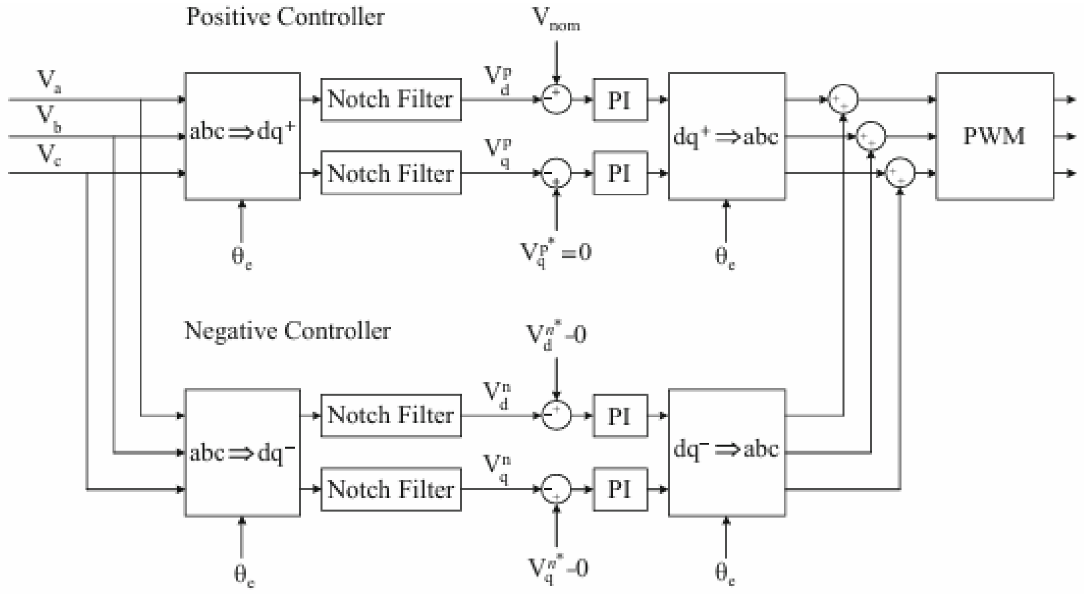


Fig. 3.14 Voltage regulation block illustration in dq reference structure

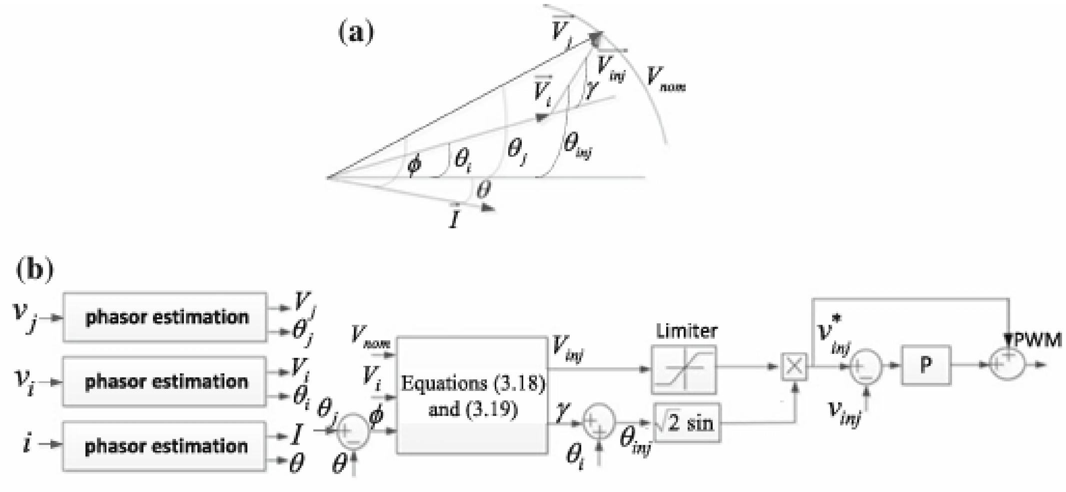


Fig. 3.15 Voltage regulation built on phasor assessment by sequence regulator, a vector scheme of the voltages and current under regulation, b block scheme of the regulation scheme

$$P_{inj} = P_{out} - P_{in} = V_J\, I \cos(\varphi) - V_i\, I \cos(\varphi - \theta_i - \theta_J) \qquad (3.17)$$

where Pout is the end point power and Pin is the commence point power. Since the regulation should be implemented by exchanging only imaginary between the chain changer and the grid, so Pinj = 0 is anticipated. In other words, the produced voltage should be positioned under 90 degrees to the current, so no active power is exchanged between the changer and the grid. By implementing a little quantity of regulations and trigonometric equations, the produced voltage value (Vinj) and c are obtained as follows:

$$\gamma = \arcsin\left(\frac{V_{nom}\cos(\varphi)}{V_i}\right) \qquad (3.18)$$

$$V_{inj} = \sqrt{V_{nom}^2 + V_i^2 - 2\, V_{nom} V_i \sin(\gamma + \varphi)} \qquad (3.19)$$

After generating the voltage sources, the inverter output voltages are produced in sequence by three single-phase transformers. To vanish the powering frequency harmonics, a low-pass filter for each phase is consumed, that is made up of the leakage inductance of the sequence transformer and the filter capacitor. As well as a shunt switch for each phase, it is consumed to route around the sequence changer in fault circumstance. An outline of the core philosophy of power transmission working and the reactive power role in the transferring network has been depicted. The transmission of imaginary power triggers additional temperature rising of the current carrier and voltage shortfalls in the grid. High imaginary power utilization by heavily demanded transmission current carriers tend to voltage falls in the network and restrict the production of the real power. Voltage and imaginary power regulation triggers that a constant, optimized, and reliable working of the power grid is attained, and use of the transferring system is optimized.

4. Voltage regulation.

Methods of Voltage Control	How will be controlled
With generator	Controlling excitation current
In transformer	Adjusting tap changer position
SVS and TCSC	Changing parameters
Capacitor banks	Adjusting values of capacitor current condition

