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Design and Implementation of Integrated Impedance Based Relay For Series Compensated Transmission Line

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Abstract

Distance Relays are unique devices used to protect the transmission line from various faults but, series compensation exerts influence on distance relays. Distance Relays are very sensitive to the apparent impedance seen by the relay and its zone. This paper presents a study about the installation of series compensation in the midpoint of the transmission line, and its effects on the operation of a conventional three-stepped distance relaying schemes that are used for the protection of the same transmission line. It also proposes and validates a new algorithm based on integrated impedance methodology to detect, locate and classify different types of faults in a series compensated EHV/UHV transmission line. Integrated impedance is defined as the ratio of the sum of voltage phasors across two ends of the transmission line to the sum of current phasors through two ends of the same transmission line. It is used in the identification of faults inside the protected line section.

Keywords: Series Capacitor(SC), Distance Relay, PSCAD, Integrated impedance

I. INTRODUCTION

Owing to the constraints of land availability, infrastructure and several environmental problems, it has become imperative to increase the existing power transmission capability of the contemporary power systems networks which is facing the scarcity of the power generation as compared to power demand. Flexible alternating current transmission systems (FACTS) technology opens up a new opportunity for controlling power and enhancing the usable capacity of existing lines. On the other-hand, implementation of FACT devices in existing power system produces dynamic instability into the power system. These dynamics can be; i) sudden variation in the line parameters such as impedance of the line, line current and power angle, ii) injection of harmonics and iii) Effect of transient behavior of control action into the power lines. These dynamic changes due to FACTS devices severely affect the setting of the existing protection scheme of the transmission line.

Transmission lines are used to transmit electric power to large distant load centers. These lines are exposed to faults as a result of lightning, short circuits, faulty equipments, mal-operation, human errors, overload, and aging. Many electrical faults manifest in mechanical damages, which must be repaired before returning the line to service. So the protection of the transmission line becomes essential one. The philosophy of protection is that a faulty section alone should be isolated and adjacent healthy section should not be disturbed. The protection system is expected to readily operate during faults and abnormal conditions and isolate the faulty equipment from the service, immediately. Fast detecting, isolating, locating and repairing of these faults are critical in maintaining a reliable power system operation.

There are various protection schemes employed in protection of transmission lines. Among this widely used scheme of protection is distance protection. Distance protection of a transmission line is reliable and selective form of protection for the lines where the line terminals are relatively far apart. Operation of distance relay depends on the predetermined value of voltage to current ratio and it is nothing but impedance.

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The relay will operate only when the measured impedance of the line becomes less than the set impedance. Since the impedance of a transmission line is proportional to its length, for distance measurement it is appropriate to use a relay capable of measuring the impedance of a line up to a predetermined point called as reach point of the relay.

It was always recognized that ac power transmission over long lines was primarily limited by the series reactive impedance of the line. Series capacitive compensation was introduced decades ago to reduce a portion of the reactive line impedance and thereby increase the power transmittable capacity of the line. Subsequently, within the FACTS initiative, it has been demonstrated that variable series compensation is highly effective in both controlling power flow in the line and in improving stability. Series Compensation (SC) in transmission line introduces several problems like voltage and current inversion, sub-synchronous resonance (with mechanical system), ferro-resonance (with line inductance) and reaching problems (distance measurements). SC badly affects accuracy, selectivity and reliability of mho relay which leads to an unsecure power system. It is responsible for mal-operation of mho relays, particularly the reaching characteristic of the relay. In this project a new algorithm based on integrated impedance methodology is proposed to detect, locate and classify different types of faults in a series compensated EHV/UHV transmission line.

II. IMPACT OF SC ON DISTANCE PROTECTION RELAY

When a fault occurs in series compensated transmission line, it presents very complicated impedance characteristic and exerts influence on distance relay. Distance Relays are very sensitive to the apparent impedance seen by the relay and its zones. When a FACTS device say as TCSC is incorporated into the existing transmission line in order to improve the voltage profile, power flow, stability etc. it introduce problems in distance protection scheme in the measurement of the apparent impedance seen by the relay. Due to this significant change in the apparent impedance seen by the relay, it will lead to the mal operation of distance relay.

The major problems on relaying schemes on transmission line protection with series capacitors are those related to the voltage reversals, current reversals and over-reach. A voltage reversal will occur, for a fault near a series capacitor when the impedance from the potential location to the fault is capacitive rather than the inductive value. As a result, the voltage measured at relay location will be shifted approximately 180 degrees from the normal position.

