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ELECTRICAL STATUS SPACE FOR CLEARING PROCEDURES IN ELECTRICAL INSTALLATIONS

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Abstract

Maintenance personnel must take the clearing procedures , operating the necessary steps to assure that the system or portion of the system on which they plan to work is in an electrically safe working condition [1].

The accepted, reliable way to provide safety is to de-energize the equipment first, then to connect the equipment to ground so that it cannot be re-energized. If there is no electrical power, there is no risk of electrical injury.

Complexity of the electrical system normally determines the level of detail planning required for system clearing procedures. The clearing procedures should be completely written, checked and understood by all persons involved before applying them to any portion of the power distribution system.

This paper reviews and enhances a previous paper [2]. It investigates the basic concepts and definitions to give prominence to operating bonds and to help the procedure-project. It proposes some simple rules , a graphical representation and an algebraic model of electrical status to execute an auto-check of the clearing procedure. The model allows to memorize visually the logic procedures and to count the necessary locks.

SYMBOLS

The symbols in the Figures and in the text are :

MVS	Medium Voltage Switchboard
BR	Bus Riser Unity
GS	Ground Switch: in the unity, it operates in the opposite side of the bus.
CB-BI	Circuit Breaker Unity with a bus isolator and a ground switch
CB-DBI	Circuit Breaker Unity with double bus isolator
IS	Isolator Switch Unity with a ground switch
LVCB-DO	Low Voltage Circuit Breaker in Draw-Out version
1	“energized” condition conventionally indicates as “one status ” (logic value 1), is the live condition of the electric system or/and of the component; this status can be assumed as the reference condition;
0	“open or locally de-energized” condition represents as “zero status ” (logic value 0), is the open condition or locally de-energized;
G	“grounded” condition represents as “grounded status ” (logic value -1), which is the condition of generally de-energized,
S	“in safety” condition represents as “safe status ” (logic value -2), which is the condition of locked grounded and safe de-energized.
=	Parity bond, symbol signed on a status of a coupled unity: in a pair of coupled unities (perfect unity), the operation on the one requests the same signed starting status on the other coupled unity
∇	Priority bond, symbol signed on a status of a device in an unity : in an unity with a pair of devices, the operation on the one, signed on the starting status, requests the priority of the end status on the other local device

1. INTRODUCTION

In order to execute operations of electrical maintenance, on a portion or components of the system, it is necessary to use more elaborate clearing procedures and written switching instructions for systems together with a single-line diagram [1]. Complex power distribution systems that may have several sources into an area require several switching steps to isolate a portion of the system.

“Electrical steady condition” of the electric system, of portion of the system or of electrical equipment, is defined as the “electric status” of the corresponding element. The following is a list of four possible conditions of duty: -“energized” (symbol 1) , the status of the live condition, -“open” (symbol 0) , the status of the locally de-energized ” or the status the open condition or locally de-energized, - “grounded” (symbol G), the status of generally de-energized, when there are two or more sources in the upstream-side and in the downstream-side; - "in safety" (symbol S), the "safe status", which is the condition of locked grounded and safe de-energized, that guarantees an electrically safe work condition for the operator. It is really a safety bond, but it is so fundamental that it must be considered a status.

Operating of electrical system, of a portion of the system or of its electrical equipment, means changing the system from a status to another, by use of appropriate devices. Each electrical operation is a transient condition or transition between two status.

In most cases (in Europe belong to medium and high-voltage, in USA belong to low and high-voltage), appropriate devices are adopted to determine and to maintain each electrical status. Devices performances and locks, which fix the status of system, are reported below .

- Circuit-breaker determines two electric status of duty (1,0). It is normally used to guarantee the "1 status" of energized system or component;
- Isolator switch joined to a grounding switch can determine generally three electrical status of duty (1,0,G) . The isolator switch is normally used to guarantee the "0 status" of open or locally de-energized system or component. The grounding switch is used to guarantee the " G status" of generally de-energized system or component;
- Padlocks or similar are used to guarantee the "S status" of locked grounded.

