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4. Enhance Power Transfer in Existing Transmission Line by Simultaneous AC-DC Transmission

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ABSTRACT

The power transfer through the existing long AC transmission line is limited by SIL (surge impedance loading) limit which is much below the thermal limit of conductor due to large inductive reactance of line. To increase power transfer capacity either new lines are erected or SIL increasing by restructuring the existing line. So instead of erecting newlines the existing AC lines are modified to simultaneous AC-DC lines to increase their power transfer capability close to their thermal limits. This paper presents the method to convert an existing double circuit EHVAC line into a simultaneous AC-DC transmission line. Double circuit line is compared with AC DC line Sending end power, receiving end power and transmission losses of both the systems are found out.

Introduction:

The maximum power transfer through EHV ac transmission line is limited by surge impedance loading and the line is not loaded to its thermal limit to keep sufficient margin for transient stability. Flexible AC Transmission System (FACTS) is used in existing ac transmission line to improve load carrying capability along with the overall system performance [1-2]. Series compensation with mechanical switch can be other option for increasing the loadability of existing transmission line [3]. Now a days, for power flow and stability improvement HVDC line is operating in parallel with HVAC line [4].

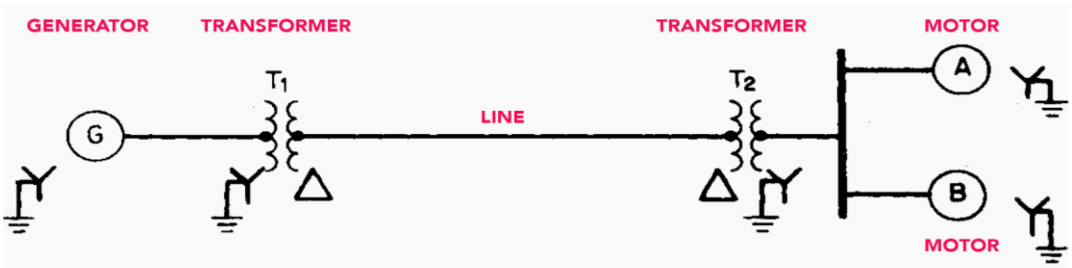
Simultaneous ac-dc transmission is a new approach for the increase of power flow through the existing line proposed in [5]. The simultaneous ac-dc power flow derives the benefit of parallel HVDC line without constructing it. In this system of power transmission existing ac line conductors are used to carry ac power along with dc power simultaneously. The proponents of this new approach conducted the numerical analysis considering only transmission line, disregarding the whole system from generator to infinite bus. A feasibility study is performed for small power tapping from simultaneous ac-dc transmission line in [6]. Simulation results clearly indicate that the tapping of a small amount of ac power from the composite ac–dc transmission line has a negligible impact on the normal functioning of the composite ac–dc power transmission system. In references [5, 6] simultaneous ac-dc power transmission was first proposed through a single circuit actransmission line. In these proposals Mono-polar dctransmission with ground as return path was used. However, there were certain limitations due to use of ground return path. Moreover, the instantaneous value of each conductor voltage with respect to ground increases by an amount equal to dcvoltage added and more discs are to be added in each string insulator to withstand this increased voltage. However, no change was required in the conductor separation distance, asthe line-to-line voltage remains unchanged. Unlike in reference [7], there is no need to modify the tower structures and insulator strings (i.e. ac insulator disc replacement with dc insulator disc of high creepage distance). The sole aim is to gain the advantage of parallel ac-dc transmission and to load existing ac line close to its thermal limit.

Existing Transmission system:

To date, HVAC and HVDC are the ways to transfer electrical power for longer distances. A new concept of power transmission is emerging that is simultaneous AC-DC power transmission system. In the new system conductors will be allowed to carry AC current along with the DC current at the same time. AC transmission system can be converted to simultaneous AC-DC system without bringing any change in the existing infrastructure of the transmission lines. Before going through the simultaneous AC-DC system a brief overview of the existing power transmission systems are presented below.

HVAC System

A simple AC transmission system is presented in Fig.1 where a generating unit evacuates power to an infinite bus through a long transmission line.



The expression of power flow and current are given below.