A. *Current and Voltage Inversion:*

A current reversal is occurring when the current appears to be entering at one end of the line and leaving at the other, just as would occur during an external fault for an internal fault. That is possible only when the source impedance is less than the capacitive reactance.

This will cause difficulty for the distance protection to clearly identify the correct direction of the fault. This may be an impractical condition for a bolted fault due to the large fault current which rapidly bypasses the capacitors. However, in the case of faults with large fault resistance, the fault impedance can reduce the fault current below the bypass level.

B. *Non-linearity of the line impedance:*

In order to protect the series capacitor bank against transient over-voltages, the MOV is typically used. During the normal condition of the power system the MOV is not conducting. When a fault occurs the current in the series capacitor will increase, and so the voltage as well. When this voltage increases, the MOV starts conducting in order to protect the series capacitor. However, it should be noted that the MOV presents a non-linear behaviour, and the distance protection will see the measured impedance as a combination of RLC parameters. It must be mentioned that this behaviour depends very much on the level of fault current.

III. PROPOSED PROTECTION SCHEME

A. *Integrated Impedance*

Integrated impedance is the ratio of the sum of the voltage phasors at the two ends of the transmission line to the sum of the current phasors through the two ends of the same transmission line. The integrated impedance of the transmission line is used to determine the existence of the fault inside the protected line.

Fig.1 shows the system model with an internal fault at point F. Fig.2 shows equivalent circuit for fault with TCSC is in middle, where E_m and E_n are voltages of power sources at ends m and n, respectively. U_m, U_n I_m and I_n are the voltage and current phasors measured at ends m and n, respectively. I_{mc} and I_{nc} are currents through the equivalent capacitance at ends m and n, respectively. I_f is the current through the fault branch, and R_F is fault resistance. Z_m is the equivalent impedance of power source m, Z_n is the equivalent impedance of power source n. The transmission line is modeled as π equivalent circuit, and Z_{mc} and Z_{nc} are the equivalent capacitive impedances of the line. Z_{lm} is the line impedance from line end m to point F, and. Z_{ln} is the line impedance from end n to point F, and $Z_l = Z_{lm} + Z_{ln}$ is the entire line impedance.

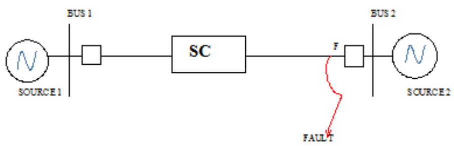

Fig. 1. One-line diagram of the system model

Voltage at both ends and current at both ends of the transmission line are used to find integrated impedance.Z_{cd} is defined as integrated impedance, which is

$$Z_{cd} = \frac{U_{cd}}{I_{cd}} \quad (1)$$

Where $U_{cd} = U_m + U_n$; $I_{cd} = I_m + I_n$ and I_{cd} is called differential current.

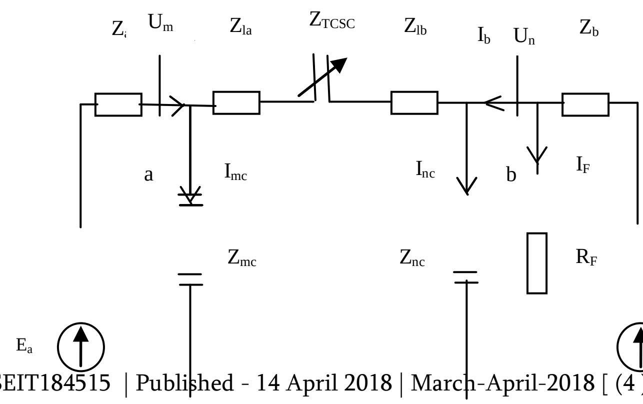

Fig. 2. Equivalent circuit for an external fault when TCSC is in the middle

Integrated impedance characteristics are depending upon series capacitor position. Integrated impedance is used to detect internal fault, so its characteristics are different for internal and external fault.

B. Characteristics Of Integrated Impedance

Variations in characteristics of integrated impedance in case of an external fault and internal fault for different TCSC placements are described as follows:

1) External fault:

a. TCSC installed in the middle of the line:

The differential current consists of only capacitive current when an external fault occurs. Fig.2 shows the system equivalent circuit with an external fault.