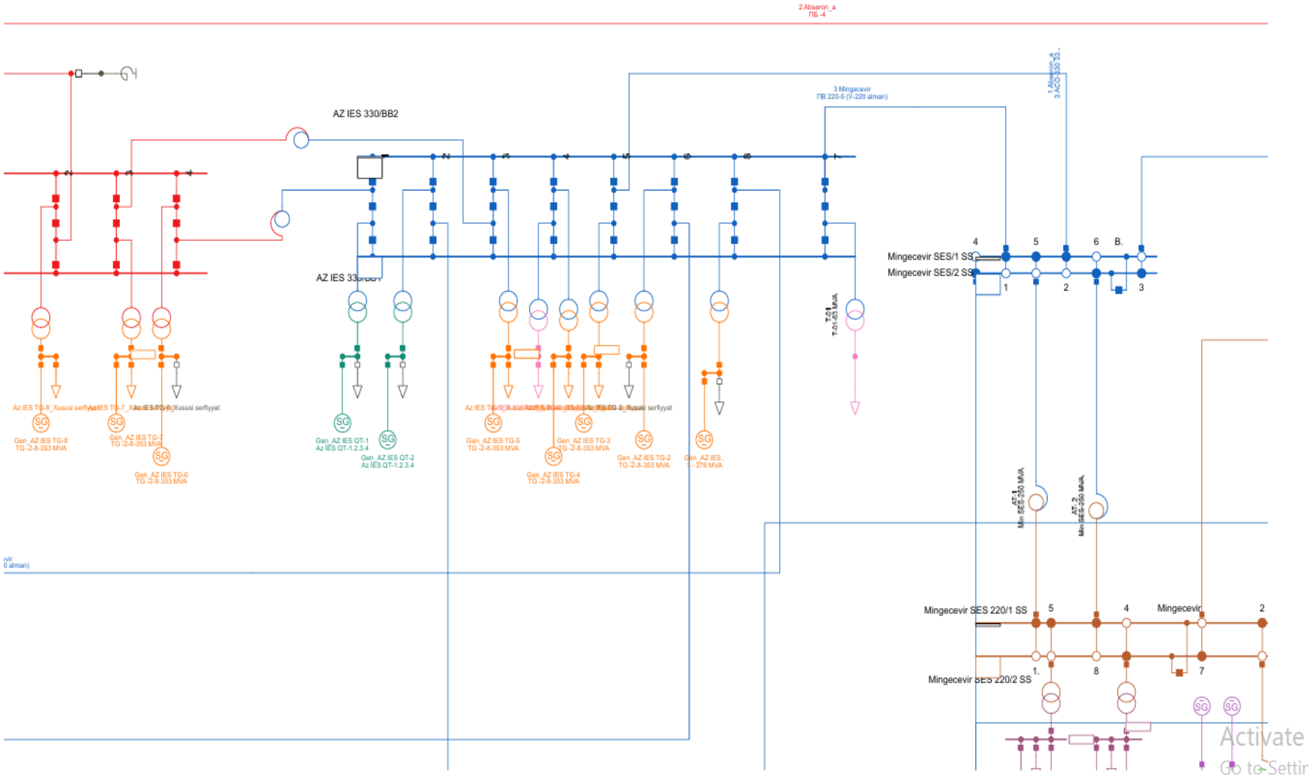


Figure 4.1 General scheme of connections in Digsilent Powerfactory program.

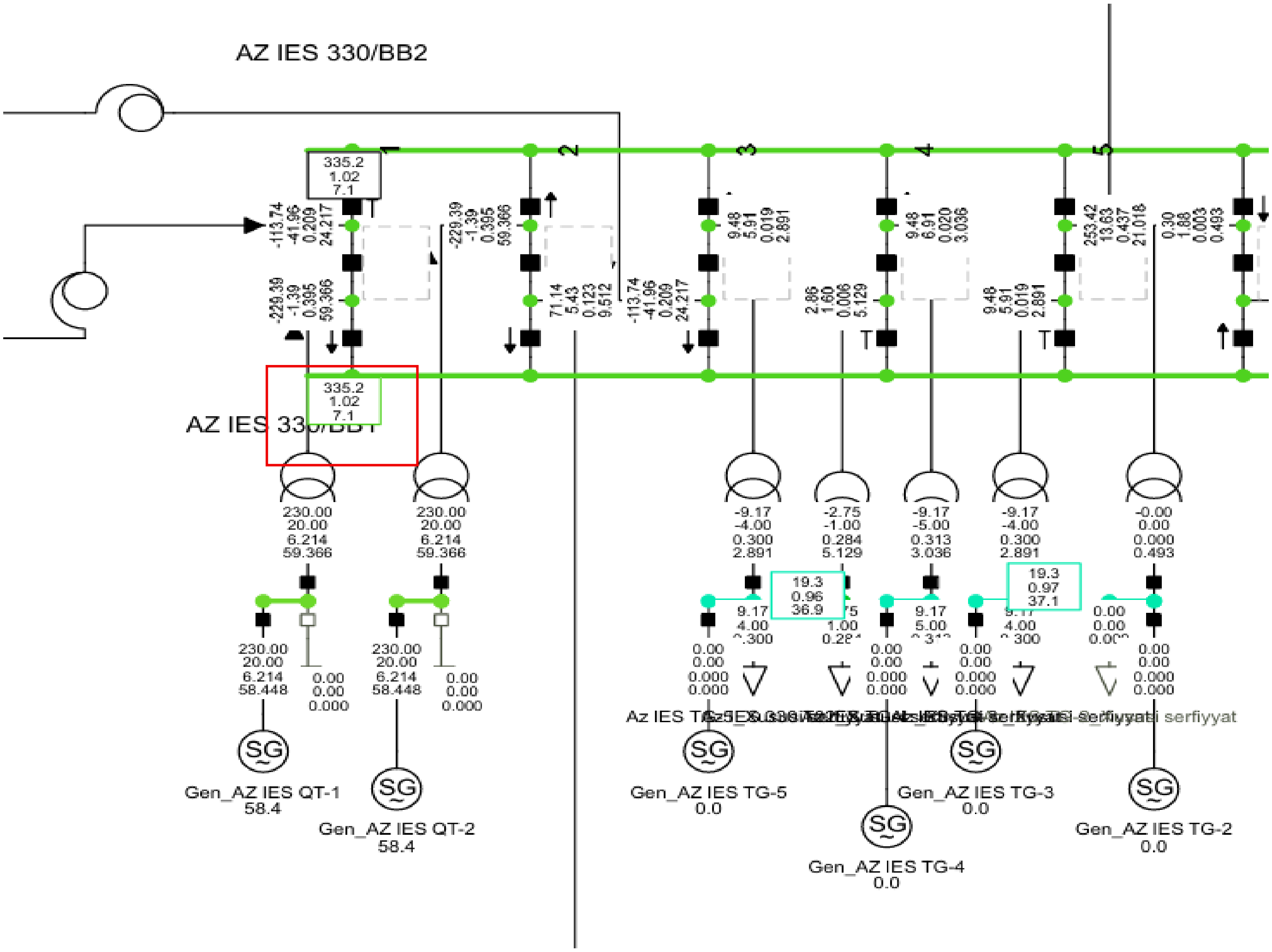
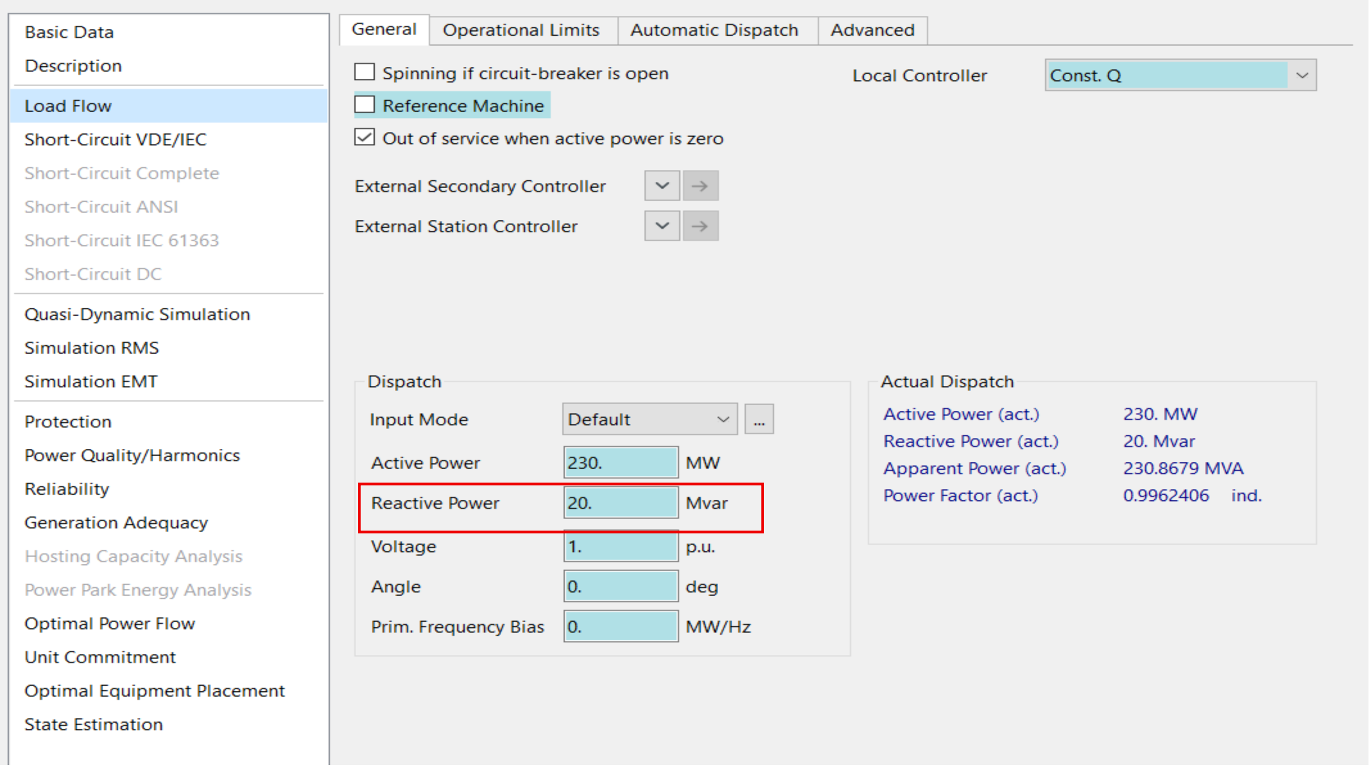


