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INTELLIGENT SYSTEM FOR MEASURING ACTUAL POWER LOSSES OF AC OVERHEAD LINE

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YÜKSƏK GƏRGİNLİKLİ DƏYİŞƏN CƏRƏYAN AC HAVA XƏTİNİN GÜÇ İTKİLƏRİNİN ÖLÇÜLMƏSİNİN İNTELLEKTUAL SİSTEM

Xülasə

İdarəetmədə nəzarətin intellektuallaşdırılması müasir elektrik enerjisi sənayesinin inkişafında əsas tendensiyadır. Elektrik enerjisi sənayesində fərdi kompüterlər əsasında rejim parametrlərinin ölçülməsi və qeydə alınması üçün universal ölçü komplekslərinin və ixtisaslaşdırılmış cihazların tətbiqi ilə xəttin uclarında aktiv güclərin ölçülməsi yolu ilə hava xəttində ümumi aktiv enerji itkilərinin müəyyən edilməsinə maraq artmışdır. və korona güc itkilərini onlardan təcrid etmək. Kipnis-Şamir relinearizasiya metodu əsasında birbaşa vəziyyətin qiymətləndirilməsi. Yaranan yeni qeyri-xətti ölçü tənlikləri düzbucaqlı koordinat sistemində kvadrat gərginlikli polinomlara çevrilir. Metod, kvadrat dəyişənləri təkrarlanmayan şəkildə həll etmək üçün orijinal sistemin daha yüksək ölçülü sistemə iki çevrilməsindən istifadə edir. Dəqiq ölçmələrlə bu üsul çəkili ən kiçik kvadratlar üsulu ilə eyni nəticələr verir. Həddindən artıq yüksək gərginlikli hava xəttinin uclarında cərəyan rejim parametrləri əsasında rejim parametrlərinin və hava xəttinin dövrəsinin operativ qiymətləndirilməsinin monitorinqi üçün ixtisaslaşmış sistemdən istifadə edilməsi təklif olunur. Ölçmə sisteminin sistematik xətası müəyyən edilir. Hava xəttinin uclarında rejim parametrlərinin eyni vaxtda ölçülməsinin eksperimental tədqiqatları intellektual ölçmə vasitələrini və ixtisaslaşdırılmış ölçmə sistemlərini özündə birləşdirən avtomatlaşdırılmış sistem əsasında Azərbaycan enerji sisteminin ultra yüksək gərginlikli hava xəttinin nümunəsində aparılmışdır. 7 gün ərzində orta hesabla 10 dəqiqə qeydiyyata alınmış fərdi kompüterlərlə. Hava xətlərinin başlanğıcında və sonunda hava xətlərinin elektrik parametrlərinin monitorinqində sistematik səhvlər təxminən 0,1 faiz təşkil edir və ölçmələrin mütləq dəyərləri 0,5 MVt daxilində dəyişir. Müəyyən edilmişdir ki, ölçmə dəqiqliyi müasir intellektual ölçmə sistemlərinin əldə etdiyi hədlər daxilindədir. İterativ olmayan relinearizasiya metodu əsasında rejim parametrlərinin vəziyyətinin qiymətləndirilməsinin nəticələri yüksək gərginlikli hava xətlərinin rejimlərinə operativ nəzarət zamanı həllin cəldliyi və etibarlılığı baxımından üstünlüklərə malikdir.

Açar sözlər: hava xətləri, yüksək gərginliklər, PMU ölçmələri, aktiv enerji itkiləri, tac itkiləri.

