DIRECT CURRENT SYSTEMS

INDEX **PAG.**

1 - PURPOSE

The purpose of this informative is to make considerations about configurations of direct current systems, problems and solutions, sizing, rated voltages, characteristics of equipment and components of direct current systems of hydroelectric plants, which can also be applied to other types of installations.

2 - INITIAL CONSIDERATIONS

This informative considers the evolution that has occurred, mainly, in batteries, molded case circuit breakers and digital supervision and control systems. One cannot help but consider that sealed batteries are a reality and that ventilated batteries will no longer be used. The resources of molded case circuit breakers are increasing and their costs more affordable. The capacity and resources of the supervisory and control systems evolve very quickly, and their costs are also being reduced.

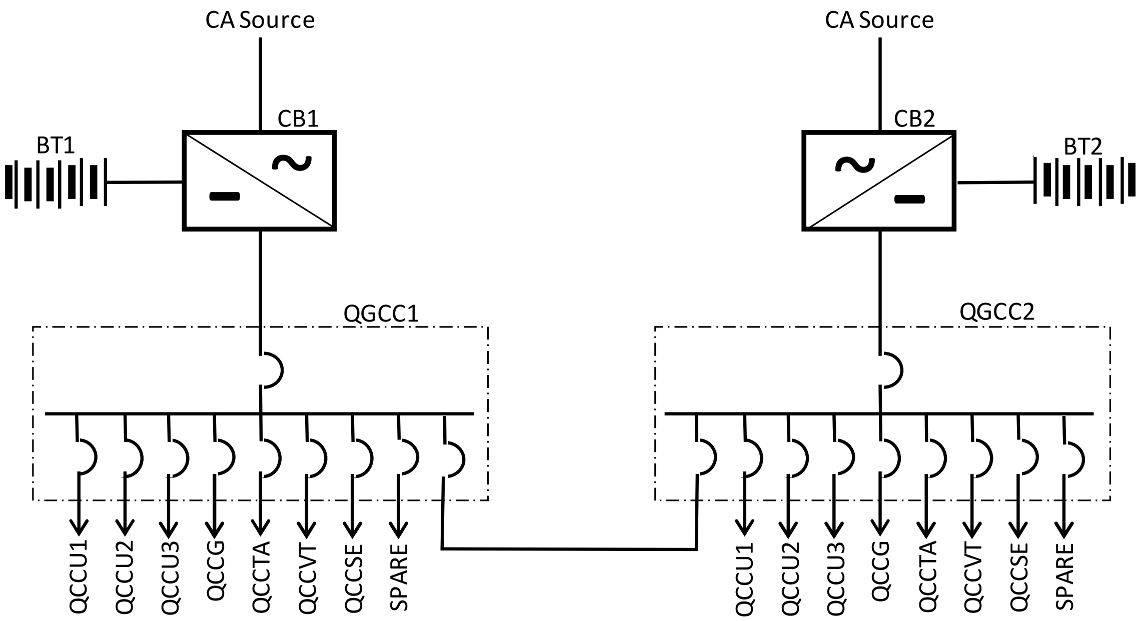
Depending on the above considerations, sealed batteries will be considered as those indicated for use in direct current systems. However, most of the considerations for sealed batteries also apply to ventilated batteries, which are still used in many existing installations.

Molded case circuit breaker manufacturers already provide a wide variety of types, with important information such as curve types, passing energy values, selectivity tables, and accessories such as state and defect auxiliary contacts. These circuit breakers fully meet the needs of direct current installations.

Digital supervisory and control systems, which were initially very expensive and with limited resources, now have a very large capacity of resources and possibilities of control and supervision, which allows to increase the amount of information that can be administered remotely. Therefore, although not fully used, all possible information intended for supervision and control systems should be made available.

3 - SYSTEM CONFIGURATIONS

The typical configuration of a direct current system of a hydroelectric power plant is, or may be, the one indicated in the figure below:



The system consists of two sets of batteries (BT1 and BT2) and chargers (CB1 and CB2), which feed two general panels (QGCC1 and QGCC2), which in turn feed the plant's distribution panels (QCCU1, QCCU2, QCCU3, QCCG, QCCTA, QCCVT and QCCSE). Note that the two direct current general panels (QGCC1 and QGCC2) are totally independent and the interconnection between them is made by two circuit breakers, one in each frame, to allow electrically isolating any panel.

The purposes of DC panels are:

QCCU1, 2, 3 - Direct Current Panel of Units 1, 2 and 3.

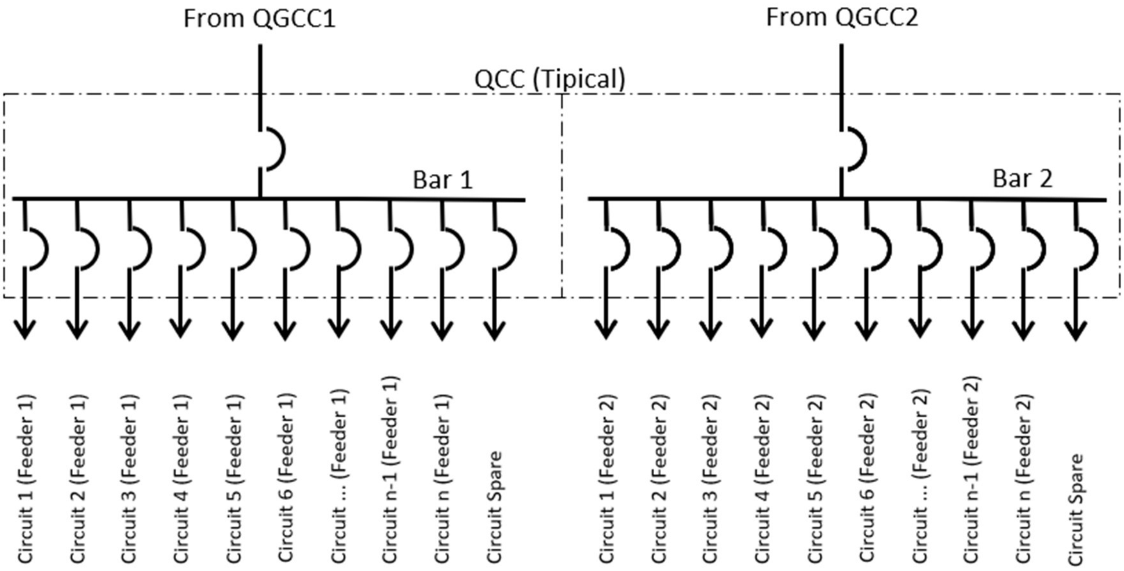
QCCG - General Loads Direct Current Panel.

QCCUTA - Water Intake Direct Current Panel.

QCCUVT – Spillway’s Direct Current Panel

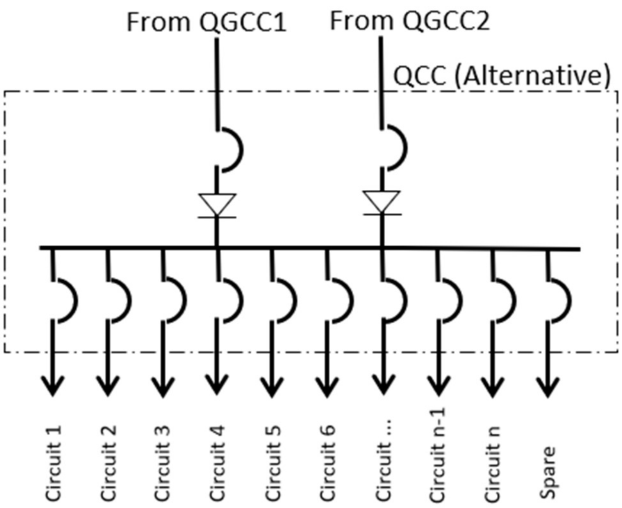
QCCSE - Substation Direct Current Panel.