Figure 4.2 Load flow analysis for voltage regulation.

To regulate voltage in electrical power systems we will consume three methods, and they are considered three case A, case B and case C.

In case A for regulation system voltage in bus which the generators connected it the excitation current will be adjusted that cause to change reactive power of generator. If the excitation current increase it will cause increase voltage output terminal of generator. If the excitation current decrease it will cause decrease voltage of output terminal of generator. So, by adjusting reactive power of generator we can adjust the voltage of electrical power system.



☐ Spinning if circuit-breaker is open

☐ Reference Machine

☑ Out of service when active power is zero

Local Controller: Const. Q

Dispatch

Input Mode	Default	
Active Power	230.	MW
Reactive Power	20.	Mvar
Voltage	1.	p.u.
Angle	0.	deg
Prim. Frequency Bias	0.	MW/Hz

Actual Dispatch

Active Power (act.)	230. MW
Reactive Power (act.)	20. Mvar
Apparent Power (act.)	230.8679 MVA
Power Factor (act.)	0.9962406 ind.

Figure 4.3 Parameters of generator in Digsilent Powerfactory program

To adjust the voltage the indicated parameter that depicted red rectangular form will be adjusted. To carry out the work 230 MVA generator will be used which is connected to 330 kV bus system in Azerbaijan Thermal Power plant. As depicted in figure 4.3 without adjusting voltage the voltage value is 335.2 kV on the bus. For regulating the voltage, the reactive power of generator increases 30 MVAr the adjusted voltage reaches its 335.5 kV value. If the adjusting processes carry out to reactive power value of 50 MVAr the voltage on the bus adjusted to 336kV. In the end 220 MVAr reactive power value the voltage on the bus reach 340 kV value that is maximum acceptable level on the bus for 330 kV electrical power system.

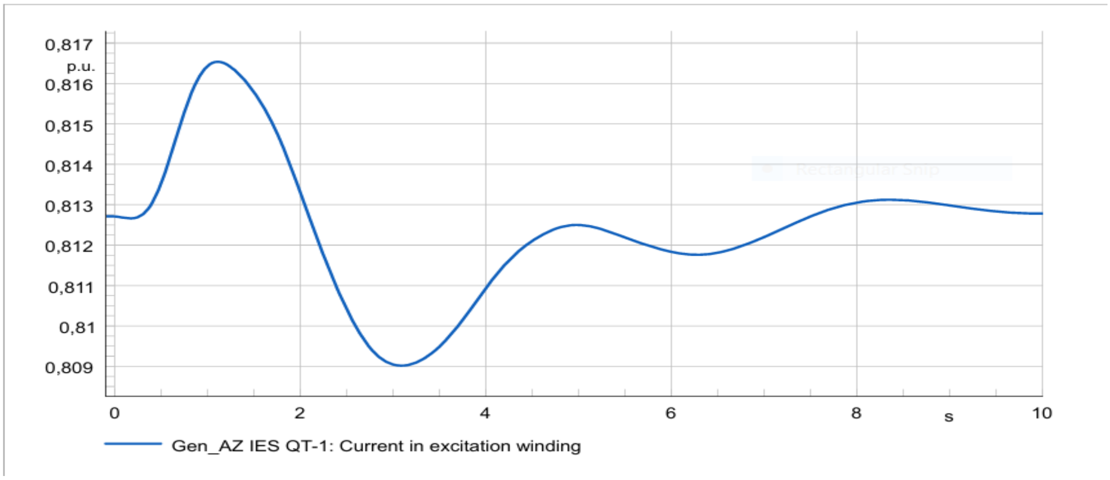


Figure 4.4 graph of excitation current in excitation winding of generator.

To adjust the voltage the excitation current of the generator is adjusted and the adjustment of excitation generator is indicated below.

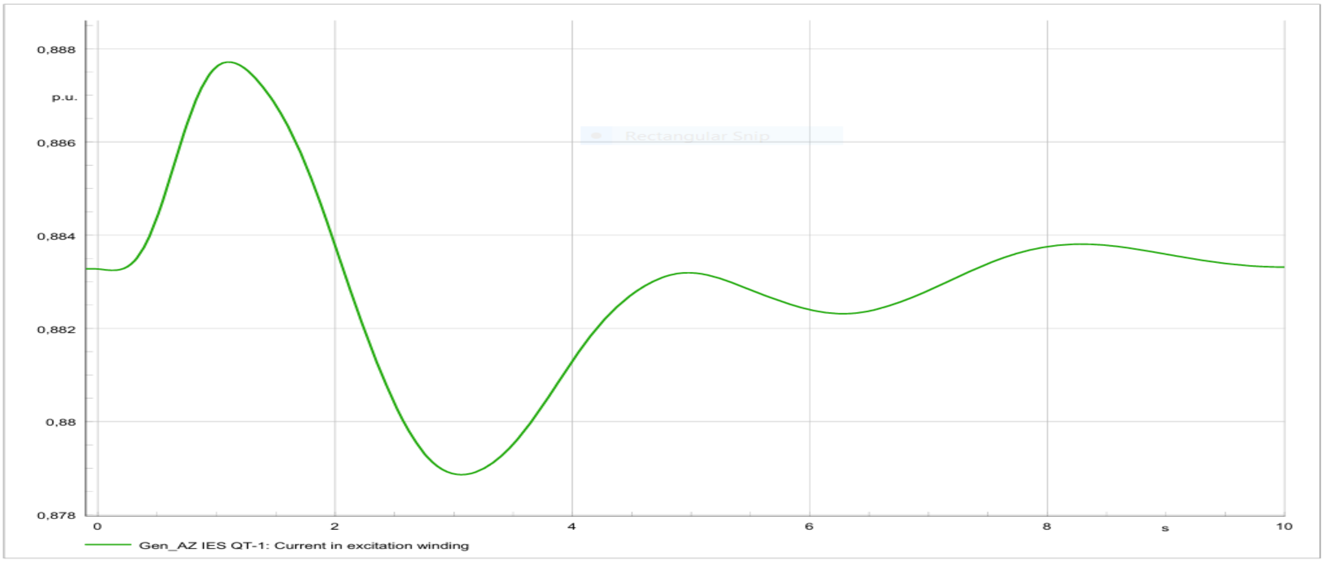


Figure 4.5 graph of excitation current in excitation winding of generator.