INTELLIGENT SYSTEM FOR MEASURING ACTUAL POWER LOSSES OF AC OVERHEAD LINE

Summary

Intellectualization of control is the main trend in the development of modern electric power industry. With the introduction of universal measuring complexes and specialized devices for measuring and recording mode parameters based on personal computers in the electric power industry, interest has increased in determining the total active power losses in an overhead line by measuring active powers at the ends of the line and isolating corona power losses from them. Direct state estimation based on the Kipnis-Shamir relinearization method. The resulting new nonlinear measurement equations become quadratic voltage polynomials in a rectangular coordinate system. The method uses two transformations of the original system into a system of higher dimension to solve quadratic variables in a non-iterative way. With accurate measurements, this method gives the same results as the weighted least squares method. It is proposed to use a specialized system for monitoring the operational assessment of the mode parameters and the overhead line circuit based on the current mode parameters at the ends of the ultrahigh voltage overhead line. The systematic error of the measurement system is determined. Experimental studies of simultaneous measurements of the mode parameters at the ends of the overhead line were carried out using the example of an overhead line of ultra-high voltage of the Azerbaijan energy system based on an automated system that includes intelligent measuring instruments and specialized measurement systems with personal computers with registration with an averaging time of 10 minutes over a period of seven days. Systematic errors in monitoring the electrical parameters of overhead lines at the beginning and end of overhead lines are about 0.1 percent, and the absolute values of measurements vary within 0.5 MW. It has been established that the measurement accuracy lies within the limits obtained by modern intelligent measurement systems. The results of estimating the state of the mode parameters based on the non-iterative relinearization method have advantages in terms of speed and reliability of obtaining a solution in the operational control of modes of overhead lines of ultrahigh voltage.

Key words: overhead lines, extra-high voltages, PMU measurements, active power losses, corona losses.

ИНТЕЛЛЕКТУАЛЬНАЯ СИСТЕМА ИЗМЕРЕНИЯ ПОТЕРЬ АКТИВНОЙ МОЩНОСТИ ВОЗДУШНОЙ ЛИНИИ ПЕРЕМЕННОГО ТОКА

Аннотация

Интеллектуализация управления является основной тенденцией развития современной электроэнергетики. С внедрением универсальных измерительных комплексов и специализированных устройств измерения и регистрации параметров режима на основе персональных компьютеров в электроэнергетике, повысился интерес определению суммарных потерь активной мощности в воздушной линии по измерениям активных мощностей на концах линии и выделению из них потерь мощности на корону. Непосредственное оценивание состояния основанная на методе релинеаризации Кипниса-Шамира. Полученные новые нелинейные уравнения измерений становятся квадратичными полиномами напряжения в прямоугольной системе координат. В методе используется два преобразования исходной системы в систему большей размерности для решения квадратичных переменных не итерационным способом. При точных измерениях этот метод дает те же результаты, что и метод взвешенных наименьших квадратов. Предлагается использование специализированной системы мониторинга оперативной оценки параметров режима и схемы воздушной линии по текущим параметрам режима на концах воздушной линии сверхвысокого напряжения. Определяется систематическая погрешность системы измерения. Проведены экспериментальные исследования одновременных измерений параметров режима по концам воздушной линии на примере воздушной линии сверхвысокого напряжения Азербайджанской энергосистемы на базе автоматизированной системы включающие интеллектуальные измерительные приборы и специализированные системы измерений с персональными компьютерами регистрацией с временем усреднения 10 мин за промежуток времени семи суток. Систематические погрешности мониторинга электрических параметров воздушных линий в начале и конце ВЛ составляет около 0.1 процентов, а абсолютные значения измерений меняются в пределах 0.5 МВт. Установлено, что точность измерений лежать в пределах, получаемых по современным интеллектуальным системам измерения. Результаты оценивания состояния параметров режима на основании без итерационного метода релинеаризации имеет преимущества по быстродействию и надежности получения решения при оперативном управлении режимами воздушной линий сверхвысоких напряжений.

Ключевые слова: воздушные линии, сверхвысокие напряжения, измерения PMU, потери активной мощности, потери на корону.

1. Introduction

Active resistance, active and capacitive line conductivity and, accordingly, power losses for wire heating and corona in real conditions vary depending on the ambient temperature and meteorological conditions of the line route. Wire resistance is a function of current density, ambient temperature, and wind speed and rainfall rate. In this regard, the operational identification of the parameters of high voltage overhead lines, taking into account real operating conditions, is of great importance. Measurements of corona power losses on operating transmission lines are necessary to study corona losses; optimal control of voltage and reactive power modes; technical and economic analysis of the operation of OHL, in the exchange of electrical energy between power systems. Recently, a concept has been developed for a high-voltage network using a Phasor Measurement Unit (PMU) monitoring system, FACTS (flexible alternative current transmission system) devices, intelligent computer methods [1-2].