The loads are fed by the distribution panels, the configuration of which is as shown in the following figure:



In the above configuration the distribution panels can have two direct current bars or, preferably, be formed by two independent sections, each powered by one of the direct current sources of the plant. From the panels are made the feeds of the direct current loads of the plant, with a feeder of each bar.

Another panel configuration that can be adopted is the following figure.



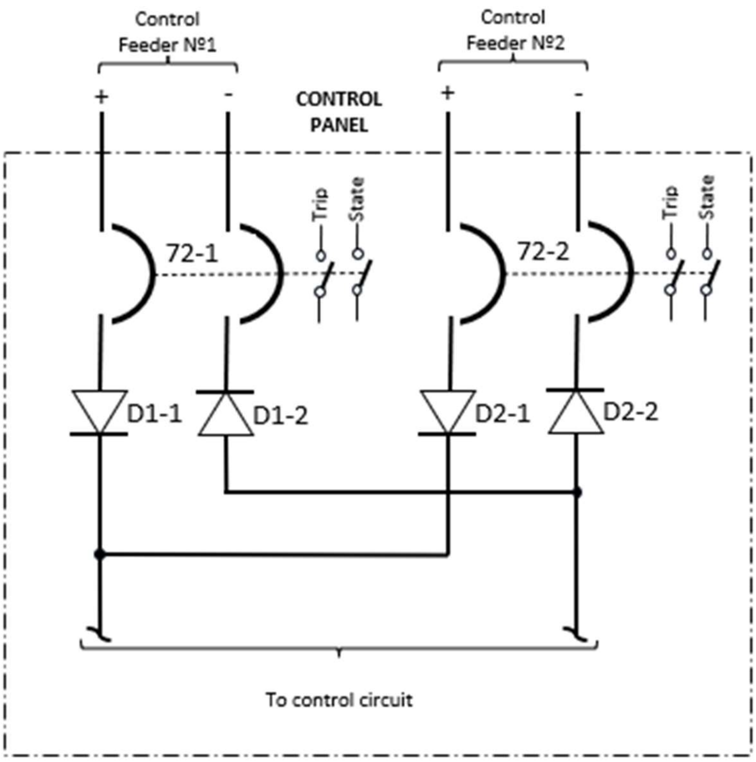
In this configuration, the parallelism of the sources is done in the distribution panels instead of in the local control panels. Because the panels are located close to the loads, the paths from the feeders to the control circuits are small and the risk of failure in these feeders is small. In this way, practically the number of output circuits of the panels is reduced by half and the power supplies of the control circuits are simplified. However, this configuration applies to all circuits that do not simultaneously require double power from different sources, because in this configuration, although the power is met by different sources, the requirement of double power at the destination is clearly not met. In this case, only for loads that require this condition, the configuration with two independent buses should be used.

To ensure selectivity between the protective devices, only fuses were used in series with non-automatic switches instead of circuit breakers, since the type of fuse tests allowed to guarantee this selectivity. To ensure the selectivity of the circuits using fuses, the nominal currents of the adjacent fuses must have a ratio equal to or greater than 1.6 because it is guaranteed that the maximum interruption time of the downstream fuse and less than the minimum interruption time of the upstream fuse.

With the resources of molded case circuit breakers, information and selectivity tables made available by manufacturers, especially mini circuit breakers, it is possible to make studies that allow optimizing the selection of these components with the necessary degree of confidence.

In the past, when the power supply of the control circuits was made by two sources of direct current, the transfer of the feeds was made through relays, which caused the momentary interruption of the power during the transfer. This momentary interruption was sometimes supplied by capacitors installed in the control circuits. Currently, the power supply of the controls is made through diodes, which maintain the supply of uninterrupted direct current, in case of lack of voltage from one of the sources.

The power configuration of the dual-power control circuits is shown in the figure below. This configuration has implications for the operation of the direct current system, with its problems and solutions, which are part of the purpose of this newsletter.

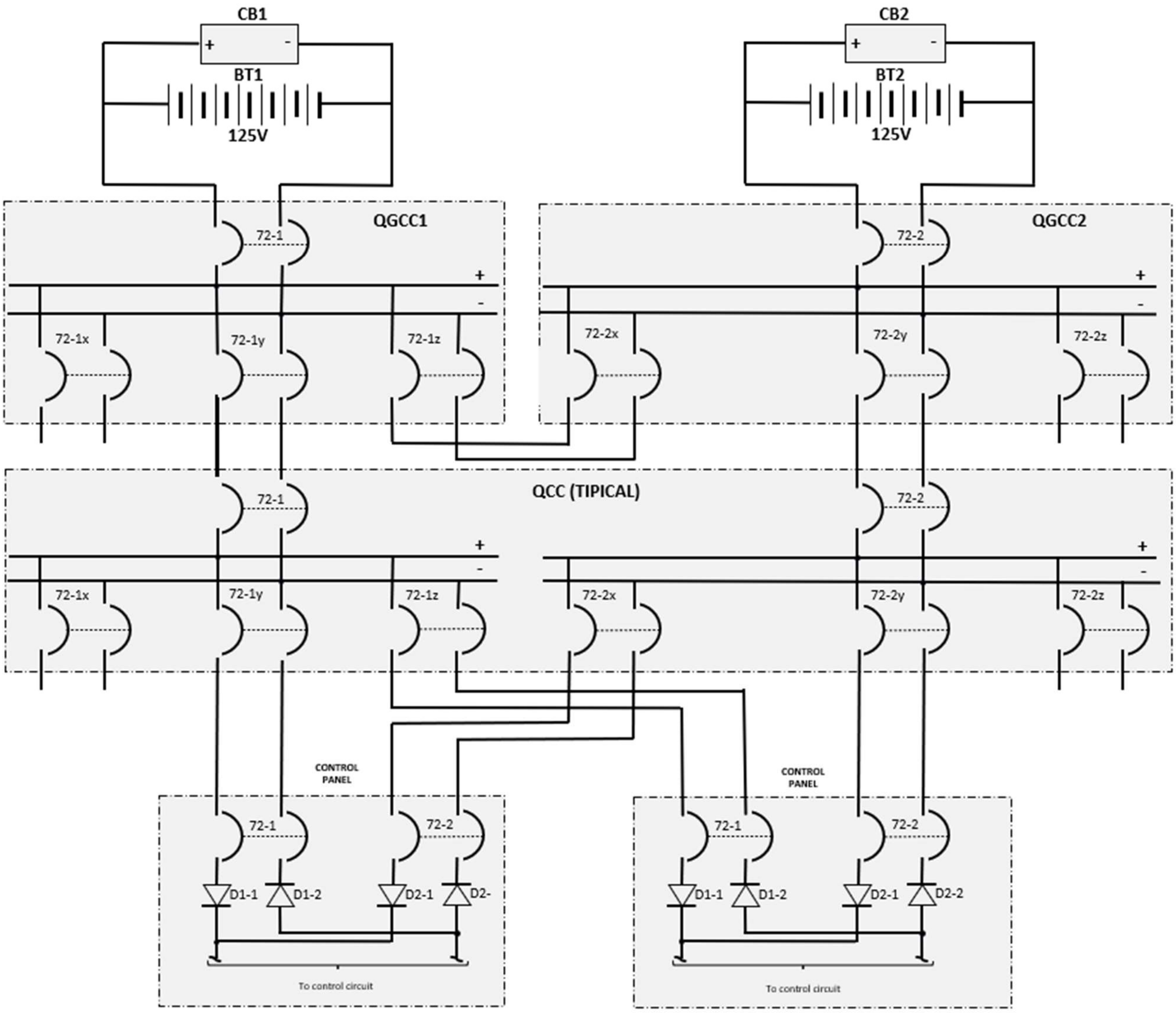


4 - CONFIGURATION ANALYSIS

The use of diodes in control circuits has brought a solution to the problem of transfer between power supplies, but it also has implications that are often not visualized by users and, consequently, are not evaluated or solved. In this newsletter, the analysis of the configurations is more focused on 125V systems, but they apply to other voltages with the appropriate adaptations.

