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Methods and Models for Decision-Making Support at Emergency Events in Power Systems

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Abstract: - This paper presents two models which are used as a part of the theoretical foundation for a system of decision–making support during emergency situations in power systems. The presented model of the parameter signal distortion during emergency situations and the model of determination of emergency event position serve as the underlying models for building a geoinformation system, responsible for the control of emergency situations in power systems.

Key Words: - Signal Distortion Model, Fault Allocation

1 Introduction

The present paper is a continuation of the preceding paper "Identification of Operation Modes and Emergency Events in Power Systems". This paper presents two other methods, which complement the theoretical foundation of the decision-making support system during emergency situations in power systems. Logically, the system (fig.1) must identify the operation mode of the power system, and if an emergency event occurs, the system must determine the fault location and produce control solutions which assist the dispatcher to effectively fix the fault. Section two introduces the model of parameter signal distortion and the model of fault allocation, which are used to control emergency situations in power systems.

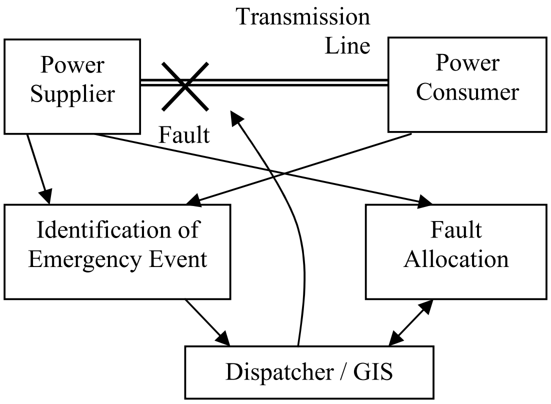

Figure 1 – Control of emergency events

2 Development of models to be used in the control of emergency situations in power systems

2.1 The model of parameter signal distortion during emergency situations

The control of the power system modes urges the tasks of assurance of the parameter signal transmission accuracy and avoiding its distortion. Therefore, the development of methods and algorithms for the restoration of the original information, as well as the correction of phase distortions in the information transmission channel in complex-organized systems becomes necessary.

Let us consider the model of transmission distortion of the mode parameter signal in the power system. The model of determined chaotic processes is taken as a model of signal transmission distortion [2]. This model is based on combinatory-topological transformation of binary information. The mathematical model of distortions is based on the theoretical-set topological properties of the input elements (a_i) and output elements (b_i) of the subset (v_i), which constitute the information system channel (V) [1], where phase distortions exist.

The subsets $(a_i)\in[A]$ and $(b_j)\in[B]$ meet the axioms of general topology and axioms of closure operations. They also possess the closure and separation properties, and a countable base. The given subsets form a topological space (Ω,ω) with the topological discrete basis ω. Any two elements $[A]$ and $(b_k),(b_l)\in[B]$ of the subset Ω have disjoint neighborhoods. Let us introduce a local coordinate system, where the subset $(a_{ij})\subset[A]$ is represented in a matrix form and the substitution transformations are applied to it to disorder the mapping: $(b_{kl})\subset[B]$. Thus, for (a_{ij}) and (b_{kl}) the order of elements is determined by the following matrices:

$$[A]=\sum_{i=1}^{m}\sum_{j=1}^{n}a_{ij}\,, \tag{1}$$

$$[B]=\sum_{k=1}^{p}\sum_{l=1}^{s}b_{kl} \tag{2}$$

Let us introduce the operator K of the substitution transformations that maps $(a_{ij})\to(b_{kl})$ arbitrary. So:

$$[K]:\ [A]\to[B]\equiv\sum_{i=1}^{m}\sum_{j=1}^{n}(a_{ij})\to\sum_{k=1}^{p}\sum_{l=1}^{s}(b_{kl}) \tag{3}$$

Let us represent a regular binary function F on the set $[A]$ whose elements (a_{ij}) transform $[F]$ into the subset of ordered elements of the raster:

$$[F^*]=\sum_{i=1}^{m}\sum_{j=1}^{n}(a_{ij}\otimes f_{ij})\subset[A], \tag{4}$$

where $[F^*]\subseteq[F]$ - matrix $[F]$ in a raster form;
$(a_{ij}\otimes f_{ij})$ - discrete function fragments represented on (a_{ij}).