The SCADA (Supervisory control and data acquisition)measurements vector - used in the traditional formulation of electric power system (EPS) state estimation (SE) has the form: $\bar{y} = \{P_i, Q_i, P_{ij} \cdot Q_{ij}, U_i, I_i, I_{ij}\}$.

The measurements from conventional SCADA system does not contain phase angle measurements due to the technical difficulties associated with its synchronization.

Power loss estimation based on the difference in active power at the ends of transmission lines can be perform using SCADA and PMU measurements, as well as a dedicated measurement system for transmission lines [3-5].

Under equal conditions, only due to the non-simultaneity of SCADA measurements (4-10 sec), fluctuations in the difference in active power of the OHL vary within 0.5÷2 MW. In this case, the limits of change in the values of the measurement error of total losses are 2.9÷11.8% [5]. Taking into account the systematic error of the measuring complex of the power (0.2%), the errors of SCADA measurements at the ends of the OHL can be in the range of 4.5÷12.3%.

In connection with the introduction of equipment for synchronized vector measurements - PMU, the measurement accuracy of voltage module, power and phase angle reached 0.1%, 0.2% and 0.018 degree, respectively.

2. Method

The total losses of active power in the line are the sum of the losses for heating the wires $\Delta P_h$and for the corona power losses ΔP_c. The measurement of the total losses in the OHL can be perform by the difference in active powers (P1, P2) at the ends of the line.

$\Delta P_\Sigma = P_1 - P_2 + \Pi_{sys} + \Pi_{random}$, (1)

Where Π_{sys} and Π_{random} are the systematic and random components of the measurement error, respectively.

Since the values of active power at the ends of the line are quite close to each other, the error in determining the total losses can be large.

At present, there is no sufficiently developed theory of identification of the mode of ultrahigh voltage overhead lines. The analysis of modes performed using inaccurate measurements, changes in real operating conditions. In this regard, an urgent problem arises of determining the electrical parameters of power transmission lines.

Temperature change affects the change in active resistances of current transformer (CT) and voltage transformer (VT), respectively:

$$R = R_{20}(1 + \alpha(t_{amb} - 20)) \quad (2)$$

where R_{20} is the specific active resistance at a wire temperature of 20^0C; α = 0.004 – temperature coefficient of electrical resistance of steel-aluminum wires, 1/deg; t_{amb}- ambient temperature ^{0}S.

To control the operating modes of transmission lines and establish statistical regularities in the distribution of power losses to the corona by seasons and hours of the day, continuous accounting and processing of information is required. This also makes it relevant to improve the measurement technique for studying the corona power losses on the wires of existing power transmission lines in real conditions of their operation [5].

An antenna corona loss meter used at the beginning and end of the OHL [5].

Evaluation of power losses based on the difference in active power at the ends of the PTL can be performing using an automated specialized measurement system and intelligent measuring devices (see Fig.1).

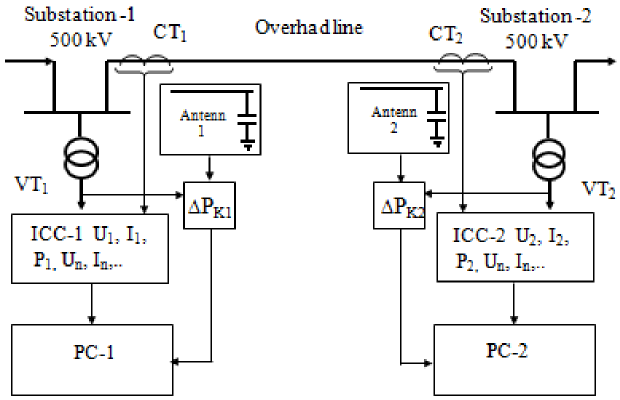

Figure 1. Circuit for measuring power losses of OHL

The weather station for automatic measurements of meteorological parameters allows measuring of: air, soil and water temperature, wind speed and direction, atmospheric pressure, amount and intensity of precipitation.

The state estimation errors, depending on the used model, have values comparable to the measurements of the mode parameters. In this regard, the requirements for the permissible errors of the method when modeling the OHL mode become relevant.

Traditionally OHL represented as π-scheme [5]. The proposed method for increasing the accuracy of modeling of the OHL mode based on its representing in the form of π-shaped sections (Fig. 1).

