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Composite AC–DC Power Transmission Lines

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Abstract—It is difficult to load long extra high voltage (EHV) ac lines to their thermal limits as a sufficient margin is kept against transient instability. With the model proposed in this paper, it will be possible to load these lines close to their thermal limits. The transmission lines are allowed to carry usual ac along with dc superimposed on it. The added dc power flow does not cause any instability. This thesis gives us 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 in order to improve stability and dampen out oscillations. The advantage of parallel ac-dc transmission for improvement of transient stability and dynamic stability and dampout oscillations has been established. Simulation has been carried out in MATLAB software package (Simulink Model). The results show the stability of power system

Keywords—*EHV(Extra High Voltage , HVDC (high voltage DC transmisssion, PU(per unit), ROW(Right of Way),CB(circuit breaker),FACTS*

I. INTRODUCTION

In recent years, environmental, right-of-way (Row), and economic concerns have delayed the construction of a new transmission line. The demand of electric power has shown steady growth but geographically it is quite uneven. The power is often not available at the growing load centres but at remote locations. Often the regulatory policies, environmental acceptability, and the economic concerns involving the availability of energy are the factors determining these locations. Now due to stability considerations, the transmission of the available energy through the existing ac lines has an upper limit. Thus, it is difficult to load long extra high voltage (EHV) ac lines to their thermal limits as a sufficient margin is kept against transient instability. The present situation demands for the fact that there is full utilization of available energy applying the new concepts to the traditional power transmission theory keeping in view the system availability and security.

The flexible ac transmission system (FACTS) concepts is based on the application of power electronic technology to the existing ac transmission system, this improves stability to achieve power transmission close to its thermal limit. Simultaneous ac–dc power transmission was earlier proposed through a single circuit ac transmission line i.e. uni-polar dc link with ground as return path was used. The limitations of ground as return path is due to the fact that the use of ground may corrode any metallic material if it comes in its path. The instantaneous value of each conductor voltage with respect to ground 3 becomes higher due to addition of dc voltage, hence more discs have to be added in each insulator string so that it can withstand this increased voltage.

The conductor separation distance was kept constant, as the line-to-line voltage remains unchanged. This thesis gives us the feasibility of converting a double circuit ac line into composite ac–dc power transmission line.

A) High Voltage DC Transmission:

The history of electricity takes us to the first commercial electricity generated (by Thomas Alva Edison) in which direct current (DC) was used for electrical power. The very first transmission systems were also direct current systems. The drawback mainly included the fact that DC power at low voltage was difficult to be transmitted over long distances, hence giving rise to extra high voltage (EHV lines) carrying alternating current. With the development of high voltage rating valves, it was possible to transmit DC power at very high voltages over long distances, known as the HVDC transmission systems. HVDC transmission system was first installed in the year 1954, (100kV, 20MW DC link) between Swedish mainland and the island of Gotland, since then a huge amount of HVDC transmission systems have been installed.

In the recent years concerning major issues such as environmental factors and control, HVDC transmission systems have become desirable for the following reasons:
1. Environmental benefits
2. It is more economical (cheapest solution)
3. Asynchronous ties are feasible
4. Control on the power flow
5. Sublime benefits to the transmission including stability, power quality etc.

B) Problems associated with HVDC:-

(a) Cost of converters:
The cost of installation at the Converter Stations is quite high, required at each end of a D.C. transmission link, whereas in an A.C. link only transformer stations are required
.
(b**)** Reactive power requirement:

Both in rectification and in inversion reactive power is required.

(c) Generation of harmonics:
The higher order harmonics are present due to the presence of Converters in the D.C. link which can be removed by the use of filters.

(d) Difficulty of circuit breaking:
In the case of D.C. natural zero crossing is not present, hence DC circuit breaking is difficult.

(e) High power generation difficult:
Due to the problems associated with commutation in D.C. machines, voltage and speed are limited. Comparitively, lower power can be generated with D.C.

(f) Absence of overload capacity:
Converters cannot be overload as in transformers.

