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The incentive scheme for maintaining or improving power supply quality

***Abstract**. The scheme for realization in system of automated control by the distributive company is offered. System Average Interruption Duration Index as dependent variable and territorial subdivisions of distribution network as independent variable in one-way analysis of variance are proposed. Examples of use System Average Interruption Duration Index as the Key Performance Indicators for an annual estimation of territorial subdivisions and workers of the distributive companies are examined.*

***Streszczenie.** Zaproponowano system realizacji w systemie automatycznej kontroli przez firmę dystrybucyjną. Wskazywany jest średni czas trwania zakłóceń systemu jako zależna zmienna i terytorialne podpodziały sieci dystrybucyjnej jako niezależnej zmiennej w jednokierunkowej analizie wariancji. Przykłady zastosowania Systemowego średniego indeksu zakłóceń jako kluczowych wskaźników wydajności dla rocznego oszacowania podziału terytorialnego i pracowników spółek dystrybucyjnych. (**System zachęt do utrzymania lub poprawy jakości zasilania**).*

Keywords: reliability indices, variance analysis, incentive scheme.
Słowa kluczowe: wskaźniki niezawodności, analiza wariancji, schemat zachęt.

Introduction

Modern power systems must supply consumers with the high-quality power with the certain continuity level (that means the term «reliability of power system's work»). There are various aspects of realization of this process (objective and subjective aspects; material, technical, organizational aspects and others). All of them must be analyzed by staff of power distribution companies for improvement of service quality and ways of power supply process perfection must be defined. Employees should use precise and clear algorithm of actions for success of the task performance. They must understand consequences and an ultimate goal. An incentive scheme must be in the power distribution companies for conscientious work of employees.

The implantation of an incentive scheme for maintaining or improving general continuity levels was one of recommendations the Council of European Electricity Regulators (CEER) that were submitted in 5-th benchmarking report [1] in 2011 year. The regulation of the service quality in European countries is considered in 6-th CEER benchmarking report on the quality of electricity and gas supply [2]. The systems of regulation are created on the basis of: Continuity measurement is a prerequisite for setting standards and reward/penalty regimes; Maintenance and improvement of general continuity levels as a result of the investment decisions of network operators with implementing reward/penalty for the achieved quality levels; Minimum standards for quality levels will guarantee that consumer will be compensated if the standard is not met by the network operator.

The review of use of incentives systems for the distributive companies in the European countries on the basis of key reliability metrics is considered in [2]. Key reliability metrics are indicated in IEEE Std. 1366-1998 Trial-Use Guide for Electric Power Distribution Reliability Indices [3]. These must definitely be interpreted and used as recommends IEEE Std. 1782-2014 Guide Collecting, Categorizing, and Utilizing Information Related to Electric Power Distribution Interruption Events [4].

Experience of an estimation of reliability by indexes of continuousness power supply in Northern America and in the Europe countries examined J. Mcdaniel, W. Friedl, and H. Caswell at the CIRED 23rd International Conference on Electricity Distribution [5]. They marked an influence on indexes of a power supply continuity of various factors, for example, of weather conditions or a percentage ratio of length of underground cable lines to the general length of distribution power lines in the country.

Except for the specified factors of an influence, distributive networks maintenance quality influences on power supply continuity too. An influence of various service strategies on indexes of power supply continuity was estimated L. Bertling, R. Allan, and R. Eriksson in [6].

The quality management system applies in the Ukraine power system also, making use of experience of many countries of the world. Under the Law of Ukraine «About the market of electric energy» [7] Regulator - the National Commission which is carrying out state Regulation in spheres of Power and Municipal Services (NCRPMS), defines the parameters of power supply quality with regard to a level of power supply continuity, of commercial quality of services on transfer, distribution and power supply, and also of voltage quality (VQ). Regulator approves their rate; defines the order and the rate of indemnification through non-observance of parameters of power supply quality. The order of indemnification to consumers through non-observance of the guaranteed standards of the commercial quality according to NCRPMS Resolution No. 1841 from 10/8/2016 [8] already takes action. Regulator introduces Rate Asset Base Tariff Regulation (RAB) in Ukraine. RAB provides motivation of achievement of target parameters of continuous supply of qualitative electric energy. These components have technical aspects. Continuous supply and VQ depends on maintenance quality of distributive networks equipment first of all.

