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# Unconventional Backup Structures Used in Smart Microgrids

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Additional information is available at the end of the chapter

<http://dx.doi.org/10.5772/intechopen.75989>

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## Abstract

The continuity of power supply to users is considered to be one of the main problems in the design and implementation of low-voltage smart microgrid configurations. Switching to the backup power supply, when using two frequency converters, one of which is alternately maintained in cold reserve, is presented. Switching to the backup power supply, in the case of low-voltage symmetrical smart microgrids, is another highlighted aspect. In the case of modern residential buildings, the automatic switching is necessary between two or more types of users, critical and noncritical ones to the available sources, like the public grid, photovoltaic panels, power generator, etc. Also, in this study, the implementation of smart power microgrids, featuring auto-reconfiguration, is proposed. It is considered the conversion of the public grids to active (distribution/using) smart power microgrids, which have the autoconfiguration option and use high-tech smart devices, like recloser type. Thus, the faults and contingencies will be limited or even removed, creating the frame for the supplied equipment (in a continuously increasing number due to the local and regional expansion) to operate until the removal of the fault.

**Keywords:** low-voltage smart microgrid, active grid, recloser device, circuit breaker, backup power supply

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## 1. Introduction

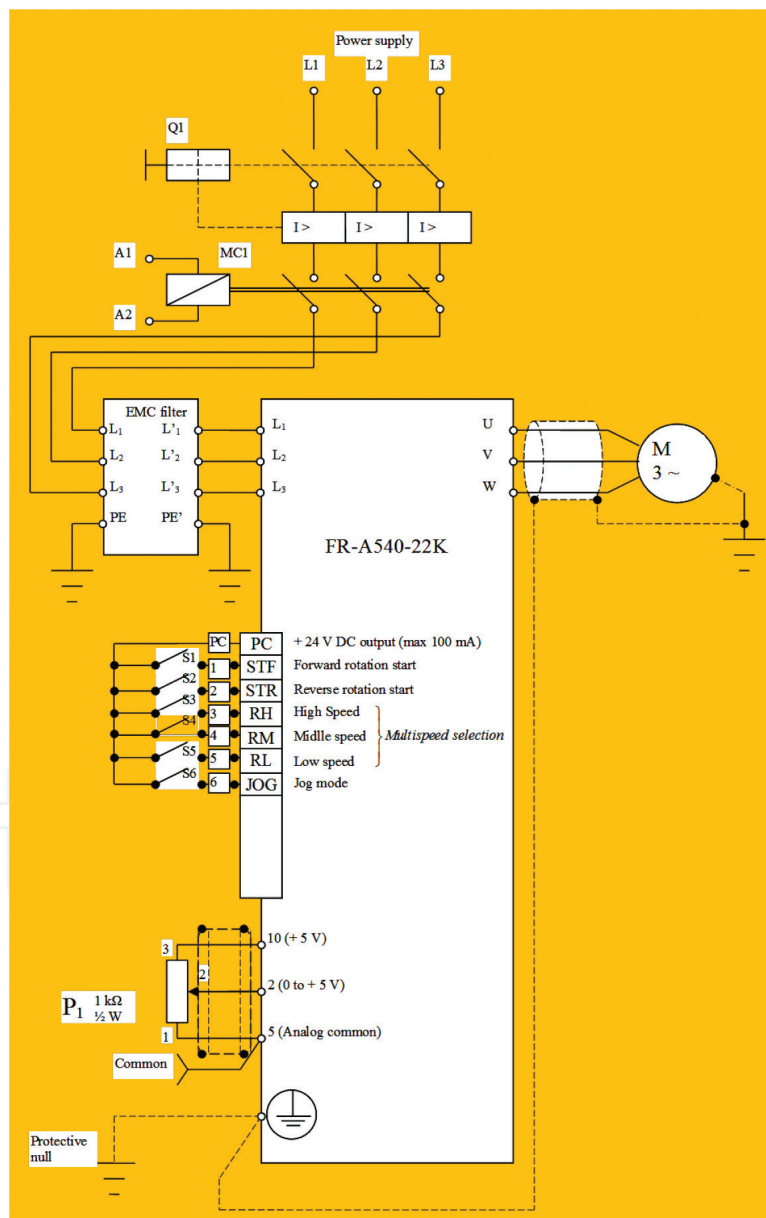
Among the automation systems used for the continuity of power supply to users, the most important one is represented by the automatic transfer switch (ATS) [1]. The scope of the ATS is to start the automatic operation of the backup power supply when the normal power supply

can no longer satisfy the requirements of the consumers. The following will illustrate, in terms of the reserve supply, some possible topologies related to low-voltage electrical grids. First of all, it is considered the switching to the backup power supply, in the case of a low-voltage symmetrical grid when using two frequency converters, one of which is alternately maintained in cold reserve. Both frequency converters are of the FR-A540-22 K Mitsubishi electric [2] type. The only user is represented by an asynchronous motor with the short-circuited rotor, having the rated active power equal to  $P = 22$  kW. The problem of ensuring continuity in power supply is all the more important if we refer to asynchronous motors powered by frequency converters that are used in applications such as gondolas and cable cars, the action of the water pumps within the drinking water abstraction and treatment plants, and the operation of large power compressors. The use of the methods described in the case of switching to the backup power supply, in the case of a low-voltage symmetrical grid when using two frequency converters, one of which is alternately maintained in cold reserve, could be a fair solution. In the second case, it is considered the switching to the backup power supply, in the case of low-voltage symmetrical smart microgrids, using in the modern residential buildings. This symmetrical low-voltage grid uses two transformers, one of them being alternatively in hot reserve. The users are divided into two categories, normal and safety ones. And for this case, one study on the ATS operation will be achieved. Also for the case of modern residential buildings, the ATS operation will be considered, in the event that they use both electric generator and photovoltaic panels. Finally a study about the implementation of recloser devices for autoconfiguration and automatic connecting/disconnecting decisions, in order to switch to the backup power supply, was initiated. Also, taking into account a series of scientific, technological, or socioeconomic aspects in terms of importance, the implementation of smart power grids is proposed [3]. This smart grids show auto-reconfiguration characteristics, by using recloser devices [4]. A very important aspect of the electrical systems is related to the safety in operation [5], lack of accidents, and extended damages. Starting from the necessity of a safe power supply system, more and more countries choose to use computerized and special telecommunications systems [6]. Moreover, in the field of electricity transmission, a high degree of operation safety is required. The characteristics of each considered microgrid determine a series of specific technical problems [7]. When considering the grid operation criteria and the specific needs of the users, the settings of the smart recloser equipment must be properly configured. Thus, the indication of the short circuits between phases, the indication of the faults between phases and earth, the signaling of defects, the signaling reset, the storage and the effective operation temperature, or the referral mode are of particular importance and may raise important shares of difficulty, in particular regarding the operation algorithm.