The task of the EPS SE consists in the calculation of the steady state conditions at information redundancy with errors. The mathematical basis of SE is the least square method (LSM).

The states (x) and given set of measurements (z) related by equation: $z_j = h_j(x) + e_j,$ where $h(x)$is the nonlinear function relating the error - free measurements to the system states and formed by load flowequations.

Weighted least square method (WLS) minimizes the criterion [3]

$$\varphi(x)=\left(y-y(\hat{x})\right)^T R_y^{-1}\left(y-y(\hat{x})\right) \quad (3)$$

where x = (δ, U) is the state vector, which consists of modules U and phase angles δ of voltages of all nodes of the EPS, except the base node phase; y = f (x) - measured mode parameters; z = φ (x) unmeasured mode parameters; R_y- diagonal measurement variances matrix.

To solve the SE problem, in [3] the method of test equations has been developed and implemented in software.

Iterative methods work well for SE, but these methods require an initial approximation and can run into convergence problems.

Thus, the SE is highly time consuming and infeasible for on-line implementation. To control complex PSs, real-time SE is required, which requires the development an application of special algorithms.

The non-iterative direct SE proposed in [6-8] based on the Kipnis-Shamir relinearization method. In this method, the measurement equations, which are the voltage value at the node of the power line and the power flow equations in rectangular coordinates. In this case, the nonlinear measurement equations become quadratic voltage polynomials. Then two transformations of the original system to a higher-dimensional system to solve the quadratic variables using non-iterative method are used. For the π-model of the transmission line shown in Fig. 2, the measurement equations presented as:

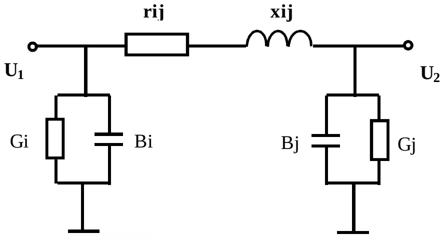

Figure: 2.□□-model of the power line

$$P_{ij}= g_{ij}\left((U_i^{'})^2+(U_i^{''})^2-U_i^{'}\cdot U_j^{'}-U_i^{''}U_j^{''}\right)+b_{ij}\cdot\left(U_i^{''}\cdot U_j^{'}-U_i^{'}\cdot U_j^{''}\right)$$

$$Q_{ij}=b_{ij}\left((U_i^{'})^2+(U_i^{''})^2-U_i^{'}\cdot U_j^{'}-U_i^{''}U_j^{''}\right)+g_{ij}\left(U_i^{'}U_j^{''}-U_i^{''}U_j^{'}\right)+b_{sh}\left((U_i^{'})^2+(U_i^{''})^2\right)$$

$$g_{ij}=\frac{R_{ij}}{Z_{ij}^2},\quad b_{ij}=\frac{X_{ij}}{Z_{ij}^2},\quad Z_{ij}^2=R_{ij}^2+X_{ij}^2$$

Where R_{ij}, X_{ij}, B_s are the active resistance, reactance and conductivity of the OHL, respectively.

Since the nodal power equations are linear with respect to the quadratic terms of the voltage, they represented in matrix form

$$A_{\xi}\xi=C \quad (6)$$

where C consist the measured values, ξ is the vector of voltage variables, and A_{ε} is the matrix of coefficients for ξ. The i and j indices are not associated with node numbers. After the transformations of the variables, system (6) represented in the form

$$\begin{bmatrix}A & B\end{bmatrix}\begin{bmatrix}Y\\ Z\end{bmatrix}=C \quad (7)$$

where A contains linearly independent columns of A_{ξ}, and B contains the remaining columns A_{ε}, Y is a vector of elements ξ corresponding to A, and Z is a vector of elements corresponding to B.

In the transformed system, Y expressed in terms of Z and measurements values C:

$$Y=d+DZ,\ d=(A^TA)^{-1}A^TC,\ D=-(A^TA)^{-1}A^TB \quad (8)$$

Software for the non-iterative SE method implementation for AC overhead line has been developed.