4.1 - Basic Configuration

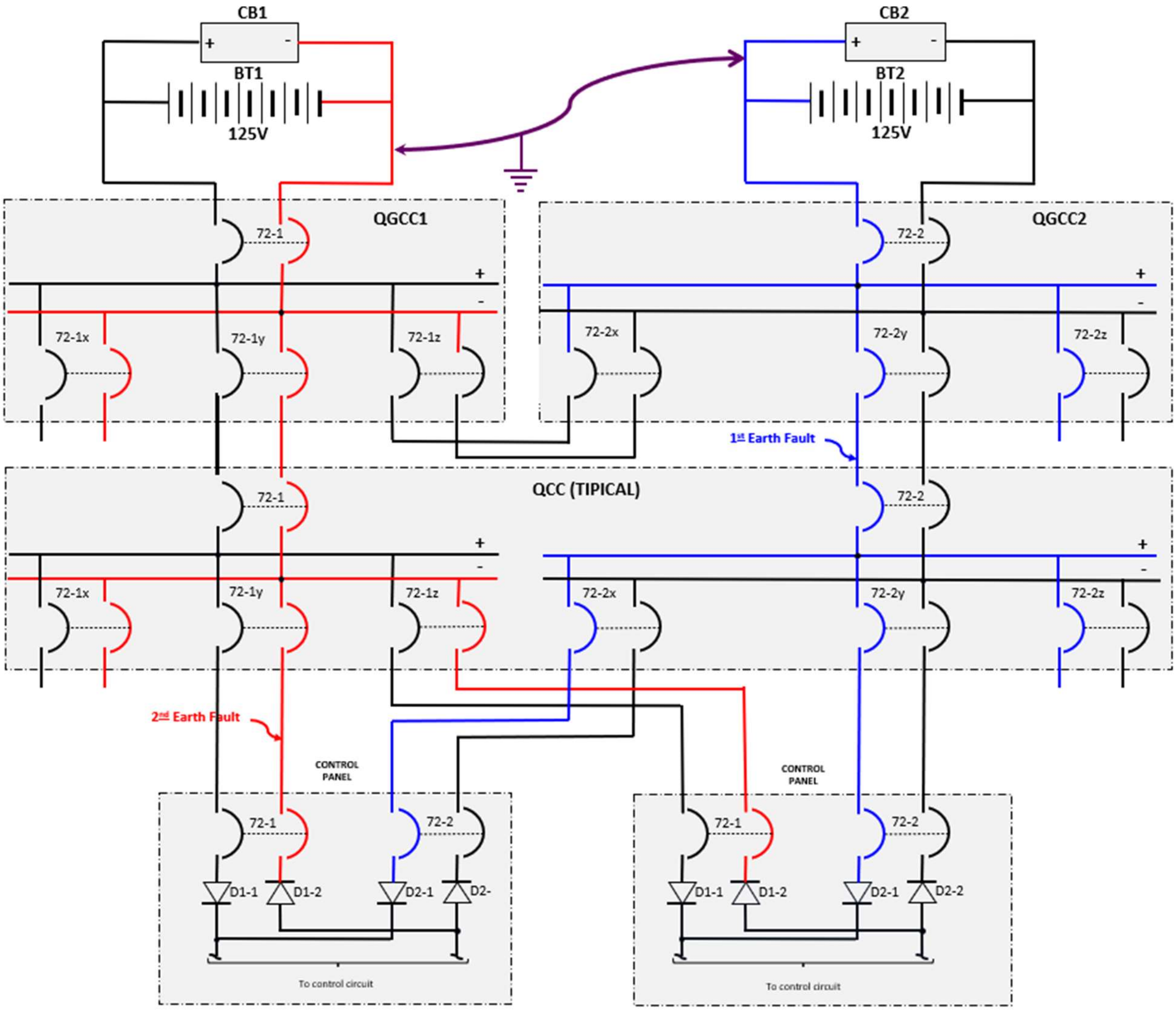
The basic configuration is shown more comprehensively in the simplified bifilar diagram in the following figure:



In the figure are indicated the battery sets (BT1 and BT2), chargers (CB1 and CB2), the general panels (QGCC1 and QGCC2), a typical direct current distribution panel (QCC) and two control panels that contain the circuits fed with the new configuration.

In the diagram not all the distribution panels are indicated and only two control panels are indicated, but this information is sufficient to analyze the problems that can occur in the direct current system.

Apparently, the new configuration of the power supply of the controls fits perfectly into the existing systems, without any implications. However, if we consider the occurrence of a ground failure, at any point of the direct current system, upstream of the power diodes of the control circuits, at the positive or negative pole, and subsequently another failure occurs at the ground, also upstream of the power diodes of the control circuits, at any point of the system, However, at the opposite pole to the first failure, we will have the situation indicated in the following figure:



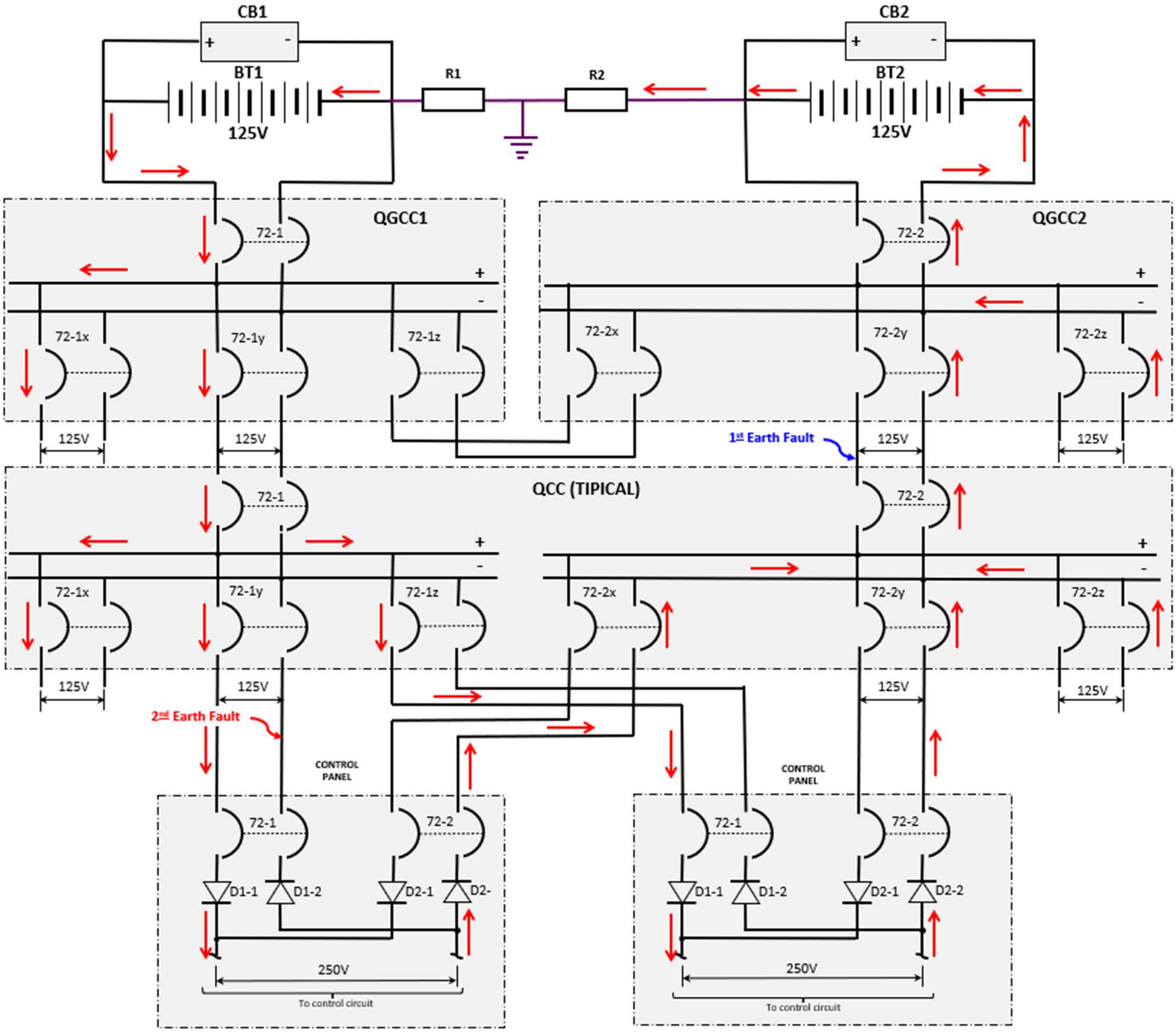
In the figure above it is indicated that the first ground failure occurs in the positive pole cable, of the panel feeder (QCC), coming from the general direct current panel (QGCC2). In this way, all the circuits of the positive pole of the system, powered by the charger and battery set (CB2 and BT2), indicated in blue color, will be at the same potential to the ground.