Subjective factors occupy the significant place among factors of influence on quality of service of the equipment of distributive networks. For example, in [9] marked among these are: the organization of equipment stock-taking, compliance with regulatory requirements about inspections, maintenance service, repairs of the equipment and others.

It demands working out an incentive scheme for maintaining or improving power system quality and reliability on basis of estimation of work of service divisions and separate workers in the power distributive companies with use of simple algorithms of actions in the accessible interface, for example Microsoft Excel or with use of the automated control systems by the distributive company.

Reliability *Indices*

Quarterly, the power distributive companies of Ukraine provide Regulator report-by-form 11-NCRPMS about the

main reliability indices: System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), Momentary Average Interruption Frequency Index (MAIFI) and Energy Not Supplied (ENS). Quarterly, the power distributive companies of Ukraine provide Regulator report-by-form 12-NCRPMS about parameters of commercial quality of given services too.

Distribution network equipment is serviced by territorial subdivisions - district electric networks (DEN). The comparative analysis of reliability indexes in power distributive companies exclude influence of weather conditions, as all DEN of one power distributive company are, as a rule, in equal weather conditions, except for significant events, for example, formation of significant ice on wires of transmission lines.

From the service quality standpoint the analysis of SAIDI database enables to appreciate the quickness of elimination of the equipment failure first of all. It is influenced by qualification and quantity of the repair personnel, provision of spare parts and consumables, etc.

The analysis of SAIFI database enables to appreciate quality of previous service (quality of the analysis of technical condition of distributive networks, timeliness and completeness of maintenance, repair, rehabilitation, modernizations of distributive networks, etc.).

The analysis of these data allows defining previously DEN with systemic shortcomings of the networks service with sufficient reasonableness for use of incentive methods for improvement of power supply quality. The subsequent more profound analysis will reveal the reasons of poor service quality and will allow developing activities for their elimination.

At that the use of widely accessible tools of the computer analysis is recommended. Following part the example of use of the Microsoft Excel Analysis ToolPak with this purpose is considering.

Analysis *of Variance of SAIDI data*

We consider the use of a one-way analysis of variance (ANOVA) of the Microsoft Excel Analysis ToolPak for definition of DEN with systemic shortcomings of the networks service.

ANOVA is a method of mathematical statistics that allows one to find in the database the significance of differences in mean values. Unlike t-test, ANOVA allows comparing the mean values of more than two groups of data. According to David M. Diez, Christopher D. Barr, Mine Cetinkaya-Rundel [10] ANOVA is suited to a wide range of practical problems. It is conceptually similar to multiple two-sample t-tests, but results in less type I error.

For example, SAIDI database from quarterly reports of eight DEN is created in power distributive company. The reasons of breaks in power supply of consumers are quarterly analyzed according to the recommendations of regulatory service documents (for example, the standard 40.1.20.576:2005 [11]). Among them there can be defects of installation, defects of repair, change properties of materials, untimely carrying out of service, etc. However, a conclusion about what DEN have systemic shortcomings of the networks service can be made on SAIDI database of several reports, for example, of four quarterly reports.

Consider an example of use of one-way ANOVA of the Microsoft Excel Analysis ToolPak. The independent variable is DEN_n (n=1, … m). We have eight categorical (m=8). Influence of factor DEN_n on a dependent metric variable is investigating. The Regulator sets targets for the continuity of power supply for SAIDI to date. So an example with SAIDI (the dependent variable) is considered. Quarterly SAIDI data of eight DEN are cited for example in Table I.

Results one-way ANOVA for data of Table 1 are presented in Tables 2 and 3.

