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FAST AND PRECISE DIAGNOSIS OF FAULT TYPE AND FAULT LOCATION IN TRANSMISSION LINES USING A NEW APPROACH BASED ON THE FAULTED PHASE VOLTAGE FUNDAMENTAL HARMONIC

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ABSTRACT:*In modern interconnected power systems, nearly 80% of faults in high voltage transmission lines are intrinsically transient. The necessity of rapid fault clearing has resulted in fast development of protection equipment. Moreover, need for reliable supply of loads has led to improvements in single phase auto-reclosing equipment. In this paper, a new and efficient method is proposed to diagnose fault location, fault type (transient or permanent) and the extinguishing time of secondary arc in power transmission line, leading to improved performance and efficiency of single phase auto-reclosing. In the occurrence of permanent faults, the proposed method is accurate and authentic. Various simulations in EMTP/ATP environment prove that the proposed method is a comprehensive protective algorithm for power transmission line.*

Keywords: Fault Type and Fault Location; Power Transmission Line; EMTP/ATP and Secondary Arc.

1. INTRODUCTION

Nowadays, due to increasing developments in electrical power applications, providing consumer requirements and preventing long interruptions are of great importance. Transmission networks, as the most essential part of the power system, establish connection between production and consumption units. Because of the widespread use and passing through different geographical regions, power systems are exposed to various faults. These faults can cause disabling of power lines and interruption in power provision in some parts of the network.

Most faults occurring in Power Transmission Lines (PTLs) are of transient fault. Over voltages caused by thunder which create an arc along the insulator, comprise major part of transient faults. Such faults can be overcome through Single Phase Auto-Reclosing (SPAR), which promotes transient stability and increases the reliability of the system. Since, only the faulty phase is disconnected, more than half of the transmitted power transits through the two robust phases.

To reattach the disconnected phase, we must consider the time required to de-ionize the arc line. In the case of SPAR, this time depends on environmental conditions, system load before the fault occurrence, fault location and performance speed of the protection system, so that even determining the approximate value of a specific system is hard.

Since instability problems may threaten the system in case the Circuit Breakers (CBs) remains open for a long time, determining the accurate time is important. On the other hand, because of further insulation break down of the air in the arc position, if the CBs is closed before the last extinguishment of the secondary arc and spreading of the ionized air, the arc is reestablished. After repeating this process and unsuccessful reconnection of the CBs, the transient fault causes the line to be disconnected permanently. On the other hand, the reclosing process of permanent faults on high PTLs occurring close to power stations causes twisting fluctuations in the generator turbine system and damages equipment [1,2].

Comparative reclosing designs that have been considered recently carry out two tasks:

1. Differentiating the permanent fault from the transient type and prevent reclosing when the fault is permanent.
2. In the case of transient fault, performs the reclosing process after the last extinguishment by recognizing the extinguishing time of the secondary arc, so that it prevents unsuccessful reclosing.

Various methods are performed for comparative reclosing [3-15]. For instance, in [5], the RMS faulty phase voltage has been used. In [6], the power of current high frequency components of one of the two robust phases which contain the load current is used. The method of [7] is based on the behavior of low frequency components of the faulty phase voltage waveform. The method of [8] uses the main component of zero sequence power in both line terminals.

Neural network is proposed to carry out this task [9]. One of the disadvantages of neural network is the necessity of teaching it for each PTL along with considering the line and system parameters. Some references have used wavelet conversion [10] and some others have made use of wavelet conversion and neural network simultaneously [11]. In [11], a method is proposed which is based on fuzzy logic [12] where one of the shortcomings is the complexity of developing fuzzy relations.

As in transient faults and during secondary arc establishment, the faulty phase voltage has a high THD (Total Harmonic Distortion), in [13] THD of faulty phase voltage is used and the secondary arc extinguishment time is determined. Recently, methods such as [14] has been proposed that able to detect fault location with high accurate moreover diagnosing the extinguishing time of secondary arc.

In this paper a new method has been proposed that only by using sampling of voltage of faulted phase, carry out three tasks:

1. Diagnosing fault location
2. Diagnosing fault type (transient or permanent)
3. Diagnosing the extinguishing time of secondary arc.

Various simulations in EMTP/ATP environment have been shown that the proposed method is a comprehensive protective method for PTL.

2. Review of SPAR

To drive a suitable method for diagnosis of mention tasks, full study of SPAR for PTL is required. Figure 1 depicts the stages of a SAPR process. In Figure 1.a normal operation of the system is depicted. A Single Line to Ground (SLG) fault occurred (Figure 1.b). High amplitude short circuit current is passed through the wires (primary arc). After a short time, protective relays open the faulty phase. Primary arc is quenched by opening high voltage breakers completely. If the

fault type is transient, because of capacitive coupling between faulted and unfaulted phases, a lower amplitude in contrast to primary fault current is created (secondary arc) (Figure 1.c)).
The secondary arc is quenched by insulator deionization and after a specific time named “Dead Time” (Figure 1.d). Thereafter, reclosing relay transmits the reclosing signals to the faulted phase breakers and the breakers are closed (Figure 1.a). But, if the fault type is permanent, after opening faulted phase, the fault is not clear and so the SPAR process is stop in stage (c).

