Improvement of Losses in High Voltage Line

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Abstract- *Electric Power request has expanded significantly while the extension of energy age and transmission frameworks has been extremely constrained because of rare assets and ecological confinements. Therefore, some transmission lines are intensely stacked and the framework soundness turns into a power exchange restricting element. This has brought about a scan for chances to expand the transmission line limit of existing lines. With the utilization of arrangement capacitors for remunerating some portion of the inductive reactance of long transmission lines typically builds the transmission line limit. It likewise builds transient soundness edges, advances stack sharing between parallel transmission lines and decreases framework misfortunes. Electric power transmission line pay infers an adjustment in the electric normal for the transmission line with the goal of expanding the power exchange capacity. On account of arrangement remuneration, the goal is to decrease the exchange reactance of the line at control recurrence by methods for arrangement capacitors. This outcomes in an improved framework strength, which is confirm through an expanded power exchange capacity of the line. Shunt remuneration strategy in down to earth applications is regularly used to manage the voltage at a given bus bar against stack varieties, or to give voltage support to the heap when, because of age or line blackouts, the limit of the sending-end framework ends up debilitated.*

Keywords- FACTS, Controllability, Static VAR Compensator, Stability limit, Transmission system

I. INTRODUCTION

Society when all is said in done has become progressively reliant on electrical vitality for financial exercises and security. Subsequently, electric power has turned out to be crucial. Power assumes a fundamental part in present day society, and the interest for high-quality and solid electrical administrations has expanded with the appearance of the innovation based economy. The expanded reliance on power implies expanded request on the power framework. Over the top dependence on cresting burdens, for example, ventilating and non-resistive loads such as induction engines, variable speed drives, fluorescent lighting, and electronic gadgets changes the demands put on the power framework. Electric Power request has increased considerably while the extension of power age and transmission systems has been severely constrained because of rare assets and environmental limitations. As a result, some transmission lines are vigorously stacked and the system strength turns into a power exchange limiting factor.

This has brought about a scan for circumstances to increase the transmission line limit of existing lines. The requirement for another arrangements and openings are essential and critical. Flexible Alternating Current Transmission Systems (FACTS) gadgets has come to spare the circumstance to some degree. Certainties gadgets are utilized to build the transmission limit, improve the solidness and dynamic conduct or guarantee better power quality in modern power frameworks. Their fundamental abilities are receptive power compensation, voltage control and power stream control. Because of their controllable power electronics, FACTS gadgets dependably give quick control activities in contrast with conventional devices like exchanged pay or stage moving transformers with mechanical on-stack tap changer. The current power transmission framework is a mind boggling system of transmission lines inter connecting all the generator stations and all the real stacking focuses in the power framework. These lines convey vast pieces of energy which by and large can be routed any coveted way on the different connections of the transmission framework to achieve the coveted monetary and execution goals. Isolate exchanging current (air conditioning) systems may be synchronously inter tied with air conditioning transmission lines to frame a power pool in which electrical vitality can be transported among and between the frameworks. This paper is a review on arrangement and shunt pay procedures as connected to control transmission frameworks to improve their execution.

II. THE ELECTRIC POWER SYSTEM

This section gives a brief over view of the electric power system, its controllability and constraints associated with it.

Power Generation, Transmission, and Distribution Systems

The main constituents of electric power system are generation, transmission (sub-transmission), distribution systems as well as the various loads with their related auxiliary support and protection equipment. In any electric power system, the generation, transmission, and utilisation of electric power is separated into three areas, which traditionally determines the way electric utility companies had been organised over the years. These, as given in Figure 1 and are:

- Generation
- Transmission
- Distribution

Figure 1 Block Diagram of Generation, Transmission and Distribution Systems

The electric power generation is by the use of rotating synchronous machines. The transmission, sub-transmission, and distribution lines are essentially distributed parameter, dominantly reactive networks designed to operate at high, medium and low alternating voltages respectively. The loads may be synchronous, non-synchronous, and passive, consuming in general both real and reactive power.