In the figure it is also indicated that a second ground failure occurs at the negative pole of the system powered by the charger and battery assembly (CB1 and BT1), this time in the feeder cable of one of the control panels, upstream of the diodes of the control circuits. In this way, all the circuits of the negative pole of the system, powered by the charger and battery set (CB1 and BT1), indicated in the red color, will be at the same potential to the earth.

As the two systems are originally isolated from the earth, the second defect to the earth will be equivalent to interconnecting the positive pole of the assembly and charger (CB2 and BT2) to the negative pole of the charger and battery assembly (CB1 and BT1), as indicated by the connection in purple color.

Depending on the location of the defects, the solidity of the faults to the ground, the resistances of the circuits, the currents involved, the performance of the protections, and in the most unfavorable situation, the voltage in **ALL** the control circuits of the plant, with double feeding of the two systems through the diodes, may be the sum of the voltages of the two systems.

The following figure illustrates the extreme condition, with the indication of the voltage in the supplies of the control circuits and the paths of the currents, The interconnection of the poles, which was indicated in purple color, was replaced by a direct connection.

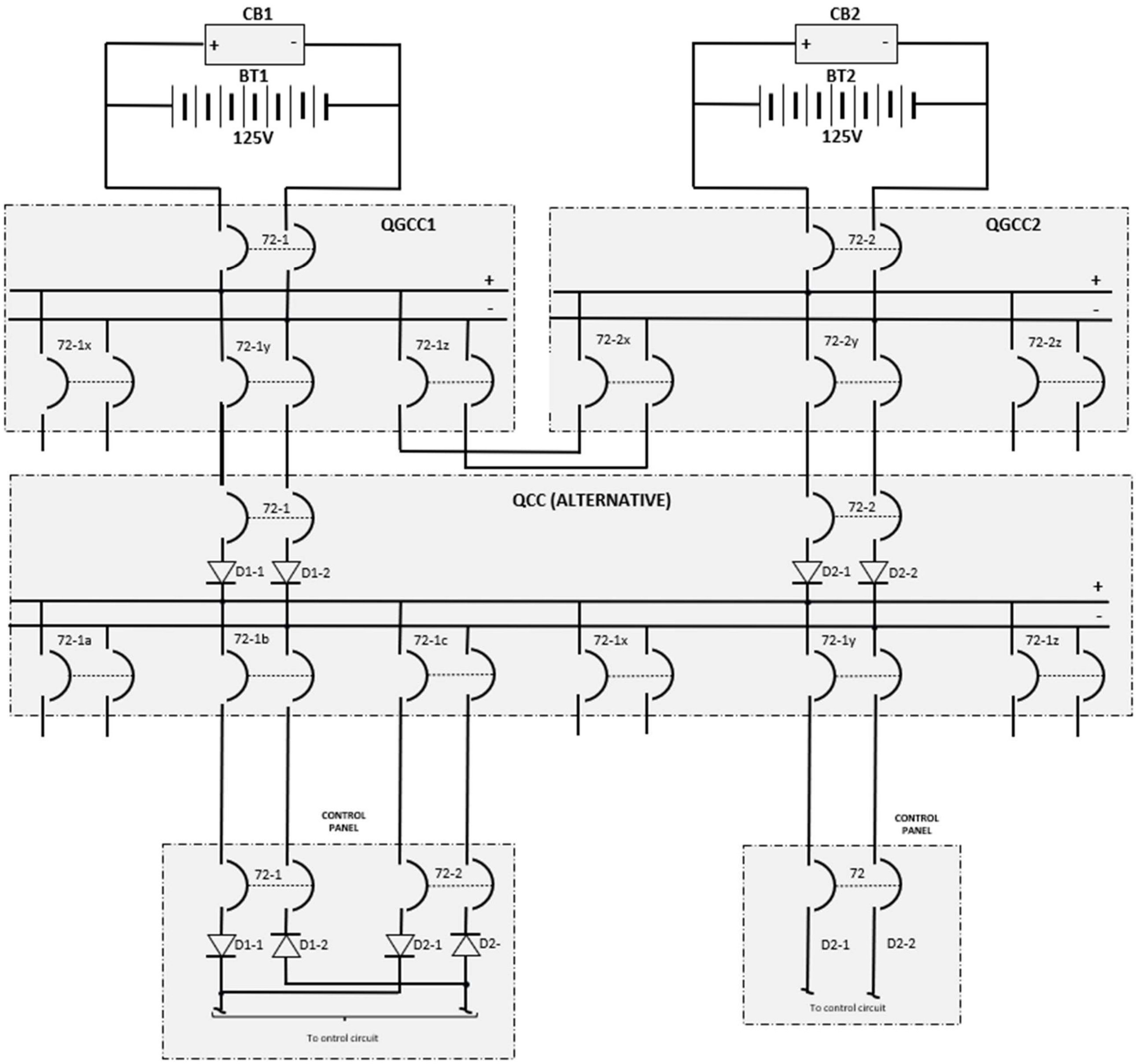


The resistors R1 and R2 represent the resistances of the faults to the ground, the value of which will depend on the severity of the failure. In the extreme condition, the voltage in the general panels (QGCC1 and QGCC2) and panels and distribution circuits represented by the QCC, will be 125V, but in all control panels and loads fed through the diodes, the voltage can reach 250V.

Of course, if the first and second failures occur in the positive and negative of the same system, a short circuit is characterized that must be signaled and eliminated by the corresponding protections.

4.2 - Alternative Configuration

The alternative configuration is shown more comprehensively in the simplified diagram in the following figure.

