ELECTRONICS AND ELECTRICAL ENGINEERING
ISSN 1392 – 1215 2011. No. 6(112)
ELEKTRONIKA IR ELEKTROTECHNIKA

SYSTEM ENGINEERING, COMPUTER TECHNOLOGY
T 120
SISTEMŲ INŽINERIJA, KOMPIUTERINĖS TECHNOLOGIJOS

Characteristics of Fault Detection System for Smart Grid Distribution Network

S. Gudzius, L. A. Markevicius, A. Morkvenas
Department of Electric Power Systems, Kaunas University of Technology,
Studentu str. 48, 51367 Kaunas, Lithuania, phone: +370 37 300283, e-mail: saulius.gudzius@ktu.lt

crossref http://dx.doi.org/10.5755/j01.eee.112.6.461

Introduction

Smart Grid is the electric power network which is more reliable, more secure, more economic, environmentally friendly and safer. According to the European Regulators Group for Electricity and Gas the smart grid is an electricity network that can efficiently integrate the behavior and actions of all users connected to it –generators, consumers and those that do both – in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety. Smart power grid combines the traditional power supply technology, modern communication systems and information technologies extended by the new network state estimation and control algorithms. New generation power networks must be flexible and essentially eliminate the divide between the power generators, power grid operators and consumers.

Generally, the smart grid is the vision of the future electric power network with high density of the distribution generation and high level of electric power supply reliability.

Some of the smart grid technologies are in the development phase while others are ready for using or have already been applied. But the main purpose of all smart grid technologies is to establish technical feasibilities for the network operator to provide reliable service to market participants, taking into account the reliability level of the main elements of the electrical network. The existing electric power distribution network has the following peculiarities:

1. Mixed structure of the network: overhead lines and cable lines;
2. Full compensation of the one phase to ground fault and significant asymmetry of the phase voltage;
3. Big number of events in the network such as temporary one phase to ground faults, electrical breakdown of the insulator;
4. Significant currents of the higher harmonics;
5. Intensive partial discharges in the cable lines which have significant impact on the cable aging processes;
6. Growing number of the consumers and generators at the distribution level.

For the power distribution network with such characteristics the new model of smart grid should be created with the following functions:

1. Fast recognition of the network state and regime that includes the fast registration of the voltages and currents during an event in the network, the registration of the components of the higher harmonics, fast data selection and analysis, multi coordinate recognition technology of the fast electromagnetic transients;
2. Fast and secure selected data transmission to the higher level of the power network control system;
3. The prognosis of indexes of the electric power quality and electric network reliability for the decision making;
4. Data analysis for the optimal network reconfiguration according to the current network state and regime;
5. The development of the smart relay protection devices.

Sometimes the smart grid is described as the compound of computer intelligence and fast communications with the electro-technical basement. For the utilization of the possibilities of this structure the new power network control systems should be created.

In this topic the principles of the fault detection, location and isolation system for the smart grid are described and appropriate methods for one phase to ground fault location are proposed.

The structure of the fault location system for the smart electric power distribution network

The key challenges of the smart grid networks are to evaluate the processes taking place in the electric power network, recognize them and make appropriate control actions. According to the proposed model of the smart grid, the location and insulation of the fault is carried out automatically. In case of the fault in the smart grid the fully automated control system in the minimum possible time should carry out the actions to recognize the fault type, to find its location, change the network configuration so that the minimum number of the higher reliability group consumers does not remain connected to the network and electrical network maintenance staff obtains the information about the fault type, location and scale. For this purpose, the fault recognition and isolation system can be used. It has the following structure:

- Fast registration of the processes and indexes (faulted line, fault place, stationary and transient processes of voltages and currents);
- Transmit the registered data to the control terminal;
- Control terminal, which has permanent communication link with dispatching center, stores the registered data, performs analysis of the situation and selects the optimal post fault configuration of the electricity distribution network;
- Control terminal independently or after permission of the dispatching center performs necessary control actions or network switching.

