SUBSTATION AUTOMATION. LOCAL AIDS TO THE POWER DISTRIBUTION NETWORK CONTROL

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Abstract. This paper presents an automatism for electrical distribution substation control. Its objective is to perform a local contribution to the whole power system control. It has been implemented using a low-cost eight bit microprocessor-based structure. The main function performed in the highest substation voltage level is the Automatic Service Restoration. In the lowest one the automatism performs a Load Shedding and the Detection and Isolation of Resistive Faulty Ground. The automatism has been exhaustively tested before its installation.

Keywords: Electrical Substation Automation. Power System Control. Microprocessors. Industrial Control. Load Regulation.

INTRODUCTION.

In this paper a microprocessor-based system is presented for local control function fullfilment in distribution substations, as a part of the whole electrical network control strategy. This local control scheme complements the centralized control functions traditionally applied to higher voltage levels of the power systems, as load-frequency control, economic dispatch, etc.

Recently several authors (Deliyannides 1980,1982, Kezunovic 1981, Nilsson 1985) have shown the advantages obtained when locally performing some protection and control functions in electrical substations. This allows a faster and efficient response in emergency states in order to improve network stability and availability of service (Phadke 1983).

Following this line, the automatism here presented distinguishes between the different voltage levels when it is applied to a substation. In the highest level the Automatic Service Restoration is the main function performed. In the lowest level the main functions are Load-Shedding and Detection and Isolation of Resistive Faulty Ground.

All the above mentioned functions have been implemented using low-cost 8 bit microprocessors widely used in substation remote terminal units (Lyons 1981, several authors 1985, Tanaka 1980).

Because of the responsibility of these functions the automatism has been exhaustively tested following a complex protocol before its installation.

The following sections present the system configuration, the automatic control functions and the tests performed on the automatism.

HARDWARE STRUCTURE

The automatism has been implemented on an eight bit low-cost microprocessor-based structure and programmed using assembly language in order to improve the response speed.

The architecture employed is shown in figure 1 and

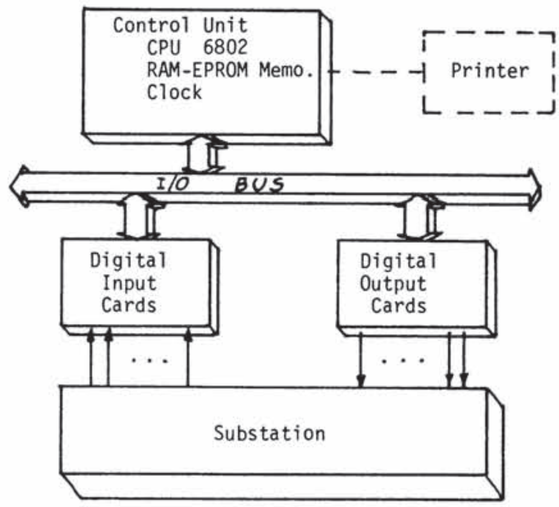

Fig. 1. Hardware structure.

has proved to be able to control typically sized substations. Figures 6 and 7 show some examples. The architecture consists of:

- Microprocessor Motorola 6802.
- EPROM memory with 16 K bytes.
- RAM memory with 1 K bytes.
- Clock generator.
- Digital input cards designed for free voltage contacts, which receive signals from the substation and from the operator (figure 2).
- Digital output cards with relays which permit to give orders to the substation and to display the status of the automatism in the operator command panel (figure 2).
- Power supply.

AUTOMATISM CONTROL FUNCTIONS

This section is devoted to describe the main functions of the automatism. It can be

