
POWER SUPPLY RESTORATION IN DISTRIBUTIVE NETWORKS

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ABSTRACT

The method and program complex realization for restoration scheme search of power consumption in networks on the basis of algorithm processing of the network count and artificial neural networks (ANN) are offered and given reason. Both algorithms work in a competing mode, mutually smoothing lacks of each separate method. Work complex principles, in particular, concerning application of the generalized error vector for ANN self-training and solution stability are theoretically proved. The program complex realized as a part for ‘the adviser of the distributive network dispatcher’, was tested on a 201 buses, 7 sources and 227 lines distribution network and one has shown good results.

Keywords: *distributive network, power restoration, automation, dispatcher adviser.*

Reliability operation performances of distributive network restoration are its time and completeness of a consumer supply in postemergency state and limiting conditions. A number of foreign [1-4, 5-13] and Russian [5-8] works, including author’s [19-26] of given paper, is devoted the specified problem. We offer a combined supply restoration method on the basis of the graph research algorithm and the artificial neural network with training and self-training modes.

The distributive network consumer majority can receive the electric power on several various circuits. At emergency state of one or groups of feeding communications in an existing mode it is necessary quickly to find a reserve circuit in a network for a power supply to the currentless consumer. Following requirements should be allowed: the consumer element overload and voltage drop cannot exceed permissible limits; in the loading restriction need less responsible consumers are disconnected the first of all.

Existing distributive network restoration methods can be united conditionally in three groups: 1) on the basis of the graph theory and the combinatory mathematics; 2) with knowledge base creation at training and the subsequent sample of scheme condition image for concrete event; 3) with artificial neural network use (ANN).

The variant finding concerns advantages of the first of them practically for any mode, including well-founded refusal in the consumer supply of those buses, which cannot be connected on physical or mode conditions, for example, at the unique and damaged feeder [2-5, 8]. However at seeming simplicity method demands viewing of variant set, hence, decision reception time increases. For reduction of variant quantity those or other restrictions are entered usually: combinational, mode etc., reducing their number to comprehensible values, but worsening their quality.

At the second approach the set of possible modes is modeled off-line mode and their target images, consumers satisfying to maintenance by a supply (communication switch state), are remembered in the knowledge base. In on-line mode the target image to gets out from base the

corresponding to entrance image (conditions of an incorrect mode) is the network scheme. Such approach allows finding the decision rather quickly. Its lack is great volume of the knowledge base which growth depends practically exponentially on number of distributive network communications. So for a distributive network on 1000 communications the volume under the knowledge base is estimated in 10^{21} Gb. Taking into account various restrictions this figure decreases, but nevertheless remains considerable. Nevertheless, works in this direction proceed [9-13].

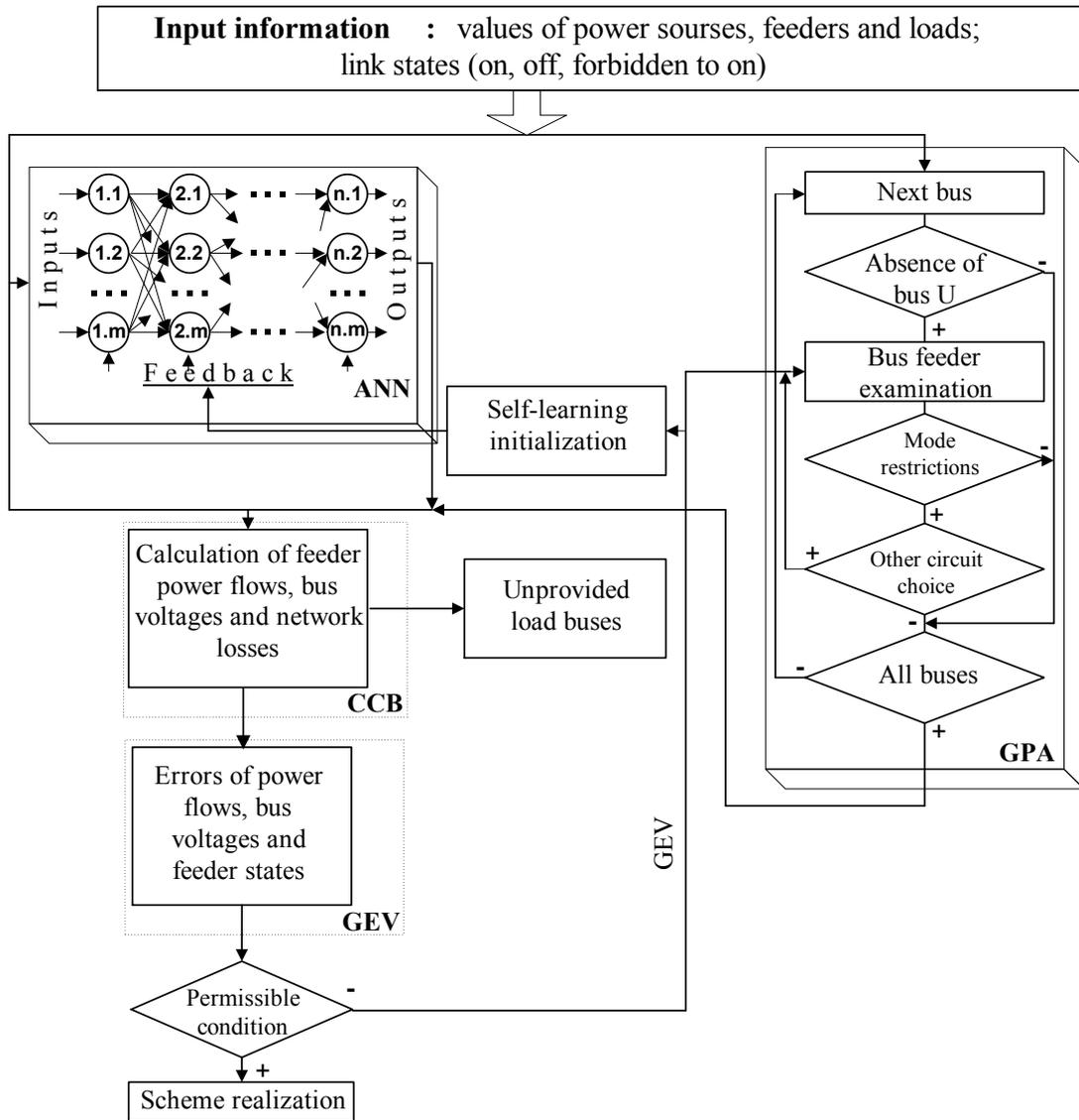
The third way, with use ANN, under the form in many respects models the second approach, but as the knowledge base the functional nonlinear converter (neural network) is used. In it a method after a well-founded structure choice and ANN long training the decision results is obtained quickly enough. However their interpretation represents certain complexity to a concrete mode in most cases and demands additional actions on mode correctness check. From our experience the decision method ANN represents good approach for its subsequent specification by methods of the first approach.

