Methods, Merits and Demerits of Improving Power Transfer Capability Based on Voltage and Surge Impedance

Gaddam Siva[1], Priyanka Rani[2], Anubhav Tiwari[3], Aditya Gaddam[4]
[1,2,3,4] (Electrical Department, Lovely Professional University, India)

Abstract: **The power delivered to the load is majorly dependent on two factors namely surge impedance and receiving end voltage. The receiving end voltage is dependent on the geometrical spacing between the conductors (lines). So, by employing a suitable method to decrease the surge impedance we can transmit maximum power from sending end to receiving end in the line. However there are certain limitations in reducing the surge impedance much. This paper presents a detailed analysis of increasing the power delivered to a line by decreasing the surge impedance of the line. This paper also presents the various factors which acts as limitations for reducing the surge impedance to a very low value.**

Keywords- Open circuit, SSSC, short circuit, STATCOM, surge impedance, surge impedance loading, UPFC

I. INTRODUCTION

To fulfill our needs we need a certain form of energy and universally we adopted electrical energy to satisfy our needs. For this purpose any form of energy which cannot be used by us directly is converted into electrical energy. The electrical energy is being generated, transmitted and then distributed to the users through service mains. These are respectively called as generation transmission and distribution. Losses occurs in each and every stage since every part or subsystem or whole system takes itself or stores in itself for the continuous operation of it. So energy is being wasted everywhere. Any how these losses cannot be reduced or prevented completely. This paper deals with the procedures or possibilities how we can increase the power transfer capability by alternate methods which reduces these losses to a maximum extent how much can be possible. The power transmitted is directly proportional to the square of the voltage and inversely proportional to the surge impedance of the line. By increasing the receiving end voltage the power transmitted can be increased. By decreasing the surge impedance of the line also we can increase the power than can be transmitted. In this paper the methods of improving the voltage and decreasing the surge impedance are explained so that the power that can be transmitted can be increased to a maximum value. Basic models of design of such systems are also given in this paper.

II. POWER TRANSMITTED

The power that can be transmitted from the sending end to the receiving end is given by the equation

$$P = V^2/Z_0 \qquad (1)$$

Where the receiving end voltage is given by V

Surge impedance is given by Z_0

If the value of V is increased the power P is increased according to the equation (1)

Similarly if the value of the surge impedance Z_0 is decreased the power P is increased according to the equation (1)

2.1 Voltage considerations

The value of voltage depends not only on distance between lines but also on certain factors which are given below

1) Thermal loading of the line
2) Melting and boiling points of the conductor materials used
3) The maximum stress that the insulation can withstand
4) The chemical properties of the material used
5) Saturation effect of the material used as a conductor in the line and so on.

Though there are these many limitations in increasing the voltage of the line, this method can be implemented up to certain extent. The table given below gives a brief idea about the limits of the voltage employed in the line.

Table1. Transmission line voltages according to the distances employed

The distance of the line (kms)	The voltage level that can be used (kv)
15 – 30	11
30 – 60	33
60 – 100	66
100 – 200	132
200 – 300	220
300 – 400	40

2.2 Surge impedance considerations

By increasing the surge impedance of the line also power can be increased. Surge impedance is the impedance of the line where the resistance of the line is zero. Though this is practically not possible to reduce the resistance to zero, but the value of the resistance can be reduced to a much lower value.

In a transmission line there is magnetic field as well as electric field according to the postulate that where ever there is a magnetic field there is an electric filed and vice versa. So in our electric supply system there is capacitance as well as inductance effect due to the presence of both magnetic and electric fields. So the line needs some internal energy for both the electric field as well as the magnetic field. These are nothing but the losses in both the magnetic as well as electric fields (capacitor losses and inductor losses). Where ever there will be capacitance effect there will be capacitive reactance and similarly there exists inductive reactance due to inductive effect. By using some suitable method, if the effects of both the inductive reactance and the capacitance are made equal then as a result both are out of phase components, the net reactance becomes zero. In such a situation the resistance of the line becomes zero for a lossless line which is practically impossible. But theoretically for a line of much less losses the surge impedance will be minimum which makes the power transmitted to be maximum.

The surge impedance of the line depends on the reactive powers flowing through the lines. If the reactive power of the line can be made zero (theoretically, practically to a very less value) then the line will have almost zero reactive power component which makes the reactive components of the impedance zero and thus maximum power can be possible. For this firstly the impedance of the line is calculated.

$$Z_0 = \sqrt{(Z/Y)} \quad (2)$$

$$Z = R + j X \quad (3)$$

$$Y = G + j B \quad (4)$$

Where R is the series resistance of the line

X is the series impedance of the line

G is the shunt conductance of the line

B is the susceptance of the line

Z is the series impedance of the line and

Y is the shunt admittance of the line

As both the shunt impedance and series resistance are very much less compared to their respective capacitances and impedances these values can be neglected. Then the equations (3) and (4) will be reduced as below

$$Z = j X \quad (5)$$

$$Y = j B \quad (6)$$

Now substituting equations (5) and (6) in equation number (2) we get impedance value as

$$Z_0 = \sqrt{L/C} \quad (7)$$

This equation number (7) denoting the value of impedance is called as the surge impedance of the line where the equation number (2) is actually called as characteristic impedance of the line. By observing equations (2) and (7) it can be justified that the surge impedance is the characteristic impedance of a lossless line.

