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ELECTRICAL POWER ENGINEERING

Analysis and Simulation of Line Fault Location on High Voltage Transmission Line by Travelling Wave Principle

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Abstract— **Power System Protection is a vital importance for power engineers and is implicated by modern techniques with efficient and effective methods by traveling wave theory which is widely implied on high voltage theoretical background and practical application for line fault location and power system protection. An electric power system comprises of generation, transmission and distribution of electric energy. The rapid growth of electric power systems over the past few decades has resulted in a large increase of the number of lines in operation and their total length. These lines are exposed to faults as a result of lightning, short circuit, faulty equipments, mis-operation, human errors, overload and aging. The importance of this research arises from the need to reduce the interruptions of electricity, especially for interconnecting transmission lines and to reduce the repair and restoration time especially in areas with difficult terrain. This can be attained by reducing the error in the fault distance estimation. In this paper, a travelling -wave scheme is used positive features of traveling wave algorithm. Validation of the fault location is performed using the Power System Dynamics Monitoring System-Time Synchronizing (PSDM-TS) transient system. The algorithm will allow utilities to accurately locate line faults with the knowledge of transient current signals. Thus this paper provides an economic approach to fault location of transmission systems consistent with today's needs, providing a good foundation for further developments.**

Keywords— **voltage, current, frequency, travelling wave, fault, velocity, distance**

I. Introduction

The growing demand for power and high transmission efficiencies has prompted construction of extra high voltage transmission lines. The complexity of the power network and the low stability margins at which they now operate have dramatically increased the occurrence of catastrophic failures in electric power systems. The greatest danger to a healthy power system is instability resulting from faults that are not cleared quickly. High speed fault isolation is required to ensure that the power system will not run into transient stability problems and also to reduce the damage due to electrodynamics and thermal stress on the equipment. The stability of the power system can be greatly improved by reducing the fault clearance time, especially of those faults in EHV lines. The travelling waves based protection schemes show fast fault detection times since the wavefronts carry the very fast information about a possible disturbance in the system. In this paper, it is decided to employ the basic theory of travelling waves as the research is focused on travelling wave based fault location which are more suitable for application to long lines. This paper has addressed the problem of fault distance estimation utilizing the measurement of wave signals from one end of a transmission line. With complex interconnected power networks today, it is difficult to assume some of the fault conditions. To facilitate all possible cases, the protection scheme may have to handle, the actual settings in use are often not optimal for any particular system state. By using a travelling wave algorithm, it provides for considering the economic approach. It also helps to keep the whole electrical power network properly with the use of travelling wave theories combining with software architecture.

II. Background Theory of Travelling Waves

When a fault occurs on a transmission line, the sudden discharge of line changes at the fault location generates transient waves. Immediately after the fault, the distortions caused by these transient waves can be observed superimposed on the steady stage voltage and current waveforms. These transient signals (traveling waves) subsequently propagate along the transmission line at a velocity close to the speed of light and reflect at discontinuities. The repeated reflection of these transient wavefronts causes the voltage and current signals to change from the pre-fault steady state valves to the post-fault values. These wavefront contain valuable information about the fault type, location of the fault and fault inception angle. The sign, magnitude and dimming between the various wavefronts arriving at the line end contain information from which the fault location can be calculated within a few milliseconds.

The travelling waves based protection schemes show fast fault detection times since the wavefronts carry the very fast information about a possible disturbance in the system. This algorithm uses a correlation technique to recognize the initial reflected wavefront returning from the fault. The distance to the fault is proportional to the time delay between the first wavefront detected at the relay location and the associated reflected wavefront from the fault.

A. *Transmission Line Equations*

All conductors of a transmission line have resistances and inductances distributed uniformly along the length of the line. It is, however, assumed in most applications that the resistance and inductance of a conductor is lumped and is, therefore, replaced by a single value. This is also true for the conductance and capacitance of a conductor. Transmission lines cannot be analysed with lumped parameters, when the length of the line is considerably small compared to the wavelength of the signal applied to the line. Power lines, which operate at 60Hz and are more than 50 km long, are considered to have distributed parameters. These lines have the following properties.

