International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 11, November - 2013

EHVAC & HVDC Transmission System for Power Upgrading of Transmission

Gollapalli Vinod Kumar, Grandhi Ramu
Electrical and Electronics Engineering Department,
Chaitanya Institute of Science and Technology,
Kakinada, A.P, India.

Abstract

The present day electric power transmission system needs the review of theory and practice, on the basis of new concepts that allow full utilization of existing transmission facilities without decreasing system availability and security. The effective way to achieve this goal with simultaneous ac–dc power transmission in which the conductors are allowed to carry superimposed dc current along with ac current. Ac and dc power flow independently and the added dc power flow does not cause any transient instability. In this paper, the feasibility study of conversion of a double circuit ac line to composite ac–dc line without altering the original line conductors, tower structures, and insulator strings has been presented. In this scheme, the dc power flow is point-to-point bipolar transmission system.

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 use of transformer for transmitting power longer distances and at higher voltage justified the use of alternating current. The poly phase induction motors which serve the majority of industrial and residential purposes are simpler and rugged in the construction and cheaper as compared to DC motors of the same ratings. For all such reasons power was generated, transmitted, distributed and consumed as alternating current. If, however, some applications needed the use of DC, alternating current was converted to direct current; however, the advantages of DC transmission suggest that there are strong technical reasons at least for two cases where the use of direct current transmission and distribution may be done by alternating current.

(1) Because of large charging currents, the use of high voltage alternating current for underground transmission over longer distances is prohibited. The transmission of power using DC has no such limitation.

(2) Parallel operation of AC with DC which increases the stability limit of the system or interconnection of two large AC systems by a DC transmission tie line. Here the DC line an asynchronous link between two rigid (frequency constant) system where otherwise slight difference in frequency of the two large systems would produce serious problems of power transfer control in the small capacity link.

The conversion of AC line to DC line for substantial power upgrading of existing AC line. However, this would require major changes in the tower structure as well as replacement of AC insulator strings with high creepage DC insulators. The novelty of our proposed scheme is that the power transfer enhancement is achieved without any alteration in the existing EHV AC line. The main object is to gain the advantage of parallel AC-DC transmission and to load the line close to its thermal limit.

2. HVDC Transmission

An HVDC converter station is normally built up of one or two 12-pulse converters as described above, depending on the system being mono- or bipolar. In some cases each pole of a bipolar system consists of two converters in series to increase the voltage and power rating of the transmission. It is not common to connect converters directly in parallel in one pole.

The poles are normally as independent as possible to improve the reliability of the system, and each pole is equipped with a DC reactor and DC filters. Additionally the converter station consists of some jointly used equipment. This can be the connection to the earth electrode, which normally is situated some distance away from the converter station area, AC filters and equipment for supply of the necessary reactive power.

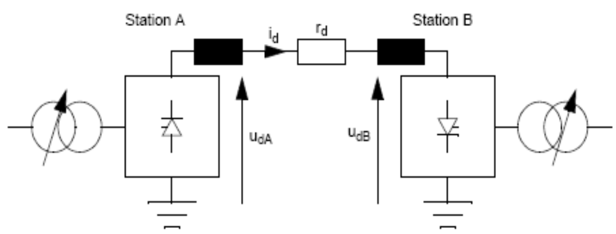

Figure 1. Mono-polar HVDC transmission Voltage in station B according to reversed polarity convention

2.1 DC transmission control

The current flowing in the DC transmission line determined by the DC voltage difference between station A and station B. where *rd* represents the total resistance of the line, we get for the DC current

$$i_d = \frac{u_{dA} - u_{dB}}{r_d}$$

And the power transmitted into station B is

$$p_d = u_{dB} \cdot i_d = u_{dB} \cdot \frac{u_{dA} - u_{dB}}{r_d}$$

In rectifier operation the firing angle α should not be decreased below a certain minimum value α_{min}, normally 3°-5° in order to make sure that there really is a positive voltage across the valve at the firing instant. In inverter operation the extinction angle should never decrease below a certain minimum value γ_{min}, normally 17°-19° otherwise the risk of commutation failures becomes too high. On the other hand, both α and γ should be as low as possible to keep the necessary nominal rating of the equipment to a minimum. Low values of α and γ also decreases the consumption of reactive power and the harmonic distortion in the AC networks. To achieve this, most HVDC systems are controlled to maintain $\gamma = \gamma$ min in normal operation.