The differential currents of the line is

$$I_{cd} = I_m + I_n = I_{mc} + I_{nc}$$

$$= \frac{U_m}{Z_{mc}} + \frac{U_n}{Z_{nc}}$$

Where $Z_{mc} = Z_{nc} = \frac{2}{Y} = Z_Y$

The integrated impedance can be obtained

$$Z_{cd} = \frac{(U_m + U_n)}{I_{cd}} = \frac{2}{Y} = Z_Y \quad (2)$$

It can be concluded that when external fault occurs, the integrated impedance is equal to Z_Y , the sign of its imaginary part is negative, and its absolute value is large compared to the impedance of the power source and the line, and is independent of the Z_{TCSC} . The same conclusion can be drawn when the line is operating normally.

b. TCSC installed at one end of the line:

Assuming that TCSC is installed at end of the line, the equivalent circuit of the system is shown in Fig.3 when an external fault occurs.

As shown in Fig.3, the differential current can be obtained

$$I_{cd} = I_m + I_n = I_{mc} + I_{nc}$$

$$= \frac{U_m - (-Z_{TCSC} \times I_m)}{Z_{mc}} + \frac{U_n}{Z_{nc}} \qquad I_{cd} = \frac{U_m + U_{TCSC} + U_n}{Z_Y}$$

Where U_{TCSC} is the voltage drop while I_m flows through the TCSC.

$$U_{TCSC} = Z_{TCSC} \times I_m$$

Assuming the compensation level of TCSC is 50%, then

$$Z_{TCSC} = -0.5Z_l$$

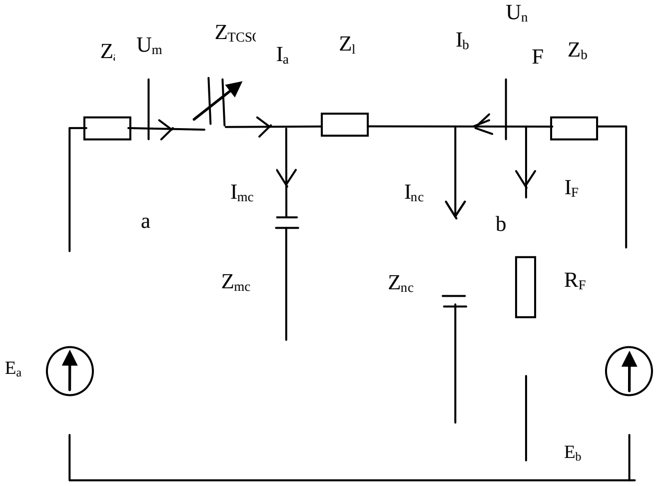

Fig. 3. Equivalent circuit for an external fault when TCSC is at the end

The integrated impedance can be obtained.

$$Z_{cd}=\frac{U_m+U_n}{(U_m+U_n+U_{TCSC})/Z_Y}=\frac{U_m+U_n}{U_m+U_n+U_{TCSC}}\times Z_Y \qquad Z_{cd}<Z_Y$$

In this case, the integrated impedance is smaller than the line capacitive impedance, but U_{TCSC} is relatively small. The absolute value of Z_{cd} is still large compared to the impedance of the power source and the line.

It can be concluded that irrespective of position of the series capacitor, absolute value of integrated impedance is larger for external fault.

2) Internal fault:

Variations in characteristics of integrated impedance in case of an internal fault for different TCSC placements are described as follows

a. *TCSC installed in the middle of the line:*

Assuming that TCSC is installed at middle of the line, the equivalent circuit of the system is shown in Fig.4 when an external fault occurs.

Assuming that the ratio of distance from the fault point to the end m to that of the entire line is p, then $Z_{lm}=pZ_l$, $Z_{ln}=(1\text{-}p)Z_l$.

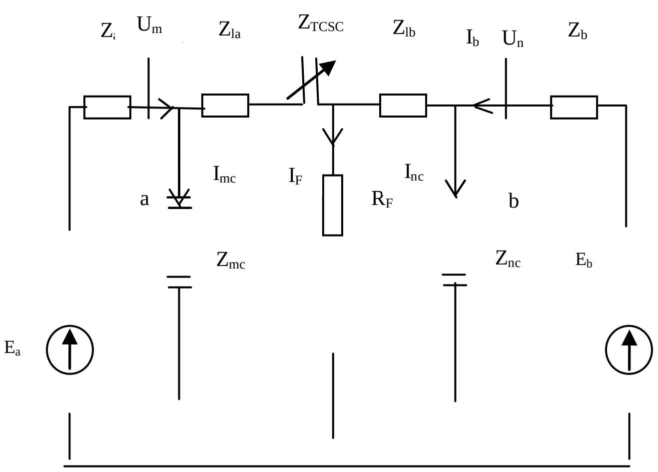

Fig. 4. Equivalent circuit for an internal fault when TCSC is in the middle

If the compensation level is 50%, $Z_{TCSC} = -0.5Z_l$

The impedances and are as follows:

1) $0 \le p \le 0.5$

$$Z_1 = Z_m + Z_{lm}$$
$$Z_2 = Z_n + Z_{ln} + Z_{TCSC}$$

2) $0.5 \le p \le 1$

$$Z_1 = Z_m + Z_{lm} + Z_{TCSC}$$
$$Z_2 = Z_n + Z_{ln}$$

Since $0 \le p \le 1$, $Z_m \le Z_1$ and $Z_n \le Z_2$ are always correct, Z_1 and Z_2 reflect the impedances of power sources and the lines of two ends m and n, respectively. When the capacitance of the line is ignored, the current through the fault branch is

$$I_f = U_{f0} / (R_F + Z_1 // Z_2)$$

Where, U_{f0} is the voltage at the fault point before the fault has occurred.

Let $U_{f0} = ke^{j\delta}(U_m + U_n)$ so

$$I_{cd} = I_m + I_n = I_{mc} + I_{nc} + I_f$$
$$= \frac{U_m}{Z_{mc}} + \frac{U_n}{Z_{nc}} + \frac{ke^{j\delta}(U_m + U_n)}{(R_F + Z_1 // Z_2)}$$

$$I_{cd} = \frac{U_m + U_n}{Z_Y} + \frac{ke^{j\delta}(U_m + U_n)}{(R_F + Z_1 // Z_2)} \quad (4)$$

Substituting (4) into (1), we can obtain

$$Z_{cd} \approx 1 \Big/ \left(\frac{1}{Z_Y} + \frac{ke^{j\delta}}{R_F + Z_1 // Z_2}\right)$$

$$Z_{cd} = Z_Y // \frac{R_F + Z_1 // Z_2}{ke^{j\delta}} \quad (5)$$

Generally, the coefficient k is about 0.5, and when the power system is under normal condition, the angle between the two equivalent power sources of the two ends of the line is less than 30^0, so $-15^0 < \delta < 15^0$. When bolted fault occurs inside the line, the current flowing into the line capacitance can be ignored because it is much less than the current flowing into the fault branch, so

$$Z_{cd} \approx \frac{R_F + Z_1 // Z_2}{ke^{j\delta}} \quad (6)$$

It can be derived from (6) that the integrated impedance Z_{cd} is related to the fault location and resistance, the power angle δ , the power-source impedances, and the line impedance. Fig. 5 shows the in the R-X coordinate diagram. It is easy to know from Fig. 5 (a) that the Z_{cd} stays in the first or second quadrant when fault without resistance or with small resistance occurs. The sign of the imaginary part of Z_{cd} is positive, and the value of the imagine part of Z_{cd} is small. Under the condition that R_F or δ is large, Z_{cd} may go into the fourth quadrant as seen in Fig. 5(b). The sign of the imaginary part of is negative, but the absolute value of its imaginary part is much less than $|Z_Y|$.

When a fault with large resistance occurs in the line, the influence of the line capacitance cannot be ignored. Because $Z_1 // Z_2 << R_F$ by ignoring $Z_1 // Z_2$ from (4.6) the following equation can be obtained:

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$$Z_{cd} \approx 1 \Big/ \left(\frac{1}{Z_Y} + \frac{ke^{j\delta}}{R_F} \right) = Z_Y // \left(R_F \big/ ke^{j\delta} \right)$$

So when a fault with large resistance occurs, Z_{cd} is equal to the impedance of the parallel connection of Z_Y with $R_F / ke^{j\delta}$. Obviously, the absolute value of the imaging part of the integrated impedance is much less than $|Z_Y|$.

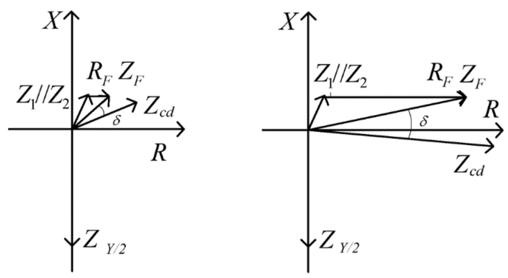

Fig. 5. Integrated impedance with an internal fault. (a) The sign of the imaginary part of is positive. (b) The sign of the imaginary part of is negative

b. TCSC Installed at one end of the line

Fig.6 shows the diagram of the equivalent circuit of the system model with an internal fault.