(1) Voltages and currents travel on the line.

(2) The velocity of propagation of these waves is finite.

One meter sections of a power transmission line can be represented by the circuits shown in Fig. 1.

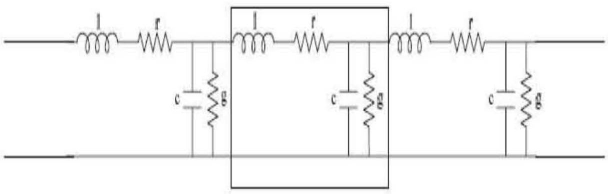

Fig. 1 Transmission line equivalent circuit
Source: [1]

Consider a small section of length, Δx of a transmission line, as shown in Fig. 2. Assume that resistance, inductance, capacitance and conductance remain constant along the length of the transmission line and do not change with time.

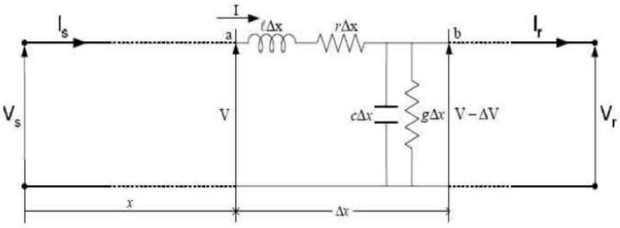

Fig. 2 Small section of a transmission line
Source: [1]

Due to distributed resistance and inductance, voltage at every point along the length of the line is different [1]. The transmission line equations can be derived as follows. Voltage drop per unit length of the line from location 'a' to location 'b' is

$$\frac{V-(V-\Delta V)}{\Delta x}=\frac{I(r\Delta x+j\omega l\Delta x)}{\Delta x} \quad (1)$$

where, r is resistance per unit length of the line, and l is inductance per unit length of the line. Rearranging this equation provides,

$$\frac{\Delta V}{\Delta x}=(r+j\omega l)I=zI \quad (2)$$

where, z is impedance per unit length of the line.

Similarly,

$$\frac{\Delta I}{\Delta x}=(g+j\omega c)V=yV \quad (3)$$

where, g is conductance per unit length of the line,
c is capacitance per unit length of the line, and
y is admittance per unit length of the line.

In this equation, γ is a complex quantity that is known as the *propagation constant* and is given by

$$\gamma=\sqrt{zy} \quad (4)$$

The propagation constant, γ, can also be expressed as

$$\gamma=\alpha+j\beta \quad (5)$$

where, α is the *attenuation constant,* and β is the *phase constant.*

The solution of the differential Equation is

$$V=Ae^{\gamma x}+Be^{-\gamma x} \quad (6)$$

A and B are constants that are usually complex quantities.

$$I=\frac{1}{Z_o}[Ae^{\gamma x}-Be^{-\gamma x}] \quad (7)$$

Z_o, called the *Characteristic impedance* of the line and is given by

$$Z_o=\sqrt{\frac{z}{y}} \quad (8)$$

$$V=[V_s\cosh(\gamma x)+Z_oI_s\sinh(\gamma x)] \quad (9)$$

$$I=\frac{1}{Z_o}[V_s\sinh(\gamma x)+Z_oI_s\cosh(\gamma x)] \quad (10)$$

B. *Travelling Wave*

A high voltage line is a circuit with distributed parameters that has a finite velocity of electromagnetic field propagation. A distinguishing nature of such a circuit is its ability to support travelling waves of voltage and current. In such a circuit, the sudden discharge of line changes and variations at the fault location produces transient waves when a fault or any disturbances on a transmission lines. These transient signals are also called travelling waves (TW).