Table 1. Quarterly SAIDI data (1 option)

DEN_n	SAIDI (quarterly data)			
	1	*2*	*3*	*4*
DEN_1	301	82	297	250
DEN_2	479	169	276	338
DEN_3	167	326	259	307
DEN_4	518	444	669	255
DEN_5	102	349	146	344
DEN_6	39	27	218	49
DEN_7	343	486	294	386
DEN_8	257	306	53	114

Table 2. ANOVA: single factor (summary, 1 option)

SUMMARY				
Groups	*Count*	*Sum*	*Average*	*Variance*
Rows 1	4	930	232	10653
Rows 2	4	1261	315	16679
Rows 3	4	1059	265	5048
Rows 4	4	1886	472	29584
Rows 5	4	940	235	16888
Rows 6	4	333	83	8140
Rows 7	4	1508	377	6669
Rows 8	4	730	182	14077

Table 3. ANOVA: single factor (ANOVA, 1 option)

Source of Variance	Between Groups	Within Groups	Total
SS	397446	323213	720659
df	7	24	31
MS	56778	13467	
F	4.22		
P-value	0.0037		
F crit	2.42		

Conclusion: F > F crit (4.22 > 2.42) and P-value is 0.0037, which is less than the significance level, we reject the null hypothesis. Accordingly, the hypothesis that DEN is the influential factor on SAIDI is accepted.

It is the preliminary opportunity to draw a conclusion that in DEN_4, where the greatest average value SAIDI for a year, there is a poor quality of maintenance of distributive networks (as major factor of influence on power supply continuity) and systemic shortcomings in the work. Other option of quarterly SAIDI data of eight DEN are cited for example in Table 4. Results one-way ANOVA for data of Table 4 are presented in Tables 5 and 6.

Table 4. QUARTERLY SAIDI DATA (2option)

DEN_n	SAIDI (quarterly data)			
	1	*2*	*3*	*4*
DEN_1	285	47	91	188
DEN_2	164	364	136	452
DEN_3	142	369	114	302
DEN_4	650	83	294	280
DEN_5	390	321	136	511
DEN_6	229	129	160	152
DEN_7	52	150	50	398
DEN_8	134	73	270	280

Table 5. ANOVA: single factor (summary, 2 option)

SUMMARY				
Groups	*Count*	*Sum*	*Average*	*Variance*
Rows 1	4	611	153	11297
Rows 2	4	1116	279	23703
Rows 3	4	927	232	15194
Rows 4	4	1308	327	55663
Rows 5	4	1358	340	24667
Rows 6	4	670	167	1869
Rows 7	4	650	162	26805
Rows 8	4	758	190	10418

Table 6. ANOVA: single factor (ANOVA, 2 option)

Source of Variance	Between Groups	Within Groups	Total
SS	159404	508847	668251
df	7	24	31
MS	22772	21202	
F	1.07		
P-value	0.41		
F crit	2.42		

Received ANOVA result endorses, that the probability of a null hypothesis cannot be rejected (P-value is 0.41). The difference in data is not essential. Check of Fisher's statistics of testifies: 1.07 < 2.42. Accordingly, it is an example when it is impossible to accept a hypothesis about DEN is the influencing factor on SAIDI.

SAIDI is a factor of incentive scheme for maintaining or improving power supply quality

Monitoring and expansionary action of achievement of the best results of activity of companies divisions and workers for improvement of power supply quality is used.

Key Performance Indicators (KPI) has started to use in the distributive companies for an annual estimation. It is an estimation system which helps the distributive companies in achieving of the strategic purposes (in particular, improvement of power supply quality). An incentive scheme on the basis of KPI is created.

For example, annual bonus (AB) for management of DEN can be defined by using the following formula

$$AB = X \cdot B \cdot \sum_{i=1}^{k} \left(KPI_i \cdot P_i \right) / 100 , \quad (1)$$

where B is the base official salary; P_i is the specific weight of i-th KPI; X is the factor which defines, what part of the base official salary B is used for calculation annual bonus AB.

Result one-way ANOVA for data of 1 option became acceptance of a hypothesis that DEN is the influencing factor on SAIDI. Therefore, is suggested to choose the coefficient X according to DEN's rank in the rating which we denote by r (r=1, … m).

The example of a choice of factor X according to DEN's rank in the rating is given in Table 7.

