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Comparative Analysis of Voltage Stability Between AC Transmission and Hybrid AC - DC Transmission Systems

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***Abstract*— There are many transmission methods which are being used now a day. This paper deals with the two of the transmission technology, one which is being used from the early times and another one which is a recent invention. In this thesis comparative study will be done between AC transmission system and simultaneous AC- DC transmission system based on the voltage stability in both the systems. Simulations will be carried out for both the systems and results of both the models will be taken and compared to reach the conclusion. Here, double circuit transmission system will be used for both AC and simultaneous AC-DC systems. The simulations will be carried out for the EHV transmission of the power. MATLAB/SIMULINK will be used for the modeling and simulation of both the systems.**

***Key words*—Reactive power,equipment,economy. EHV, hybrid**

I. INTRODUCTION

The need of power system is to generate power from sending end to the load center of the system, as we know that the load demand has been increasing vigorously specially in the developing countries of the different parts of the world, therefore to meet this load demand we have to develop the power system accordingly and have to find the new ways to meet the demand and provide the power with good power quality. Now a days, the supply of power i.e. reliability of the power is much needed part of the daily lives, with this the quality of power has to be maintained simultaneously. To meet this aspect of the system we have to develop over power system in order to provide reliable power of good quality and maintain the quality which is required for the optimal working of equipment used in our daily lives. Since, to meet all the aspects we are talking about here, we have to develop the power system too, which is now a days getting more complex than before. Now a days, to improve the stability of the system and to provide economic dispatch there are many new technologies coming up, as we all know to transmit power from one country to another as well as inside the country also EHV lines are used which cannot be loaded to their maximum thermal limits, Which when loaded causes voltage instability. To solve this problem there are many new methods like FACTS (Flexible AC transmission system) and HVDC which are being used in the different parts of the world.

Now a days, a new technology called as simultaneous AC-DC transmission system is coming into the picture which uses AC power as well as DC power at same time for the supply of power. In this method double circuit AC lines are used which can be converted into AC-DC lines without any major change in the infra structures.

II. TRANSMISSION SYSTEMS

Since, transmission is being done using many different processes which are already existing in all the power system which is being used till date. So, below are some of the different transmission system which are being used in present era.

HVDC Ttransmission Systems:

HVDC i.e. High Voltage Direct Current transmission systems uses DC power for the transmission of extra high voltage long distance transmission. DC was used earlier for the low voltage applications but after the introduction of new DC valves high voltage transmission is also possible now. It is cheaper and more reliable than AC transmission when compared for long distance transmission. But, in case of short distance transmission system AC systems are only preferred till now because of the extra equipment which are added in the DC transmission system increase the cost of the power system. Rectifiers and inverters are needed in this system to convert AC into DC in the sending end and again from DC to AC at the receiving end of the power system. This small conversion and elements used for it may increase the cost of the power system for the short distance transmission of the power. But, in long distance transmission it becomes cheaper as compared to AC transmission system. Since, less no. of conductors are used in it and also the circuits are better and cheaper for DC systems.

In HVDC links the power flow of the system can be controlled without considering the phase angle between source and the load, so there is much possibility that it can provide better stability against the disturbances which occurs due to the sudden and rapid fluctuations in the power. HVDC links are also used to transfer the power between two incompatible networks by allowing transfer of power between two grids which are running on different frequencies such as 50 Hz and 60 Hz. This particular property of the HVDC system helps in improving the stability and economy of each grid which is connected to each other through this HVDC link. As, said above in the paragraph the low voltage transmission for long distance in DC system is inefficient thus, AC systems are used there but again because of the use of DC valves this particular problem is solved in the DC systems and now it can be used for both high voltage as well as low voltage power supply in the system. In 1954, the first commercial form of the HVDC was installed and after that it is being used by many countries in the different parts of the world. HVDC systems are also employed in some parts of our country for long distance transmission.