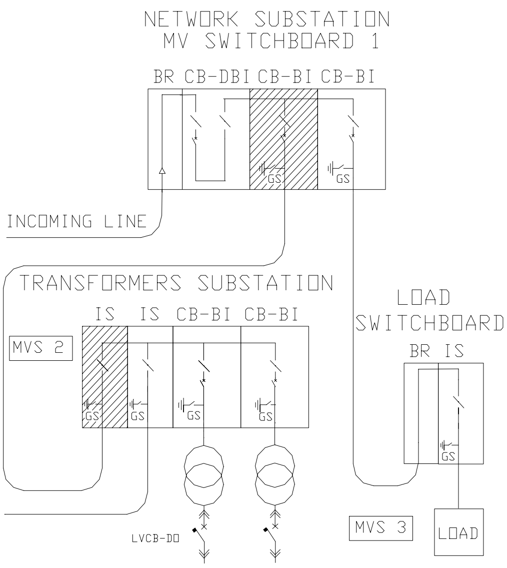


Fig. 1 A sample case of Medium Voltage System

The maintenance operator him-self must be considered as an integral component in the system, so that he must constrain the beginning and all his activity to the system grounded padlocked status, the only one that allows to work easily in a safe condition.

In Figure 1 is shown a sample case of Medium Voltage System of reference. In this single-line diagram it is possible to point out that some MV unities are "perfect unities" , that is independent or without functional bonds with other unities in the clearing procedures. The CB-DBI unity is intrinsically independent: the double bus isolator guarantees the independence of operations on the unity. The load operating IS unity and the own protection CB-BI unity , in the upstream side, are independent also. They are independent considering that are without functional bonds with other unities in the clearing procedures.

Instead, in Fig.1 the pair of darkened unities (protection CB-BI unity and operating IS unity of line) must be considered coupled and together they form a perfect unity. As reference for the following, this coupled pair of unity is shown in Fig. 2 as a case study.

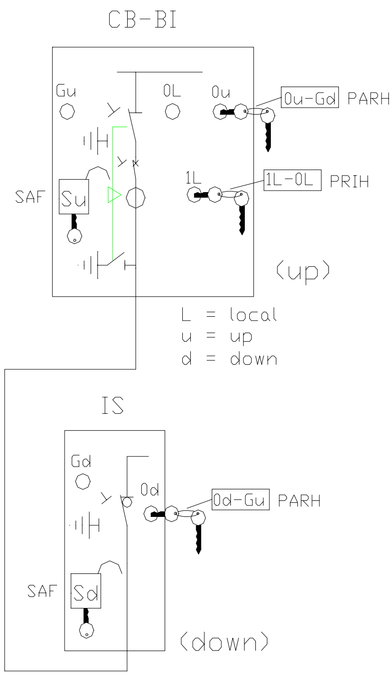


Fig. 2 Case study of Medium Voltage coupled unities as perfect unity. For a clearing procedure example: the start condition of energized system is shown.

The bus systems, supplying the devices, are assumed to be energized up to proven otherwise.

Generally, a grounding switch doesn't operate on the bus side, but on the opposite side (line-load). However, the bus riser unity has the particularity of inverting line with bus and vice versa.

2. Clearing Procedures

Some basic elements are identified and discussed in order to fix a general routine or correct sequence of operations and of locks and in order to avoid working incorrectly.

Let us consider the case study of Figure 2 .

In upstream location, there is the CB-BI unity: a pair of devices, a circuit-breaker CB and an isolator-grounding switch IS, is provided for upstream side protection of a MV line.

A priority bond exists, because there is locally the couple of devices, where the CB has the priority of the opening operation on the IS. In the opposite case of closing operation, the priority is of the IS on CB.

In downstream location of Figure 2, an IS unity is provided for downstream side operating of the same line. A parity bond exists between the IS components of the two coupled unities: the operation to the grounded status (G) of the downstream switch IS is constrained to the balanced open status (parity to 0) on the other coupled components in upstream side, where is the supplying source. The same parity bond there is for the IS of the upstream side, if also in downstream side there is a supplying source.

"Correct procedure" is that which carry out operating in the way and with the right sequence in an electrically safe work condition.

Correct procedure is similar to a relay race , where each condition (steady and transient condition) is similar to each runner which turns only a portion of total procedure, bringing the "witness" of the game.

Only a condition for time has the witness of game. Each condition is free to go forward or to come back.

"Lockout of safety" is a device that prevents the wrong sequence and consents the right sequence. A "lock" exists for each operation with a bond.

As a worst case, considering the two locations for operating of Figure 2 and considering that should be a source in each side, they exist local locks 1_{local}, 0_{local}, the crossed locks in two locations 0_{up}, 0_{down}, G_{up}, G_{down} and the safety locks S_{up}, S_{down} . Each lock (in example 1local) : allows the operating of component 1 (CB) with the key (1_{local}) which is present and locked (bringing the witness)

clears the key with locked operating on the component (handing over the witness).