PMU measurements modeled by noising the power flow results according to the normal random numbers distribution law. Reference measurements: $U_1^{'}=1.02;\ U_1^{''}=0\ U_2^{'}=0.95633;U_2^{''}=-0.2923$,P$_{12}$=7.20544, Q$_{12}$=-0.8483, Where $U^{'}$ - true, and $U^{''}$ - is imaginary part of voltage, respectively $x_1=U_1^{'};\ x_2=U_2^{'}\ x_3=U_1^{''}\ x_4=U_2^{''}$

Let’s form matrices of measurements and coefficients C, A, B:

$$C=\begin{pmatrix}1.03886771\\ 1.00132711\\ 7.22125355\\ -0.84807473\end{pmatrix}\quad A=\begin{pmatrix}1 & 0 & 0 & 0\\ 0 & 1 & 0 & 0\\ 2.30241519 & 0 & -2.29541519 & -23.66652208\\ 22.03027208 & 0 & -23.66652208 & 2.29541519\end{pmatrix}\quad B=\begin{pmatrix}0\\ 1\\ 0\\ 0\end{pmatrix}$$

$$Y=d+D\cdot Z$$

$$D := -\left(A^T \cdot A\right)^{-1} \cdot A^T \cdot B = \begin{pmatrix} 0 \\ -1 \\ 0 \\ 0 \end{pmatrix} \qquad d := \left(A^T \cdot A\right)^{-1} \cdot A^T \cdot C = \begin{pmatrix} 1.03886771 \\ 1.00132711 \\ 0.97392374 \\ -0.29851907 \end{pmatrix}$$

The unknowns are determined from the matrix equation:

$$y := \begin{pmatrix} 1.03886771 & 0 \\ 1.00132711 & -1 \\ 0.97392374 & 0 \\ -0.29851907 & 0 \end{pmatrix} \cdot \begin{pmatrix} 1 \\ z_1 \end{pmatrix} = \begin{pmatrix} 1.03886771 \\ 0.91574827 \\ 0.97392374 \\ -0.29851907 \end{pmatrix}$$

Passing to the original notation, we get: $x_1 = \sqrt{y_1} = 1.01775$; $x_3 = 0$; $x_2 = 0.95633$; $x_4 = -0.29324$.The root-mean-square error of the voltage estimate in relative units was 0.00107.

The need for a large number of measurements is a potential disadvantage of the non-iterative method.

The characteristics of the errors of CT and VT refer to a specific sample. Actually each certain CT and VT have their own specific characteristics of errors determined by mathematical models depending on the mode parameters of the measuring circuits and operating conditions.

For practical tasks, it is necessary to determine the actual values of the measurement errors. Therefore, it becomes necessary to determine the components of the MC errors, taking into account the actual operating conditions of the MC.

3. Results

To simulate the mode of OHL, calculations were carried out for 500 kV OHL with a phase structure of 3xAS-330/43, $r_0 = 0.029$ Ohm/km, $x_0 = 0.299$ Ohm/km, $b_0 = 3.74*10^{-6}$Sim/km.

The issues of economical operation of overhead lines and power losses in overhead lines analyzed. To measure the parameters of the 500 kV "2nd Absheronskaya" OHL, measuring and computing complex of the "Siemens" company was used. The measurement accuracy is less than 0.1% for voltage and current and less than 0.2% for power.

At the known measured values of the mode parameters at the ends of the line and the known value of corona losses simulated for good weather (□P_{cfw}) for the SE of measurement system we have P_{sys} = □P_h + □P_{cfw} + P_2.

The curves of the active power losses of overhead lines 500 kV at averaging time of 5 minutes, where ΔP_{meas}, ΔP_{act}, ΔP_{load}, ΔP_{cor} - the active power losses of the line respectively: total measured, total actual, determined taking into account systematic error, load losses and corona losses are presented in Fig.3.

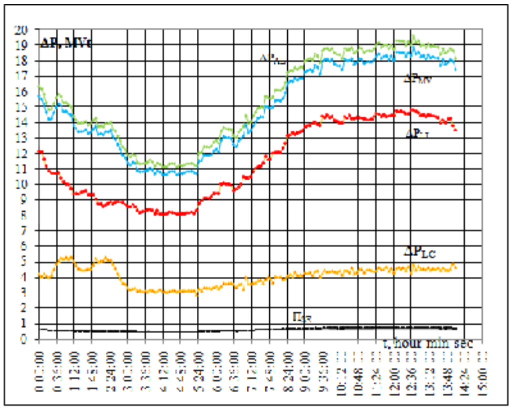

Figure: 3. Results of measuring power losses

4.Discussion

Devices and computers at the ends of the overhead line synchronized in time using the laboratory model for measuring the parameters of the overhead line. To achieve synchronous measurements of the mode parameters at the ends of the overhead line, the internal timers of personal computers synchronized to the exact time from the Internet.