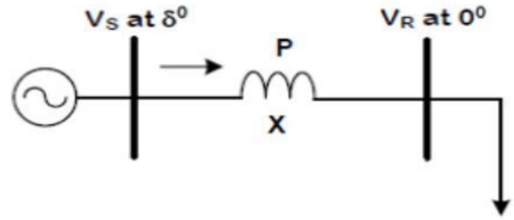
Electric Power System Constraints

Electric power frameworks world wide are being driven nearer to their solidness and warm breaking points with the emphasis on the nature of power delivery. Blewushie (2013), opined that the attributes of transmission framework bottlenecks can take numerous structures and may include at least one of the accompanying:

Steady-State Power Transfer Limit

- Voltage Stability Limit
- Dynamic Voltage Limit
- Transient Stability Limit
- Power System Oscillation Damping Limit
- Inadvertent Loop Flow Limit
- Thermal Limit
- Short-Circuit Current Limit

Each transmission bottleneck or constraint may have one or more of these system-level problems. The key to solving these problems in the most cost-effective and coordinated manner is thorough systems engineering analysis.



$$P = \frac{V_S V_R}{X} \sin\delta$$

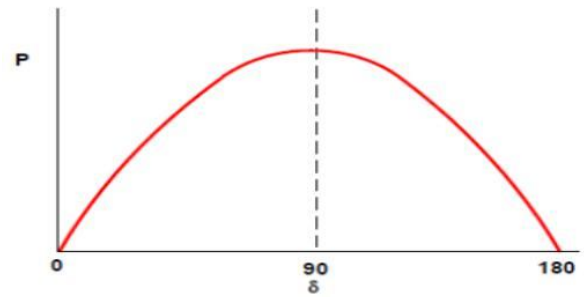


Figure 2 Controllability of Power Systems

Where, P = real power
V_S = magnitude of sending end voltage
V_R = magnitude of receiving end voltage
X = impedance
δ = phase angle between V_S and V_R

Controllability of Power Systems

A power framework has certain factors that can be controlled as given by the power point bend of Figure 2. In spite of the fact that this is a relentless state bend and the implementation of FACTS is basically for dynamic issues, this outline exhibits the point that there are principally three primary factors that can be directly controlled in the power framework to affect its performance.

These are:

- Voltage
- Angle
- Impedance

The real power, *P*, cannot be controlled without changing the reactive power demand on the sending- and receiving-ends.

Power System Stability

Power framework strength is the capacity of an electric power framework, for a given introductory operating condition, to recover a condition of working harmony in the wake of being subjected to a physical disturbance, with the majority of the framework factors limited so essentially the whole system remains intact. Integrity of the framework is preserved when for all intents and purposes the whole power framework stays in place with no stumbling of generators or loads, aside from those detached by disconnection of the blamed components or deliberately tripped to safeguard the progression of activity of whatever is left of the framework. The power framework is an exceedingly nonlinear framework that works in an always showing signs of change environment; loads, generator yields, topology, and key working parameters change ceaselessly. At the point when subjected to a transient aggravation, the steadiness of the framework relies upon the idea of the unsettling influence too as the starting working condition. The unsettling influences being alluded to could be deficiencies, load changes, generator blackouts, line blackouts, voltage crumple or some blend of these. Power system steadiness can be extensively arranged into rotor edge, voltage and recurrence strength. Each of these three sound qualities can be additionally grouped into expansive unsettling influence or little disturbance, short term or long term. The classification is as given in Figure 3.

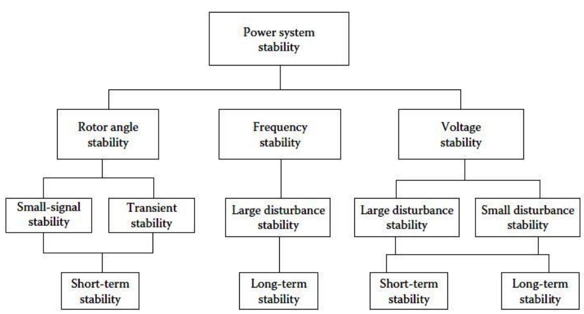


Figure 3 Classification of Power System Stability

Though, stability is classified into rotor angle, voltage and frequency stability they need not be independent isolated events. A voltage collapse at a bus can lead to large excursions in rotor angle and frequency. Similarly, large frequency deviations can lead to large changes in voltage magnitude.

