Optimization Strategies for Hybrid Power Transmission Systems

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ABSTRACT

Long extra high voltage (EHV) ac lines cannot be loaded to their thermal limits in order to keep sufficient margin against transient instability. With the scheme proposed in this paper it is possible to load these lines very close to their thermal limits. The conductors are allowed to carry usual ac along with dc superimposed on it.

The added dc power flow does not cause any transient instability. This paper gives the feasibility of converting a double circuit ac line into composite ac–dc power transmission line to get the advantages of parallel ac–dc transmission to improve stability and damping out oscillations. Simulation and experimental studies are carried out for the coordinated control as well as independent control of ac and dc power transmissions. No alterations of conductors, insulator strings, and towers of the original line are needed. Substantial gain in the load ability of the line is obtained. Master current controller senses ac current and regulates the dc current orders for converters online such that conductor current never exceeds its thermal limit.

Keywords: *Flexible ac transmission system (FACTS) ,Extra high voltage (EHV)transmission, power system computer-aided design(PSCAD),Simultaneous ac-dc power transmission.*

1 Introduction: - In recent years, environmental, right-of-way, and cost concerns have delayed the construction of a new transmission line, while demand of electric power has shown steady but geographically uneven growth. The power is often available at locations not close to the growing load centers but at remote locations. These locations are largely determined by regulatory policies, environmental acceptability, and the cost of available energy. The wheeling of this available energy through existing long ac lines to load centers has a certain upper limit due to stability considerations. Thus, these lines are not loaded to their thermal limit to keep sufficient margin against transient instability.

The present situation demands the review of traditional power transmission theory and practice, on the basis of new concepts that allow full utilization of existing transmission facilities without decreasing system availability and security. The flexible ac transmission system (FACTS) concepts, based on applying state-of-the-art power electronic technology to existing ac transmission system, improve stability to achieve power transmission close to its thermal limit.

The basic proof justifying the simultaneous ac–dc power transmission is explained in an IEEE paper "Simultaneous ac-dc power transmission," by K. P. Basu and B. H. Khan. In the above reference, simultaneous ac–dc power transmission was first proposed through a single circuit ac transmission line. In these proposals Mono-polar dc transmission with ground as return path was used. There were certain limitations due to use of ground as return path. Moreover, the instantaneous value of each conductor voltage with respect to ground becomes higher by the amount of the dc voltage, and more discs are to be added in each insulator string to withstand this increased voltage. However, there was no change in the conductor separation distance

2 Problem Definition:-

The main object of my paper is to show that by superimposing DC in AC transmission, the capacity of the transmission line can be increased by nearly 70 % of that if only AC is transmitted. In our existing transmission system, long extra high voltage (EHV) ac lines cannot be loaded to their thermal limits in order to keep sufficient margin against transient instability. With the scheme proposed in this paper, it is possible to load these lines very close to their thermal limits. The conductors are allowed to carry usual ac along with dc superimposed on it.

3 Proposed System (Simultaneous AC-DC Power Transmission):-

With the scheme proposed in this thesis, it is possible to load the transmission lines very close to their thermal limits. The conductors are allowed to carry usual ac along with dc superimposed on it. The added dc power flow does not cause any transient instability. This thesis gives the feasibility of converting a double circuit ac line into composite ac–dc power transmission line to get the advantages of parallel ac–dc transmission to improve stability and damping out oscillations. No alterations of conductors, insulator strings, and towers of the original line are needed. Substantial gain in the load ability of the line is obtained. In this thesis, the feasibility study of conversion of a single circuit ac line to composite ac–dc line without altering the transformer due to dc current. Two fluxes produced by the dc current (I_d / 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 X_d 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 zig-zag 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 X_d.

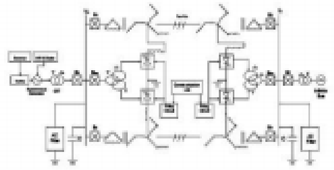


Figure: 4.1 Basic scheme for composite ac–dc transmission.

Assuming the usual constant current control of rectifier and constant extinction angle control of inverter as mentioned later, the equivalent circuit of the scheme original line conductors and tower structures has been presented.

