THE INFLUENCE OF ASYMMETRICAL REGIMES ON THE FUNCTIONING RELIABILITY OF ELECTRO-ENERGETIC SYSTEMS

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Abstract: Graph sructure variations in the distribution networks and power increase in the generating nodes lead to the appearance of asymmetrical regimes which may be accompanied by additional phenomena including varions forms of short circuits (both monoplastic and triplastic). We can conclude that, as a result of these phenomena, the reliability of respective electrical equipement will change in its turn.

This article is concerned with the analysis of asymmetrical regimes influence on the functioining reability of electrical equipement.

Key-words: Asymmetrical regimes, electrical equipments, short circuit, reliability of electro-energetic systems.

INTRODUCTION

One of the key problems in developing process of power systems and especially in those of electrical energy distribution is the problem of unbalanced regimes which appear and the phenomena accompanying these regimes and their influence on the functioning of installed equipments. From the most common phenomena which could appear in three phase systems, which create the unbalanced regimes are short circuit which joins the normal functioning regimes.

RESOLVING OF THE PROBLEM

From all the installed equipments the most often are subjected to unbalanced phenomena and transitional regimes which appear in distributional systems are the switches. From this very reason the level of functioning reliability and the functioning way of distributional system are in direct dependence from the functioning way of switches, that the most often are installed at feeder beginning. At appearance of unbalanced regimes and the phenomena of short circuit the switches must trigger in a quick way (during 4 periods) the respective electric circuit , for keeping the functioning hardness of the respective system. From studied static materials can be found, that with increasing of short circuit current values in nodes of system power the most difficult functioning conditions of switches appear then, when the value of short circuit current constitutes the size which is determined through equation (1).

$$I_{s.c.} = \frac{2}{3} I_{s.c.\max} \qquad (1)$$

where: $I_{s.c.\max}$ – the short circuit current at the beginning of network;

It was established that from all unbalanced regimes joined by transitional regimes , the most difficult at connection by switcher are those created depending on tension variation speed, (du/dt) and the electric current variation (di/dt) instead of unbalanced regimes appearance. The respective values variation in electric circuit nodes, and the switching off hardness of these regimes can be determined in an analytical way through the value of hardness coefficient, that is calculated according to this equation (2)

$$k_D = I_{scA} / I_n \qquad (2)$$

where: I_{scA} –is the expected short electric current in the electrical node.

I n-is the nominal electric current switched off by the respective switcher.

In the analyzed process of transitional influence on three phase systems created by the unbalanced regimes one of the basic elements in the function reliability of electric equipments according to [2,3]. In determination process of short electric current influence and of unbalanced regimes on the functioning reliability of switchers goes from the assumption that the described in[2,3] conditions are fulfilled and in this case the frequency of switching off is the function of switched electric current values and it expressed by the equation (3).

$$\lambda(t) = f(I_{SC}^{(1)}; I_{nom}^{(3)}); \quad \lambda(t) = \frac{1}{t_p} \int_0^{t+t_p} \omega(x)dx \qquad (3)$$

If from this formula is established that the switching off frequency will be a determined value, then the function without rejection probability of respective equipments will be determined from the expression (4)

$$p(t) = e^{-\lambda t} \qquad (4)$$

The rejection probability of respective equipments in functioning process will be determined by following expression (5)

$$q(t) = 1 - p(t) = 1 - e^{-\lambda t} \qquad (5)$$

If it is known the rejection probability of respective equipments planned at the beginning of exploitation (q_1) and that real at the stage of doing the respective, consecutive repairs (q_2) for reestablished technical properties then it can be analytical determined the reliability reserve function of respective equipments according to expression (6)

$$\Delta q = q_2(t) - q_1(t) = e^{-\Delta\lambda t} \qquad (6)$$

where: *Δq* – represents the possible value of function rejection increasing probability of respective equipments by the next consecutive repair.

$\Delta\lambda = (\lambda_2 - \lambda_1)$ – is the frequency switch off differences that is electric current values function switched off at the beginning of exploitation cycle [λ_1]and at the moment of doing the respective capital reparations [λ_2].

The operations number of respective equipments depending on frequency and probability of respective rejection occurrence can be analytic determined through the equation (7)

$$n = n_0 e^{-\Delta\lambda t} \qquad (7)$$

Where: n_o-is the minimal operations number that are possible established for respective equipments till the next reviewing and capital reparation this comes from the switched of current values.

Thus the unbalanced processes the most often are joined by the emission of the warmth ,which has a negative influence on electric equipments function ,the appears the necessity of verifying the respective equipments and at thermal hardness. It comes from the real functioning conditions. In this case if the 7 formula inequality is fulfilled it can be established that the respective equipment will respect thermal hardness.

$$I^2_{\grave{O}.nom} \cdot \tau_{\grave{O}.nom} \geq \int_0^{\tau_{T.nom}} \hat{A} \qquad (8)$$

Where: $I_{T.nom}$ - is the nominal value of the current with thermal hardness of equipments.

$\tau_{T.nom}$ - is the nominal thermal hardness time.

B - Is the integral of Jull with integral limits from 0.