2.2.1 Calculation of the surge impedance

Consider a two port network as our power system. Then the equations are

$$V_S = A V_R + B I_R \quad (8)$$

$$I_S = C V_R + D I_R \quad (9)$$

Surge impedance of the line can be calculated using the following observations

1) Keep the receiving end terminals open circuited and
2) Keep the receiving end terminals short circuited

Under open circuit conditions the current at the receiving end terminals will be zero and the sending end voltage and currents in equations (8) and (9) will be reduced to equations (10) and (11) as

$$V_S = A\,V_R \quad (10)$$

$$I_S = C\,V_R \quad (11)$$

Under short circuit conditions the receiving end voltage will be zero and the sending voltages in equations (8) and (9) will be reduced to equations (12) and (13) as

$$V_S = B\,I_R \quad (12)$$

$$I_S = D\,I_R \quad (13)$$

Now from the open circuit case the impedance will be given as

$$Z_{OC} = (V_S / I_S) = (A\,V_R / C\,V_R) = A / C \quad (14)$$

From the short circuit test case the impedance will be given as

$$Z_{SC} = (V_S / I_S) = (B\,I_R / D\,I_R) = B / D \quad (15)$$

Multiplying equations (13) and (14) we get

$$(Z_{OC})\,(Z_{SC}) = (A / C)\,(B / D) = B / D \quad (16)$$

Since for a bilateral network $D = A$

By substituting the values of the parameters B and D in equation (16) we get the final expression for the surge impedance substituting

$B = \sqrt{X/Y}\ \sin h \sqrt{YZ}$ and $C = \sqrt{Y/Z}\ \sin h \sqrt{YZ}$

$$(Z_{OC})\,(Z_{SC}) = B / C = Z_0^2 \quad (17)$$

So the surge impedance of the line is given by the equation (18)

$$Z_0 = \sqrt{Z_{OC} Z_{SC}} \quad (18)$$

2.2.2 Surge impedance loading

The load that can be delivered from the source side to the load side under unity power factor or under the conditions of a loss free line is defined as the surge impedance loading of that line. Because of negligible resistance the power delivered to the load will be high. This can be observed with the equation given below.

$$P_R = (V_R^2 / Z_0) \quad (19)$$

The two possibilities to increase the power are either to increase the voltage value as already explained before or to decrease the surge impedance of the line. While decreasing the surge impedance of the line certain limitations should be kept in mind so that the maximum power can be achieved.

Limitations of reducing the surge impedance to a very minimum value

1) While using the series capacitors for the reduction of surge impedance the line inductance decreases and hence the phase shift also gets reduced. But under short circuit conditions a very high current passes through the series capacitance which is ten times greater than the nominal current value and this results in the damage of the capacitor.
2) While using the shunt capacitance for the reduction of the surge impedance the phase shift is increased due to the increased capacitance value. If the phase gets too much deviated the stability of the system gets disturbed.

The both the limitations can be well explained by using the following equation

$$\beta = tan^{-1} \sqrt{(X_L \pm X_C)/R} \quad (20)$$

As the value of the inductance decreases the phase shift β decreases which doesn’t effect on the stability but effects on the high starting current or transient with standing capability of the capacitor. Besides, if the value of the capacitance is increased the phase shift gets too much increased which effects on the stability on the system. So care should be taken while designing a model for the reduction of the surge impedance while employing any of the above two methods.

III. TRAVELLING WAVE THEORY

The current and voltage waves on a transmission line are related to each other with proportionality of a parameter which is called surge impedance. This means, if the value of the surge impedance in a line is maintained in such a way that there exists a suitable and preferred proportionality between current and voltage, the power transmitted can be improved. Whenever there is a discontinuity in the line then the values of currents and voltages changes due to the change in the value of the surge impedance. Due to this discontinuity in the line the waves of voltage and currents gets deviated by travelling backward (reflecting) or refracting and thus reduces the overall power at the load as the power is the product of the voltage and current. This can be explained by taking the conditions of short circuit and open circuit at the line which is at the terminating end (load end).

3.1 *Short circuit*

When there occurs a short circuit then the voltage across that terminals will be reduced to zero or the entire voltage wave gets reflected to the sending end side or imposed on the sending end voltage wave. This means the sending end wave and the reflected wave gets cancels each other and the refracted wave or the sending end voltage wave will be reduced to zero making the power transmission zero.