$P_l = \frac{E_g * E_r}{X} \sin\delta$------------ [1]

X= Xte+XTr ------------- [2]

Where,

Pl = Steady state power flow through the line

Eg= Internal generated voltage of the generator

Er= Receiving end voltage

I_l= Current through the AC line

δ = Torque angle of the generator

X_{te}= Reactance that includes the reactance of generator and transformer

X_{tr}= Reactance of the transmission line

HVDC System

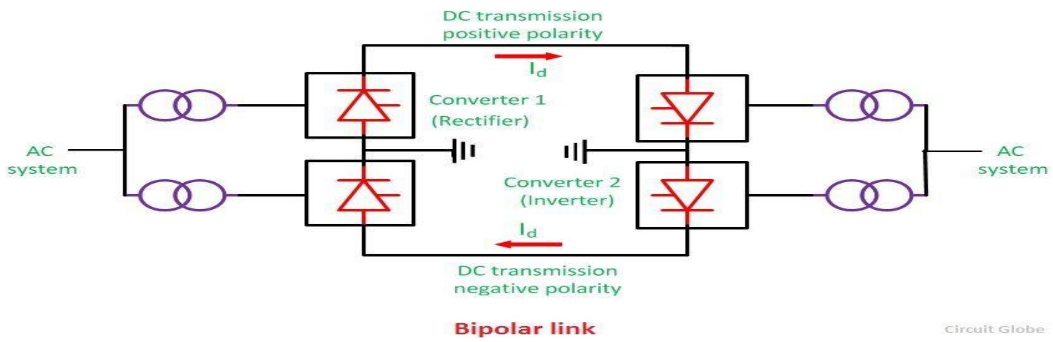


Fig.2: Bipolar HVDC link

The basic configuration of bipolar link is shown in Figure 2. It has two conductors, one positive and other negative. Each terminal has two converters of equal rated voltage connected in series on the DC side. The junction between the converters is grounded. Power can flow in both directions as the converters can be operated in both the modes of rectifier and inverter operation. In the inverter mode, the converter operates in the range of firing angles from 〖90〗^0 to 〖180〗^0 and in the rectifier mode the converter operates at the firing angle below 〖90〗^0. The expression for current, power, voltage and resistance for HVDC system are as follows

Line current in DC link $I_d=\frac{V_{dor}\cos\alpha - V_{doi}\cos\gamma}{R_{cr}+R_L-R_{ci}}$--------------- [3]

Power at rectifier end$P_{dr}=V_{dr}I_d$------------ [4]

Power at inverter end$P_{di}=V_{di}I_d$------------- [5]

DC link voltage at rectifier end$V_{dr}=V_{dor}\cos\alpha - R_{cr}I_d$---------- [6]

DC link voltage at inverter endV_{di} =$V_{doi}\cos\gamma + R_{ci}I_d$----------- [7]

Equivalent commutating resistance at rectifier endR_{cr}=$\frac{3}{\pi}X_{cr}$--------- [8]

Equivalent commutating resistance at inverter endR_{ci}=$\frac{3}{\pi}X_{ci}$---------- [9]

NO load voltage at rectifierV_{dor}=$\frac{3\sqrt{2}}{\pi}V_{cr}$----------- [10]

No load voltage at inverterV_{doi}=$\frac{3\sqrt{2}}{\pi}V_{ci}$---------- [11]

α= Ignition delay angle

γ =Extinction advance angle

V_{cr}=Line to line rms commutating voltage at rectifier

V_{ci}=Line to line rms commutating voltage at inverter

HVAC system:

