

# Use of the PMU Infrastructure to Determine the Location of Short-circuit Power Lines

N Buryanina<sup>1</sup>, Yu Korolyuk<sup>2</sup>, M Koryakina<sup>2</sup>, K Suslov<sup>3</sup>, N Solonina<sup>3</sup> and E Lesnykh<sup>4</sup>

<sup>1</sup>Chukotka Branch of North-Eastern Federal University named after M.K. Ammosova, Studencheskaya St., 3, Anadyr, 698000, Russia

<sup>2</sup>Department of General Disciplines, Chukotka Branch of North-Eastern Federal University named after M.K. Ammosova, Studencheskaya St., 3, Anadyr, 698000, Russia

<sup>3</sup>Department of Power Supply and electrical engineering, Irkutsk National Research Technical University, Lermontova St., 83, Irkutsk, 664074, Russia

<sup>4</sup>Siberian Transport University, Dusi Kovalchuk St., 191, Novosibirsk, 630049, Russia

E-mail: bns2005\_56@mail.ru

**Abstract.** One of the serious problems of the normal operation of power systems is a violation of efficiency of overhead power lines. Short circuits are especially dangerous. The probability of occurrence of faults is reduced, but not reduced to zero, with an increase in the quality of installation, reliability, insulators and conductive materials. The proposed method is based on the fact that the short circuit current at the beginning of the transmission line of power electric system depends on the distance (location) to the fault point. This article discusses the following topics: theoretical possibility of fault location on the time of arrival of the responses to the beginning and end of the line, the development of the algorithm processing of information, the development of the block diagram of additional devices that are not included in the phasor measurement units (PMU). The article gives an example of the application of this technique.

## 1. Introduction

Reduction in losses for the economic entities by the improvement in reliability and power supply quality is a topical task. At present some measures are taken to meet the requirements on reliability and quality of power supply. A serious problem facing electric power systems is failure of overhead and cable transmission lines [1-4]. Short circuits in transmission lines represent a particular danger. The probability of short circuits decreases but does not disappear with an increase in the quality of installation, reliability of insulators and conducting materials of transmission lines. Short-circuits cause disconnection of individual consumers and entire regions. This imposes high requirements on reliability and fast operation of relay protection. However, if a short circuit has occurred and relay protection has successfully operated there remains the task to promptly and where possible accurately detect coordinates of the short circuit. This, in the final analysis, allows us to quickly restore the transmission line and place it into operation which in turn minimizes economic losses.

## 2. The state of the research

Recently, power electric systems are one of the most dynamic sectors which employ the advances of fundamental and applied knowledge. Right now the opportunity has appeared to pay special attention



to the global system of universal time. Even two decades ago the universal time was the province of special organizations dealing with space, industry, defense, astrophysics, etc. The adoption of the Global positioning system has made it possible to receive the standard time signals at an individual substation and use this precise time for solving a wide range of problems. Based on these technologies it has become possible to develop and implement adopt intelligent power electric systems, Smart Grids and PMU.

In the electric power industry there are two possible types of research: active and passive experiments [5-7]. As an active experiment, it is possible to study the error of the transmission line with the help of short current pulses and an estimate of the response time. This time depends on the distance between the source end of the transmission line and a short circuit point. A disadvantage of active experiments is the necessity to apply special equipment and the time to get prepared to the experiment. There is a great variety of methods for detection of overhead and cable line fault locations [5-12, etc]. The pulse method is based on measuring time intervals between the moment of transmitting a probe pulse of alternating current and the moment of receiving a reflected pulse from the fault location. To make measurements by the method of oscillation discharge the voltage supplied to the faulted cable conductor is gradually raised to the voltage of cable fault. The loop method is based on measuring resistances by the direct current bridge. The capacitance method suggests measuring capacitance of a broken conductor by measuring bridges. The acoustic method supposes creation of a spark discharge at the fault location and listening to sound vibrations that occur above the fault point. There is also the induction method and others [5].