They propagate along the transmission line at a certain velocity and give reflection back with discontinuities. The reflected wavefronts of these transient signals cause the voltage and current signals to change from pre-fault steady state to the post-fault one. They carry essential information about the fault type and location of the fault within a few milliseconds. In this algorithm, one correlation technique is used to recognize the initial reflected wavefront returning from the fault.

If a travelling wave arrives at a point where the impedance suddenly changes, the wave is partly transmitted and partly reflected loading points, line-cable junctions and even faults, consisting of discontinuities and its polarity that provide different voltage and current levels at the meeting point. Detail discussion about transmission line parameters and their corresponding equations are in [1].The following equations are the relationship of the velocity of propagation of wave v, the inductance of line per unit length L, the capacitance of line per unit length C, the back emf E, and the current I, considering a small section of length ∂x of a transmission line.

$$E = I L \frac{\delta x}{\delta t} \quad (11)$$

$$I = E C \frac{\delta x}{\delta t} \quad (12)$$

Multiplying these equation and let $\frac{\delta x}{\delta t} = v$,

$$E I = I L \frac{\delta x}{\delta t} v \times E C \frac{\delta x}{\delta t} v \quad (13)$$

$$v = \sqrt{\frac{1}{LC}} \quad (14)$$

The velocity of propagation is the same as the velocity of light, but it has to be assumed a resistance less line. In practice, it will be from 5 to 10 percent less than this. Normally a velocity of approximately of 285 m/μs is assumed [1], [4].

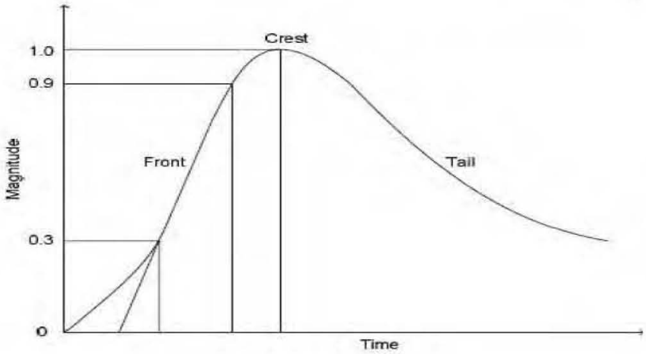

Fig. 3 A positive travelling waves
Source: [2]

A typical positive travelling wave, as shown in Fig. 3, has the following properties

1. Crest: This is the maximum amplitude attained by the wave.
2. Front: This is the part of wave before crest, when the wave is rising to attain the maximum value.
3. Tail: This is part of the wave beyond crest. In this portion, the wave gradually decreases in amplitude.
4. Polarity: Polarity of a travelling wave, positive or negative, is the polarity of crest of the wave.

III. Fault Location Techniques

The two digital techniques, single-ended and double-ended, for detecting and locating faults on transmission lines are described in the following sections. The single ended technique takes voltage and current inputs from one end of the transmission line. The double-ended technique takes voltage and current inputs from both ends of the transmission line; the information from the remote end is obtained over a communication channel between the two ends of the transmission line [3].

A. *Single-Ended Technique: Single Circuit Line*

In a sample power system, a single circuit transmission line is shown in Fig. 4 connecting bus A and bus B [1]. A travelling wave digital fault reader, Ra, is located at the bus A terminal of the line [1], [2]. This relay takes input voltages and currents from the local terminal and calculates modal voltages and currents. The aerial modes, 1 and 2, of the voltages and currents are passed through the sequence filters.

