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Power Upgrading of Transmission Line by Combining AC–DC Transmission

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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 project, 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 project 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.

Index Terms— Extra high voltage (EHV) transmission, flexible ac transmission system (FACTS), power system computer-aided design (PSCAD) 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. Another way to achieve the same goal is 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.

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. 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.

II. SIMULTANEOUS AC–DC POWER TRANSMISSION

A. Basic scheme for composite ac–dc transmission.

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.

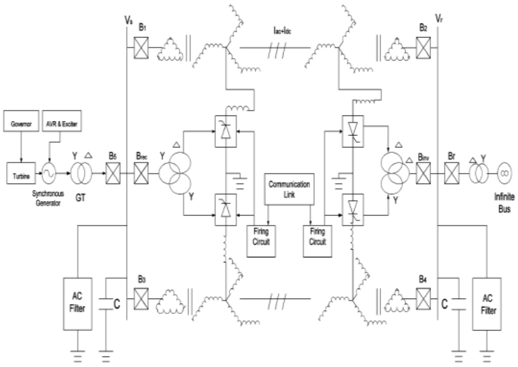


Fig. 1 depicts the basic scheme for simultaneous ac–dc power flow through a double circuit ac transmission line.

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 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. 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 are the maximum values of rectifier and inverter side dc voltages and are 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, and D parameters of each line may be written as

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

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

$$P_S+JQ_S= - E_S{*}E_R/B^{*}+D^{*}E_S^{2}/B^{*} \quad (3)$$

$$P_R+jQ_R= E_S{*}E_R/B^{*}-A{*}\,E_R^{2}/B^{*}. \quad (4)$$

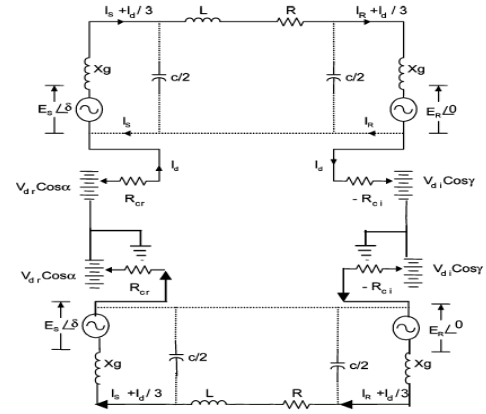


Fig. 2. Equivalent circuit.

III. DESCRIPTION OF THE SYSTEM MODEL

A. Description of the system model:

A synchronous machine is feeding power to infinite bus via a double circuit,three-phase,400KV,50Hz, 450Km ac transmission line. The 2750MVA,24KV 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. It is equipped with an IEEE type AC4A excitation system of which block diagram is shown in Fig. 3. Transmission lines are represented as the Bergeron model. It is based on a distributed LC parameter traveling wave line model, with lumped resistance. It represents the L and C elements of a PI section in a distributed manner (i.e., it does not use lumped parameters).

It is roughly equivalent to using an infinite number of PI sections, except that the resistance is lumped (1/2 in the middle of the line, 1/4 at each end). Like PI sections, the Bergeron model accurately represents the fundamental frequency only. It also represents impedances at other frequencies, except that the losses do not change. This model is suitable for studies where the fundamental frequency load flow is most important. The converters on each end of dc link are modeled as line commutated two six- pulse bridge (12-pulse), Their control system consist of constant current (CC) and constant extinction angle (CEA) and voltage dependent current order limiters (VDCOL) control. The converters are connected to ac buses via Y-Y and Y- converter transformers. Each bridge is a compact power system computer-aided design (SIMULINK) representation of a dc converter, which includes a built in six-pulse Graetz converter bridge (can be inverter or rectifier), an internal phase locked oscillator (PLO), firing and valve blocking controls, and firing angle /extinction α angle γ measurements. It also includes built in RC snubber circuits for each thyristor. The controls used in dc system are those of CIGRE Benchmark, modified to suit at desired dc voltage. Ac filters at each end on ac sides of converter transformers are connected to filter out 11th and 13th harmonics. These filters and shunt capacitor supply reactive power requirements of converters.

