JYOTHISHMATHI INSTITUTE OF TECHNOLOGY AND SCIENCE

EHVAC TRANSMISSION
IV B.TECH II SEM– EEE

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Series and Shunt Compensation

Series Compensation

Series compensation is basically a powerful tool to improve the performance of EHV lines. It consists of capacitors connected in series with the line at suitable locations.

Advantages of Series Compensation

1. Increase in transmission capacity
   - The power transfer capacity of a line is given by

$$P = \frac{E.V}{X}\sin\delta$$

where, E is sending end voltage

V is receiving end voltage

X is reactance of line

δ is phase angle between E and V

- Power transfer without and with compensation:

$$P_1 = \frac{E.V}{X_L}\sin\delta$$

$$P_2 = \frac{E.V}{(X_L - X_C)}\sin\delta$$

$$\frac{P_2}{P_1} = \frac{X_L}{(X_L - X_C)} = \frac{1}{(1 - X_C / X_L)} = \frac{1}{1 - K}$$

where *K* is degree of compensation.

The economic degree of compensation lies in the range of 40-70%

(K < 1, i.e. 0.4-0.7)

2. Improvement of System Stability

- For same amount of power transfer and same value of E and V, the δ in the case of series compensated line is less than that of uncompensated line.

$$P = \frac{E.V}{X_L} \sin \delta_1$$

$$P = \frac{E.V}{(X_L - X_C)} \sin \delta_2$$

$$\frac{\sin \delta_2}{\sin \delta_1} = \frac{(X_L - X_C)}{X_L}$$

- A lower δ means better system stability
- Series compensation offers most economic solution for system stability as compared to other methods (reducing generator, x-mer reactance, bundled conductors, increase no. of parallel circuits

3. Load Division between Parallel Circuits

- When a system is to be strengthen by the addition of a new line or when one of the existing circuit is to be adjusted for parallel operation in order to achieve maximum power transfer or minimize losses, series compensation can be used.
- It is observed in Sweden that the cost of the series compensation in the 420 kV system was entirely recovered due to decrease in losses in the 220 kV system operating in parallel with the 420 kV system.

4. Less installation Time

- The installation time of the series capacitor is smaller (2 years approx.) as compared to installation time of the parallel circuit line (5 years approx.)
- This reduces the risk factor.
- Hence used to hit the current thermal limit.
- The life of x-mission line and capacitor is generally 20-25 years.

Disadvantages

1. Increase in fault current
2. Mal operation of distance relay- if the degree of compensation and location is not proper.
3. High recovery voltage of lines- across the circuit breaker contacts and is harmful.

Location of Series Capacitor

- The choice of the location of the series capacitor depends on many technical and economical consideration.
- In each case, a special system study concerning load flow, stability, transient overvoltage, protection requirements, system voltage profile etc. is necessary before the optimal location is chosen.

1. Location along the line

- In this method the capacitor bank is located at the middle of the line (if one bank) or at 1/3rd distance along the line (if two banks).
- This has advantage of better voltage profile along the line, lesser short circuit current through the capacitor in the event of fault and simpler protection of capacitor.
- The capacitor stations are generally unattended.

2. Location at one or both ends of line section on the line side in the switching station

- The main advantage of this location is that the capacitor installation is near the manned sub-stations.
- However, requires more advanced line protection.
- For the same degree of compensation, more MVAr capacity is needed as compared to method 1.

3. Location within bus bars within Switching Stations

Shunt Compensation

- For high voltage transmission line the line capacitance is high and plays a significant role in voltage conditions of the receiving end.
- When the line is loaded then the reactive power demand of the load is partially met by the reactive power generated by the line capacitance and the remaining reactive power demand is met by the reactive power flow through the line from sending end to the receiving end.

Shunt Compensation (continued…)

- When load is high (more than SIL) then a large reactive power flows from sending end to the receiving end resulting in large voltage drop in the line.
- To improve the voltage at the receiving end shunt capacitors may be connected at the receiving end to generate and feed the reactive power to the load so that reactive power flow through the line and consequently the voltage drop in the line is reduced.

Shunt Compensation (continued…)

- To control the receiving end voltage a bank of capacitors (large number of capacitors connected in parallel) is installed at the receiving end and suitable number of capacitors are switched in during high load condition depending upon the load demand.
- Thus the capacitors provide leading VAr to partially meet reactive power demand of the load to control the voltage.

Shunt Compensation (continued…)

- If $X_C = 1/\omega C$ be the reactance of the shunt capacitor then the reactive power generated of leading VAr supplied by the capacitor:

$$Q_C = \frac{|V_2|^2}{X_C} = |V_2|^2 \omega C$$

- where, $|V_2|$ is the magnitude of receiving end voltage.