The system continually traces the state of the network and its elements and periodically performs the analysis of the reliability indexes of the electric power network.

Challenges of smart grid fault location system

Due to commutations or external impact, the voltage in electrical network during transient process can exceed maximum permissible operating value. Such voltage rise (overvoltages) is dangerous to the proper operation of the equipment insulation. Overvoltages level depends on different transient processes. In electricity distribution network with insulated or compensated neutral, the transient process can start due to phase grounding fault, arc re-ignition in fault place, idle transformer disconnection, capacitor bank disconnection, line switching-on, resonance and ferroresonance in the network. The most dangerous overvoltage in distribution networks can form during the phase to earth fault and arc re-ignition in such fault place, in case of line commutation when the phase to earth fault exists in the network or in the case of line tripping when the residual charge remains in the disconnected line due to short disconnecting time. It should be noted that transient wave spreads through the whole galvanically connected electrical network and can cause dangerous overvoltages in the lines, and it can damage the weak insulation of healthy phases in different lines [1-4].

That is why the development of the diagnostic and fault location technologies are needed for the operation of smart grid [5]. These technologies must integrate the following elements:

- The registration and automatic characteristics analysis of fast electromagnetic processes, overvoltages, overcurrents and non-stationary disturbances;
- One phase to ground fault detection after the insulation damage in distribution network with an insulated or compensated neutral;
- One phase to ground fault spot location according to the initial current transient process in the distribution network with cable and overhead lines;
- The control of the resource of the equipment insulation.

The basis of all of these technological elements is the registrations and analysis of the fast electromagnetic processes.

Fast electromagnetic transient processes of current and voltage initiated by disturbances in electric distribution system are usually registered at the beginning of the feeder. The registering equipment of processes was connected to the voltage transformer open triangle and zero sequence transformer terminals of the line. Installation of the circuit of the registration system of the fast electromagnetic transients is shown in Fig. 1 [6,7].

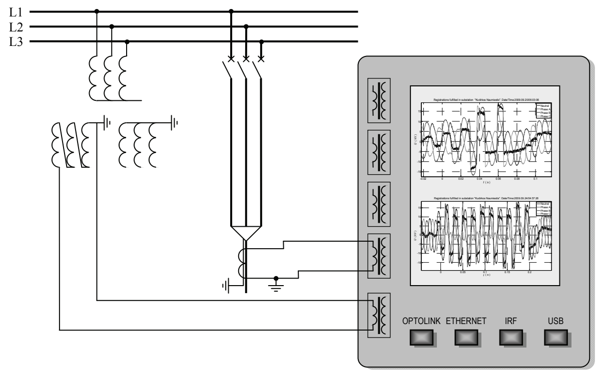

Fig. 1. Registration system of the fast electromagnetic transients

The registrations results of the zero sequence current and voltage transient processes are shown in Fig. 2. The curves show the initial process of the first phase to ground fault in line.

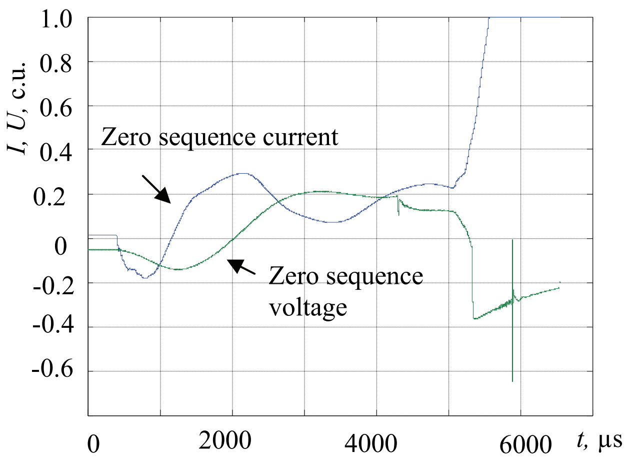

Fig. 2. The initial processes of zero sequence current and voltage during one phase to ground fault

As it can be seen from the curves, after 5 ms seconds earth faults occur in another line and in a different phase. The earth faults in different phases are two-phase short circuit and they are recognised by relay protection equipment and they are disconnected.