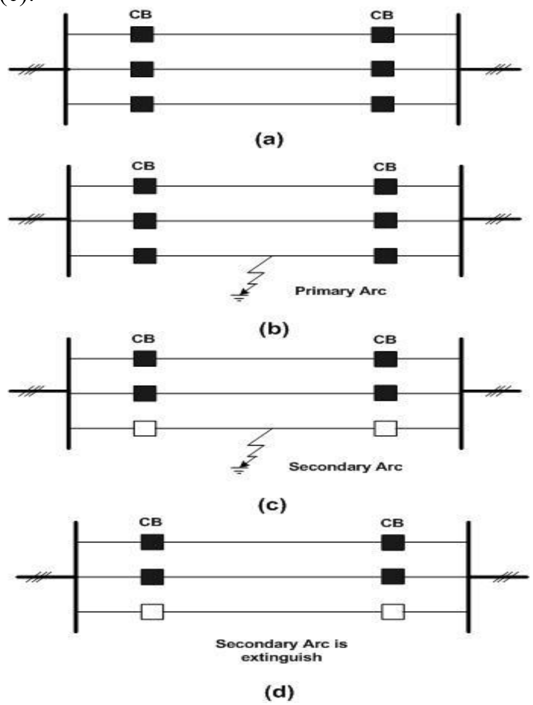


Figure 1. SPAR sequences of operation

3. Arc Modeling

During 50 years experience of using arc model many models and functional approaches have been developed. However a valid and standard approach has not been developed yet and precautious measures are taken in the application of these models. However rapid developments in this area, especially after introducing accurate digital measurement devices and appropriate computers, have resulted in several successful approaches.
Application of the arc modeling approaches consists the following steps:

- Choosing a model equation
- Experimentation with measuring voltage and current during the period that the arc and circuit have mutual effects.
- Computing the arc parameters.
- Numerical simulations of interruption processes in different circuits.

Choosing the model, measuring and computing parameters are not independent from each other and should be considered at the same time. Generally, increasing the number of free parameters increases the conformity and the need for more measurement data. This necessarily does not increase the ability of prediction. In order to predict the transient response in transmission systems, it is necessary to use accurate models with details, especially when they are in touch with faults appeared by the arc. These faults comprise a major part of transmission network faults. Complexity in the arc process makes it difficult to be modeled, because many factors such as the arc line, the amount of coolness and the geometric figure cannot be defined with high certainty.
In this paper we have used the experimental approaches [13] to obtain the actual model of the arc. By dividing the arc into two states, primary and secondary arc, we have obtained interesting results.

A. Dynamical Property of The Primary Arc

When a short circuit occurs between the insulator and the ground, an intense short circuit current passes through the primary arc during the fault continuation, thus the arc does not last long and its voltage appears at the two sides of the main column. Storm experimental [15] tests, are highly concerned with modeling the primary arc due to considering high current arcs. The dynamical property of this kind of arc that is created upon the fault occurrence can be considered as follows:

$$\frac{dg_p}{dt} = \frac{1}{T_p}(G_p - g_p) \qquad (1)$$

where g_p is the primary arc time variable conductance, T_p is the constant of time and G_p is the primary arc conductance that can be considered as the static property of the arc and is defined as follows:

$$G_p = \frac{|i|}{V_p L_p} \qquad (2)$$

where L_p is arc length, V_p is the parameter of voltage per primary arc length unit and i is the arc current. It is worth mentioning that even though G_p is taken as the static property of the arc, but due to the variation of i in the considered time zones, G_p takes a certain value in each time interval.
To obtain the constant of time T_p using the experimental curves in the primary arc dynamical property equation, we should proceed as follows:

$$T_p = \frac{\alpha I_p}{L_p} \qquad (3)$$

where I_p is the normalized peak current of the arc which is obtained using line computations, assuming that a SLG fault has occurred.
The amount of α is obtained from experimental curves.