Table 7. A choice of X according to DEN's rank in the rating

DEN	DEN's rank in the rating	SAIDI	Xr
DEN_6	1	83	1
DEN_8	2	182	0.85
DEN_1	3	232	0.7
DEN_5	4	235	0.55
DEN_3	5	265	0.4
DEN_2	6	315	0.25
DEN_7	7	377	0.1
DEN_4	8	472	0

Such conditions in Table VII for choice X according to DEN's rank in the rating are realized:

$$\left.\begin{array}{c} X_r = 1, \ r = 1; \\ X_r = 0, \ r = m; \\ X_r = (X_{r-1} - 0.15), \ r = (2,...m-1). \end{array}\right\} \quad (2)$$

In the generalized kind of a condition (2) it is possible to present as

$$\left.\begin{array}{c} X_r = 1, \ r = 1; \\ X_r = 0, \ r = m; \\ X_r = (X_{r-1} - Y), \ r = (2,...m-1); \\ Y = 1/(m-1). \end{array}\right\} \quad (3)$$

Thus director, deputy director and chief engineer of DEN_4 (DEN with systemic shortcomings in the maintenance of distributive networks) will not receive annual bonus for fiscal year.

Other approach is definition of factor X by proportionally of SAIDI. It is recommended in cases when impossible to accept a hypothesis about DEN is the influencing factor on SAIDI. If that's the case, then definition of factor X is offered with realization of such conditions:

$$\left.\begin{array}{c} X_1 = 1, \quad SAIDI_1 = SAIDI_{p\min}; \\ X_p = \left(X_{p-1} - \dfrac{SAIDI_p}{\sum_{p=1}^{m} SAIDI_p} \right), \quad p = (2,...m). \end{array}\right\} \quad (4)$$

The example of definition of factor X by proportionally of SAIDI in Table 8 for data 2 option (see tables 4 to 6) is presented.

Table 8. Definition of X by proportionally of SAIDI

DEN	SAIDI	Xp
DEN_1	153	1.00
DEN_7	162	0.91
DEN_6	167	0.82
DEN_8	190	0.72
DEN_3	232	0.59
DEN_2	279	0.44
DEN_4	327	0.27
DEN_5	340	0.08

The average annual value of SAIDI can be used as one of key parameters of results of DEN's board activity too. However, not one parameter is used for an annual estimation of workers' productivity. We shall consider an example, when for achievement of the strategic purpose (improvement of power supply quality) for an annual estimation of results of DEN's managers activities in the distributive company are used such key parameters:

K1 – the average annual value of SAIDI, min;

K2 - percent of untimely granting of service for measuring indicators of VQ, %;

K3 - the number of bilateral acts about VQ for the year (for not the population), when the indicators of VQ did not comply with the contract, pcs;

K4 - the number of bilateral acts about VQ for the year (for the population), when the indicators of VQ did not comply with the contract, pcs.

A conditional example is considered because the quantity of key parameters, as a rule, much more and they takes into account not only parameters which characterize a power supply continuity and VQ. Results of calculation example for DEN_7 (data of 1 option) based on four key parameters are presented in the KPI matrix in Table IX. DEN performs maintenance of rural distributive networks in this example. Target for SAIDI is 300 minute for Ukraine rural distributive networks today. 150 minute is SAIDI target for Ukraine urban distributive networks.

Table 9. The KPI matrix

Key indicator	Specific weight (P_i)	Factors for KPI			KPIi, %
		Norm	*Target*	*Fact*	
K1	0.8	320	300	377	85
K2	0.1	2,5	0	2	125
K3	0.05	4	0	4	100
K4	0.05	2	0	2	100
Coefficient of effectiveness ($\sum KPI_i \cdot Pi$)					90

From this it follows that

$$AB = 0.1 \cdot B \cdot 0.9 / 100 = 0.09 \cdot B. \quad (5)$$

That is annual bonus for managers of DEN (of director, deputy director and chief engineer) will be at the rate of 9% from the base official salary. But KPI - the average annual value of SAIDI is only 85 %, both KPI - the numbers of bilateral acts are 100% and KPI - percent of untimely granting of service for measuring indicators of VQ is 125 %. The efficiency factor is equal to 90% as a result.