Problem in the specified methods is modernization of a distributive network. If in the first case an input or addition of its new elements increases number of considered variants, then for two last cases network area which modernization of communications and buses influences, it is necessary to repeat all process of training [11].

Certain complexity is made by coordination of computer complex work on power supply circuit search for distributive network consumers with information base of its dispatching point and with mode management automatics. Regarding the information are usually necessary: full scheme model of a distributive network, switch states (switched on, switched off, switched off and forbidden to on), loading levels for moment of prefault conditions (it is considered that whenever possible it is necessary to provide such loadings in postfault mode) and power flows on feeders. Here the network condition estimations, in detail, considered in a number of works [14-17] are not discussed. As to automatics it is considered to be that the complex searches for the network scheme decision after automatic reclose and fallback, and other automatics working off, taking into account the condition which have been with feeders after work of automatics.

We offer a *complex restoration scheme search method for consumer power supply* (fig. 1), working on a decision combination on graph processing algorithm (GPA) and by means of an ANN. Comparative simplicity used GPA, on the one hand, allows to find quickly the scheme for the majority of buses, on another - does not lead to cycling of its search in a difficult network configuration. ANN works faster in the presence of the decision in training sample. Such combination allows to lower requirements to computing complex resources for scheme search in comparison with known methods and to reduce decision time. Scheme restoration co-ordinates with information base of a control office and mode control automatics, particularly, on feeder states and loading levels for a mode prefault moment.

The absent data is restored by settlement methods [19]. The account of "mode weighting" before restoration of normal conditions in a network is carried out by corresponding factors of "load weighting". Conditions-restrictions in decision search are: mode – inadmissibility of an feeder overload and a voltage drop in buses more than specified value; priority – in load restriction need the less responsible consumers [20] first of all should be disconnected. GPA substantially models operation personnel actions in a concrete situation taking into account listed above restrictions. In parallel with it on the basis of training sample the ANN tries to find the new scheme of the network satisfying specified above restrictions.



All offered schemes are checked by the condition calculating block (CCB) which participates in formation of the generalized error vector (GEV). GEV specifies GPA and ANN acceptability / unacceptability of the offered scheme and in the latter case a search direction of the new decision. GPA searches for the new scheme taking into account the specified GEV restrictions. ANN passes in a self-training mode, being retargeted according to GEV. GPA and ANN blocks in a competing mode find the power supply scheme, satisfying to mode admissible conditions. Thus redistribution of consumers between power sources for load alignment is considered.

Advantage GPA is decision completeness without dependence from feeder initial conditions. Buses, which can be provided by energy, are provided with it. On those buses, which are not provided with energy because of mode or configuration conditions, the information on the reasons of such situation is outputted. A method lack is rather big decision search time to computer measures (from shares to tens seconds depending on scheme complexity).

Advantage ANN – almost instant decision on scheme conditions, which have entered into sample of training. In the condition absence in training sample the decision search time in the course of self-training is comparable with similar GPA time. Revealing of the unconnection reasons is more difficult than for loadings in GPA method. However, input of the decision for a new scheme condition in training sample at condition repetition leads to fast decision definition further.

The condition calculating block uses the information on necessary consumer loadings, had capacities and voltages in root network buses, feeder parameters, their states (switched on, switched

off, switched off and forbidden to on) and restrictions in a network configuration. The mode calculation basis in view of its traditional character is not resulted. Its result is a finding of power flows on feeders and voltages in buses.