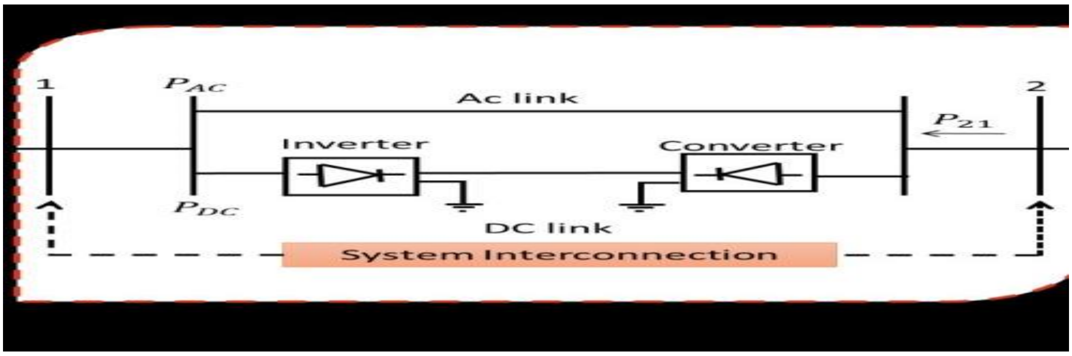


Fig.3: AC-DC parallel system

In case of AC-DC parallel system HVDC line is connected in parallel with the HVAC line and a simple form of this system is presented in figure 3.AC-DC parallel line is much better than AC-AC parallel line because it has higher loadability and stability.

The power transmitted by the DC link is independent of the angular difference between its AC terminals.

In case of any emergency period DC link power can be increased or decreased momentarily by the converter control and that gives rise a high degree of stable operation of the system.

P_{total}=P_{ac} + P_{dc}------- [12]

Simultaneous AC-DC Power Transmission System:

In case of pure AC transmission system the line reactance limits the power flowing capacity of the line and stability of the system. There are some other problems involved with the AC system such as switching surge causes severe transient over voltage, high degree of corona loss, voltage rise at the receiving end due Ferranti effect, huge radio interference in communication system and higher resistance due to skin effect. To overcome these problems extra high voltage long AC transmission line can be converted into HVDC transmission line. In this case of conversion, the line infrastructures are to be changed. Such as, the AC insulators must be replaced by DC insulators, creepage distance and clearing distance must be increased. But, due to the geographical location of the existing line, in many cases, it becomes very difficult to change the line infrastructures. In such cases, for converting the AC transmission line into the pure DC line keeping the line infrastructure unchanged the DC voltage level has to be lowered.

The basic scheme for simultaneous ac-dc power flow through a double circuit ac transmission line is shown in fig.4.

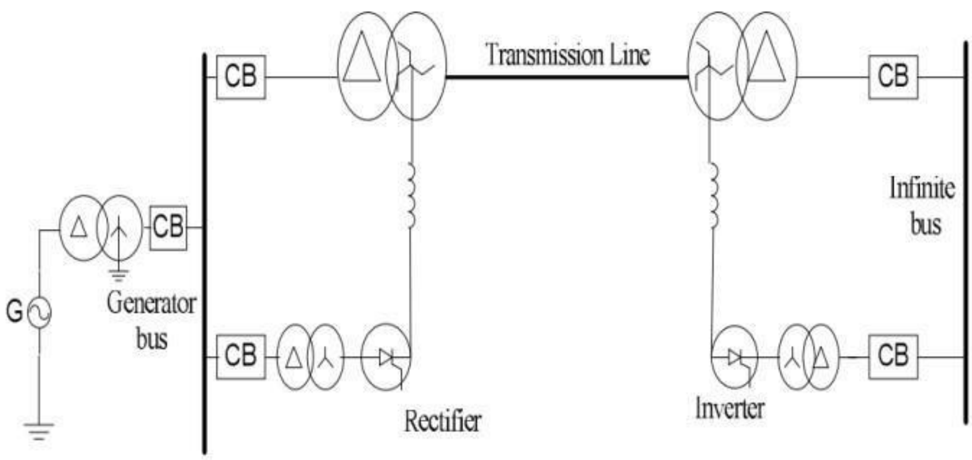


Fig.4: Single line diagram of simultaneous AC-DC system

The dc power is obtained through line commutated 12-pulse rectifier bridge used in conventional HVDC and injected to the neutral point of the zig-zag connected secondary of sending end transformer, is reconverted to ac again by the conventional line commutated 12-pulse bridge inverter at the receiving end. The inverter bridge is again connected to the neutral of zig-zag connected winding of the receiving end transformer.

As the secondary windings as well as lines corresponding to each phase are identical, the dc current injected at the neutral will be equally divided among all the three phase. Each conductor of each line carries one third of the total dc current along with ac current Ia .The double circuit ac transmission line carriers both 3-phase ac and dc power.