2.4.1Rotor Angle Stability

The rotor angle of a generator depends on the balance between the electromagnetic torque due to the generator electric power output and mechanical torque due to the input mechanical power through a prime mover. Remaining in synchronism means that all the generators‟ electromagnetic torque is exactly equal to the mechanical torque in the opposite direction. If in a generator the balance between electromagnetic and mechanical torque is disturbed, due to disturbances in the system, then this will lead to oscillations in the rotor angle. Rotor angle stability is therefore, the ability of the generator to remain in synchronism when subjected to a disturbance. Rotor angle stability is further classified into small disturbance angle stability and large disturbance angle stability as depicted in Figure 3.

Small-disturbance or small-signal angle stability

It is the ability of the system to remain in synchronism when subjected to small disturbances. If a disturbance is small enough so that the nonlinear power system can be approximated by a linear system, then the study of rotor angle stability of that particular system is known as small-disturbance angle stability analysis. Small disturbances can be small load changes like switching on or off of small loads, line tripping, small generators tripping etc.

Frequency Stability

Recurrence dependability relies upon the capacity to reestablish equilibrium between framework age and load, with least loss of load. Recurrence unsteadiness may lead to managed recurrence swings prompting stumbling of producing units or burdens. It alludes to the capacity of a power framework to keep up unfaltering recurrence following a severe disturbance amongst age and load. During frequency excursions, the trademark times of the procedures and gadgets that are enacted will range from division of seconds like under recurrence control to a few minutes, comparing to the response of gadgets, for example, prime mover and thus, recurrence security might be a short-term phenomenon or a long haul marvel.

Voltage Stability

Not at all like point soundness, voltage steadiness can likewise be a long haul wonder. In a circumstance whereby voltage variances happen because of quick acting gadgets like enlistment engines, control electronic drive, High Voltage Direct Current (HVDC) and so forth., at that point the time span for understanding the soundness is inside the scope of 10-20 s and consequently, can be dealt with as here and now bus bars where responsive power request builds, bus bar voltage can be controlled by connecting capacitor banks in parallel with a slacking load. The capacitor banks supply part or full receptive energy to the heap, therefore decreasing the magnitude of the source current important to supply the heap. Therefore, the voltage drops between the sending end and the heap or accepting end gets diminished, enhancing power factor and expanded active power yield is accessible from the source. Depending upon the heap request, the capacitor banks might be for all time associated with the framework or can be changed by turning on or off the parallel connected capacitor banks either physically or naturally. Figure 4 gives a solitary line diagram of an uncompensated transmission line and its voltage-phasor graph, though Figure 5 gives a solitary chart of a remunerated transmission line and its voltage-phasor outline.

Traditional Transmission Line Compensation and Power Flow Control Techniques

It has long been established that the steady-state transmittable power can be increased and the voltage profile along the transmission line controlled by an appropriate reactive compensationas a power system is mostly reactive. However, the lack of reactive power can cause voltage collapse in the power system. A device that is connected in parallel with a transmission line is called a shunt compensator, while a device that is connected in series with the transmission line is called a series compensator. These are referred to as compensators since they compensate for the reactive power in the ac system. The purpose of this reactive compensation is to change the natural electrical characteristics of the transmission line to make it more compatible with the prevailing load demand. Thus, shunt connected, fixed or mechanically switched reactors are applied to minimize line overvoltage under light load conditions, and shunt connected, fixed or mechanically switched capacitors are applied to maintain voltage levels under heavy load conditions.

