J. Electrical Systems 20-3 (2024): 3194-3199

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Effectiveness of Travelling Wave Protection Scheme to Develop Fastest Protection Scheme for Transmission Line

Abstract: - Fast protection in transmission lines is prime requirement for maintaining the stability and reliability of power systems. It not only safeguards the transmission line but also protects connected equipment such as transformers, generators, and other connected equipment. Now a day, for developing smart grids, it is necessary to develop a relay which can sense the fault quickly. This results into isolation of faulty part and preventing damage to the equipment. Tripping signal of relay based on steady state components does not warranty faster tripping. The proposed method is an attempt to find solution of faster tripping by using 0, α and β components using clarke's transformation of travelling waves that are produced when fault occurs.

Keywords: Fast protection scheme, transmission line, relay signals, travelling waves.

I. INTRODUCTION

As the demand for electricity continues to rise, power grids are experiencing higher stress levels resulting into faults and disturbances. Moreover, complexity of interconnection of power systems demands reliable and uninterrupted power supply. Relay tripping based on conventional steady state component of voltage and current requires tripping time of few cycles and hence does not give quick isolation. A protection system is expected to meet sensitivity and selectivity requirements. Sensitivity refers to the ability to detect and isolate faulted regions fast enough to avoid damaging the other equipment in the power system. Selectivity refers to the intelligent and optimized isolation of faults to minimize the number of customers experiencing power outage. Synchronous generators produce up to six times the rated current during fault conditions [3]. Therefore, the proposed work has developed tripping schemes based on high frequency signals which are generated on impact of disturbances or faults and not based on steady state components. Travelling wave protection scheme depends on high-frequency measurements and determining the arrival time of the trip signal. The high frequency electromagnetic transient propagates through the system at the speed of light, allowing the protection equipment to detect the wave in less than 1ms after the fault.

This paper discusses the protection scheme of quick protection using the precise arrival times of the wave; travelling wave protection schemes provide very fine accuracy for determining the location of the fault on the line, which improves repair times by accurately dispatching crews. Travelling wave protection provides the benefits of accuracy and reliability for the grid of the future with renewable inverter-based generation.

II. PROBLEM FORMULATION

Wherever Now a days, biggest challenge to power engineers is to maintain power system stability because of the interconnected networks in the deregulated power supply system. Since fault can create disturbance in the power system, they must be isolated as quick as possible. Hence quick clearing of fault is much needed, which improves the transient stability of the power system. The need is to have faster tripping schemes where trip time is few mili seconds only, and not in cycles, which the conventional method is taking.

Moreover finding the accurate location of a fault has always been a challenge for electric utility. Conventional method of fault location is to use the voltage and current data measured at one or more points along the power networks. Knowing the line impedance per unit length, the fault distance can be approximated from the calculated impedance obtained from voltage and current data. This impedance method, however, is subjected to errors caused by e.g. high resistance ground faults, teed circuits topologies, and the interconnection to multiple sources [1]. The proposed methodology helps in determining location of fault more accurately. Moreover, as the method uses high frequency components, this method is undoubtedly the quickest possible scheme for fault detection.

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III. DEVELOPMENT OF METHODOLOGY FOR FASTEST PROTECTION OF TRANSMISSION LINE

A. *Steps to be followed are:*

1. Calculation of frequency of travelling waves generated
2. Obtaining propagation velocity of travelling waves.
3. Obtaining trip signal for the relay.
4. Calculating tripping time.
5. Obtaining fault location

To have velocity of propagation of travelling waves, positive & zero sequence inductances & capacitances have to be known [7].

$\upsilon\, 0 = \surd\ (1/L0C0)$ m/sec

$\upsilon\, 1 = \surd\ (1/L1C1)$ m/sec

Where,

$\upsilon 0$= velocity of propagation of 0 mode waves.

$\upsilon 1$= velocity of propagation of α & β mode waves.

L0 & C0= zero sequence inductance & capacitance respectively.

L1 & C1= positive sequence inductance & capacitance respectively.

