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Upgradation of Power flow in EHV AC transmission

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Abstract: **Transient stability plays key role for the loading of Extra High Voltage AC lines under their thermal limits. It is not possible to load these EHV lines near the thermal limits. But, with the proposed scheme in this paper, it is possible to load these lines very close to their thermal limits. Master current controller senses ac current and regulates the dc current orders for converters online such that conductor current never exceeds its thermal limit. In this scheme, the ac line conductors are superimposed with dc power flow and it doesn't cause any transient instability. This paper presents the converting of an ac line into composite ac-dc power transmission line to improve transient stability and damping out the oscillations. With Matlab/Simulink software the thermal limits are satisfactory and the gain in the load ability of the line is obtained.**

***Index Terms*—Extra high voltage (EHV) transmission, flexible ac transmission system (FACTS), MATLAB simulation, simultaneous ac–dc power transmission.**

I. 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, as the line-to-line voltage remains unchanged. 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.

II. HIGH VOLTAGE DC TRANSMISSION

It has been widely documented in the history of the electricity industry, that the first commercial electricity generated (by Thomas Alva Edison) was direct current (DC) electrical power. The first electricity transmission systems were also direct current systems. However, DC power at low voltage could not be transmitted over long distances, thus giving rise to high voltage alternating current (AC) electrical systems. Nevertheless, with the development of high voltage valves, it was possible to once again transmit DC power at high voltages and over long distances, giving rise to HVDC transmission systems. Since the first commercial installation in 1954 a huge amount of HVDC transmission systems have been installed around the world.

The HVDC transmission system depends on many factors, such as power capacity to be transmitted, type of transmission medium, environmental conditions and other safety, regulatory requirements etc. Even when these are available, the options available for optimal design different commutation techniques, variety of filters, transformers etc.) render for an HVDC system.

In today electricity industry, in view of the liberalization and increased effects to conserve the environment, HVDC solutions have become more desirable for the following reasons:

1. Environmental advantages
2. Economical (cheapest solution)
3. Asynchronous interconnections
4. Power flow control
5. Added benefits to the transmission (stability, power quality etc.)

III. HIGH VOLTAGE AC TRANSMISSION

Industrial-minded countries of the world require a vast amount of energy of which electrical energy forms a major fraction. The world has already consumed major portion of its natural resources and is looking for sources of energy other than Hydro and Thermal to cater for the rapid rate of consumption which is outpacing the discovery of new resources. This will not slow down with time and therefore there exists a need to reduce the rate of annual increase in energy consumption by any intelligent society if resources have to be preserved for posterity. This requires very high voltages for transmission. The very rapid stride taken by development of dc transmission since 1950 is playing a major role in extra-long-distance transmission, complementing or supplementing E.H.V. ac transmission. They have their roles to play and a country must make intelligent assessment of both in order to decide which is best suited for the country's economy.

Problems posed in using such HVAC are encountered as:

a. Increased Current Density because of increase in line loading by using series capacitors.
b. Use of bundled conductors.
c. High surface voltage gradient on conductors.
d. Corona problems: Audible Noise, Radio Interference, Corona Energy Loss, Carrier Interference, and TV Interference.
e. High electrostatic field under the line.
f. Switching Surge Overvoltage's which cause more havoc to air-gap insulation than lightning or power frequency voltages.
g. Increased Short-Circuit currents and possibility of Ferro resonance conditions.
h. Use of gapless metal-oxide arresters replacing the conventional gap-type Silicon Carbide arresters, for both lightning and switching-surge duty.
i. Shunt reactor compensation and use of series capacitors, resulting in possible sub synchronous resonance conditions and high short circuit currents.
j. Insulation coordination based upon switching impulse levels.
k. Single-pole reclosing to improve stability, but causing problems with arcing.

IV. POWER UPGRADING BY COMBINING AC & DC

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 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.

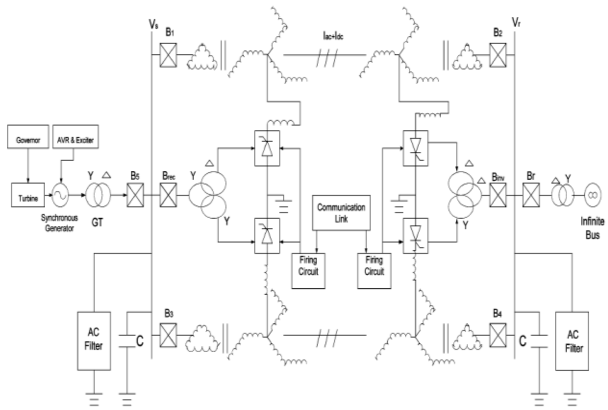

Figure: 1 Basic scheme for composite ac–dc transmission.

