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COMPUTER BASED TOOLS FOR DISTRIBUTION NETWORK AUTOMATION

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ABSTRACT

A reliable and flexible on-line management and control system of the distribution electric network is described: it has been implemented step by step in the last years by the author's team, by using advanced hardware and software technologies. The results obtained show the reliability of the realized lab model. The decentralized control is carried out by Programmable Logic Controllers (PLCs), which perform protection of the feeders, fault clearing, reconfiguration of the network and data acquisition, under the central control of an expert system, running on a personal computer. The expert system performs monitoring of the system, network reconfiguration policy, overload forecasting and updating of the load diagrams of each feeder. The various functions have been carefully tested. The system is rather complex: a very accurate test on the field is needed before the actual realization. Anyway, its didactic importance is relevant: therefore, the various pieces have been analyzed from this point of view and will be proposed to some groups of undergraduates as a coordinated work. The students will be greatly involved and can suggest alternative solutions.

KEY WORDS

On-line management, electric distribution automation, expert system, neural network, educational activity.

1. Introduction

In the last few years the interest of the researchers for the automation of the distribution systems has grown up for many reasons:

- first of all, the electric distribution network is a very large portion of the power system: at this level a complex set of different phenomena takes place, mainly due to faults and sudden load variations. These events can cause disconnection of some feeders, and consequently loss of service continuity, or even unstable working conditions, following random variations of a considerable load;
- secondly, the drastic recent development in the hardware and software tools suggests the actual possibility of completely changing the operation logic, by introducing an on-line control and management at the M.V. level; software technology has recently developed some very useful tools that can significantly change the scenario of the possibilities for the management of the distribution network;
- finally, there is a need of greatly improving the reliability and the quality of the electric system; moreover, the deregulation requires the minimization of costs and a high quality level.

Reconfiguration of the distribution network can overcome some drawbacks: in particular, it can improve the continuity service index and moreover, it can reduce the losses by load balancing [1]; this technique must be adopted at the planning level, in order to realize a correct co-ordination of the connections [2], particularly if the automation of the distribution system is required [3].

A high quality level can be the milestone in the next future, in the deregulated market: in order to satisfy such requirements, a Flexible, Reliable and Intelligent electrical Energy Delivery System has been proposed [4] and FACTS devices are widely adopted [5].

The target of the author's work is the on-line management and control of the distribution electric system, by using advanced hardware and software technologies [6]. It has been carried out step-by-step, and the results obtained at each step have been verified by simulation [7] and have been tested on laboratory models [8, 9], in order to guarantee the effectiveness of the proposed procedure.

By using the proposed management procedure an expert assistant to the manager has been build up [10]. Taking into account the main aspects of the developed technique, which is flexible and reliable, this paper will review the various problems and the implemented solutions, because the flexibility of the suggested management logic can enable the designer to choose the suitable functions that should be adopted in the particular case under consideration (design of a new distribution electric system, modification of an existing one, etc.).

The paper is organized as follows:

- in the first section the proposed on-line management and control logic is presented;
- in the second section the adopted hardware and the implemented software are outlined;

- in the third section the performed experimental tests are emphasized.

On the basis of the promising results it can be affirmed that the complete automation of the distribution electric system will be realized in the next future.

Moreover, new configurations of the network as well as new functions can be planned, taking into account the changing scenario of the hardware in the field.

2. On-line management and control

The suggested on-line management and control logic has been implemented in a decentralized way, at least for the following reasons:

- the decision velocity will be increased;
- the reliability will be improved; in fact, even in case of damage of the central system (which performs the control of the first level) some functions can be locally performed (at the second level, on the field), as it is shown in fig.1.

In the step-by-step development of the suggested strategy, the following functions have been implemented:

1) monitoring the status of the complete distribution system connected to the corresponding primary unit substation: the load level and the working conditions of each line are detected by the PLC; it should be pointed out that in this way even the faults on the low-voltage side of the secondary unit substation can be detected and signaled.