B. Dynamical Property of The Secondary Arc

This arc is created after the functioning of the CBs. Secondary arc is very complicated and one of its outstanding features is the restoration of the arc that causes successive extinguishment of some parts of the arc and further functioning of it until the permanent extinguishment occurs. To model this state, Storm experiments [15] for low current arcs have been utilized. Thus, the secondary arc dynamical property is considered as follows:

$$\frac{dg_s}{dt} = \frac{1}{T_s}(G_s - g_s) \qquad (4)$$

where g_s is the secondary arc time variable conductance and G_s is the secondary arc conductance which is related to the secondary arc length and is defined as follows:

$$G_s = \frac{|i|}{V_s L_s(t_r)} \qquad (5)$$

Where t_r is the starting time of the secondary arc. Arc length variation (L_s) is related to the wind speed and speeds up to 1 m/s are calculated approximately as follows:

$$\frac{L_s(t_r)}{L_{S0}} = \begin{cases} 10t_r & t_r > 0.1s \\ 1 & t_r \le 0.1s \end{cases} \qquad (6)$$

According to the above equation, the arc length value depends on the arc restarting time after opening the main CBs and the insulator chain length (L_{so}).

Voltage parameter value per unit of length (V_s) and the time constant (T_s) are defined as follows:

$$V_s = 75\, I_s^{-0.4} \qquad (7)$$

$$T_s = \frac{\beta\, I_s^{-1/4}}{L_s(t_r)} \;,\; \beta = 2.5\times10^{-3} \qquad (8)$$

In secondary arc, the recovery voltage is obtained from the following experimental equation:

$$V_r(t_r) = \left[5 + 1620\frac{T_e}{(2.15 + I_s)}\right](T_r - T_e)h(T_r - T_e) \qquad (9)$$

where T_r is the starting time of the secondary arc. T_e is equal to T_r while the arc is conducting. When the arc is extinguished T_e is held in its previous value.

$$h(T_r - T_e) = \begin{cases} 1 & T_r > T_e \\ 0 & T_r \le T_e \end{cases} \qquad (10)$$

4. Under Study Power System

A power system is considered for this study whose data are from Hormozgan province, an area of Iran's national grid. A system element modeling includes nonlinear characteristics and frequency dependencies of the element and the wave impedances of the sources are also considered. Besides, earth resistivity is assumed to be 100 Ω.m. The line is modeled with Jmarti model and skin effect is also considered. The corresponding impedances of the network at two sides of the transmission line are demonstrated in Table 1.

Figure 2 demonstrates the single line diagram of the PTL simulated in the EMTP/ATP program. The PTL parameters are given as:

Positive and zero sequence resistance, inductance and capacitance are R_1 = 0.01526 Ω/km, L_1 = 0.8838 mH/km, C_1 = 0.0126 µF/km, R_0 = 0.04624 Ω/km, L_0 = 2.6563 mH/km, and C_0= 0.0043 µF/km, respectively. The distributed line parameter model of EMTP is intentionally selected to account for the unsymmetrical faults.

Table 1

IMPEDANCE DATA OF NETWORK

Impedance	$R_+[\Omega]$	$X_+[\Omega]$	$R_0[\Omega]$	$X_0[\Omega]$
Sending end	2.49	35.70	0.35	8.75
Receiving end	3.12	35.80	1.18	16.3

Figures 3 and 4 demonstrate voltage and current at the beginning of a 300 *km*, 400 *kV* transmission line when a transient fault occurs at t = 150 millisecond.

A SLG fault occurs on phase C at t = 0.150 second, secondary arc is started at t = 210 milliseconds

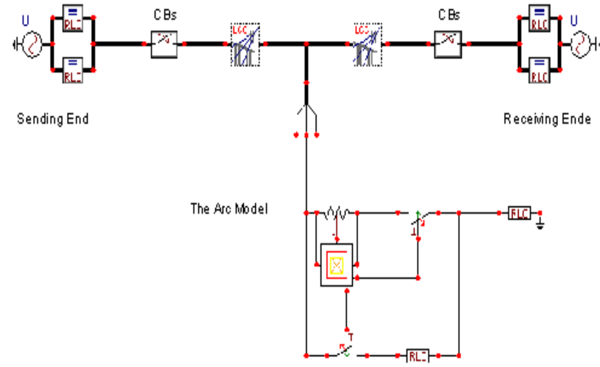


Figure 2. The under study power system

(Figure 3) and voiding phase C. After 940 millisecond from starting secondary arc (Dead Time), high voltage breakers are closed. As shown in Figure 3, fault period is divided into five periods: prefault (a), primary arc (b), secondary arc (c), quenching of arc (d) and post fault (e). Obviously, voltage waveform of the faulty phase is distorted compared to the sinusoidal waveform in the pre-fault condition. Moreover, this waveform is changed in secondary arc period. In addition, the voltage of the faulty phase starts increasing at the moment of quenching the secondary arc. This concept is the key point in calculating secondary arc period. The arc caused by faults is a high power arc in weather. The arc is essentially nonlinear and affected by some factors. An electric arc may be considered as an element in the power system and due to its resistive nature, a pure resistor. In short circuit studies and from viewpoint of accuracy, it is unavoidable to consider the fault arc. Therefore, arc can be considered as a harmonic source disturbing voltage waveform.