So, each condition with witness can lock it-self and hands over the witness. For example, the 0,0 status of the CB-BI unity has the key–witness like the end condition of the game-operation G,0 – 0,0 , it has also the key–witness like the start condition of the game-operation 0,0 – 1,0. So it is free to change in 1,0 status or in G,0 status: in the first case, for instance, it locks it-self (handing over the witness) and authorizes the operation of the 1 component (CB), which brings the witness.

Owing to the operation with bonds, they are determined three hierarchies of key locks (H).

Each hierarchy H has the own couple of keys "ringed" together.

Let's consider the adjacent couples of operating 1-0, 0-G and G-S

On the operating 1-0 there is a priority bond, when the couple CB IS exists in the same unity: the priority hierarchy is so a local bond.

On the operating 0-G there is a parity bond, when two coupled IS exists (see Figure2): the parity hierarchy is so a crossed bond. An hierarchy (couple of keys "ringed") exists for each source.

The safety hierarchy exists always considering that it is necessary to put in safety the system.

The priority local hierarchy PRIH determines two keys: one key on circuit breaker and one key on isolators switch, respectively 1_{local}, 0_{local}" ringed".

- The parity crossed hierarchy PARH determines two keys on isolators switches ($0_{crossed}$, $G_{crossed}$, ringed, where "crossed" is crossed 0_{up} with G_{down} and 0_{down} with G_{up}, in the two couple).

-The safety hierarchy SAFH determines one key or padlock on isolators switches ($S_{crossed}$ where "crossed" is "up" or "down": this key must be considered "ringed" at the man-operator).

3. The Electrical Status Space for the Clearing Procedures: A Graphical Representation

The electric status of a system , of portion of a system or of electrical equipment, is established by a device or by a combination of these different devices in a protection unity.

A graphical representation is possible to introduce in a "electrical status-space" for the clearing procedures, to study the operations on the devices of the system. So, in this space, it is

possible to establish a correspondence between each device of a MV unity and the axis of the space. The correlation can be fixed on the basis of increasing priority of the local operation versus the energized status: X as first, Y as second and, if it is necessary, Z.
The status of the electric system, of portion of the system or of electrical equipment can be represented in this special space, “the electrical status space for the clearing procedures”, where singular points can usefully correspond to the same status. At this aim , to each status 1,0,G,S it is possible to appoint the logic values and coordinates 1, 0, G=-1 and S=–2, respectively.
In Fig.3a the X-axis is correspondent to a device; the points 1,0, -1 and -2 correspond to the four conditions of the device in a complete clearing procedure. For clearness, conventionally, the coordinates –1 and –2 on the X-axis are reported as G and S in all cases. A pair of devices (see MV unity in upstream location of Fig. 2) can be represented by the X-Y axis on the plane (Fig.3b). The status G and S are reported by one coordinate, owing to the crossing by the 0,0 status is necessary, but they can be indicated as G,0 and S,0.

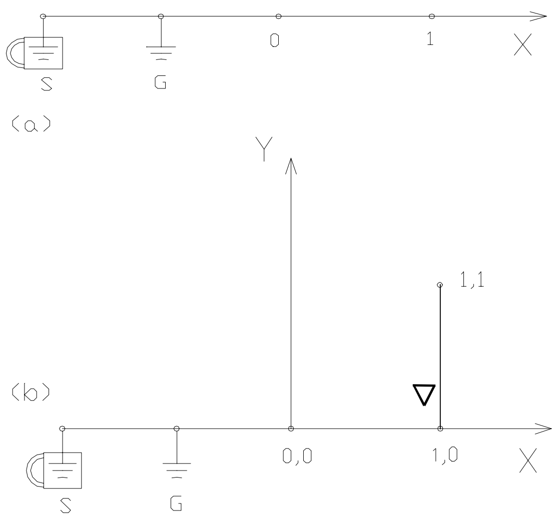


Fig. 3 Clearing procedures, graphical representation: a) case of a single device, X-axis, b) case of a pair of devices, X-Y-plane. The shown polyline, interconnecting the status coordinates 1,1 – 1,0 – 0,0 – G – S, indicates the correct operating sequence in the clearing procedure. It is shown the priority bond symbol ∇.