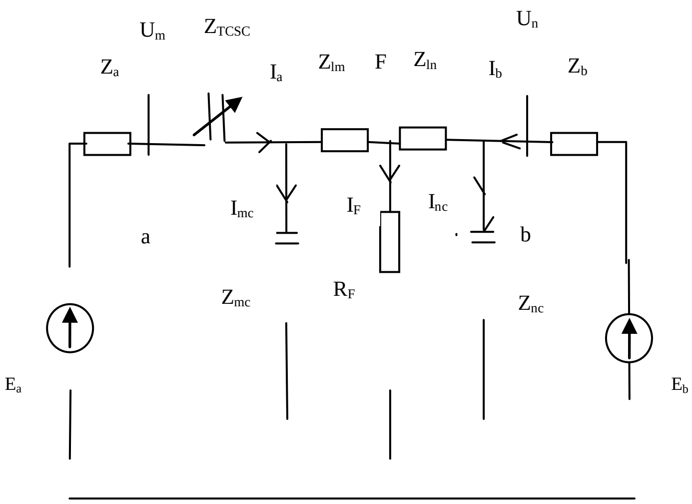

Fig.6. Equivalent circuit for an internal fault when TCSC is at the end

Assuming that the ratio of distance from the fault point to the end m to that of the entire line is p, then

$$Z_{lm} = pZ_l, \quad Z_{ln} = (1\text{-}p)Z_l$$

If the compensation level is 50%, $Z_{TCSC} = -0.5Z_l$. The Impedances Z_1 and Z_2 are as follows:

$$Z_1 = Z_m + Z_{lm} + Z_{TCSC} = Z_m + (p - 0.5)Z_l$$

$$Z_2 = Z_n + Z_{ln} = Z_n + (1 - p)Z_l$$

From the analysis above, we can obtain

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$$Z_{cd} \approx \frac{R_F + Z_1 // Z_2}{ke^{j\delta}}$$

Where Z_1 and Z_2 change with the different fault location as follows

1) When $0.5 \le p \le 1$, $Z_m \le Z_1$ and $Z_n \le Z_2$ are correct. Z_1 and Z_2 reflect the impedances of the power sources and the line of two ends m and n, respectively. Z_{cd} stays generally in the first or second quadrant. The sign of the imaginary part of Z_{cd} is positive. Under the condition that R_F or δ is large, Z_{cd} may move into the fourth quadrant, but the absolute value of its imaginary part is much less than $|Z_Y|$.

2) When $0 \le p \le 0.5$, $(Z_m - 0.5Z_l) \le Z_1$ and $Z_n \le Z_2$ are correct. When $Z_m > 0.5Z_l$, Z_1 reflects the impedance of the power source m and Z_2 reflects the impedance of the power source and the line of the end n. Z_{cd} with a positive imaginary part stays generally in the first or second quadrant, and the value of its imaginary part is much less than $|Z_Y|$.

3) When $Z_m < 0.5Z_l$ and the fault occurs near the end m, the imaginary part of Z_1 will be negative, but Z_2 is still inductive and reflects the impedance of the power source and the line of the end n. In this case, Z_{cd} stays in the fourth quadrant, but the value of its imaginary part is much less than $|Z_Y|$.

From the above analysis it is clear that integrated impedance can be used to detect internal fault in a transmission line. For an external fault integrated impedance is a large value with a negative sign. But for an internal fault, integrated impedance depends on fault location, fault resistance, the power angle, the power source impedances and the line impedance.

IV. SIMULATION AND RESULTS

The proposed integrated impedance based algorithm for identifying the internal fault in an EHV/UHV transmission line has been modelled and tested using Power System Computer Aided Design (PSCAD) software. PSCAD is a Graphical User Interface (GUI) based professional's simulation tool for analyzing power systems transients. It is also known as PSCAD/EMTDC. Electromagnetic Transients Including DC (EMTDC) is the simulation engine, which is now the integral part of PSCAD.

A test system has been modelled in PSCAD/EMTDC and issues related to the series compensated transmission line has been analysed. An algorithm based on integrated impedance has been implemented and tested.