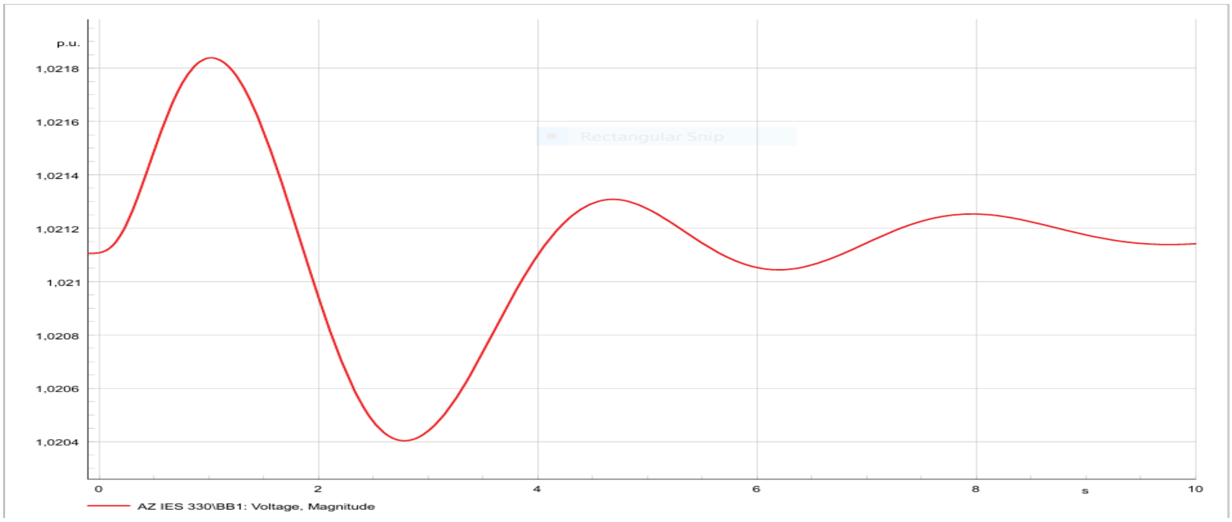


Figure 4.5 graph of Voltage in 330 kV bus system in Azerbaijan thermal power plant.

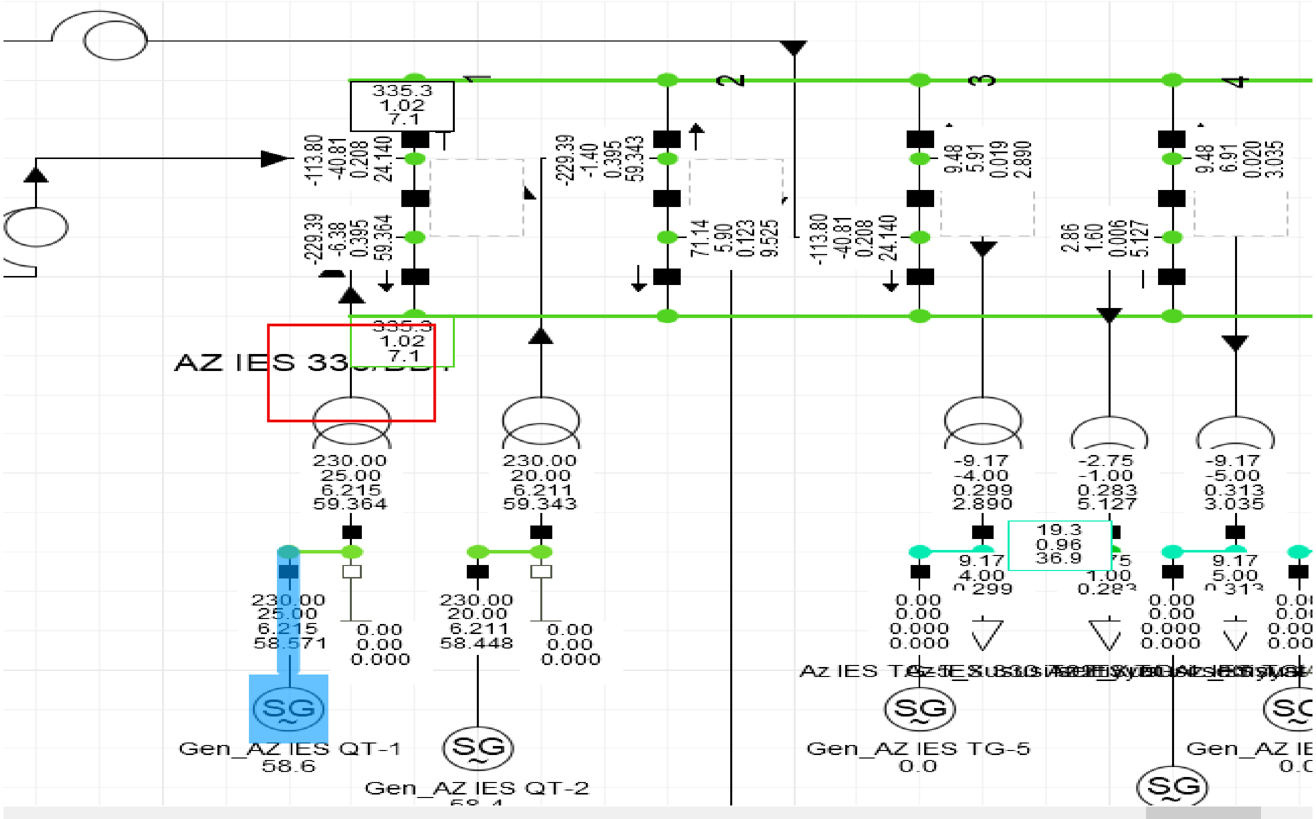


Figure 4.4 Example of voltage regulation in generator with adjusting reactive power of generator.

Adjusted Reactive Power, MVAr	10	20	30	40	50	60	70	80	90	100	160	190	220
Result Voltage, kV	334.9	335.2	335.5	335.7	336	336.3	336.52	336.8	337	337.3	338.7	339	339.8

Schedule 4.1 Voltage regulation with generator excitation current.

4.2 in case B voltage will be regulated by with SVC.

For regulation of voltage with parallel compensation the SVS will be used in ready model that has been depicted figure 4.5.