3.1 Introduction:-

Fig. 1 depicts the basic scheme for simultaneous ac–dc power flow through a double circuit ac transmission line. The dc power is obtained through line commutated 12-pulse rectifier bridge used in conventional HVDC and injected to the neutral point of the zigzag connected secondary of sending end transformer and 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.

The double circuit ac transmission line carriers both three-phase ac and dc power. Each conductor of each line carries one third of the total dc current along with ac current. Resistance being equal in all the three phases of secondary winding of zig-zag transformer as well as the three conductors of the line, the dc current is equally divided among all the three phases.

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 under normal steady-state operating condition is given in Fig. 2. The dotted lines in the figure show the path of ac return current only. The second transmission line carries the return dc current, and each conductor of the line carries $(I_d / 3)$ along with the ac current per phase and V_{dro} and V_{dio} are the maximum values of rectifier and inverter side dc voltages and are equal to $3\sqrt{2}$ times converter ac input line-to-line voltage. R, L and C are the line parameters per phase of each line. R_{cr} and R_{ci} are commutating resistances, and, α, γ are firing and extinction angles of rectifier and inverter, respectively.

3.2 Proof with Equations:-

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, and D parameters of each line may be written as

$$E_S = AE_R + BI_R \qquad [3.1]$$

$I_S = CE_R + DI_R$

[3.2]

$P_S + j\,Q_S = -E_S E_R^{*} / B^{*} + [D^{*} E_S^{2} / B^{*}]$ [3.3]

$P_R + j\,Q_R = E_R E_S^{*} / B^{*} - [A^{*} E_R^{2} / B^{*}]$ [3.4]

Neglecting ac resistance drop in the line and transformer, the dc power P_{dr} and P_{di} of each rectifier and inverter are given by

$P_{dr} = V_{dr} I_d$ [3.5]

$P_{di} = V_{di} I_d$ [3.6]

Reactive powers required by the converters are

$Q_{dr} = P_{dr} \tan\theta_r$

[3.7]

$Q_{di} = P_{di} \tan\theta_i$

[3.8]

$\cos\theta_r = [\cos\alpha + \cos(\alpha + \mu_r)]/2$ [3.9]

$\cos\theta_i = [\cos\gamma + \cos(\gamma + \mu_i)]/2$ [3.10]

where X_i and X_r are commutation angles of inverter and rectifier, respectively, and total active and reactive powers at the two ends are

$P_{st} = P_s + P_{dr}$ and $P_{rt} = P_R + P_{di}$ [3.11]

$\mathbf{P_{st} = P_s + P_{dr}}$ $P_{rt} = P_R - P_{di}$ [3.12]

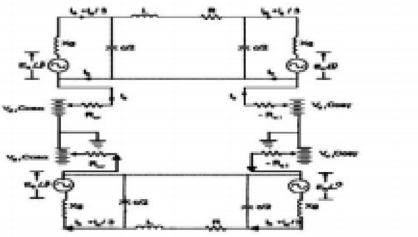


Figure: 4.2 Equivalent Circuit

Transmission loss for each line is

$P_L = (P_S + P_{dr}) - (P_R + P_{di})$

[3.13]

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

$I = [I_a^2 + (I_d/3)^2]^{1/2}$

Power loss for each line = $P_L = 3I^2R$

The net current 'I' in any conductor is offseted from zero. 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. The current in any conductor is no more offseted. Circuit breakers (CBs) are then tripped at both ends to isolate the faulty line. CBs connected at the two ends of transmission line interrupt current at natural current zeroes, and no special dc CB is required. Now, allowing the net current through the conductor equal to its thermal limit I_{th}.