The analysis algorithms of the fast electromagnetic transients are a good basis for the development of the diagnostic, fault location and isolation technologies which can be integrated into the structure of the smart grid control system. One of these algorithms is a one phase to ground fault location algorithm.

Method for one phase to ground fault location

One phase to ground fault is the most common event in the distribution network with insulated or compensated neutral. Nearly 80 percent of ground faults are temporary and have negative impact on the condition of the electrical equipment insulation. That is why the evaluation of the processes, taking place in the electric power network in case of temporary ground fault, is very important for the network state evaluation and control action making. In case of permanent fault it is necessary detect the faulted line fast and reliably and to clear the ground fault to prevent other faults as shown in Fig. 2. Especially, it must be done quickly in cable lines. Fault place location permits the maintenance services of the electricity distribution network to eliminate efficiently the occurred earth fault and/or to prevent possible faults, which might occur for some reasons (the spark, touch of the tree branches, etc.). Well-known methods allow the identification of a permanent one phase to ground faults, but short term self-disappearing fault detection is still an unsolved problem [8]. For this reason, a new fault location method has been created. It allows not only to detect the faulted line and the fault place more precisely but also to find a place of the short term self-disappearing earth faults [9-11].

The method is based on the registrations of the fault initiated zero sequence voltage and current transients. The registration is obtained using fast transient processes registration system (Fig. 1). The better accuracy and speed of the fault location are achieved by using smaller than 100 ns discretization step and small analysis window which is no longer than 100 μs.

For the solution of the processes identification tasks according to transient processes analysis, it is necessary to have an accurate numerical model of electrical network evaluating asymmetry of line parameters, parameters of lumped capacitances in nodes, number of lines connected to bus-bars and line parameters dependence on frequency.

The place of earth fault and model element parameters, i.e. the simulated voltage and current transient characteristics in a model as well as the feeder's wave parameters and node capacity are found by minimising goal function, which is the function of the difference between the registered and simulated process [12].

The results of the calculations are the fault distance from the beginning of the section to the earth fault place, section number and identification reliability where earth fault has occurred. This information is delivered to the control terminal or directly to the dispatching center for appropriate control actions to be taken.

The process of the on phase to ground location in the feeders' sections contains the following stages:

1) At the first stage it is checked whether the earth fault has occurred in the line protected by the device. One phase to ground is supposed to occur in the line if number (1) has a positive sign

$$p = \sum_{j=1}^{n_1} i_j u_j \; ; \tag{1}$$

here i_j – current j registration; u_j – voltage value j registration; n_1 – number of part of current values of all N registrations: $n_1<N$.

2) If the first stage confirms earth fault occurrence in the line, i.e. if number (1) is positive – it fulfils the second stage, during which by minimising goal function f_1 the parameters of transitional characteristics of current and voltage measuring transformers are defined

$$f_1 = \sum_{j=1}^{n_2} \left| \mathrm{rem}\left(\boldsymbol{F}_1, \mathrm{derem}\left(\frac{\boldsymbol{1} - \mathrm{derem}(\boldsymbol{I}_1, \boldsymbol{U}_1)}{\boldsymbol{1} + \mathrm{derem}(\boldsymbol{I}_1, \boldsymbol{U}_1)} \right) \right) \right| = \min \; ; \tag{2}$$

here $\boldsymbol{I}_1$ – vector: $\boldsymbol{I}_1 = [i_1, i_2, ..., i_{n2}]$, $\boldsymbol{U}_1$ – vector: $\boldsymbol{U}_1 = [u_1, u_2, ..., u_{n2}]$, $\boldsymbol{F}_1$ – n_2 value vector of a definite form impulse function ($n_2 < N$), $\boldsymbol{1} = [1, 1, ..., 1]_{n2}$; rem and derem – algebra operations for equal clearance vectors characterised by the following formulas:

$$(z_k)_n = \mathrm{rem}((x_k)_n, (y_k)_n) \; ; \tag{3}$$

$$z_k = \sum_{j=1}^{n} x_j (y_{k+1-j} - \mathrm{d}\, y_{k+1-j}) \; ; \tag{4}$$

$$(\mathrm{d}\, y_k)_n = [0, y_1, y_2, ..., y_{n-1}] \; ; \tag{5}$$

$$(x_k)_n = \mathrm{derem}((z_k)_n, (y_k)_n) \, . \tag{6}$$

3) The third stage by minimising goal function f_2 determines the feeder's section where the earth fault has occurred and the distance in meters from the beginning of the section to the place of the earth fault

$$f_2 = \sum_{k=1}^{L} \left| \mathrm{rem}(\boldsymbol{F}_2, \tilde{\boldsymbol{S}}_k) - \mathrm{rem}(\boldsymbol{F}_2, \boldsymbol{S}_k) \right| = \min \; ; \tag{7}$$

here $\boldsymbol{F}_2$ – M values vector of a definite form impulse function ($N = LM$; $L \geq 1$); L – positive integer; $\boldsymbol{S}$ and $\tilde{\boldsymbol{S}}$ – vectors obtained from registrations and found in a model are calculated using the following formulas:

$$\hat{\boldsymbol{S}}_k = \frac{(\hat{s}_{M(k-1)+j})_M}{a_k} \; ; \tag{8}$$

$$a_k \in \left\{ \left|\hat{s}_{M(k-1)+1}\right|, \left|\hat{s}_{M(k-1)+2}\right|, ..., \left|\hat{s}_{M(k-1)+M}\right| \right\}; \tag{9}$$

$$\hat{s}_{M(k-1)+j} = \hat{u}_{M(k-1)+j} - w\hat{i}_{M(k-1)+j} \, . \tag{10}$$

here $\hat{u}$ and $\hat{i}$ – voltage and current values obtained in registrations and calculated in a model; w – non-negative rational number.

The proposed method is tested in different substations of the electric distribution network with different grid structure and total line length [13]. The tests results show that the new one phase to ground location method works more reliably and precisely than well-known methods and is able to locate short term self-disappearing earth faults.

Conclusions

1. The smart grid automatic control system should continually trace the state of the network and its elements, periodically perform the analysis of the reliability indexes of the electric power network and make appropriate control actions.
2. New methods of fast initial processes analysis in electric power network can be used for the processes recognition and evaluation, fault identification and location, and they are the primary information source for the smart grid automatic control system.
3. The accuracy of proposed method of the one phase to ground fault location depends on how precisely the transient process was registered, and how exactly the mathematic analysis of the process was carried out. The accuracy of the detection of the earth-fault location is predetermined by the process discreet registration.