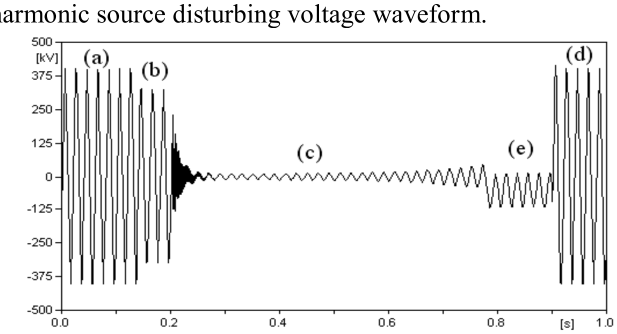


Figure 3. Voltage waveform of faulted phase at the beginning of line

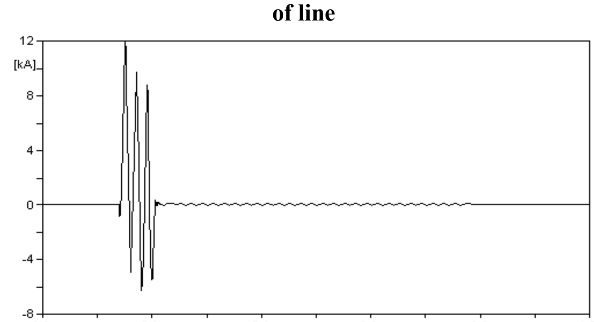


Figure 4. Current waveform of faulted phase at the beginning of line

5. New Criteria for Diagnising Fault Type and The Extinguishing Time of Secondary Arc

A new and simple approach is introduced in this paper to recognize the fault type (transient or permanent). This approach utilizes the inverse of the faulty phase first order voltage harmonic. Figure 5 shows the faulty phase voltage waveform for a transient fault along with $1/V_1$. It is clear that the voltage value is in terms of per unit. Besides the reasons will explain in section VII, the per unit voltage is utilized because it simplifies computations. Careful consideration of Figure 5 shows that for a voltage waveform the $1/V_1$ value equals 1 before the fault occurrence (because the value of V_1 equals 1 in this region). As soon as a SLG fault occurs at t = 200 millisecond and before opening the CBs at the two sides of the faulty phase, the value of $1/V_1$ begins to increase because the voltage waveform has dropped due to the SLG fault. Along with opening the CBs, because of the intensity of the created transient state, the value of$1/V_1$ increases dramatically so it reaches a final value (78 here). From this time on, because of the transient fault type and inherent property of the created secondary arc, the faulted phase voltage waveform increases to approach a sinusoidal waveform and this means that $1/V_1$ begins to decrease. This reduction continues so that the created secondary arc extinguishes thoroughly. It can be observed that from this time on, because of the recovery voltage $1/V_1$ begins to increase again. The final extinguishment of the secondary arc can be differentiated from this time. Therefore, in addition to recognizing the fault, this approach can recognize the secondary arc extinguishing time in an on-line method. Which means this approach is adaptive. Figure 6 shows the faulted configuration of the phase voltage in perunit along with $1/V_1$ (first-order voltage harmonic), for a permanent fault. Like the previous state, the SLG fault starts at t=200 millisecond and the quantity of $1/V_1$ equals 1 before the occurrence of the fault. As soon as the SLG fault occurs, just before the opening of the CBs at the two sides of the faulted phase, the quantity of $1/V_1$ begins to increase. While opening the CBs, $1/V_1$ begins to increase dramatically so it reaches a final state. Then, because of the nature of the permanent fault that causes the behavior of the voltage waveform which approaches the sinusoidal waveform, the quantity of $1/V_1$ remains approximately constant. As it is explained in the sequel, if the $1/V_1$ waveform remains constant after reaching the final state, the fault is permanent fault or else if it continues to decrease, the fault is transient fault. As was explained before, if the fault is of transient fault, considering Figs. 5 and 6 the fault type recognition algorithm and the secondary arc extinguishing moment are determined as follows: If the quantity $1/V_1[k]$ (the quantity $1/V_1$ at time k) begins to increase, which means that $((1/V_1[k]- 1/V_1[k\text{-}1])>0)$, an SLG fault has occurred and a disconnection command must be sent to the CBs at the two sides of the faulted phase. Then the quantity $(1/V_1[k]- 1/V_1[k\text{-}1])$ can be computed at any time. If this quantity is zero after some time $((1/V_1[k]- 1/V_1[k\text{-}1])=0)$, the fault is of permanent type otherwise if it is negative $(1/V_1[k]- 1/V_1[k\text{-}1])$ the fault is of transient type. If the fault type is permanent, the reclosure relay of the related phase must be locked so that it would not allow the CBs at the two sides of the faulted phase to close under any condition. If the fault type is transient, again $(1/V_1[k]- 1/V_1[k\text{-}1])$ can be computed at any time. The value of this expression is negative before the complete extinguishing of the secondary arc. The positive or zero value of this expression shows the extinguishing time of the secondary arc. At present, a reconnection command can be sent to CBs at the two sides of the faulted phase. The flowchart of this approach is shown in Figure 7.