During decision, having received the current entrance function close to $\mathbf{r}(\mathbf{k})$, the network restores on a target function $\mathbf{u}(\mathbf{k})$. For the cases which have not got to training sample, target function not always leads to an admissible mode. CCB carries out check on mode admissibility; in result the error vector GEV is formed (fig. 2). Last initializes ANN self-training [23].

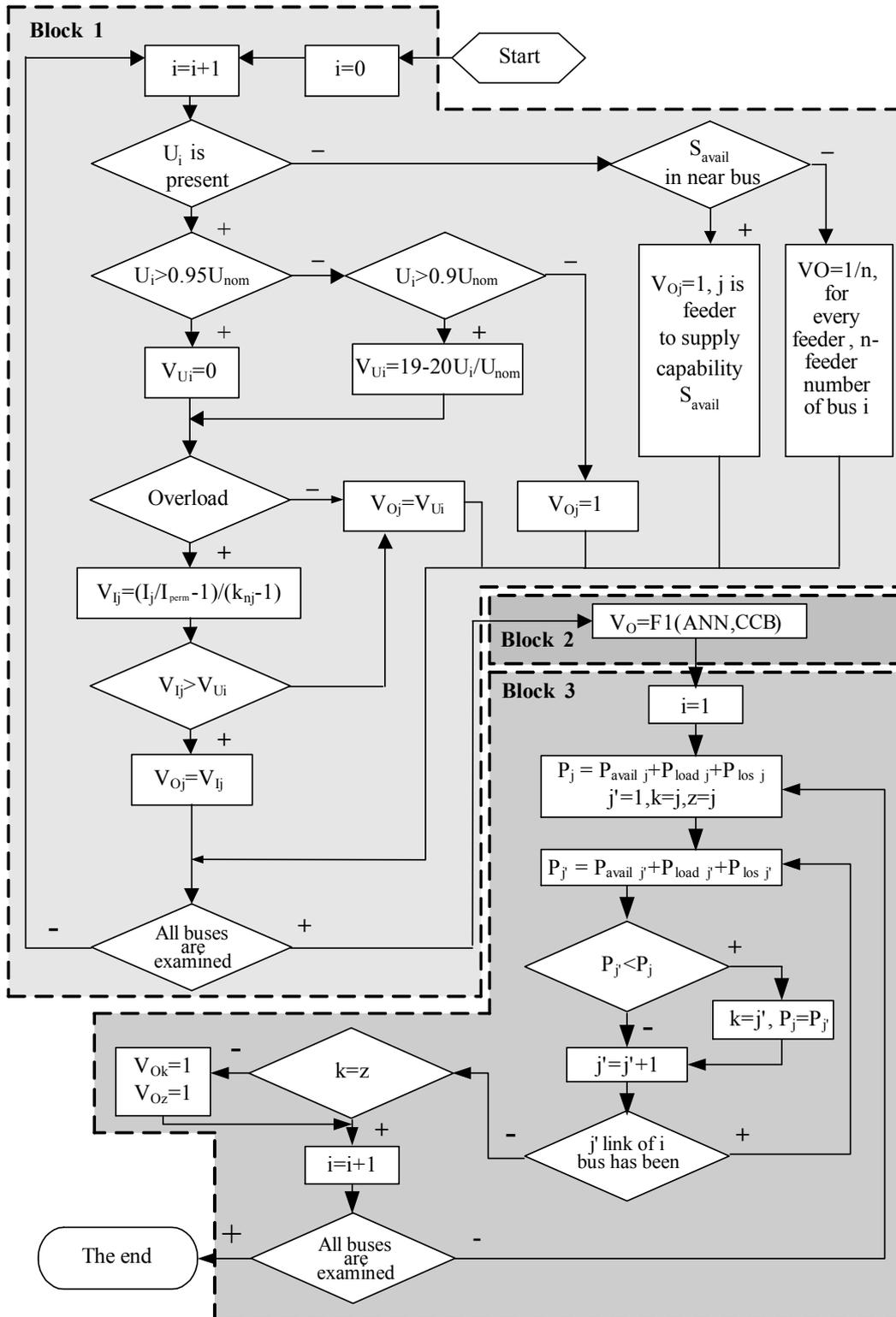


Fig. 2. Flow chart of the generalized error vector forming.

The structure of GPA work is reflected by the integrated block-diagram (fig. 1, block GPA). After damage switch-off the information on a breaker state and voltage in buses of a network at the calculating moment in GPA, and also consumer loadings in buses before network disturbance are entered. The disconnected buses are defined, and their number comes to light. If quantity of the disconnected buses is more than half they are carried out by algorithm of initial load connection [21], allowing quickly to restore the basic scheme part with the account of bus supply importance. If number of the disconnected buses small the bus, having the highest supply reliability importance and the greatest demanded load capacity, gets out first from their entire list. From the chosen bus to the nearest bus, having necessary capacity, the chain is found. The chain search algorithm is based on source search in the scheme graph [22]. Difference is that search is conducted at first at width, and then in depth. Such algorithm reorganization allows connecting bus to the nearest one, having necessary capacity that reduces losses on power flows. Regime parameter calculation occurs in CCB and the regime condition checking – in GEV block. If necessary link is not found, the information on the disconnected bus and the reasons are deduced on the monitor.