Another index that characterizes the capacity and probability of respective equipments in respective node of electric system is the switched of capacity of electric parameters in different possible situations, as in normal functioning regime so in unbalanced regimes of accident. According to [4] the switched off capacity of respective equipments estimated from the nominal switched off current value. Id.nom and the nominal unbalance of switched of current in the moment (β_{nom}) of switched off, that may be determined according to expression (9):

$$\beta_{nom} = \frac{i_{a.\tau}}{I_{o.nom}\sqrt{2}} \qquad (9)$$

Where: $i_{a\tau}$ - is the a periodic component value of electric current of short circuit in the moment of switching off the respective regime.

The functioning reliability of respective electric equipments (including switches)in this case is the function of electric current value of switching off and the variation speed of the transitional and restored tension in the respective moment, the probability of the functioning without rejection and the respective operations number that were done.

In analytical way the respective dependence can be presented according to expression (10).

$$R(t) = \frac{1}{n\sqrt{2\pi}} \int_0^t I^{(3)}_{\hat{E}\c{C}}(t) \int_0^t (\omega \cdot t + \gamma \cdot t)dt. \qquad (10)$$

The reliability functioning dependence of the electric equipments as function of electric switched off current values and the done cycles number for respective equipments (including switch) installed in systems of different tension level, for different exploration periods (period 1980-2007) in various systems can be different, but for concrete analyzed system is presented in chart **1**

Chart 1

$I_{о\ ном}$ (кА)	20	30	40	50	63
$I_{кз}/I_{о.\ ном}$	0,16	0,25	0,50	0,75	1,0
N	30	25	20	12	10
R	0,996	0,998	0,999	0,993	0,991

From the numeric value analysis of functioning reliability presented in (chart 1) is explained that the reject frequency variation(intensity) of the electric equipments and the reject probability in time, can be presented in the respective graph by showed curves (1) and (2) from figure 1, which point out that the respective values correspond to the reestablished classic functions of the elements that enjoin the processes of restoration in time.

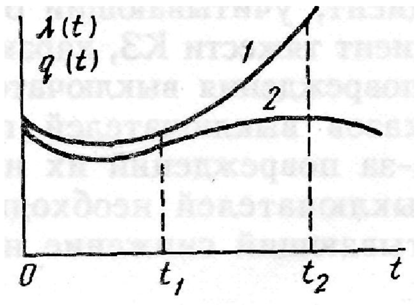

Fig. 1

The probability of functioning without rejection is a parameter that characterizes the electric equipment working reliability (including switches) that depends on the exploitation time can be analytical determined by the expression (11).

$$p(t) = e^{-\int_0^t \lambda(t)dt} \qquad (11)$$

The electric equipments frequency rejection (including switches) q(t) is determined paying attention to the intensity working without rejection p(t) and analytical will be calculated according to (12):

$$q(t) = 1 - p(t) = 1 - e^{-\int_0^t \lambda(t)dt} \qquad (12)$$

The analysis work process of electric equipments in three phase systems at occurrence of transitional systems can be established that approximately 25% from disconnection are spent in basis of the unbalanced regimes that appear in respective systems.

From this very conditions the equipments function reliability systems of distribution can be determined paying attention to the respective distribution phenomena and it will be determined according to the expression(13)

$$R(t) = K\frac{K_T}{n\sqrt{2\pi}} \int_0^t [w\tau + \gamma\lambda\tau]d\tau / (I_{SC} / I_{\hat{\imath}.Nom}) \qquad (13)$$

Conclusions.

From all that was presented we established that transitional processes that accompany the unbalanced regimes of the respective electric equipments functioning that can be expressed through the functioning reliability of respective equipments.

In our thesis it is proposed a mathematical model and an algorithm that can modify the functioning reliability of electric equipments that depends on the unbalanced switched off current and of the variation reestablished tension speed at the bases of respective equipments.

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Аннотация. Статья посвящена использованию метода Годунова для анализа переходных процессов в распределительных системах и их влияние на функциональную надежность составных элементов и особенно выключателей

Переходные процессы, возникающие в электроэнергетических системах, имеют существенное влияние на функциональную надежность большинства элементов системы и особенно выключателей и поэтому надежная работа большей части системы зависит от функциональной надежности выключателей.

При возникновении переходных процессов в электрических сетях различного уровня напряжений электроэнергетических систем, функциональная надежность выключателей является функцией ряда определенных и неопределенных факторов.

Возникающие переходные процессы в узлах ЭЭС являются функцией нескольких составляющих, таких как значения отключаемых токов, значения переходной восстанавливающейся напряжение место где происходит переходной процесс, значения параметров возникающей электрической дуги и скорости их изменения во времени.

В данной статьи рассматривается переходные процессы, возникающие при не удаленных коротких замыканиях, которые считаются наиболее тяжелыми и которые описаны в /1/.

Формы кривых возникающих в таких случаях переходных процессов и принципы их образования подробно описаны /2/.

Однолинейная электрическая схема конкретного рассматриваемого электрического узла со всеми его электрическими связями представлена на рис. 1.

Рис. 1.