6. Diagnosis of Fault Location

In previous section a new criterion was presented which recognizes the fault type in PTL and the extinguishing time of the secondary arc. An interesting application of the criterion mentioned above is presented in the sequel. As a matter of fact, it is shown that not only the fault type and the extinguishing time, but the fault occurrence location can be determined by the same criterion. This is a lateral and very important application, because in order to recognize the fault occurrence location, it is not necessary to sample and use the phase current.

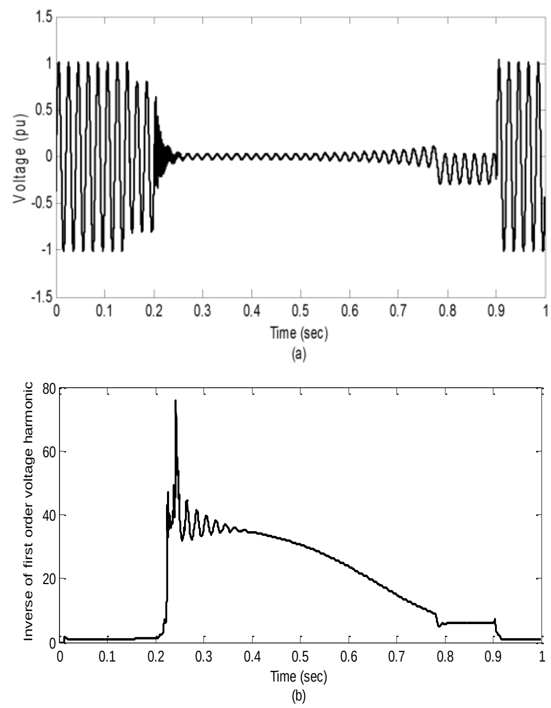
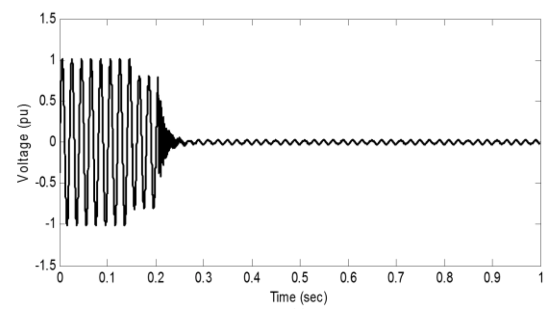


Figure 5. Voltage waveform of faulted phase at the Sending end of line along with 1/V1 for a transient fault



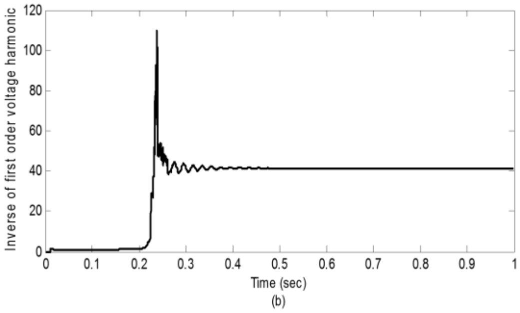


Figure 6. Voltage waveform of faulted phase at the Sending end of line along with 1/V1 for a permanent fault

In a study, three SLG faults were placed at different locatio ns in the PTL introduced in section IV. The fault locations were 25%, 50% and 75% far from the voltage measurement location (Sending end). Figure 8 only shows $1/V_1$ waveforms of the faulted phase for each of these states:

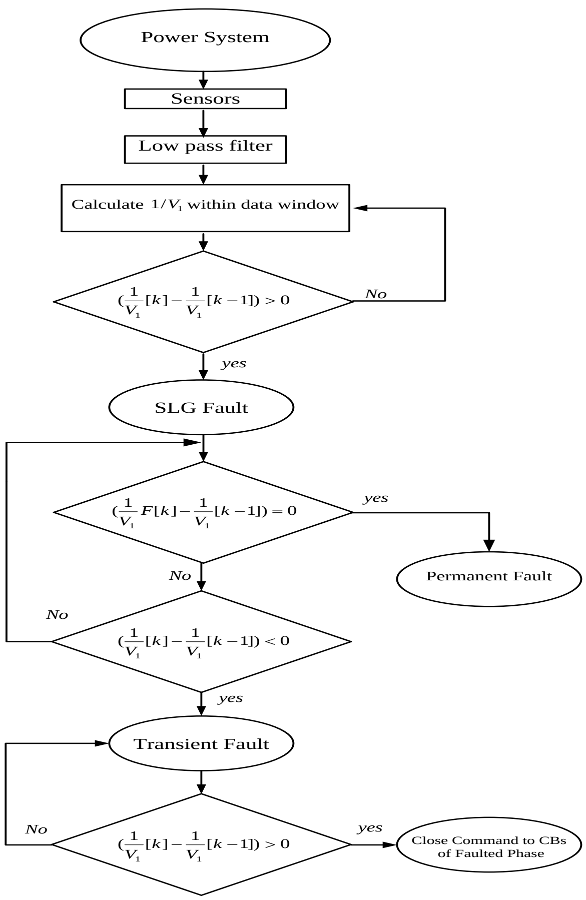


Figure 7. Flowchart of proposed method for diagnosing fault typeand the extinguishing time of secondary arc in PTL

Considering the criterion introduced in section V, it is clear that apart from the permanent type, this criterion reaches a final state after the fault occurrence. Looking at Figure 8 shows that this final state differs for the three fault types. Table 2 shows the fault type and its location along with the final index value for these faults.

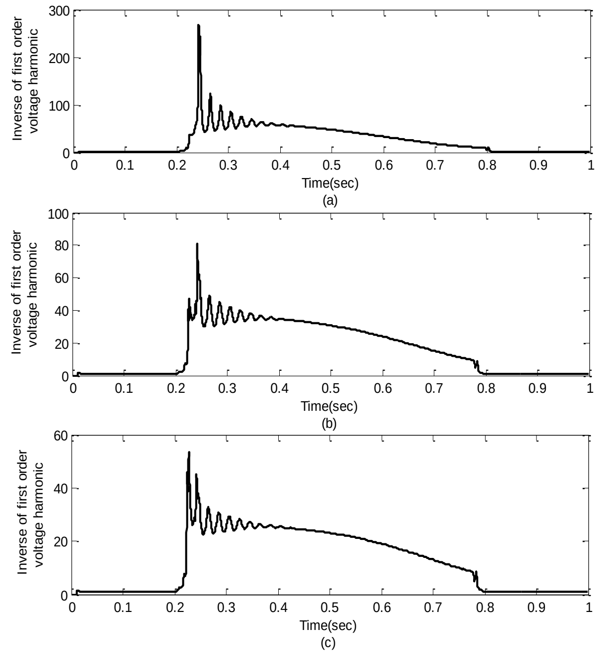


Figure 8. 1/V1 waveforms of the faulted phase for each of fault locations a) 25% b) 50% and c) 75% far from the voltage measurement location

Table 2

FAULT TYPE AND ITS LOCATION ALONG WITH THE FINAL INDEX VALUE FOR THREE FAULTS

The location of fault	Fault type	The value of the inverse of the faulty phase first order voltage harmonic
75 km	Transient	268.772
150 km	Transient	80.667
225 km	Transient	53.563

It is turned out that by getting far from the voltage measurement location, the final recommended index decreases gradually as the SLG fault occurs. Certainly, this behavior is predictable, because as the fault location gets far from the voltage sampling location, voltage drop decreases and this means that $1/V_1$ takes a smaller value. It is also observed that the reduction procedure is nonlinear; this is expected because the voltage drop is large at the nearest location, but it is very small at the farthest location.

As explained above, considering the simulation results, it is turned out that only by measuring the final recommended index value; the fault location can be estimated. The main problem is how to estimate the fault location and what factors can influence the recognition of the correct fault location. These cases are discussed in the following section.

7. SIMULATION AND RESULTS

Considering the simulations, it is determined that three factors can influence the correct recognition of the recommended criterion. These factors include: fault impedance, PTL voltage level and PTL length. In order to inspect the issue carefully, three different experiments have been carried out. In this section each of the experiments are studied separately.

A. Experiment I: Fault Location Impedance

The first factor that might influence this approach is the fault location impedance, that is, faults impedance. The faults occurred on the PTL are divided into two categories: HIF (High Impedance Fault) and LIF (Low Impedance Fault).

The HIF impedance value is significant. Because of the large fault location impedance value, comparing to the LIF faults a very small short circuit current will flow throughout the lines, which causes an insignificant voltage drop in the sampling location. In fact, because of its nature, recognizing these faults (HIF) is hard, although many approaches have been proposed by scientific researchers.

Since the studies carried out on reclosure only concern the LIF faults, and the fault location impedance is not considerable. Therefore it turns out from the simulation results that in case the SLG fault is of type LIF, the fault location impedance has no effect on recognizing the fault location using the proposed approach in this paper.