HVAC Transmission systems:

HVAC transmission system is being used from very early times of the electrical power. As we know that there are many different industries and domestic areas too which needs the electric power. In order to cope up with the increasing demand of the era high voltage supply became the necessity for setting up the equilibrium between demand and the supply part. But as we all know, HVAC transmission lines cannot be loaded to their thermal limits, it will not cope up with the supply and instability occurs in the voltage. There are certain disadvantages of this system or can be said as the problems which encounters while using the HVAC system for the transmission of electrical power they are as follows [4] :

- There is increment in current density due to increase in the loading of the line using series capacitor.
- In this system group of conductors are used which are bundled.
- In AC systems conductor carries high surface voltage gradient over it.
- There are Corona problems occurring in the system resulting in audible noise.
- Interference occurs in AC systems which effects the television screens.
- Under the conductor lines, there is a high volume of electrostatic field.
- There are switching over voltages in AC systems which causes more problems than lightning over voltages.
- In AC transmission, Ferro resonance also occurs in the system in which impedance behaves like resistance.
- Compensation done in the AC transmission system induces sub synchronous resonance.

Simultaneous AC-DC Transmission:

Simultaneous AC-DC transmission system uses AC as well as DC power at a time to supply power from sending end to the receiving end. In this system each conductor of line carries AC power with the DC power super imposed over it. The DC power which is added externally do not make any clutter or interference in the power supply. This particular transmission technology uses double circuit transmission lines could be AC lines only which is modified to some level to accommodate DC power in it with the AC going along. The dual circuit AC transmission lines are used in long distance transmission for inter country as well as intra country transmission of the power for better stability then the single circuit transmission lines which are normally used for transmission purpose. In this transmission system AC and DC both run parallel in all the three phases. DC is injected into each phase of the transmission lines. As we know, the power generated at the station remain AC has to be converted into DC for the supply of the simultaneous power. There is a converter or a rectifier used to convert the AC supply into DC and then the DC is injected into the system. The rectifier bridge is connected to the neutral of the zigzag transformer which is at the sending end. The DC power which is injected is equally divided among all the three phases of the transmission network. This DC power is again re-converted or say inverted by the help of an inverter bridge, which is connected to the neutral of the zigzag transformer connected at the receiving end of the power system. All the transmission lines used are connected in between the zigzag transformer. This transmission technique uses double circuit transmission line in which both the power AC as well as DC can be supplied at a time. Since, DC power flows into the transformer; zigzag winding connection for secondary is used to avoid the saturation of the core of the transformer.

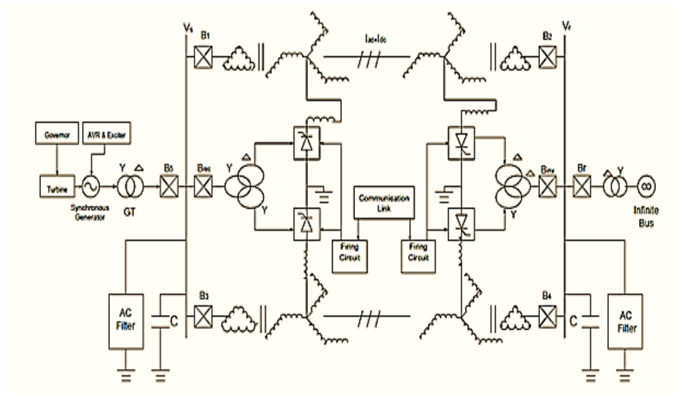

Fig 1 Basic scheme for simultaneous AC-DC transmission

III SIMULTANEOUS AC-DC TRANSMISSION

In the simultaneous AC-DC transmission AC and DC at same time are used to supply the power from sending end to the receiving end. Simultaneous AC-DC means AC as well as dc at one particular time is supplied in the double circuit line. It uses dual circuit line in which AC as well as DC is supplied at the same time which helps in loading the long distance extra high voltage line to its thermal limit without any voltage instability.In fig 1, there is basic diagram of simultaneous AC- DC transmission. For DC power, first of all AC power is converted into DC by using

12 pulse rectifier bridge which is connected to the neutral of the zigzag transformer at the sending end of the power system and then it is divided equally among the three phases of the transmission line i.e. in each line there is $I_d/3$ DC available which run along with the AC power. Now, after the distribution and transmission of DC, there again it has to be reconverted or inverted using 12 pulse inverter which is connected to the neutral of the zigzag transformer which is at the receiving end of the power system.