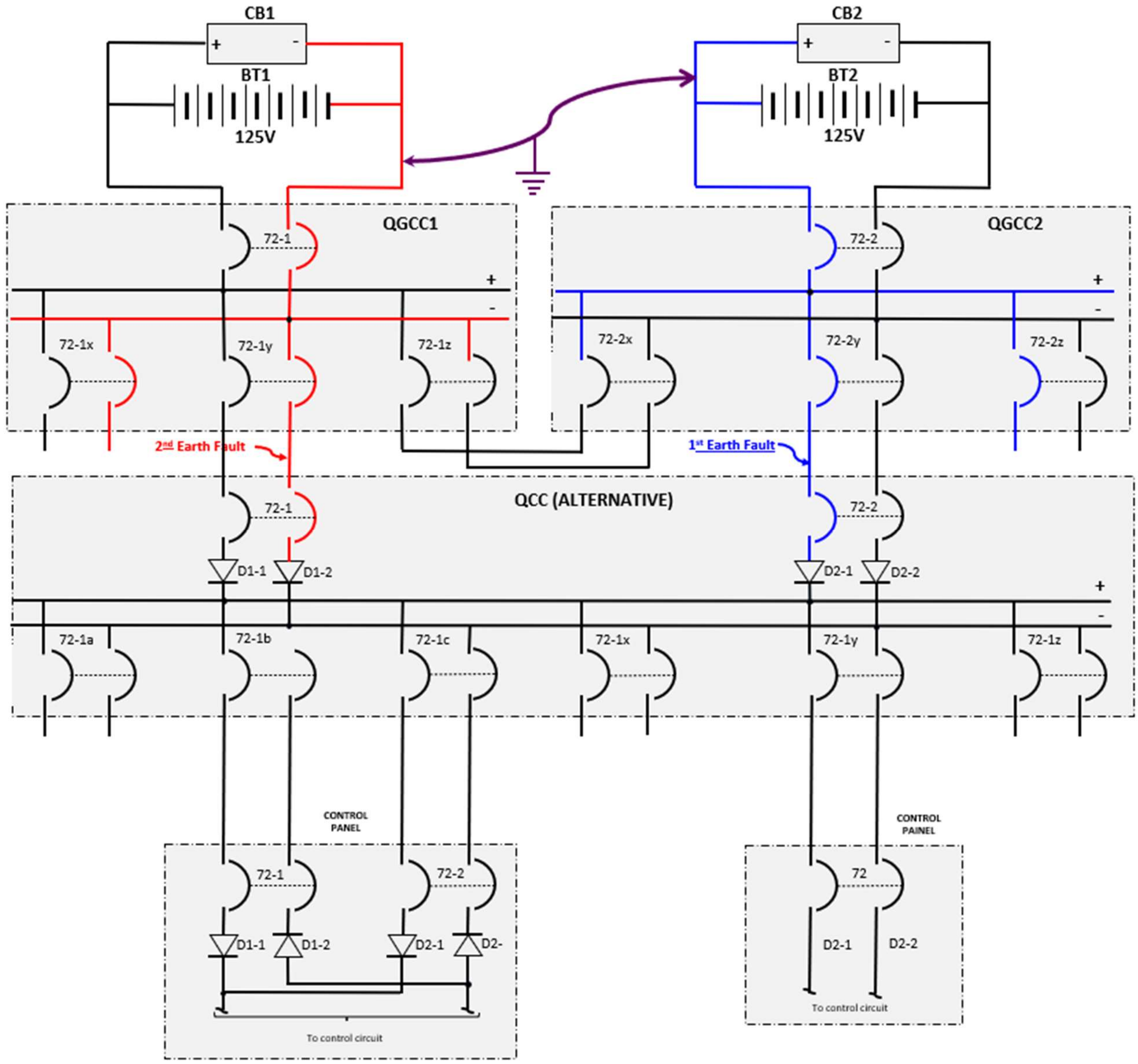


In the bifilar circuit above are indicated the battery sets (BT1 and BT2), chargers (CB1 and CB2), the general panels (QGCC1 and QGCC2), a typical direct current distribution board (QCC), a control panel containing the new configuration with dual power and a control panel without double power.

In this configuration are indicated two types of local controls, the first, which considers a control circuit with the parallelism of the feeds being made in the control panel itself, through the diodes, and the second, which does not have double feeding, because it considers that the double feed exists in the QCC distribution board, where the transfer of sources is done through the diodes installed in the QCC panel.

The first type of control has redundancy for failure in one of the feeds, but during the battery discharge period, due to the existence of two more diodes in series in the circuit, the voltage in the charge will be reduced by almost 1.5V.

If we consider the occurrence of a fault to the ground, at any point of the direct current system, upstream of the power diodes of the panels, at the positive or negative pole, and subsequently another failure occurs to the ground, also upstream of the power diodes of the panels, at any point of the system, however, at the opposite pole to the first fault, we will have situation indicated in the following figure:



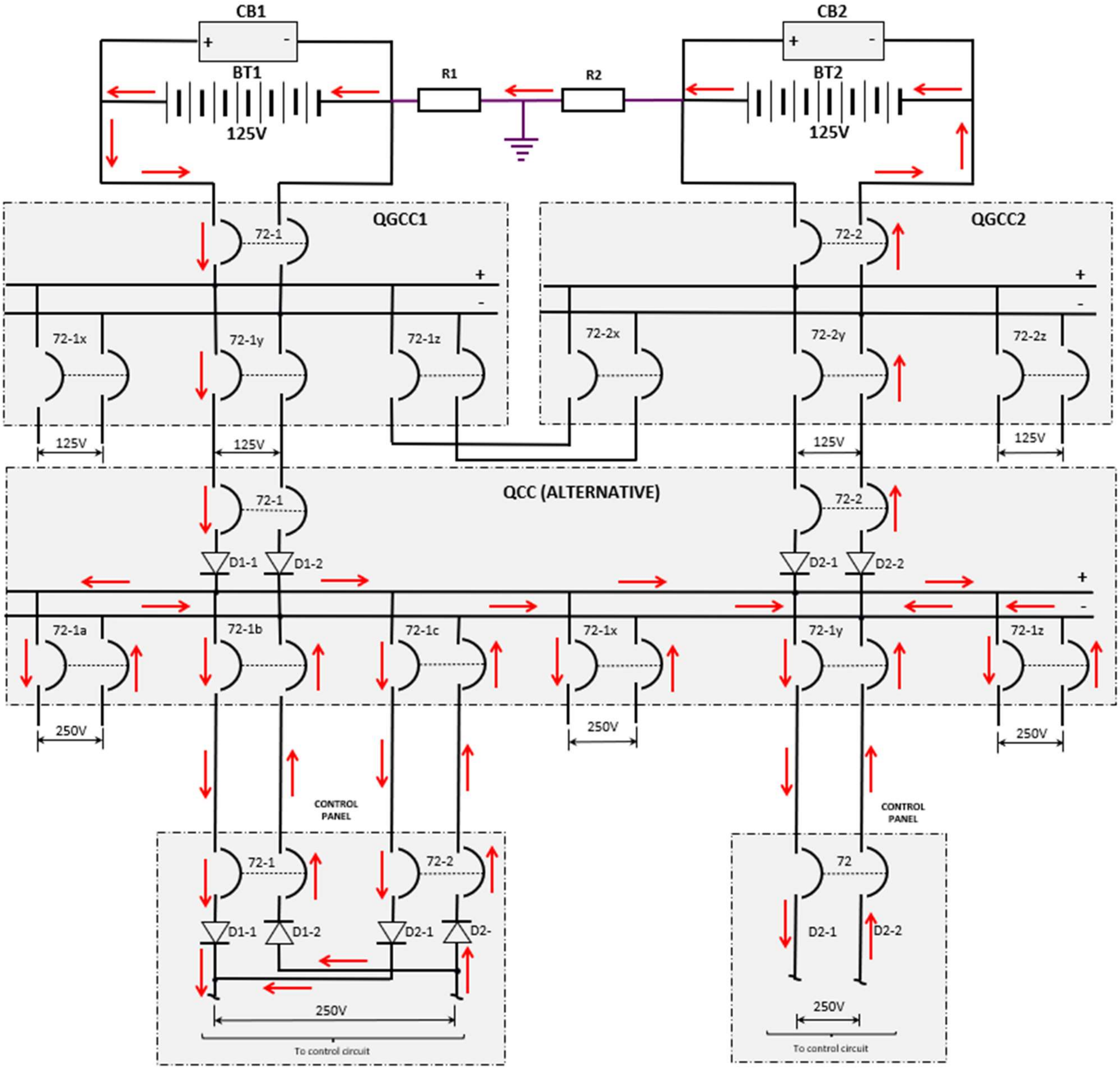
In the figure above it is indicated that the first ground failure occurs in the positive pole cable, of the panel feeder (QCC), coming from the general direct current panel (QGCC2). In this way, all the circuits of the positive pole of the system, powered by the charger and battery set (CB2 and BT2), indicated in blue color, will be at the same potential to the ground.