3.2 *Open circuit*

Similarly under open circuit conditions the current wave at the receiving end becomes zero since the current wave reflects back and cancels with the incident current wave. Thus the product of current and voltage again becomes zero.

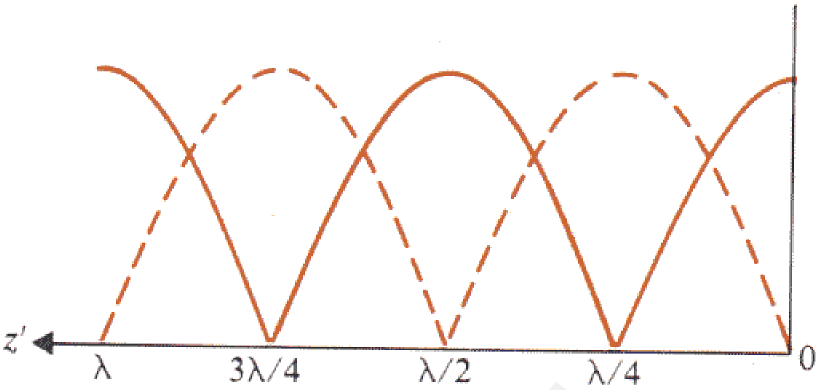

Figure1. Voltage and current waves of short circuited and open circuited lines

Dark line denotes the voltage for open circuit line and current for short circuit line. Similarly dashed line denotes current for open circuit line and voltage for short circuit line.

Now considering equation (18) it can be stated that the open circuit impedance and short circuit impedance can be reduced but not to zero value as the total power transmitted will be zero according to the travelling wave theory. This conclusion holds well not only for wave theory but also for the particle nature.

IV. METHODS OF REDUCING THE SURGE IMPEDANCE OF THE LINE

4.1 **By using the series and shunt capacitance:** the effect of using the series and shunt capacitance as merit and demerit is already explained in the former article. But still this method is used due to the simplicity. But however for better performance the later methods are used.

4.2 **By using SSSC:** static synchronous series compensator is a series device. By the use of this compensator the series impedance of a line or the open circuit impedance of a line is decreased as this is in series with the line. SSSC is a series element which is modeled as a constant voltage source inserted in between the sending end and receiving end such that a voltage value is inserted in phase with the reactive voltage component such that the reduction in the voltage causes the overall impedance of the line to be reduced.

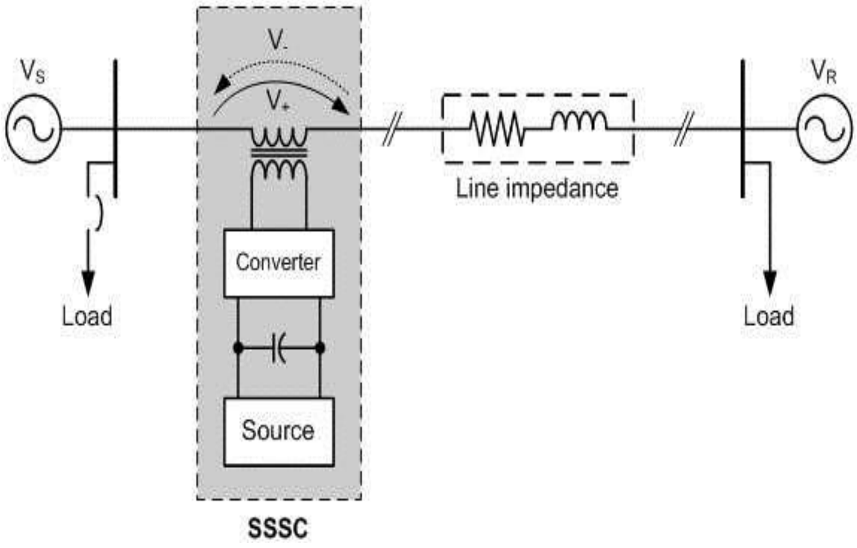

Figure2. Model of SSSC

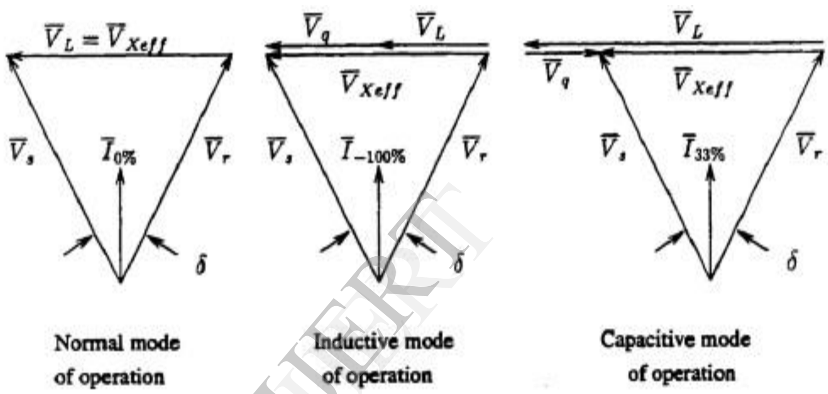

Figure3. Operating modes of SSSC

The operations can be achieved either for capacitor or inductor mode including the normal mode of operation. This means by the use of the SSSC in capacitive mode and inductive mode there will be no abnormalities or malfunctions for the normal operation.