As it is said, earlier in above paragraph that inverter is connected to the neutral of zig-zag transformer to recover the AC voltage at the receiving end of the system. The transmission line used in this technique is dual circuit transmission line in which there is simultaneous AC and DC power supply. As we know, there are three conductors used in the transmission each conductor carries one third of the DC current with the AC superimposed over it. In all the three phases of secondary winding of zig-zag transformer, the resistances are equal and same is in all the three conductors of the line which are being used here, that is the reason that DC is divided equally in all the here phases of the transmission system. For the return path of the DC current the another line of the conductor is used. As, we know that at each conductor DC ($i_{d/3}$) flows and with return path of DC in the zigzag transformer because of equal and opposite direction, the net DC flux becomes zero. So, the saturation of the core due to the DC power is removed when the DC net flux becomes equal to zero. $X_d$is used as reactor of higher value lessen the harmonic induced in DC current. DC harmonics can be removed using this method.

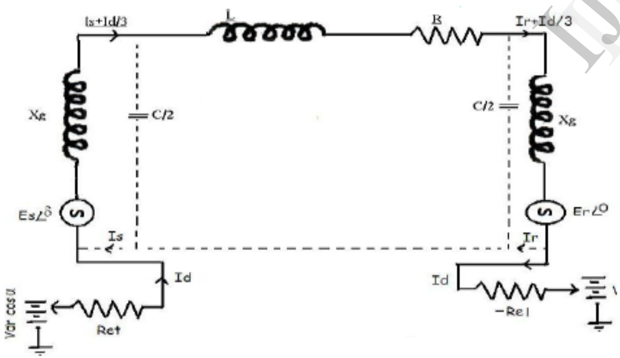

Fig 2: Equivalent circuit of single phase AC-DC transmission

Let us assume that the rectifier's current control to be remain as constant and inverter's extinction angle control be also as constant. Under normal operating conditions the equivalent circuit can be shown as Fig.2.1. Return path of the AC current only can be shown by the dotted lines in the figure. [5]The DC power carried by each conductor of the line will be (Id / 3) along with the AC current per phase and the maximum values of rectifier and inverter side DC voltages can be given by E_{dro} and E_{dio} respectively. Line parameters in each phase of each line are R, L and C. R_{cr} and $R_{ci}$are the resistances which are commutating resistances and α is the firing angle and γ is the extinction angles of rectifier and inverter. The ground only carries the full DC current and all the other conductor have only Id/3 along with the AC super imposed on it. The AC voltage and current and the power equations in terms of A, B, C and D parameters of each line can be given as, when there is resistive drop in transformer winding and in the line conductors due to DC current are neglected. The expression can be given as[5]:

Sending end voltage:

$$Es = AE_R + BI_R \quad (2.1)$$

Sending end current:

$$Is = CE_R + DI_R \quad (2.2)$$

Sending end power:

$$P_s + jQ_S = (- E_S \text{ X } E_R)/B + (D \text{ X } Es^2/B) \quad (2.3)$$

Receiving end power:

$$P_R + jQ_R = (E_S \text{ X } E_R)/B - (A \text{ X } E_R^2/B) \quad (2.4)$$

Now, the expressions for DC current and the DC power can be given as shown below, when the ac resistive drop in the line and transformer are neglected then,

Dc current:

$$I_d = (E_{dr}\cos\alpha - E_{di}\cos\gamma)/(R_{er} + (R/3) - R_{ci}) \quad (2.5)$$

Power in inverter:

$$P_{di} = E_{di} \text{ x } I_d \quad (2.6)$$

Power in rectifier:

$$P_{dr} = E_{dr} \text{ x } I_d \quad (2.7)$$

Where,

R = line resistance per conductor.