The DC voltage level is controlled by the transformer tap changer in inverter station B. The DC current is controlled by varying the DC voltage in rectifier station A, and thereby the voltage difference between A and B.

Due to the small DC resistances in such a system, only a small voltage difference is required and small variations in rectifier voltage gives large variations in current and transmitted power. The DC current through a converter cannot change the direction of flow. So the only way to change the direction of power flow through a DC transmission line is to reverse the voltage of the line. But the sign of the voltage difference has to be kept constantly positive to keep the current flowing. To keep the firing angle α as low as possible, the transformer tap changer in rectifier station A is operated to keep α on an operating value which gives only the necessary margin to α min to be able to control the current.

2.2 Converter current/voltage characteristics

The resistive voltage drop in converter and transformer, as well as the non current voltage drop in the thyristor valves are often disregarded in practical analysis, as they are normally in the magnitude of 0.5 % of the normal operating voltage. The commutation voltage drop, however, has to be taken into account as this is in the magnitude of 5 to 10 % of the normal operating voltage. The direct voltage U_d from a 6-pulse bridge converter can then be expressed by

$$u_d = u_{dio} \cdot \left[\cos\alpha - d_{xN} \cdot \frac{i_d}{i_{dN}} \cdot \frac{u_{dioN}}{u_{dio}} \right]$$

Where α is the firing angle,

If the converter is operating as inverter it is more convenient to operate with extinction angle γ instead of firing angle α .

The extinction angle is defined as the angle between the end of commutation to the next zero crossing of the commutation voltage. Firing angle α, commutation angle μ and extinction angle γ are related by

$$\alpha + \mu + \gamma = 180^0$$

In inverter mode, the direct voltage from the inverter can be written as

$$u_d = -u_{dio} \cdot \left[\cos\gamma - d_{xN} \cdot \frac{i_d}{i_{dN}} \cdot \frac{u_{dioN}}{u_{dio}} \right]$$

The current/voltage characteristics expressed in above are shown for normal values of i_d and $d_x N$. In order to create a characteristic diagram for the complete transmission, it is usual to define positive voltage in inverter operation in the opposite direction compared to rectifier operation. It is clear that to operate both converters on a constant firing/extinction angle principle is like leaving them without control. This will not give a stable point of operation, as both characteristics have approximately the same slope. Small differences appear due to variations in transformer data and voltage drop along the line. To gain the best possible control the characteristics should cross at as close to a right angle as possible. This means that one of the characteristics should preferably be constant current.

This can only be achieved by a current controller. If the current/voltage diagram of the rectifier is combined with a constant current controller characteristic we get the steady state for converter station A.

3. Simultaneous AC-DC Power Transmission

The basic scheme for simultaneous AC-DC power flow through a double circuit AC transmission line is shown on the fig 2. 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.

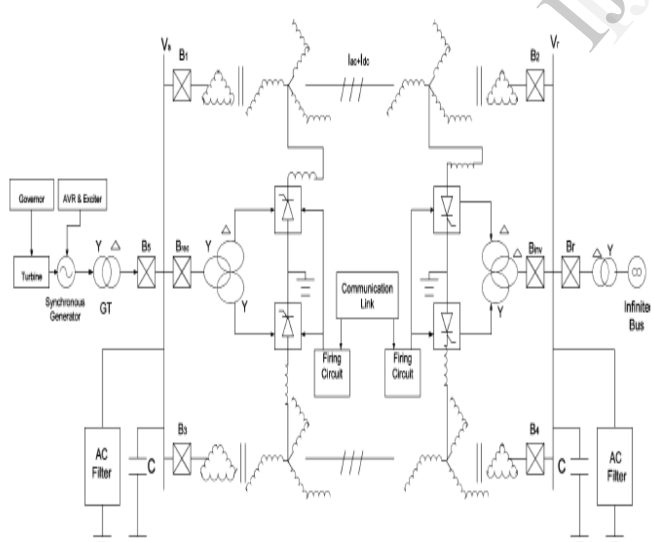

Figure 2 Basic scheme for composite ac–dc transmission

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 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 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 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 X_d.