After the $[K]$ substitution transformation (3) the function $[F]$ on $[B]$ can be represented in the following form:

$$[F^{**}]=\sum_{k=1}^{p}\sum_{l=1}^{s}(b_{kl}\otimes f_{kl})\subset[B], \tag{5}$$

where $[F^{**}]\subset[F]$ - matrix of a chaotically transformed function $[F^*]$ in raster form of representation;
$(b_{kl}\otimes f_{kl})$ - discrete function fragments represented on (b_j).

The operator $[K]$ can be assigned by a numeric coefficient that defines the degree of combinative substitution (chaotic character) (b_{kl}) on the subset $[B]$:

$$R=\sum_{k=1}^{p}\sum_{l=1}^{s}b_{kl}\,/(p\times s) \tag{6}$$

where (b_{kl}) - number of substitution elements on the subset $[B]$;
$(p\times s)$ - total number of elements (b_{kl}) on the subset $[B]$.

The coefficient R is defined on the interval $0\le R\le 1$, and if $R=0$, than elements (b_{kl}) and (a_{ij}) of the sets $[B]$ and $[A]$ as well as these sets theirself are isomorphous. So, $[F^*]\equiv[F^{**}]$.

If $R=1$ the transformations (4-5) define chaos on the set $[B]$ and $[F^*]\neq[F^{**}]$. If we define the coefficient R in (6) within the interval $0\le R\le 1$, then distortions can be generated. Applying the $[K]$ transformation (5) to the subset $(b_{kl})\subset[B]$, we can split it into two subsets. The first subset:

$$[\Phi] = \bigcup (b_{kl}) \tag{7}$$

consists of all substitutions of the elements (b_{kl}).
The second subset:

$$[\Lambda] = \bigcup (b_{ty}) \leftrightarrow \bigcup (a_{ty}) \tag{8}$$

consisting of all elements (b_{ty}), isomorphous to (a_{ty}).

The sets $[A]$ and $[B]$ are represented as follows:

$$[A] \cong [\Lambda] \subset (\Omega, \omega) \tag{9}$$

$$(\Omega, \omega) \supset [B] = \bigcup \{[\Lambda] \vee [\Phi]\}. \tag{10}$$

The topological space (Ω, ω) defines the union as topologically similar to set $[A]$, and sets $[\Lambda]$ and $[\Phi]$, which are homeomorphous to a circle. Discrete fragments $(f_{kl}) \subset [F^{**}] \leftrightarrow [F^{*}]$, which are represented by the set $[\Lambda]$ on the set $[B]$, have a distribution equivalent on the set $[A]$. For all fragments $(f_{ty}) \subset [F^{**}] \subset [\Phi]$ the distribution on $[B]$ is random.

The determining characteristic of the attractor of a dynamic system is the property of structural stability. The proposed model of substitutions can be considered as the dynamic model with weak or strong ergodicity. The slightest change $[F]$, which is mapped on the subset (a_{ij}), leads to a new and random order of fragments (f_{kl}) on the set $[B]$.

Thus, the defined function $[F]$ can be used for modeling of distortions in the system channel. In order to model the distortion, it is enough to assign the function $[F]$ by any affine transformation on the set $[A]$. So, the comprehensive model of the parameter signal distortion at emergency situations is developed.

2.2 The determination of fault position during an emergency event

The following basic groups of fault allocation methods are to be found using the theory of fault allocation in the power transmission line:

1. The topographic methods are based on determination of the topographic point of the fault.
2. The pulse methods of fault allocation are based on measuring time intervals that are necessary for propagation of electromagnetic waves through the transmission line.