B. Experiment II: The PTL Voltage Level

The second factor pointed out, is the studied PTL voltage level. In studying the reclosure event it must seriously be considered that the PTL voltage level is a very important factor in the secondary arc distinguishing time, that is the dead time. For example, the equation below for estimating the dead time is presented in [5]:

$$t = 10.5 + \frac{kV}{34.5} \quad \text{Cycles} \qquad (11)$$

Where kV is the network or studied line voltage level and t is in terms of cycle in power frequency of 60 Hz. Certainly, the equation above regards the three phase reclosure. The time obtained for the SPAR is approximately twice the time obtained in the equation above. For example, in case the voltage level of a PTL equals 400 kV, the relative dead time equals 22 power frequency cycles or 0.36 seconds, whereas, if the PTL voltage level equals 765 kV, the relative dead time equals 32.67 power frequency cycles or 0.54 seconds.

In spite of the above, it can be concluded that the PTL voltage level is an important factor in the dead time. But as will be explained in the sequel, the PTL voltage level does not influence the fault location recognition using the proposed approach.

In this paper, in order to eliminate the transmission line voltage level the technique of introducing the measured voltage in per unit has been used. Besides the simplicity of computations, this approach has an interesting feature, that is, the elimination of the voltage level throughout the study. As was pointed out, because estimating the fault location requires the final index value introduced in section V, provided that the used voltage is the voltage in per unit, the PTL voltage level does not influence the determination of the final index value. The results of the simulation confirm this fact.

C. Experiment III: The PTL Length

The third significant factor in estimating the fault location via the proposed approach is the PTL length considered.

As was explained thoroughly in Experiment II, the occurrence of the SLG fault in a farther location from the voltage sampling point causes the final proposed index value to decrease. Therefore, it is concluded that as a result of modification of the PTL length, quantities obtained from the final proposed index value are totally different from previous values, causing the estimation of fault location to face difficulty.

In other words, in order to estimate the fault location (specially) in a single PTL, it is necessary to use the off-line data obtained for that line, which is not useful for another PTL. Therefore, it seems that this approach does not apply to all lines. It is shown in the sequel that this problem can be overcome and the method can be generalized.

In fact, similar to Experiment II, in this experiment, the perunited length is used. The perunited length is obtained from dividing the PTL length by its own length.

If an SLG fault occurs at the initial 0.6 of a 300 km PTL, it means the fault has occurred at the 180 km. In order to accurately inspect the influence of different lengths of PTLs, several simulations have been carried out in this experiment which will be explained in the sequel.

The simulations were carried out on two networks: 400 kV and 765 kV. The PTL lengths were assigned as follows: 300 km for the first, 400 km for the second and 500 km for the third situation. In each case, approximately 600 faults were considered at different locations from permanent and transient type. The simulations are carried out in EMTP. Table 3 shows some of the results of the simulation:

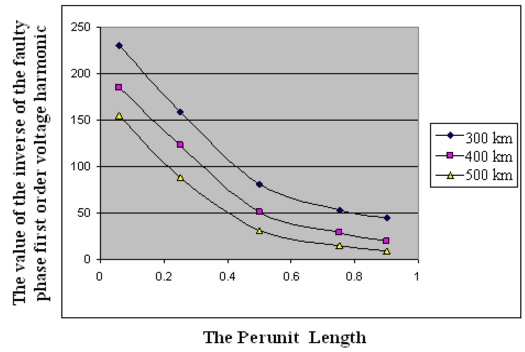
Table 3

SIMULATION RESULTS FOR EXPERIMENT III

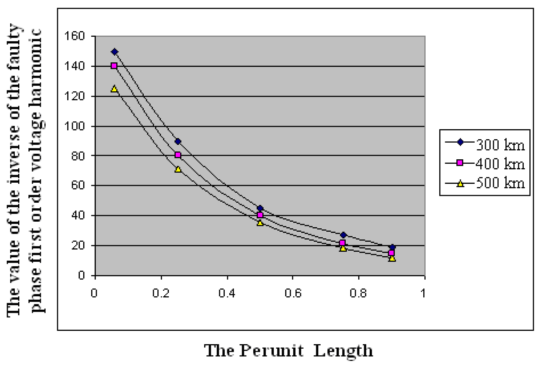
The level of Voltage of PTL	The Length of PTL	The Location of Fault	The Value of Inverse of The Faulty Phase First Order Voltage Harmonic
400 kV	300 km	75 km	158.772
		150 km	80.667
		225 km	53.563
	400 km	100 km	122.395
		200 km	51.161
		300 km	28.888
	500 km	125 km	87.790
		250 km	31.731
		375 km	14.634
765 kV	300 km	75 km	89.451
		150 km	45.507
		225 km	27.703
	400 km	100 km	80.107
		200 km	40.076
		300 km	21.496
	500 km	125 km	70.962
		250 km	35.342
		375 km	18.856

In order to observe the results clearly, the graphical form of Table 3 is shown in Figure 9, which presents the criteria proposed value in terms of the perunited length:

Considering Figure 9, the descending process of the proposed index is quite obvious in each case. Modifying the PTL length only causes the curve to move up or down.