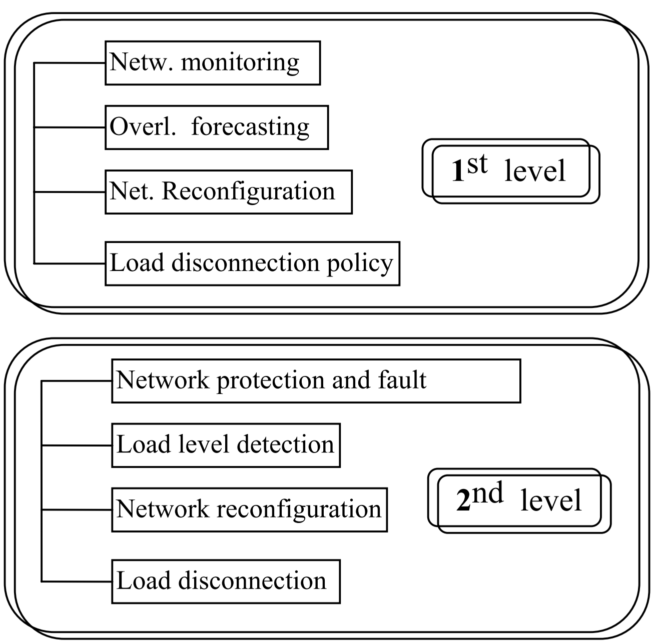

Fig. 1: Decentralized management strategy.

2) protection of the feeders: this function is performed directly by the PLC, which detects and promptly clears the fault. The use of the PLCs suggests the possibility of adopting a different logic, based on the co-ordination of the protections and the reconfiguration of the network. For sake of simplicity, it is supposed that the feeder can be divided in three sections, each one being protected by an individual system with a suitable intervention time. If a fault occurs in the last section, only this part will be disconnected and the operation time of other protections will be modified in a dynamic way, according to the new situation. If the fault occurs either in the first section or in the second one, after disconnecting only the faulted section, the procedure will look for the possibility of a reconfiguration of the network by means of auxiliary cables. The implementation of this function will dramatically improve the protection system and the service continuity.

3) overload condition at the busbars of the primary substation.

Taking into account the values of the voltage at the busbars of the primary substation and of the neighboring substations, the maximum load that can be supplied by the considered substation can be evaluated. At the M.V. level, an overload can be very dangerous and must be detected and eliminated, in order to prevent the voltage instability or even the voltage collapse, particularly if tap-change transformers are adopted (in spite of the adopted sophisticated protection system, events of extreme danger can happen, even a black out!). Consequently, when an overload is detected in the primary substation, a load shedding procedure must be performed, by considering a priority table, in order to restore the system to a normal working condition.

4) overload condition management: single feeder case. Overload in a single feeder is an anomalous working condition that can give rise to dangerous effects, among them the increase in power losses and in fault probability or, at least, in the interrupt duration index.

This situation can only occur in some circumstances, for instance when the load diagrams of the various feeders are different: nevertheless, it has been taken into account because the management of this overload condition requires a network reconfiguration. A suitable hypothesis has been adopted, which consists in the possibility of disconnecting the last part of the overloaded feeder and connecting it to the nearest underloaded one, through a connecting cable. As an alternative solution, it can be connected to a feeder, supplied by a different primary unit substation.

As a generalization, the network reconfiguration has been suggested in order to balance the load among the various feeders, in order to achieve the minimization of the losses.

5) overload forecasting and detection; it is often possible to avoid disconnecting an overloaded line by rearranging the configuration of the distribution system: this procedure can be carried out on the basis of the characteristics of the loads, stored in a data base.
This function has been implemented in this way: the expert system can compare the information obtained by the load diagrams and the measures performed by the PLC in real time.

6) load disconnection: this procedure is performed when it is impossible to find out alternative solution for supplying the load that must be disconnected in order to eliminate the overload, as well as when a given amount of load must be suddenly shed, according to known priorities, in order either to recover the system from the emergency condition or to prevent the system from entering an emergency condition: in the last case the behavior of the complete system will be improved.

3. Hardware and Software

The hardware system which can perform the suggested procedure consists of:

- a central organ located near the primary substation;
- some peripheral elements represented by the PLCs (Programmable Logic Controllers), located near the secondary substation;
- a communication network which links each peripheral organ to the central one.

In fig. 2 the electric distribution system with the control equipment is presented.