References

1. **Markowska R., Wiater J., Sowa A.** Measurements of Surge Currents and Potentials in a Radio Base Station for Estimation of Lightning Threat // Electronics and Electrical Engineering. – Kaunas: Technologija, 2011. – No. 1(107). – P. 93–98.
2. **Hashmi M., Lehtonen M., Hänninen S.** Modelling and Analysis of Switching Overvoltages Caused by Short Circuits in MV Cables Connected with Overhead Lines // Electronics and Electrical Engineering. – Kaunas: Technologija, 2011. – No. 1(107). – P. 107–110.
3. **Greitans M.; Hermanis E.; Selivanovs A.** Sensor Based Diagnosis of Three-Phase Power Transmission Lines // Electronics and Electrical Engineering. – Kaunas: Technologija, 2009. – No. 6(94). – P. 23–26.
4. **Czapp S.** Comparison of Residual Current Devices Tripping Characteristics for Selected Residual Current Waveforms // Electronics and Electrical Engineering. – Kaunas: Technologija, 2010. – No. 4(100). – P. 7–10.
5. **Ciufudean C., Filote C., Larionescu A.** New Digraph Models for Diagnosis of Electric Cables // Electronics and Electrical Engineering. – Kaunas: Technologija, 2009. – No. 6(94). – P. 65–68.
6. **Rafajdus P., Bracinik P., Hrabovcova V.** The Current Transformer Parameters Investigation and Simulations // Electronics and Electrical Engineering. – Kaunas: Technologija, 2010. – No. 4(100). – P. 29–32.
7. **Siozinys V.** Transmission Line Fault Distance Measurement Based on Time Difference between Travelling Wave Reflection and Refraction // Electronics and Electrical Engineering. – Kaunas: Technologija, 2010. – No. 2(98). – P. 25–28.
8. **Druml G., Seifert O., Fickert L.** New improvements for transient relays // Seminar, Methods and techniques for earth fault detection, indication and location. – Espoo, Finland, 2011. – P.50 – 68.
9. **Gudžius S., Markevičius L. A., Morkvėnas A., Markevičius L.** The spotting reliability of the transient processes during one phase to ground fault // Proceedings of the XVII International Conference on Electromagnetic Disturbances EMD'2007. – Bialystok: Bialystok Technical University, 2007. – P. 183–186.
10. **Gudžius S., Markevičius L. A., Morkvėnas A., Markevičius L.** Patent US, EU Pub. No.: WO2007/011196 A1. A method of earth fault identification and location in three-phase electrical network. 20070125. - 10 p.
11. **Gudžius S., Markevičius L. A., Morkvėnas A.** Recursive method to examine electromagnetic transient processes in cable network // IV Sympozjum, Metody matematyczne W elektroenergetyce (MMwEE'98). – Zakopane, 1998. – P. 235– 244.
12. **Gudžius S., Markevičius L. A., Morkvėnas A., Markevičius L.** Recognition of Fast Electromagnetic Transients in HV Overhead Lines // Electronics and Electrical Engineering. – Kaunas: Technologija, 2011. – No. 1(107). – P. 103–106.
13. **Gudžius S., Gvozdas V., Markevičius L. A., Morkvėnas A.** Real Time Monitoring of the State of Smart Grid // Electronics and Electrical Engineering. – Kaunas: Technologija, 2010. – No. 10(106). – P. 57–62.

Received 2011 04 07

S. Gudzius, L. A. Markevicius, A. Morkvenas. Characteristics of Fault Detection System for Smart Grid Distribution Network // Electronics and Electrical Engineering. – Kaunas: Technologija, 2011. – No. 6(112). – P. 123–126.

The smart grid is the vision of the electric power network which integrates the electrotechnical, communication and informatics technologies. This integration allows developing new fault location technologies which are based on methods of fast transients analysis. The usage of these methods allows to locate the fault faster and more reliably or to prevent possible faults. The topic explains the structure of the fault location system for the smart electric power distribution network, discusses the challenges of smart grid fault location system and describes the method for one phase to ground fault location which is based on fast transient analysis. Ill. 2, bibl. 13 (in English; abstracts in English and Lithuanian).

S. Gudžius, L. A. Markevičius, A. Morkvėnas. Sumaniojo elektros paskirstymo tinklo gedimo vietos nustatymo sistemos charakteristikos // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2011. – Nr. 6(112). – P. 123–126.

Sumanusis elektros tinklas – tai elektros tinklas, jungiantis elektrotechnines, ryšių ir informacines technologijas. Šių technologijų integravimas leidžia sukurti naujas elektros tinklo gedimo vietos nustatymo technologijas, pagrįstas greitų pereinamųjų vyksmų analizės metodais. Taikant šiuos metodus galima greitai ir patikimai nustatyti elektros tinklo gedimo vietą ar išvengti galimų gedimų. Straipsnyje apibūdinama sumaniojo elektros paskirstymo tinklo gedimo vietos nustatymo sistemos struktūra, aptariami reikalavimai sumaniojo elektros tinklo gedimų nustatymo sistemai, aprašomas vienfazio įžemėjimo vietos nustatymo metodas, pagrįstas greitų pereinamųjų vyksmų analize. Il. 2, bibl. 13 (anglų kalba; santraukos anglų ir lietuvių k.).