Перечисленные явления, сопровождающие переходные процессы согласно /3-5/ аналитически могут быть описаны следующими дифференциальными уравнениями.

$$\frac{di_D}{d\tau} = d\left(I_m e^{-j\omega\tau}\right)/\,d\tau \qquad (1)$$

$$\frac{dU_D}{d\tau} = Zv\frac{n}{n-1}\frac{di_D}{d\tau} \qquad (2)$$

$$\frac{dQ}{d\tau} = -Q_0\left(\frac{1}{i_{Д}^{-1}}\frac{di_{Д}^{-1}}{d\tau}\bullet\frac{1}{U_{Д}}\frac{dU_{Д}}{d\tau}\right) = -Q\Bigg[\frac{dU_{Д}}{U_{Д}}\bullet\Bigg(\frac{dU}{i_{Д}} \qquad (3)$$

В приведенных уравнениях:

Zv – волновое сопротивление контура, где имеет место переходной процесс.

n – количество линий, присоединенных к шинам, где установлен выключатель и имеет место переходной процесс;

$\boldsymbol{I_m}$. – амплитудное значение отключаемого тока;

ω - угловая частота переменного тока.

Полученные дифференциальные уравнения являются нелинейными и для их решения может быть использован метод Годунова, который согласно /4/ позволяет получить конкретные значения параметров, характеризующие переходные процессы и электрические дуги в выключателях.

Полученные результаты анализа и оценки переходных процессов и описание электрической дуги в высоковольтных выключателях различного типа, показывает их высокую степень точности и соответствие опыту эксплуатации. Это способствует упрощение математической модели и соответствующего описания электрической дуги по сравнению с /1-3 /.

Все это дает основание считать, что использование метода Годунова, способствует повышению точности расчета параметров переходных процессов в электроэнергетических системах и более детальное определение функциональной надежности высоковольтных выключателей (особенно воздушных и вакуумных) при расчете переходных процессов в электроэнергетических системах.

Основой для разработке математического модели электрической дуги может служить уравнения непрерывности, сохранения импульса и энергии и закон Ома.

Исследование несимметричных режимов, которые могут иметь различные формы и продолжительности и сопровождаемые электрическими дугами, которые могут возникнуть при отключении различных видов короткого замыкания, которые сопровождают несимметричные переходные процессы в электрических сетях различного уровня напряжения проводится согласно /5-6/ с учетом ее симметричности и классифицируется следующим образом:

Уравнение непрерывности электрической дуги имеет форму:

$$\partial \rho/\partial t + (\rho v_z)\partial v_z/\partial z + (r\rho v_r)\partial v_z/r\partial r = 0 \qquad (4)$$

Уравнение сохранения аксиальной проекции

импульса имеет форму:

$$\rho\partial v_z/\partial t + \rho v_z\partial v_z/\partial z + \rho v_r\partial v_z/\partial r = -\partial \rho/\partial z + \partial[(\eta+\eta_r)r\partial v_z/\partial r]/r\partial r \qquad (5)$$

При таких условиях уравнение сохранения

энергии импульса имеет форму:

$$\rho\partial h_0/\partial t + \rho v_z\partial h_0/\partial z + \rho v_r\partial h_0/\partial r = \sigma E^2 - U + \partial[(k+k_T)r\partial T/\partial r]/r\partial r \qquad (6)$$

Если соблюдаются условия 4-6 , то закон Ома может быть представлен в виде:

$$I = E\int_0^{r1} 2\pi\sigma\, rdr = 2\pi E\int_0^{r1} \sigma\, rdr \qquad (7)$$

где: **ρ** - плотность среды;**V_z** - осевая ,**V_r** – радиальная компоненты скорости среды; **p** – давление; **η** – вязкость скреды; **η_T** – турбулентная вязкость; **E** – напряженность; **σ** – электропроводность;**U** – эффективный коэффициент излучения; **h_0**- полная энталпия; **k** – молекулярная теплопроводность; **k_T** – турбулентная теплопроводность; **r-** радиус дуги.

Если уравнения 4-6 интегрировать по радиусу ***r*** с учетом соблюдения соответствующих пределов $a \le r \le b$ то представленные уравненя 4-6 примут следующую форму:

Уравнение непрерывности состояния

$$\partial\int_a^b 2\pi\rho v_z\, rdr/\partial t + \partial\int_a^b 2\pi\rho v_r\, rdr/\partial z + q(b) - q(a) - \lambda(b) + \lambda(a) = 0 \qquad (8)$$

Уравнение сохранения аксиальной проекции импульса имеет форму:

$$\partial\int_a^b 2\pi\rho h_0\, rdr/\partial t + \partial\int_a^b 2\pi\rho v_r^2\, rdr/\partial z - \Phi(b) + \Phi(a) + q(b)v_z(b) - q(a)v_z(a) = \partial\rho\pi^2(b^2 - a^2)/\partial z - 2\pi[bS(b) - aS(a)] \qquad (9)$$

При этих условиях уравнение сохранения

энергии импульса будет имееть форму:

$$\partial\int_a^b 2\pi\rho v_z\, rdr/\partial t + \partial\int_a^b 2\pi\rho v_r h_0 rdr/\partial z - \Psi(b) + \Psi(a) + q(b)h_0(b) - q(a)h_0(a) = \int_a^b 2\pi r[\sigma E^2 - U]dr - 2\pi[W(a) - W(b)] \qquad (10)$$