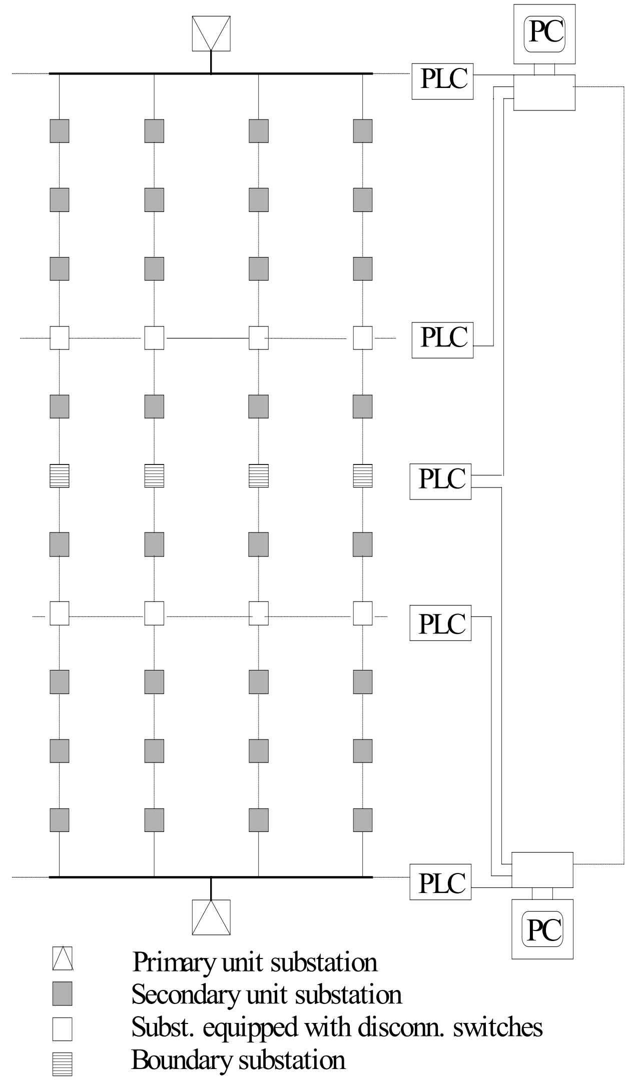

Fig. 2: Distribution system and control equipment.

In fig. 3 the functions performed by each component are shown.

The central organ consists of a personal computer which performs the tasks of the first level control by means of an expert system, a suitable data base and the data supplied by the PLCs.

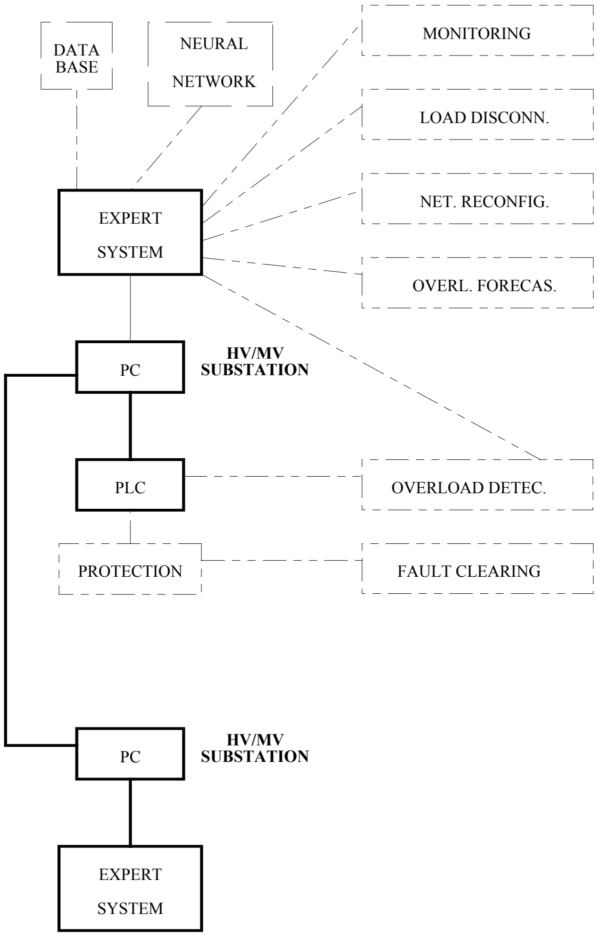

Fig. 3: Hardware, software and performed functions.

The decentralized control is performed by the PLCs, which can be divided in :

- the PLCs located in the primary substation at the starting point of the M.V. feeders;
- the PLCs located in the secondary substations.