## **2. Switching to the backup power supply, in the case of a low-voltage symmetrical grid when using two frequency converters, one of which is alternately maintained in cold reserve**

In practice, the situations where electrical power systems need to be fed redundant can be solved through a backup of power supplies. Ensuring backup in this case must follow

a logic sequence of power so that the consumer can be powered at any time from a single power source. Also, providing short circuits and overload protection is an important aspect. If an asynchronous motor with nominal active power  $P = 22 \text{ kW}$  is powered by a single frequency converter, FR-A540-22 K Mitsubishi electric type, a low-voltage grid configuration can be used as in **Figure 1**. Switching to the backup power supply, in the case of a low-voltage symmetrical grid when using two frequency converters, one of which is alternately maintained in cold reserve, can only be done by microprogramming the two frequency converters. It is considered a low-voltage grid configuration using two frequency converters, **Figure 2**, FR-A540-22 K Mitsubishi electric type, in which one of the converters is alternatively cold reserve depending on the need. The only consumer is an asynchronous



**Figure 1.** Mitsubishi electric frequency converter FR-A540-22 K type, used to power an asynchronous motor with a short-circuit rotor with nominal active power  $P = 22 \text{ kW}$ .

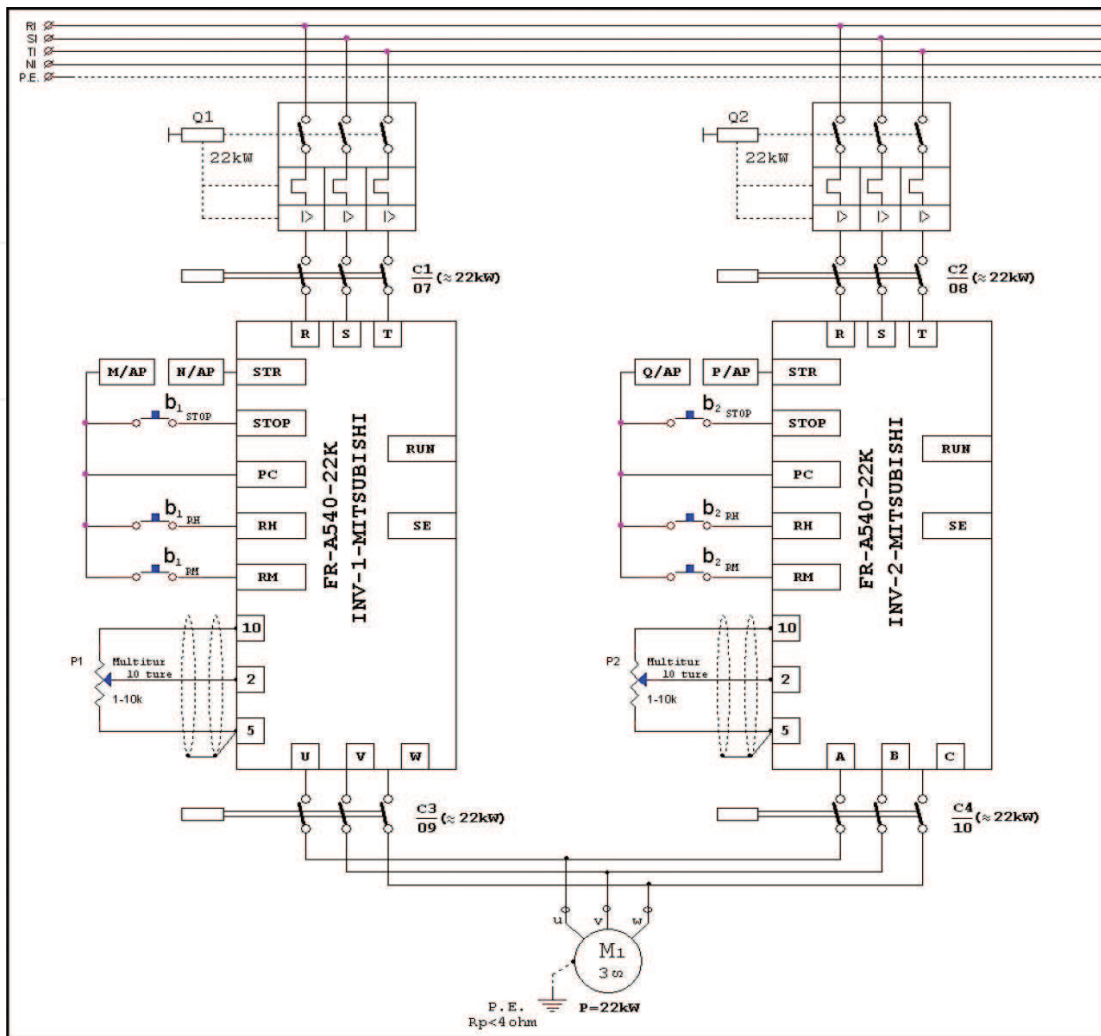


Figure 2. Switching to the backup power supply, in the case of a low-voltage symmetrical grid using two frequency converters managed by a programmable microautomaton [1].

motor with a short-circuit rotor with nominal active power  $P = 22 \text{ kW}$ . When considering redundant backup drives, using two frequency converters in order to ensure the power supply continuity, it is desirable that the interlocking management as well as the activation/deactivation commands be achieved by means of a programmable micro-automat, with software-established logic. The digital inputs of the two frequency converters, such as the frequency converter activation/deactivation commands, are performed via OUT 1 and OUT 2 outputs, **Table 1**, and are managed by a microprogrammable automaton, [8, 9] Alpha Mitsubishi, AL 2-24 MR-D type, **Figure 3**. When using two frequency converters, one of which is alternately maintained in cold reserve, the output interlock management of the frequency converters is very important. The interlock aspect is achieved by C3 and C4 switches, **Figure 2**, activated by the OUT 8 and OUT 9 output of the microprogrammable automaton Alpha Mitsubishi, AL 2-24 MR-D type, **Table 1**.

By a key selection,  $b_5$  and  $b_6$ , respectively, **Figure 4** [1], it is decided which of the converters will supply the load, represented by the M1 asynchronous motor with the short-circuited rotor.