Frequency of travelling waves for $0\alpha\beta$ modes, $f0 = \upsilon 0/L$ Hz

$f1 = \upsilon 1/L$ Hz , Where L= length of transmission

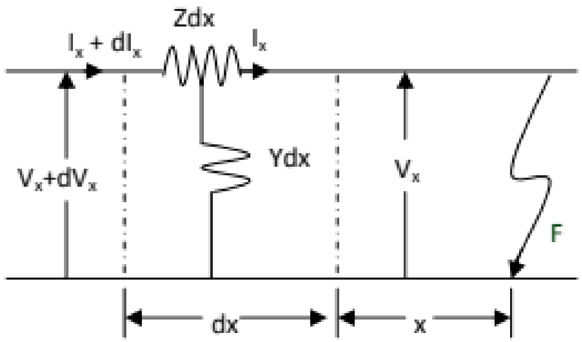

Fig 1 Schematic diagram of a long line

For the differential section shown in Fig. 1, following travelling wave equaltion can be written [7].

$V1 = ((Vf + Zc\ If) / 2)\ e\ \alpha\ x\ e\ j(\omega t + \beta\ x)$ and is called as forward travelling voltage wave.

$V2 = ((Vf - Zc\ If) / 2)\ e - \alpha\ x\ e - j(\omega t + \beta\ x)$ and is called as reverse travelling voltage wave.

Similarly,

$Ix = I1 - I2$

Where, $I1 = ((Vf /Zc + If) / 2)\ e\ \alpha\ x\ e\ j(\omega t + \beta x)$ and is called as forward travelling current wave.

$I2 = ((Vf /Zc - If) / 2)\ e - \alpha\ x\ e - j(\omega t + \beta x)$ and is called as reverse travelling current wave. Hence using the above equations, forward and backward travelling waves for all phases can be found.

Vf and If are post fault voltage and current respectively.

Using the Clarke transformation, forward and backward travelling waves of three phases are being transformed into $0\alpha\beta$ components. The Clarke transformation,

$$\begin{pmatrix} V0 \\ V\alpha \\ V\beta \end{pmatrix} = 1/3 \begin{pmatrix} 1 & 1 & 1 \\ 2 & -1 & -1 \\ 0 & \sqrt{3} & -\sqrt{3} \end{pmatrix} \begin{pmatrix} Va \\ Vb \\ Vc \end{pmatrix}$$

$$\begin{pmatrix} I\,0 \\ I\,\alpha \\ I\,\beta \end{pmatrix} = 1/3 \begin{pmatrix} 1 & 1 & 1 \\ 2 & -1 & -1 \\ 0 & \sqrt{3} & -\sqrt{3} \end{pmatrix} \begin{pmatrix} I\,a \\ I\,b \\ I\,c \end{pmatrix}$$

As the voltage at any point on the line is addition of forward and reverse travelling waves, voltage at any point on a 3-Φ transmission line is,

$V0 = V10 (x - \upsilon0t) + V20 (x + \upsilon0t)$

$V\alpha = V1\alpha (x - \upsilon0t) + V2\alpha (x + \upsilon0t)$

$V\beta = V1\beta (x - \upsilon0t) + V2\beta (x + \upsilon0t)$

And current on 3-Φ transmission line,

$I0 = I10 - I20$

$I\alpha = I1\alpha - I2\alpha$

$I\beta = I1\beta - I2\beta$

The discriminant function df and dr associated with the forward and reverse waves will be uses as the forward and backward relaying signals in the travelling wave relay.

Where,

$df = V + ZI$

$dr = V - ZI$

V and I are the modal voltages and currents (0, α or β components) at the relay location.

The relay treats the currents flowing into the line as positive. Hence the forward current wave If appears as positive to the relay; while the reverse current wave Ir appears to be negative.

$df = V + ZI$

$= (V f + V r) + Z (I f - I r)$

$= (V f + Z I f) + (V r - Z I r)$

$= V f + Z I f$ (since $V r = Z I r$)

$df = 2V f$ Similarly, (since $V f = Z I f$)

$dr = V - ZI$

$dr = 2V r$

Both the signals will have zero magnitude during healthy conditions.