The three conductors of the second line provide return path for the dc current. Zig-zag connected winding is used at both ends to avoid saturation of transformer due to dc current. Two fluxes produced by the dc current (Id /3) flowing through each of a winding in each limb of the core of a zig-zag transformer are equal in magnitude and opposite in direction. So the net dc flux at any instant of time becomes zero in each limb of the core. Thus the dc saturation of the core is avoided. A high value of reactor Xd is used to reduce harmonics in dc current.

In the absence of zero sequence and third harmonics or its multiple harmonic voltages, under normal operating conditions, the ac current flow through each transmission line will be restricted between the zigzag connected windings and the three conductors of the transmission line. Even the presence of these components of voltages may only be able to produce negligible current through the ground due to high value of reactor. Assuming the usual constant current control of rectifier and constant extinction angle control of inverter, the equivalent circuit of the scheme under normal steady state operating condition is given in fig.5.

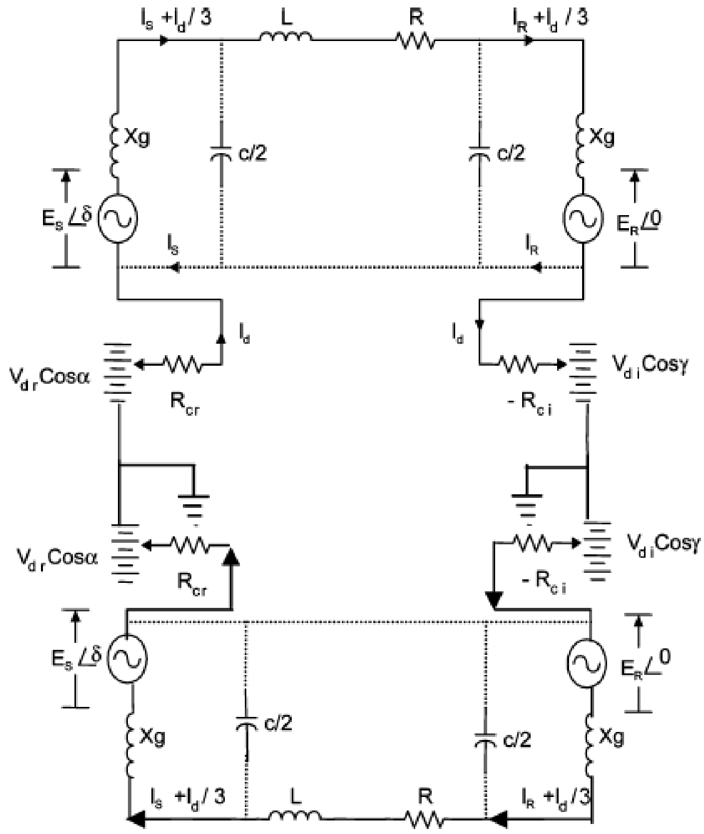


Fig.5: Equivalent circuit of double circuit simultaneous AC-DC system

The dotted lines in the figure show the path of ac return current only. The second transmission line carries the return dc current I_d and each conductor of the line carries $I_d/3$

along with the ac current per phase. V_{dro} And V_{dio} are the no load voltage of rectifier and inverter side dc voltages and are equal to 1.35 times converter ac input line-to-line voltage. R, L, C are the line parameters per phase of each line. R_{cr}, R_{ci} are commutating resistances and α, γ are firing and extinction angles of rectifier and inverter respectively. Neglecting the resistive drops in the line conductors and transformer windings due to dc current, expressions for ac voltage and current, and for active and reactive powers in terms of A, B, C, D parameters of each line may be written as:

E_s = AE_r + BI_r ----- [13]

I_s = CE_r + DI_r ------ [14]

P_s + jQ_s = -$E_s E_r$*/B* + D*E_s^2/B* ----- [15]

P_r + jQ_r = E_s*E_r/B* - A*E_r^2/B* ----- [16]

Neglecting ac resistive drop in the line and transformer, the dc current I_d, dc power P_{dr} and P_{di} of each rectifier and inverter may be expressed as:

$I_d = \frac{V_{dor}\cos\alpha - V_{doi}\cos\gamma}{R_{cr}+R_L-R_{ci}}$ --------------- [17]