Basically, in the power networks with effectively grounded neutral, the devices based on double-way methods of fault allocation are used according to the emergency mode parameters. According to operational practice a linear calculated distance to fault places in electric systems with effectively grounded neutral is equal to 5.4% [3]. Currently this value does not meet the requirements of the power system control specialists, and it must be decreased. The analysis of existing methods and tools for transmission line fault allocation result in the following conclusions:

1. The topographic methods of fault allocation are the most accurate; however they are complicated and require lot of time for their implementation, which is a very significant disadvantage.
2. The pulse methods of fault allocation are characterized by the additional side pulse reflection and refraction in the heterogeneous places of the transmission line. It usually leads to inefficiency of such methods.
3. The double-way methods of fault allocation according to emergency mode parameters based on multipole theory are highly accurate; however they require an additional funding for their implementation, and also they are characterized by poor reliability.
4. The single-way methods of fault allocation according to emergency mode parameters are characterized by unknown information about transition resistance and system parameters from opposite sides of the transmission line that leads to significant errors in fault allocation.

So, to increase accuracy of fault allocation in power systems with an effectively grounded neutral it is necessary to improve the single-way fault allocation according to emergency mode parameters by decreasing the influence of unknown information. For the solution of the given task the perspective research was carried out. As a result of this research some mathematical equations and dependencies were determined. These results are presented in this section.

Firstly, let us introduce some mathematical dependence that relate the single-way emergency mode parameters to fault coordinates, where the transient resistance value is excluded and the influence of the opposite side of the transmission line is considered. In case of single-phase short circuit (SC) the distance to fault is determined by the following statement [3]:

$$L_{sc} = \frac{\mathrm{Re}(U_{ph})}{\mathrm{Re}(\Delta \underline{U}r) - ctg\varphi_{ad} \cdot \mathrm{Im}(\Delta \underline{U}r)} \qquad (11)$$

where U_{ph} – phase voltage,

$\Delta \underline{U}r$ - voltage drop per 1 km of length on a line section to fault place,

$$ctg\,\varphi_{ad} = \frac{\mathrm{Re}\,(I_{ad})}{\mathrm{Im}\,(I_{ad})},$$

$$ctg\varphi_{ad} = \frac{\mathrm{Re}(I_0^I) + \mathrm{Re}(I_0^{II}) + \mathrm{Re}(I_0^{C2})}{\mathrm{Im}(I_0^I) + \mathrm{Im}(I_0^{II}) + \mathrm{Im}(I_0^{C2})}. \qquad (12)$$

In a case of double-phase SC [4]:

$$\mathrm{L}_{sc} = \frac{A+B}{C+D} \cdot \frac{1}{\mathrm{X}r}, \qquad (13)$$

where $A = \left[\mathrm{Re}(\underline{\mathrm{U}}_\mathrm{B}) - \mathrm{Re}(\underline{\mathrm{U}}_\mathrm{C})\right]$;

$B = \left[\mathrm{Im}(\underline{\mathrm{U}}_\mathrm{B}) - \mathrm{Im}(\underline{\mathrm{U}}_\mathrm{C})\right] \cdot \mathrm{tg}\varphi_{\mathrm{A2}}$;

$C = \left[\mathrm{Re}(\underline{\mathrm{I}}_\mathrm{B}) - \mathrm{Re}(\underline{\mathrm{I}}_\mathrm{C})\right] \cdot \left(\mathrm{K}_{ad} + \mathrm{tg}\varphi_{\mathrm{A2}}\right)$;