II.BLOCK DIAGRAM

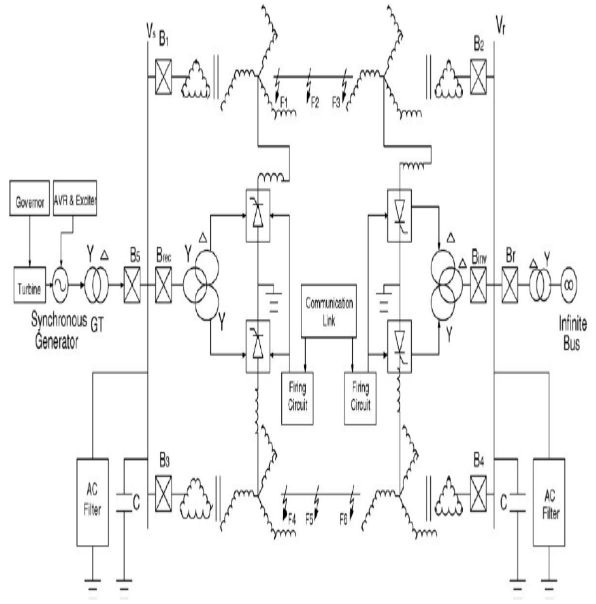


Fig 1: Block diagram of proposed system

Fig. 1 depicts the basic model for simultaneous ac-dc power flow through a dual circuit ac transmission line. Line commutated 12-pulse rectifier bridge is used in conventional HVDC and the dc power is injected to the neutral point of the zig-zag connected secondary of sending end transformer and is recovered back to ac again by the line commutated 12-pulse bridge inverter at 9 the receiving end side. The inverter bridge is also connected to the neutral of zig-zag connected winding of the receiving end transformer to recover back the dc current to the inverter. The dual circuit ac transmission line carriers both three-phase ac and dc power. Each conductor of each transmission line carries one third of the total dc current with ac current superimposed. Since the resistance is equal in all the three phases of secondary winding of zig-zag transformer and the three conductors of the line, the dc current is equally divided in all the three phases. The conductor of the second transmission line provides return path for the dc current to flow. The saturation of transformer due to dc current can be removed by using zig-zag connected winding at both ends. The fluxes produced by the dc current (Id / 3) flowing through each winding of the core of a zig-zag transformer have equal magnitude and opposite in direction and hence cancel each other. At any instant of time the net dc flux becomes zero. Thus, the dc saturation of the core is removed. A reactor Xd with higher value is used to reduce harmonics in dc current.
In the absence of third order harmonics or its multiple and zero sequence, under normal operating conditions, the ac current flow through each transmission line gets restricted between the zig-zag connected windings and the conductors of the transmission line. The presence of these components may only be able to produce negligible current through the ground due to higher value of Xd.

A) Single line diagram of power tap substation

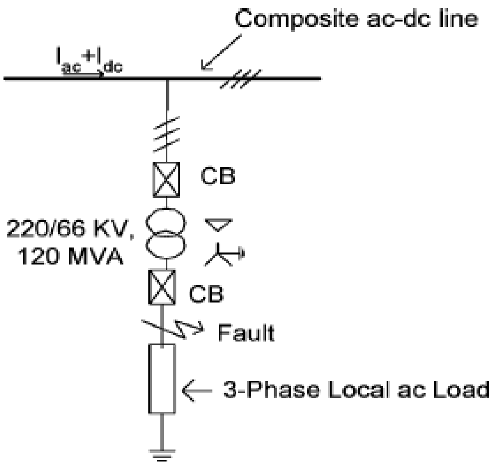


Fig 2: single line diagram of power tap substation

The tapping stations considered in this study are of fairly small power rating, up to 10% of the total transfer capacity of the composite ac-dc power transmission line. Short interruption of the power supplies should be tolerable at the occurrence of temporary earth faults on the main simultaneous ac–dc power transmission system. Further, any fault occurring within tapping station and its local ac network is to be cleared by local CBs. These tapping stations will not depend upon the telecommunication links with the main composite ac–dc transmission system.

III. SMALL POWER TAPPING STATION REQUIREMENTS

The main requirements of a small power tapping stations are as follows.

