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The Model of Smart Grid Reliability Evaluation

S. Gudzius, S. Gecys, L. A. Markevicius, R. Miliune, A. Morkvenas
Department of Electric Power Systems, Kaunas University of Technology,
Studentu str. 48-146, 51367 Kaunas, e-mail: saulius.gudzius@ktu.lt

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Introduction

Many countries around the world deal with the energetic independency, global warming, energy efficiency and reliability of energy delivery by promoting energy networks upgrade [1].

The development of the sustainable and efficient economy ensures the balanced use of the natural resources, delicate climate change and protection of our environment [2]. These efforts are in the centre of the public attention. Ambitious policy framework is provided in the EU "Climate and Energy Package" for the evaluation of the infrastructure of service for the public needs.

Electric power distribution networks are the key structure of the electric power energy supply system and they are the main electricity source for the majority of the consumers, consequently the biggest part of the outlay (80-90%) belongs to them. The main objective of the electric power distribution network is to provide reliable and high quality electric power to the consumers.

The new realities for the distribution network are the rapidly growing amount of the small scale generation units, the liberalized electricity market and the consumers/generators. This situation raises the new challenges for the electric power distribution network planning, operation and control. These challenges can be overcome by the introduction of the new philosophy of the distribution network management – Smart Grid.

Smart Grid based distribution systems have the purpose of monitoring electric power distribution, carrying out consumer energy management, ensuring the reliability of power distribution and encompassing two parts of electricity distribution company activity: metering and engineering. The most critical issue for the electricity distribution utilities worldwide is the improvement of electricity supply reliability and availability. The new high performance computing and communications technologies have brought new opportunities for embedding intelligences of the smart distribution grid and developing fast electromagnetic transient analysis based on self-healing technologies that allow real-time response to the electricity distribution system disturbances and the prevention of outages.

In this paper the main consideration is shown for the review of the intelligent networks, grid development trends and the evaluation of grid reliability.

The paper describes the mathematical model of electric power line reliability evaluation which can be used for smart distribution network operation and maintenance planning.

The characteristic of intelligent distribution grid

The philosophy of the Smart Grid is the road map for the development of the more efficient, reliable and more secure electric power distribution network [3].

To improve the reliability of electricity networks, it is necessary to install more reliable grid elements, improve network schemes, mount automatically controlled disconnector stations, coordinate the protection against overvoltages and install the devices for fast and reliable fault place location and post fault regime optimization. All of these steps allow the number of faults to be reduced significantly, and in case of fault, it allows to reduce the time of fault place location, minimize the outage costs for the customers and optimize the restoration of the electric power network operation.

Digital technologies integrated into electricity networks form smart grid in which two-way communication might be used for electricity transmission between producers and consumers [2]. This system might control the customer's electrical devices to save energy, reduce electricity price, improve power quality and transmission reliability. Distributed generation energy sources will be connected to smart grid which will eliminate the ridge between producers and consumers because of its extreme flexibility and reliability [4, 5]. Nowadays power grid comparison with intelligent networks is presented in Table 1.

Table 1. Today's grid comparison with smart grid

Characteristic	Today's grid	Smart's grid
Active collaboration with energy consumers	Homogeneous customers, no collaboration	Consumers are well informed, involved and active, managing their energy dependences, consumption and resources
Compatibility of energy generation and storage	Domination of main generation sources	Distributed generation, attention paid to renewable energy
New products, services and markets	Limited and poorly integrated wholesale market, limited consumers abilities	Mature, well-integrated wholesale market. Growth of new electricity markets
Energy quality	Focused on the outage. Low level of responsibility for the energy quality	Energy quality is an essential quality / price relation factor
Optimized expenses and operation efficiency	Low degree of integration with operating system information	Full integration with information of network parameters
Reaction to disturbances	The aim is to prevent system from more damage. Focused on protection of the resources, which are needed to restore system	Automatically detects problems and acts reasonably. Focused on prevention and minimum impact to the customer
Flexible work during an event of natural or other disaster	High degree of vulnerability	Flexibility and quick restoration

Traditional electricity industry infrastructure is based on centralised electricity distribution technologies and limited automated facilities control. Electric energy is generated in large scale power stations and transmitted to customers through long distances. Indeed, huge resources are needed for reconstruction, however all these problems can be solved by smart grids.

The structure of smart distribution network

High speed electromagnetic processes analysis and identification based on nanosecond technologies, which are widely used for experimental development of problem solving, are highly viable [6]. Smart grid components (devices) can be developed using algorithms and experimental models suitable for this network. The scheme of smart grid devices is presented in Fig. 1.

Fast-operation devices should be designed for the development of smart grid. These devices should be able to quickly identify fault type, its location and cause, and optimally change the grid structure by eliminating fault location [7– 9].

