PMU for Detection of Short-circuit Point in the Transmission Line

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Abstract: One of the challenges facing energy systems is failure of overhead and cable transmission lines. Short circuits pose a particular danger. The improvement of the quality of installation, and reliability of insulators and conducting materials decreases the probability of short circuits but does not eliminate it. Short circuits result in disconnection of certain companies and even regions. The suggested method is based on the fact that the short circuit current at the source end of the line depends on the distance to the point of short circuit. The paper considers the following issues: theoretical possibility of detecting the point of fault on the basis of time when the short circuit response arrives at the source and load ends of the line; development of an algorithm for primary data processing, development of a structural scheme of additional devices which are not envisaged within phasor measurement units.

1 INTRODUCTION

Electric power industry is one of the most dynamic sectors which employs the advances of fundamental and applied sciences. At this very stage special attention is paid to the global system of universal time. Even two decades ago the universal time was the province of special organizations dealing with space, industry, defence, 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 adopt intelligent electric systems, Smart Grids, and phasor measurement units (PMU).

A serious problem facing energy systems is failure of overhead and cable transmission lines. Short circuits 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. Short circuits lead to disconnection of individual consumers and the 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 end allows us to quickly restore the transmission line and place it into operation which in turn will minimize economic losses.

There can be two types of research in the electric power industry: active and passive experiments. An active experiment can be exemplified by probing the faulty transmission line with the help of short pulses of current and assessing the response time. This time depends on the distance between the source end of the 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. Let us enumerate them in brief.

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

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also the induction method and others.

Passive experiment however makes it possible to use modern high speed digital technologies, and obtain data (instant values of current and voltage, voltage and current phases) directly from the signals associated with the processes that occur in transmission lines after a short circuit, i.e. in real time. 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 (Gilany, 2005, Hajjar, 2004, Ferreira, 2012, Chengjiang Wang, 2011, Provoost 2005, Suslov 2012). 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. The authors suggest the use of time factors related to the final velocity (v_F) of power (electric signal) transmission along the transmission 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.

The paper focuses on the following issues:

- Consideration of the theoretical possibility of determining the fault place on the basis of time when responses come to the source end and load end of the 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;

Development of a block diagram of additional devices which are not envisaged within PMU.

2 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 (Fig.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 λ (λ≈5000 km at the frequency of 50 Hz).

We can also assume that the instant values of current and voltage in the steady state are constant along the whole line.

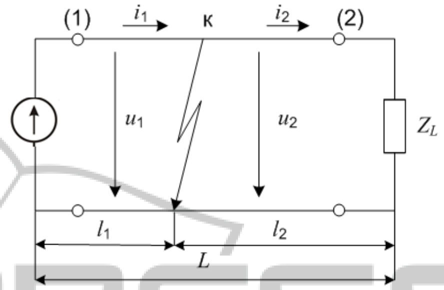

Figure 1: Design scheme of a short circuit in a line.

In Figure 1: L-length of the line; l_1, l_2 – distances from the short circuit point to the source and load ends of the 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.

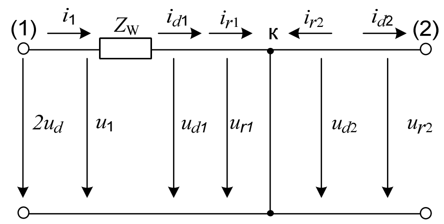

Figure 2: Model of the line for calculation of transient process in the line

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.

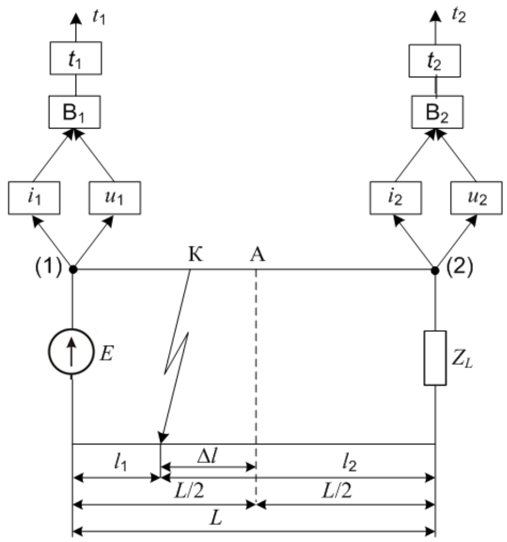

Figure 3: A scheme of devising an algorithm for determining the place of point K.

In 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; Δl – distance from the center of Line A to the short circuit point K.

Using this scheme we determine Δt_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 Δt_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 Δl

$$\Delta l = -\frac{(t_1 - t_2)\,V_\Phi}{2} \qquad (1)$$

Knowing Δl, we find l_1 and l_2 by the equations

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

$$l_2 = \frac{l}{2} - \Delta l \qquad (3)$$

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 phasor measurement units (Fig. 4).

Phasor Measurement Units (PMU) make it possible to take phasor measurements of currents and voltages at the given points of the power system. 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. In fact, the measurement of effective values and phases of current and voltage is not a new problem. However, such measurements, 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.

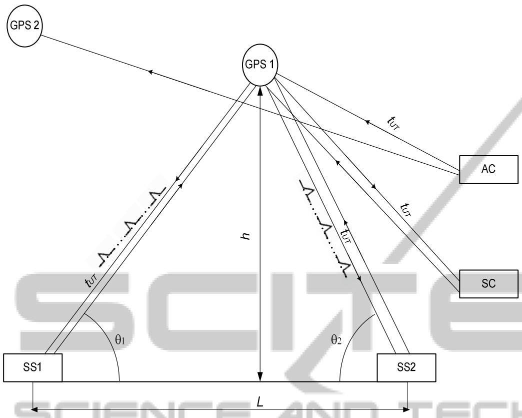

Figure 4: PMU infrastructure. (where SS1- feeding substation; SS2- receiving substation; *L*– length of the line; AC- atomic clock; GPS1, GPS2 – satellites sending time signals; SC – control center; SS1, SS2 – network substations; t_{UT} – time pulse of the atomic clock; *h* – height of the satellite 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.

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^{-9} 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 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):

$$t_1 - t_2 = (n - m)dt$$

Knowing t_1 and t_2, we find Δl, l_1, l_2 according to expressions (1), (2), (3).

3 CONCLUSIONS

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 method allows to determine the coordinates of the damage in real time. The error is not more than 50 meters. This figure will be adjusted to the experiments conducted.

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