A. *Test System*

The overall simulation setup of the considered test system in PSCAD software is shown in fig.7. It is a doubly fed system of transmission line which is represented as a distributed nominal π-model.

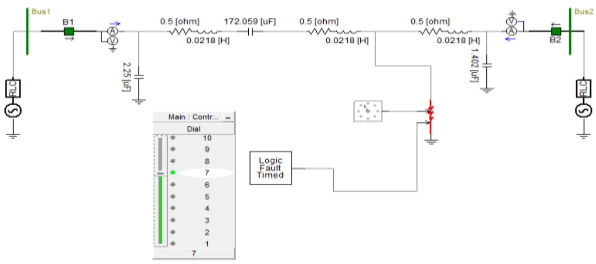

Fig. 7. Simulation diagram of test system in PSCAD

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The parameters of the system shown in fig.7 is given in Table 1

Table.1. system parameters

Sl No.	Parameter/Devices	Rating/Range
1	System voltage	100 V, 50Hz
2	Source 1	100 V, 50Hz, δ=0^0
3	Source 2	100 V, 50Hz, δ=0^0
4	Transmission Line Parameter	R=0.01Ω/km, L=0.436mH/km, C=2.25μF/km Length: 100 km
5	Series Capacitor	50% Compensation

For the modeled system operating at 400 kV, an integrated impedance based relay is designed and tested under various constions.

B. Implementation Of The Integrated Impedance Based Relay

As discussed in chapter 4 the integrated impedance based relay algorithm is implemented as shown in fig.8. The overall system is divded into three subsystems for easy design and undestanding.

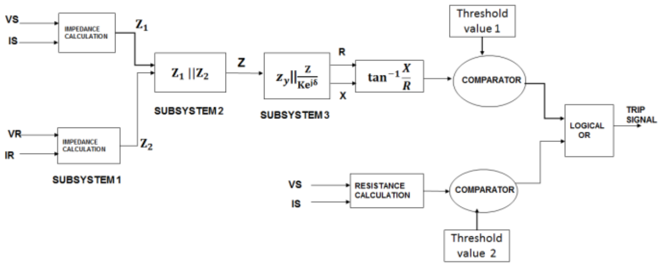

Fig. 8. Block diagram of proposed algorithm

1) Subsystem **1:**

Subsystem 1 calculates the impedance seen from both sides of the transmission line using voltage and current data measured at that location as shown in Fig.9. The magnitude and phase angle of positive, negative and zero sequence components of voltage and current have been extracted through FFT block in PSCAD.

Phase angle of positive sequence voltage and current is used to find the impedance angle. The subsystem1 estimates the impedances (Z_1 and Z_2) seen at both the ends of the transmission line. These impedances are given as inputs to the subsystem 2 shown in Fig. 10.

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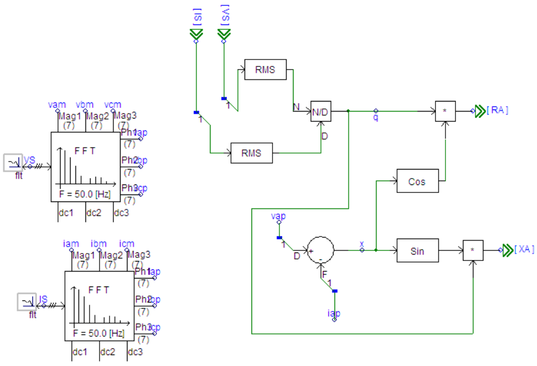

Fig. 9. Subsystem 1

2) Subsystem 2

Subsystem-2, shown in Fig. 10 calculates the parallel combination of impedances seen from both sides of the transmission line.

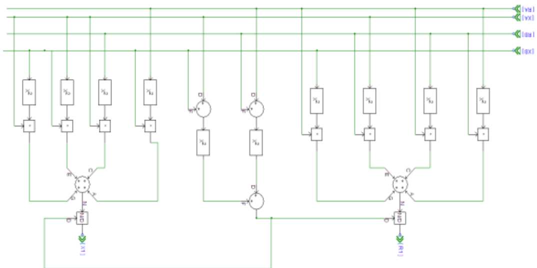

Fig. 10. Subsystem 2

The estimated impedances in subsystem1 are used for this computation in the subsystem2.