The use of modern devices with technical characteristics similar to "SIMEAS Q" for the measuring of active power with an averaging period of 1 sec and an accuracy class of 0.2 allows for the measuring of current active power losses and the separation of corona losses of the EHV OHL with the accuracy sufficient for practice. During the studies, transmission modes from 450 to 650 MW observed for 4 days under various weather conditions.

The results of statistical processing and smoothing show that for the measuring of the current losses in the overhead line, one can select the smoothing period of 60-80 s.

During measurements for 4 days, the minimum value came on 02.21.2008 from 4:00 to 11:00 at averaging time of 10 minutes. The range of changes in corona losses and other components on the days of measurements ranged within 1.69 ÷5.4 MW.

Simplified simulation results in 1.5% error in loss simulation. Operational modeling of systematic errors of the measurement system taking into account real operating conditions and correction of the measurement result using the example of 500 kV overhead line show that due to error compensation,

The accuracy of measuring of active power at the beginning of the overhead line for the observed modes improved within 0.6 ÷ 0.72 percent.

At the end of the OH this accuracy changes within 0.5 ÷ 0.64 percent. The total estimate of the relative improvement of active power measurements on the days of mode measurements was about 0.9 percent of the measured power value.

The systematic errors of the electrical parameters of overhead lines at the beginning and end of the overhead line are about 0.1%, and the absolute values of the measurement complex vary within 0.1-0.8 MW (0.6 ÷ 4.7%).

5. Conclusion

1. It has been established that the errors of the method of modeling the mode of ultrahigh voltage transmission lines by simplified equations are comparable with the accuracy of measurements obtained using modern intelligent measuring systems.

2. Representation of overhead lines by 3-5 links allows obtaining the accuracy corresponding to the PMU accuracy.

3. Experimental studies of the mode parameters at the ends of a 500 kV overhead line using a specialized measuring system show that an averaging period of 1-10 s can be used to measure losses.

4. The solution of the OS problem by the non-iterative Kipnis-Shamir method does not depend on the initial approximation and has no convergence problems.

6. References

1. Phadke A.G. Synchronized Phasor Measurements. A Historical Overview. // IEEE/PES Transmission and Distribution Conference. 2002, Vol.1, p.476-479.
2. F. Schweppe, J. Wildes, ”Power System Static-State Estimation, Part I: Exact Model”, Power Apparatus and Systems, IEEE Transactions on, Vol. PAS - 89, January 1970, Page(s):120 - 125;
3. Gamm A.Z., Glazunova A.M., GrishinYu.A., Kolosok I.N., Korkina E.S. Development of algorithms for assessing the state of the electric power system based on the integration of SCADA and SVI / Electricity data. 2009, no. 6, p. 2-9.
4. Dyakov FA, Kononov Yu. G. A new approach to monitoring of ice formation on overhead lines 330 - 750 kV, Energetic 2009 No. 4, p. 4-10.
5. Balametov A.B. Coronation of wires of overhead power lines. Simulation in steady-state modes. Monograph. Saarbruken, Deutschland: LAP. 2013, 310 p.
6. Kipnis A, Shamir A. Cryptanalysis of the HFE public key cryptosystem. In: Proceedings of Crypto ’99. Santa Barbara (CA); 1999. p. 19–30.
7. Balametov A.B., Halilov E.D., & Isayeva T.M. An Adequate Mathematical Model of an Ultrahigh-Voltage Overhead Transmission Line Using Synchronized Phasor Measurements. Iranian Journal of Science and Technology - Transactions of Electrical Engineering. (2019). p-p. 1-9.

Balametov A.B., Khalilov E.D., Salimova A.K., Isaeva T.M. Assessment of the state of an overhead AC line by the relinearization method. Electricity, №4 2021, p. 17-24.