In the figure it is also indicated that a second fault to the ground occurs at the negative pole, of the distribution panel feeder (QCC), coming from the general direct current panel (QGCC2). In this way, all the circuits of the negative pole of the system, powered by the charger and battery set (CB1 and BT1), indicated in the red color, will be at the same potential to the earth. The second ground failure could have occurred in the feeder of any distribution panel.

As the two systems are originally isolated from the earth, the second defect to the earth will be equivalent to interconnecting the positive pole of the assembly and charger (CB2 and BT2) to the negative pole of the charger and battery assembly (CB1 and BT1), as indicated by the connection in purple color.

Depending on the location of the defects, the solidity of the faults to the ground, the resistances of the circuits, the currents involved, the performance of the protections, and in the most unfavorable situation, the voltage in **ALL** the distribution boards of the plant, with double feeding of the two systems through the diodes, may be the sum of the voltages of the two systems.

The following figure illustrates the extreme condition, with the indication of the voltage in the circuit supplies and the current paths, The interconnection of the poles, which was indicated in purple, was replaced by a direct connection.



The resistors R1 and R2 represent the resistances of the faults to the ground, the value of which will depend on the severity of the failure. In the extreme condition, the voltage in the general frames (QGCC1 and QGCC2) will be 125V, but in all switchboards and their loads it can reach 250V.

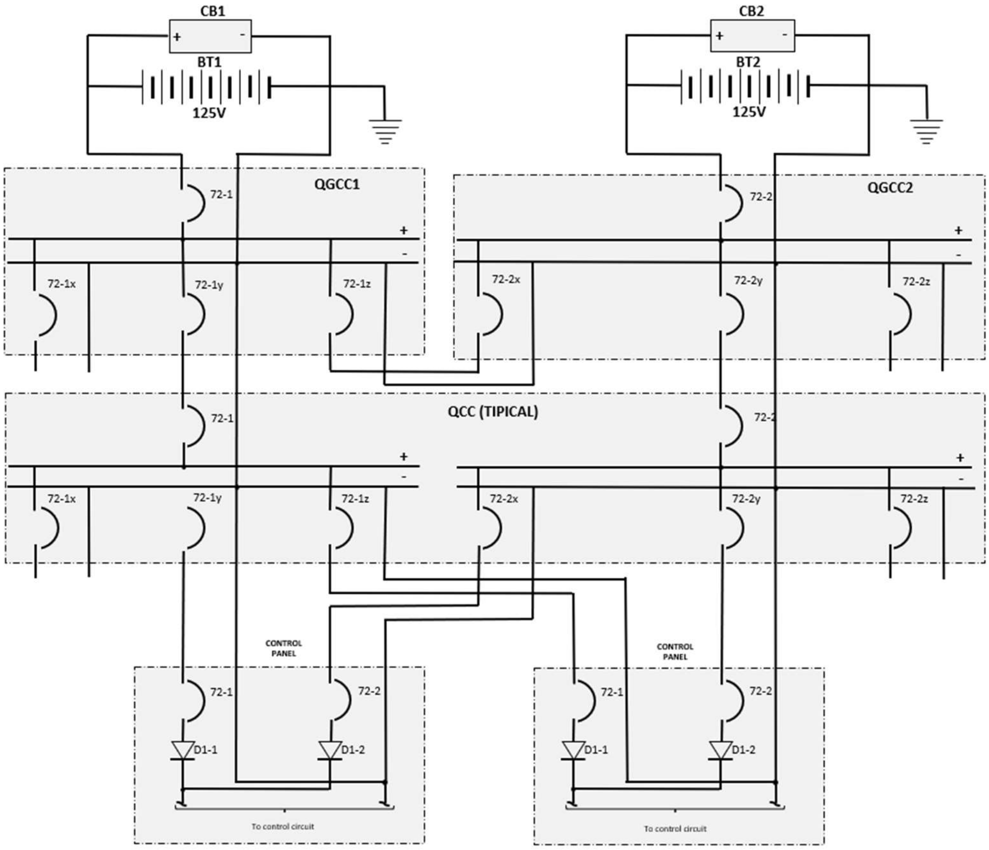
Of course, if the first and second failures occur in the positive and negative of the same system, a short circuit is characterized that must be signaled and eliminated by the corresponding protections.

4.3 - Solutions to Avoid Overvoltage

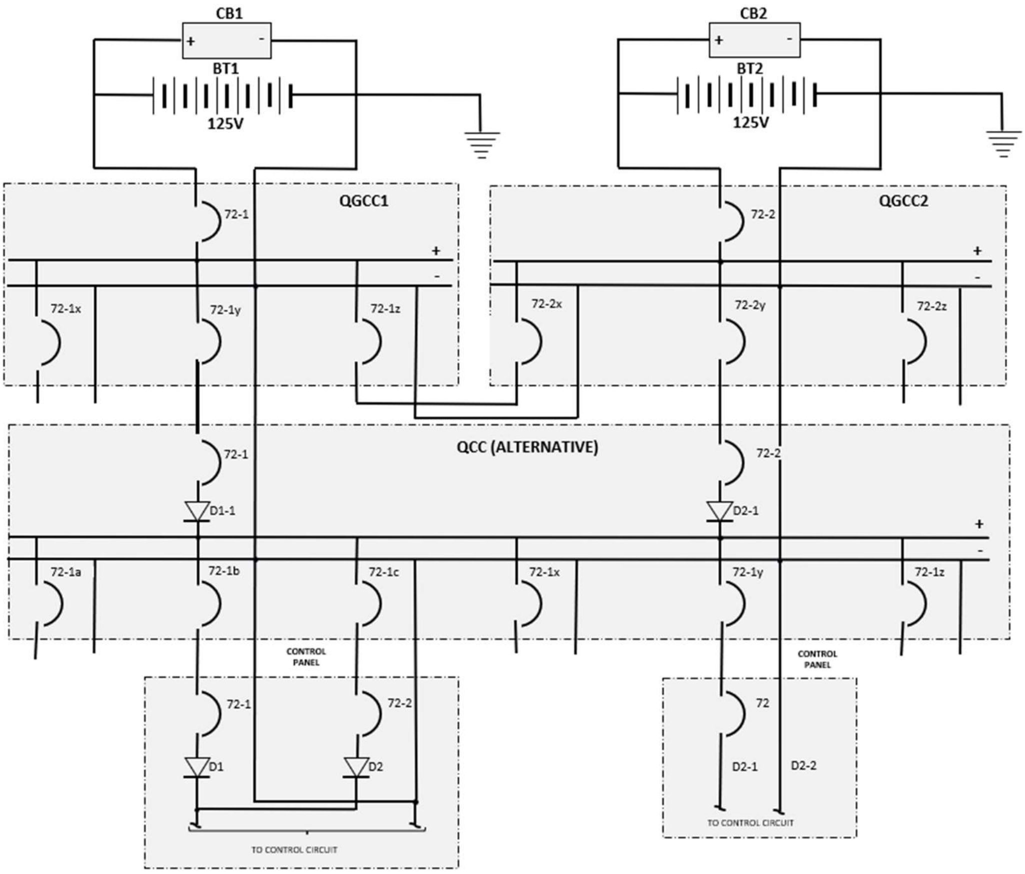
There are two solutions to avoid the overvoltage that can occur in direct current systems, caused using diodes in the installations.