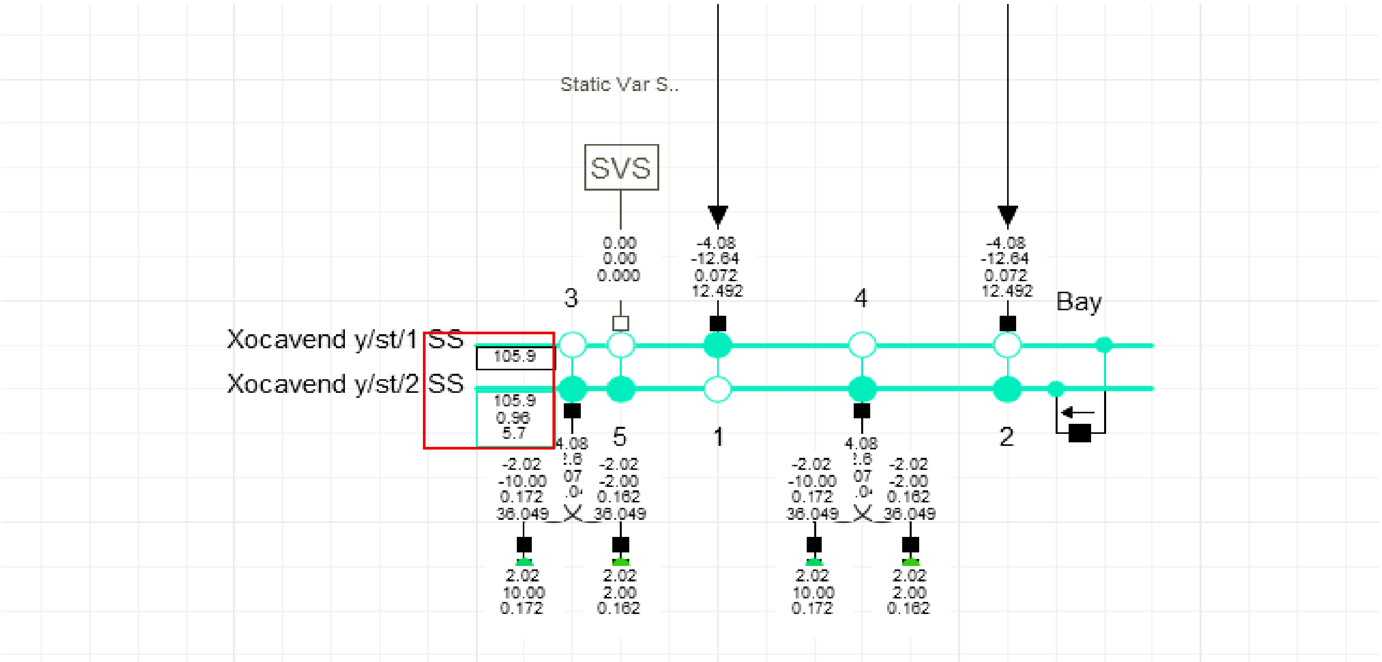


Figure 4.5 The model without any compensation

The power flow results are depicted in figure 4.5, and there is not any regulation by SVS, and results of power flow are indicated inside of red rectangular form.

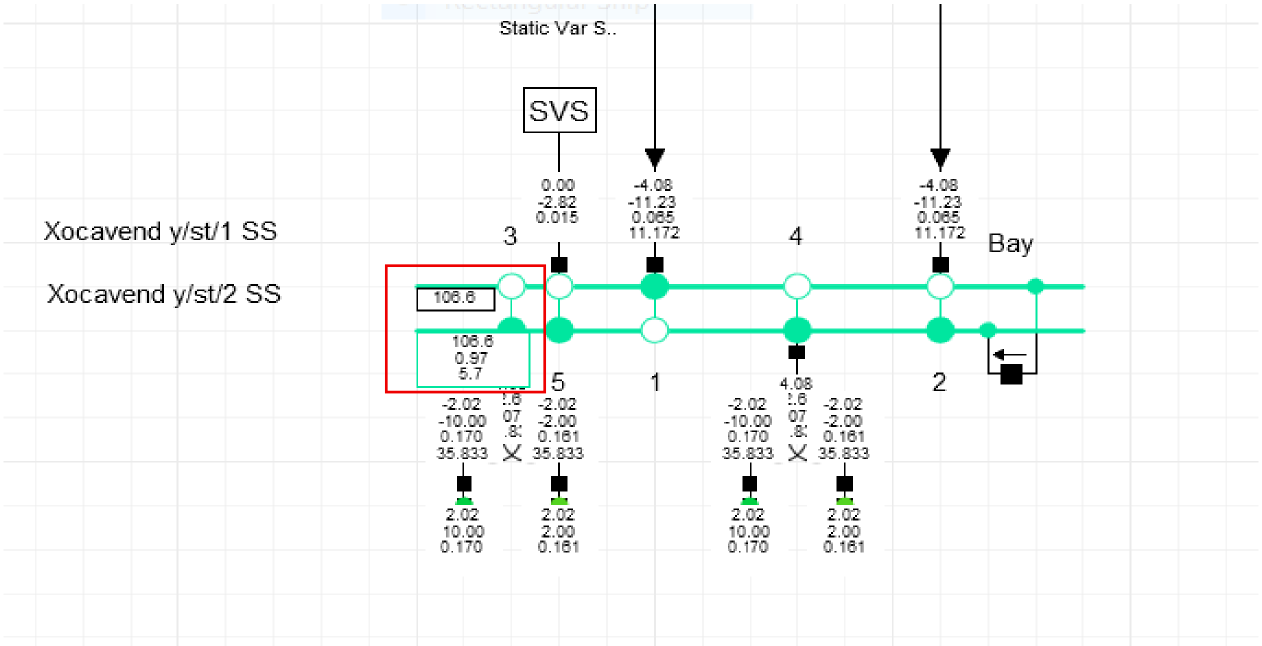


Figure 4.6 With SVC regulation.

The regulation results are depicted numerically, so for illustration graphical representation of voltage regulation the RMS simulation is executed.

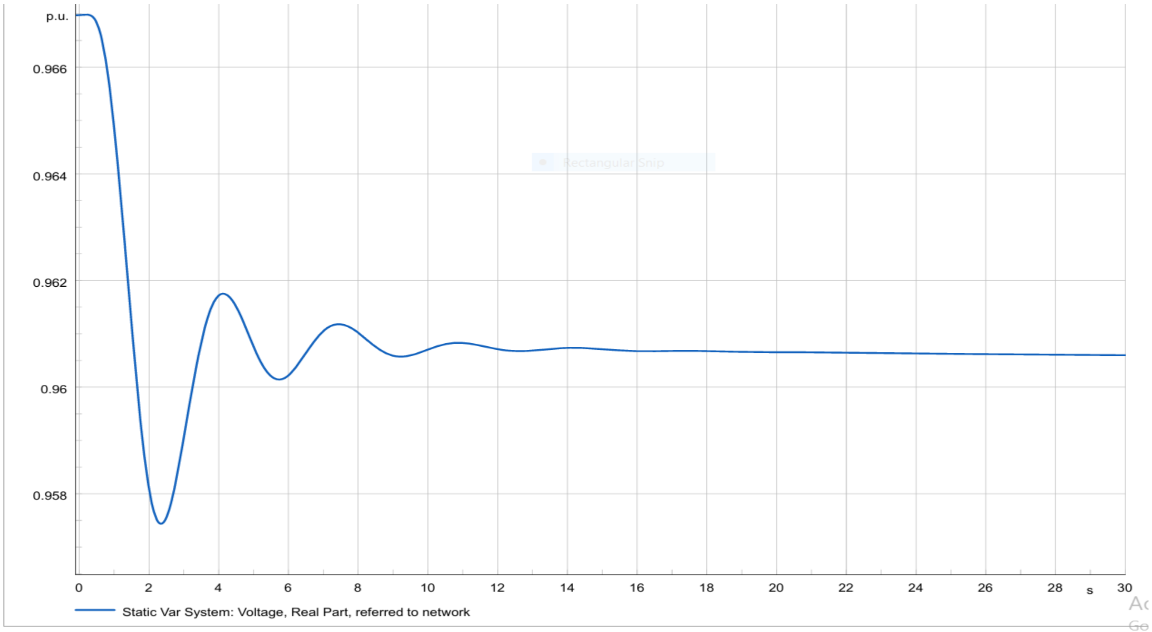


Figure 4.7 RMS simulation result of SVS which connect to Xocavend substation.