Functions of smart grid devices:

- RESU – the device with nanosecond step which identifies one phase to ground fault line and fault location according to the initial transient process;
- RCU – the device which records overvoltage transient processes, identifies and analyses the source of overvoltages, evaluates expenditure of insulation resource of electrical equipment, that is connected to the electric power network, due to overvoltages;
- RCD – the device which selects the optimal post-fault structure of the power grid according to the information about the fault in the network and pre-fault network regime.

Timing delays needed for the fast-operation devices to control smart grid are given in Fig. 2.

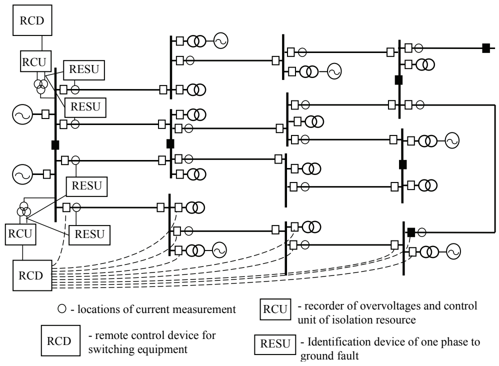

Fig. 1. The scheme of fast-operating devices in the smart grid

The fast-operation devices have been tested variously. A part of the devices has been tested using digital algorithms, modern microelectronic technologies and simulation mathematical models, other devices have been tested under natural conditions. The strategic objective is to apply FPGA microprocessor based equipment which is fully capable to combine functions of smart grid control devices.

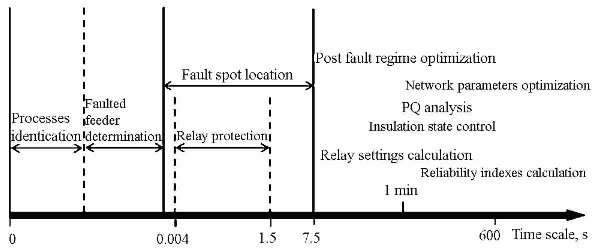

Fig. 2. Process duration in electrical network

Splitting smart grid system into components by dividing them according to functionality, FPGA based technologies would allow to unify most of the separate components and therefore, to adjust the designed device to the most of the grid elements produced by the different manufacturers.

Analysis models of smart grid working regimes

The electric power distribution network regimes identification and optimization is the most important problem for the network operation, maintenance and restoration planning. For this purpose the following electric power network regimes analysis models, control algorithms
and technologies must be developed:

The models for the electric power network regimes analysis:

– The development of the digital model of electric power system with three-phase isolated or compensated electric power network and small scale generation units;

– The development of the method and software for the recognition of the damaged feeder and increased leakage currents in phases according to the registrations of the stationary regime parameters of the distribution network.

The models for the analysis of the overvoltages and coordination of the protection against overvoltages:

– The digital model of lightning overvoltages analysis in three-phase power system;

– The digital model of internal overvoltages analysis in three-phase isolated or compensated power system with small scale generation units;

– The digital model for the calculation of the reliability of the electrical power network insulation;

– The digital model for the evaluation of the reliability of the protection devices against overvoltages;

– The digital model for the evaluation of the electric power network aging;

– The development of the devices for overvoltages registration and analysis;

– The analysis model of registered data and software for the electric power line reliability evaluation and power network reliability indexes calculation.

The models and technologies for the electric power network maintenance service:

– The development of the technology for optimal power network reconfiguration according to the measurements of the electric power grid voltages, currents, their higher harmonics and event analysis;

– The development of the technology for the optimization of the electric power network configuration for the minimization of the total costs of the operation;

– the development of the software for the fault isolation planning and customer outage cost minimization;

– The development of the software for the network maintenance or restoration optimization and maintenance or restoration outage minimization.

Specific relay protection and automation framework:

– The development of specific relay pattern for the accelerated network management;

– The development of technology for the identification of the faulted feeder and one phase to ground fault place location according to the measurement of the fast initial electromagnetic transient processes;

– The development of the technology for the automatic identification of the optimal protection relay settings according to the registrations of fast electromagnetic transient processes.

The model for the power lines reliability evaluation

The evaluation of power line reliability is one of the most important problems for electric power utilities.

The power line insulation working duration until the isolation is exhausted, is occasional and depends on the random electric strength character of isolation, environmental factors (temperature, pressure, humidity, radiation, mechanical disturbance, etc.) and stochastic overvoltage values. The duration of line operation, from the installation or repair till the breakdown, after which additional line repair is needed to be done, distributes itself by (gamma) exponential statistical law which distribution function has the expression

$$F_T(t) = 1 - \exp\left(-\frac{t}{\tau}\right); \qquad (1)$$

where T and τ – occasional and average operation time, t – independent argument of function (for example, one year).