The restoration scheme search block on ANN (fig. 1, ANN block) represents multilayered fully connected neuron network into which the information on current network conditions is entered in first layer. The target layer forms the offered decision of feeder states. The quantity of internal elements and layers is being determinates by researches.

At training mode the ANN adjusts weight element factors by means of back propagation algorithm (BP) [18] so that for entrance function $\mathbf{r}(\mathbf{k})$ to approximate function of decisions $\mathbf{u}(\mathbf{k})$ training function $\mathbf{u}^*(\mathbf{k})$ for $\mathbf{k} \in [1, \mathbf{N}]$, where \mathbf{N} is a set of training sample examples.

Application of ANN algorithm with self-training for a solved problem is connected with a convergence substantiation of its decision. Such analysis is spent on the basis of the elementary scheme from three links with three switching devices (fig. 3). Examination of all possible conditions of its switching devices and definition of the generalized error vector in each set of states for influence on ANN makes it possible [24]. The specified approach is connected with possibility of equivalent transformation of a network to the elementary scheme. It is shown that after several iterations (from one to three for the resulted example) GEV becomes zero, hence, for the specified scheme the decision convergence is provided. But as in GEV definition each link is considered separately any other possible schemes with various switch state combinations and available or/and consumed power are reduced to one of the cases considered on the elementary scheme.

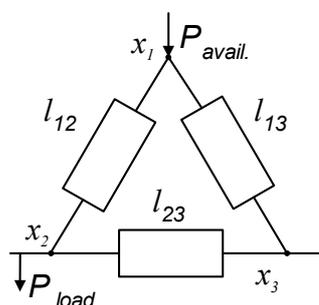


Fig.3. Elementary cell of distributive network.

As it is noted above, at restoration of a power supply it is important to consider their importance on supply reliability. Last characteristic is considered through a priority of bus in a network. Priority values of each bus taking into account its importance are initially set by the expert and (tab. 1 [22]) are stored in the data table on buses. In algorithms with serial processing of buses (GPA, CCB) their order is defined by current priority value on decrease.

It is necessary to notice that for correct ANN work the bus priority rationing system is entered. All bus priorities are limited by frameworks from 0.7 to 1. Values less than 0.7 are not used, as their efficiency at algorithm work is low, it is especially at presence of bus with several communication lines. Transformation of real priorities in rationing ones occurs automatically, agrees simple linear dependence, i.e. to maximum priority bus corresponds $Q=1$, and to minimum priority bus – $Q=0.7$. It is obvious that priorities of buses should not differ in hundreds and thousand times, otherwise distinction between buses with close priorities for algorithm will be weak and inefficient from the point of view of program time expenses.

In a manual mode of bus priority formation for the higher priority it is recommended to use values $Q=0.9$ and above, for buses of the average priority – $Q=0.8 \dots 0.85$, for the lower priority – $Q=0.7 \dots 0.75$. It is obvious that among buses of an identical priority, for example, buses which are necessary for connecting first from all exist higher priority ones. For possibility of realization of such feature the interval of values q also is entered. Thus, the above value q , the bus will be more necessarily connected. For optimum algorithm work (from the point of view of time expenses) it is not recommended to specify the bus priority value of lower within 0.75-0.8, and for the average 0.85-0.9 as it will lead to boundary effect when on the importance of maintenance with the power the lower priority bus will come nearer to average priority buses, and the average priority bus will come nearer to the higher priority buses, accordingly.

Such difference in bus connection error formation, on the one hand, "will force" algorithm to connect higher priority buses even at capacity available deficiency for maintenance of all network buses, and on the other hand, will not admit switching off of knot with a high priority for connection of buses with a smaller priority.