Inputs	Outputs	Allocated inputs	Allocated outputs	Input/output account
—	OUT 1	—	START/STOP MSB1	Enable/disable the Mitsubishi 1 inverter
—	OUT 2	—	START/STOP MSB2	Enable/disable the Mitsubishi 2 inverter
—	OUT 3	—	h1	The signaling lamp 220 V~—Mitsubishi 1 inverter fault
—	OUT 4	—	h2	The signaling lamp 220 V~—Mitsubishi 2 inverter fault
—	OUT 5	—	C5	Activates the C5 switch coil which controls the brake
—	OUT 6	—	C1	Activates the C1 switch coil of the force circuit
—	OUT 7	—	C2	Activates the C2 switch coil of the force circuit
—	OUT 8	—	C3	Activates the C3 switch coil of the force circuit
—	OUT 9	—	C4	Activates the C4 switch coil of the force circuit
IN 1	—	$b_1, b_2, b_3, b_4$	—	4 × HUPA, mushroom-type buttons NI, operated when faults are produced
IN 2	—	$b_5$	—	The ND contact—left selector key on the left Zero—right
IN 3	—	$b_6$	—	The ND contact—right from the key selector is left Zero—right
IN 4	—	$b_7$	—	Commands the state START/STOP of Mitsubishi 1 inverter
IN 5	—	$b_8$	—	Commands the state START/STOP of Mitsubishi 2 inverter
IN 6	—	$b_9$	—	Auxiliary ND of the C5 switch which controls the brake
IN 7	—	$b_{10}$	—	The pin NI of the heat block from the break circuit
IN 8	—	$b_{11}$	—	Auxiliary ND of the C3 switch
IN 9	—	$b_{12}$	—	Auxiliary ND of the C4 switch
IN 10	—	$b_{13}$	—	Auxiliary ND of the C1 switch
IN 11	—	$b_{14}$	—	Auxiliary ND of the C2 switch
IN 12	—	$b_{15}$	—	Pin for the S1 proximity sensor
IN 13	—	$b_{16}$	—	Fault removal

**Table 1.** The assignment of the inputs and outputs for microprogrammable automaton.



Figure 3. Microprogrammable automaton Alpha Mitsubishi, AL 2-24 MR-D type.

Also, the enabling/disabling command management for the frequency converters is achieved by the OUT 1 and OUT 2 programmable micro-automaton outputs, Table 1.

In Figure 5, it is presented the flowchart where the logic of switching as well as electrifications can be seen (it is preferable to study together with Figures 2, 4, and Table 1).

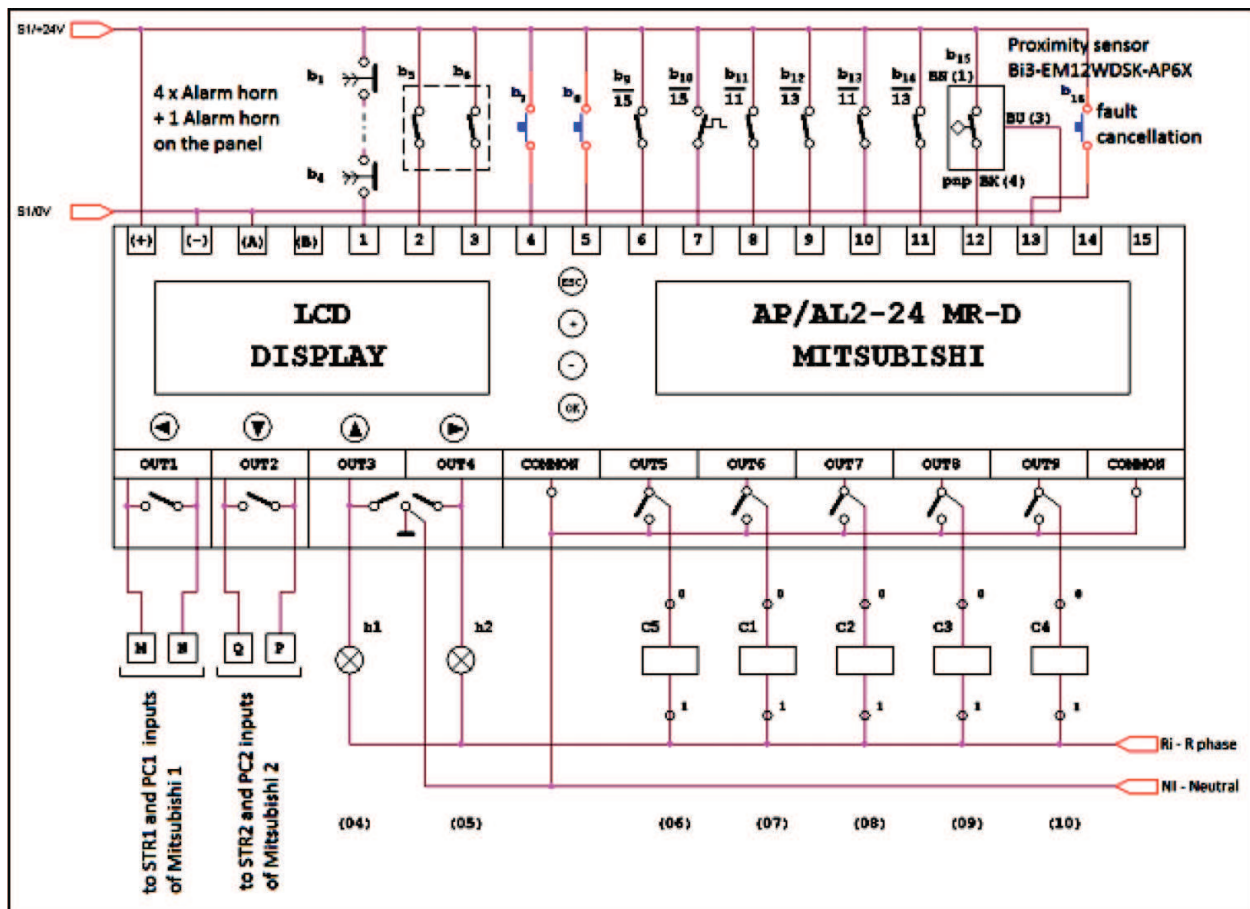
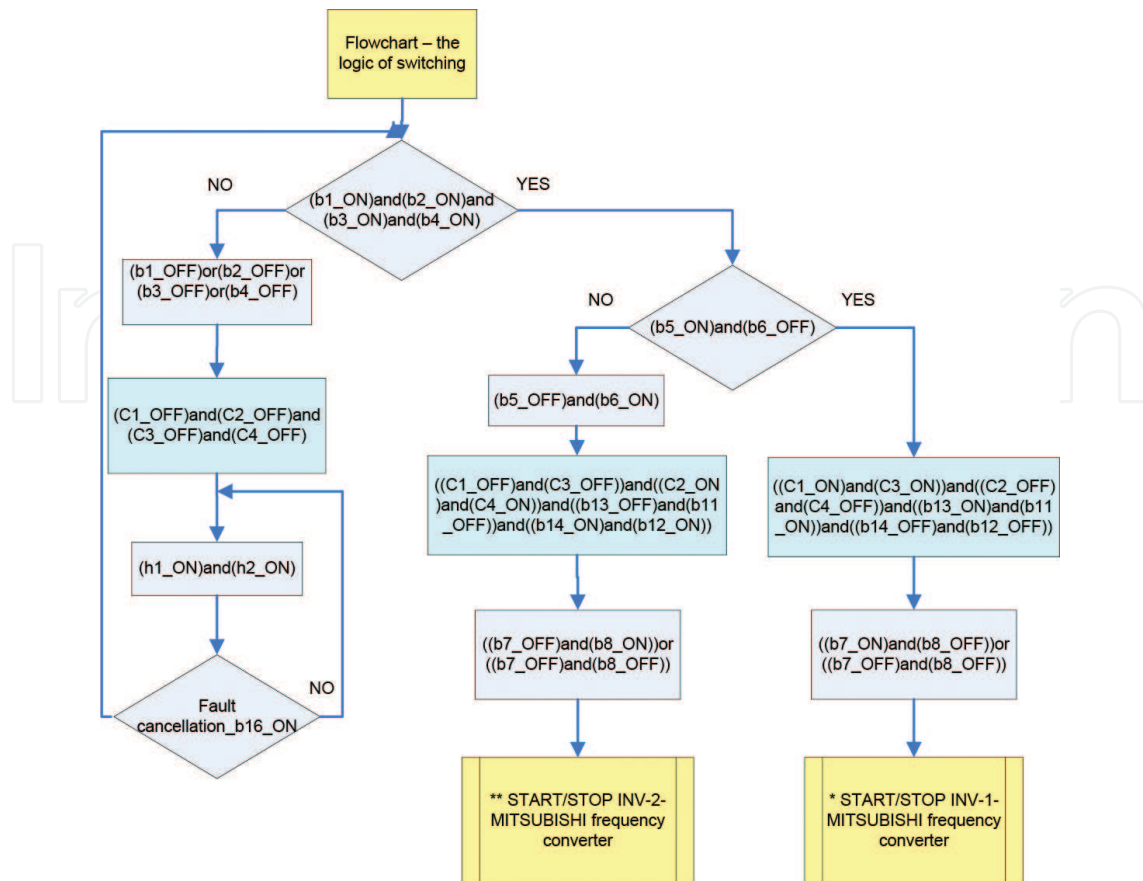