Passive experiment however makes it possible to use modern high speed digital technologies, and obtain data directly from the signals associated with the processes that occur in transmission lines after a short circuit, i.e. in real time. Such data can be the instant values of current and voltage, voltage and current phases. One of the possible solutions to this problem is related to the dependence of currents at the source end of a line on the distance to the short circuit point [13-17]. However, there are reasons that decrease the accuracy of the fault point detection, namely: variations in the effective values of voltage at the transmission line connection point, as well as the dependence of current amplitude on voltage phase at the time of short circuit. We suggest the use of time factors related to the final velocity (vF) of power (electric signal) transmission along the considered line. It is obvious that there will be a response (echo) spreading in both directions along the line, that will have the form of a front of increasing or declining voltage or current and the time of the response arrival at the source end or load end of the line can be recorded with a high accuracy.

This paper focuses on the following issues:

- Consideration of possibility of determining the fault place on the basis of time when responses come to the source end and load end of the transmission line;
- Determination of the possibility of using the available infrastructure of PMU to determine the above time instants and transfer the data to the processing center;
- Development of an algorithm for primary data processing, obtained from primary measuring devices;
- Development of a block diagram of additional devices which are not envisaged within PMU.

### 3. The main principles of the approach

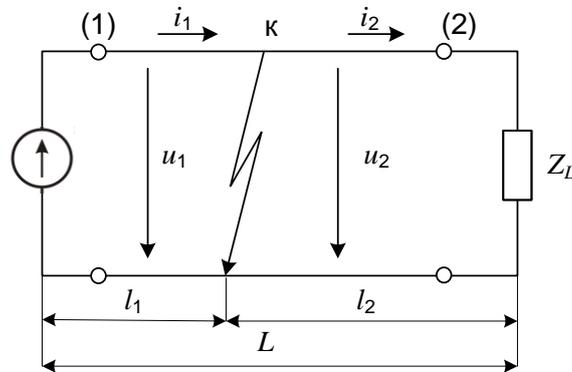
We will consider the idea of the suggested method on the example of a transmission line without branches with one-way supply.

Figure 1 shows the calculation scheme for the determination of the short circuit place, taking into consideration the time of signal arrival at the source and load ends of the line.

Let the short circuit occur at time  $t_{sc}$  at point K (Figure 1) and a transient process start. For the sake of simplification we make the following assumptions:

- voltage at point K drops to zero;
- length of the considered line is much shorter than the length of the incident current wave  $\lambda$  ( $\lambda \approx 6000$  km at the frequency of 50 Hz);

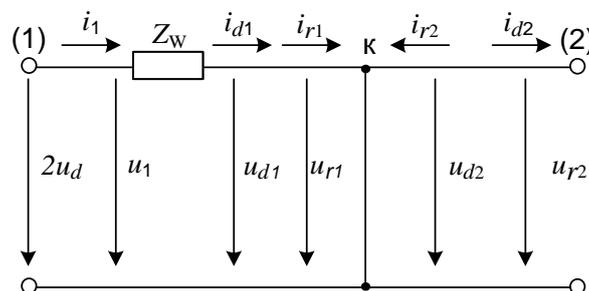
- the instant values of current and voltage in the steady state are constant along the whole line.



**Figure 1.** Design scheme of a short circuit in a line.

In Figure 1:  $L$ -length of the transmission line;  $l_1, l_2$  – distances from the short circuit point to the source and load ends of the transmission line, respectively;  $i_1, i_2, u_1, u_2$  – current and voltage of the first and second sections of the line, respectively.

Figure 2 presents a model of the line with lumped parameters for the calculation of transient process in the line with distributed parameters.



**Figure 2.** Model of the transmission line for calculation of transient process.

In Figure 2:  $Z_w$ - wave impedance of the line;  $i_{d1}$  - incident current wave of the first section, i.e. from the source end to the short circuit point;  $i_{r1}$  – reflected current wave of the first section;  $u_{d1}$ – incident voltage wave of the first section;  $u_{r1}$  – reflected voltage wave of the first section;  $i_{d2}$  - incident current wave of the second section, i.e. from the short circuit point to the load end of the line;  $i_{r2}$  – reflected current wave of the second section;  $u_{d2}$  – incident voltage wave of the second section;  $u_{r2}$  – reflected voltage wave of the second section.