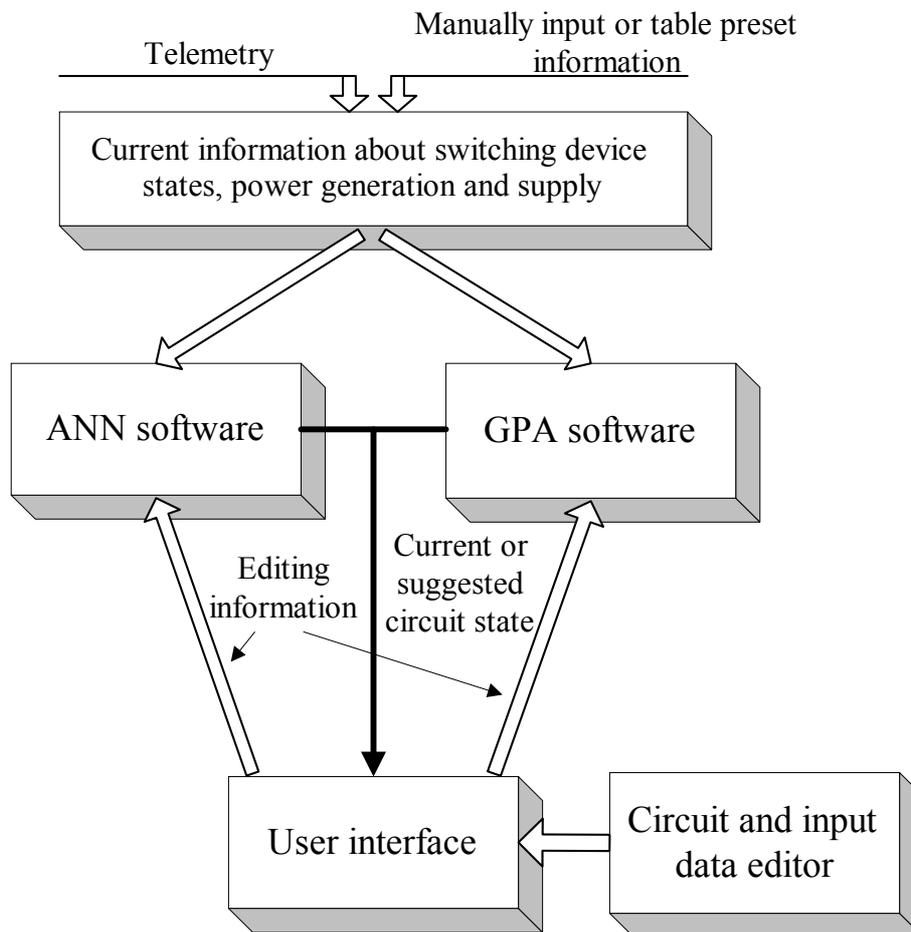


Fig. 4. Restoration system software.

Definition process of link state error weight q depends on a bus priority which feeder can connect. We will admit, feeder j can connect buses i_1 (priority Q_1) and i_2 (priority Q_2). Then a priority of this communication $q_j = Q_1$ if feeding bus will be i_2 , and $q_j = Q_2$ if feeding bus will be i_1 .

The program part can be divided into conditionally independent five blocks (fig. 4). The basis of search algorithm is made by GPA and ANN blocks. Initially in algorithm structure competitive processing of two various processes by decision search has been put. Processes are carried out mutually independently, but use the same entrance information. Thus, decision finding average time for enough big sample of required decisions should be reduced essentially.

The information is formed in the table of the bus and feeder characteristic (tab. 1). In its integer part (uzi, lni) it is described the network topology, bus states (is included/is disconnected) also bus supply priorities. Regarding values from a floating comma (uzf, lnf) remain parameters for buses and feeders on the voltage, available and consumed power, their power flows, admissions on an overload etc. Here are allocated in the italics the parameters set by the operator, or received from an operative measuring complex (SCADA). The direct font notes the parameters counted by programs.

Table 1

Parameters, links and states of scheme elements

| Variable | s | Bus specification | Bus number, (n) | | | |
|------------------------|---|---|-----------------|---|-----|-------|
| | | | 1 | 2 | ... | n_u |
| <i>uzi[n,s]</i> | 1 | State (attribute + switch off/switch on) | | | | |
| | 2 | Supply feeder number | | | | |
| | 3 | Plug-in bus priority | | | | |
| <i>uzf[n,s]</i> | 1 | <i>Gener./load active power (load with +)</i> | | | | |
| | 2 | <i>Gener./load reactive power (inductive with +)</i> | | | | |
| | 3 | Bus active power (total) | | | | |
| | 4 | Bus reactive power (total) | | | | |
| | 5 | Bus available active power | | | | |
| | 6 | Bus available reactive power | | | | |
| | 7 | Bus voltage | | | | |
| Variable | s | Feeder specification | Bus number, (n) | | | |
| | | | 1 | 2 | ... | n_l |
| <i>lni[n,s]</i> | 1 | Feeder starting bus | | | | |
| | 2 | Feeder end bus | | | | |
| | 3 | Feeder state (switched on, switched off or forbidden to switch) | | | | |
| <i>lnf[n,s]</i> | 1 | <i>Resistance</i> | | | | |
| | 2 | <i>Reactance</i> | | | | |
| | 3 | <i>Admissible continuous current</i> | | | | |
| | 4 | Carrying current value | | | | |
| | 5 | Active power flow | | | | |
| | 6 | Reactive power flow | | | | |
| | 7 | Voltage loss | | | | |
| | 8 | Active power loss | | | | |
| | 9 | Reactive power loss | | | | |
| 10 | Admissible overload factor on preset time | | | | | |

Program realization of the considered approach is based on use MS Visual C⁺⁺. By this time it was possible to realize two independent GPA and ANN modules which are united in one program however can be executed in parallel on different processors of multiprocessor computers or computing clusters. Program code feature is convenience of additional module inclusion (competing processes) to search the decision with other method use. Hence, it is possible not only to modernize constantly already used algorithms, but also to estimate quality, computing and time expenses for new algorithms. One more positive side of the chosen program architecture is that the interface of the user on formation, change and addition of test distributive networks is completely separated from decision search problems, serves only for preparation of the entrance data and can change irrespective of the specified tasks.

The time estimation of its performance during algorithm working out was a separate problem as in known publications to us time for decision search sharply increased at increase in elements of a distributive network [25]. There was a danger that positively proved on this parameter at small quantity of bus and interbus links the algorithm will sharply worsen the results at increase in network elements. Check of this parameter is shown below at algorithm approbation.