Assuming the usual constant current control of rectifier and constant extinction angle control of inverter as mentioned later, the equivalent circuit of the scheme 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.

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

$$Es = A\,Er + B\,Ir \quad [1]$$

$$Is = CEr + DIr \quad [2]$$

$$Ps + jQs = -\frac{EsE_r^*}{B^*} + \frac{D^*E_S^2}{B^*} \quad [3]$$

$$Pr + jQr = \frac{ErE_S^*}{B^*} - \frac{A^*E_r^2}{B^*} \quad [4]$$

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

$$P_{dr} = V_{dr}I_d \quad [5]$$

$$P_{di} = V_{di}I_d \quad [6]$$

Reactive powers required by the converters are

$$Q_{dr} = P_{dr}tan\theta_r \quad [7]$$

$$Q_{di} = P_{di}tan\theta_i \quad [8]$$

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

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

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

$$P_{st} = P_s + P_{dr}\ and\ P_{rt} = P_r + P_{di} \quad [11]$$

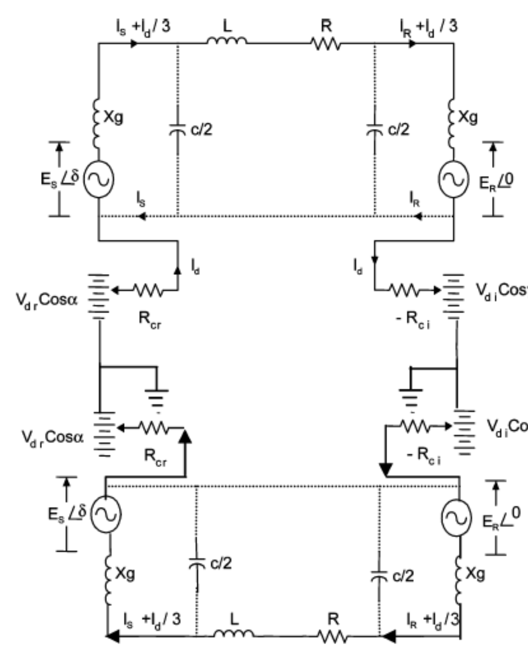

Figure : 2 Equivalent Circuit

Transmission loss for each line is

$$P_L = (P_s + P_{dr}) - (P_r + P_{di}) \quad [12]$$

I_a being the RMS AC current per conductor at any point of the line, the total RMS current per conductor becomes

$$I = \left[I_a^2 + \left(\frac{I_d}{3}\right)^2\right]^{1/2} \quad [13]$$

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

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 offset. 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}.

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

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 to,

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

Electric field produced by any conductor possesses a dc component superimpose on it a 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;

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

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

$$P'_{total} \approx 3V_{ph}^2 \sin\delta_1 / X \quad [17]$$

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

$$P'_{total} = 2 * M * SIL \quad [18]$$

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

$$P_{total} = P_{ac} + P_{dc}$$
$$P_{total} = 3\,V_a^2 \sin\delta_2/X + 2V_d I_d \quad [19]$$

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

$$I_a = V\,(\sin\delta/2)/X \quad [20]$$

The rectifier dc current order is adjusted online as

$$I_d = 3\sqrt{I_{th}^{*2} - I_a^{*2}}. \quad [21]$$

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.

V. SIMULATION RESULTS

A synchronous machine is feeding power to infinite bus via a double circuit, three-phase, 400-KV, 50-Hz, 450-Km ac transmission line. The 2750-MVA (5 * 550), 24.0-KV synchronous machine is dynamically modeled, a field coil on d-axis and a damper coil on q-axis, by Park's equations with the frame of reference based in rotor [4]. It is equipped with an IEEE type AC4A excitation system of which block diagram is shown in Fig. 3.