$P_{dr} = V_{dr} I_d$ -------------------- [18]

$P_{di} = V_{di} I_d$ ------------------ [19]

Reactive powers required by the converters are:

$Q_{dr} = P_{dr}\tan\theta_r$-------- [20]

$Q_{di} = P_{di}\tan\theta_i$--------- [21]

$\cos\theta_r$= [$\cos\alpha$ +$\cos(\alpha+\mu_r)$]/2 --- [22]

$\cos\theta_i$= [$\cos\gamma$ +$\cos(\gamma+\mu_i)$]/2 ---- [23]

μ_r And μ_i are commutation angles of inverter and rectifier respectively and total active and reactive powers at the two ends are:

$P_{st} = P_r + P_{dr}$ and $P_{rt} = P_r + P_{di}$ ------ [24]

$Q_{st} = Q_s + Q_{dr}$ and $Q_{rt} = Q_r + Q_{di}$ ------- [25]

Transmission loss for each line is:

$P_l = (P_s + P_{dr}) - (P_r + P_{di})$ --------------[26]

Let I_a being the rms ac current per conductor at any point of the line, the total rms current per conductor becomes:

$$I = \sqrt{[I_a^2 + (I_d/3)^2]} \text{----------------- [27]}$$

Power loss for each line = PL ≈ $3I^2$R. -------------- [28]

The net current I in any conductor is offseted from zero. Now allowing the net current through the conductor equal to its thermal limit (I_{th}):

$$I_{th} = \sqrt{[I_a^2 + (I_d/3)^2]} \text{ --------- [29]}$$

Let V_{ph} be per phase rms voltage of original ac line. Let also V_a be the per phase voltage of ac component of simultaneous ac-dc line with dc voltage V_d superimposed on it. As insulators remain unchanged, the peak voltage in both cases should be equal.

$$V_{max} = \sqrt{2}V_{ph} = V_d + \sqrt{2}V_a \text{ ------ [30]}$$

In converting existing AC transmission line into simultaneous AC-DC system three things such as insulator, creep age distance and clearing distance must be taken into account. If the line infrastructures remain the same the maximum value of the phase voltage of AC-DC composite system must be same as that of pure AC system since the insulators have been designed on the basis of maximum phase voltage.

Moreover, the electric field produced by the combined voltage would be such that the instantaneous electric field polarity changes its sign twice in a cycle. The stresses due to alternating electric field on the insulator surface are quite different from those with the unidirectional field. If DC field is applied on the insulator that is designed for AC the evolved problems are shown in fig.6

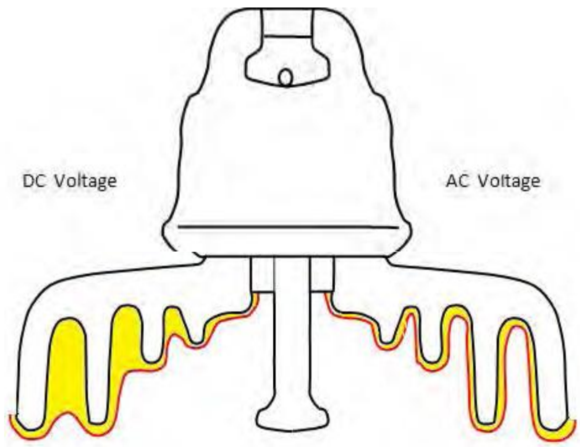


Fig.6: Impact of DC voltage applied on AC insulator

In fig.6 it is seen that DC local discharge on the insulator surface is apt to continue for a long time due to no-polarity alteration and hence the partial arcs easily bridge over the tips of adjacent ribs in case of AC insulator. These arcs actually damage the surface of the insulator.