3) Subsystem 3

This subsystem is used to find the integrated impedance of the transmission line. The equation (7) is implemented in subsystem 3.

$$Z_Y \parallel \frac{Z}{ke^{j\delta}} \quad (7)$$

Where k=0.5, δ is the power angle, Z is the impedance obtained from subsystem2 and Z_Y is the capacitive impedance of the transmission line.

Then angle of impedance obtained from subsystem 3 is compared with a predetermined value and then relay is activated for internal fault. Fig.11 shows the simulation diagram for subsystem 3.

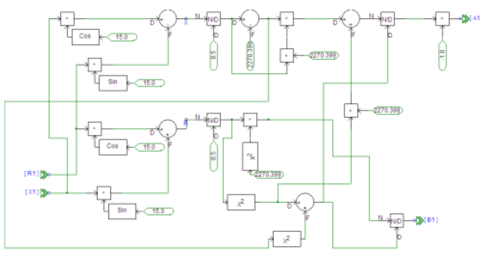

Fig. 11. Subsystem 3

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For some cases according to the compensation level the fault has been wrongly detected. To rectify this problem an additional algorithm based on resistance is used.

C. Fault Location Algorithm

Fig.12 shows the block diagram of the fault location algorithm where VS, IS, VR and IR represents the voltage and current signals from both ends of the transmission line.

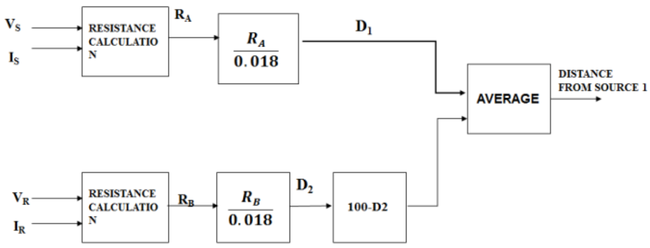

Fig. 12. Block diagram of fault location algorithm

Using voltage and current signal, resistance is calculated then it is dividing by per km resistance value of the transmission line. Average of the distance calculated from both sides is taken as location of fault.

D. Results

Relay based on integrated impedance methodology has implemented and effectively for different locations of fault in a series compensated transmission line. This algorithm is implemented to protect 80% of the transmission line.

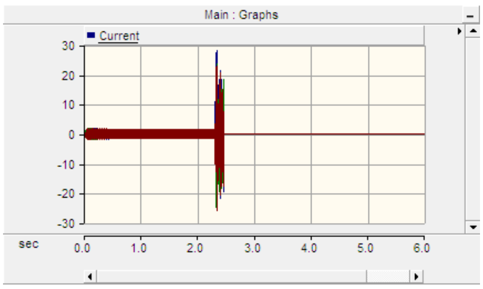

Fig. 13. Current waveform of the relay

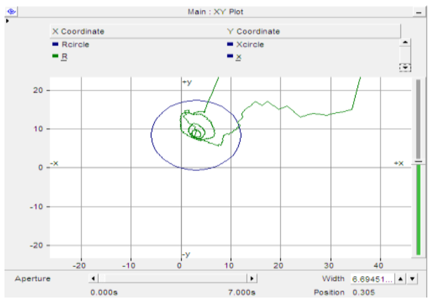

Fig. 14. Impedance trajectory of the relay for fault at 120 km

Trip signal and impedance trajectory of the relay for fault at 120 km of the transmission line is shown in fig.15 and fig. 14 respectively. Here also fault has given at 0.3 sec and trip signal is activated at 0.6 sec and from fig. 14 it is evident that impedance trajectory is coming inside mho circle and the after clearing fault it is again going outside the circle.