To estimate requirements to memory at increase in a distributive network at one i an element (bus, feeder, switching element) it is possible proceeding from the formula: $\Delta M = k \cdot T_i$, where $k = 1.07$ – defined experimentally factor, and T_i – memory byte quantity, necessary for a data storage about i element of the scheme. For bus ($i=1$) $T_1 = 130$ byte; for feeder ($i=2$) $T_2 = 234$ bytes; for a switching element ($i=3$) $T_3 = 30$ byte. Let a test scheme contains 201 buses, 227 feeders, 7 power supply source, including 5 diesel generators, and 165 switching elements. Then in the test scheme total used memory amount for tested distributive network scheme are easy for counting up under the formula:

$$M = 1.07 \cdot [201 \cdot (130 + 7) + 227 \cdot 234 + 165 \cdot 30] + R \approx 91598 + R,$$

where R is a memory size occupied without dependence from element quantity, present at the scheme. This memory is not a constant, its size fluctuates depending on what dimension is used ANN.

Debugging of a program complex was spent on the test scheme [21]. Despite the simplicity, the scheme gave the chance to check up all basic cases arising in real distributive networks, such as: use of a reserve line at an outage the basic one, loading switching on bus with greater available capacity and/or with the least losses, impossibility of consumer maintenance by the electric power in connection with mode restrictions or feeder malfunction of the given bus. On the other hand, scheme simplicity did program complex work the evident, allowing to check at once program results, verifying them with the received manually data.

Transition to more difficult scheme was a following stage of testing of the program. It has been decided to use the part of power distributive network of Komi power system. Its parameters are given above. As it was already marked, authors were ready to increase in time delays and increase of requirements to memory resources, but as has shown experiment, serious changes have not occurred. It is obvious that with increase in scheme elements, each of which contains some data about the structure and physical properties, the memory size increases inevitably, but this dependence has linear character, and its factor is approximately equal to unit (the computer operative memory expense are considered necessary for program work).

During algorithm work speed measurement on various dimension schemes it was found out that the increase in time expenses, as well as in a case with memory resources, has almost linear character with multiplication to the constant factor close to two. It is caused first of all by inevitable increase in ANN dimension both on entrance and target layers, and on internal structure. Time expenses for initial ANN training in calculations were not considered, as take place in offline mode with exponential growth at increase in dimension and number of examples for processing.

Program interface feature is multiwindow intuitively clear approach, as at scheme creation and its processing, and at reflexion of current processes in a distributive network (fig. 5). He allows displaying on the monitor as a preemergency scheme state with corresponding conditions of

switching devices, power flows and loadings, and the offered decision on supply scheme restoration. Nevertheless, there is number of principles, which it is necessary to adhere at scheme formatting and editing. Some conditions are not critical, i.e. obligatory, at the same time can in the subsequent essentially (by 5-10 %) to increase decision finding speed and also to increase scheme display information capability.

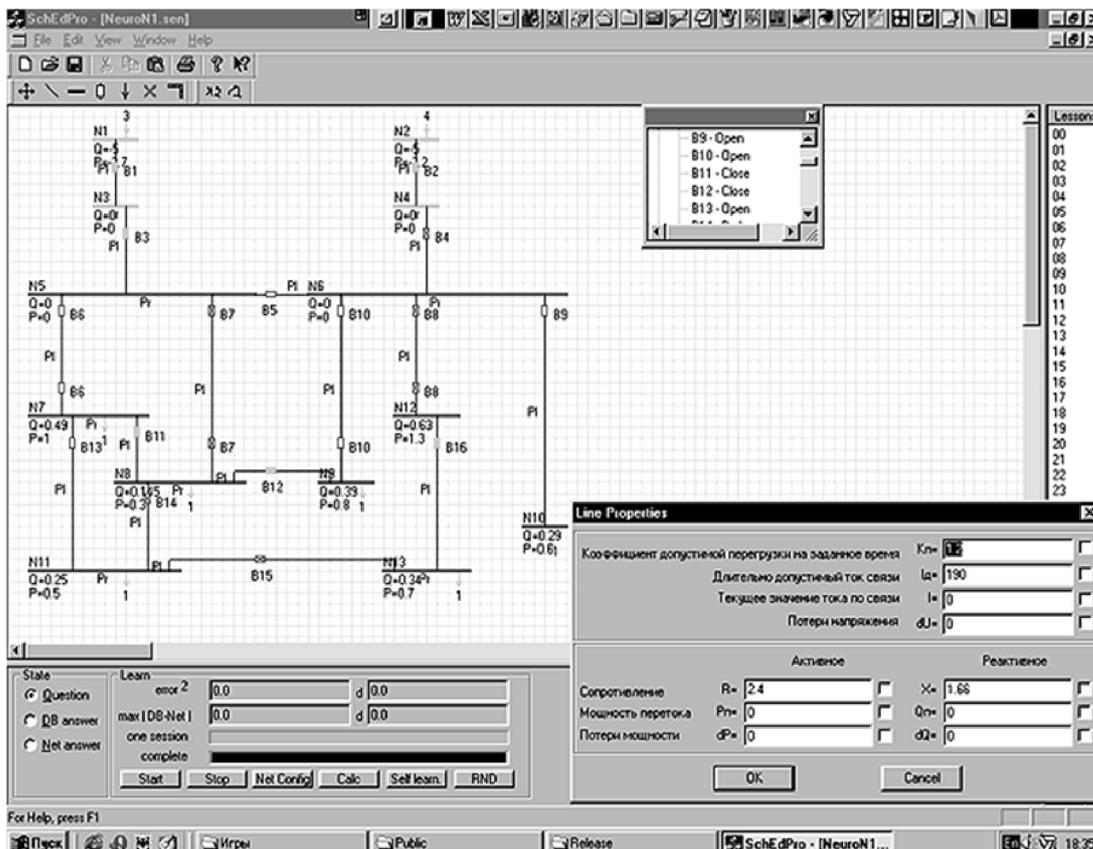


Fig. 5. Window of restoration system for distributive network.