R_{cr} and R_{ci} = commutating resistances.

α and γ = firing and extinction angles of rectifier and inverter respectively.

V_{dr} and V_{di}= maximum dc voltages of rectifier and inverter side respectively.

Values of E_{dr} and E_{di} are 1.35 times line to line tertiary winding AC voltages of respective sides.

Reactive power required by the converters are:

$$Q_{di} = P_{di}\tan\theta I \quad (2.8)$$

$$Q_{dr} = P_{dr}\tan\theta r \quad (2.9)$$

$$\text{Cos}\theta I = (\cos\gamma + \cos(\gamma + \mu i))/2 \quad (2.10)$$

$$\text{Cos}\theta r = (\cos\alpha + \cos(\alpha + \mu r))/2 \quad (2.11)$$

Where, μI and μr 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 $P_{rt} = P_R + P_{di}$ (2.12)

$Q_{st} = Q_s + Q_{dr}$ and $Q_{rt} = Q_R + Q_{di}$ (2.13)

Total transmission line loss is:

$P_L = (P_s + P_{dr}) - (P_R + P_{di})$ (2.14)

Ia being the rms AC current per conductor at any point of the line, total rms current per conductor in 3 phase becomes :

$I = \sqrt{(Ia2 + (Id/3)2)}$ and $P_L = 3I^2R$ (2.15)

If the rated conductor current corresponds to its allowable temperature rise is I_{th} and

$I_a = X\ xI_{th}$; X being less than one, the DC current gets to:

$I_d = 3\ x\ (\sqrt{(1 - x2)})\ I_{th}$ (2.16)

The total current I in any conductor is asymmetrical but two natural zero-crossings in each cycle in current wave are obtained for (Id/3Ia) <1.414.

The instant value of each conductor voltage with respect to ground becomes the DC voltage $V_d$with a superimposed sinusoidally varying AC voltages having rms value E_{ph} and the peak value being:

$E_{max} = V + 1.414\ Eph$

Electric field produced by any conductor voltage have a DC component which is superimposed with varying AC component. Though, the electric field polarity changes its sign twice in cycle if (V_d/E_{ph}) <1.414. So, higher creep age distance requirement for insulator discs used for HVDC lines are not required in this system. Each conductor is to be insulated for maximum voltage (E_{max}) but the line to line voltage has no DC component and ELL(max) = 2.45 E_{ph}. Therefore, separation between two conductor distance is determined only by rated AC voltage of the line.

Let,

$V_d/E_{ph} = k$

$P_{dc}/P_{ac}\ (V_d * I_d)/(3* E_{ph}*Ia*cosT) = (k *\sqrt{(1 - x2)})/(x*cosT)$ (2.17)

Total power can be given by

$P_t = P_{dc} + P_{ac} = (1+ [k\ x\sqrt{(1 - x2)}]/(x * cosT)) * P_{ac}$ (2.18)

SCRs blocks the fault current and the damaged caused by the faults in case if any fault occurs in the system and also when the fault clears this SCRs are released after the successful work of protecting the system. Circuit breakers are then tripped at both ends to isolate the complete system and is mentioned earlier, if (I_d 3I_a) <1.414 [5], no other special circuit breakers for DC is required. The circuit breakers which are used at both the ends of transmission line will ensure to operate at zero current. The security of transmission lines can be ensured by giving proper tripping signals to the circuit breakers which is given when the current signal crosses zero which is determined by the zero crossing detector. Else, circuit breakers which are connected to the other side of transformer may be used to protect the system from faults [5].