4.3 *By using STATCOM*: STATCOM is a shunt element which is modeled as a constant current source. By using the STATCOM a current can be inducted into the system or drawn by the system. However for the improvement of power transfer by reducing surge impedance considers only the current drawing phenomena since the aim is to reduce the overall impedance of the system. By use of STATCOM a current which is in phase with the reactive current is inducted in the system such that the overall reactive current will become less. This makes the surge impedance to be reduced again.

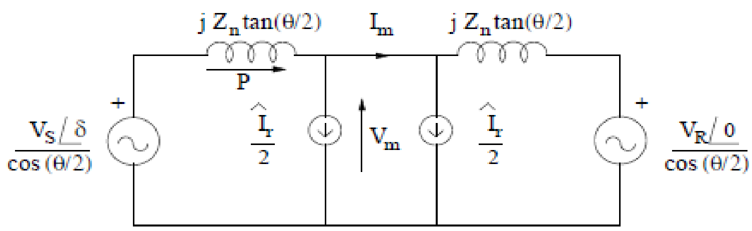

Figure4. Equivalent circuit of the line using STATCOM

By using SSSC and STATCOM either the short circuit impedance or the open circuit impedance can be reduced individually which makes it complicated because of the use of two different control techniques. To overcome this drawback UPFC is designed which is designated as unified power flow controller. In this controller both the open circuit and short circuit impedances can be reduced which reduces the overall impedance or the surge impedance of the line making the power transfer maximum.

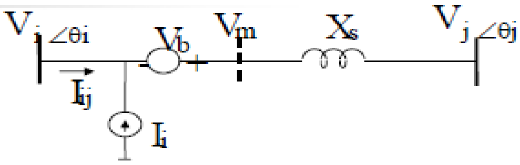

Figure5. Equivalent circuit using UPFC

In the above diagram it can be clearly understood that there are two sources namely current source and voltage source. The current source injects an out of phase or in phase component into the system such that the overall reactive current will be reduced to a possible minimum value. Similarly the voltage source induces an in phase or out of phase component of voltage such that the overall reactive component of voltage reduces to a minimum value. As both the voltage and current values in reactive components are reduced the losses in the lines gets reduced which can be otherwise stated as the surge impedance in the line is decreased.

V. CONCLUSION

There are many methods to increase the power transfer capability in a power system besides their limitations. So if a proper compromise is made between their advantages and limitations according to the case where it is going to be used or according to the investment considerations a better power system can be achieved. In some cases cost may be a major factor, there capacitors can be used. Similarly there are certain areas where the efficiency is the major goal, and then we can go for controllers like UPFC. However UPFC is a prototype and if further studies and researches are done under this area the daily needs of electricity can be possibly satisfied.

REFERENCES

1. GUO Jianbo, technical measures of transferring capability improvement in power system, PES transmission and distribution conference and exhibition, 2005, 1-4
2. R.N. Nayak, Y K Sehgal, and Subir Sen, EHV Transmission Line Capacity Enhancement through Increase in Surge Impedance Loading Level, IEEE, 2006, 1-4
3. Heinz K. Tyll, *SM, IEEE*, and Dr. Frank Schettler1, Historical overview on dynamic reactive power compensation solutions from the begin of AC power transmission towards present applications, IEEE, 2009, 1-7
4. Allen greenwood, *electrical transients in power systems* (second edition, 2010)
5. Phattarakrit Srisathian and Peerapol Jirapong, Optimal Capacitor Allocation for Power Transfer Capability and Power Loss Improvements in Power Transmission Systems Using Evolutionary Programming, The 8th Electrical Engineering/ Electronics, Computer, Telecommunications and Information Technology (ECTI) Association of Thailand - Conference 2011, 692-695
6. J.B.Gupta, *a course in power systems*(tenth edidtion, 2012)
7. K.R.Padiyar, *facts controllers in power transmission and distribution* (new age international publishers)
8. Dr.M.S.Raviprakash and Dr.K.Ramar, maximum power transfer in A.C. transmission limited by voltage stability, 766-781
9. R.D. Evans, H.K.Sels, power limitations of transmission systems, A.I.E.E