To the indispensable conditions connected with editing of initial schemes and data, concern:

- 1) presence of two switching elements (breakers) on each feeder between the generating bus and any another;
- 2) feeder should be from both ends connected to buses;
- 3) on any line can be noted no more than two switching elements and if on a line two switching elements they work synchronously, i.e. both are simultaneously switched on, switched off or forbidden to switch. The line segment between two tapings in programs is presented as a line without switching devices. In this case its state is defined on voltage presence on its ends which can or be absent on both ends and then the line is considered disconnected, or to be present, and then the line is considered switched on;
- 4) buses on the monitor screen can settle down only horizontally that is connected with bus programming specificity;
- 5) switching elements and lines can vertically settle down or horizontally;
- 6) the bus with generated capacity is set as bus with negative consuming capacity.

To desirable, but not to editing indispensable conditions the following concerns:

- 1) the line should begin by bus which is usually feeding, and to come to an end in bus which is usually consuming that accelerates restoration scheme finding process;
- 2) between the generating bus and

the first bus with consumption should settle down "the empty" or "virtual" bus, i.e. bus with zero consumption and zero generation that is connected with program technology of a generating bus finding; 3) necessary element scheme parameters, such as should be set: line type, length and wire type, line potential levels. Admissible values of currents, feeder resistance and reactance are defined automatically under the help data in the scheme editor.

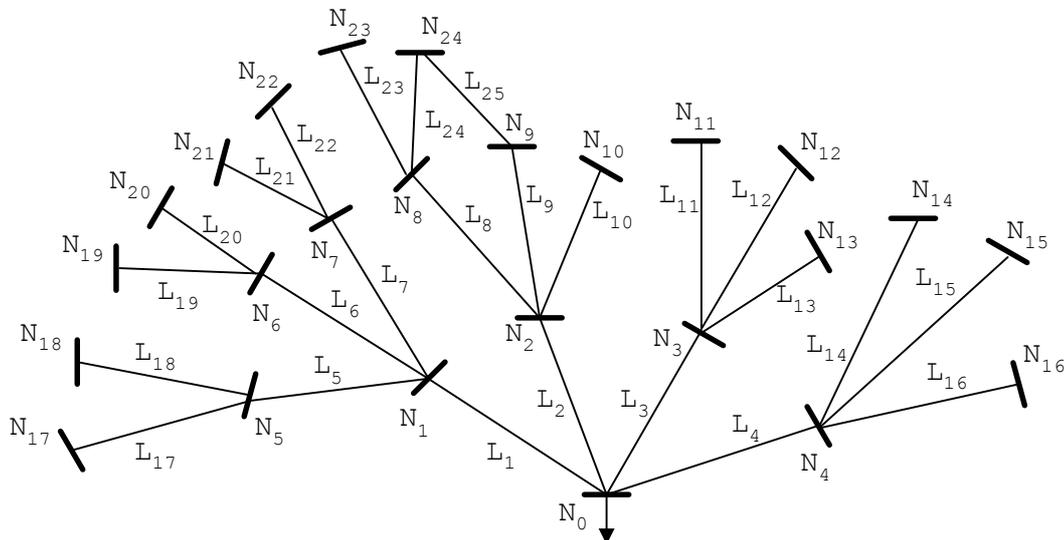


Fig.6. Part of distribution network.

Values of generated and consumed active and reactive power in buses, and also states of switching devices whenever possible arrive on telemetry channels of system. For buses and feeders on which the current data cannot be received in the specified form, there is a possibility to set their tabular form depending on the set conditions, or to correct manually. The full list of parameters necessary for calculation and their placing in information tables are given in [22]; 4) it is desirable to reduce quantity of the information demanded for display about each scheme element, having reduced it to its minimum necessary.

All operating modes were checked on the computer of class Intel Pentium MMX-166, with RAM volume in 64 Mb. The time tests were carried out at start of the program from compiler Visual C++ 6.0 in a debugging mode. Even in such not optimum conditions the program has shown good results on decision finding time which made no more than 0.5 s where on a share of display of the information it was necessary 0.3 s. In agreement with statistics of expense time increase rate at increase in scheme element quantity with program start in the worker, instead of a debugging mode, it is possible to make the assumption that time for the problem decision in schemes with element quantity reflected in programs, an order of 10 thousand (in their considered example more than 600) can make no more than 6 s. At increase in processor and subsystem video capacity three times, that corresponds to possibilities of modern computers, it is possible to realize supply restoration scheme search in complicated networks in a real time mode.

Conclusion

The offered method allows automating distributive network consumer supply restoration by computer means at failures and mode restrictions and to lower error probability of the personnel.