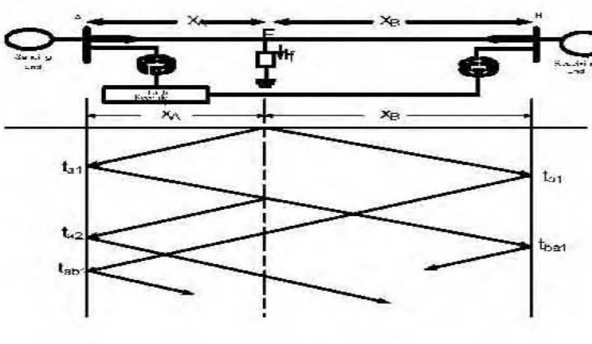

Fig. 4 Travelling waves on a single circuit transmission line
Source: [2]

The voltage and current traveling waves originate and propagate on the line away from the fault. When a fault occurs on the transmission line, one wave travels to wards bus A and the other wave travels towards bus B. The traveling waves, after a few microseconds, arrive at bus A. When the traveling waves are detected by the relay, the timer is turned on. The opposite polarities of the voltage and current spikes confirm the occurrence of a fault. A bus acts as a discontinuity in the path of the traveling waves. On reaching a bus, a part of the voltage wave and a part of the current traveling wave is reflected, and rest passes through. The reflected waves arrive at the fault, where a part of the voltage wave and a part of the current wave is reflected. These waves arrive at bus A, the second time. The arrival of the waves is detected by the recorder, Ra. The timer is stopped and the time is noted as a T_a. The distance traveled by the traveling waves is twice the distance of the fault from bus A. Therefore, the distance of the fault can be calculated as

$$D = \frac{T_a}{2} \times v \quad (15)$$

where, v is the velocity of propagation of the traveling waves.

If the distance, D is less than the length of the protected transmission line, the relay sends trip signals to the circuit breakers to isolate the faulted line from the rest of the system. If the value of D is greater than the length of the protected line, the relay is reset and normal operation is resumed.

A. *Single-Ended Technique: Double Circuit Line*

The following figure shows a double circuit transmission line connecting bus A and bus B. The traveling wave digital relays are located at bus A terminal of both circuits. The relays take the input voltages and currents from the local terminals and transform them into modal components. The aerial modes, 1 and 2, of the voltages and currents are passed through the sequence filters.

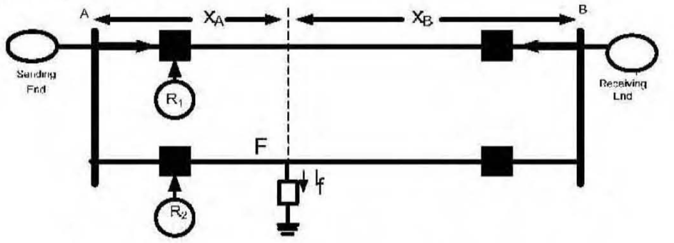

Fig. 5 Power system with a double circuit transmission line
Source: [3]

When a fault occurs on one of the circuits of the transmission line, the voltage and current travelling waves originate and propagate away from the fault. The travelling waves also exist on the healthy circuit due to magnetic induction. The voltage and current travelling waves, which arrive at bus A, are detected by the relays, R_1 and R_2. The first set of spikes corresponding to the initial voltage and current travelling waves at relay R_2 of faulted line.

The polarity of the voltage spike is opposite than the polarity of the current spike, which indicates that the fault is on circuit 2. The timer in Relay, R_2, is turned on. The first set of spikes in voltage and current are detected by the relay, R_1, on circuit 1 .The polarities of these spikes are same; therefore, fault is not on circuit 1.If, the time recorded by the relay is a T_a, the distance of the fault from bus A can be calculated as

$$D = \frac{T_a}{2} \times v \tag{16}$$

where, v is the velocity of propagation of the travelling waves.

IV. Case Discussion

The case with the single-ended technique, implemented for protecting EHV transmission lines is discussed in the following section. In order to know the reliability of travelling wave fault algorithm, case study has done at Hlawga substation of Myanmar National Grid. Figure 3 shows one line diagram of Hlawga Substation (230 kV, 60 MVA). In this substation, a fault recorder panel (Power System Dynamics Monitoring System-Time Synchronizing, PSDM-TS) has already set up [5]. There are four feeder groups in this recorder consisting of analog 16 channels/digital 32 channels. This recorder can show the data whenever the fault occurs on line. But the data given by this recorder cannot show the fault location, especially, high impedance in fault. This is the reason why the travelling wave algorithm is proposed to use in this substation.