It is easy to see from the model that at time  $t_{sc}$ :

$$i_{r1} = i_{d1} \text{ and } u_{r1} = -u_{d1}$$

Thus, a positive current wave front and a negative voltage wave front travel at velocity  $v_F$  in the direction from point K to the source end of the line. The fronts can be detected with the aid of current and voltage sensors. Time  $t_1$  of their arrival at the source end of the line can be recorded with high accuracy thanks to the clock showing the time synchronized with the universal time.

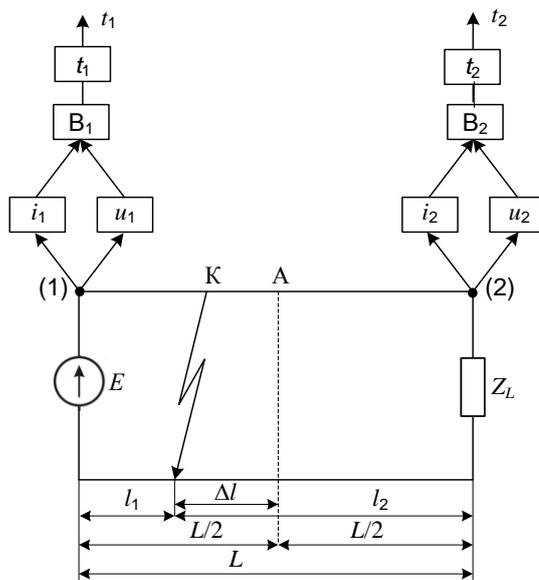
At the second section of the line there is also a transient process. At time  $t_{sc}$  current  $i_2$  and voltage  $u_2$  at the beginning of the second section vanish which means that

$$i_{d2} + i_{r2} = 0, i_{r2} = -i_{d2}$$

$$u_{d2} + u_{r2} = 0, u_{r2} = -u_{d2}$$

Hence, from point K negative fronts of current and voltage travel to the load end of the line. Time  $t_2$ , when these fronts arrive at the load end of the line can be recorded with the aid of current and voltage sensors as well as with high precision clock.

Let us show that knowing  $t_1$  and  $t_2$ , we can detect the place of short circuit. To this end we will consider a geometric model of the short-circuited transmission line. The technique of identifying the short circuit place is explained in Figure 3.



**Figure 3.** A scheme of devising an algorithm for determining the place of point K in transmission line.

In Figure 3: (1), (2) are the sites at which the chronometers ( $t$ ) and primary current ( $i$ ) and voltage ( $u$ ) sensors are installed; A – geometric center of the line; B – modules for processing the data from current and voltage sensors;  $\Delta l$  – distance from the center of Line A to the short circuit point K.

Using this scheme we determine  $\Delta t_1$  - the time of wave propagation from the short circuit point to the source end of the line:

$$\Delta t_1 = \frac{l_1}{V_\phi}$$

In the same way we find  $\Delta t_2$  - the time of wave propagation from the short circuit point to the load end of the line:

$$\Delta t_2 = \frac{l_2}{V_\phi}$$

Express time  $t_1$  of the signal (response) arrival at the source end of the line through the short circuit time:

$$t_1 = t_{sc} + \Delta t_1$$

Similarly find time  $t_2$  of the response arrival at the load end of the line:

$$t_2 = t_{sc} + \Delta t_2$$

Determine the difference between the time of response arrival at the source end of the line and the time of response arrival at its load end:

$$t_1 - t_2 = \Delta t_1 - \Delta t_2 = \frac{l_1}{V_\phi} - \frac{l_2}{V_\phi} = -\frac{2\Delta l}{V_\phi}$$

