Chapter-6

DESIGN APPROACH TO POWER CAPACITORS AND POWER INDUCTORS

6.1 Introduction

There are three parameters of an electric circuit- the resistance, inductance and the capacitance. The resistance parameter is dissipative, the other two are storage elements. The capacitor stores energy by electrostatic action while connected to a source of voltage. The inductor, on the other hand, stores energy while a current passes through them.

In a direct current circuit, the capacitor behaves as an open circuit and an inductor behaves as a short-circuit in the steady state. They react to alternating current, adding a reactance component to the resistance in quadrature, thus increasing the impedance of the circuit. The capacitive reactance is straight way in opposition to the inductive reactance. Thus the effect of inductance can be fully or partly offset by inserting a capacitor in the circuit [134].

6.1.1 Capacitors

The forms of practical capacitors vary widely. Capacitors used as parts of electrical systems generally consist of metal foils separated by a thin layer of insulating film. The value of the capacitance becomes high as the gap between the conductors is made small and the dielectric constant of the insulating film chosen is high [25].

In electrical power system they are used for p.f. improvement of distribution lines, shunt and series compensation of transmission lines, for self-excitation of induction generators etc. Capacitors are also widely used in electronic circuits for blocking direct current while allowing alternating current to pass, in filter networks, for smoothing the output of power supplies, in the resonant circuits that tune radios to particular frequencies and for many other purposes. Another application of capacitors is as capacitive voltage transformers(CVT)[23].

6.1.2 Capacitor voltage transformer (CVT)

It is also known as capacitance coupled voltage transformer (CCVT). It is a transformer used in power systems to step down EHV signals to LV signals, for making them compatible with measuring instruments and protective relays. In its most basic form the device consists of three parts: two capacitors across which the transmission line signal is split, an inductive element to tune the device to the line frequency, and a transformer to isolate and further step down the voltage for the instrumentation or protective relay. The tuning of the divider to the line frequency makes the overall division ratio less sensitive to changes in the burden of the connected metering or protection devices. The device has at least four terminals: a terminal for connection to the high voltage signal, a ground terminal, and two secondary terminals which connect to the instrumentation or protective relay. CVTs are typically single-phase devices used for measuring voltages in excess of one hundred kilovolts where the use of wound primary voltage transformers would be uneconomical. In practice, capacitor C_1 is often constructed as a stack of smaller capacitors connected in series. This provides a large voltage drop across C_1 and a relatively small voltage drop across C_2 [24].

The CVT is also useful in communication systems. CVTs in combination with wave traps are used for filtering high frequency communication signals from power frequency. This forms a carrier communication system throughout the transmission network.

6.2 Application of capacitors for inductive VAR compensation and p.f. improvement

The aggregate load of a power system is inductive by nature. Up to medium length high voltage line, inductive VAR dominates over capacitive VAR. As such the power factor is invariably lagging. The lagging VAR gives rise to larger voltage regulation which is unwanted. Also, it increases the line current, thus increasing the ohmic losses and reducing the efficiency of transmission/distribution. In power system prone to poor voltage profile capacitive support may have to be given at the end-point of a transmission line. Also, capacitors may have to be installed at the end of high voltage feeders to improve the receiving end voltage and the power factor [55].

The procedure for finding out required amount of capacitance to be connected to the end-points of a transmission line for shunt compensation and at load-terminal of a feeder for power factor improvement has been given in the subsequent paragraphs. Also, the procedure for designing capacitors for the purpose has been given. The design has been made to meet given specifications, without violating any constraint, in the most economic way. The construction uses Aluminium foils with impregnated paper dielectric pressed in between wound on a mandrel. Each unit has been split into a no of sections. A no of units have been placed in parallel for the facility of switching in and out with variation in load. It is an economic way to improve the power factor, and thereby reduce the voltage regulation. It also reduces line losses and saves in tariff. The addition/alteration is made by power system relaying [120].

6.3 Constructional features

A capacitor consists of two conductors separated by a non-conductive region, called the dielectric [63]. Examples of dielectric mediums are glass, air, paper, vacuum, and even a semiconductordepletion region chemically identical to the conductors. A capacitor is assumed to be self-contained and isolated, with no net electric charge and no influence from any external electric field. The conductors thus hold equal and opposite charges on their facing surfaces, and the dielectric develops an electric field. An ideal capacitor is wholly characterized by a constant capacitance *C*, defined as the ratio of charge ±*Q* on each conductor to the voltage *V*, between them.