In the case of long transmission lines, series capacitive compensation is often employed to establish a virtual short line by reducing the inductive line impedance and for that matter the electrical length, □, of the line given by Equation (1):

$$\theta = \sqrt{x_l + x_c} \quad (1)$$

Where, X_l = series inductive reactance
X_c= shunt capacitive reactance

Shunt Compensation Technique

Reactive power compensation technique is often the most effective way to improve both power transfer capability and voltage stability of the transmission line. The control of voltage levels is accomplished by controlling the production, absorption and flow of reactive power. The generating units provide the basic means of voltage control, since the automatic voltage regulators control field excitation to maintain scheduled voltage level at the terminals of the generators. To control the voltage throughout the system, use must be made of additional devices to compensate reactive power. The primary purposes of transmission system shunt compensation near load centres are voltage control and load stabilisation. At the substation Of the electric power system to maintain steady state voltages at all the system buses when subjected to a disturbance. If the disturbance is large enough, then it is known as large-disturbance voltage stability, and if the disturbance is small, it is referred to as small-disturbance voltage stability. The main difference between voltage stability and rotor angle stability is that voltage stability depends on the balance of reactive power demand and generation in the system whereas the rotor angle stability mainly depends on the balance between real power generation and demand. phenomenon. On the other hand, if the voltage variations are due to a slow change in load, over loading of transmission lines, generators hitting reactive power supply limits, tap changing transformers etc., then time frame for voltage stability can stretch from one minute to several minutes. Voltage stability is the ability

Steady-state Limits of Power Transmission

The maximum power, *Pmax*= V^2 ,transmittable over a lossless line at a given-Xtransmission voltage, *V*, is totally determined by the line reactance *X* and thus sets the theoretical limit for steady state power transmission. A practical limit for an actual line with resistance *R* may be imposed by the I^2R loss that heats the conductor. At a certain temperature the physical characteristics of the conductor could irreversibly change by being deformed with a permanent sag**.** This sets a thermal limit for the maximum transmittable power. Generally, for long lines *X*, and for short lines *R* would provide the main transmission limitations.AC loads are generally sensitive to the magnitude, and may as well be sensitive to the frequency of the applied alternating voltage. Alternating current (ac) power systems are generally operated at a substantially constant frequency of 50 Hz or 60 Hz. The voltage levels in ac systems may moderately vary, but are not allowed to exceed typical well defined limits such as +5 and -10%. This tight voltage tolerance may impose the primary transmission limitation for long radial lines where there is no generation at the receiving end and for tapped-lines, which feed a number of relatively small loads along the transmission line. Steady-state power transmission may also be limited by parallel and loop power flows. These flows often occur in a multi-line, interconnected power system, as a consequence of basic circuit laws which define current flows by the impedance rather than the current capacity of the lines. These can result in overloaded lines with thermal and voltage level problems.

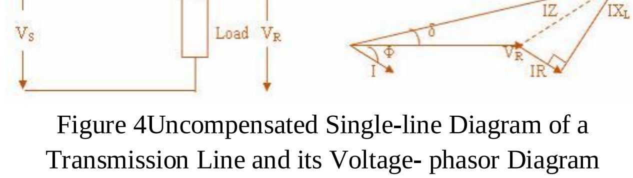


Figure 4Uncompensated Single-line Diagram of a Transmission Line and its Voltage- phasor Diagram

The voltage drops, V_D along the line assuming a lagging power factor can be approximated from the voltage-phasor diagram by Equation(2):

$$V_D = I_R R + I_X X_L \text{ (volt)(2)}$$

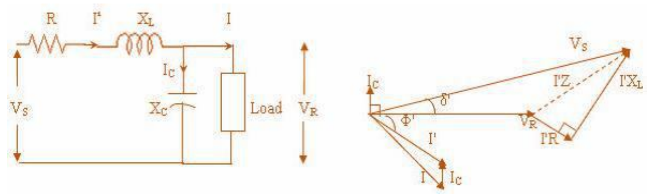


Figure 5 Compensated Single-line Diagram of a Transmission Line and its Voltage-phasor Diagram