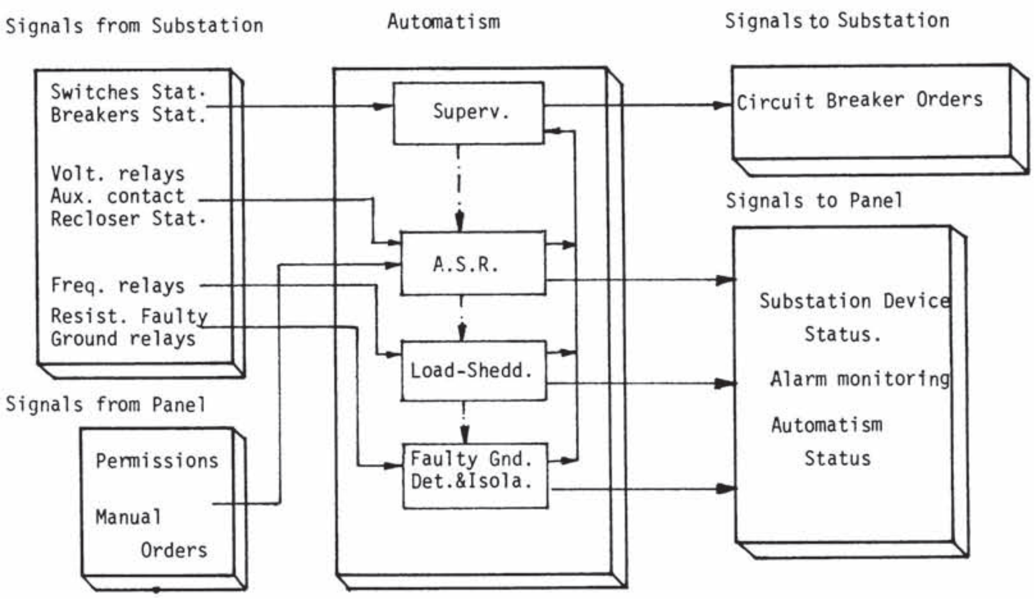

Fig. 2. Input and Output Signals.

distinguished between the highest and the lowest voltage part of the substation. In the former, an automatic service restoration is applied. In the latter a resistive faulty ground isolation and a load shedding are the main functions.

A supervisory program performs the topologic analisys of the substation depending on switches, circuit breakers and transducers' status. It also takes care of the correctness of the manoeuvres and visualizes the alarms. The main functions of the automatism are activated by this program, which solves the possible collisions prioritizing them.

The automatism installation is facilitated by means of a powerful data-base that contains the substation structure, the type and number of lines and transformers, the position of the substation signals in the input-output cards (these signals are resumed in figure 2), lines included in each load-shedding block, etc.

In what follows the characteristic functions applied to each part of the substation are described.

Highest Voltage Part (66, 132 KV).

Three functions are performed at this voltage level. The main one is the automatic service restoration and the other two are related to it.

- Automatic service restoration (ASR).

The growing complexity of the electric power systems requires a fast and secure operation in critical situations. That is the case of service restoration after a substation outage.

The ASR purpose is to detect the conditions required to restore and then, reenergize the substation busbars and feeders as soon as possible. The basic sequence of a restoration after a substation outage is:

- Detect and verify a busbar voltage stoppage.
- Open the feeders not tripped by protective relays.
- Remain in a wait state until one or more lines of the substation meet the necessary restoration conditions.
- Energize busbars.
- Perform a sequence of succesive service restoration in lines and transformers that were in service prior to the outage.

Because of the responsibility associated to busbar energization the automatism previously performs a complete test, including the verification of certain conditions: the energizing line is able to inject power to the substation, the line switches are in an adequate state, the line has not been previously marked as defective, etc.

The above sequence has been described in a very simple case. Actually the complete sequence is more complex. Consider, for instance, the cases that can occur when a reenergized line is defective. In the same way consider the different treatment that must be applied to line, transformer and coupler cells. Many other complex situations can be devised and the automatism recognizes them and takes the adequate actions.

In Franquelo (1983) an exhaustive description of the testing and restoring procedure performed by the automatism is presented including the treatment of the coupler cell and especial topological considerations.

- Line testing.

In some cases, after the reclosure action during a transient fault, the protective relay trips again the line due to a short reclosing interval. The automatism tests the line, performing, when possible, a second reclosure after a programmable delay.

Figure 3 presents a timing diagram of a line testing: in t_1 the line is tripped by the protective relay. The recloser action is taken in t_2. In t_3 the protection trips the line again. The automatism waits t_4-t_3 seconds before trying a second reclosure. In the case shown the fault is transient and the service is finally restored in the line.