The reliability value p is the probability of the event that the actual operation time is greater than the established (agreed) value of t

$$p = 1 - q = P(T > t) = 1 - F_T(t); \qquad (2)$$

where q – probability of failure.

Line insulation can be damaged or completely destroyed by accidental internal or lightning overvoltages in the electrical network. Such event, which requires at least a repair, probability can be evaluated using distribution correlation between overvoltage and isolation dielectric strength

$$q = \int_{\max(V)}^{\min(V)} f_V(u) F_U(u) du; \qquad (3)$$

where f_V and F_U – distribution density of overvoltages and distribution function of insulation electric strength for such overvoltages type; q – probability of failure of the insulation if such overvoltage occurred, or probability of a random event ($V>U$), when overvoltage amplitude is greater than the limit of electrical strength; min (V) and max (V) – minimum and maximum possible overvoltage values in the network.

Probability of failure is the product of multiplication of functions f_V and F_U (V and U correlation). The $s = f_V \cdot F_U$ curve bounds the area. This curve and the distribution functions are shown in Fig. 3.

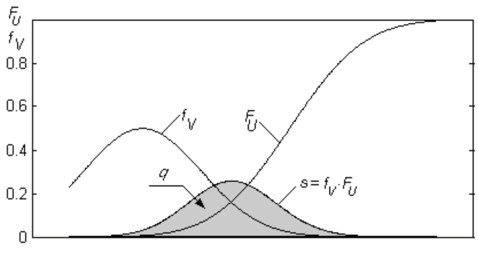

Fig. 3. Distribution density of overvoltage (f_v), distribution function of isolation electric strength (F_U) and their product (s)

For the illustration purposes, the area corresponding to the probability of q is increased by 10 times.

In order to evaluate isolation reliability change after environment and overvoltage level variation it is necessary to identify not only the change of isolation electric protection and stochastic, but also the dispersion of overvoltage values.

Conclusions

1. The smart electric power distribution grids are easier to manage; they are more reliable and more

transparent than today's grids. The smart grid allows integrating different electric power generation sources and guaranty reliable electric power supply for customers on the liberal market conditions.
2. The line insulation working duration until the isolation is exhausted, is occasional and depends on the random electric strength character of isolation, environmental factors (temperature, pressure, humidity, radiation, mechanical disturbance, etc.) and stochastic overvoltage values.
3. For the evaluation of the insulation reliability dependency from environmental factors and overvoltages level it is necessary to determine the change of the insulation electrical strength and the distribution of the overvoltages values.
4. The modernization of electric power distribution systems and implementation of modern fault location, insulation resource monitoring and post-fault regime optimization equipment allow the significant reduction of the fault location time and costs of maintenance.

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Smart electricity grids, the essence of development, prospects and trends of electrical grids are described, the model of reliability evaluation is composed in this work. Smart grids enable traditional energy consumers to become active participants in energy markets who can choose when to consume or generate energy in the network. Many countries around the world are promoting the network upgrade, also dealing with energy independence, global warming, energy efficiency and security of supply issues. The system development of smart electrical grid is performed using small distributed generation sources which should be generally evaluated – electric network structure and locations change according to recorded speed of isolation expenditure resources and electric network reliability parameters change. Ill. 3, bibl. 9, tabl. 1 (in English; abstracts in English and Lithuanian).

S. Gudžius, S. Gečys, L. A. Markevičius, R. Miliūnė, A. Morkvėnas. Išmanaus elektros tinklo patikimumo įvertinimo modelis // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2011. – Nr. 10(116). – P. 25–28.

Darbe išnagrinėti išmanieji skirstomieji elektros tinklai, jų plėtra, esmė, perspektyvos bei tendencijos, sudarytas patikimumo įvertinimo modelis. Išmanieji tinklai įgalina tradicinius energijos vartotojus tapti aktyviais energetikos rinkos dalyviais, galinčiais rinktis, kada vartoti energiją, o kada tiekti ją į tinklą. Daugelis pasaulio šalių skatina tinklų atnaujinimą, taip spręsdamos energetinės nepriklausomybės, globalinio klimato atšilimo, energijos naudojimo efektyvumo ir tiekimo patikimumo klausimus. Išmanaus elektros tinklo sistema plėtojama naudojant daug mažą galią generuojančių šaltinių, kurie turi būti kompleksiškai įvertinti – registruoti veiksniai, turintys įtakos izoliacijos ištekliaus sąnaudų kitimo greičiui, taip pat elektros tinklo patikimumo parametrų pokyčiai, keičiantis elektros tinklo struktūrai ir gedimo vietai bei pobūdžiui elektros tinkle. Il. 3, bibl. 9, lent. 1 (anglų kalba; santraukos anglų ir lietuvių k.).