The voltage drops, $V_D$based on the phasor diagram can be approximated by Equation (3):

$$V_D = I_R R + I_X XL - I_C X_L \text{(volt)(3)}$$

Where,
V_D = voltage drop
E or V_s = sending end voltage
V_R= receiving end voltage
Z = circuit impedance
I_R= current flow through the resistive component of the circuit
R = resistor
I_X= current flowing through the inductive reactance component of the circuit
X_L = inductive reactance
I_C = current flowing through the capacitive reactance component of the circuit
X_C= capacitive reactance
I = line current
I^1= load current
Φ or $Φ^1$= phase angle between V_R and I δ or $δ^1$ = phase angle between V_s and V_R

Shunt remuneration method experiences the accompanying downsides

- Shunt remuneration don't influence current or power factor past their purpose of use
- The responsive power provided by the shunt capacitor banks is straightforwardly relative to the transport voltage
- When the receptive power required is less on light loads, capacitor bank yield will be high. This issue can be dispensed with by the utilization of switch shunt remuneration procedure by shifting the capacitive reactance relying upon stack prerequisite
- For voltage crises, the receptive power yield drops with the voltage squared
- For transient voltage flimsiness, the exchanging may not be sufficiently quick to counteract acceptance engine slowing down
- Precise and quick control of voltage isn't conceivable
  Shunt compensation method in down to earth applications is regularly used to control the voltage at a given bus bar against stack varieties, or to give voltage support to the heap when, due to age or line blackouts, the limit of the sending-end framework becomes impaired.

Series Compensation Technique

The essential thought behind arrangement capacitive remuneration strategy is to diminish the overall effective arrangement transmission impedance from the sending-end to the less than desirable end. The customary view is that the impedance of the series associated repaying capacitor crosses out a part of the real line reactance and accordingly the viable transmission impedance is decreased as though the line was physically abbreviated. When a heap with slacking power factor is associated toward the finish of the transmission line, voltage drop, VD along the transmission line is given by Equation (4):
$V_D = I(R \cos Φ + X_L \sin Φ)$ (volt)(4)
If a capacitance „C" with reactance *Xc* is connected in series with the line, then, reduction in capacitive reactance is given by Equation (5) which results in reduction in voltage drop along the transmission line.
$X_L – X_C$ (5)

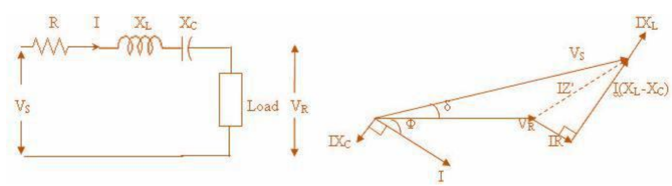


Figure 6 Single-line Diagram of a Series Compensated Transmission Line and its Voltage-phasor Diagram

An equivalent circuit of a transmission line with series reactive compensation and its phasor diagram is give in Figure 6.

Based on the phasor diagram of Figure 6, there induced voltage drops, V_D along a series compensated transmission line is given by Equation (6)

$$V_D = I(R \cos Φ + (X_L - X_C) \sin Φ)\text{(volt) (6)}$$

Effects of series compensation

Arrangement remuneration procedure has the accompanying impacts on electric power transmission lines:

1. The diminished line impedance enhances security: When the transmission line is arrangement adjusted, the rotor edge, δ lessens for a similar measure of energy exchange due to the impact of the remuneration. Diminishment in rotor point δ enables rotor to work at a lower rotor edge with expanded security constrain.

2. The diminished transmission line impedance enhances voltage control: By repaying the transmission line, the net impedance of the line lessens bringing about negligible voltage drop along the transmission line coming about in

a better voltage direction.

3. Series remuneration is a methods for controlling the heap among a few transmission lines: By controlling the level of pay along a few bus bars, the measure of load shared among the lines can be controlled. It gives a better control of load among a few transmission lines.

4. Increasing the stacking limit of the transmission line enhances the use of the transmission framework, and in this way, a superior profit for the capital contributed. Arrangement repaid transmission lines permit control exchange at a similar voltage level over longer transmission lines than uncompensated transmission lines. This brings about a superior usage of the current transmission organize, which is likewise financially savvy contrasted with the development of new or extra parallel transmission lines.