To the first group of PLCs the following tasks are given:

1) the supervisory control and fault management;

2) local management of the overload; on the basis of a suitable operating characteristic, which could be modified by the expert system, it determines the operating instant; in normal working condition of the suggested management technique, an overload condition on a feeder should have been forecast by the expert system, which should have send to the PLC the suitable information. As soon as the PLC will detect the overload, an other control bit will be activated. Consequently, the central organ can start the procedure that performs the reconfiguration of the network. Moreover, the PLC can detect a different kind of fault condition, in which case it is able to autonomously carry out the proper managing action.

3) data acquisition and pre-processing: the PLC carries out measurements on the relevant quantities of the feeder. The instantaneous values are varying in a random way, consequently a pre-processing operation is needed; in fact, the expert system requires detecting a meaningful value of the power (in a first approximation the average can be taken into account, fuzzy logic seems to be more useful) over a suitable time interval (15 minutes), in order to evaluate the correct load curve.

4) sending of the pre-processed data and the state signals to the central organ, to which it is connected in a master-slave configuration.

The PLCs located in the boundary substations and the ones located in the substations equipped with disconnecting switches will perform the protection activity. Moreover, they will receive the rearrangement signals from the central organ, in order to perform the reconfiguration operations as soon as they will receive the start signal. In order to perform the function 2) a close co-ordination is required.

The use of a distributed network of PLCs suggests the possibility of introducing a selective protection of each feeder, in order to improve the service continuity.

4. Simulation and experimental tests

A simulation test on the developed expert system has been carried out. A simplified distribution network has been considered, which consists of four feeders connected to the M.V. busbars of a primary station. Some typical load diagrams have been taken into account as a working hypothesis. The simulation of the expert system operation for one day has been carried out. The output for each sample interval consists of a set of values that the expert system will send to each PLC connected in a master-slave configuration.

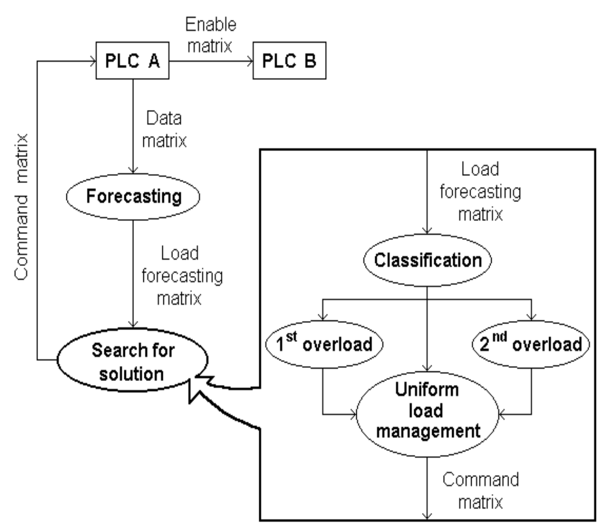

Fig. 4: Neural Networks based test.

The results emphasize the correct operation of the expert system.

Additionally, a structure of some neural networks has been realized in order to analyze various aspects of the proposed procedure.

In fig. 4 the implemented neural networks are classified on the basis of the performed functions.
The main tasks carried out are the overload solution research, the uniform load distribution performance, the load amount forecasting and the detection of the number of overloaded feeders.

At a fixed time interval, the PLC A detects the load level and supplies the following block with the actual data. After a first stage dedicated to the forecast of the load on the feeders and a second one in which the characteristics of a possible overload are identified, the uniform load distribution and overload solution is sought, and this result is send to the man-machine interface in the form of a command matrix as a suggested solution for any foreseen event.

The PLC gives information on the state of the switches in each feeder and the duration of any emergency event (overload and not uniform distribution of the load). It tests whether the forecast event actually takes place in the foreseen feeder or else if another emergency event occurs and consequently gives orders to the PLC B. Therefore it becomes considerably important to detect whether the overload occurs in one or more feeders. This kind of classification is carried out by a two stages of neural networks acting in a hierarchical way. The former detects the kind of the occurred event, and the latter estimates a solution to the problem.

The characteristics of both the input signals (load levels) and the decisions of the expert system (in yes/no form) make the neural networks useful and reliable.

A simplified laboratory model has been realized in order to carry out the experimental test of the suggested procedure, and in particular the connection between the expert system and the PLC. Firstly, a d.c. model has been chosen with only three lines supplied by the equivalent primary unit substation. As a load, a suitable number of lamps, uniformly distributed along the lines has been used.

In order to detect the load level in each line operational amplifier based circuits have been used.