Two types of constructions are in general use:

i. A multi-plate capacitor, with a suitable dielectric between the plates (impregnated paper, micanite etc.). The odd no plates are connected to one electrode and the even no plates to another. The gap between the plates is decided upon by the operating voltage and the dielectric used. If there be n no of plates, then the capacitance is given as:

$$C = \frac{A\varepsilon_0\varepsilon_r}{d}(n-1), \qquad 6.1$$

Where n = no of plates, A = Area of the plate, d= thickness of the dielectric, ε_0 and ε_r are the absolute and the relative permittivity of free space.

ii. A single plate, generally in the form of an Al-foil wound over a mandrel with a layer of dielectric pressed between the foils. The dielectric may be paper impregnated with oil and its thickness depends on the allowable voltage stress. In another arrangement, there is a packet of rolled section tightened between two metallic plates of Al, with the aid of a yoke, and filled with a liquid dielectric within a hermetically sealed case. Terminals are brought out from the electrodes from the upper wooden board. The sections are connected in series-parallel combination depending upon the voltage and the power rating. Packing of electro press board is placed between the sections which serve as an insulation. The sections are also insulated by a few layers of insulating papers from the earthed metallic tightening parts and the case. Arrangements for forced water-cooling are provided for large units for keeping the temperature within limits [24].

6.4 Capacitive compensation

Capacitive compensation is made at the load end to improve the power factor. The benefits arising out of shunt capacitive compensation are as outlined below:

i. An overhead feeder is equivalent to a short line, for which the voltage drop is given as: V.D. = $R\cos(\varphi) + X_L \sin(\varphi)$, where the line impedance is: $Z = R + j.X_L$; 6.2

X_L is normally much greater than R. Hence, the voltage regulation falls off with poorer and poorer p.f. This problem can be obviated by inserting shunt capacitive compensation at the receiving end.

ii. The line current decreases with increasing p.f. thus reducing the line losses, active as well as reactive.

iii. The utilities offer benefits in tariff with better p.f. which remains an incentive for installing shunt capacitors at the load end.

A feeder line with variable load and variable capacitive compensation is shown in fig. 6.1.

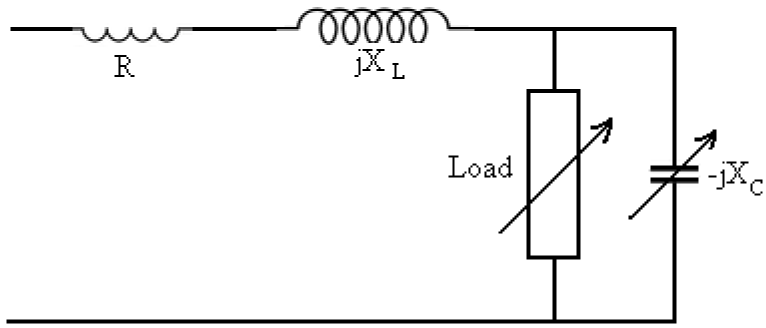

Fig. 6.1 Feeder line with capacitive compensation

The pertinent question is: how much compensation should be made and whether the compensation should be switchable. The compensation should be made on the consideration of best possible economy such that:

Z = capital cost in installing capacitors (interest + depreciation + maintenance) + running cost (towards line losses) – tariff benefit $\rightarrow$ minimum

This is a cost accounting problem and is not a subject of this paper. However, it has been observed that the objective function reaches minimality at a p.f. of 0.94 to 0.95 lag. The reactive VAR of the capacitors and the capacitance are found out against this consideration. The rating of the capacitor bank should be:

$$S_C = 3.\omega.C.V^2 = S.\sin(\varphi_1) - S.\cos(\varphi_1).\tan(\varphi_2) \quad 6.3$$

where, S = Apparent power drawn by the load, φ_1 and φ_2 are the operating and desired p.f. angles, C = capacitance/phase, and ω = angular frequency in r/s =2πf, f = frequency in Hz.

The capacitor bank should be switchable as the compensation required for the line changes with the load conditions. Otherwise, there will be overcompensation during the lean load period.