Figure 4. Connecting the inputs/outputs of the microprogrammable automaton alpha Mitsubishi, AL 2-24 MR-D type [1].



**Figure 5.** Flowchart, the logic of switching and electrifications. \*There is the possibility to obtain a variable frequency by actuating the P1 potentiometer, **Figure 2**. \*\*There is the possibility to obtain a variable frequency by actuating the P2 potentiometer, **Figure 2**.

### 3. Switching to the backup power supply, in the case of low-voltage symmetrical smart microgrids in the modern residential buildings

In the case of modern residential buildings, the automatic switching between the three-phase public grid and an electric generator can be achieved by the automatic changeover source, with automatic transfer switch (ATS) function, located in the low-voltage electrical station, **Figure 6**. The microgrid is symmetrical and uses two identically transformers, T1 and T2, one of the transformers being alternately in hot reserve state [1]. The users are divided into two categories: critical (b) and noncritical ones (a), **Figure 6**. When the users are supplied from the public grid by using one of the transformers, T1 or T2, correspondingly, one of the circuit breakers MP1 or MP2 is closed, while the “C” couple is also closed. The two circuit breakers (TN) NS250 types are closed, and the other two circuit breakers (TS) NS250 types are open so that the backup power supply path is maintained disconnected. In this case, all users are supplied, both (a) and (b) categories, from the three-phase public grid as shown in **Figure 6**. In a low-voltage grid, two distinct situations can occur:



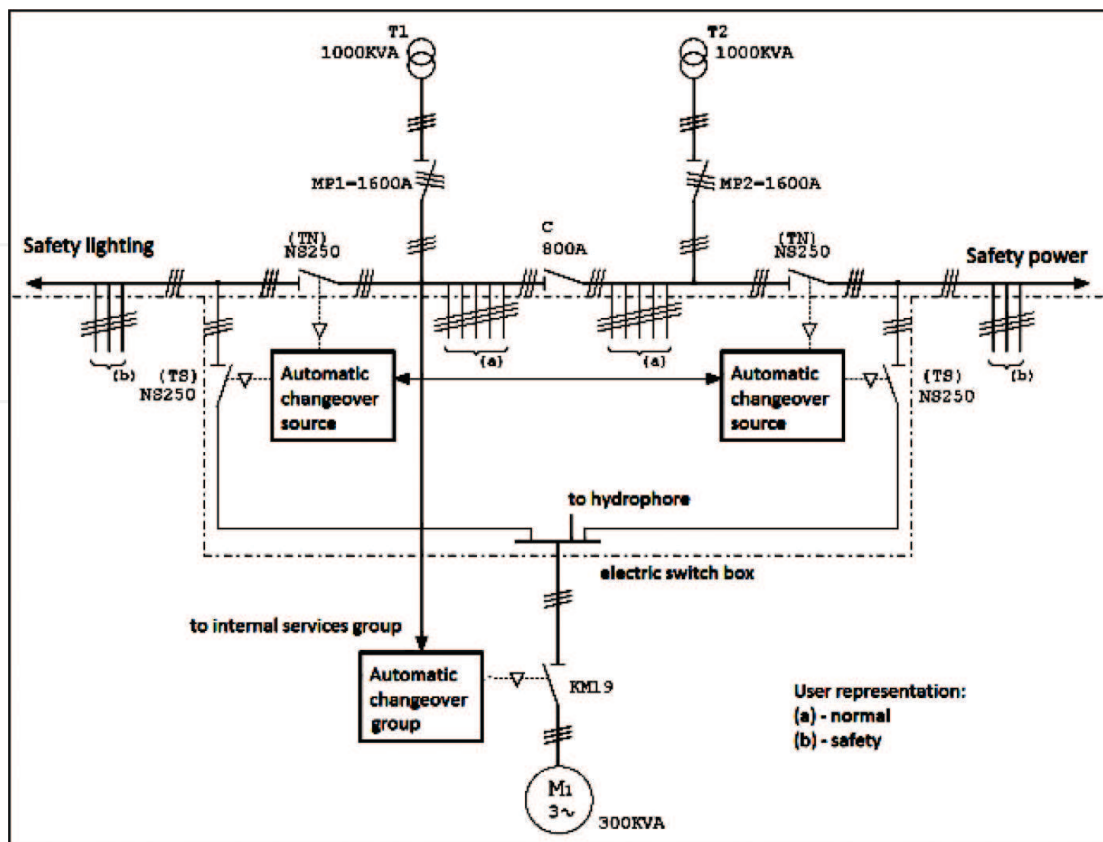


Figure 6. Single-line diagram of force for switching to the backup power supply in the case of a low-voltage symmetrical grid using two transformers and an electric generator [1].