To illustrate regulation results the result in the substation the RMS simulation result for 110 kV I bus is depicted below.

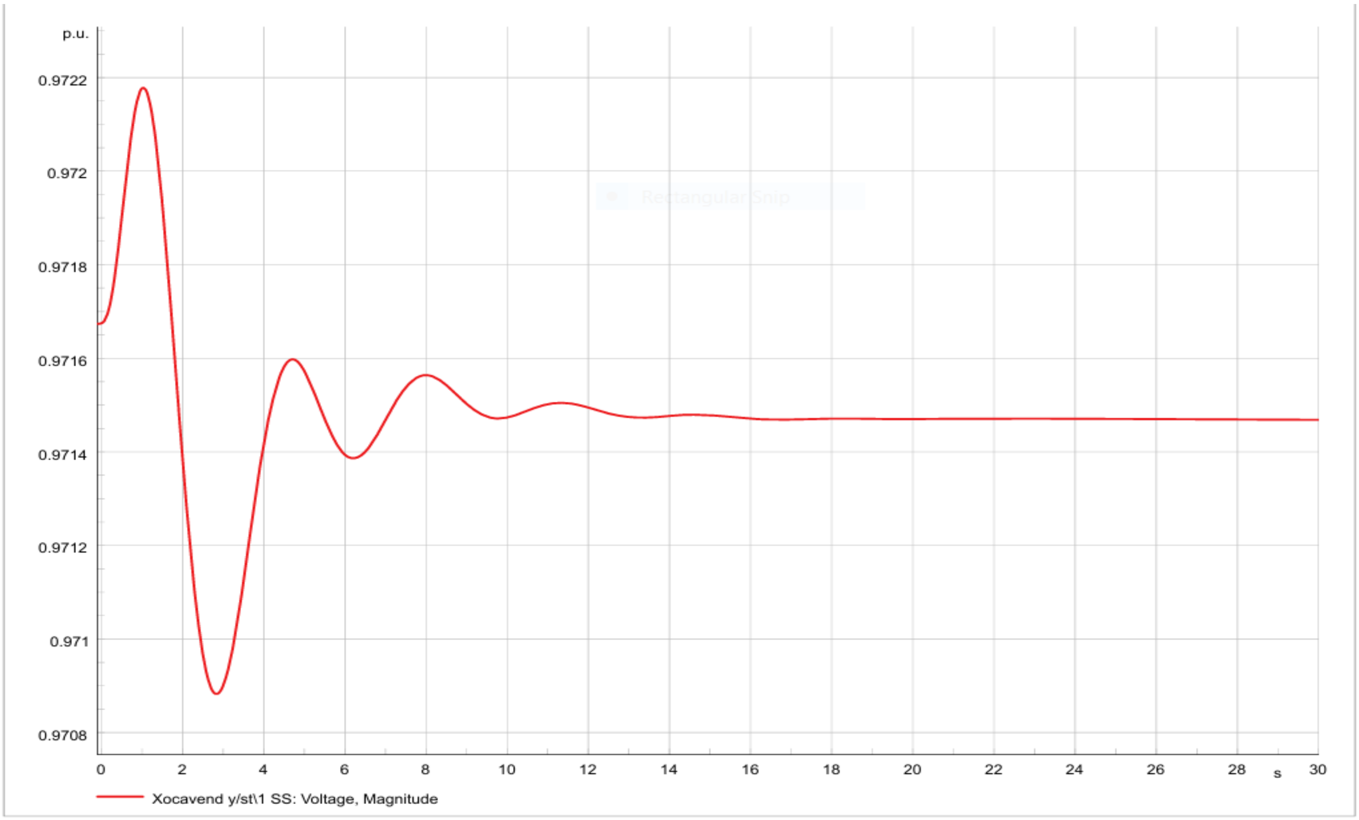


Figure 4.8 The result of RMS simulation in 110 kV I bus of Xocavend substation.

The simulation is carried out for other values and results are depicted below. For instance, 10 MVAr reactive power.

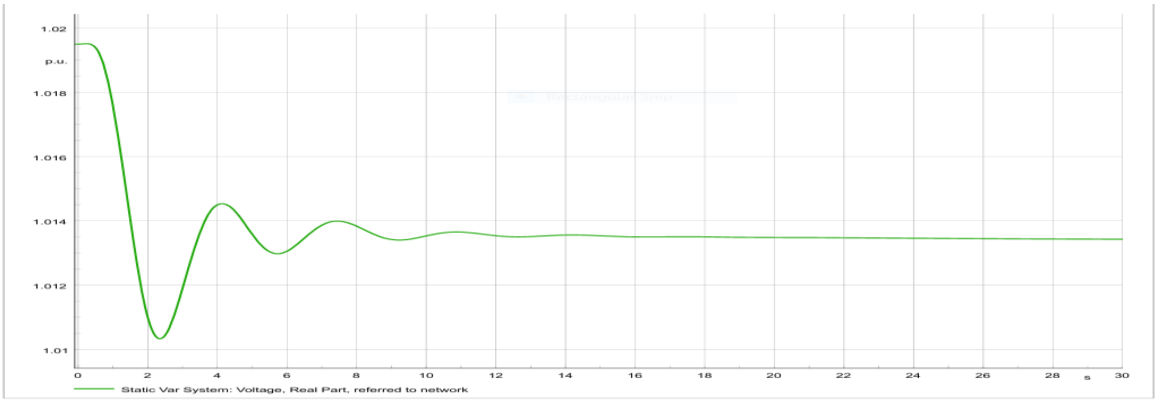


Figure 4.9 RMS simulation in SVS for 10 MVAr reactive power.

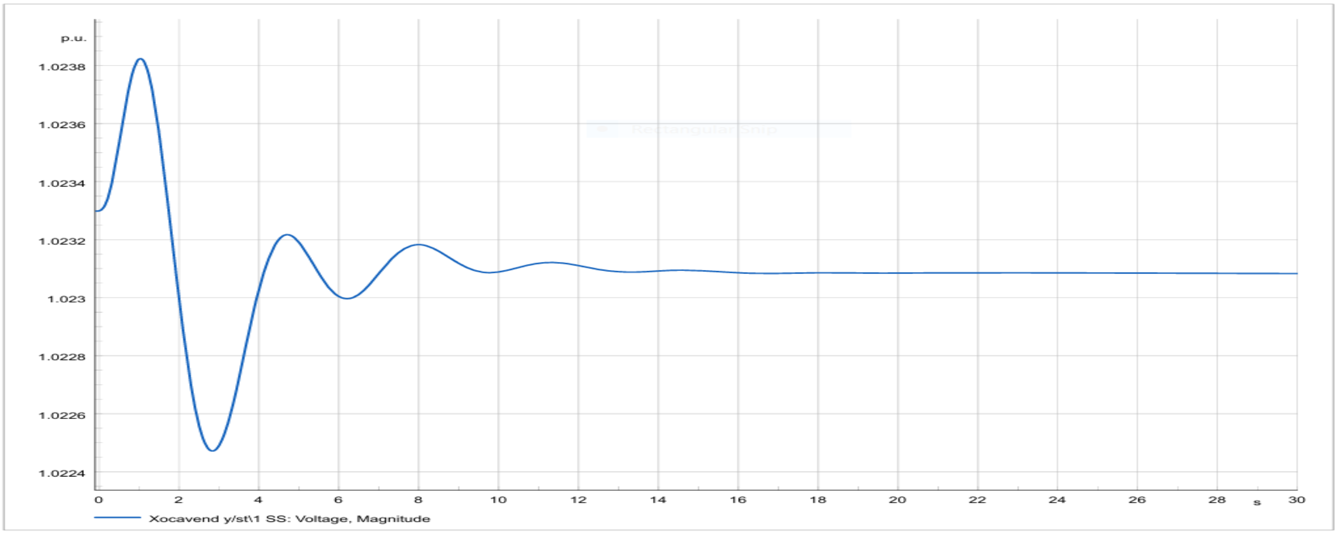


Figure 4.9 RMS simulation in 110 kV I bus of Xocavend for 10 MVAr reactive power.