6.5 Design procedure

The design is made in two parts. At first, the average peak load and its power factor are estimated from sub-station data. Then the capacitive VAR requirement has to be determined with a look to best possible economy. The cost optimality is obtained while the capital cost plus cost of the lost KwHrs in feeding the power assumes the smallest value. In absence of data on cost coefficients, it has been assumed that the best economy is obtained if power factor is raised to 0.94, which is quite realistic. Then the capacitive VAR requirement for (partial) compensation and the corresponding value of the capacitance are found out [62, 63] .

After finding out the capacitance required, the design of the power capacitor is taken up. It is made up of a number of units, such that switched operation can be made with variation in load. Generally 5 to 6 units are used. The pressed construction with Al-foils wound over a mandrel, separated by adequate thickness of insulating papers, has been used for economy. For high voltage operation, a no of sections should be put in series so that the voltage across each section gets reduced. The thickness of insulation depends on the voltage across each section. After finding out the dimension of the capacitor part, the dimension of the casing is found out. Then the dielectric loss is estimated and adequate measure is taken for cooling if temperature rise crosses the acceptable limit .

6.6 Algorithm

The algorithm to be followed for the entire design is given below:

1. Read KW and p.f. of load & desired p.f.
2. Read receiving end line voltage and frequency
3. Choose delta-connected bank.
4. Choose pressed construction with impregnated paper between Al-foils
5. Read relative permittivity of the dielectric
6. Find out the capacitive VAR to be installed

7. Find out capacitance /per phase required.
8. Choose no of sections and find voltage between Al-foils.
9. Choose the thickness of Al-foil and the normal stress in the dielectric in KV(rms)/mm
10. Find out the thickness of the dielectric and the total thickness between layers.
11. Find out the no of turns on the mandrel, its inner and outer diameters.
12. Find out width & effective length of the Al-foils.
13. Find out the capacitance per section
14. Find out no of sections in parallel i.e. no of units/phase
15. Find out the dimensions of the hermetically sealed casing, allowing space for wooden board, collar etc. There should be separate casing for each unit for the facility of switching on/off.
16. Read the cooling coefficient.
17. Find out the dielectric loss at the rated operating voltage and the exposed surface
18. Find out the temperature rise (Forced cooling is required if it is more than 40^o C)

6.7 Case-study on capacitor design

The case-study has been made on a feeder line supplying peak power of 3 MW at 0.82 lagging power factor. An improved power factor of 0.94 lag has been assumed to be economically optimal. A specially constructed program has been used for the design. The computer print-out converted to word-format is given below:

Finding out reactive compensation required for a feeder

Power carried by the feeder, in KW = 3000

Power factor & angle of lag:0.82 ; 34.92^o

Power factor is being improved to 0.94 ; Angle of lag = 18.84^o

Reactive power drawn/reactive power required in KVAr: 2094 ; 1248

Reactive power to be generated in power capacitors in KVAr: 845.8

Delta-connected bank: Line voltage= 11 Kv

Line frequency = 50 Hz.

Per phase susceptance in mho, capacitance in µF: 0.002.33 ; 7.419

Pressed construction with impregnated paper between Aluminium-foils is being used.

Units are formed with units in series. No. of sections in series = 5

Voltage between Al-foils = 2.2 Kv

Thickness of dielectric/Al. foil in mm:0.88 ; 0.2

Total Thickness = 1.08 mm

No of turns on mandrel = 80

Inner/Outer/Average diameter before pressing.m = 0.32 ; .4928 ; .4064

Width, Effective length of Al-foil in m: 0.4 ; 201.7

Relative permittivity of dielectric material = 3.8

Capacitance of individual section = 6.1617 μ-F

Number of sections in parallel = No of units/phase = 6

Total no of units = 18

Width of each section (with 1 mm clearance) = 173.8 mm

Width of 5 sections (with 1 mm clearance) = 873 mm

Corresponding length of each section = 502 mm

Height of the sections = 400 mm

Thickness of metallic collar and casing has been taken as 10 mm.

Space occupied by wooden board, links etc above metallic collar has been taken as 40% of the height of the sections.