- The P.U cost of the tap must be strongly constrained (i.e., the fixed cost must be kept as low as possible).
- The tap must have a negligible impact on the reliability of the ac–dc system. This implies that any fault in the tap must not be able to shut down the full system.
- The tap controller should not interfere with the main system (i.e., the tap control system has to be strictly local). Failure to achieve this leads to a complex control system requirement and, thus, cost of hardware is high
- Small tap stations having a total rating less than 10% of the main terminal rating have potential applications where small, remote communities or industries require economic electric power.

IV. SYSTEM UNDER STUDY

The network depicted in Fig. 1(a) has been taken up for the feasibility of a small power tap for remote communities from the composite ac–dc power transmission system. The details of power tap substations are shown in Fig. 1(b). The modelling details of the network components are described in [2]. A synchronous machine is delivering power to an infinite bus via a double-circuit three-phase, 400-kV, 50-Hz, 450-km ac transmission line. The minimum value of ac phase voltage and maximum value of dc voltage with respect to ground of the converted composite ac–dc line, respectively, are 1/2 and times that of per phase voltage before conversion of the conventional pure EHV ac line [2]. The line considered is converted to a composite ac–dc transmission line with an ac rated voltage of 220 kV and a dc voltage of 320 kV. In a composite ac–dc transmission line, the dc component is obtained by converting a part of the ac through a line-commutated 12-pulse rectifier bridge similar to that used in a conventional HVDC. The dc current thus obtained is injected into the neutral point of the zig-zag-connected secondary windings of sending end transformer.

A)Equations

The chief methodology of solving the equations is by neglecting the resistive drops because of dc currents giving a set of algebraic expressions for ac voltage and current, and also for active and reactive powers in terms of A, B, C, D parameters of each line. These may be written as:

Es = AER + BIR----------------(1)
Is = CER + DIR ----------------(2)
Ps + jQs = -Es*ER*/B* + D*ES2/B* ------------(3)
PR + jQR = Es*ER/B* - A*ER2/B* ---------------(4)

If we neglect the resistive drops in the zigzag transformers and the tie lines, the dc current Id, dc power Pdr and Pdi of each rectifier and inverter may be expressed as:

Id=[Vdro Cos_ - Vdio Cos _]/[Rcr +Req - Rci] -----(5)
Pdr = Vdr*Id ------------(6)
Pdi = Vdi*Id ------------(7)

Reactive powers needed by the converters are:

Qdr = Pdr *tan_r --------(8)
Qdi = Pdi *tan_i ---------(9)
cos_r = [cos_ + cos(_ + µr)]/2 ------(10)
cos_i = [cos_ + cos(_ + µi)]/2 -------(11)

µi is the commutation angles of inverter and µr is the commutation angle of rectifier and the overall active and reactive powers at both the ends are:

Pst = Ps + Pdr and Prt = PR + Pdi -----------(12)
Qst = Qs + Qdr and Qrt = QR + Qdi ------- (13)

Transmission loss for each line is:

PL = (PS + Pdr) – (PR + Pdi) ------------------(14)

Ia is the rms ac current through the conductor at any part of the line, the rms current per conductor of the line becomes:

I = [Ia2 + (Id/3)2]1/2;

Power loss for each line = PL _ 3I2R.

The total current I in any of the conductors is offset from zero. Now by setting the net current through the conductor similar to its thermal limit(Ith):

Ith = [Ia2 + (Id/3)2]1/2 ------------(15)

Let Vp be per phase rms voltage of the initial ac line. Also Let us consider Va be the per phase voltage of the ac part of simultaneous ac-dc tie line with constant dc voltage Vd composed on it. As the insulators are unchanged, the peak voltage in the two cases must be equal. If the rated conductor current with respect to its allowable temperature increase is Ith and Ia = X * Ith; X (too less than unity) hence the dc current becomes:

Id = 3 x (sqrt (1-x2)) Ith --------(16)

The total current I in all the conductors are` asymmetrical but the two original zero-crossings in each one cycle in current wave are possessed for (Id/3Ia) <1.414. The instantaneous value of voltage of each conductor that is phase to ground voltage can be written as the dc voltage Vd with a composition of sinusoidally varying ac voltages that has rms value Eph and the peak value being:

Emax = V + 1.414 Eph

Electric field of the composite AC-DC line also consists of the field produced by the dc line feeding power and also the ac line creating a superimposed effect of electric fields. It can be easily seen that the sudden changes in electric field polarity occurs and it changes its sign twice in a single cycle if (Vd/Eph) < 1.414. Therefore, we are free from incurring

higher creepage distance for insulator discs used in HVDC lines . Each conductor has to be insulated for the maximum Emax but the fact is line to line voltage has no component of dc voltages and ELL(max) = 2.45 Eph. Therefore, we come to the conclusion that conductor to conductor separated distance is found out only by ac voltage of the line in lieu of
the total superimposed one.

Assuming Vd/Eph = k

Pdc/Pac = (Vd * Id)/(3 * Eph * Ia * cos_) = (k * sqrt(1x2))/(x* cos_) ------------(17)

Total power

Pt = Pdc + Pac = (1 + [k * sqrt (1-x2)]/(x * cos_)) * Pac ------------(18)

Detailed analysis of the filter and instrumentation networking which are required for the proposed scheme and also short current ac design for protective scheme is out the scope of present work, but preliminary analysis qualitatively presented below says that generally used techniques in HVDC/ac composite system can be adopted solely for this purpose. Different values of ac filters and dc filters are used in HVDC system and these may be connected to the delta side of the transformer and zigzag neutral respectively to filter out higher harmonics that is (n*p+1)th order and the (n*p)th order from dc and ac supplies. Moreover ,filters also may be omitted for very low values of Vd and Id. In the neutral terminals of zigzag transformer winding dc current and dc voltages can be found out by incorporating common methods that are used in HVDC system. Conventional cvts or capacitive voltage transformer as used in EHV ac lines to measure stepped down ac component of transmission line voltage. The composite ac-dc voltage in the transmission line does not trouble the working of cvts. Linear couplers that has high air-gap core may be used for measuring ac component of line current as the dc component of line current cannot saturate high air-gap cores.

B) 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

Simulation diagram and results

a) Simulation diagram of proposed system

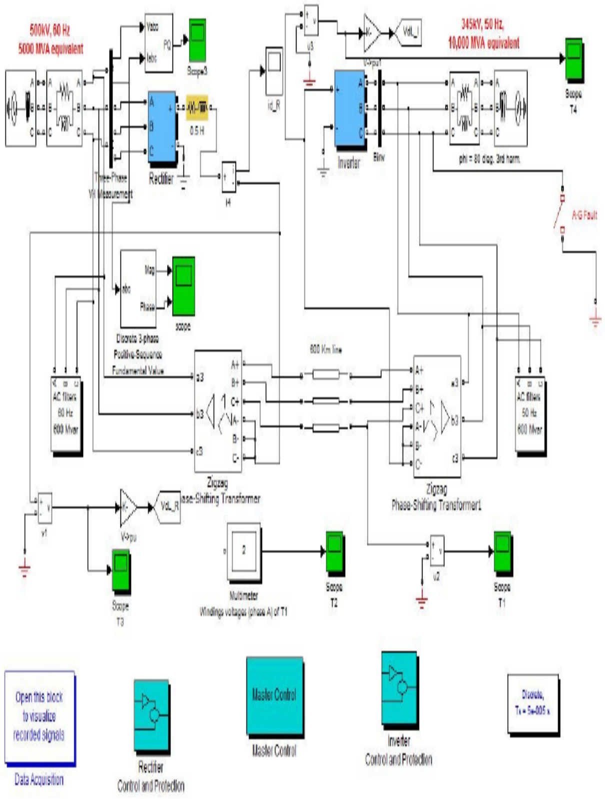
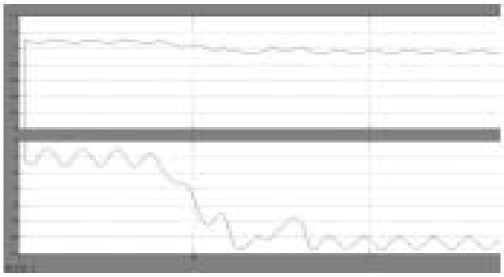