and finally determine  $\Delta l$

$$\Delta l = -\frac{(t_1 - t_2)V_\phi}{2} \quad (1)$$

Knowing  $\Delta l$ , we find  $l_1$  and  $l_2$  by the equations

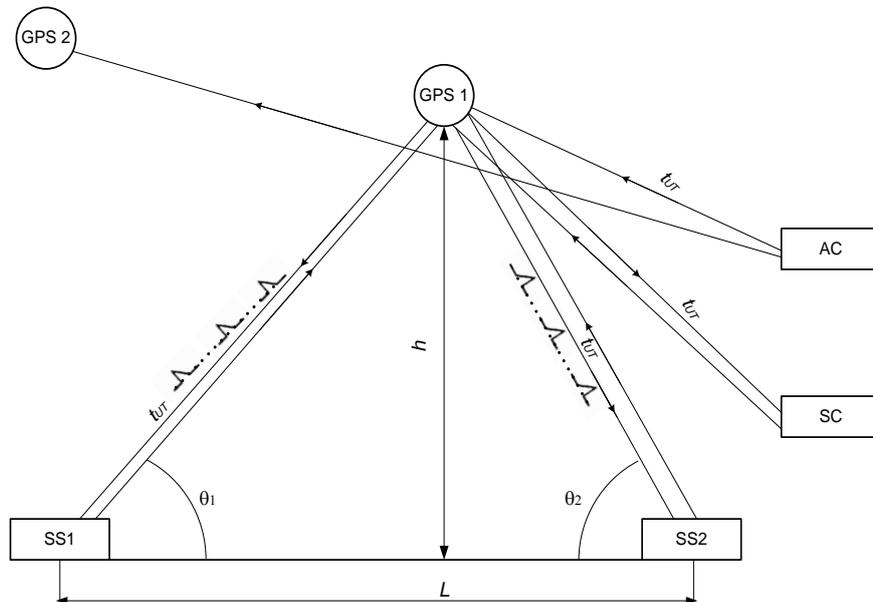
$$l_1 = \frac{l}{2} - \Delta l, \quad (2)$$

$$l_2 = \frac{l}{2} + \Delta l \quad (3)$$

If point K is closer to the source end of the line (to the left of point A), then  $\Delta l > 0$ . If point K is closer to the load end of the line, then  $\Delta l < 0$ .

When the time aspect is taken into consideration the issue of accurate determination of the time instants  $t_1$  and  $t_2$  is particularly important.

We suggest using the available infrastructure of PMU (Figure 4). PMU make it possible to take phasor measurements of currents and voltages at the given points of the power system [18, 19].



**Figure 4.** PMU infrastructure. (where SS1- feeding substation; SS2- receiving substation;  $L$ - length of the line; AC- atomic clock; GPS1, GPS2 – satellites sending time signals; SC – control centre; SS1, SS2 – network substations;  $t_{UT}$  – time pulse of the atomic clock;  $h$  – height of the satellite above the Earth in the area, where the substations are located;  $Q_1, Q_2$  – angles at which the satellite is seen from SS1 and SS2, respectively).

Phasor measurement implies simultaneous measurement of both the effective value and the phase of current and voltage. These parameters allow us to calculate current values of transmitted power, voltage drops in the sections of the transmission line, power loss in the transmission line, etc. Meas-

urement of effective values and phases of current and voltage, although possible, have not become widespread, since the control of the system under dynamic operating conditions requires that the data be definitely connected with the universal time. For instance, in order to determine losses in the line we should simultaneously measure active power at the source and load ends of the line precisely at the same time.

The time measurement resolution of PMU is not sufficient to accurately determine the time of the event. Therefore, at the measurement points we should form our own time (count) pulses with a short time interval of, for example,  $10^{-6}$  seconds, using additional devices.

Consider the use of the PMU and additional devices for accurate determination of time  $t_1$  and  $t_2$ . These pulses are formed by the pulse generators installed in modules  $B_1$  and  $B_2$ , and received at the input of the pulse counters located in modules  $t$ . The pulses are generated with the same frequency. At the outputs of modules  $t$  we obtain  $t_1$  and  $t_2$ , respectively, in the following form:

$$t_1 = t_{gps} + ndt \quad (4)$$

$$t_2 = t_{gps} + mdt \quad (5)$$

where  $t_{gps}$  – a synchronizing pulse from GPS satellite, that contains complete information about the universal time, namely: year, month, day, hour, minute, second, milliseconds;

$n, m$  – number of count pulses from the arrival of  $t_{gps}$  to the moment, when the response to the short circuit is received at the source end and load end of the line, respectively.