Length of the hermetically sealed case = 893 mm

Width of the hermetically sealed case = 522 mm

Height of the hermetically sealed case = 560 mm

Separate casings are provided for the sections in parallel- made as units such that they can be individually switched in or out.

Ohmic loss/unit = 936.9 W

Exposed surface of a unit = 2.0509 m^2

Loss angle of the dielectric = 0.02

Cooling coefficient for the stationary structure = 0.04

Average temperature rise = 18.272°C

It is within limits. So no external cooling is required.

6.8 Power Inductor

In the earlier regime, only capacitive compensation was used for transmission lines, either in shunt or in series. Shunt capacitor compensation, mostly in switching mode, was used at vulnerable points for VAR generation and to keep a reasonably good voltage profile[33]. The use of shunt capacitors also improved the operating power factor of the alternators, reducing excitation current and field copper losses. Switched capacitor banks were also used at feeding points for improving the load power factor, with a look to saving in the tariff and reducing the voltage regulation. Series capacitive compensation was used, generally at the mid-point of a transmission line to partially offset the effect of inductance of the transmission line, improve the voltage regulation of the power line and increase the stability limit [33, 132].

Longer and longer transmission lines operating at extra high voltage (400 KV and higher) have come to use in the recent times, in order to meet the ever-increasing power demand. The basic idea is to generate power economically, by thermal power stations situated near to the source points of fossil fuel and/or by hydel power stations situated in remote hilly places. Long lines are required to transfer the power from the point of generation to the load centers. The long lines are highly capacitive, more capacitive than inductive. They act as VAR-generators, improving the power factor of the system during peak hours but they create problem during the lean hours by forcing the power factor leading zone, a phenomenon known as VAR-IN. This is highly undesirable as it reduces the excitation too much thus reducing the stability margin [41,128]. In order to obviate this difficulty, fixed or switchable power inductors are connected in shunt at the terminals of the transmission lines. The rating is chosen judiciously for the average operating conditions. Generally they compensate for about 80% of the capacitive VAR drawn by the line. The following sections are devoted to finding out inductive compensation required for an EHV transmission line at its terminals. It also presents the design methodology for the power inductor. The 3-phase power inductor is similar in construction to a 3-phase core-type transformer with the exception that it has only one winding per phase and each limb is provided with an air-gap, the length of which is decided upon by the inductance required [26,27,28]. The design should be cost-optimal [89]-D. Bortis has showed a method towards optimality.

Power inductors are also used for HVDC lines as a protective device [2].

6.9 Mathematical description

The circuit diagram of a long transmission line represented by equivalent-π along with shunt inductors at the terminals is given in fig. 6.2.

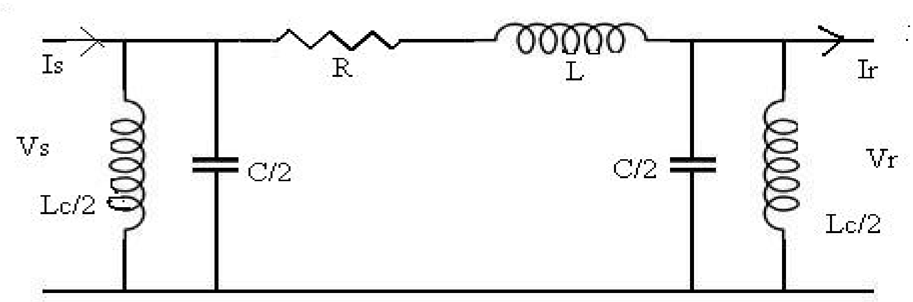

Fig. 6.2 Long transmission line with inductive compensation

For short and medium transmission lines, the line parameters are assumed to be lumped. However, this approach gives inaccurate result for long transmission lines for which the distributed parameter approach has to be undertaken [104]. Leaving aside the compensating inductors, the sending and receiving end quantities of such a line, taking distribution effects into account, are given by the following equations:

$$V_S = \cosh(\gamma l) V_R + Z_O \sinh(\gamma l) I_R \qquad 6.4$$

$$I_S = (1/Z_O)\sinh(\gamma l) V_R + \cosh(\gamma l) I_R \qquad 6.5$$

where, γ = propagation constant = α + j.β ; α = attenuation constant, β = phase constant Z_O = characteristic impedance, l = length of the line, V_S & I_S are the sending voltage and current, V_R & I_R are the receiving end voltage and current. The characteristic impedance (as well as admittance) and the propagation constants are determined by the series impedance and the shunt admittance per unit length of the line. They are given as:

$$Z_O = \sqrt{z/y}\ ,\ Y_O = 1/Z_O \text{ and } \gamma = \sqrt{yz} \qquad 6.6$$

These parameters are of great importance in shaping the behavior of the transmission line. To simplify the modeling, the equivalent-π approach is made. The shunt impedance and the series admittance parameters of the equivalent-π are given as:

