ЕЛЕКТРОМЕХАНІКА, ЕЛЕКТРОТЕХНІКА ТА ЕНЕРГЕТИКА

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ASSESSMENT OF THE CONDITION OF THE DISTRIBUTION ELECTRICAL NETWORK WITH DIFFERENT COMPLETENESS OF INPUT DATA

The most effective measure to ensure the observation of electric distribution networks is the integration of intelligent metering devices with the ability to store and transmit data based on Smart Metering technology into automated commercial electricity metering systems. Automated systems of commercial electricity metering systems and intelligent metering devices are designed to provide reliable and timely information about electricity metering on the basis of which financial settlements are made between market participants. However, today the use of automated systems of commercial electricity metering of intelligent metering devices in distribution networks is limited, and the available information does not make it possible to ensure the observation of electric distribution networks and, as a result, to determine the components of electricity losses in the structure of the electricity balance with sufficient accuracy.

That is why the article analyzes the possibility of improving the observability of electrical distribution networks using Smart Metering devices. The expediency of applying the results of assessing the state of distribution electric networks in information systems for the purpose of detailed analysis of the functioning of electric networks is investigated. A mathematical model for assessing the state of the distribution electrical network and the quality of measurements in it is applied.

Smart Measuring Information Systems accumulate information about measured power consumption schedules, the use of which allows to form an element-by-element structure of electricity losses with reference to the time period of operation of network elements, as well as determine local cells with the greatest impact on total electricity losses. In addition, commercial expenses included in the balance sheet structure do not have an independent mathematical description. Therefore, it is difficult to assess their economically justified level. They are determined from the structure of the electricity balance, as the difference between actual losses and calculated technological losses. An increase in the profit of energy supply companies depends on the reduction of the commercial component. Thus, the urgent task is to develop methods and tools for analyzing technical and commercial electricity losses in electric distribution networks and introduce software tools for their implementation using Smart Metering databases and Information Systems.

Keywords: distribution power networks, state estimation, Smart Metering.

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ОЦІНКА СТАНУ РОЗПОДІЛЬНОЇ ЕЛЕКТРИЧНОЇ МЕРЕЖІ ЗА РІЗНОЇ ПОВНОТИ ВХІДНИХ ДАНИХ

Найефективнішим заходом для забезпечення спостереження за електророзподільними мережами є інтеграція інтелектуальних приладів обліку з можливістю зберігання та передачі даних на основі технології Smart Metering в автоматизовані комерційні системи обліку електроенергії. Автоматизовані системи комерційних систем обліку електроенергії та інтелектуальні прилади обліку призначені для надання достовірної та своєчасної інформації про облік електричної енергії, на основі якої здійснюються фінансові розрахунки між учасниками ринку. Проте на сьогоднішній день використання автоматизованих систем комерційного обліку електроенергії приладів інтелектуального обліку в розподільчих мережах обмежене, а наявна інформація не дає можливості забезпечити спостереження за електророзподільними мережами і, як наслідок, визначити складові втрати електроенергії в структурі електричного балансу з достатньою точністю.

Тому в статті аналізується можливість покращення спостережливості електророзподільних мереж за допомогою приладів Smart Metering. Досліджено доцільність застосування результатів оцінки стану розподільних електричних мереж в інформаційних системах з метою детального аналізу функціонування електричних мереж. Застосовано математичну модель для оцінки стану розподільної електричної мережі та якості вимірювань у ній.

Розумні вимірювальні інформаційні системи накопичують інформацію про виміряні графіки споживання електроенергії, використання якої дозволяє сформувати поелементну структуру втрат електроенергії з прив'язкою до періоду часу роботи елементів мережі, а також визначити локальні комірки з найбільшими вплив на загальні втрати електроенергії. Крім того, комерційні витрати, що входять до структури балансу, не мають самостійного математичного опису. Тому оцінити їх економічно обґрунтований рівень важко. Вони визначаються зі структури балансу електроенергії, як різниця між фактичними і розрахунковими технологічними втратами. Збільшення прибутку енергопостачальних компаній залежить від зменшення комерційної складової. Таким чином, актуальним завданням є розробка методів та інструментів для аналізу технічних та комерційних втрат електроенергії в електричних розподільних мережах та впровадження програмних засобів для їх реалізації з використанням баз даних та інформаційних систем Smart Metering.

Ключові слова: розподільні електричні мережі, оцінка стану, Smart Metering.

Problem statement

The task of static state assessment (SA) is to estimate the complex values of Phase voltages (States) on the buses of the distribution network nodes. The input data is information about the measured mode parameters, such as power flow, voltage and current values, as well as information about the status of switches, power line parameters, transformers, capacitors and reactors. The types of measurements, their location, and accuracy vary depending on each topology of the electrical network [1].