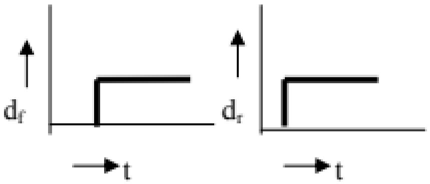

Fig. 2 Relay trip signals

IV. IMPLEMENTATION OF PROPOSED METHOD

Considering a 500 kv test system as below:

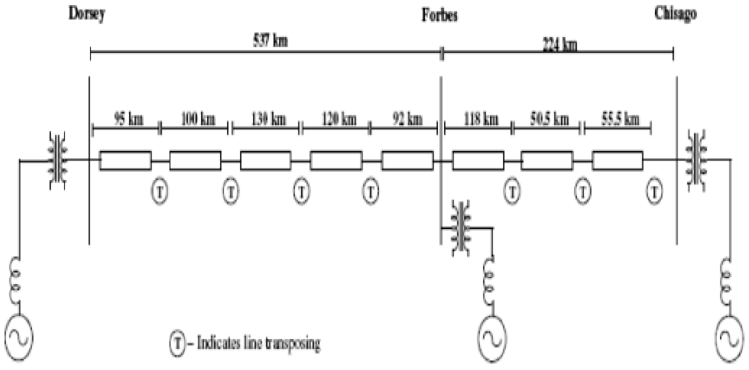

Fig 3 Line configuration of 500 kV system

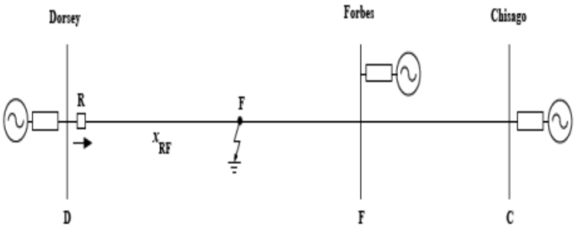

Fig 4 fault occurs at F (525km away from relay location)

Line configuration data:
Height of outer conductors, hc = 28.956 m
Height of centre conductor, hc+ho = 38.648 m
Horizontal space between phases, Xc = 6.71m
Conductor radius, r = 1.65354×10-2 m
No. of conductor in a bundle N = 3
Line parameter: Conductor DC resistance = 0.0489 Ω/km
Considering 3-phase fault at location F;
The waveforms obtained in MATLAB are as below:

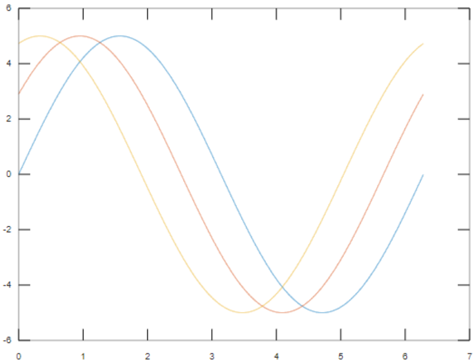

Fig. 5 post fault voltages

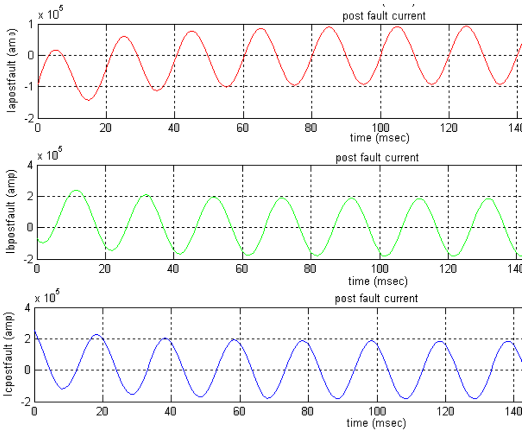

Fig. 6 post fault currents

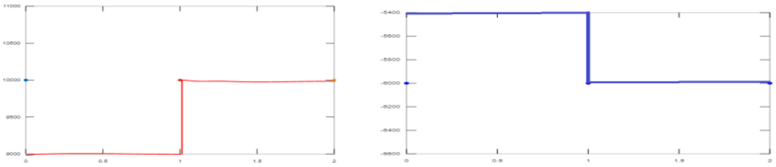

Fig 7 forward and backward trip signals

From Fig. 7, dr is equal to -6043.2 and it picks up at 1.7371 msec
df is equal to 9932.9 and it picks up at 1.7437 msec

τ1 = 5.2179 msec, τ2 = 1.7437 msec Hence distance to the fault x = 524.99 km (calculated) and Distance to the fault = 525 km (Estimated).