Series impedance = $Z^{'} = Z_O \sinh(\gamma l)/(\gamma l)$ 6.8

Shunt admittance = $Y^{'} = Y_O \tanh(\gamma l/2)$ 6.9

While compensating inductors of admittance $Y_C/2$ are added at the terminals, the equivalent shunt admittance becomes:

Shunt admittance = $Y_e/2 = Y^{'}/2 + Y_C/2$ 6.10

The ABCD parameters of the line with compensation are given as:

$$A = D = 1 + Y_e.Z^{'}/2\ ;\quad B = Z; \qquad C = Y_e(1 + Y_e Z^{'}/4) \tag{6.11}$$

The performance evaluation of the line is to be made using these modified parameters.

6.10 Design approach towards optimality

The power inductor functions on the principle of electromagnetism. A 3-phase power inductor is similar in construction to a 3-phase transformer. But it contains a single coil for each phase and there is an air-gap in each limb. The length of the air-gap is adjusted to get the required inductance [135]. Generally, 3-phase core type construction is used for best possible economy. Only one coil of required number of turns is placed in each limb. An air gap of appropriate length is inserted in each limb to get the required inductance. The design is similar to that of a 3-phase core type transformer but the rating is halved as there is only one coil. The auxiliaries are similar to that of a 3-phase core type transformer [129,130].

6.11 The design variables and constraints

The key variables, chosen to optimize a design problem, depend on the objective function [124]. Here the objective is to reduce the cost to its minimum by changing the design variables subject to usual design constraints e.g. limits imposed on iron loss, copper loss and temperature rise. Accordingly, the flux density and the current density are kept at their maximum possible values without violating the design constraints [125]. In such a case, the following design variables affect the cost:

i. The e.m.f. constant K (in eqn. $E_t = K.\sqrt{S}$, where E_t = e.m.f. per turn, S = KVA rating/2.
ii. The ratio of window height to window width: $R_w = H_w/W_w$
iii. The choice of core material- costlier CRGOS may be more economic than cheaper HRS
iv. The choice of conductor materials- costlier copper may have to be used considering over all performance and cost.
v. The ratio of iron loss to copper loss: (P_i/P_c)

The design constraints are: iron loss<0.075%; copper loss< 0.25%; temperature rise without radiators< 35^o C

The techniques for minimizing cost of production, subject to given design constraints have been discussed in the following sections.

6.12 The design procedure

The following choice of materials has been made [20,22,135]:

Core material: CRGOS as the rating is large. The magnetic characteristic of the core material determines the iron loss. Therefore, experimental studies should be made on core loss beforehand to find out suitability of the core material [90].

Conductor materials: Copper as the rating is large.

The value of flux-density and the current density have been kept at their maximum values, as stated earlier. Now, the task is to choose such values of K and R_w which give rise to minimum cost of production without violating the design constraints. IEEE standard general requirements are to be satisfied [18,19]. The selling cost is the objective function. Its minima are to be sought against two variables only. Therefore the method of exhaustive search (without getting into more difficult optimizing techniques) has been adopted using nested loops as the computer run-time has been found to be negligibly small. The algorithm for the computer program developed for the purpose is given below [124,125]:

6.13 Algorithm

The following algorithm has been used to solve the design problem

Step 1: Input specifications of the power inductor

Step 2: Input user-specified data for design variables: flux density, B_m; current density δ No of core steps N_{st} etc.