A master current controller (MCC), shown in Fig. 4, is used to control the current order for converters. It measures the conductor ac current, computes the permissible dc current, and produces dc current order for inverters and rectifiers.

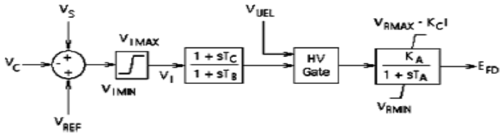


Fig. 3. IEEE type AC4A excitation system.

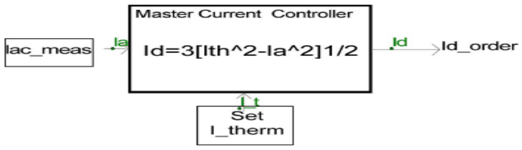


Fig. 4. Master current controller.

IV. HIGH VOLTAGE DC TRANSMISSION

This chapter describes an overview of the importance of the HVDC systems in the present world. Then it discusses about the various parameters dealing with the HVDC systems. Over long distances bulk power transfer can be carried out by a high voltage direct current (HVDC) connection cheaper than by a long distance AC transmission line**.** HVDC transmission can also be used where an AC transmission scheme could not (e.g. through very long cables or across borders where the two AC systems are not synchronized or operating at the same frequency). However, in order to achieve these long distance transmission links, power converter equipment is required, which is a possible point of failure and any interruption in delivered power can be costly. It is therefore of critical importance to design a HVDC scheme for a given availability. The HVDC technology is a high power electronics technology used in electric power systems. It is an efficient and flexible method to transmit large amounts of electric power over long distances by overhead transmission lines or underground/submarine cables. It can also be used to interconnect asynchronous power systems. The fundamental process that occurs in an HVDC system is the conversion of electrical current from AC to DC (rectifier) at the transmitting end and from DC to AC (inverter) at the receiving end.

A. Technology involved in an HVDC system:

There are three ways of achieving conversion

1. Natural commutated converters
2. Capacitor Commutated Converters
3. Forced Commutated Converters

1. Natural commutated converter: (NCC):

NCC are most used in the HVDC systems as of today. The component that enables this conversion process is the thyristor, which is a controllable semiconductor that can carry very high currents **(**4000 A**)** and is able to block very high voltages **(**up to 10 kV). By means of connecting the thyristors in series it is possible to build up a thyristor valve, which is able to operate at very high voltages **(**several hundred of kV).The thyristor valve is operated at net frequency (50 Hz or 60 Hz) and by means of a control angle it is possible to change the DC voltage level of the bridge.

2. Capacitor Commutated Converters (CCC):

An improvement in the thyristor-based Commutation, the CCC concept is characterized by the use of commutation capacitors inserted in series between the converter transformers and the thyristor valves. The commutation capacitors improve the commutation failure performance of the converters when connected to weak networks.

3. Forced Commutated Converters:

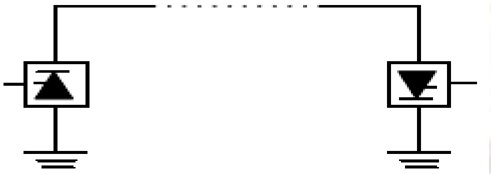
This type of converters introduces a spectrum of advantages, e.g. feed of passive networks (without generation), independent control of active and reactive power, power quality. The valves of these converters are built up it semiconductors with the ability not only to turn-on but also to turn-off. They are known as Voltage Source Converters (VSC). Two types of semiconductors are normally used in voltage source converters: the GTO (Gate Turn-Off Thyristor) or the IGBT (Insulated Gate Bipolar Transistor). Both of them have been in frequent use in industrial application, since the early eighties. The VSC commutates with high frequency (not with the net frequency). The operation of the converter is achieved by Pulse Width Modulation (PWM).With PWM it is possible to create any phase angle or amplitude (up to certain limit) by changing the PWM pattern, which can be done almost instantaneously. Thus, PWM offers the possibility to control both active and reactive power independently. This makes the PWM Voltage Source Converter a close to ideal component in the transmission network. From a transmission network viewpoint, it acts as a motor or generator without mass that can control active and reactive power almost instantaneously.