We can determine the difference between the time the responses arrive at the source end of the transmission line and the time they arrive at its load end, using expressions (4) and (5):

$$t_1 - t_2 = (n - m)dt \quad (6)$$

Knowing  $t_1$  and  $t_2$ , we find  $\Delta l, l_1, l_2$  according to expressions (1), (2), (3).

#### 4. Results

Consider a short-circuit of line with equal parameters in phases. At a short-circuit point, in the event of a ground fault, instantaneous phase voltage drop occurs. This causes the appearance of rectangular waves moving from the point of short circuit to both sides. A line with phase equal parameters can be described in a transient process by three independent channels –  $\alpha, \beta$  and 0. And the parameters of the line in the channels  $\alpha$  and  $\beta$  are equal to the parameters in the positive and negative sequences, and the parameters in the zero channel are identical with the parameters of the zero sequence.

Line parameters for different channels with a particular phase A are defined as

$$u_0 = \frac{u_a + u_b + u_c}{3}, \quad i_0 = \frac{i_a + i_b + i_c}{3} \quad (7)$$

$$u_\alpha = u_a - u_0, \quad i_\alpha = i_a - i_0 \quad (8)$$

$$u_\beta = \frac{u_b - u_c}{\sqrt{3}}, \quad i_\beta = \frac{i_b - i_c}{\sqrt{3}} \quad (9)$$

The proposal consists in fixing the difference in the appearance times at the installation site of protection through the channels  $\alpha$  and  $\beta$ . Consider a specific 220 kV line with AS-120 wire.

$$Z_\alpha = j0,43 \Omega/\text{km}, \quad Y_\alpha = 2,65 \cdot 10^{-6} \text{ S}/\text{km}$$

$$Z_0 = j1,2 \Omega/\text{km}, \quad Y_0 = 1,94 \cdot 10^{-6} \text{ S}/\text{km}$$

The constants for distribution channels are:

$$\beta_{\alpha} = \sqrt{x_{\alpha} b_{\alpha}} = 1,067 \cdot 10^{-3} \text{ rad/km}$$

$$\beta_0 = \sqrt{x_0 b_0} = 1,526 \cdot 10^{-3} \text{ rad/km}$$

Velocities of wave motion along channels:

$$V_{\alpha} = \frac{\omega}{\beta_{\alpha}} = 2,943 \cdot 10^{-6} \text{ km/s}$$

$$V_0 = \frac{\omega}{\beta_0} = 2,059 \cdot 10^{-6} \text{ km/s}$$

One kilometer the wave on the zero channel moves for a time - 4.86 ms, on channel  $\alpha$  - for a time - 3.4 ms. The distance from the place of measurement of the time of appearance of wave fronts is equal to:

$$L_{cs} = \frac{t_{\alpha} - t_0}{4,86 - 3,4}$$

Thus, it is possible to determine the point of a short circuit on the line with one-sided fixation of waves.

## 5. Conclusion

Other The proposed method is very promising, since it mainly uses PMU devices, and the costs related to the development and use of additional devices are insufficient. This is due to the fact that it is proposed to use the existing infrastructure of power systems.

It is suggested that the moments of time and information transmission to the processing center should be determined with the help of PMU, up-to-date tools of digital communication and UT system.

We propose that the structural schemes of auxiliary devices, which are not foreseen in PMU, should be added to the available tools.

This method allows to determine the location of the short-circuit in real time. Studies have shown that this method has very high accuracy.