В приведенных уравнениях используются

следующие обозначения:

q(a),q(b)- потоки массы в радиальном направлении через границы a и b;

λ,Φ,Ψ- функции перемен времени, d, ρ,v_z, h_0 на этих же границах;

S(a),S(b) – функции характеризующие радиальный поток импульса и энергии через границу ***r = b,*** которое определяется соотношениями (11-14):

$$S(a) = [(\eta+\eta_r)\,\partial v_z/\partial r]_{r=a} \qquad (11)$$

$$S(b) = [(\eta+\eta_r)\,\partial v_z/\partial r]_{r=b} \qquad (12)$$

$$W(a) = [(k+k_r)\,\partial T/\partial r]_{r=a} \qquad (13)$$

$$W(b) = [(k+k_r)\,\partial T/\partial r]_{r=b} \qquad (14)$$

Приведенные интегральные уравнения (8-10) могут характеризовать переходной процесс сопровождаемый электрической дугой возникающая на контактах выключателей в зависимости от скорости протекания процесса и место его нахождения относительно рассматриваемого выключателя.

Используя метод Годунова приведенные нелинейные уравнения, при помощи которых с можно линеаризировать и в таком случае переходной процесс и процесс гашения электрической дуги в выключателях различного можно рассматривать при помощи линейных эквивалентных уравнений.

Выводы.

Использование метод Годунова для анализа переходных процессов сопровождаемые возникновением электрической дуги на контактах выключателей позволяет нелинейные кривые и соответствующие дифференциальные уравнения, которые могут изображать данные процессы линеаризировать по определенным участкам и переходить от дифференциально-интегральных уравнений, которые описывают данный процесс к эквивалентным линейным уравнениям.

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Abstract - The paper is structured in five parts. In the first part is evoked the importance of the topic and current concerns. In the second part are presented the general pattern of reliability of the relay - the core of the protection subsystems (SSP). In part three are presented the models for evaluation of the proposed development of the reliability of the SSP, based on the general model, given the structure of the SSP and their functions in urban medium voltage electrical networks (UMVEN). In part four are given the results of operational reliability evaluation for SSP as in the last part of the analysis the conclusions are presented.

Keywords: modelling, reliability protection system, electrical network.

1. INTRODUCTION

Reliability analysis and automatic protection system (APS) of UMVEN structure are subordinated to the objectives of maximizing the availability of energy and UMVEN security. By maximizing the availability of energy is obtained also the maximizing of economic efficiency of UMVEN. Sometimes there is a tendency to minimize the importance of APS of UMVEN performance, because they are more reliable than the primary equipment (RPE). In fact, as shown analytically [1, 2, 3, 4, 5], APS and its elements are at a higher level plan in which the RPE and equipment of the structure, the position that "intended" and if necessary, "occur" within the meaning of correct functioning of the RPE and all UMVEN.

In a schematic form, UMVEN of APS integration can be as in Fig. 1.

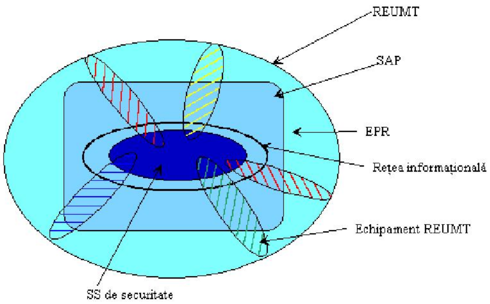

Fig. 1. Schematic representation of UMVEN and its components

Although APS and its components by its position in UMVEN (tracking and intervention) involves certain features and treatment of reliability approach to conduct these tests should be considered the interference between components of the RPE and APS (Fig. 1) and decisive impact of the reality on the UMVEN performances.

The study of reliability requires a comprehensive approach of the APS related issues. Reliability is treated, from simple to complex as [6]:

- simple relay, as part of itself;
- relay complex consisting of several simple relays;
- protection subsystem (SSP) or subsystem automation (SSA), composed from one or more relays in connection with the complex measuring transformers, current sources and elements of the actuator;
- SSP or SSA and the actuator plus switching device (switch);
- protected element / automated and two cells, which is connected to power system;
- protected element, including "n" cells whose switching equipment, is controlled by APS.

The main specificities in reliability analysis of APS from UMVEN structure result from the operation and features of the failure:

- need to operation request (intermittent);
- by unexpected power failure or refusal of operation.

APS modelling in reliability study of UMVEN may be made only by locating their correct line diagrams of their schemes and correct analysis of the effects of their operation or malfunction.

SSP notifies a failure occurring, fault localizing and triggering control switches, which makes the connection between the primary elements of integrity and failure.

Two categories of indicators recommended for APS components [7, 8]

a) Classical indicators (mainstream);

- Probability of good service (safety time): R (t);
- Mean time between the failures: MTBF;
- The probability of rejection (risk of not responding to the request):

$$q(\tau) = \frac{\lambda \cdot \tau}{2} + \gamma \; ; \tau \hat{=} MTTR \qquad (1)$$

γ – probability of failure upon request.