(a)



(b)

Figure 9. The criteria proposed value based on perunit length a) The voltage level is 400 kV b) The voltage level is 765 kV

Comprehensive fault type recognition algorithm in PTL and the estimation of fault location.

The method proposed in this paper is a comprehensive algorithm for recognizing the fault type (transient or permanent), the time extinguishing of secondary arc and estimating the fault location in PTL.

To carry out these three tasks, the method samples the phase voltage only, which is a great advantage. Initially, it recognizes the SLG fault. Simultaneously, it recognizes the fault type and estimates the fault location. If the fault is from transient type, it also determines the extinguishing time of the secondary arc, in an on-line process. The method samples the voltage of each phase. It calculates the first order harmonic voltage waveform and samples the voltage simultaneously. In each time step, $(1/V_I[k]- 1/V_I[k\text{-}1])$ is computed. In case the quantity of this expression is positive, it means that an SLG fault has occurred in the related phase. By sending a disconnection command to the CBs at the two sides of the faulted phase, it keeps computing $(1/V_I[k]- 1/V_I[k\text{-}1])$, and the quantity of $1/V_I[k]$ is stored at each time step so that the final value is obtained. If the quantity of $(1/V_I[k]- 1/V_I[k\text{-}1])$, which is increasing, equals zero or else becomes negative then the value of $1/V_I[k]$ is considered as the final index value.

At this time, by referring to a look-up table (the criteria proposed value in terms of the perunited length are obtained from computer simulation for different power systems and stored in a lookup table), the fault location is estimated. If the value of $(1/V_I[k]- 1/V_I[k\text{-}1])$ equals zero, a locking command is sent to the reclosure relay or else if negative, it keeps computing $(1/V_I[k]- 1/V_I[k\text{-}1])$. In case the value of this expression alters from negative to zero or positive, it means that a reconnection command can be sent the CBs of the faulted phase.

Figure 10 shows the flow chart of the method. To examine the accuracy of the proposed approach and to compute the fault location estimation error, several experiments have been conducted. The results are shown in Table 4. It turns out that the error of this approach is less than 0.05 %.

8. CONCLUSION

In this paper, a new intelligent method based on harmonic analysis is proposed to that only by using sampling of voltage of faulted phase, carry out three tasks in PTL:

1. Diagnosis of fault type location
2. Diagnosis of fault type (transient or permanent)
3. Diagnosis of the time of extinguish of secondary arc.

Simulation results in EMTP/ATP environment have been shown that proposed method can carry out mention tasks correctly. This result is a reliable and accurate solution for fault type discrimination and fault location in high voltage PTLs and great advance in PTL protection.

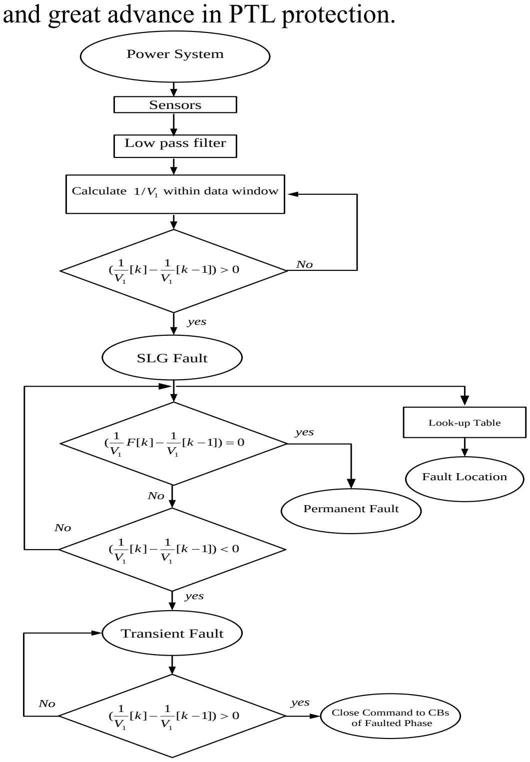


Figure 10.Flowchart of proposed method for diagnosing fault type, the extinguishing time of secondary arc and fault location in PTL

Table 4

SIMULATION RESULTS FOR DIAGNOSIS ABILITY OF PROPOSED METHOD

The Real Location of Fault (km)	Detection of Fault location by Proposed Method (km)	Detection of Fault Type by Proposed Method		Error (%)
		Transient	Permanent	
29	28.985	✓		0.05
58	53.976		✓	0.04
110.5	110.448	✓		0.047
180.7	180.629	✓		0.039
278	277.880		✓	0.043
The Voltage Level of PTL: 400 kV The PTL Length: 300 km				

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