5. Increased power exchange ability: Series remunerated transmission lines have decreased net exchange reactance, control exchange capacity of the framework incredibly expands contrasted with an uncompensated transmission line. This technique for expanding power exchange ability of a current transmission framework may kill the requirement for building parallel transmission lines for expanded load request.

Notwithstanding the various focal points of arrangement remuneration strategy.

- Increase in blame current
- It makes certain complexities in the over reach and under achieve activity of impedance transfers
- Mal activity of separation hand-off if the level of pay and area isn't appropriate
- Often imagines the voltage and the current
- High recuperation voltage of lines-over the electrical switch contacts and is destructive
- Difficulties of ferro-reverberation
- Difficulties because of sub-synchronous reverberation
- Reduced age limit
- Reduced transmission limit
- Reduced circulation substation limit

The accompanying advantages of energy framework remuneration applies to the conveyance perspective:

- Reduced vitality (copper) misfortunes
- Reduced voltage drop and subsequently enhanced voltage direction
- Released limit of feeder and related mechanical assembly
- Postponement or disposal of capital use because of framework change and extension
- Increment in income because of voltage upgrades

The Emergence of Flexible AC Transmission Systems

Versatile AC Transmission Systems, alluded to similarly as FACTS, is a well known term for higher controllability in control structures by techniques for control electronic devices. Fundamental limitations, for instance, detachment, security, and controllability of stream of excellent cooling power transmission system have required the under-utilization of transmission lines and other assets, and the capacity of mitigating these obstacles cost reasonably by controlled pay, gave the incentives to introduce control contraptions based control for responsive compensation. Several FACTS-devices have been exhibited for various applications worldwide. Different new sorts of contraptions are in the period of being introduced in sharpen. In most of the applications the controllability is used to keep up a vital separation from cost concentrated or landscape requiring increases of vitality systems, for instance like upgrades or additions of substations and power transmission lines. Convictions devices give a better adjustment than fluctuating operational conditions and improve the usage of existing foundations. The FACTS action was at first impelled to solve the rising structure issues as a result of constrainments on transmission line advancement, and to energize the creating power charge and import and wheeling transactions among utilities, with two basic goals being:

1. To increment the power exchange ability of transmission frameworks.

2. To keep control stream over assigned courses.

The fundamental uses of FACTS-gadgets are:

- Power stream control;
- Increase of transmission capacity;
- Voltage control;
- Reactive power pay;
- Stability change;

- Power quality change;
- Power molding;
- Flicker moderation; and

- Interconnection of inexhaustible and conveyed age and stockpiles .Configurations of FACTS-Devices

Shunt Devices

The most utilized FACTS-gadget is the Static Var Compensator (SVC) or the rendition with Voltage Source Converter called Static Synchronous Compensator (STATCOM). These shunt gadgets are working as responsive power compensators. The fundamental applications in transmission, appropriation and industrial networks are:

- Reduction of undesirable responsive power streams and along these lines lessened system Losses;
- Keeping of legally binding force trades with adjusted receptive power;
- Compensation of shoppers and change of energy quality particularly with huge request variances like mechanical machines, metal liquefying plants, railway or underground prepare frameworks;
- Compensation of Thyristor converters e.g. in customary HVDC lines, and
- Improvement of static or transient solidness.

Electrical burdens do create and assimilate responsive power. As the power being transmitted differs impressively every once in a while, the responsive power adjust in the power framework changes too. The outcome can be unsuitable voltage adequacy varieties or even a voltage wretchedness, at the extraordinary a voltage crumple can happen. A quickly working Static SVC can persistently give the responsive power required to control dynamic voltage motions under different framework conditions and consequently enhance the power framework transmission and dissemination soundness. Installing an SVC at least one reasonable focuses in the transmission framework can expand transfer capability and decrease misfortunes while keeping up a smooth voltage profile under different network conditions. Also, a SVC can alleviate dynamic power oscillations through voltage sufficiency tweak.