Method feature is joint application of competing decision search processes by algorithms of GPA and ANN, using advantage of each and reducing search time in a concrete situation.

In the absence of the ready decision in ANN training sample its dynamic self-training is made in real time on developed a technique and GEV definition algorithm. The found new decision fills up the specified sample.

Method approbation on test schemes of a distributive network has shown its working capacity.

Appendix 1

Processing algorithm of the scheme graph

In the scheme (fig. 6) it is necessary to find a circuit, including nodes and connections from the disconnected node N_0 to node N_x , which has necessary capacity. All nodes are determined over available capacity and loading. All connections are described over power capacity. The distribution network is described over a node matrix (**NM**) connecting nodes and lines.

The algorithm carries out search N_x at first into breadth, next into depth, what allows connecting N_0 to the nearest node. Decision tracking occurs in tab. 2. Search begins into **NM** with depth of step $S=1$. Nodes of a first step (fig. 7) are looked thru and the opportunity of connection to node N_1 is being estimated. The available capacity in N_1 and the power capacity of connection L_1 are being checked.

Table 2

Solution search

| Step | Loading node | Previous connection | Analyzed connection | Required active power | Required reactive power |
|------|--------------|---------------------|---------------------|-----------------------|-------------------------|
| 1 | N_0 | ... | ... | P_0 | Q_0 |
| ... | ... | ... | ... | ... | ... |
| n | N_x | ... | ... | ... | ... |

Here it is being checked, whether is boundary (the last in an analyzed circuit, for example, nodes $N_{10}-N_{24}$). At non-compliance with the conditions (**Cond.**) the following node N_2 is being analyzed and so on up to N_4 . If on a first step the supply node is not found, $S=2$, nodes N_5-N_{16} are being analyzed and further for $S=3 - N_{17}-N_{24}$.

At condition executions in forming of nodes and of connections a necessary circuit are being defined from tab. 2. On example (fig. 7) this circuit is formed to node N_{19} .

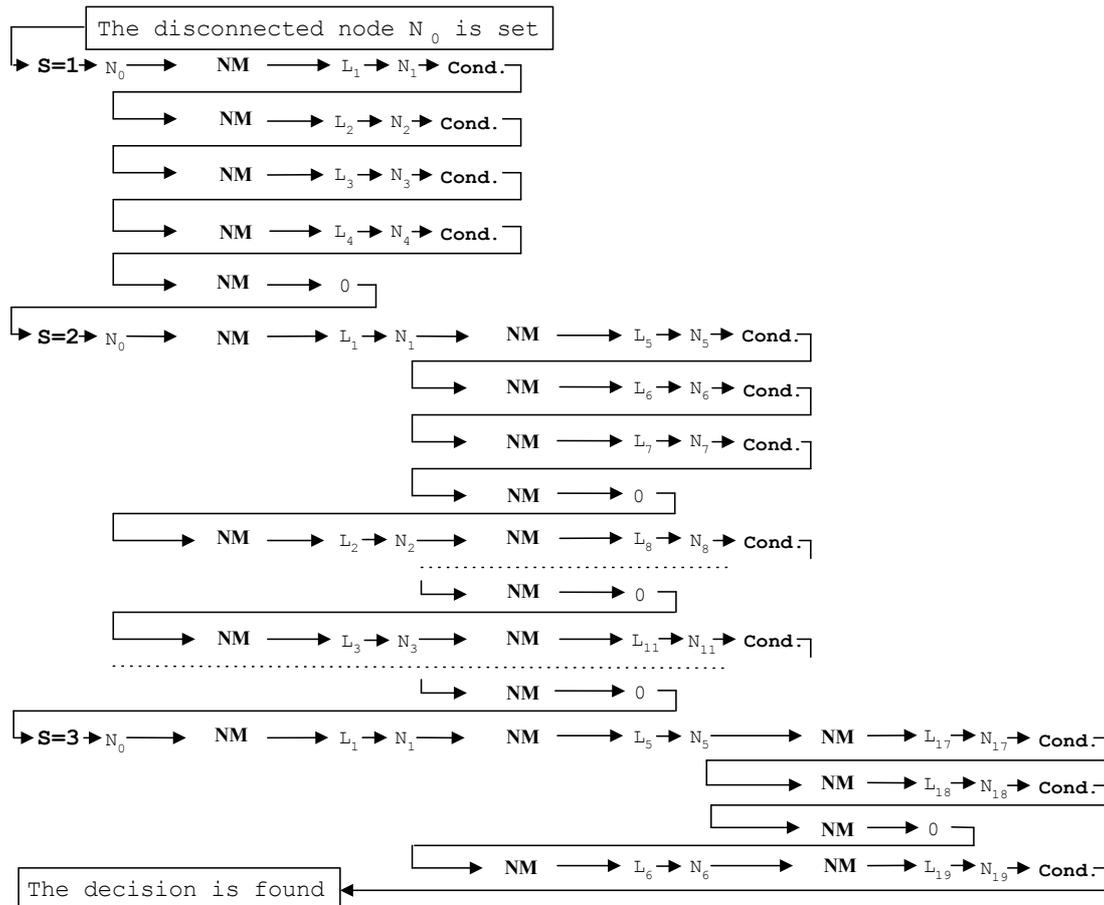


Fig.7 Process of solution search

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