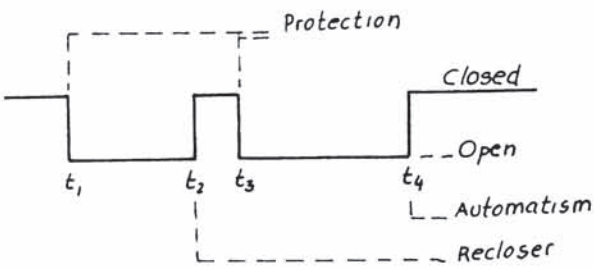

Fig. 3. Line Test Timing Diagram.

- Recloser substitution.

In case of malfuctioning of this device, the automatism substitutes its action after a programmable delay.

All the above mentioned functions can be avoided by the operator in order to perform these operations manually. Anyway, the automatism reproduces the operator or substation devices actions without conflicts.

Lowest Voltage Part (15, 20 KV).

Two functions are mainly applied on this voltage level: Load-Shedding and Detection and Isolation of Resistive Faulty Ground. The former is related with system stability and the latter with people and equipment safety.

- Load shedding

Load frequency control is a classical technique to deal with power system stability. Nevertheless, in extreme cases, when load large exceeds generation, load frequency control actions are insufficient and load-shedding is necessary to preserve system stability.

Note that a local load shedding has only appreciable effects on system stability when it is performed in most of the substations of the system.

The automatism distinguishes up to four frequency steps (see figure 4). Every step has associated a set of lines of the substation defined in the automatism data-base. When the system frequency drops below a frequency step its related lines are tripped.

When nominal frequency is reached ($f > f_{res}$) the system waits for a programmable time delay prior to restoration. Each substation has associated a different time delay in order to avoid simultaneous restoration.

- Detection and isolation of resistive faulty ground.

A resistive faulty ground occurs when a resistive contact takes place between one or more phases and ground potencial. The resistive nature of the contact masks the fault avoiding the action of the protective devices. Nevertheless this type of fault is dangerous for people and equipment and has to be isolated.

These faults can be individually (line to line) or globally sensed. The latter option is the most economic one. In the present case the fault is sensed (globally) using detectors placed in the neutral of the transformers. In order to locate and isolate the fault, the automatism performs a trial-and-error sequence. This sequence is complex due to the topological complex paths than can occur in a real substation and is composed of three stages (figure 5).

The first one consits of succesive line tripping, testing and, whenever the fault persits, reclosing. This sequence is extended to all the lines in service in the substation until a defective line is found. In this stage the automatism is able to isolate single line faults.

In case of the fault had not been located in stage one, the automatism starts the second stage tripping all the lines of the substation.

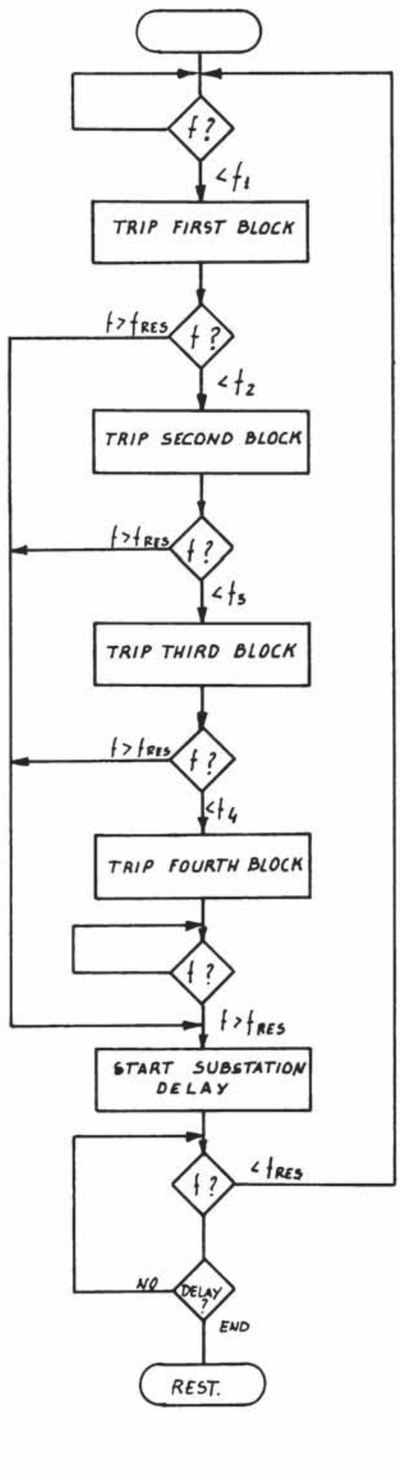

Fig. 4. Load Shedding Sequence.