B. Configurations of HVDC:

There are different types of HVDC systems which are

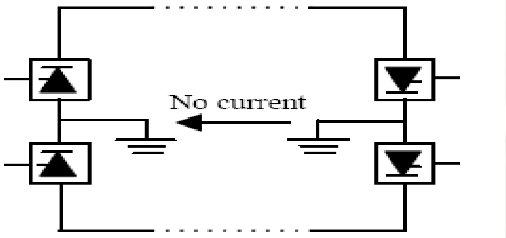
1. Mono-polar HVDC system:

In the mono-polar configuration, two converters are connected by a single pole line and a positive or a negative DC voltage is used. In Fig. There is only one Insulated transmission conductor installed and the ground or sea provides the path for the return current.



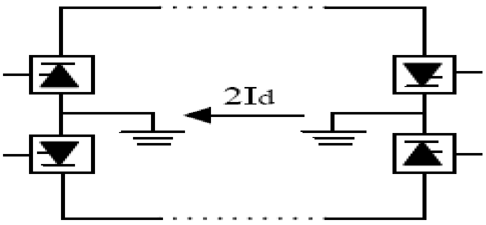
2. Bipolar HVDC system:

This is the most commonly used configuration of HVDC transmission systems. The bipolar configuration, shown in Fig. Uses two insulated conductors as Positive and negative poles. The two poles can be operated independently if both Neutrals are grounded. The bipolar configuration increases the power transfer capacity. Under normal operation, the currents flowing in both poles are identical and there is no ground current. In case of failure of one pole power transmission can continue in the other pole which increases the reliability. Most overhead line HVDC transmission systems use the bipolar configuration.

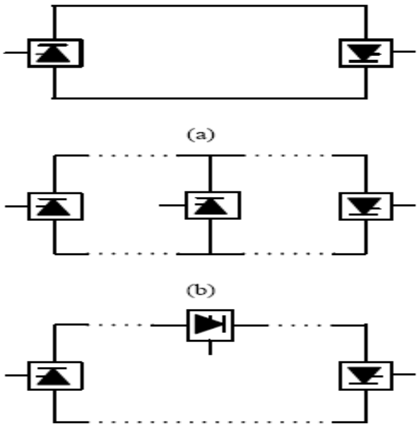


3. Homo-polar HVDC system:

In the homo polar configuration, shown in Fig. Two or more conductors have the negative polarity and can be operated with ground or a metallic return. With two Poles operated in parallel, the homo polar configuration reduces the insulation costs. However, the large earth return current is the major disadvantage.



4. Multi-terminal HVDC system:



In the multi terminal configuration, three or more HVDC converter stations are geographically separated and interconnected through transmission lines or cables. The System can be either parallel, where all converter stations are connected to the same voltage as shown in Fig(b). or series multiterminal system, where one or more converter stations are connected in series in one or both poles as shown in Fig. (c). A hybrid multiterminal system contains a combination of parallel and series connections of converter stations.

C. DC transmission control:

The current flowing in the DC transmission line shown in Figure below is determined by the DC voltage difference between station A and station B. Using the notation shown in the figure, 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

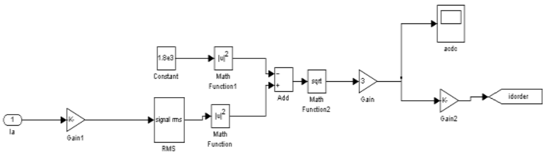
$$p_d = u_{dB} \cdot i_d = u_{dB} \cdot \frac{u_{dA} - u_{dB}}{r_d}$$

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 decrease 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 αmin to be able to control the current.

D. Master control system:

The master control, however, is usually system specific and individually designed. Depending on the requirements of the transmission, the control can be designed for constant current or constant power transmitted, or it can be designed to help stabilizing the frequency in one of the AC networks by varying the amount of active power transmitted. The control systems are normally identical in both converter systems in a transmission, but the master control is only active in the station selected to act as the master station, which controls the current command. The calculated current command is transmitted by a communication system to the slave converter station, where the pre-designed current margin is added if the slave is to act as rectifier, subtracted if it is to act as inverter. In order to synchronize the two converters and assure that they operate with same current command, a tele-communications channel is required.