Shunt Compensation (continued…)

- When load is small (less than SIL) then the load reactive power demand may even be lesser than the reactive power generated by the line capacitor. Under these conditions the reactive power flow through the line becomes negative, i.e., the reactive power flows from receiving end to sending end, and the receiving end voltage is higher than sending end voltage (Ferranti effect).
- To control the voltage at the receiving end it is necessary to absorb or sink reactive power. This is achieved by connecting shunt reactors at the receiving end.

Shunt Compensation (continued…)

- If $X_L = \omega L$ be the reactance of the shunt reactor (inductor) then the reactive VAr absorbed by the shunt rector:

$$Q_L = \frac{|V_2|^2}{X_L} = |V_2|^2 / \omega L$$

- where, $|V_2|$ is the magnitude of receiving end voltage.

Shunt Compensation (continued…)

- To control the receiving end voltage generally one shunt rector is installed and switched in during the light load condition.
- To meet the variable reactive power demands requisite number of shunt capacitors are switched in, in addition to the shunt reactor, which results in adjustable reactive power absorption by the combination.

Degree of series compensation

We know that the surge impedance

$$Z_C = \sqrt{\frac{L}{C}} = \sqrt{\frac{j\omega L}{j\omega C}} = \sqrt{xx_L}$$

Suppose C_{se} is the series capacitance per unit length for series compensation. Therefore total series reactance will be

$$j\omega L' = j\omega L - \frac{j}{\omega C_{se}} = j\omega L - \frac{j}{\omega C_{se}} \cdot \frac{j\omega L}{j\omega L}$$

$$= j\omega L\left(1 - \frac{1}{\omega^2 LC_{se}}\right) = j\omega L\left(1 - \frac{X_{cse}}{X_L}\right) = j\omega L(1-\gamma_{se})$$

where $\boldsymbol{\gamma_{se}}$ is known as **degree of series compensation**. Therefore, virtual surge impedance

$$Z_C^{'} = \sqrt{\frac{j\omega L(1-\gamma_{se})}{j\omega C}} = Z_C\sqrt{(1-\gamma_{se})}$$

Degree of shunt compensation

We know that the surge impedance

$$Z_C = \sqrt{\frac{L}{C}} = \sqrt{\frac{j\omega L}{j\omega C}} = \sqrt{x_L x_L}$$

Suppose shunt inductance L_{sh} per unit length is used for shunt compensation. Therefore the net shunt susceptance will be

$$j\omega C' = j\omega C + \frac{1}{j\omega L_{sh}} = j\omega C - \frac{j}{\omega L_{sh}} \cdot \frac{\omega C}{\omega C}$$

$$= j\omega C\left(1 - \frac{1}{\omega^2 C L_{sh}}\right) = j\omega C\left(1 - \frac{X_c}{X_{Lsh}}\right) = j\omega C(1-\gamma_{sh})$$

where $\boldsymbol{\gamma_{sh}}$ is known as **degree of shunt compensation**. Therefore, virtual surge impedance

$$Z_C^{'} = \sqrt{\frac{j\omega L}{j\omega C(1-\gamma_{sh})}} = \frac{Z_C}{\sqrt{(1-\gamma_{sh})}}$$

- Considering both series and shunt compensation simultaneously:

$$Z_C^{'} = \sqrt{\frac{j\omega L'}{j\omega C'}} = Zc\sqrt{\frac{1-\gamma_{se}}{1-\gamma_{sh}}}$$

- Therefore, the virtual surge impedance loading

$$P_C^{'} = Pc\sqrt{\frac{1-\gamma_{sh}}{1-\gamma_{se}}}$$

- It is clear that a fixed degree of series compensation and capacitive shunt compensation decreases the virtual surge impedance of line.
- However, inductive shunt compensation increases the virtual surge impedance and decreases the virtual surge impedance loading of line. If inductive shunt comp. is 100%, the virtual surge impedance becomes infinite and loading zero.

- Suppose, we want flat voltage profile corresponding to 1.2 P_C without series compensation, the shunt capacitance compensation required will be:

$$P_C' = Pc / \sqrt{1-\gamma_{se}}$$

$$1.2P_C = P_C / \sqrt{1-\gamma_{se}}$$

$$\gamma_{se} = 0.306\, pu$$

- Now, assuming shunt compensation to be zero, the series compensation required corresponding to 1.2 P_C :

$$P_C' = Pc\sqrt{1-\gamma_{sh}}$$

$$1.2P_C = P_C\sqrt{1-\gamma_{sh}}$$

$$\gamma_{sh} = -0.44\, pu$$

- However, because of lumped nature of series capacitor, voltage control using series capacitors is not recommended.
- Normally used for improving stability limits of the system.