- Average number of unanswered requests during the "T":

$$\nu(T) = \nu_{EPR}(T) \cdot q(\tau) \qquad (2)$$

Classical indices can’t fully characterize the reliability of APS and its components, whereas only refer to refusals ($\overline{RC}$) and quantifies their effect unexpected operation (INT ≡ false).

b) Complementary indicators

These indicators are intended for full characterization, (along with the classical one) the reliability of APS and its components.

- incorrect operation intensity (ER) of components / subsystems of APS is expressed as:

$$\lambda_{ER} = \lambda_{\overline{RC}} + \lambda_{INT} \qquad (3)$$

where,

$\lambda_{\overline{RC}}$ - intensity events "refusal response to commands" ($\overline{RC}$);

λ_{INT} - intensity of transmission of unexpected orders (false).

- Appear risk of events ($\overline{RC}$, INT):

$$q_j(t) = 1 - e^{-\int_0^t \lambda_j(t)dt} \quad j = \{\overline{RC}, \mathrm{INT}\} \qquad (4)$$

- The statistics about of the reliability of APS and its components, will refer to variables:

t_j – operating time without the variables “j”

$\nu_{i(T)}$ – number of events of “j” type during “T”, period, where, j={$\overline{RC}$, INT, ER}

- intensity of failure of ensemble:

$$\lambda_{ANS} = \lambda_{EPR} + \lambda_{\overline{RC}} + \lambda_{INT} \qquad (5)$$

The relay is the heart of the SSP, for which modelling and reliability evaluation of the SSP, that APS is necessary to start from opinions about the reliability of the relay which are generally divided between two different issues pertaining to safety and security [9]. To improve both security and safety tests must be conducted to ascertain appropriate and protection system [10].

Modern digital relays are normally equipped with devices and monitoring of self. Impact on relay performance and expected benefits from the use of these devices are discussed in various papers [11, 12, 13].

There are many methods which can be used to improve the reliability of relay. These include different operating principles, redundancy in the relay, local safety methods and distance. Redundancy method is generally applied because too high costs and its complexity [14]. Reliability of a relay can also be improved by including in the design, monitoring of embedded devices and of self.

2. GENERAL MODEL OF RELIABILITY OF RELAY FROM APS STRUCTURE OF UMVEN (R-APS)

For R-APS is a general pattern of reliability suitable containing five states, presented in Fig. 2, taking into account the two main modes of failure of protective relay, i.e. lack of response ($\overline{RC}$) operation when needed and when not needed (INT).

R-APS is a major part of his life in an energized state but static. In this state, the relay is "healthy" (working properly), and monitor an RPE. This state (S_1) can be termed "unnecessary and functional relay. The term "functional" refers on the fact that is willing and able to perform its function.

In state S_2, the "functionally necessary" R-APS operates successfully when called upon. In this state, the relay is operating normally and responds to any anomalous condition associated with protected components. Probability associated with this condition is the reliability of the relay.

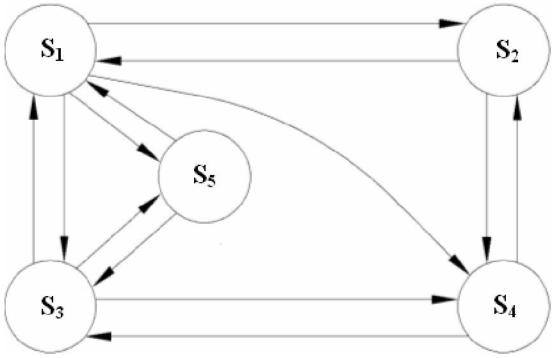

Fig. 2. General model of reliability of relay

In state S_3, the "unnecessary and unworkable", R-APS is neither requested nor prepared to work. Not required because there has been no damage. Not ready because the relay is either failed or it is subjected to a routine test or inspection of self. This condition can be called state of "unavailability of R-APS.

The S_4 state is called as "necessary and inoperative relay, the relay does not fulfil the function of ($\overline{RC}$). In this case, failure occurs when the relay is unavailable.

In state S_5, "operation necessary, when the relay operates when doesn't require to operate (INT). A high probability of being in this state indicates a low safety relay.

States S_3, S_4 and S_5 are considered undesirable and failure states. The main objective is to minimize the probabilities associated with these three states and maximize the protection or operation of probabilities associated with states S_1 and S_2. It is noted that the probabilities associated with S_2 state depend mainly on the rate of failure and recovery time when the fault is isolated RPE.

Typically, statistics on operational reliability of R-APS refers on states that reflect its failure when it would be necessary (S_4, S_5).

Reliability analysis in the context of R-APS functions that have to refer to a UMVEN RPE leads to the development of reliable detailed model of R-APS operation involving 17 states [10].

3. RELIABILITY MODELING OF SSP OF UMVEN STRUCTURE

The UMVEN uses mainly the following SSP:

- Maximum current protection delay;
- Protection by cutting power;
- Maximum protection from targeted and delayed current;
- Longitudinal and transversal differential protection;
- Distance protection.

In [15, 16] are described in detail SSP and relays used for the various SSP. The general methods are presented in [6, 7, 10], this framework will illustrate the application of forecasting reliability analysis with reference to two SSP.

3.1. Modelling the previsional reliability of the maximal 2 steps current protection (SPMC2)

This SSP is formed [15, 16] by a fast part dedicated to current break (stage I) and a delay part (step II) - Fig. 3.