$I_{th} = [I_a^2 + (I_d/3)^2]^{1/2}$

[3.14]

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 composite ac–dc line with dc voltage V_d superimposed on it. As insulators remain unchanged, the peak voltage in both cases should be equal to

$V_{max} = \sqrt{2}V_{ph} = V_d + \sqrt{2}V_a$

[3.15]

Electric field produced by any conductor possesses a dc component superimpose on it a sinusoidal varying ac component. However, the instantaneous electric field polarity changes its sign twice in a cycle if $(V_d/V_a) < \sqrt{2}$ 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 $V_{LLmax} = \sqrt{6}V_a$ .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;

$V_d = V_{ph}/\sqrt{2}$ and $V_a = V_{ph}/2$ [3.16]

The total power transfer through the double circuit line before conversion is as follows

$$P'_{total} \approx 3V_{ph}^2 \sin\delta_1/X$$ [3.17]

where ‘X’ is the transfer reactance per phase of the single circuit line, and δ_1 is the power angle between the voltages at the two ends. To keep sufficient stability margin, δ_1 is generally kept low for long lines and seldom exceeds 30^0. With the increasing length of line, the load ability of the line is decreased. An approximate value of δ_1 may be computed from the loadability curve by knowing the values of surge impedance loading (SIL) and transfer reactance of the line

$$P'_{total} = 2.M.SIL$$

[3.18]

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 composite line

$$P_{total} = P_{ac} + P_{dc}$$

$$P_{total}=3V_a^2\sin\delta_2/X+2V_dI_d$$ [3...19]

A surge diverter connected between the zig-zag neutral and the ground protects the converter bridge against any over voltage.

4 Simulation:-

4.1 Simulink Model Using AC Transmission:-

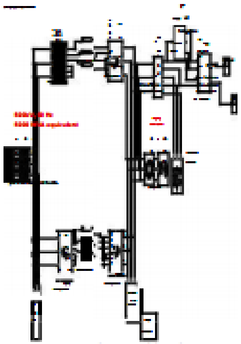


Figure: 4.1 Simulink model using AC Transmission

4.2 Simulink Model Using AC –DC Transmission:-

The power angle δ_{-z} between the ac voltages at the two ends of the composite line may be increased to a high value due to fast controllability of dc component of power. For a constant value of total power, P_{ac} 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

$$I_a = V(\sin \delta/2)/X \qquad [3.20]$$

The rectifier dc current order is adjusted online as

$$I_d = 3\sqrt{I_{th}^{*2} - I_a^{*2}} \qquad [3.21]$$

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 complete system.

Figure: 6.2 Simulink model using combined AC – DC Transmission.

6 Results:-

6.1 AC Configuration only

The laudability of Moose (commercial name), ACSR, twin bundle conductor, 400-kV, 50-Hz, 450-km single circuit line has been computed.

The parameters of the line are

$Z = 0.6054 + j0.66172$ Z/km/ph/ckt

$Y = j6.67594 * 10^{-6}$ s/km/ph/ckt

Current carrying capacity of each sub conductor =.9 kA

I_{th} = 1.8 kA/ckt .SIL = 511MW/ckt.

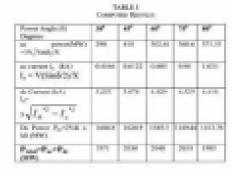
Using (17)–(20), the computed power at receiving end and conductor current is

$P'_{total} = 1124.2$ MW

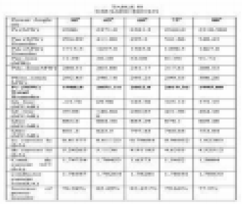
$I_{ph/ckt} = 0.803$ kA.

5 Results:-

5.1Both AC-DC Configuration:-



5.2 Simulated Results



6 Conclusion and Future Scope

6.1 Conclusion

The feasibility to convert ac transmission line to a composite ac–dc line has been demonstrated. For the particular system studied, there is substantial increase (about 83.45%) in the loadability of the

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line. The line is loaded to its thermal limit with the superimposed dc current. The dc power flow does not impose any stability problem. The advantage of parallel ac–dc transmission is obtained. Dc current regulator may modulate ac power flow. There is no need for any modification in the size of conductors, insulator strings, and towers structure of the original line. The optimum values of ac and dc voltage components of the converted composite line are 1/2 and 1/√2 times the ac voltage before conversion, respectively.

6.2 Future Scope

In this paper, it is shown that by injecting DC power in AC power transmission lines, we can improve the transmission capacity of the line by 2 to 4 times without altering the physical equipment. This work can be extended for analyzing the effect of faults on this type of transmission. This work is done on double circuit AC transmission lines but it can be extended to other types of transmission methods.

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