The STATCOM has a trademark comparable to the synchronous condenser, yet as an electronic gadget it has no idleness and is superior to the synchronous condenser in a few courses, for example, better elements, a lower speculation cost and lower working and support costs. The fundamental advantage of a STATCOM is that the receptive power arrangement is free from the actual voltage on the association point. What this implies is that notwithstanding amid most extreme possibilities, the STATCOM keeps its full capacity.

Series Devices

Series Compensation is utilized as a part of request to diminish the exchange reactance of a power transmission line at rated recurrence. An arrangement capacitor establishment produces receptive power that in a self-directing way adjusts a small amount of the line's exchange reactance. The result is that the line is electrically abbreviated, which enhances precise stability, voltage security and power sharing between parallel transmission lines. The arrangement gadgets were produced from settled or mechanically switched compensation gadgets, the Thyristor Controlled Series Compensation (TCSC) or the Voltage Source Converter based gadgets. The fundamental applications are:

- Reduction of arrangement voltage decrease in extent and point over an electrical cable;
- Reduction of voltage vacillations inside characterized limits;
- Improvement of framework damping motions; and
- Limitation of short out streams in the transmission systems or substations;

Thyristor Controlled Series Capacitors (TCSC) is utilized for particular dynamical problems in transmission frameworks, for example,

- Increment in damping when huge electrical systems are interconnected.
- To defeat the issue of Sub-Synchronous Resonance (SSR), a marvel that includes an association between large warm producing units and arrangement remunerated transmission frameworks.

The TCSC's fast exchanging capacity gives an instrument to controlling transmission line control stream, which permits expanded stacking of existing transmission lines, and licenses quick rearrangement of transmission line control stream in light of various contingencies. The TCSC additionally can manage relentless state control stream inside its rating limits.

The primary standards of the TCSC idea are:

- To give electromechanical damping between substantial electrical frameworks by changing the reactance of a particular interconnecting electrical cables; along these lines, the TCSC is to give a variable capacitive reactance.
- The TCSC might change its clear impedance as observed by the line current for sub-synchronous

frequencies, with the end goal that a planned sub-synchronous resonance is avoided.

A voltage source inverter could be associated in arrangement with the transmission line. This gadget is called static synchronous arrangement compensator (SSSC). On a basic level, a SSSC is fit for trading dynamic and receptive energy with the power framework. Notwithstanding, if just responsive power pay is intended, the size of the vitality source could be very little. The infused voltage could be controlled in greatness and in stage if adequate vitality source is given. For there active power compensator work, just the extent of the voltage is controlled since the vector of the embedded voltage is opposite to the line current. For this situation the arrangement infused voltage can either lead or slack the line current by 90 degrees. This implies the SSSC can be easily controlled at any esteem driving or slacking inside the working scope of the voltage source inverter (VSI). Along these lines, the behaviour of a SSSC can be compared to a controllable arrangement capacitor and a controllable arrangement reactor. The fundamental contrast is that the voltage infused by SSSC isn't identified with the line current and can be freely controlled. The importance of this trademark is that a SSSC is compelling for both low and high loading.

III. CONCLUSION

This audit took a gander at the remuneration methods accessible to expand the transmission line limit of existing transmission lines. Receptive power remuneration method is frequently the best method to enhance both power exchange capacity and voltage strength of the transmission line. The control of voltage levels is expert by controlling the creation, retention and stream of responsive power. The unfaltering state transmittable power can be expanded and the voltage profile along the transmission line controlled by a proper receptive pay as a power framework is for the most part responsive. The fundamental thought behind arrangement capacitive pay system is to diminish the general successful arrangement transmission impedance from the sending-end to the less than desirable end. The main roles of transmission framework shunt pay close load focuses are voltage control and load adjustment. Realities gadgets are utilized to build the transmission limit, enhance the strength and dynamic conduct or guarantee better power quality in present day control frameworks. Their principle capacities are responsive power pay, voltage control and power stream control.

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