The regulation results are depicted in schedule 4.2 step by step.

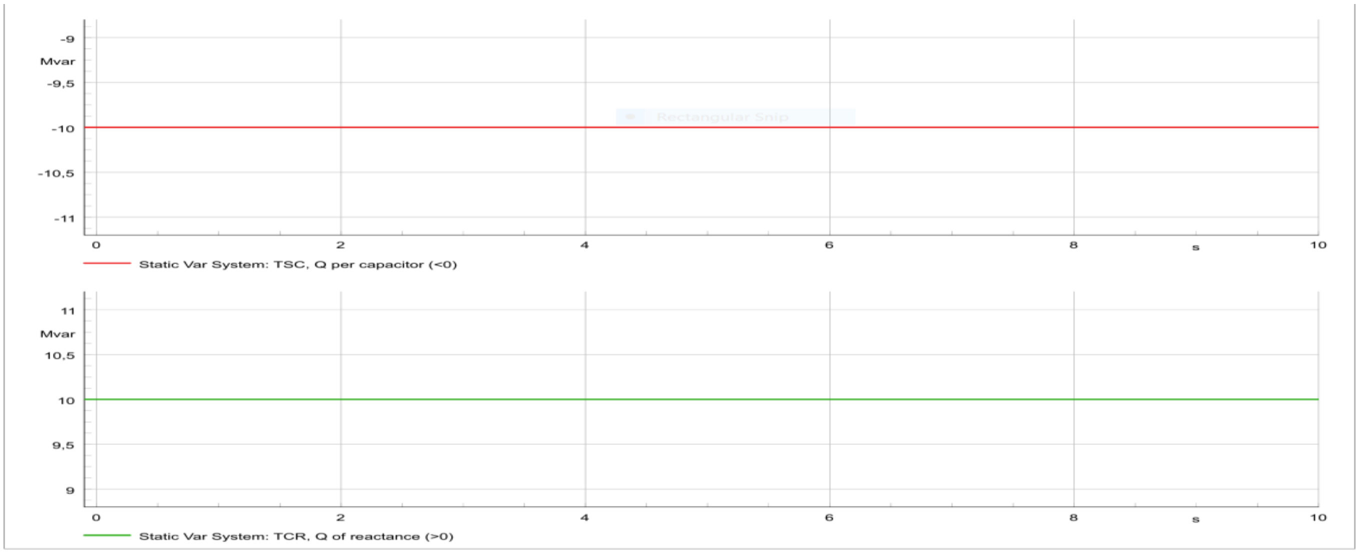


Figure 4.10 Minimum and maximum reactive power of SVS.

SVC, MVAr	0.5	1	1.5	2	2.5	3	4	5	7	10	13	15
Regulated Voltage, KV	106.6	107.2	107.8	108.5	109.2	109.8	110	110	110.5	112.6	114.7	116.2

Schedule 4.2 step by step regulation of voltage in 110 kV I bus of Xocavend substation.

The results depict the last regulation is executed in 13 MVAr reactive power value, and the regulation end voltage value is 114.7kV that is required value.

4.3 in case c voltage will be regulated by TCSC.

Controlling voltage with TCSC belongs to series compensation method. Depending on the regime the TCSC controls the effective reactance to adjust voltage in system buses. To simulate voltage regulation in dig silent "Dig SILENT Power Factory" program the six buses system are consumed. The rated power of generators and transformers are 1700 MVA and 1000 MVA and rated voltage are 20kV and 500 kV.

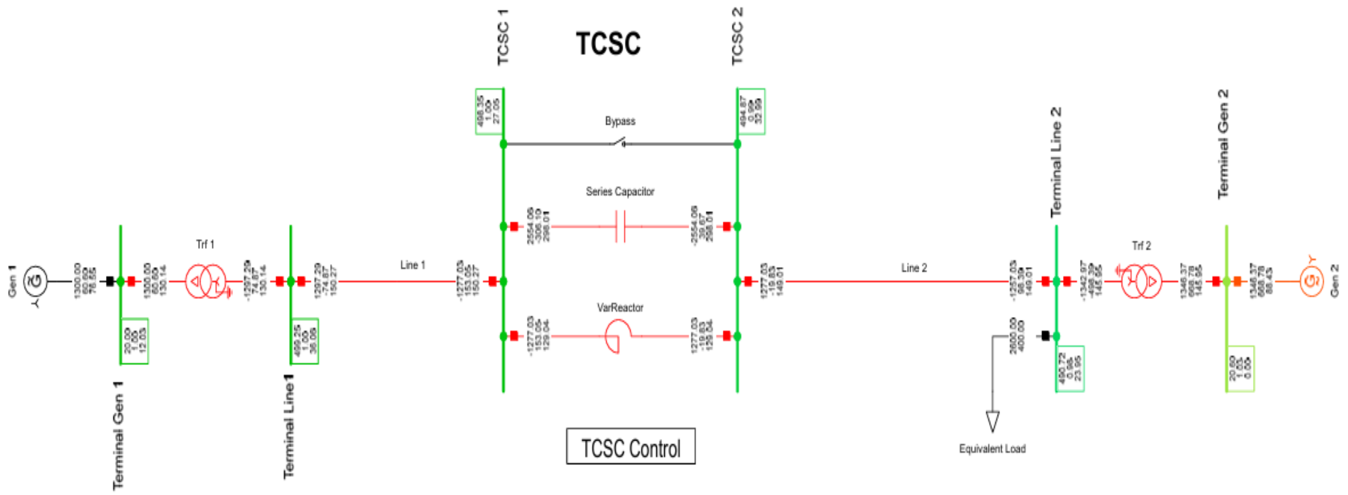


Figure 4.11 "Dig SILENT Power Factory" model of TCSC.