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. 3

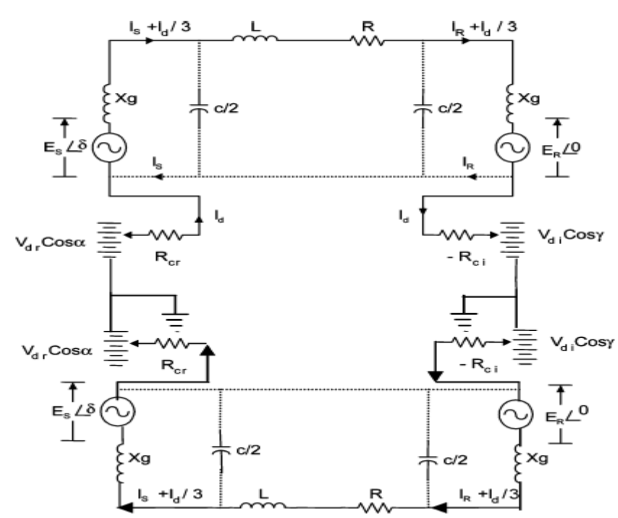

Figure 3 Equivalent circuit

The dotted lines in the figure 2 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 are the maximum values of rectifier and inverter side DC voltages and are equal to $3\sqrt{2}/\pi$ times converter AC input line-to-line voltage. R, L, and C are the line parameters per phase of each line. R_{cr}, R_{ci} is 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, and D parameters of each line may be written as

$$E_S = AE_R + BI_R \quad (1)$$

$$I_S = CE_R + DI_R \quad (2)$$

$$P_S + j\,Q_S = -E_S E^*_R / B^* + D^* E^2_S / B^* \quad (3)$$

$$P_R + j\,Q_R = E^*_S E_R / B^* - A^* E^2_R / B^* \quad (4)$$

Neglecting AC resistive drop in the line and transformer, the DC power P_{dr} and P_{dc} of each rectifier and inverter may be expressed as

$$P_{dr} = V_{dr} I_d \quad (5)$$

$$P_{di} = V_{di} I_d \quad (6)$$

Reactive power required by the converters are

$$Q_{dr} = P_{dr} \tan\theta_r \quad (7)$$

$$Q_{di} = P_{di} \tan\theta_i \quad (8)$$

$$\cos\theta_r = [\cos\alpha + \cos(\alpha + \mu_r)]/2 \quad (9)$$

$$\cos\theta_i = [\cos\gamma + \cos(\gamma + \mu_i)]/2 \quad (10)$$

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

$$P_{st} = P_s + P_{dr} \text{ and } P_{rt} = P_R + P_{di} \quad (11)$$

$$Q_{st} = Q_s + Q_{dr} \text{ and } Q_{rt} = Q_R + Q_{di} \quad (12)$$

Transmission loss for each line is

$$P_L = (P_S + P_{dr}) - (P_R + P_{di}) \quad (13)$$

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 = $P = 3I^2$

The net current I in any conductor is offset 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 to its net current through the conductor equal thermal limit (I_{th}).

$$I_{th} = [I_a^2 + (I_d/3)^2]^{1/2} \quad (14)$$

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

$$V_{max} = \sqrt{2}\, V_{ph} = V_d + \sqrt{2}\, V_a \quad (15)$$

Electric field produced by any conductor possesses a DC component superimpose on it a sinusoidally 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 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 $V_{LL\ max} = \sqrt{6}\, V_a$. 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;

$$V_d = V_{ph}/\sqrt{2} \text{ and } V_a = V_{ph}/2 \quad (16)$$

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

$$P'_{total} = 3V_{ph}^2 \sin\delta_1 / X \quad (17)$$

Where X is the transfer reactance per phase of the double circuit line, δ_1 and 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 loadability 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 X, of the line

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

$P_{total} = P_{ac} + P_{dc} = 3V_a^2 \sin\delta_2 / X + 2V_d I_d$ (19)

The power angle δ_2 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

$I_a = V(\sin\delta/2)/X$ (20)

The rectifier DC current order is adjusted online as

$I_d = 3\sqrt{I^{*2}_{th} - I^{*2}_{a}}$ (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. A surge diverter connected between the zig-zag neutral and the ground protects the converter bridge against any over voltage.