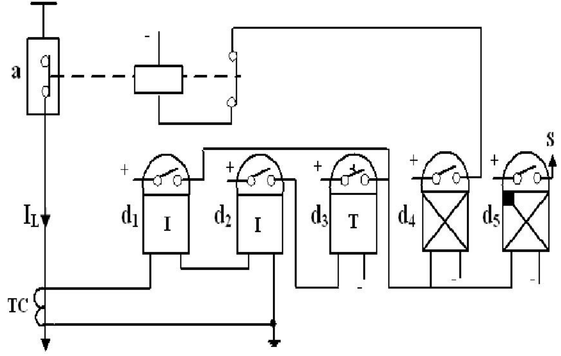

Fig. 3. Scheme of the SPMC2

In table 1 are given the correlations between specific states of general reliability model (Fig. 2) and structural elements SPMC2 states.

Table 1. Impact of SPMC2 element states on general states of SPMC2

General states of SPMC2		States of EPR State structural elements witch causing general state of SPMC2
Marking	Significance	
S_1	Unnecessary and functional	**$I_L < I_{PII}$** Element is operacional: TC. The other elements are functional.
S_2	Necessary and functional (in operation)	**If: $I_L \in [I_{PII}, I_{PI}]$** Work: TC, d_2, d_3, d_4. Not work (not action) d_1 but is functional. **If: $I_L \geq I_{PI}$** Work: TC, d_1, d_4. Are working: d_2 and d_3. relay $d_2$work (action) but d_4 does not realize action time. In both cases d_5 is functional.
S_3	Unnecessary and unfunctional	**$I_L < I_{PII}$** Any element failed (unoperational
S_4	Necessary and unfunctional	**If: $I_L \in [I_{PII}, I_{PI}]$** Any of elements TC, d_2, d_3, d_4, are unoperational (failed) **If: $I_L \geq I_{PI}$**

		Any of elements TC, d_1, d_4, are unoperational (faults).
S_5	Unexpected operation	**$I_L < I_{PII}$ and** failed TC (short-circuit in secondary winding) or Failure (unexpected action) one of relays d_1, d_2, d_3, d_4.

I_{PI} – current of starting (activation) in step I;
I_{PII} - current of starting (activation) in step II.

SPMC2 has the following functions:

- f_1 – short circuit current referral;
- f2 – data processing and activation of corresponding step;
- f_3 – control of switcher (a).

Basing on the above mentioned functions (f_1, f_2, f_3) may be developed the previsional reliability analyses by using the state graphs, similarly to analyze presented for AAR. To evaluate the provisional reliability of SPMC, basing on the events tree and failures, is suggestive and expedient.

In this procedure will be presented on example referring on the undesired event “unoperation SPMC2 in step I (Quick) fig.4.

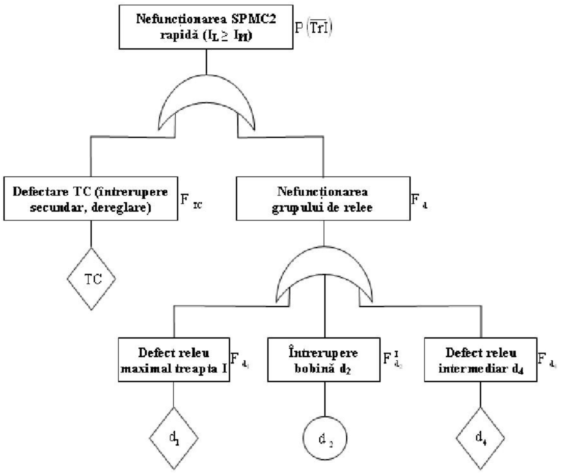

Fig. 4. Tree of events and failures for SPMC2 referring on undesired event “unoperation of fast protection”

To evaluate indicator "F_d", referring on relays d_1 and d_4, are taken into account all modes of failures, as referring on d_2 is taken only the failure mode, wire “break” when is the current is also broken through the coil of d_1 relay.

It is obtained:

$$F_d = F_{d_1} + F^I_{d_2} + F_{d_4} \qquad (6)$$

The probability of the undesired event;

$$P(\overline{T_r I}) = Prob(\overline{TC} \cup \overline{d}) = F_d + F_{TC} - F_d \cdot F_{TC} \qquad (7)$$

3.2. Modelling the previsional reliability of PDLCC

The differential longitudinal protection is realized in two variants [16, 17]:

- with currents of circulation (PDLCC), when it is made a comparison of the currents sense against the two ends of the line;
- with voltage balancing (PDLET), when the voltage drops are compared at the terminals of some resistors, mounted in the secondary of the TC of the two lines. The diagram of PDLCC is given in fig. 5.

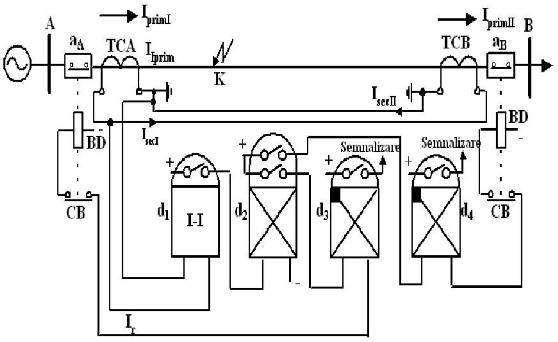

Fig. 5. Diagram of PDLCC

The functions PDLCC are similarly to other APS:

f_1 – referral of short circuit ($I_r \geq I_{pr}$);
f_2 – processing and transmitting of information;
f_3 – adequate control of switchers (a_A, a_B).