1. The situation where ATS intervention is required.
2. The situation where ATS intervention is unnecessary.

For the ATS facility to distinguish between these two situations, it must meet the following conditions simultaneously:

- a. To get into action when the voltage level on the consumers' bars drops below a certain minimum value.
- b. The automatic action of the reserve should not be made immediately, but only after a certain time period, called ATS time delay ( $t_{ATS}$ ).
- c. Switching the backup path to achieve only after the disconnection of the normal power supply.
- d. It operates once, so that if after the operation of the ATS a new activation command is given, the ATS should not work again.

When the condition of minimum voltage on the station's bars is not satisfied in accordance to the abovementioned conditions, (a)–(d), the power supply is ensured by the M1 electric generator, Figure 6.

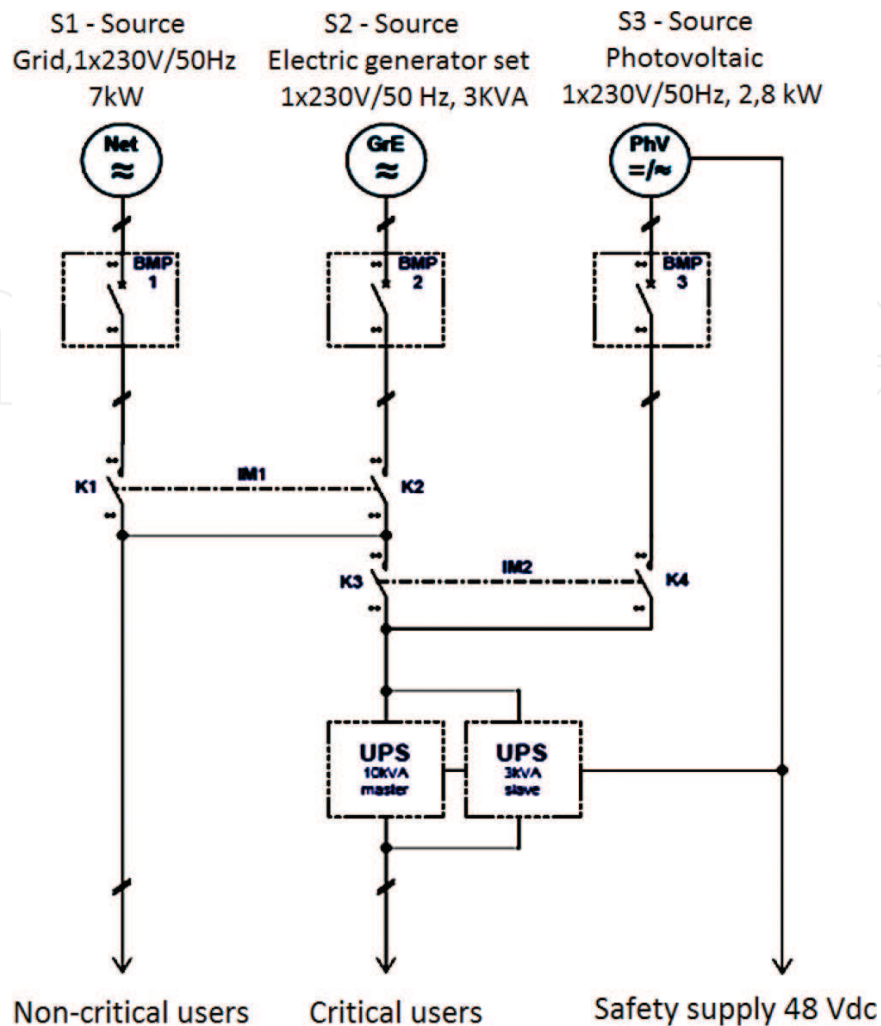
The minimum voltage coils of the “MP1” or the “MP2” circuit breakers (as the case may be) and of the “C” couple, respectively, **Figure 6**, can determine their triggering, if the voltage drops well below the nominal limit. It achieves disconnecting the normal power supply path (the public grid), and for a time  $t_{ATS}$ , both consumers in group (a) as well as consumers of the group (b) will not be powered. Note that the ATS facility is composed in this case of two systems, “automatic changeover source” type, **Figure 6**. The ATS function of the automatic changeover source commands the two (TN) NS 250 circuit breakers, by opening them, and the other two (TS) NS 250, by closing them. Another important aspect is the existence of the “automatic changeover group” type, **Figure 6**, which is absolutely necessary for triggering a delay timing,  $t_{GROUP}$  in starting the M1 electric power generator and the automatic closing of the KM 19 switch, only after the transient phenomena has been removed and a permanent regime of the electric generator has been set. Obviously  $t_{ATS} < t_{GROUP}$ . The electric generator’s services must be ensured at all times. If during timeout  $t_{ATS}$  the voltage on the bars is not found (allowing the ATS to operate), the electric power generator will be started. After the expiration of time  $t_{GROUP}$  the automatic closing of the KM 19 switch is achieved, the M1 electric power generator injects electric power on the base station bars and supplies power only the (b) group users, referred in **Figure 6** as safety power and emergency lighting. When the tension on bars returns, after “delay timing”  $t_{STOP}$  has been passing, the following processes take place: firstly, the automatic changeover group command stops of the M1 electric power generator and then the automatic opening of the KM 19 switch is achieved. Obviously  $t_{ATS} < t_{STOP}$ . Next, the ATS function of the automatic changeover source commands the two (TN) NS 250 circuit breakers, by closing them, and the other two (TS) NS 250, by opening them. Finally, closing the breaker MP1 or MP2 (as the case may be) and of the “C” couple, respectively, it can also be done automatically or manually.

#### **4. Switching to the backup power supply, in the case of a low-voltage smart microgrids using an electric generator set and the photovoltaic panels**

In the case of modern residential buildings that use an electric generator set and the photovoltaic panels, the functions that are provided by the ATS regard the following:

- a. When the three-phase public grid is available and connected, all the users are powered from this grid.
- b. When the three-phase public grid is not available, the electric generator will be connected. Both critical and noncritical users will be powered by the electric generator.
- c. When the three-phase public grid and the electric generator set are not available, the critical users are supplied by the photovoltaic panels’ energy generation.