The following types of measurements are most often used:

- flow-flows of active and reactive power measured in power lines or at Transformer inputs;
- setpoint power of nodes-full generation of active and reactive power on System buses;
- voltage values-measured on System buses;
- current values - currents measured in power lines or at Transformer inputs.

In addition to the measured parameters, additional values are also used that complement the information model to improve the efficiency of state assessment:

virtual measurements-measurement values that are known due to restrictions on mode parameters. The most commonly used virtual measurements are base node voltages;

pseudo-measurements -- measurement values that are predicted based on statistical data to fill in a set of measurements in poorly controlled locations. Examples of such measurements are: projected loads or projected power output schedules on generator buses.

In Fig. 1 is shown a diagram of functional dependencies between state evaluation blocks. To get a state estimate, pre-filtering of data is provided to identify and eliminate measurements that are clearly false (negative voltage values, out-of-range Flow Power, etc.). In parallel with filtering, the topology of the electrical network is analyzed and a mathematical model of the electrical network is constructed. The mathematical model is supplemented with statistical data from the statistics database and non-observable sections of the electrical network are selected.

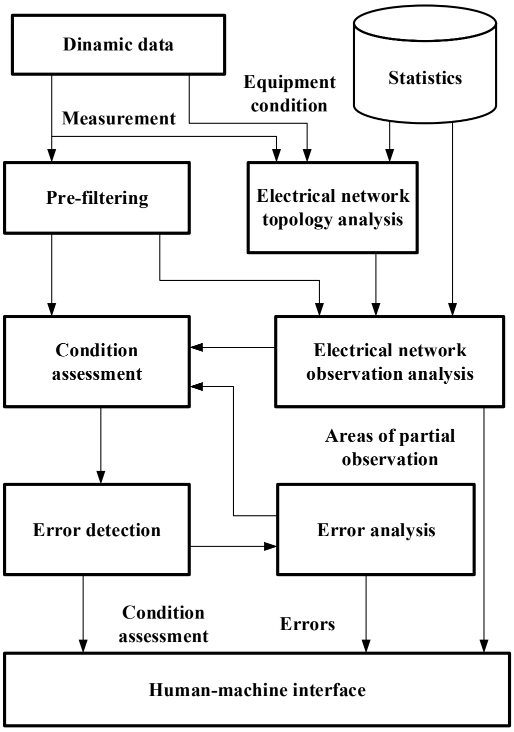

Fig. 1. Functional dependencies and data exchange between state evaluation blocks

The tested and supplemented model is used in the state detection procedure that best matches a given set of mode parameters and its topology, taking into account the accuracy of available measurements. Additionally, error detection and analysis is performed. If the number of errors does not exceed the allowed number, they can be detected and corrected. The resulting results are transmitted for display.

Modern state assessment tools are also able to detect topological errors and clarify the values of questionable mode parameters.

Thus, the state assessment serves as a large-scale filter between remote measurements and higher-level applications.

Analysis of recent sources

Today, several approaches are used to synchronize, recover lost and verify measured information [2]:

- Big Data Technologies;
- calculations based on non-lost data;
- using typical electrical load schedules;

- application of state assessment methods.

The main general requirement of these approaches is the availability of non-lost data. In other words, a part of the network requires measurements in volumes sufficient to restore information. In the absence of measurements, retrospective data is used to recover them and detect emissions in the measurements.

According to the analysis, it is promising to use a combined approach of methods for assessing the State [3] - [7] for time synchronization of information and the use of typical graphs of electrical loads to restore time-aggregated information [8] - [9] about the flow of electricity. The advantage of using this approach is the ability to analyze the energy efficiency of distribution EN with a significant share of dispersed energy sources. This is especially true for photovoltaic power plants, as they have a fairly predictable generation schedule in accordance with a typical Metrological year [10], [11]. This makes it possible to use it in a mathematical model as a standard one, along with power consumption graphs.

The purpose of the work is: systematization and research of the possibility of improving the observability of electrical distribution networks using Smart Metering devices.

Presentation of the main material

Mathematical model for estimating network status and measurement quality

The static state assessment function is used to monitor system performance during normal operation, when the system is in a pseudo-stationary state, responding to slow load changes and network generation. In view of this model, all available measurement types can be expressed as a function of the parameters of the electrical network mode in the form of a state vector. These expressions are non-linear and do not take into account possible errors due to network parameter uncertainty, measurement errors, or noise that may occur in telecommunications systems.