IV SIMULATION

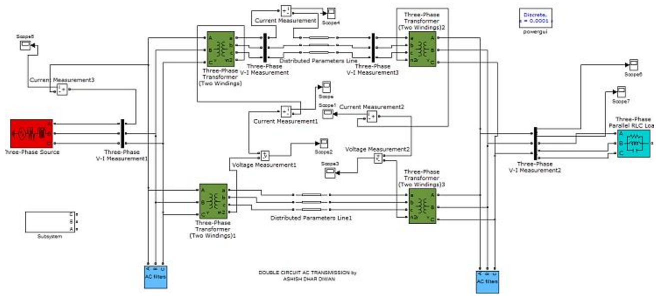

Fig 3: Simulation model of Double circuit AC Transmission system

All the simulation and modeling process has been done by using SIMULINK package in MATLAB. The above figure shown is the Simulink model of double circuit AC transmission line which is used for the comparison with the double circuit AC-DC transmission which is again modeled again in the Simulink and results are taken and compared between both the models shown. Results are taken and compared in the various points, which will be helpful in finding the level of voltage stability in both the systems shown here in Fig 3 Fig 4.

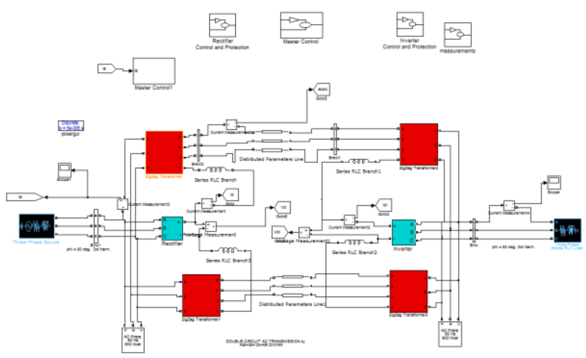

Fig 4: Simulation model of Double Circuit Hybrid AC-DC transmission system

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V RESULTS

Power Angle	30	45	60	75	80
P_s (MW)	2306	2371	2381.3	2342	2318.3
P_{AC}(MW)	294.89	411.0	495.3	541.86	548.83
P_{DC}(MW)	1715.5	1657.0	1585.8	1498.5	1467.0
P_{AC} _loss(MW)	11.94	30.30	54.08	81.94	91.73
P_{DC}_loss(MW)	280.51	265.88	241.17	217.61	208.53
P_{loss}_total(MW)	292.45	296.18	295.25	299.55	300.26
P_r(MW) Total Transfer	1988.8	2051.14	2062.0	2019.3 6	1995.0 8
Q_s_line(MVAR)	-13.78	69.98	185.58	325.12	375.35
Q_r_line(MVAR)	39.08	146.84	280.85	431.96	484.38
Q_{rec}(MVAR)	883.6	884.36	885.29	878.1	869.48
AC current I_a(kA)	0.4157 7	0.61123	0.79684	0.9695 2	1.0238 3
DC current I_d(kA)	5.2426 3	5.1136	4.91185	4.6355	4.5251 2
Conductor current (kA)	1.7858 7	71.7826 4	1.78281	1.7864 1	1.7883 3
Increase in power transfer	76.94 %	82.49%	83.451 %	79.66%	77.5%

Table 1 Simulated results with AC-DC transmission system

After the simulation of both the transmission system the simulated results of the different aspects of power, current and power transfer has been found out which is shown in the above Table 1 and easily we can see the increment in the power transfer capabilities of the AC systems after converting it to AC-DC systems. Following are the different wave shapes which are taken after the simulation. These wave forms are taken from the Simulink diagram shown in fig 4 i.e. simulation model of hybrid AC-DC transmission system.