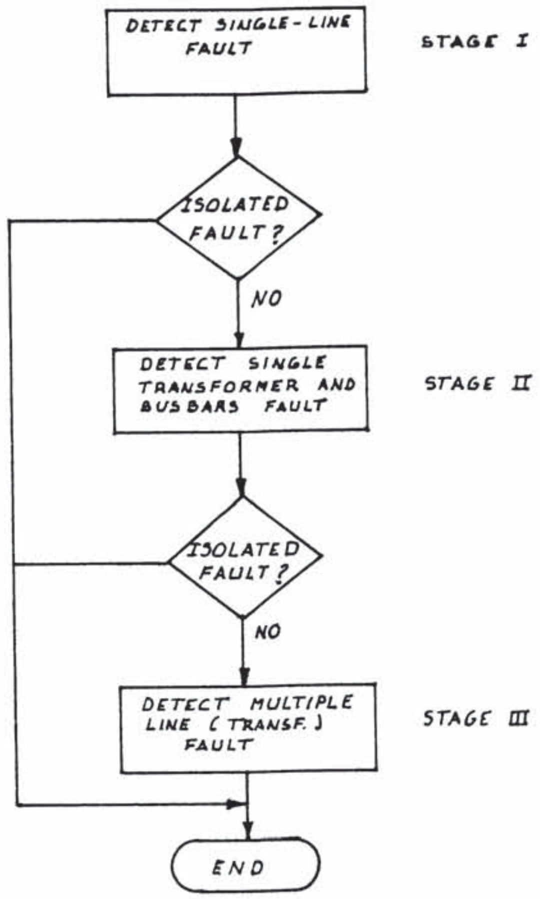

Fig. 5. Faulty Ground Detection Sequence.

If the defect does not disappear when all the lines in the substation are tripped, there are two possible cases (or both simultaneously): the fault is located in a transformer cell or it is located in substation busbars.

In order to test the transformers, the automatism performs the above described trip-test-reclose sequence extended, in this case, to all the transformers in service in the substation. If a defective transformer is not detected, all the transformers are tripped. If the defect does not persits when all the transformers are open, a busbar fault is finally identified and the isolation sequence of the automatism stops.

In this second stage the automatism can isolate single transformer or busbar faults.

In a third stage the previously tripped lines (and, possibly, transformers) are reclosed following the reverse order. After every reclosure a test is performed. Whenever the fault reappears the last line (transformer) reclosed is considered defective and definitively tripped.

In the third stage the automatism detects and isolates multiple line (transformer) faults.

TESTING THE AUTOMATISM.

Prior to apply the automatism to a real substation it has been fully tested. In the first stages of development, on-line testing is not possible due to the risk of damaging expensive equipment or people and then, a substation simulator becomes necessary.

A software simulator based on a Petri Net approach has been implemented. In order to make it highly programmable a net description language (Camacho, 1983) has been especially designed for this application. Substation devices are defined using Petri Nets. These nets are described using the previously mentioned language. It is possible to define MACROS avoiding repetitive definitions of substation devices.

The simulator considers all the aspects of the substation that are relevant to the automatism; that is, circuit breakers, line switches, reclosers, protections, voltage and resistive ground fault transmission through the substation and manual operations.