In table 2 is presented the correspondence between the specific states of the general reliability model (fig.1) and the states of structural elements of PDLCC

Table 2. Impact of PDLCC elements state on general states of PDLCC

General state of PDLCC		State RPE Structural elements state that provoke the general state of PDLCC
Marking	Significance	
S_1	Necessary and unoperational	**$I_r < I_{pr}$** Operating elements: TCA, TCB and d_1. Other elements are functional.
S_2	Necessary and functional (in operation)	**$I_r \geq I_{pr}$** All elements are in operation.
S_3	Necessary and unfunctional	**$I_r < I_{pr}$** Any element failed (unfunctional).
S_4	Necessary and unfunctional	**$I_r \geq I_{pr}$** Any element is unfunctional (failed).
S_5	Intempestive operation	**$I_r < I_{pr}$** Failed a current transformer(short circuit between the wires) or Failed (intempestive action) of a relay from (d_1, d_2, d_3, d_4).

I_r – current in the relay (d_1);
I_{pr} – the adjusted current for driving of the relay (d_1).

The previsional reliability analyze of PDLCC are made as in the other cases of APS, basing on the structure or by reporting to its function. Will be exemplified the mode of analyse basing on the tree of events and failure, referring on the undesired event „PDLCC is in state S_4" – fig. 6.

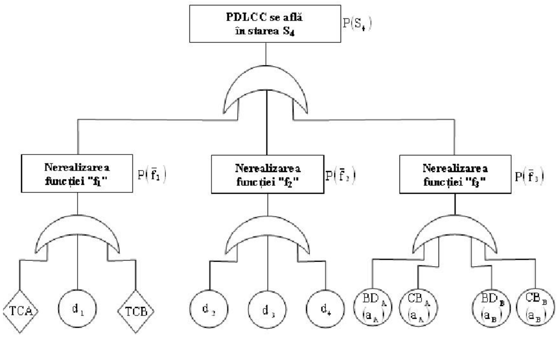

Fig. 6 – Trees of events and failures of PDLCC referring on the undesired events cu „PDLCC is in state of S_4"

The probability of undesired event apparition is:

$$P(S_4) = P(\overline{f}_1) + P(\overline{f}_2) + P(\overline{f}_3) \tag{8}$$

where,

$$\begin{cases} P(\overline{f}_1) = F_{TCA} + F_{d_1} + F_{TCB} \\ P(\overline{f}_2) = F_{d_2} + F_{d_3} + F_{d_4} \\ P(\overline{f}_3) = F_{BDA} + F_{BDB} + F_{CBA} + F_{CBB} \end{cases} \tag{9}$$

4. ASSESSMENT OF OPERATIONAL RELIABILITY OF SOME SSP

By monitoring the operational behaviour of APS serving Brasov SDEE for a period of six year, were determined indicators of operational reliability. In this framework are given a summary of the results, emphasizing the specificities of the SSP. The obtained results wich refere of the performance intensity for each type of protection are sown in fig. 7÷10.

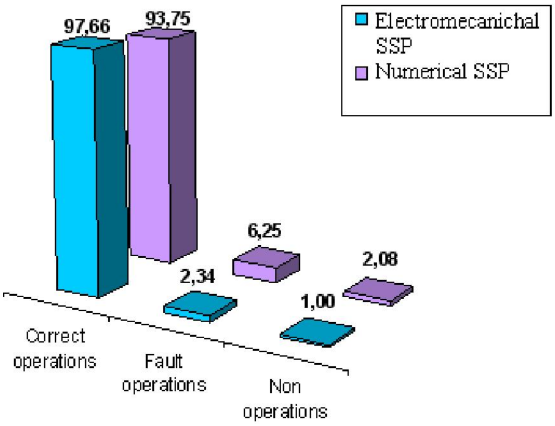

Fig. 7. The performance intensity of the distance protections

We observe a high percentage of performance intensity for numerical protection systems, identified by the study events that may be caused by human error on setting the operation characteristic of numerical protection. Relation to the electromechanically protection systems, the errors results from the distance protection type PD 3/2, which has low reliability, with numerous fault operations, that leads to change this kind of equipment.

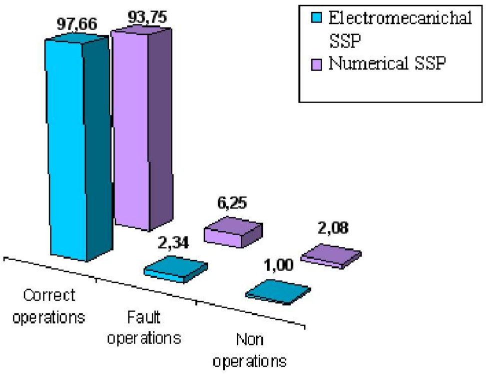

Fig. 8. The performance intensity of the maximal current protections

The study of the maximal current protection identifies a satisfactory functionality of the electromechanically protection systems considering the long functionality time. In case of numerical protections, it considers that from the point of view of advanced technology, the result of the study is not the best. By identify the type of numerical protection with the low reliability; it finds out that the EPAM relays has more fault operations. The problem is solved by sending this relay type to the manufacturer.

