OUTAGE MONITORING AND MANAGEMENT IN OVERHEAD AND CABLE NETWORKS WITH VARIOUS TYPES OF ARCHITECTURE

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ABSTRACT

An aggregate data processing from the intelligent monitoring system sensors, which is based on heuristic algorithms, brings an opportunity to manage problems before accident occurs. Thus the modern distribution network monitoring and management systems should be adaptive and susceptible to a simple modernization when new devices are being integrated into an existing grid. The most important part of the hardware-software system of the distribution network monitoring is the possession of the instruments for running the occurring processes analysis and the ability of supplying the dispatching personnel with information. The integrated systems of overhead lines and underground power cables outage monitoring and management provide a simple solution in terms of the power system reliability enhancement and remove the problem of false operating and functional losses of separate diagnostic devices. Implementing modern hardware-software systems that are using complex data processing algorithms, deriving data from various diagnostic devices, is a vital component of an effective decision-making. The implementation of the outage monitoring and management systems provides not only a continuous control of grid line conditions but also the employment of predictive diagnostics and the enhancement of the power system reliability.

INTRODUCTION

Today the electric power industry is passing through fundamental transformation from centralized to decentralized model. There is an "energy transition" based on the concept of an active consumer - a new energy subject, which, in addition to the traditional function of energy consumption from external sources, also performs the function of energy accumulation and generation. Power supply becomes an ecosystem of power generators and consumers, which are freely integrating in general infrastructure and energy exchange.

Such a model, called "Internet of Energy", is an integrated dynamic network infrastructure, a set of electric and digital communication channels and generally accepted protocols that allow you to organize automatic communication between the subjects of the electricity market. The basis of a new technological paradigm in power distribution become consumer’s end devices with manageable demand as well as distributed generation and systems of energy storage located on the consumer side or in the distribution networks of low and medium voltage in the immediate vicinity of consumers.[1]

Transformed networks architecture requires continuous two-way information exchange between energy supply and demand in it. New technologies of flexible network construction and its intelligent management form new principles for monitoring systems organization in order to provide the required reliability and quality characteristics and to implement economically optimal use of own capacities in combination with the consumption of electricity from the existing power system. Creation of an effective monitoring system for power transmission lines and power facilities based only on hardware devices without using software-analytical complexes, which employ deterministic and probabilistic approaches, is impossible.

MAIN FUNCTIONS OF A MONITORING SYSTEM IN THE MODEL “INTERNET OF ENERGY”

While building a network of “Internet of Energy” model one of the most important moments becomes a control of new subjects inclusion in energy system and obtaining the information about needs and power capacity supply. It is necessary to control the process real-time of electrical capacity income to the system, where three main points can be highlighted: 1) network sections reliability evaluation, 2) lines transmission capacity dynamic determination, 3) accurate measurement of amplitudes and voltage phases in the line for the energizing lines phase synchronization.

Renewable energy sources, which have stochastic nature of generation, while connecting to the system can, disrupt the optimality of active and reactive power flows. This causes overloading of particular network sections and power losses increase. Small generation sources are low inertia sources, that why they have small margin of transient stability during abrupt mode change, for example, in case of short circuit on a line. In case of connection a large volume of generation to a network using renewable energy sources, voltage fluctuation and higher-order harmonics generation in the system are amplified. The cases of load shedding necessity at the moment of emerging disturbances appearance using particular switched on generating equipment, as well as capacity balancing while energy system operation, become frequent because of the difficulties in RES power output prediction.[2]

In order to solve above mentioned problems of distributed generation and to identify potentially dangerous energy system section it is necessary to evaluate in real-time conditions the system reliability and timely implement front-rank technologies. Network The grid monitoring system should have predictive capabilities and the functionality of the optimal energy transmission path determination. Implementation of modern hardware-software systems that are using complex data processing algorithms, deriving data from various diagnostic devices, allows you to meet all power system monitoring tasks. At the same time, such a complex should be able to process data using probabilistic methods for false data detection, provide predictive diagnostics and apply mechanisms of machine intelligence.