$D = \left[\mathrm{Im}(\underline{\mathrm{I}}_\mathrm{B}) - \mathrm{Im}(\underline{\mathrm{I}}_\mathrm{C})\right] \cdot \left(\mathrm{K}_{ad} \cdot \mathrm{tg}\varphi_{\mathrm{A2}} - 1\right)$;

$$\mathrm{tg}\varphi_{\mathrm{A2}} = \frac{\mathrm{Im}(\underline{\mathrm{I}}_{\mathrm{A2}}) + \mathrm{Im}(\underline{\mathrm{I}}_{\mathrm{A2}}^{\mathrm{C2}})}{\mathrm{Re}(\underline{\mathrm{I}}_{\mathrm{A2}}) + \mathrm{Re}(\underline{\mathrm{I}}_{\mathrm{A2}}^{\mathrm{C2}})};$$

$\mathrm{K}_\mathrm{R} = \mathrm{R}_{\mathrm{lin}} / \mathrm{X}_{\mathrm{lin}}$;

$\underline{\mathrm{U}}_\mathrm{B}, \underline{\mathrm{U}}_\mathrm{C}, \underline{\mathrm{I}}_\mathrm{B}, \underline{\mathrm{I}}_\mathrm{C}$ - voltages and currents in the fault phases;

Re – reactive resistance.

In a case of triple-phase SC [4]:

$$\mathrm{L}_{sc} = \frac{\mathrm{U}_{ph} \cdot \sin\varphi}{\mathrm{I}_{ph} \cdot \mathrm{X}_r} \qquad (14)$$

where φ - an angle between voltage and current of the same phase.

The obtained expressions, on the one hand, are characterized by the existence of two unknown values, i.e. the distance to the fault place and the short current from the opposite to the measured line end, on the other hand, by the expressions dependence on the SC phase current at the opposite to the fault line end. Considering that SC currents in the power systems of the same voltage level are close in phases, the following assumption can be made: it is not necessary to take into account the short current from the opposite to the measured line end because it does not cause any significant error. On the basis of the considered assumption the expressions (11)-(14) are fully determined at the one-side measurement.

Then the mathematical dependencies relating the single-way parameters of emergency mode and parameters of the system at the opposite to the measured line end [5] with fault place coordinates are obtained. These parameters are defined as follows:

$$\underline{\mathrm{Z}}_0^{\mathrm{C2}} = \frac{1}{2} \cdot \left(\frac{\underline{\mathrm{U}}_{\mathrm{ph}\,0}}{\underline{\mathrm{I}}_0} - \underline{\mathrm{Z}}_{0\mathrm{lin}} - \underline{\mathrm{Z}}_{\mathrm{in}} \right), \qquad (15)$$

$$\underline{\mathrm{Z}}_2^{\mathrm{C2}} = \frac{1}{2} \cdot \left(\frac{\underline{\mathrm{U}}_{\mathrm{ph}\,2}}{\underline{\mathrm{I}}_2} - \underline{\mathrm{Z}}_{2\mathrm{lin}} \right), \qquad (16)$$

$$\underline{\mathrm{E}}_{\mathrm{C2}} \approx \underline{\mathrm{U}}_{\mathrm{ph1}} - \underline{\mathrm{I}}_1 \cdot (\underline{\mathrm{Z}}_{1\mathrm{lin}} + 2 \cdot \underline{\mathrm{Z}}_2^{\mathrm{C2}}). \qquad (17)$$

After this, the mathematical dependencies relating the single-way parameters of an emergency mode and parameters of the system at the opposite line end with fault place coordinates [5] are obtained. Unknown short currents from the system of the opposite to measurement line end are determined as follows:

$$\underline{\mathrm{I}}_0^{\mathrm{C2}} = \frac{\underline{\mathrm{I}}_0^{\mathrm{I}} \cdot \underline{\mathrm{Z}}_{0l} + \underline{\mathrm{I}}_0^{\mathrm{II}} \cdot \underline{\mathrm{Z}}_{\mathrm{inL}} - \underline{\mathrm{I}}_0^{\mathrm{II}} \cdot \underline{\mathrm{Z}}_{0(\mathrm{L}\text{-}l)} - \underline{\mathrm{U}}_{\mathrm{ph0}}}{\underline{\mathrm{Z}}_{0(\mathrm{L}-l)} + \underline{\mathrm{Z}}_0^{\mathrm{C2}}}, \qquad (18)$$