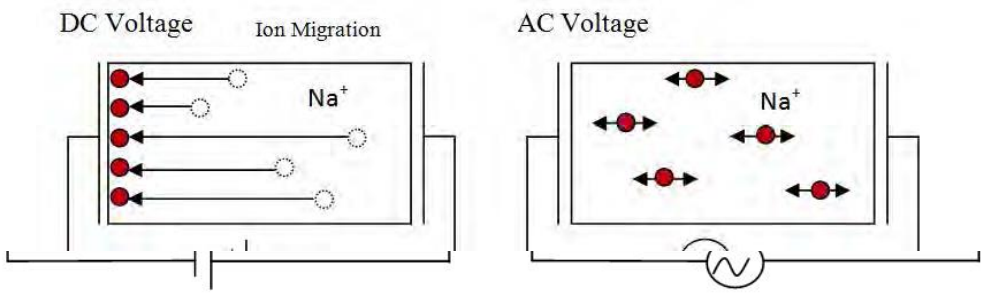
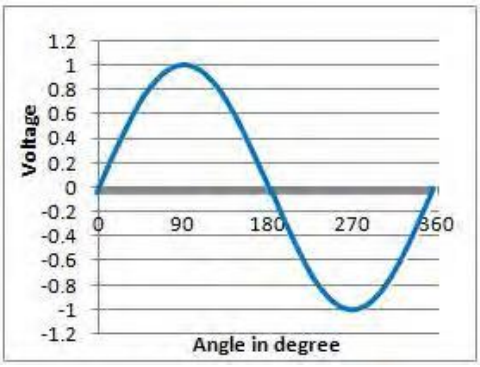


Fig.7: Ion migration on insulator surface

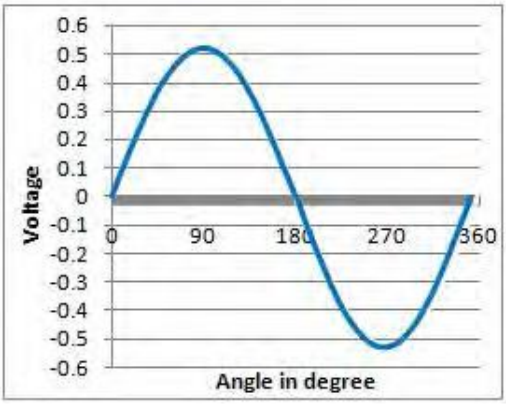
The ion migration processes on the insulator surface are also shown in fig.7. The Ions such as Na+ in the insulating body move to negative side under DC stress and the accumulation of ions at one side causes deterioration in electrical and mechanical performance. Electric field produced by any conductor possesses a dc component superimpose on it a sinusoidally varying ac component. But the instantaneous electric field polarity changes its sign twice in a cycle if (V_d /V_a) < √2 is insured. Therefore, higher creepage distance requirement for insulator discs used for HVDC lines are not required. Each conductor is to be insulated for V_{max} but the line-to line Voltage has no dc component and V_{llmax} = √6V_a. Therefore, conductor to conductor separation distance of each line is determined only by rated ac voltage of the line. Allowing maximum permissible voltage offset such that the composite voltage wave just touches zero in each every cycle;

V_d = Vph/√2 and V_a = V_{ph}/2 ------- -- [31]

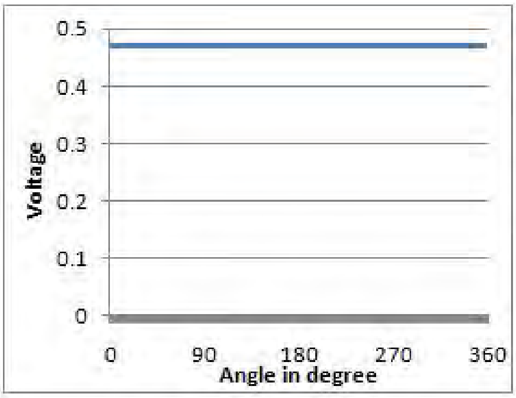
It is clearly observed that the DC voltage mix must be lower than the 50% of the maximum phase voltage of pure AC system. If the maximum phase voltage of pure AC system is considered as unity then the highest value of DC voltage mix is less than 0.5.