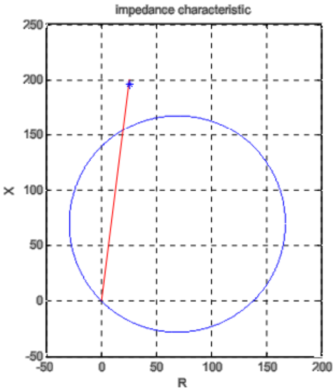

Fig. 8 Mho relay characteristic

Fig 8 shows that Mho relay may face under reach issue, as fault is close its reach. While scheme using travelling relay received forward and backward signals, hence will trip in 1.7 mSec, which is very quick.

V. COMPARISON OF PROPOSED METHOD

The method has been applied on 500 kV test system given in Reference paper [4]. The results shown are obtained and are compared with the results given in reference paper [4]. In reference paper [4], correlation technique is used. According to correlation technique, for the relay to trip, relaying signal S1 should pick up first, pick value of relaying signals must be higher than the threshold value and pick value of output of correlator must be larger than the threshold value.

By proposed method:

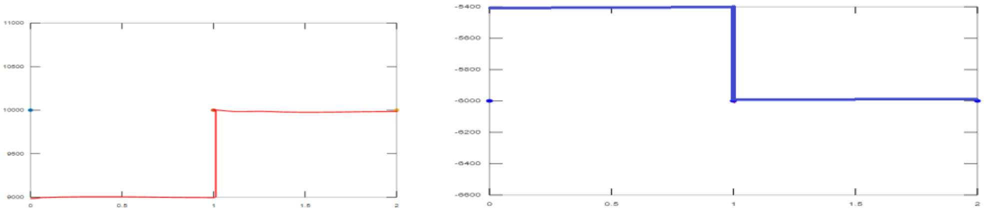

Fig 9 relay trip signals

By method mentioned in reference paper [4]

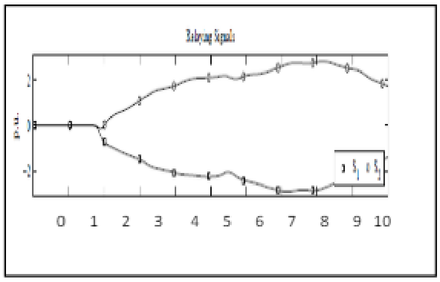

Fig 10 relay trip signals

Both the methods find same trip signals with almost same tripping time. Both the cases identify forward fault as forward signal is received later than backward signal. Moreover location of fault obtained from proposed method also matches with the reference paper [4].

VI. ANALYSIS OF RESULTS

1. From the relay signals in given case, dr picks up before df . Hence fault is in forward direction.
2. Full length of line is 537 km. Hence fault at 525km may be seen as outside fault by simple distance relay due to under reach issue of it (relay is generally set for 80% of its full length). But protection using travelling wave always sees it as forward fault and trips for it.
3. Location of fault calculated is within the zone of protection as travelling wave relay is provided to protect the full 537 km length. Mho relay cannot operate as fault is out of its reach.

VII. FUTURE SCOPE

The proposed methodology can be applied to various systems, at various fault locations and for various types of faults to check its correctness and versatility. It may be observed that for close faults, distance relay may trip faster than travelling wave relay. Hence for effectiveness of the method, the proposed scheme may be used in hybrid mode i.e. travelling wave relay along with Mho relay as back relay too.

VIII. CONCLUSION

Proposed methodology was implemented on 500 kV transmission line system. Relaying signals were obtained. Comparison of proposed work was done with technique shown in Ref. paper [4] for 500 kV test system. Relaying signals were compared with the Ref. paper [4]. Combination of Travelling wave relay and Mho relay can be used for tripping hybrid relay which gives faster as well as more reliable protection scheme.

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