4. Simulation Results

The proposed composite AC-DC power scheme shown in figure.2 has been simulated in steady-state mode as a real system using MATLAB software package. The readings at various points on the system are tabulated in Table I.

DC power loss, P_{dc} includes line loss due to DC current and converter losses. AC power loss, P_{ac} is line loss due to AC current only. The total power at receiving end, Pr is the actual net power transfer after subtracting all losses like circuit breakers, transformers, etc.

It has been seen from computation that the maximum power transfer of 2062.0 MW transmitted by composite AC-DC line occurs at power angle of 60^0 The same amount of power transfer through conventional double circuit line would require a power angle of $73^0.68'$, which is beyond the safe limit for power angle.

Table. Combining AC-DC Power Transmission Computed Results

Power angel (δ) Degrees	30^0	45^0	60^0	75^0	80^0
Ps (MW) [Pr + P loss_total]	2256	2320	2332	2295	2270
Pac transfer (MW) = [$3V_a^2 \sin\delta / X$]	290	410	502.61	560.6	571.55
Pdc transfer (MW) [$P_{dc} = 2V_{di} \times I_{di}$]	1684.8	1624.9	1545.5	1449.28	1413.76
Pac_ loss (MW) = [$R \times (Id/3)^2$]	15.238	32.907	56.899	84.326	94.057
Pdc loss (MW) = [$R \times (Ia)^2$]	269.2	251.37	227.3	199.9	190.2
P loss_total (MW) = [Pac loss + Pdc loss]	284.43	284.27	284.19	284.22	284.25
Pr =[$P_{ac} + P_{dc}$] (MW)	1971	2035	2048	2010	1985
ac current I_a (kA) I_a =[V(sin $\delta/2$) /X]	0.4166	0.6122	0.805	0.98	1.035
Dc current (kA) I_d = [$3\sqrt{I_{th}^{*2} - I_a^{*2}}$]	5.253	5.078	4.829	4.529	4.418
Cond.dc current Id/3 (kA)	1.751	1.692	1.609	1.509	1.472
Conductor current I_{sim} (KA)	1.7651	1.7626	1.7623	1.7662	1.7687

5. Conclusions

Combined AC-DC power transmission line simulation circuit diagram shown in fig. 2. We can transmit both AC & DC combined in order to improve the power transfer capability of the transmission line. The DC supply in the circuit is derived from the AC supply by using a rectifier station. In order to transmit both AC and DC combined it required to inject the DC power at zero voltage which is a neutral point in the zigzag transformer in order to nullify the flux due to the DC supply if not it leads to saturation of the core. And then at the receiving end the the DC power is converted to AC power by using an inverter station and fed to load.

6. References

1. H. Rahman and B H Khan “Possibility of Power Tapping from Composite AC-DC Power ransmission Lines” *IEEE Transactionon Power Delivery*, Vol.23,July 2008 ,pp 1464-1471.

2. L. K. Gyugyi, “Unified power flow concept for flexible A.C. transmission system,” Proc. Inst. Elect. Eng., p. 323, Jul. 1992.

3. L. K. Gyugyi et al., “The unified power flow controller; a new approach to power transmission control,” IEEE Trans. Power Del., vol. 10, no. 2, pp. 1085–1097, Apr. 1995.

4. N. G. Hingorani, “FACTS—flexible A.C. transmission system,” in Proc. Inst. Elect. Eng. 5th. Int. Conf. A.C. D.C. Power Transmission, London, U.K., 1991.

5. P. S. Kundur, Power System Stability and Control. New York: Mc- Graw-Hill, 1994.

6. K. P. Basu and B. H. Khan, “Simultaneous AC-Dc power transmission,” Inst. Eng. (India) J.-EL, vol. 82, pp. 32–35, Jun. 2001.

7. H. Rahman and B. H. Khan, “Enhanced power transfer by simultaneous transmission of AC-DC: a new FACTS concept,” in Proc. Inst. Elect. Eng. Conf. Power Electronics, Machines, Drives, Edinburgh, U.K., Mar. 31–Apr. 2 2004, vol. 1, pp. 186–191.