1) Single-Ended Technique Case :Single Phase to Ground Fault Location at Line (Hlawga-Ywama)

A phase 'a' to ground fault, at a distance of nearly 10 km from Hlawga bus, is applied on the transmission line, *(Hlawga-Ywama)* . The high-speed digital fault recorder, located at bus Hlawga substation takes phase voltages and currents as inputs from the system.

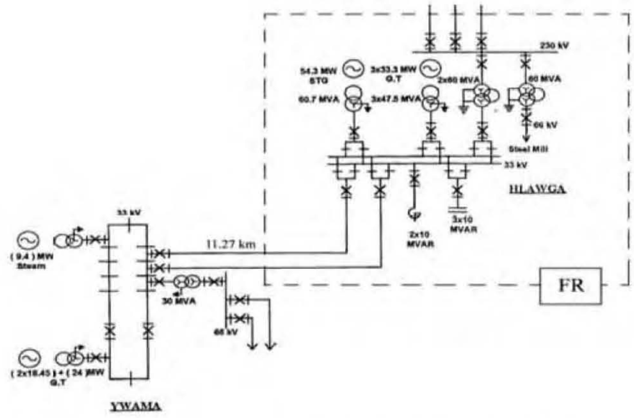

Fig. 6 One line diagram of Hlawga substation with fault recorder
Sourse.[5]

The spikes in the outputs indicate the arrival of travelling waves at the relays. The different polarities of the spikes in the outputs of the voltage and current sequence filters at Hlawga confirm the occurrence of a fault. The time recorded by the relay on line at the arrival of the first set of travelling waves, is 133 μs. The set of travelling waves, which arrived after reflection from the fault, is recorded by the relay at the time, 199 μs. The distance of fault, calculated by the relay, is as follows

$$D = \frac{(0.000199 - 0.000133)}{2} \times v = 9.89\,km$$

where, v, assuming the velocity of propagation of the travelling waves = 299792.468 km/s.

The calculated distance is less than the length of the transmission line; therefore, a fault has occurred on the transmission line, (Hlawga-Ywama). Relay sends a trip signal to the circuit breakers and the line is isolated from the rest of the system.

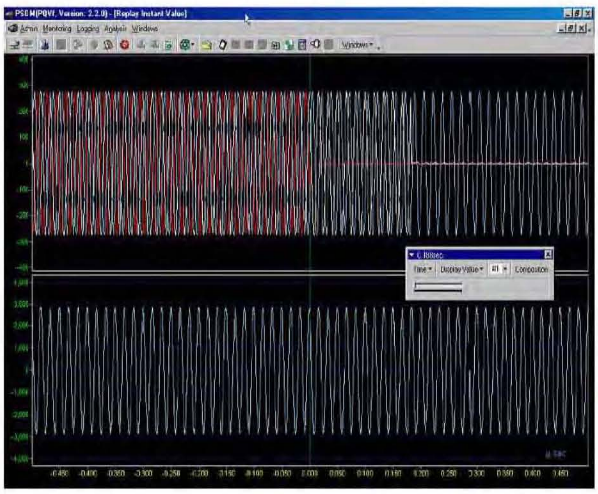

Fig. 7 Arrival of travelling waves at the fault recorder

V. CONCLUSION

This study allows focusing that the system can get quickly recovery by knowing the almost exact location of fault point in long lines. Since fault detection speed has been an important feature, the faster the fault detection is done, the less damage to the power system and the less impact on the economy. By analysing the fault data of existed one with TW principle helps to find out fault point very fast. The reliability of the algorithm can be seen from case study of Hlawga substation. Thus, the result from this can supervise the next efforts in order to realize the accurate fault location computation in power system of Myanmar.

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