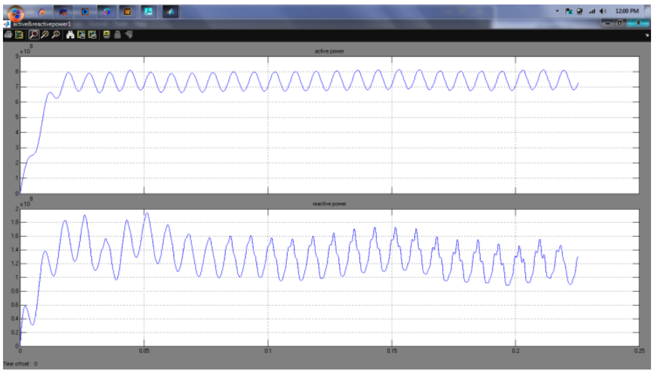

Fig 5: Active and Reactive power

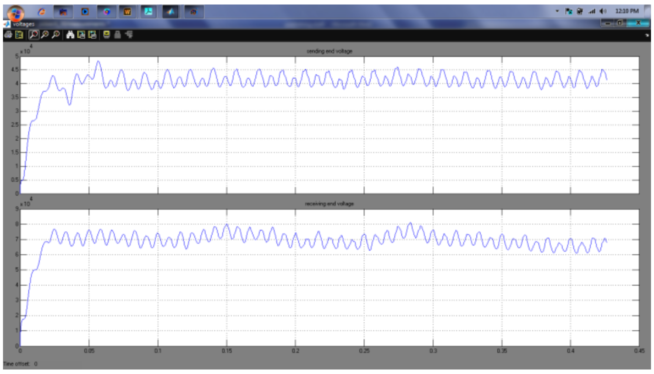

Fig 6: Sending and receiving end voltages

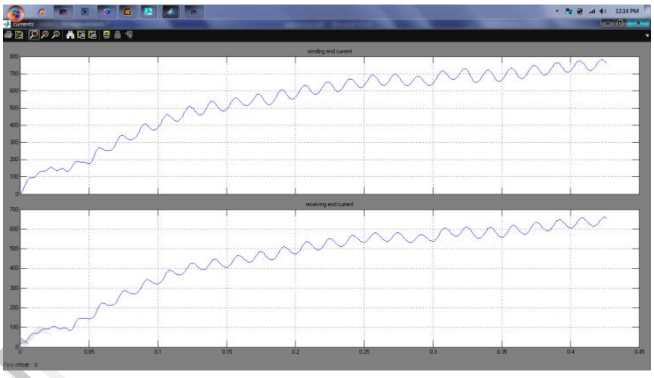

Fig 7: Sending and receiving end currents

Fig 8: AC current

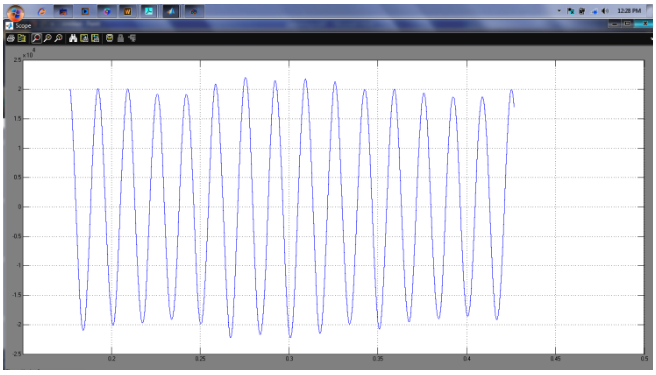

Fig 8: Combined AC-DC current

VI CONCLUSION

In the above discussion, we have seen the difference in the AC and AC-DC transmission systems. There is substantial increase in the power transfer capabilities of the line and the stability issues in AC-DC system as compared to AC transmission systems. As new can see in the table 1 when the different values which varies as the power angle changes and there is 80% of the increase in power transfer capabilities of the line in the simultaneous AC-DC transmission system. The stability aspects up to 80^0power angle have been reported in reference [12]. Now, it is better to use hybrid AD-DC transmission rather than AC transmission because of the benefits mentioned above in the paper. Since there is no huge amount of extra cost is required for changing the existing AC networks to AC-DC networks.No modification is required in the size of conductors, insulator strings and towers structure of the original line[12].

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