$$\underline{\mathrm{I}}_1^{\mathrm{C2}} = \frac{\underline{\mathrm{E}}^{\mathrm{C2}} - \underline{\mathrm{U}}_{\mathrm{ph1}} + \underline{\mathrm{I}}_1^{\mathrm{I}} \cdot \underline{\mathrm{Z}}_{\mathrm{lin}} - \underline{\mathrm{I}}_1^{\mathrm{II}} \cdot \underline{\mathrm{Z}}_{1(\mathrm{L}\text{-}l)}}{\underline{\mathrm{Z}}_{1(\mathrm{L}\text{-}l)} + \underline{\mathrm{Z}}_1^{\mathrm{C2}}}, \qquad (19)$$

$$\underline{\mathrm{I}}_1^{\mathrm{C2}} = \frac{\underline{\mathrm{E}}^{\mathrm{C2}} - \underline{\mathrm{U}}_{\mathrm{ph1}} + \underline{\mathrm{I}}_1^{\mathrm{I}} \cdot \underline{\mathrm{Z}}_{\mathrm{lin}} - \underline{\mathrm{I}}_1^{\mathrm{II}} \cdot \underline{\mathrm{Z}}_{1(\mathrm{L}\text{-}l)}}{\underline{\mathrm{Z}}_{1(\mathrm{L}\text{-}l)} + \underline{\mathrm{Z}}_2^{\mathrm{C2}}}. \qquad (20)$$

Based on the presented dependencies the algorithm of single-way fault allocation according to emergency mode parameters that includes both stages is developed and described in [6]. Briefly the algorithm works as follows: firstly, preliminary distances to the fault, without consideration of the system at the opposite line end, is performed; then during the second stage, the adjusted distance determination of the fault place is performed considering the system at the opposite line end. Thus, the offered consideration of the system at the opposite line end allows elimination all the unknown information, which is concerning to the single-way fault allocation.

The proposed two models as well as the other two models described in [1] serve as a theoretical foundation for effective fault allocation in power systems.

3 Development of tools for the system of decision-making support at emergency situations in power systems

The system of decision-making support at emergency situations is briefly described in [1], and consists of an Analyzer of operation modes and emergency events and the dispatcher's workstation (fig.2), which includes the geoinformation systems (GIS) responsible for processing the parameter signals and fault allocation. The dispatcher workstation structure with the integrated geoinformation control system is presented in fig.2.

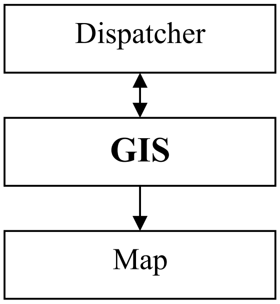

Figure2 – Dispatcher's workstation

The GIS is responsible for further processing of the emergency event record, which includes:

- pre-processing of the received information and associating the information about the emergency event with geographic coordinates;
- spacing and timing representation of the information on a geographic map;
- analyzing data of the event;
- recording the information about the event in the dispatcher's database;
- generating the information record of the event;
- determining coordinates of the emergency event;
- generating optimal decisions for fixing damages invoked by the event;
- optimization of the route for a team of electricians for fixing the damages;
- supervising the route based on the global positioning technology.

Finally, the event position, as well as fixing recommendations, are displayed on the Map.

4 Conclusion

The use of the proposed models effectively improves the decision-making process during regular and emergency situations in power systems, namely for fault allocation and fault fixing. The use of the presented system for operation of some faults in air power lines with the voltage of 110kV was recorded. The examination of offered theoretical approach of the one-way determination according to emergency mode parameters was carried out on this information foundation. The determination error did not exceed 2.5%.

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