Fig 3: simulation diagram of proposed system

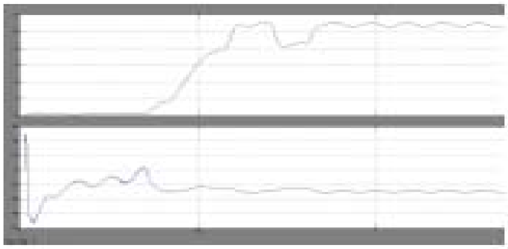
Results

Normal Response Without Fault:

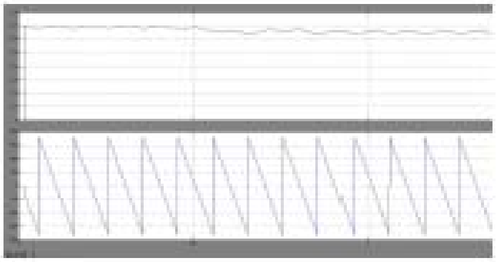
A) Sending end voltage magnitude and phase



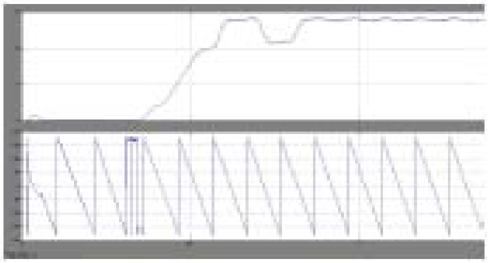
B) Sending end current magnitude and phase



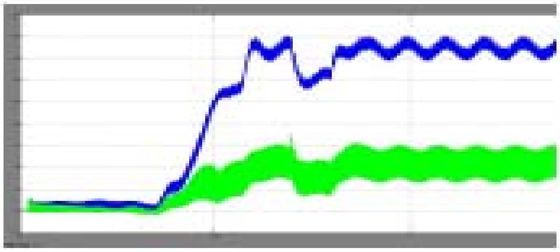
C) Receiving end voltage magnitude and phase



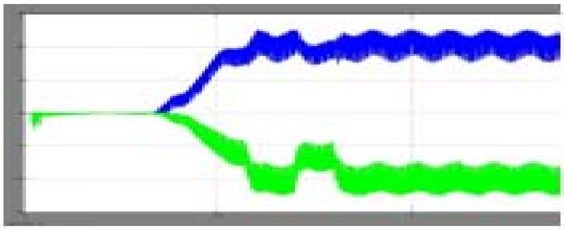
D) **Receiving end current mag. and phase**



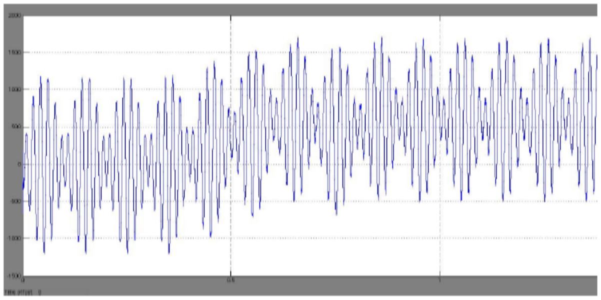
e) P,Q sending end side



F) P,Q RECEIVING END SIDE



G) Total current under no fault



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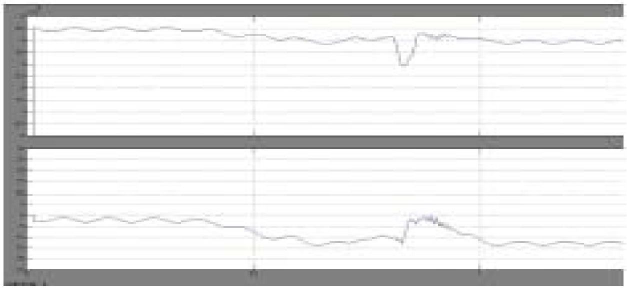
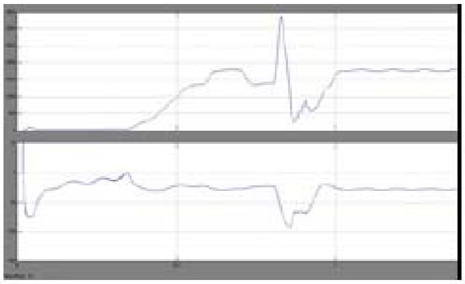
Response Under Fault:

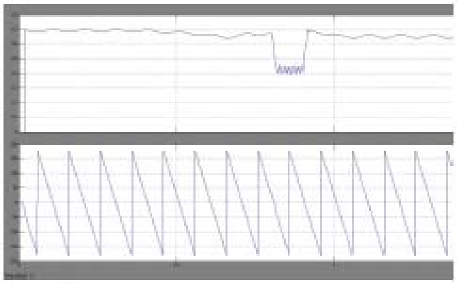
A) Sending end voltage mag. and phase



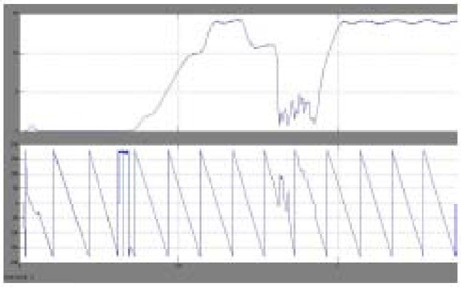
B) Sending end current mag. and phase



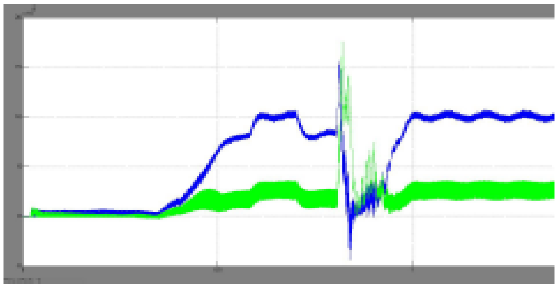
C) Receiving end voltage mag. and phase



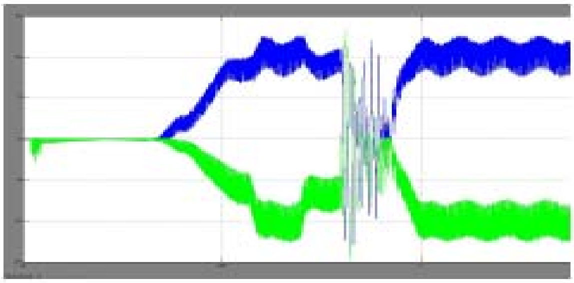
D) Receiving end current mag. and phase



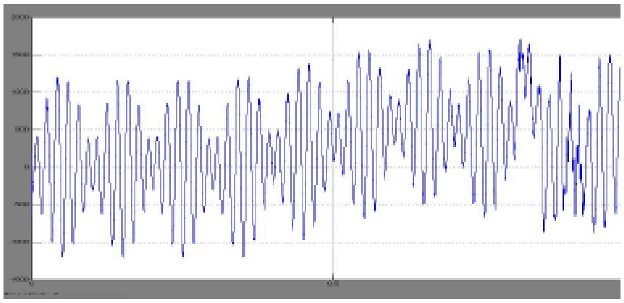
E) P,Q sending end side



E) P,Q receiving end side



F) Total current under no fault



CONCLUSION

The EHV ac lines, because of inherent transient stability problem cannot be loaded to their maximum thermal limit. With the present simultaneous ac-dc transmission it is feasible to load these tie lines close to thermal limits specified in the data sheets. Here the conductors are carrying superimposed dc current with ac current. The added dc power flow is flawless and is not the cause of any transient instability. This thesis shows the possibility of converting a dual circuit ac line into simultaneous ac-dc power transmission block to improve power transfer as well as to achieve reliability in the power transfer. Simulation studies are being made for the co-ordinated control and also individually the control of ac and dc power transmitted through the lines. There is no physical alteration in insulator strings, towers and arresters of the original line .There is substantial gain in the loading capability of the line .There is a master controller which controls the overall current that is flowing in the lines so in case of fault also the current is limited and stability is enhanced .

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