The automatic switching is necessary between the two types of users, critical and noncritical ones to the available sources, in this case the three-phase public grid, an electric generator set, and photovoltaic panels that are shown in **Figure 7**.



**Figure 7.** Electric power diagram for switching to backup power supply in the case of a low-voltage smart microgrid using an electric generator set and the photovoltaic panels (courtesy of Sirius Trading & Services srl, Romania).

To implement the above basic functions and the control algorithm, the system also integrates the following additional functions:

- Monitoring the presence of voltage on the three sources (three-phase public grid, an electric generator set and photovoltaic panels).
- Monitoring the state signals of the electric power generator set, such as the presence and level of fuel, the good operation of the filter, the command temperature of the shock, as well as the heating resistor's temperature of the fuel (command).
- Connecting/disconnecting of the electric power generator set when the three-phase public grid is available/unavailable, respectively.
- Checking confirmation commands from the circuit's commutation wires and providing alternatives if commands are unconfirmed.
- Counting the number of three-phase public grid voltage drops, disconnection time of the public grid, the number of connections, and time of operation per electric generator set

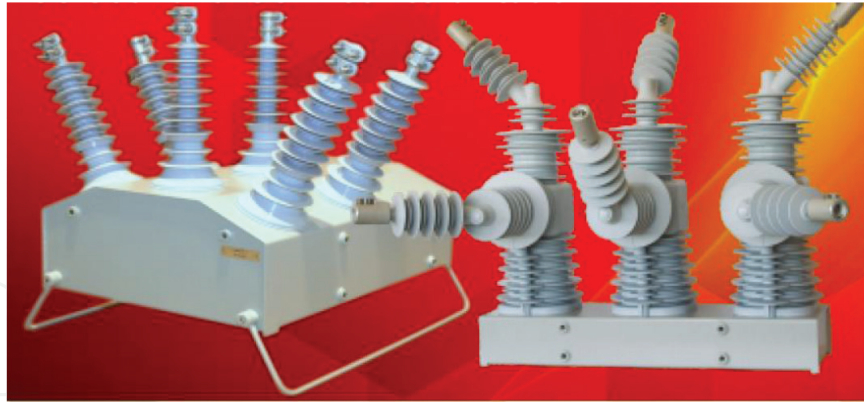
and photovoltaic source time. These functions are performed through a software program [9] which is implemented on an AL 2–24 MR-D, Alpha Mitsubishi programmable micro-automat, **Figure 3**.

In this case, the ATS automation must work in the following way:

- When the public grid is not available, the triggering delay timing of the electric generator set is initiated; if the voltage grid does not reappear during this delay timing, the startup procedure of the electric generator set will be initiated.
- Several connecting attempts are possible, their number being set by the user. The duration of the connecting command and the related pause between the attempts can also be established by the user.
- When the electric generator set is connected and the output voltage is detected, the connecting command is maintained for another short period of time in order to avoid its disconnection.
- After switching on the electric generator set and expiring the timer entry (also set by the user), critical and noncritical users are switched to the electric generator set circuit.
- Upon reappearance of the voltage on the public grid and after the end of the public grid stabilization (user settable), the users are disconnected from the electric generator and reconnected to the public grid.
- Simultaneously for the electric generator set, the stopping procedure is initiated with the fuel shutdown and timed with the activation of the group shutdown command.
- In the case of public grid and group unavailability, vital consumers are supplied by the photovoltaic panels' energy generation.
- Fault and nonconfirmation conditions are stored and remain active even if the system is disconnected and then reconnected; resetting requires operator intervention to repair the causes that triggered them and press the reset button.

## **5. The implementation of recloser devices for autoconfiguration and automatic connecting/disconnecting decisions, in order to switch on the backup power supply**

As smart grids are composed of sensitive equipment at voltage interruptions in increasing proportion, higher-power-quality issues have become increasingly important. In order to reduce the rate of long-term interruptions and thus improve the quality of energy, for medium voltage (MV) distribution networks, it is proposed to use the recloser devices. Thus, it can prevent long outages by eliminating temporary malfunctions, before the fuses are operating in the system. Reclosers also offer control, measurement, automation, and telecommunication capabilities. This makes it possible to control in real time the intelligent network that now allows maneuvers for various purposes. Reclosers also provide consecutive automatic



**Figure 8.** The Tavrida electric recloser concept, up to 40.5 kV (RMS) rated maximum voltage and up to 1250 A (RMS) rated continuous current [10] (courtesy of Tavrida electric).

closing cycles to eliminate transient faults and minimize network interruption. The reclosers, **Figures 8, 9, and 10**, incorporate some breakers with vacuum extinguishing chambers (vacuum breaker), inside a polycarbonate shell for each pole, **Figures 11 and 12**. Each breaker, corresponding to each pole, is embedded in a polymer bush. This bush includes both current and voltage sensors. The breaker with contacts in vacuum is considered a nonmaintenance electrical switching apparatus. The drive mechanism has a high reliability and requires a revision at about 10 years or after 10,000 maneuvers.

The implementation of the smart devices, as recloser type for automatic connecting/disconnecting decisions so that the branched or even looped operation could be possible by using the lines without any faults until the removal of the existing ones, allows auto-configuration of the smart microgrids.

Voltage sensing is carried out by conductive rubber screens that are capacitively coupled to the high-voltage (HV) terminals, and current sensing is performed by six Rogowski sensors,



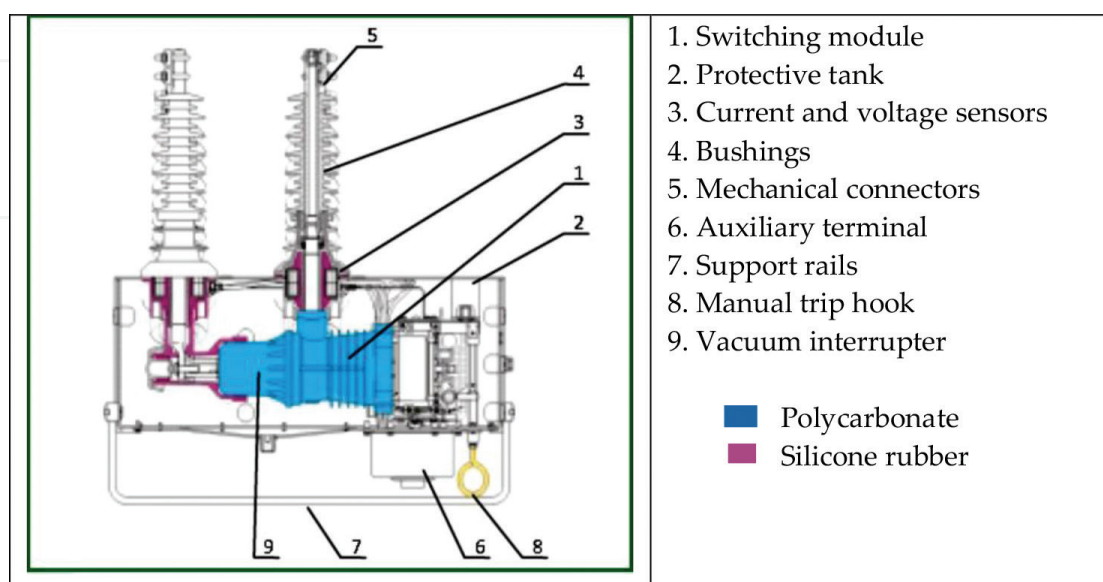
**Figure 9.** The Thomas & Betts recloser concept, up to 38 kV (RMS) rated maximum voltage and up to 800 A (RMS) rated continuous current [11] (courtesy of Thomas & Betts).