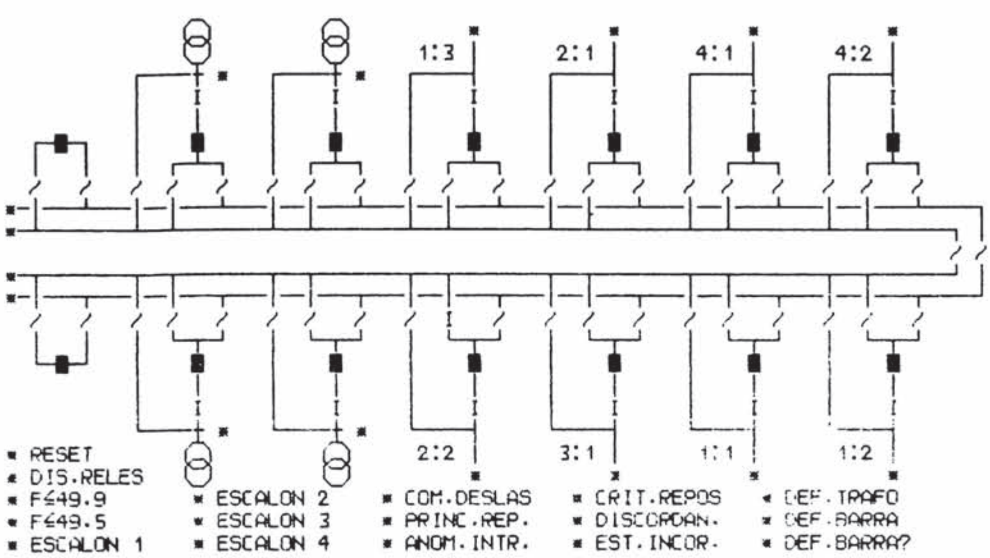

Fig. 6. Distribution Part of the Substation.

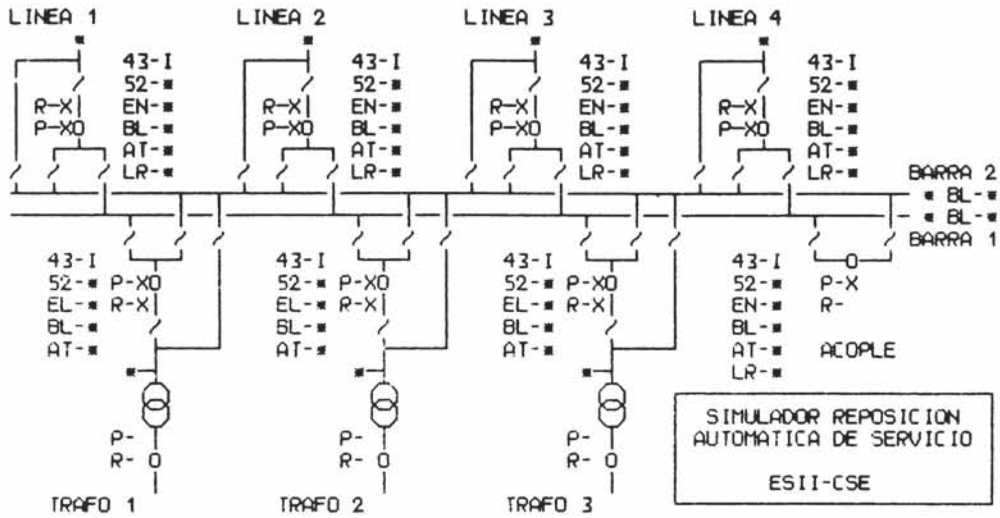

Fig. 7. Substransmission Part of the Substation.

A CRT is used to interface with the operator. The screen represents the state of the main devices superimposed on a mimic of the substation and the keyboard allows manual operation.

The simulator has been implemented on a MC68000 microprocessor programmed in assembly language in order to reduce response time. With the model of the substation shown in Figure 7 the simulator has a cycle time of about 80 milliseconds.

A very complex test protocol has been defined in order to test the automatism in the large number of different cases that can occur in a real application. The complexity of this protocol sequence made necessary the incorporation of an automatic testing procedure to prevent from operator errors.

Afterwards, the automatism has been applied to a substation of the electrical utility which supported this project. Experiences obtained up to now have shown an automatism behaviour in agreement with the specified requirements.

CONCLUSIONS.

A microprocessor-based substation controller has been presented in order to fullfil a local contribution to the whole power system control. The automatism performs different functions related to system stability (load shedding), people and equipment safety (detection and isolation of resistive faulty ground) and availability of service (automatic service restoration). The automatism has been installed in a real substation. An exhaustive test procedure was previously performed due to its high responsibility.

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