DIAGNOSTIC DEVICES AS A PART OF A MONITORING SYSTEM

Undoubtedly, high-precision monitoring devices are one of the main parts of a modern hardware-software monitoring complex that efficiently operates in the power grid "cellular" structure. Synchronized vector phase measurements of currents and voltages in the network are required for power exchange analysis. Data synchronization in a single time scale allow you to operate with phasors in order to analyze line state and technological electricity losses, as well as to apply traveling wave method for accurate localization of fault location. The dynamic capacity factor control performed by intelligent sensors allows you to signal the malfunction in reactive power compensation devices operation and is used for intelligent compensation devices adjustment, which is extremely important for line operating modes optimizing and its transmission capacitance increasing. Continuous monitoring of load currents symmetry also allows you to identify undesirable modes of line operation and the trends of their development.

Conductor slack sensors, sensors of frequency and amplitude of wire swinging, vibration parameters sensors allow provide predictive diagnostics of overhead lines mechanical damage for further repair. Ambient parameters sensors (weather stations) and wire icing sensors make it possible to timely remove the ice from a wire. Continuous monitoring performed by conductor temperature sensors together with current measurement provide evaluation of line load and its possible increasing in particular line section, that is necessary for network configuration optimization, retrofitting planning, making a right choice of configuration in an emergency case. Measurement of slack point of the wire, ambient temperature, wire temperature and current values allows you to determine hazardous operating modes and change the operating mode for each segment of the network if necessary.[3]

For real-time data synchronization from various devices, reliable communication channels in the monitoring complex are required. At the moment, several channels are traditional for power equipment: 1) cellular networks GSM/3G/4G with low measure of reliability in case of overload or in difficult weather conditions; 2) WiFi/WiMax coverage, as a rule, significantly territorially limited; 3) communication using PLS and LoRa, which has a speed limit. The Fiber Optic channels laying along all transmission lines is an ideal solution to the problem of data transmission, but this task requires a significant investment of electric grid companies. A number of power equipment transfers data according self-organizing network (Mesh) technology, with data transfer from one device to another. The permanent availability of three or more Mesh network nodes for each diagnostic device installed on the power line provides channel reservation. This allows you to effectively solve the task of load balancing. Data transmission via Mesh-RF, Mesh-PLC communication channels which provide ease reconfiguration, high speed and reliability is the best solution in terms of data transfer in monitoring system of the distribution network with “cellular” structure.

PROGRAM-ANALYTICAL FUNCTIONS OF A MONITORING SYSTEM

Successful operation of the monitoring system in a grid with a "cellular" structure implies a simple integration of data from various devices. The network state analysis is based on the algorithm of real measurements results and archive events processing. The monitoring system should be able for real time processing a network structure, which is a weighted graph, and take into account possible negative values (in case of low level of reliability) for the edges of this graph. The most effective path between two active users, it is recommended to detect via dynamic algorithms according the Floyd-Warshall method.

Consider an example of calculation the optimal path of energy distribution form one prosumer to another, taking them as graph nodes $\boldsymbol{G=(V,\ E)}$, $|\boldsymbol{V}|=\boldsymbol{n}$ numbered from 1 to $\boldsymbol{n}$ and entered the notation $\boldsymbol{d_{ij}^k}$ for the shortest path length from $\boldsymbol{i}$ to $\boldsymbol{j}$, which apart from the nodes themselves $\boldsymbol{i}$, $\mathbf{j}$ passes only through nodes 1...$\boldsymbol{k}$. Then the recurrence formula for $\boldsymbol{d_{ij}^k}$ has the form:

$\boldsymbol{d_{ij}^0}$ — edge length $(\boldsymbol{i}, \boldsymbol{j})$,

$\boldsymbol{d_{ij}^k} = \min(\boldsymbol{d_{ij}^{k-1}}, \boldsymbol{d_{ik}^{k-1}} + \boldsymbol{d_{kj}^{k-1}})$.

Floyd-Warshall algorithm sequentially computes all values d_{ij}^{k}, $\forall i$, j for k from 1 to n. By this means, the system will obtain data about optimal path of energy transmission taking into account data on the reliability of energy cluster lines.

In order to provide stable and trouble-free monitoring system operation, the algorithms of data processing must solve the problem of false tripping or individual diagnostic devices failure. Construction of graphical probabilistic model based on Bayesian network makes it possible to minimize false decision-making while fault location detection. Let's consider more detailed a method of data processing from several monitoring devices.