Consider a vector **z** containing a set of dimensions that can be recalculated in the mode parameters [1]:

$$\boldsymbol{z}=\begin{bmatrix} z_1 \\ z_2 \\ \vdots \\ z_m \end{bmatrix}=\begin{bmatrix} h_1(x_1,x_2,\dots,x_n \\ h_2(x_1,x_2,\dots,x_n \\ \vdots \\ h_m(x_1,x_2,\dots,x_n \end{bmatrix}+\begin{bmatrix} e_1 \\ e_2 \\ \vdots \\ e_m \end{bmatrix}=h(x)+e \quad , \tag{1}$$

where $\boldsymbol{h}^T=[h_1(x),h_2(x),\dots h_m(x)]$;

$h_i(x)$ - nonlinear function linking measurements *i* and the state vector variable *x*;

$\boldsymbol{x}^T=[x_1,x_2,\dots x_m]$- system state vector;

$\boldsymbol{e}^T=[e_1,e_2,\dots e_m]$ - measurement error vector.

The state vector is usually constructed in an extended form, where Cartesian or polar coordinates are used to represent each component of the state variable (bus voltage) by its two separate components – the real and imaginary components, or the module and phase. Similarly, the measurement Vector will contain real records z_i, which correspond to the flow of active or reactive power and the generation of the node, or the value of Phase voltages or currents.

Usually as state variables x_i accept the module U_i and the phase angle δ_i voltage in independent nodes of the electrical network. The measured parameters in EN are the voltage modules in individual nodes $U_i^{в}$, active users $P_i^{в}$ and reactive $Q_i^{в}$ capacities in loading and generation units equipped with ASCME facilities are active $P_j^{в}$ and reactive $Q_j^{в}$ power flows in power lines equipped with TV measuring devices.

Functions h_i (*x*) which link measurements **z** with a state vector **x** they are functions of a mathematical model of an electrical network and its parameters that have the following form in polar coordinates:

for power measurements in nodes:

$$P_i=U_i\sum_{j=1}^{N}U_j(G_{ij}\cos\delta_{ij}+B_{ij}\sin\delta_{ij}),$$

$$Q_i==U_i\sum_{j=1}^{N}U_j(G_{ij}\sin\delta_{ij}-B_{ij}\cos\delta_{ij}),i=1,2,\dots,N,$$

for measuring power flows in branches:

$$P_{ij}=U_iU_j(G_{ij}\cos\delta_{ij}+B_{ij}\sin\delta_{ij})-G_{ij}{U_i}^2,$$

$$Q_{ij}=U_iU_j(G_{ij}\sin\delta_{ij}-B_{ij}\cos\delta_{ij})+U_i^2(B_{ij}-b_{s,ij}).$$

The following assumptions are used in the calculation:

Errors are distributed according to the normal distribution law.

Mathematical expectation the values of all errors are zero, i.e. $E(e_i)=0$,i=1,…,m.

The errors are independent, i.e. the mathematical expectation of the product of the errors is zero, i.e. $E(e_ie_j)=0$. Therefore, the error covariance is calculated by the expression: $\mathrm{Cov}(e)=E[e\cdot e^T]=R=\mathrm{diag}\{\sigma_1^2,\sigma_2^2,\dots\sigma_m^2\}$.

Standard deviation σ_i everyone *i-th* measurement method is calculated in such a way as to reflect the expected accuracy of the measurement device used. In [12] it is proposed to calculate the standard deviation of measurement by the device as follows:

$$\sigma_i = 0{,}0067S_i + 0{,}0016 \cdot \mathrm{FS}_i, \qquad (2)$$

where

$$S_i = \begin{cases} \sqrt{P_{km}^2 + Q_{km}^2} \text{ to measure the flow of the branch } k - m, \\ \sqrt{P_k^2 + Q_k^2} \text{ to measure the power in the node } k, \\ |V_k| \text{ for the voltage value in } k; \end{cases}$$

$FS_i =$ division of the measurement scale.

The formulation of the state assessment problem is based on the concept of maximum verisimilitude, which uses certain assumptions.

The first assumption is that errors are distributed according to the normal distribution law. Random variable *z* has a normal distribution if its probability density is - *f*(*z*), set as follows:

$$f(z) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{1}{2}(z-\mu)/\sigma^2}, \qquad (3)$$

where *z* - random variable;

μ - mathematical expectation of the value *z*, *μ* =*E*(*z*);

σ - standard deviation *z*.

A special feature of distribution networks is the insufficiency of the observation vector **z**. That is, using purely measured parameters, it is not possible to identify the EN state, because Problem (3) has no solutions. Adding a vector **z** with information from standard load graphs (pseudo-measurements) for EN nodes, it will attract the resources of existing measurement and monitoring tools to ensure the observability of the electrical network without additional financial costs.

Conclusion

The possibilities of improving the observability of electric distribution networks using Smart measuring devices, aggregated information from automated commercial electricity metering systems and pseudo-measurements are systematized and investigated. The expediency of applying the results of assessing the state of distribution electric networks in information systems for analyzing the energy efficiency of electric networks should be checked experimentally.

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