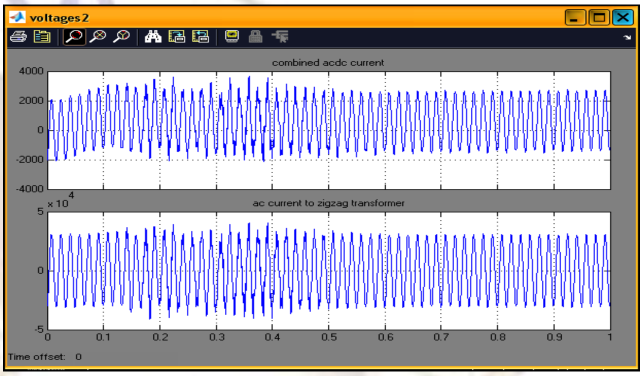


Should the telecommunications system fail for any reason, the current commands to both converters are frozen, thus allowing the transmission to stay in operation. The requirements for the telecommunications system are especially high if the transmission is required to have a fast control of the transmitted power, and the time delay in processing and transmitting these signals will influence the dynamics of the total control system.

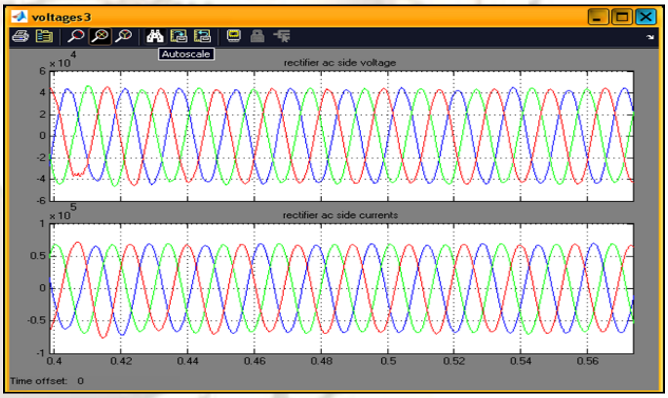
V. SIMULATION RESULTS

The performance of the proposed control system was evaluated with a detailed simulation model using the MATLAB/Simulink, SimPowerSystems to represent the master control, transformers, sources and transmission lines, and Simulink blocks to simulate the control system.

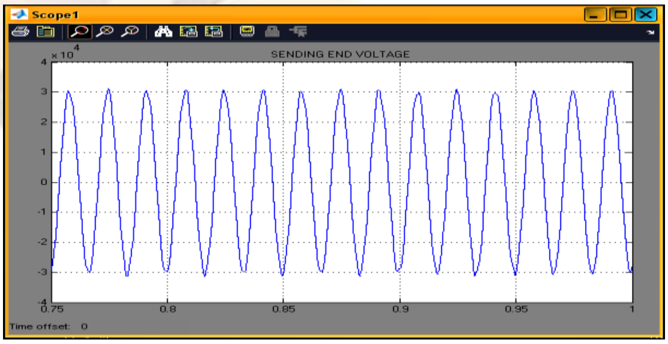
Combined ac dc current and ac current in zigzag transformer:-



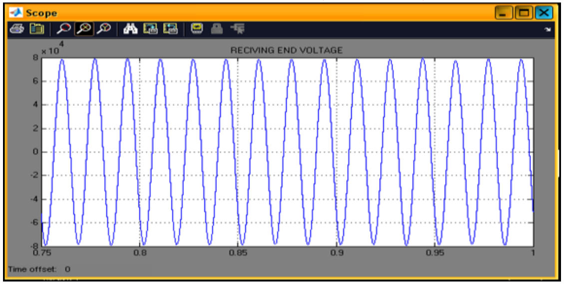
Rectifier ac voltage and current:-



Sending end voltage:-



Receiving end voltage:-



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 load ability 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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