Step 3: Choose copper as conductor material, CRGOS as core material

Step 4: For K = 0.2 to 0.5 in steps of 0.1 do

Step 5: For R_w = 2.0 to 4.0 in steps of 0.1 do

Step 6: Goto inductor design sub-routine and find out the performance variables

Step 7: If iron loss > 0.3% goto step 12

Step 8: If the copper loss > 1% goto step 12

Step 9: If the temperature rises without radiators > 150^o C goto step 12

Step 10: Find the overall cost

Step 11: If the current cost is less than previous minimum then set minimum cost = current cost, preserve the corresponding values of K and R_w

Step 12:endfor

Step 13: endfor

Step 14: Goto transformer design subroutine with values of K, R_w for which the cost has been found to be minimum.

Step 15: Print out results

Step 16:Stop

Step 17:End

6.14 Case-study on power inductor design

i. Inductive compensation of a long transmission line

The case-study has been made on inductive compensation of a 400 Kv long transmission line running from Farakka super thermal power station to Jeerut substation, near Bandel TPS. The parameters of the equivalent π-representation for the transmission line (on 100 MVA-base) are given below [138]:

$R + jX_L =$ 0.0043 + j0. 0489 ; $Y/2$ = j 0.6513

The VAR generation at each end at 1.0 p.u. voltage equals 65.13 MVAr. This is extremely large which is liable to cause high voltage at cross-country points by Ferranti effect. It has been considered enough to compensate for at least 75-80% of the generation. As such, a rating of 50 MVAr has been recommended.

ii. Power inductor design

The design details of the cost-optimal power inductor are given below:

MVA-rating of the inductor = 50

Rated line voltage in Kv = 400

Nominal frequency in Hz.= 50

Connection: Y

Conductor material: Copper

The EMF- constant = 0.4

No of turns of the coil = 3651

Current in coil = Phase current = 72.169 A

Current density in A/mm^2 = 3.2

Cross section of the conductor in mm^2 = 22.553

Net area of core iron in m^2 = 0.16758

Stacking factor = 0.972

Gross area of core iron in m^2 = 0.17241

3-stepped core has been used.

Diameter of the core circle in m = 0.51110

Length of the core sides in m: = 0.463; 0.361; 0.217

Area of the window in m^2 = 0.82340

Window height/width ratio= 3.6

Window height/width in m: 1.722 / 0.478

Distance between core centers in m = 0.941

Width/height of yoke in m: 0.463; 0.373

Total length of core in m = 2.441

Total height of core in m = 2.467

Volume of iron in m^3 = 1.6838

Weight of iron in Kg = 12881

Iron loss/Kg at the chosen flux-density = 2.0966

Iron loss in W = 27006

% Iron loss = 0.054

Mean length of turn in m= 2.2067

Resistance of the coil in Ω = 7.8591

Copper loss in W = 122798

% Copper loss = 0.2456

Total % loss = 0.2996

The tank length, width, height: 3.0395 ; 1.1008 ; 2.8672

Artificial cooling by air-blast on radiators is being used.

The velocity of blast in m/s = 5

The blast constant (with some non-uniformity in blast) = 1.1

The dissipation constant in $W/m^2/^oC$= 35.234

The no. of elliptical tubes (75x25 mm) in the radiator= 268

The cost of sheet metal/Kg = Rs. 50 /-

The weight / cost of tank: 2427.8 Kg; Rs. 121391 /-

The cost of oil/litre = Rs. 40 /-

The volume/ cost of oil: 9.5932 cu.m.; Rs. 383729 /-

Volume of iron in m^3 = 1.6838

Weight of iron in Kg = 12881

Cost of iron/Kg = Rs. 150 /-

Cost of iron = Rs. 1932161/-

Volume of copper in m^3 = 0.54509

Weight of copper in Kg = 4851

Cost of copper/Kg = Rs. 380 /-

Cost of copper = Rs. 1843502/-

Direct cost allowing 15 % labour charge = Rs. 4922899/-

Selling cost allowing 25 % overhead = Rs. 6153624/-

6.14.1 Performance analysis with and without compensation

The performance analysis of the line has been made using another program once without inductive compensation and then using compensation. The results are given below:

This programme finds ABCD- Parameters of a Long T.L. The line is between stations: FARAKKA-400 and JEERUT-400 [138]. It evaluates the performance of the uncompensated line and then finds out net VAR-generation with inductive compensation. The line parameters are given below:

Line length= 250 Km

Base MVA= 100 ; Base Kv = 400

Line resistance in Ω/km =0.02752 ;

Total line resistance = 6.88 Ω

Line reactance =0.29376 Ω/km

Total line reactance =73.44 Ω

Line charging susceptance = 1.62825E-06/Km

Total line charging susceptance = 4.070625E-04

Line resistance= 0.0043 p.u.