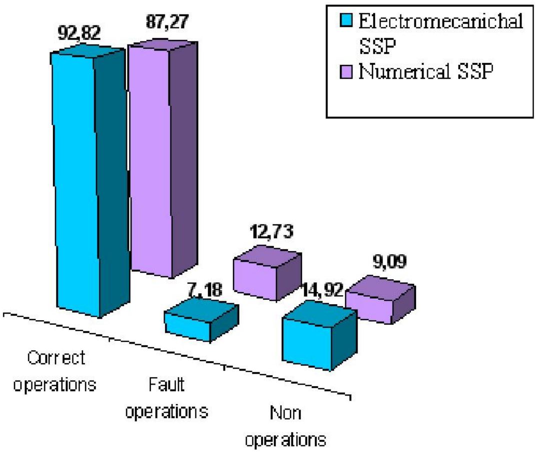

Fig. 9. The performance intensity of the differential protections

In case of differential protections it finds out that in most cases, the faults appears from the secondary circuits fault, like the damage of the cable or contacts.

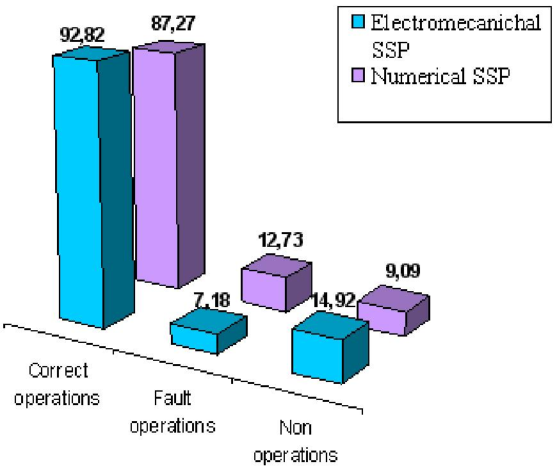

Fig. 10. The performance intensity of the earth protections

By study the functionality of the earth protections it reveals that are more faults operation percentage in case of numerical protections. In this case the errors appear, by analyzing the events, from the incorrect settings applied to the REF-ABB numerical earth protection for resistance compensation. In case of the electromechanically protections, the faults operating are caused by the over aged.

To be estimate the functionality of the protection systems is used to analyze the correct operations intensity, of the fault operations intensity ($\lambda_{\overline{INT}}$) and non operations intensity ($\lambda_{\overline{RC}}$). These parameters will be determined using the values from the table 1, which refers on the correct operations, the fault operations and non operations for each type of protection, and the followings relations [2]:

$$\lambda_c = \frac{Correct\ operations}{Total\ equipments} \qquad (10)$$

$$\lambda_{\overline{INT}} = \frac{Fault\ operations}{Total\ equipments} \qquad (11)$$

$$\lambda_{\overline{RC}} = \frac{Non\ operations}{Total\ equipments} \qquad (12)$$

The results are presented in table 4.

Table 4. Comparative study between electromechanically and numerical protection

Protection type	Total installed protection	λ_c	$\lambda_{\overline{INT}}$	$\lambda_{\overline{RC}}$
Electro mechanic				
Distance protection	57	4.65	0.18	0.05
Max. current protection	973	1.80	0.04	0.02
Differential protection	55	0.09	0.05	0.00
Earth protection	121	1.39	0.11	0.22
Numerical				
Distance protection	5	2.40	0.40	0.00
Max. current protection	10	4.50	0.30	0.10
Differential protection	101	0.04	0.01	0.00
Earth protection	64	0.75	0.11	0.08

5. CONCLUSION

To modelling the previsional reliability of APS, we must start from the fundamental structures of system - relays. Referring on relays, two levels of analyses lends itself to reliability forecast:

- general model, where are evidenced five states and the transitions between them;
- detailed model, there are evidenced 17 states and the transitions between them.

For APS, from UMVEN are possible three variants (levels) of previsional reliability modelling:

- modelling basing on the structure, starting from the diagram of equivalent reliability;
- modelling basing on the functions of UMVEN, based on the state of the graphs;
- analysing the modes of failures, basing on the trees of events and failures.

For each type of SA SSP (maximal of current, differential, distance, etc.) may be stabilized a correspondence between the general states of components and specific general states of any type of relay, as well as between the states of components and SSP function's degree of satisfaction in UMVEN.

Regarding the operational reliability analyse of SSP in the structure of electric networks managed by SDEE Brasov reflects the followings:

- the electromechanical SSP are majors to all functional kinds, against the numerical SSP;
- the electromechanical SSPs are more reliable as the numerical one, for all functional types: protection on distance, deferential, protection of grounding;
- the numerical SSP destined to maximal current protection are more reliable as the electromechanic SSPs, with the same destination;
- it is necessary to deepen the operational reliability analyses to evidence the failed elements and the failure mode in SSP

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