Improvement of Power Transfer Capacity by Injecting DC Power into AC Line with the Help of Zigzag Transformer

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Abstract: -Due to increasing power demand there are huge requirements for construction of new transmission lines. But ROW (Right of Way) problems are hindering the erection of transmission lines. So instead of erecting new lines the existing AC lines are modified to simultaneous AC-DC lines to increase their power transfer capability close to their thermal limits. This thesis presents the method to convert an existing double circuit EHVAC line into a simultaneous AC-DC transmission line. A triple circuit ac transmission line is compared with a simultaneous AC-DC line. Both the systems are studied and transmission angle of double circuit line is varied up to 800 which is generally not possible for a pure ac line. Sending end power, receiving end power and transmission losses of both the systems are found out. Simulation is carried out using MATLAB/SIMULINK.

Key words: - SIMULINK simulation, simultaneous ac–dc power transmission, small power tapping.

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 [1]–[4]. 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.

The authors of this paper have earlier shown that extra high voltage (EHV) ac line may be loaded to a very high level by using it for simultaneous ac–dc power transmission as reported in references [5] and [6]. The basic proof justifying the simultaneous ac–dc power transmission is explained in reference [6]. In the above references, 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. In this scheme, the dc power flow is point-to-point bipolar transmission system. Clerici et al. [7] suggested 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 creep age 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.

II. SIMULTANEOUS AC-DC TRANSMISSION

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 carries 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 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 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. Assuming the usual constant current control of rectifier and constant extinction angle control of inverter [4], [8]–[10], 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 along with the ac current per phase.

![Figure 1: Basic scheme for composite AC–DC transmission](image1)

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 creepage distance requirement for insulator discs used for HVDC lines are not required.

Each conductor is to be insulated for \(V_{\text{max}}\), but the line-to-line voltage has no dc component and \(V_{\text{LLmax}} = \sqrt{6}V_a\). 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;
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.

III. DESCRIPTION OF THE SYSTEM MODEL:

The network depicted in Fig. 1 was studied using PSCAD/EMTDC. A synchronous machine is feeding power to infinite bus via a double circuit, three-phase, 400-KV, 50-Hz, 450-Kmac 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].

Transmission lines are represented as the Bergeron model. It is based on a distributed LC parameter travelling 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 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 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 (\( \alpha \))/extinction angle (\( \gamma \)) measurements. It also includes built in RC snubber circuits for each thyristor. The controls used in dc system are those of CIGRE Benchmark [14], 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. 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.
IV. SIMULATION RESULTS

![Figure 6: (a) AC input to primary of Rectifier (b) DC output at secondary of Rectifier (c) Combined AC-DC transmission output (d) Active & Reactive power in AC-DC transmission line (e) DC input to the HV side of the Inverter (f) AC output at the LV side of the Inverter](image)

V. CONCLUSION

The feasibility to convert AC Transmission to a composite AC-DC line has been discussed. The Transmission line is loaded to its Thermal limit with the superimposed DC current through Zigzag transformer. Master current controller senses AC current and regulates the DC current order for converter online such that conductor current never exceeds its thermal limit. The DC power flow does not impose any stability problem. The advantage of parallel AC-DC Transmission is obtained injecting DC Power with AC Power. DC current regulator may modulate AC power flow. There is no need for any modification in the size of conductors, insulators strings, and towers structure of the original line.

REFERENCES