**Figure 10.** The REVAC recloser concept, up to 36 kV (RMS) rated maximum voltage and up to 630 A (RMS) rated continuous current [12] (courtesy of REVAC).

one sensor per HV terminal, **Figures 11** and **12** (Tavrída Electric recloser). Rogowski sensors are current sensors that produce a safe, low-voltage output [10]. The mechanism is operated by three separate magnetic actuators, one per pole, **Figure 11**. These magnetic actuators are mechanically interlocked to guarantee correct a three-phase operation. The device is latched into the closed position by magnetic latching. Each magnetic actuator utilizes a single coil which is used for both opening and reclosing operations [10] (Tavrída Electric recloser).

These recloser's devices can be successfully applied to the electric grids without isolated neutral. The conversion of the public grids to active (distribution/using) grids that use the high-tech smart devices like reclosers is expected to make in the future. Moreover, there is also considered



**Figure 11.** The Tavrída Electric recloser, the components of a pole (courtesy of Tavrída Electric) [10].

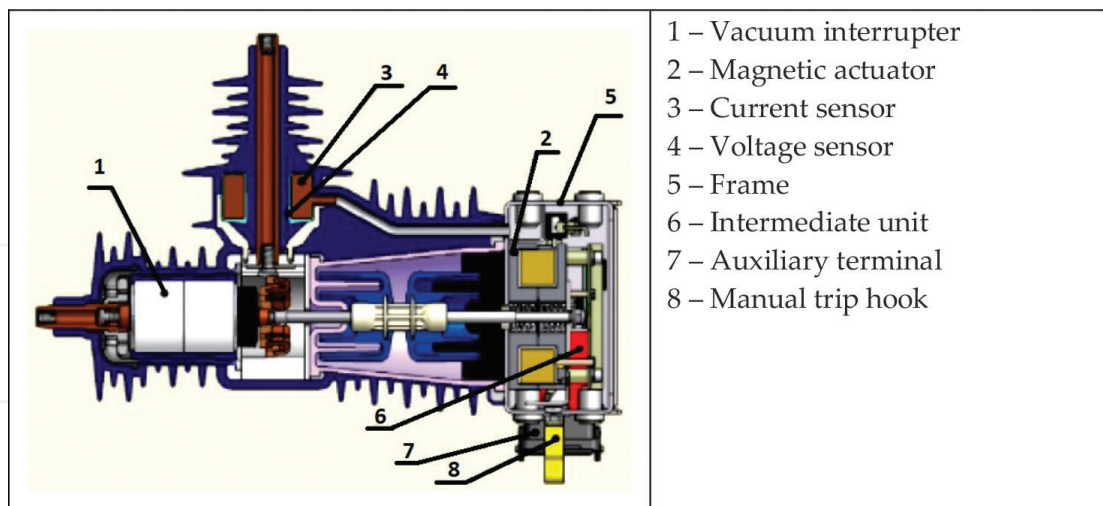


Figure 12. The Tavrida Electric recloser, actuating the vacuum interrupter (courtesy of Tavrida Electric) [10].

grouping these within smart microgrids which have the autoconfiguration option [13]. Thus, the faults and contingencies will be limited or even removed, creating the frame for the supplied equipment (in a continuously increasing number due to the local and regional expansion) to operate until the removal of the fault. The characteristics of the analyzed public grids with isolated neutral regard their operation in general with a radial structure, **Figure 13**. Thereby, when a fault is produced, all the equipment is disconnected until the removal of the fault.

In order to switch on the backup power supply, Substation 1 or Substation 2, respectively, **Figure 14**, is possible to the implementation of the recloser devices for autoconfiguration and automatic connecting/disconnecting decisions, in conjunction with a circuit breaker. And more important for this configuration is that this circuit breaker can also be assimilated with a smart recloser device, recloser 3, **Figure 14**.

These smart recloser devices can be used in order to monitor both the isolation resistance and other parameters of the considered microgrids. The actual implementation of the recloser devices for programming connecting/disconnecting process is also considered. Thus, the lines without any faults allow the continuity of power supply to consumers until the faults' removal. Furthermore, these electric grids, already active, are able to reconfigure based on the recloser devices to the initial operation mode, previous to the fault

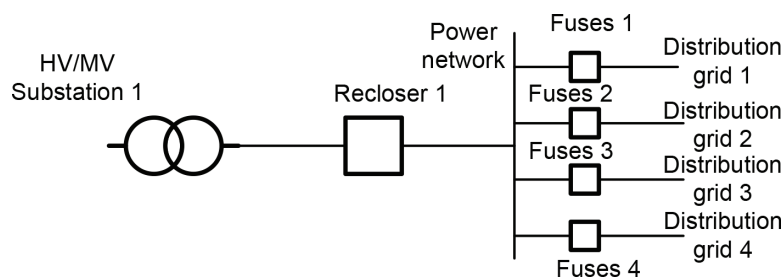
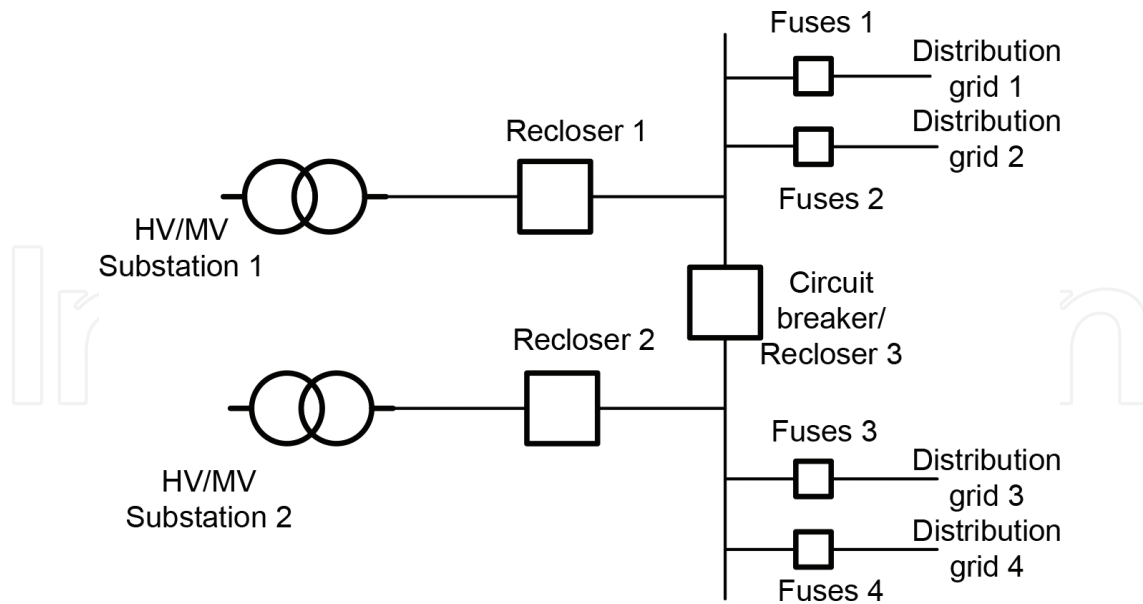