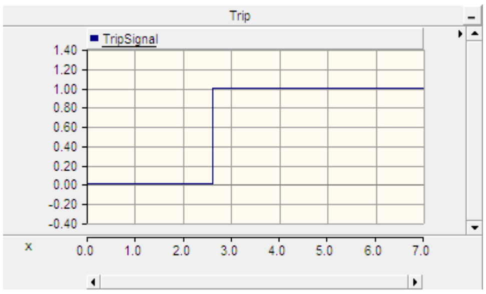

Fig. 15 Trip signal of the relay for fault at 135 km

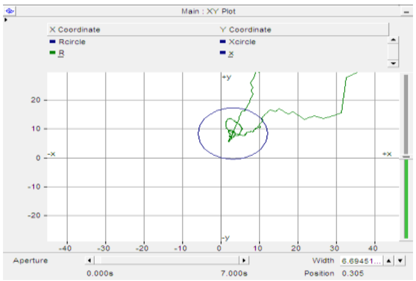

Fig. 16. Impedance trajectory of the relay for fault at 135 km

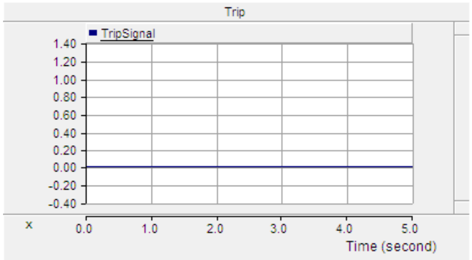

Fig. 17 Trip signal of the relay for fault at 135 km

Fig.17 and 16 shows the trip signal and impedance trajectory for fault at 135 km. Even though the mho characteristics shows that there is a fault in the transmission line, the relay is not detecting it because 80% of the transmission line is protected using angle criterion of the integrated impedance based algorithm.

Problems faced by the distance relay in a series compensated transmission line is analysed and Simulation of a typical power system with fault at different locations is carried out. Integrated impedance based relay is used to distinguish between internal and external fault. Angle of integrated impedance is used as a criterion for detecting fault and which is implemented in PSCAD.

V. CONCLUSION

Due to the presence of a complicated impedance characteristics in a series compensated transmission line, during the fault detection the conventional distance relay faces serious problem. In order to modify this drawback a different algorithm based on integrated impedance is presented in this thesis. The mathematical modeling of the relay has been extensively studied and presented in this thesis.

The designed integrated impedance based algorithm has been verified by the analytical simulation tool of PSCAD. The algorithm has been tested for a 400 kV doubly fed transmission system with 50% midpoint series compensation. The location of the fault is continuously varied from the relay location to the other end of the transmission line to validate the reach of the designed relay.

It has been identified that, simply magnitude estimation of integrated impedance will not help in detecting the fault after some fault location. Especially a fault at 90 km from the relay location is over-reached by the conventional integrated impedance method. The over-reach of the relay has been rectified by adding the angle of integrated impedance also a decision making quantity. This algorithm can have further future applications in the detection of unsymmetrical faults and zonal protection.

VI. REFERENCES

[1] Shien He, Jiale Suonan, and Z. Q. Bo, Senior Member, IEEE, "Integrated Impedance-Based Pilot Protection Scheme for the TCSC-Compensated EHV/UHV Transmission Lines", IEEE Transactions On Power Delivery, VOL. 28, NO. 2, pp. 835-844 ,APRIL 2013.

[2] Dash P. K., Ganapati Panda and S. R. Samantaray, "Fault Classification and Section Identification of an Advanced Series-Compensated Transmission Line Using Support Vector Machine", IEEE Transactions on power delivery, 22, pp. 67-73, 2007.

[3] Mohammad R. Dadash Zadeh and Tirath Pal S. Bains, "Supplementary Impedance-Based Fault-Location Algorithm for Series-Compensated Lines", IEEE transactions on power delivery, 31, pp. 334-342, 2016.

[4] Manoj Tripathy and Om Hari Gupta,"An Integrated Impedance Based Pilot Protection Scheme for SVC Compensated Transmission Line",2014.

[5] Pallavi M. Tonape, A. R. Thorat and M. M. Tonape, "Modified Design of Distance Relay for Series Compensated Transmission Line", International Conference on Circuit, Power and Computing Technologies, 2016.

[6] Chen D. S, X. Z. Duan, X. G. Yin, J. Yu and W. G. Wang, "The impact of TCSC on distance protection relay", in Proc. Int. Conf. Power System Technol.,. 1, pp. 382–388, 1998.

[7] Biswarup Das , Rudra Prakash Maheshwari and Urmil B. Parikh, "Combined Wavelet-SVM Technique for Fault Zone Detection in a Series Compensated Transmission Line", 23, pp. 1789- 1794,2008.

[8] Sanjay Dambhare, S. A. Soman and M. C. Chandorkar, "Adaptive Current Differential Protection Schemes for Transmission-Line protection", IEEE transactions on power delivery 24, pp. 1832-1841,2009.

[9] Hingorani, N.G., L.Gyugyi. Understanding FACTS concepts and technology of flexible AC transmission systems. New York: IEEE Press, 2000.

[10] Paithankar, Y.G. and S.R. Bhide. Fundamentals of Power System Protection. New Delhi: PHI Learning Private Limited, 2008