The first solution is to ground one of the poles of the two sources of direct current, however, the system will lose in reliability, one of its important characteristics, which is the possibility of continuing to operate when one of the poles of the system goes to earth.

The following is the bifilar diagram of the basic configuration considered (parallelism in the local control panels):



The following is the bifilar diagram of the alternate configuration (parallelism in DC distribution frames):

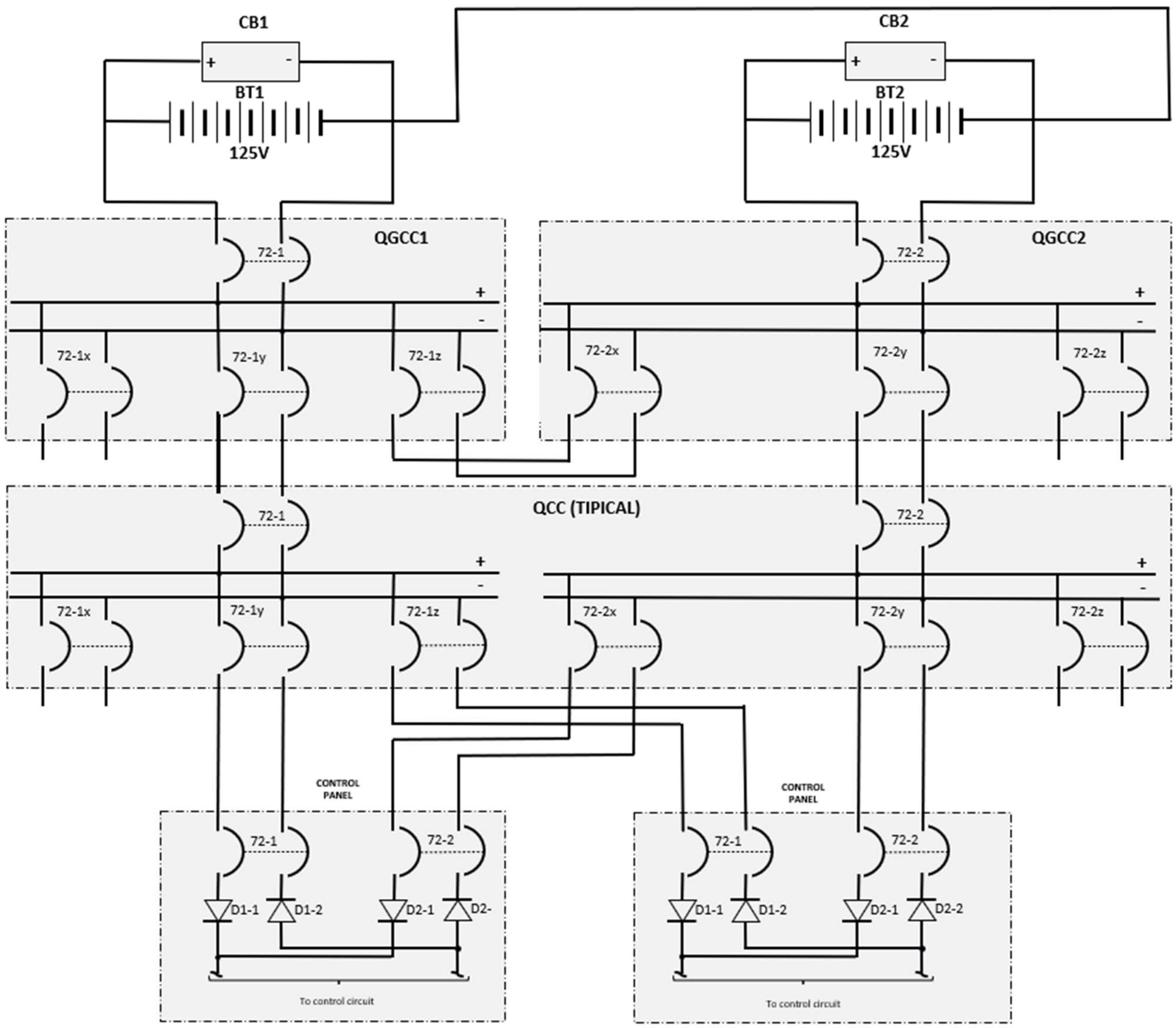


In this solution, any defect to the earth will cause the faulty circuit to shut down. If this solution is adopted, it is not necessary for the circuit breakers to be bipolar, as the system is grounded.

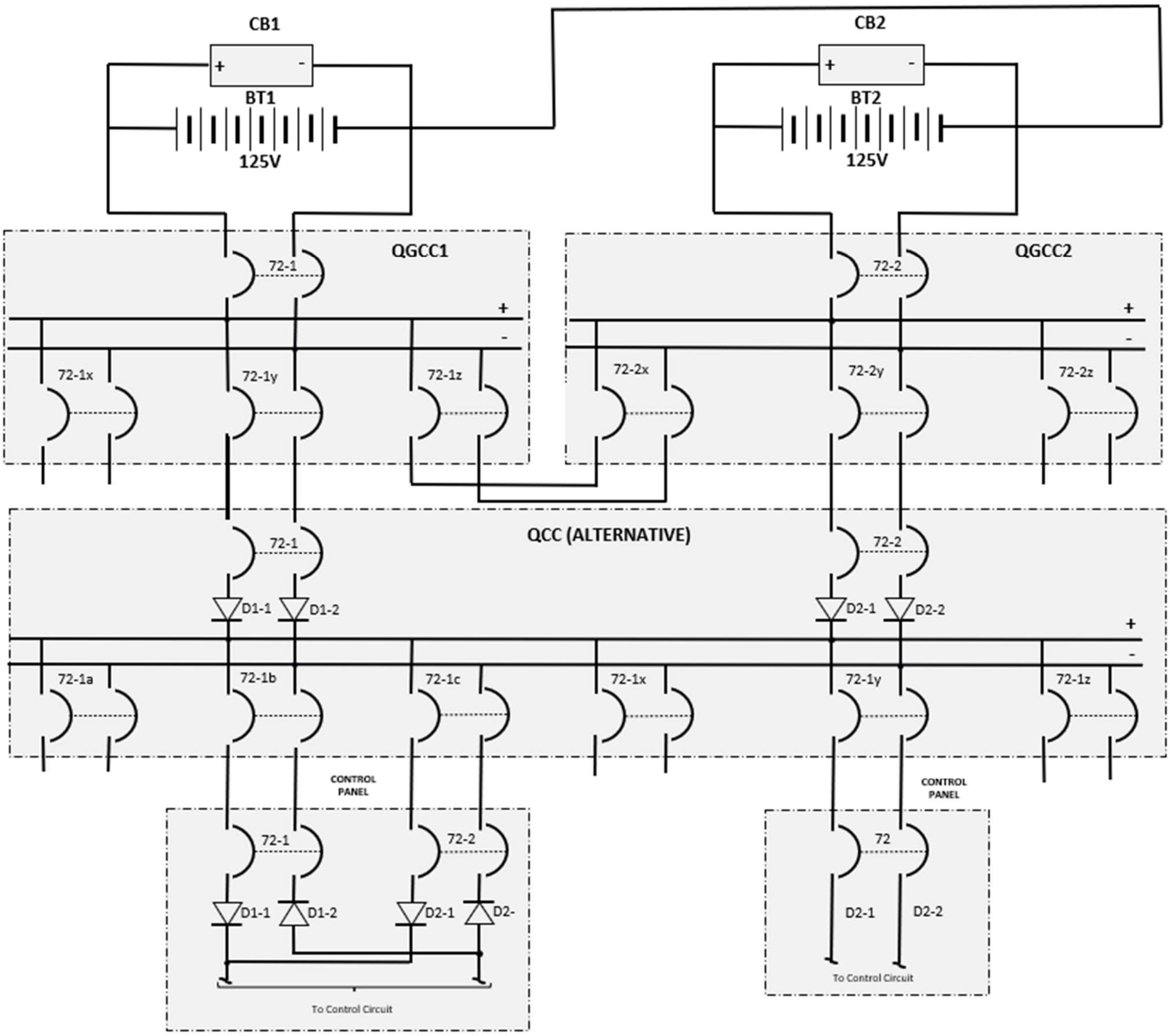
The second solution is to interconnect one of the poles of the same name of the two systems, that is, to interconnect the positive or negative poles of the battery charger sets. This connection must be made at the source, that is, in the sets of chargers and batteries to ensure that it is not interrupted. This solution is recommended because it avoids the overvoltage problems shown in the previous items and maintains the advantages of isolated systems.