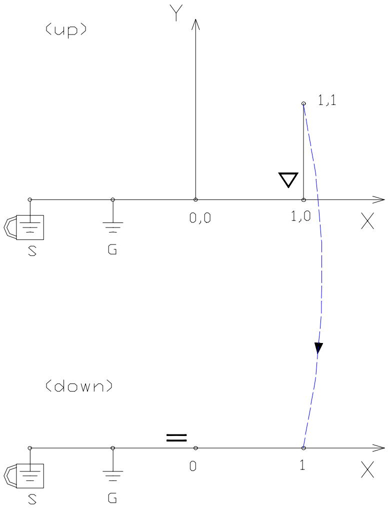
It is evident that operations between the 1, 0, G and S status must have the natural order indicated in the direction of the safe status and vice versa.

3.1 Case study of a Medium Voltage Unity without bonds (Figure 3a).

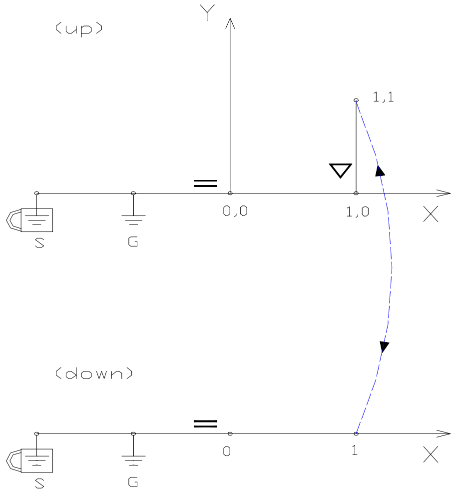
Let us consider in Figure 1 the load operating unity, equal as constitution to MV unity in downstream location of Fig. 2.
The operations on the single device IS, joined to a GS, are represented on X-axis : the Fig.3a shows the four conditions.

3.2 Case study of a Medium Voltage protection unity with a priority bond(Figure 3b): local operating 1,1 – 1,0- 0,0 and vice versa.

Let us consider in Figure 1 the protection CB-BI unity upstream the load, equal as constitution to MV unity in upstream location of Fig. 2.
In Figure 3b the devices pair of the circuit-breaker (Y-axis for priority) and of the isolator-grounding switch (X-axis) is shown on the status space. Generally, a devices pair of a circuit-breaker and of an isolator-grounding switch allows :
- to energize the part or the component of the electrical system (coordinates 1,1 on the X-Y plane); - to locally de-energize the same part or component (coordinates 0,0 of the X-Y plane).
The closing of circuit-breaker (operation- vector from 0-status to 1-status) is constrained to the 1-status of the isolator, which must be ready to be energized. In the Figure 3b the symbol of the priority bond ∇ is signed on the 0 status of the CB operation-vector, parallel to Y-axis
The circuit-breaker (Y-axis) has the priority in the 1-status and it is the first that allows to be opened. In other words, on Fig. 3b it is very easy to see that the correct operation-vector shall be from 1,0 to 1,1.
Therefore, the opening of an isolator (operation-vector from 1-status to-0 status) is constrained to the 0-status on the circuit-breaker. So on the 0-status the isolator is evidently the first that allows to be closed. In other words, on Fig. 3b it is very easy to see that the correct operation-vector shall be from 1,0 to 0,0.
In a logic sequence for a X-Y devices pair from all energized status X,Y = 1,1 to reach to all open status X,Y =0,0 , it is necessary to operate the transient condition X,Y = 1,0 and in synthesis from to 1,1-status to 0,0-status the sequence is 1,1; 1,0; 0,0 and vice versa 0,0; 1,0; 1,1. It is to prevent the transient condition X,Y = 0,1



a)



b)

Fig. 4 Case study of Fig.2 on the status-space: it is shown the start condition of energized unities: a) case of single source - b) case of double source. One arrow is shown for each source. The symbols = of the parity bond and ∇ of the priority bond are opportunely signed.

3.3 Case study of two coupled Medium Voltage unities with priority and parity bonds (Figure 4): local operating and crossed operating in two locations

For grounded status (G) of an isolator-grounding switch it must be considered, if there is a power source on the line side, upstream or downstream side. Figure 4 shows the case study of Fig.2 in a representation on the status-space. The start condition of energized unities is shown: the status of the MV unity in the upstream location is represented by the coordinates 1,1 on the plane X,Y; the status of the MV unity in the downstream location is represented by the coordinates 1 on the X-axis, a line connects these two points.

In Fig.4a the case of single source (on upstream side): on the connection line one arrow is shown for the single source. One symbol of parity bond is reported on the X-axis of the switch downstream side on the 0 status of the operation-vector between 0,0 and G,0 status. The bus on the down-side unity shall be energized only if the isolator switch is in closed position, as the start condition.