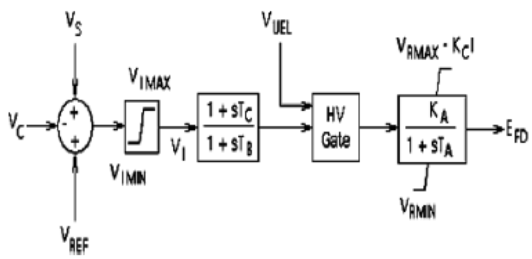

Figure 3 IEEE type AC 4A excitation system

The simulation work was carried out by MATLAB/Simulink Software and the results were shown here. Figure.4 represents output power of AC transmission alone and the combining effect of AC &DC transmission output power is shown in figure.5

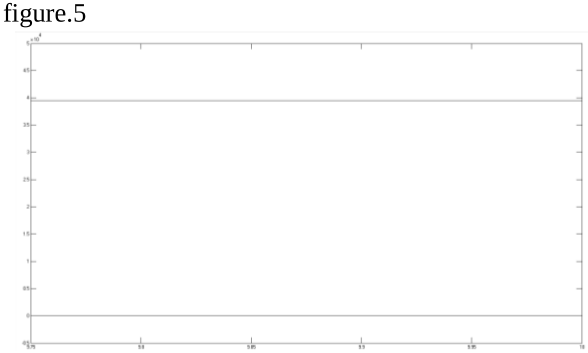

Figure.4 Output Power in AC Transmission

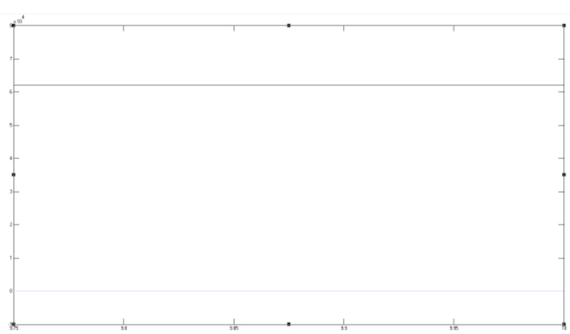

Figure.5 Output Power in AC and DC Transmission

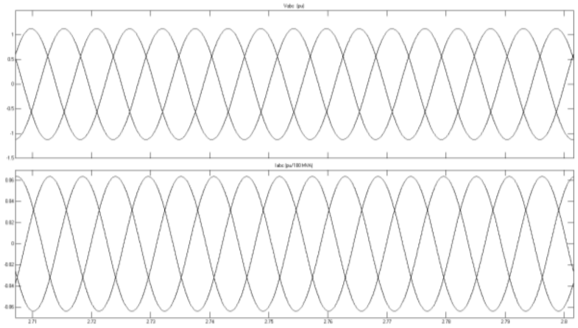

Figure.6 Input Voltage and currents for Rectifier

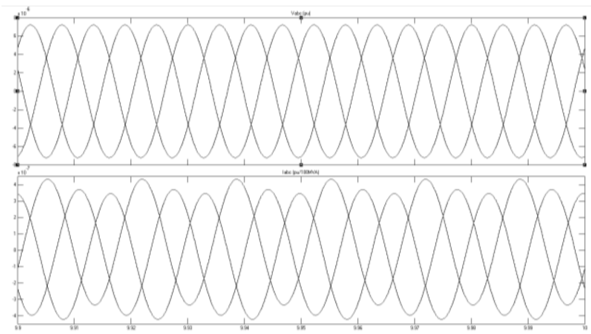

Figure: 7 Waveforms for Vabc (pu), Iabc (pu/100MVA) in inverter

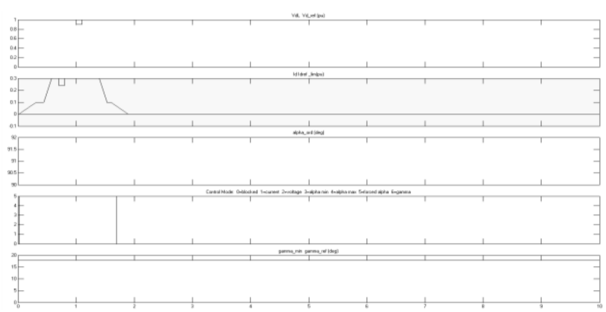

Figure: 8 Waveforms representing VdL Vd_ref (pu), Id Idref _lim(pu), alpha_ord (deg), Control Mode, gamma_min gamma_ref (deg) for inverter

VI. 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 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.

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