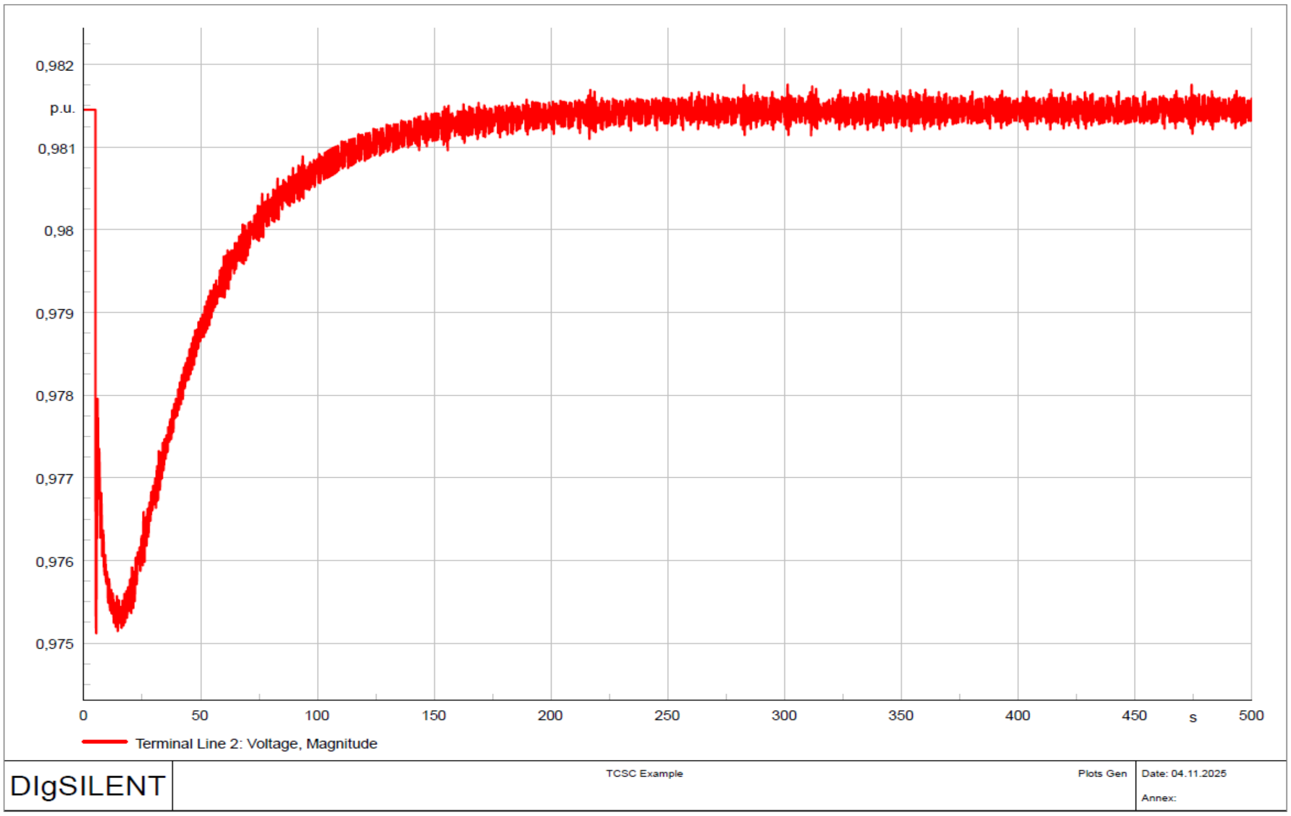


Figure 4. 12 Voltage control with TCSC.

The voltage regulation terminal line 2 bus depends on situation. The simulation is carried out during 500 seconds to illustrate dynamic simulation result clearly. TCSC regulates voltage in case power that passes through the TCSC depends on that increase or decrease the impedance.

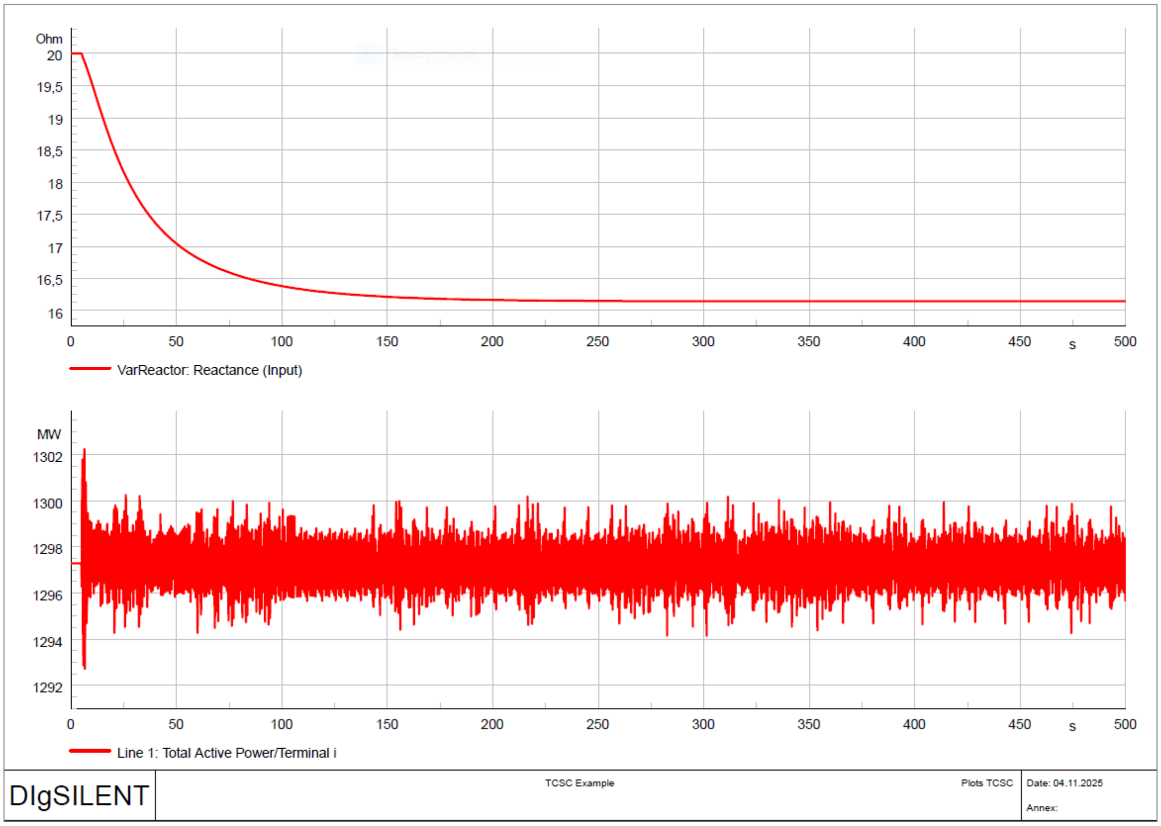


Figure 4.13 With changing power, the adjusting of impedance by TCSC.

In figure 4.12 depends on the changing of total actual power that passes through TCSC the variation of reactance is depicted.

Conclusion.

First, the topic is thoroughly researched, and recently published papers are reviewed. Based on this new edition the sophisticated technics reviewed, and which devices are used to regulation are deeply analyzed. Based on which programs are consumed for execution regulations are defined. The result of this research is three methods defined for regulation voltage in generating networks. Conventional, shunt compensation and series compensation methods. These conventional methods are modeled in “Dig SILENT Power Factory” the results are depicted in schedule 4.1 and the main disadvantage of conventional methods there are limits for regulation, and regulation outside certain range caused unwanted consequences. The second regulation method is shunt compensation method so, for adjusting voltage in system buses the SVS device is modeled in “Dig SILENT Power Factory”, and results step by step recorded in schedule in schedule 4.2, and for illustration graphical representation of shunt compensation the RMS simulation has been executed. The results of these simulations are depicted in figures 4.7, 4.8, 4.9 and 4.10. Depending on situation the shun compensation is the most convenient method. In third case the series compensation method is executed for regulation voltage on system buses. For regulation voltage on system buses by the series compensation the TCSC devices mathematically modeled in “Dig SILENT Power Factory” program so, the regulation model is created in the program then, simulation results are depicted in figure 4.11 and 4.12. depends on location of the system that regulation needed these three method applied for voltage regulation.