In this model just one programmable logic controller is needed, directly connected to the personal computer.

The results of the test on the laboratory model are very promising: the decentralized management of the distribution electric system works correctly and the various functions are performed accurately, as it is shown on the man-machine interface.

In order to carry out the last laboratory test of the complete procedure, an a.c. model has been developed.
In fig. 5 the wiring scheme of the a.c. experimental model is presented.

A single-phase system has been taken into account and the uniformly distributed load still consists of a set of lamps. In order to detect the load level of each line, a current transformer is used and a proportional voltage level is applied at the input terminals of the comparator. In spite of the simplicity, the model is a quite general one for the purpose of this work.

The various working conditions have been carefully tested, including overload and faults.

On the basis of the satisfactory results, the suggested decentralized management strategy can be considered to be ready for the on-field test.

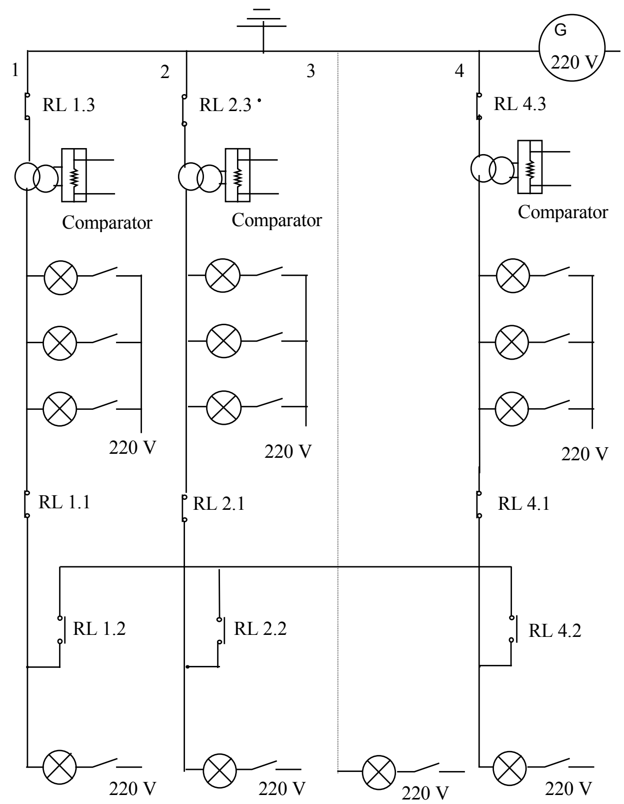

Fig. 5: Wiring scheme of the a.c. laboratory model.

5. Didactic prospects

The deep analysis developed for some years arouses didactic interests in power system training activity, at various levels. The undergraduates can make a careful study of the various complex phenomena that can happen during the working of the distribution system: among others, short circuit, overload, load shedding, disconnection signaling, etc., and, of course, the action to be performed to restore the system in the normal working conditions. A neural network based simulation tool and an implemented experimental system can be very useful at this level: the students can be involved by the advanced hardware and software technologies used.

The students at a higher level can make the thesis on a particular topic: as a meaningful example, the expert system already outlined can join together some peaces of knowledge on the distribution system. Clever students can try to implement a better experimental model, using update software and hardware technologies and a more effective presentation.

6. Conclusion

Dramatic developments have been carried out in the hardware and software for the automation of the electric distribution system. Many products are already available on the market, in particular for the protection, fault location and clearing, and network reconfiguration.

In a deregulate market, cost reduction and quality improvement are becoming very demanding tasks.

The complex on-line management and control logic, presented in the previous sections, can meet many requirements.

By using advanced technologies, some functions have been redesigned.

Accurate tests of various aspects of the implemented procedure have been carried out.

On the basis of the promising results that have been obtained in the test of each step, it can be asserted that the presented structure can be adopted for the automation of the distribution electric system.

Moreover, the logic management can be modified and different structures of the network can be considered, taking into account the development of some useful devices [11].

Future work mainly requires an effective and accurate test on the field before any actual realization, because the system is rather complex and other problems must be solved in order to assure the reliability of the distribution system automation.

Anyway, the didactic importance of the realized system is relevant and some aspects have been briefly emphasized. Moreover, the various pieces of the complete system should be analyzed from this point of view and partially be proposed to some groups of undergraduates as a coordinated work. The students are expected to be greatly involved and can suggest alternative solutions.

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