The incentive scheme for maintaining or improving power supply quality which can be realized both in the accessible interface, for example, Microsoft Excel, and in the automated control system of the distributive company is shown in Fig. 1

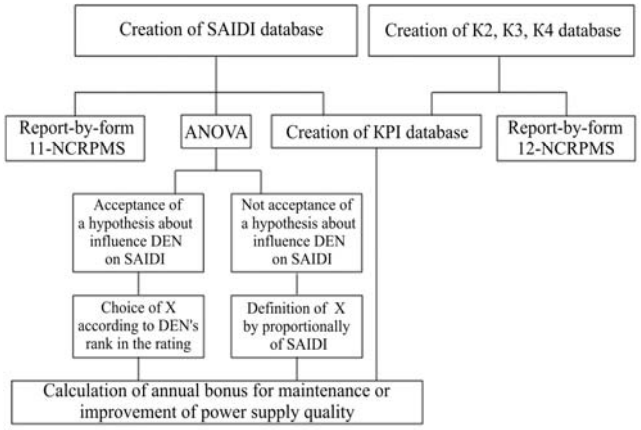

Fig. 1. The incentive scheme for maintaining or improving power supply quality

Conclusions

The use of one-way ANOVA is expedient at the first stage of definition of ways of improvement of power supply quality, in particular, of continuity. For more profound research of a question possible the multi-criteria analysis on the basis of the information not only about SAIDI, but also about SAIFI, about distribution and development of investments by everyone DEN, about quantity of the service personnel, etc.

Worked up the incentive scheme for maintaining or improving power supply quality can be used in full or in part. In the incentive scheme it is possible to use only results one-way ANOVA for calculation of factor X, which defines, what part of the base official salary is used for calculation annual bonus. Or it is possible to use only SAIDI as KPI. Also can be various specific weight of i-th KPI.

The important condition is the transparency and fairness of incentive scheme, and also an openness of results of an annual estimation of activity of territorial divisions of the distributive companies and their workers.

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REFERENCES

[1] Dechnik M., Moskwa Sz., Benchmarking of power distribution systems, *Informatyka, Automatyka, Pomiary w Gospodarce i Ochronie Środowiska - IAPGOS*, 5(2015), no. 1., 37-44

[2] Wojcik, W; Bieganski, T; Kotyra, A; et al., Application of algorithms of forecasting in the optical fibre coal dust burner monitoring system, SPIE Proc., 3189 (1997), 100-109.

[3] VIEEE Standard 1366-1998, "IEEE Trial Use Guide for Electric Power Distribution Indices".

[4] IEEE Standard 1782-2014, "IEEE Guide Collecting, Categorizing, and Utilizing Information Related to Electric Power Distribution Interruption Events".

[5] J. Mcdaniel, W. Friedl, H. Caswell, 2015,"Benchmarking of Reliability: North American and European Experience", CIRED 23rd International Conference on Electricity Distribution, Lyon, France

[6] Bertling L., Allan R., Eriksson R., A Reliability-Centered Asset Maintenance Method for Assessing the Impact of Maintenance in Power Distribution Systems, *IEEE Trans. Power Syst.*, 20(2005), no. 1, 75–82

[7] Lipnicki P., Power electronics devices in power distribution systems, *Informatyka, Automatyka, Pomiary w Gospodarce i Ochronie Środowiska - IAPGOS*, 2(2012), no. 2., 18-20

[8] NCRPMS Resolution No. 1841 dated October 8, 2016 "On Approval of the Procedure for Providing Quality Standards for Power Supply Services"

[9] Trunova I., Miroshnik O., Quality of Power Supply Services for Consumers: Monograph. Kharkiv, 2018. - 179 p.

[10] Diez, David M; Barr, Christopher D; Cetinkaya-Rundel, Mine (2017). OpenIntro Statistics (3rd ed.). OpenIntro. Retrieved 11 November 2017.

[11] Methodical instructions for the accounting and analysis in the power systems of the technical state of distribution networks with voltage 0.38-20 kV with transmission air linesr: SOU-H MPE 40.1.20.576:2005.