For derived data processing operation probabilistic model construction, we introduce the concept of R-section of a transmission line. R-section – is a network section, surrounded by installed diagnostic devices. Hereinafter, the places of devices installation will be called nodes. R-section will be the minimum segment of the power grid possible for diagnostics, allowing it to make intelligent decisions on the power flows management between the prosumers. Then the conditional probability G (the event, that the server receives the information that forms G) in case of D_k occurred (an emergency situation occurred on the site k) is equal to:

$$P(D_k|G) = \frac{P(D_k)P(G|D_k)}{\sum_{i=1}^{k} P(D_i)P(G|D_i)}$$

where $P(D_i)$ is a probability that emergency situation occurred on section i, $i=0,\ldots,K$.

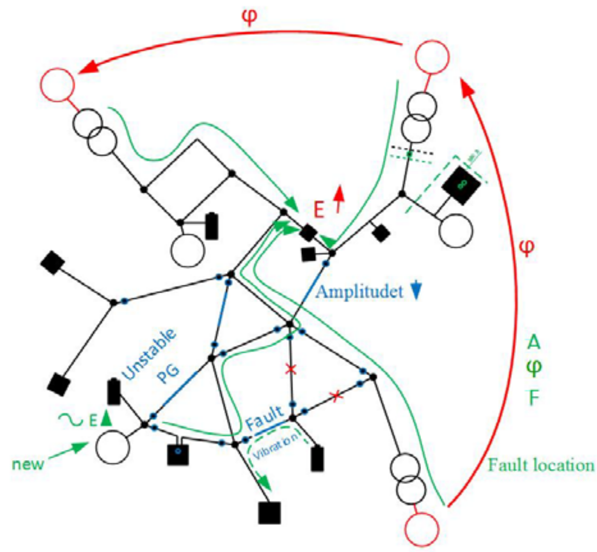
Assuming that each section has an equal probability of emergency situation occurrence there, we get a simplification:

$$P(D_k|G) = \frac{P(G|D_k)}{\sum_{i=1}^{k} P(G|D_i)}$$

When calculating k = 0, the system determines the absence of an event for the section.

The reliability of the network section is calculated also using the probabilistic models. The use of modern technologies of machine learning and neural networks allows it, by processing the received information and comparing it with the existing experience of the network operating, to rank the network sections for reliability and maximum efficiency for a consumer.[4]

The monitoring system, using standard communication protocols, should be able to interact with an expert system that calculates the loads balance and configures the network, depending on the active user needs. Due to special algorithms of current surges and transient processes analyzing, the monitoring system should form prognostic precautions, detecting the power equipment damage beginning and emergency situation probability increasing.



The monitoring system should be user-friendly and include a geographical information system that provides a graphical visualization of power facilities on a map and the devices data output, along with their exact coordinates. Geographical data storage should be implemented in the form of separate thematic layers with possibility of combining them: geographical map, network mimic diagram and power map. The storage of qualitative and quantitative characteristics of facilities should be realized as a database with on-line data transmission. Addition of new devices to the system, as well as full information from diagnostic devices should be available in a user-friendly form, according the "plug and config" ideology.

The monitoring system should be easily configured with possibility to assign users permissions and rights. Easy integration into existing system equipment via standard communication protocols and simple system adapting are required. It is also important to be able to update the already integrated elements and software applications of the system itself. The monitoring system usage protects the power system and provides its maximum efficiency for the active user.

CONCLUSION

Changed architecture of a power grid, where "branched" structure of power distribution from centralized generation sources is replaced by "cellular" structure, based on prosumers, requires new principles of monitoring system development. Effective operation of new generation monitoring systems is possible only if it is based not so much on the hardware component of diagnostic devices as on the algorithmic processing of the received data with the mathematical models construction and neural networks. Due to real-time analysis of data derived from a group of diagnostic devices, it is possible to widely evaluate processes in distribution network, optimize performance and provide reliable power supply to the consumer.

Monitoring systems, possessing machine learning technologies, widely use prognostic functions for emergency processes occurrence detection, optimal line load calculation and most effective path of network building. They are a vital component of an effective decision-making mechanism, forming a multi-level information network.

Such systems provide an opportunity of technological and economical energy supply reliability and quality enhancement, create new possibilities for consumers of choice of necessary power supply conditions and are effective for network integration and micro-grid management.

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