Line reactance = 0.0459 p.u.

Charging admittance= 0.6513 p.u.

Frequency= 50 Hz.

Surge impedance of the line = 424.75 Ω

Characteristic impedance of the line = 425.22 - j 19.875 = 425.6812∠ -2.6761 ^{o}Ω

Propagation constant/Km= 0.000693∠ 87.324 ^{o}

Attenuation constant = 0.000032

Phase constant = 0.000692

ABCD- parameters are given below:

A= D= 0.9850896 + j 0.001393 = 0.985091∠ 0.081037

B = 6.8115860 + j 73.077840 = 73.394600∠ 84.674640

C =-0.0000002 + j 0.000405 = 0.000405∠ 90.026800

Finding out sending end variables from receiving end variables-

R.E. voltage = 1 p.u. ; R.E. current = 1 p.u.

R.E. power factor = 0.85 lag

S.E. Voltage= 1.01348 ∠2.14726 p.u.

S.E. Current = 0.84783∠8.84169 p.u.

S.E. Power Factor = 0.99318 lead

There is VAR-IN phenomenon.

Active loss in T.L. = 0.33999 MW

Reactive loss in series inductance = 3.89154 MVAR

Reactive generation in shunt capacitance =132.03 MVAR

Now, compensating inductors of 50 MVA each are inserted at both ends

Reactive power drain in 50 MVA-inductors =101.36 MVAR

Net reduced reactive generation = 30.67 MVAR

This is within limits and does not pose any operating difficulty.

6.15 Conclusion

Power factor of the load current drawn by a H.V. feeder is important for several reasons. The power factor of the composite load is generally lagging and as low as 0.8 to 0.82. It causes large amount of voltage drop during the peak hours, particularly because capacitive generation by the feeder is negligible. The use of switchable capacitor banks at the load end to improve the power factor is gainful, as it improves the voltage regulation as well as it reduces the line losses (for which tariff benefits are obtained.). The power handling capability of a transmission line also gets reduced if it has to carry bulk of reactive power. The voltage profile is adversely affected particularly during the peak hours. This is true for short and medium transmission lines where capacitive generation of VAR is relatively small. Under such circumstances, shunt capacitive compensation at one or both ends is advisable. The rating of the capacitor bank is determined by cost-benefit analysis.

To generate reactive power at relatively less cost is the motto. In order to achieve this target, capacitor units are built up by winding Aluminum foils round a mandrel with layers of dielectric pressed in between. The thickness of the dielectric is chosen according to the voltage it has to support. In another type liquid dielectric is inserted between metallic plates. The insertion of dielectric also increases the value of the capacitance and hence the rating of the unit. For large units, the dielectric losses are significantly high and special cooling arrangements may have to be provided to keep the temperature rise within acceptable limits. A no. of sections in parallel has been recommended so that switching may be done according to the power flow at a particular time. The case study reveals that the dimensions of the entire capacitor bank, and hence the cost, are not very high. It can be easily accommodated in a room of the sub-station.

Long transmission lines are characterized by large amount of shunt capacitance compared to their series inductance. This gives rise to tremendous amount of VAR-generation which is beneficial at peak hours to improve the power factor and to reduce the VAR-flow in the line but is detrimental at lean hours due to VAR-IN phenomenon and Ferranti effect. It also forces the generators to run at reduced excitation, thus increasing the power angle and reducing the angle margin. The operating point is forced to the 2^{nd}. quadrant of the capability curve. This is highly undesirable. To obviate this difficulty, static inductive compensation is made at the terminals of the long transmission lines. Rating of the power inductor is chosen for 75 to 80% compensation which is considered to be sufficient. In the case study the EHV long line from Faraakka to Jeerut operating at 400Kv has been taken into consideration. It generates 63.13 MVARs at each end. It is compensated by 77% by installing a 50 MVAR power inductor at its terminals. It improves the performance of the line to a great extent at relatively small additional cost. Still better control is possible, if the inductor is a switchable bank.

Power inductors also find application in switched mode inverters and in other power electronic circuits.

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