In Fig.4b the case of double source (on upstream side and on downstream side): on the connection line two arrows are shown for the two sources. Two symbols of parity bond are reported on the X-axis of two switches on the transient operation between 0,0 and G,0 status.

The connection line and the presence of the arrows shall follow the change of the status by the clearing operations.

The parity bond characterizes the crossed operating: the operation-vector to the grounded status (G) of an isolator is constrained to start from the balanced open status (parity to 0) on the other coupled isolator: 0_{up},= 0 $_{down}$ status. To allow the complete de-energized status, it is important to remark that the coupled components determine the operating in two locations, up and down side, (not locally operating).

So in the grounded status the grounding switch has the priority to be opened.

The grounded status need the logic sequence 0_{up}, 0_{down}, G_{down} , G_{up} status. The Figure 5 shows the operations of the clearing procedure to follow for changing the general energized status into the safe status.

Similarly, it is possible to study the case of the perfect unity in Fig.1 constituted by the unity couple of the transformer CB-BI and the LVCB-DO. The case is similar to that of Fig. 4b, but adopting to axis X-Y also for the LVCB-DO.

5. An Algebraic Model. Conclusions

The status of the system or of part of the system , that is possible to see in a graphic representation, is possible to verify algebraically by the logic value, sum of the status indices (1,0,G,S) of each device, considering that only zero isn't considered in sum to another logic value (for instance, 0+G=G).

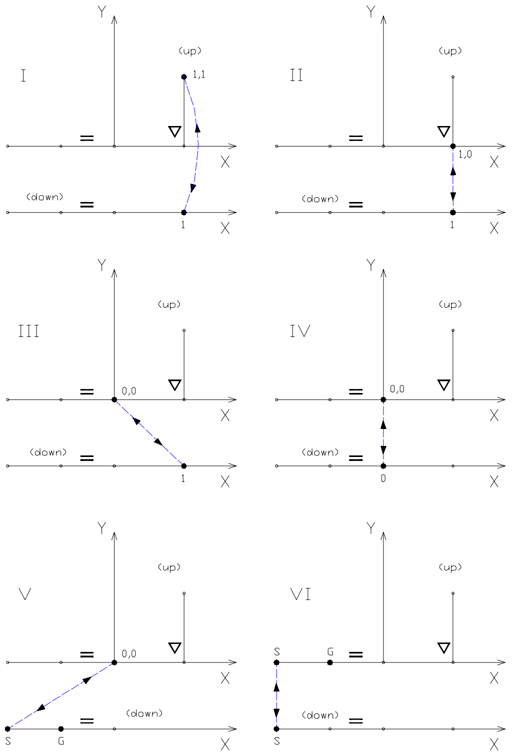


Fig. 5 Case study of the Fig.2: the six pictures show the operations of the clearing procedure to follow for changing the general energized status into the safe status.

If the sum is equal to 1 or more (as 2, 3, 1G !, etc.) the status is energized; if the sum is equal to 0 the status is generally de-energized ; if the logic sum is equal to G the status is grounded ; if the logic sum is equal to S the status is safe.Let consider the case study of Fig. 2: the procedure to follow from the general energized status to the safe status, shown in Fig. 5, is :

location	devices	operations							
upstream	XY up	**1**1	**10**	00	00	00	00	**G0**	**S**0
downstream	X down	1	1	**1**	**0**	**G**	**S**	S	S
sum-check									
locally up		2	1	0	0	0	0	G	S
locally down		1	1	1	0	G	S	S	S
generally		3	2	1	0	G	S	GS	SS

“Lockout” and “tagout” procedures to ensure safety are universally accepted. Details of developing and applying lockout/tagout procedures can vary. This paper presents an approach to the planning and control of lockout/tagout procedures. More detailed treatment and other implements of the subject are available.

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Giuseppe Parise (M'82) was born in Luzzi (CS) Italy on September 3, 1947. In 1972 he received his degree in Electrotechnical Engineering from the University of Rome. In this University, from 1973 to 1979 he was researcher and Assistant Professor. In 1980, he was appointed Associated Professor of Electrical Power Systems at the University of Rome. His research, design, consultant activities cover the areas of design, planning, safety, security, energy management of power systems. Since 1983, he is member of Superior Council of Ministry of Public Works as expert of power systems. He is member of the Italian Electrotechnical Commission (CEI) CT/SC 11A “Generation, transmission and distribution systems of electric power” and of the IEEE\IAS Power Systems Grounding Subcommittee. He is president of the Electrical Commission of Engineers Association of Rome’s Province.

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