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## References

- [1] Yang Z, Zhong H, Xia Q and Kang C 2016 Optimal transmission switching with short-circuit current limitation constraints *IEEE Transactions on Power Systems* **31(2)** 1278-88
- [2] Chai Y, Jiang C, K Zhang and S Xu 2016 Safe operation improvement of an electrical power system by superconducting fault current limiters *Chinese Control and Decision Conf., CCDC* (Yinchuan, China) pp 28-30
- [3] Gao F, Ai S, Ding R and Huang Y 2015 Development and experiment of fast breaker-type fault current limiter *5th Int. Conf. on Electric Utility Deregulation and Restructuring and Power Technologies, DRPT* (Changsha, China) pp. 1790–1794
- [4] Phadke A, Wu Z and Zora L 2015 Simultaneous transmission line parameter and PMU measurement calibration *IEEE Power & Energy Society General Meeting* (Denver, USA) pp 7286115
- [5] Ferreira V H, Zanghi R, Fortes M Z, Sotelo G G, Silva R B M, Souza J C S, Guimarães C H C and Gomes Jr S 2016 A survey on intelligent system application to fault diagnosis in electric

- power system transmission lines *Electric Power Systems Research* **136** 135-53
- [6] Mohamed E A and Talaat H A 2010 Khamis Fault diagnosis system for tapped power transmission lines *Electric Power Systems Research* **80** 599-613
- [7] Suslov K V, Solonina N N and Smirnov A S 2011 Smart Grid: A new way of receiving primary information on electric power system state *2nd IEEE PES Int. Conf. and Exhibition on Innovative Smart Grid Technologie* (Manchester, UK) pp 6162654
- [8] Bahmanyar A, Jamali S, Estebasari A and Bompard E 2017 A comparison framework for distribution system outage and fault location methods *Electric Power Systems Research* **145** 19-34
- [9] Rafinia A and Moshtagh J 2014 A new approach to fault location in three-phase underground distribution system using combination of wavelet analysis with ANN and FLS *Int. J. of Electrical Power & Energy Systems* **55** 261-74
- [10] Gururajapathy S S, Mokhlis H and Illias H A 2017 Fault location and detection techniques in power distribution systems with distributed generation: A review *Renewable and Sustainable Energy Reviews* **74** 949-58
- [11] Gazzana D S, Ferreira G D, Bretas A S, Bettiol A L, Carniato A, Passos L F N, Ferreira A H and Silva J E M 2014 An integrated technique for fault location and section identification in distribution systems *Electric Power Systems Research* **115** 65-73
- [12] Liao Y 2011 Generalized fault-location methods for overhead electric distribution systems *Trans. Power Deliv* **26** 53–64
- [13] Gilany M, El Din E S T, Aziz M M A and Ibrahim D K 2005 An accurate scheme for fault location in combined overhead line with underground power cable *IEEE Power Eng. Society General Meeting* (San Francisco, USA) pp 489308
- [14] Hajjar A A, Mansour M M and Talaat H A 2004 High-phase order power transmission lines relaying approach based on the wavelet analysis of the fault generated traveling waves *39th Int. Universities Power Eng. Conf. UPEC 2004* (Bristol, UK) vol 2 pp 847660
- [15] Ferreira G D, Gazzana D S, Bretas A S and Netto A S 2012 A unified impedance-based fault location method for generalized distribution systems *2012 IEEE Power and Energy Society General Meeting* (San Diego, CA, USA)
- [16] Wang C, Zhang B, Li G, Yan L, and Zhao J 2011 One practical method of fault location for transmission lines based on dual-voltage fault components *Int. Conf. on Electrical and Control Eng.* (Yichang, China) pp 6057787
- [17] van Erp F T G, van Riet M J M, van Rasing J F G, Provoost F and van Deursen A P J 2005 Modelling and live measurements of step and touch voltages at LV customers in urban areas caused by MV faults *CIGRE 18th Int. Conf. and Exhibition on Electricity Distribution* (Turin, Italy) pp 0203
- [18] Suslov K V, Stepanov V S and Solonina N N 2014 PMU for detection of short-circuit point in the transmission line *3rd Int. Conf. on Smart Grids and Green IT Systems SMARTGREENS Barcelona, Spain*) pp 63-7
- [19] Suslov K V, Stepanov V S and Solonina N N 2012 Improving the reliability of operation Microgrids *IEEE Int. Energy Conf. and Exhibition (ENERGYCON)* (Florence, Italy) pp 6348275