Figure 13. Radial structure of a public grid with isolated neutral.

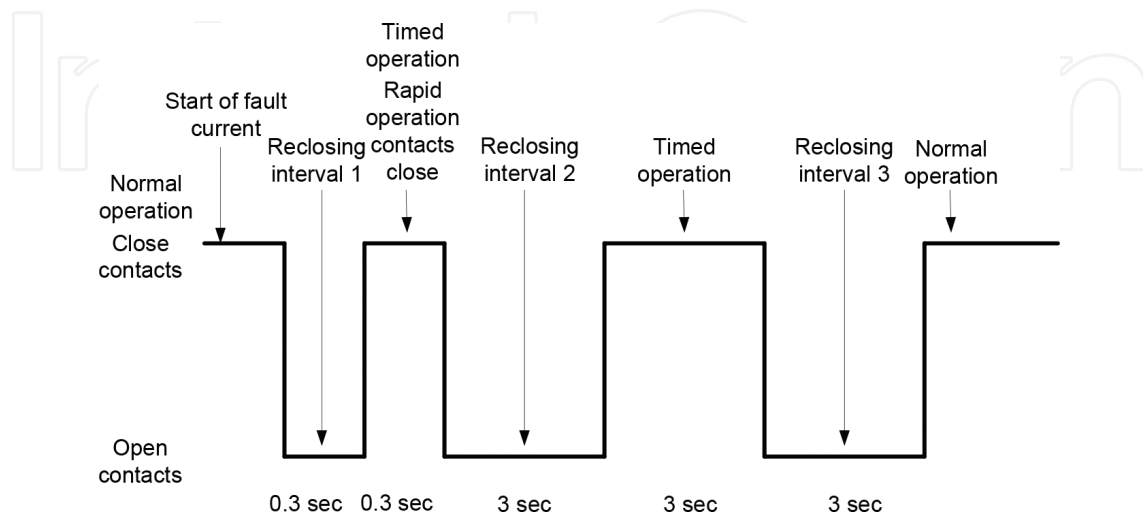


**Figure 14.** Implementation of the recloser type devices for switching on the backup power supply. The case of two radial structures of a public grid with isolated neutral.

propagation. This is done by programming an opening/closing sequence, depending on the characteristics of the microgrid. For example, **Figure 15** is showing a possible process of reclosing.

Reclosing interval can be defined: the open-circuit time between an automatic opening and the succeeding automatic reclosure [14]. Obviously, as reclosing interval increases, “risk of arc” reignition (RAR) will decrease.

Among the advantages of using these smart recloser devices, the following are mentioned:



**Figure 15.** Recloser operation mode, a possible process of programming reclosing.



- Increased economic efficiency: the unpredictable blackouts of electrical grids are removed, the maintenance time and costs are reduced, the weak points of the installations are quickly observed, and better organization of investment is possible.
- Increased operation safety: accidental interruptions of electrical grids are not possible due to insulation faults, the exact location of the insulation faults can be established, the electrical installations are maintained at a high operation level, and the circuits are being monitored both online (under load) and offline (off).
- Optimal maintenance: The insulation faults are found and quickly indicated, automatic location of a system section (subcircuits) with isolation faults is possible, optimal personnel and repairing time planning, complete and centralized information regarding the electrical installation state, monitoring and remote diagnosis via the Internet/Ethernet.
- Enhanced protection against fire: the insulation faults are found in incipient phase. Thus, there are no major isolation faults, the isolation faults representing the main fire starters. The use of insulation transformers as well as monitoring and remote diagnosis via Internet/Ethernet allows the separation of certain sections (electrical subgrids) that can be exposed to fire from the rest of the power system.
- Enhanced protection against accidents: the removal of electroshocks by disconnecting the faulted systems or circuits and the prevention of disturbances in the control circuits of various equipment and electric machines.

## 6. Conclusions

This chapter proposes some solutions about the topics of unconventional backup structures used in smart microgrids. The issue is of interest particularly in connection with the problem of ensuring continuity in power supply. In this context, firstly the case of the switching to the backup power supply, in the case of a low-voltage symmetrical grid when using two frequency converters, one of which is alternately maintained in cold reserve, is presented. The only consumer is an asynchronous motor with a short-circuit rotor with nominal active power  $P = 22$  kW. The logic of switching and electrifications is ensured by using an associated software of a microprogrammable automaton. Secondly, the switching to the backup power supply, in the case of low-voltage symmetrical smart microgrids using an electric generator set or using an electric generator set and the photovoltaic panels, in the case of modern residential buildings, is proposed. The microgrid is symmetrical and uses two identically transformers, T1 and T2, one of the transformers being alternately in hot reserve state. The users are divided into two categories: critical and noncritical ones. Finally, the implementation of recloser devices for autoconfiguration and automatic connecting/disconnecting decisions, in order to switch on the backup power supply, is presented. It is expected in the future realized the conversion of the public grids to active (distribution/using) grids that use high-tech smart devices like reclosers. The grouping together of these smart microgrids that have the auto-reconfiguration option through implementation of the recloser type devices is also considered in the development of smart grids. In this context the implementation of the recloser-type devices for switching on the backup power supply, for the case of a two radial structures of a public grid with isolated neutral, is presented.

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