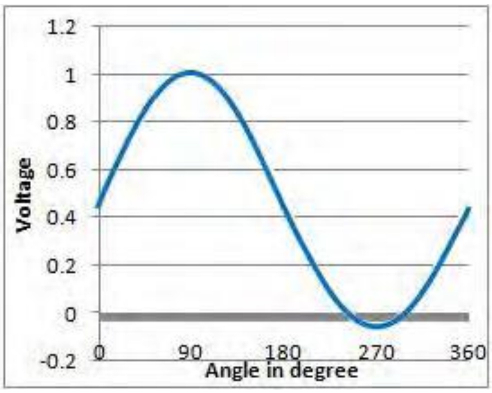
(a)



(b)



(c)



(d)

Fig.8: (a) Pure AC system phase voltage, (b) Combined system AC voltage,

(c) Combined system DC voltage, (d) combined system phase voltage

Fig.8 clearly shows the nature of the voltage profile for simultaneous AC-DC system where the maximum value of the phase voltage for pure AC system is assumed unity.The output DC current of rectifier is equally divided among all the three phases and each conductor in AC-DC composite system carries modulated current wave.

For insulation design point of view:

Let us define factor K1 such that

K1=dc withstand voltage/rms ac withstand voltage If calculated in straightforward manner for overhead line

K1=√2

The factor K2 may be defined as;

K2=ac insulation level/rated ac voltage

For overhead line K2 ≈ 2.5

This is because high transient over voltages are possible forac lines.

Similarly for dc side design, a factor K3 may be defined as;

K3=dc insulation level/rated dc voltage

For overhead line K3 ≈ 1.7

The actual ratio of insulation level is (ac/dc):

K=K1 $\frac{K2Vph}{K3Vd}$------ [32]

Thus converted ac line voltage may be selected a little higher than V_a = V_{ph}/2 to have two natural zero crossing in phase voltage (V_a) wave cycle. The total power transfer through the double circuit line before conversion is;

$P_{total} \approx 3{V_{ph}}^2 \sin \delta_1$/X ------- [33]

X is the transfer reactance per phase of the double circuit line and δ1 is the power angle between the voltages at the two ends. To keep sufficient stability margin, δ1 is generally kept low for long lines and seldom exceeds30^0.

With the increasing length of line, the loadability of the line is decreased. An approximate value of δ1 may be computed from the loadability curve by knowing the values of Surge Impedance Loading (SIL) and transfer reactance X of the line.

P_{total} = 2.M.SIL ----------------- [34]

Where M is the multiplying factor and its magnitude decreases with the length of line. The value of M can be obtained from the loadability curve. The total power transfer through the simultaneous ac-dc line is

$\mathrm{P_{total}}$ = P_{ac} + P_{dc} = $3Va^2 \sin\delta_2$/X + $2V_d I_d$ ----- [35]

The power angle δ_2 between the ac voltages at the two ends of the simultaneous ac-dc line may be increased to a high value due to fast controllability of dc component of power. For a constant value of total power, Pac may be modulated by fast control of the current controller of dc power converters. Approximate value of ac current per phase per circuit of the double circuit line may be computed as;

$I_a \approx$ V (sin δ/2)/X ----------- [36]

The on-line dc current order for rectifier is adjusted as

I_d=3 $\sqrt{[I_{th}^{*2} - I_a^{*2}]}$-------- [37]

Preliminary qualitative analysis suggests that commonly used techniques in HVDC/AC system may be adopted for the purpose of the design of protective scheme, filter and instrumentation network to be used with the composite line for simultaneous ac-dc power flow. In case of a fault in the transmission system gate signals to all the SCRs are blocked and that to the bypass SCRs are released to protect rectifier and inverter bridges. CBs are then tripped at both ends to isolate the faulty line. A surge diverter connected between the zig-zag neutral and the ground protects the converter bridge against any over voltage.

Conclusion

Power transmission capacity of line has to be increased for reveling congestion. This paper has studied and reviewed the papers on HVAC and HVDC transmission. HVAC has advantage of conveniently stepped up and stepped down of voltage. Also power can be generated at high voltage as there is no commutation problem.

High voltage transmission of ac reduces losses. Whereas HVDC has advantage of economical transfer of bulk power, power transfer can be controllable which improves system stability, lines can be loaded up to thermal limit. FACT devices such as TCSC, UPFC, etc. has a vital role to increase the transmission capability.

Over all above methods AC-DC transmission has an upper hand. It has advantages of both AC and DC transmission. It has advantage of increasing power transfer capacity of existing transmission line up to thermal limit, with-out causing any transient instability. This proposed method can positively change the transmission technology in future.

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