In this solution, in case of a defect in one of the poles, the system will continue operating.

This solution for the basic configuration, interconnecting the negative poles of the battery charger assemblies, is represented in the bifilar diagram of the following figure:



This solution for the alternative configuration, interconnecting the negative poles of the battery charger assemblies, is represented in the bifilar diagram of the following figure:



4.4 - Evaluation of Solutions

The risk of occur overvoltage in the DC system, due to the use of diodes to transfer the power supplies of the circuits, must be made by the user. The problem is that most of the time, the user is unaware of the risk and, for this reason, does not take any action.

As seen earlier, overvoltage will occur if the second defect occurs to the earth and this defect occurs at the opposite pole of the other source, that is, if the first defect occurs at the positive pole of one source and the second defect occurs at the negative pole of the other source. The value of the overvoltage will depend on the solidity of the defect, the resistances of the circuits and the currents of the loads. Because load currents are typically not high, even if ground connections are weak, fault points can cause overvoltage in all control circuits in the plant or facility. The overvoltage, even if they do not reach levels to the point of doubling the voltage of the system, will cause the burning of the components of some circuits and, as the burns occur, the currents of the loads will decrease, facilitating the circulation of the currents, with the consequent increase of the voltage in the installations. Since this risk can be solved in a relatively simple way, one should not take these risks.

Over the years the installations become more prone to defects and ground failures become more frequent. For this reason, one of the solutions to avoid overvoltage should be adopted.

The grounding of the systems or the interconnection of system poles is necessary to avoid the risk of overvoltage in all loads of the installation since values of the overvoltage and their consequences are unpredictable.

The solution of interconnecting the poles is more indicated because the system maintains the characteristics of the system with the two poles isolated from the earth and, if a second defect occurs, no overvoltage problems will occur. For this reason, from this point on, only the configuration of the system with interconnected poles will be analyzed.

The alternative solution is more economical, because the parallelism of the sources is made in the distribution panels and, from them, only one power comes out for each control circuit. In case of any requirement, two feeds can be made, but the same configuration of the basic solution must be adopted at the destination so that, in case of a defect in one of the feeders, the other can continue operating normally.

The recommended basic solution is the most reliable in terms of power, as the feeders are duplicated to the destination, where the parallelism of the sources is done.

5 - FACILITIES AND EQUIPMENTS - GENERAL

Because these are not specifications or equipment manuals, and although it is not the specific purpose of this informative, some considerations will be made about DC installations and equipment.

5.1 - Protections and Selectivity

Due to the different levels of protection, it may be difficult to ensure selectivity among all protections.

5.1.1 - Protections of Diodes

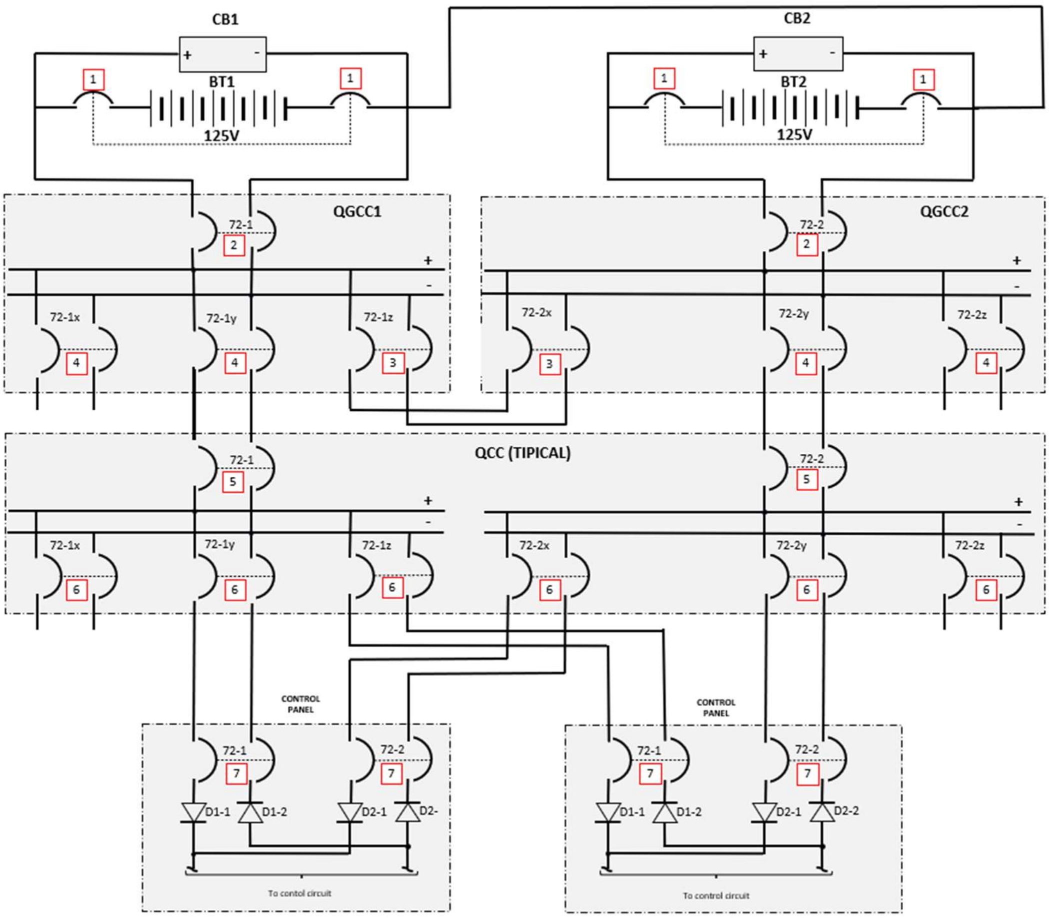
The protection of all diodes in the installation must be guaranteed by the devices (fuses or circuit breakers), so that the energy passing through the protection device is always lower than the passing energy supported by the protected diode. This guarantee is important to ensure that, in case of defect in the control circuit, the protection devices act without damage to the diodes. The rated current of the diodes must also be compatible with the supplied circuits.

5.1.2 - Selectivity of Protections

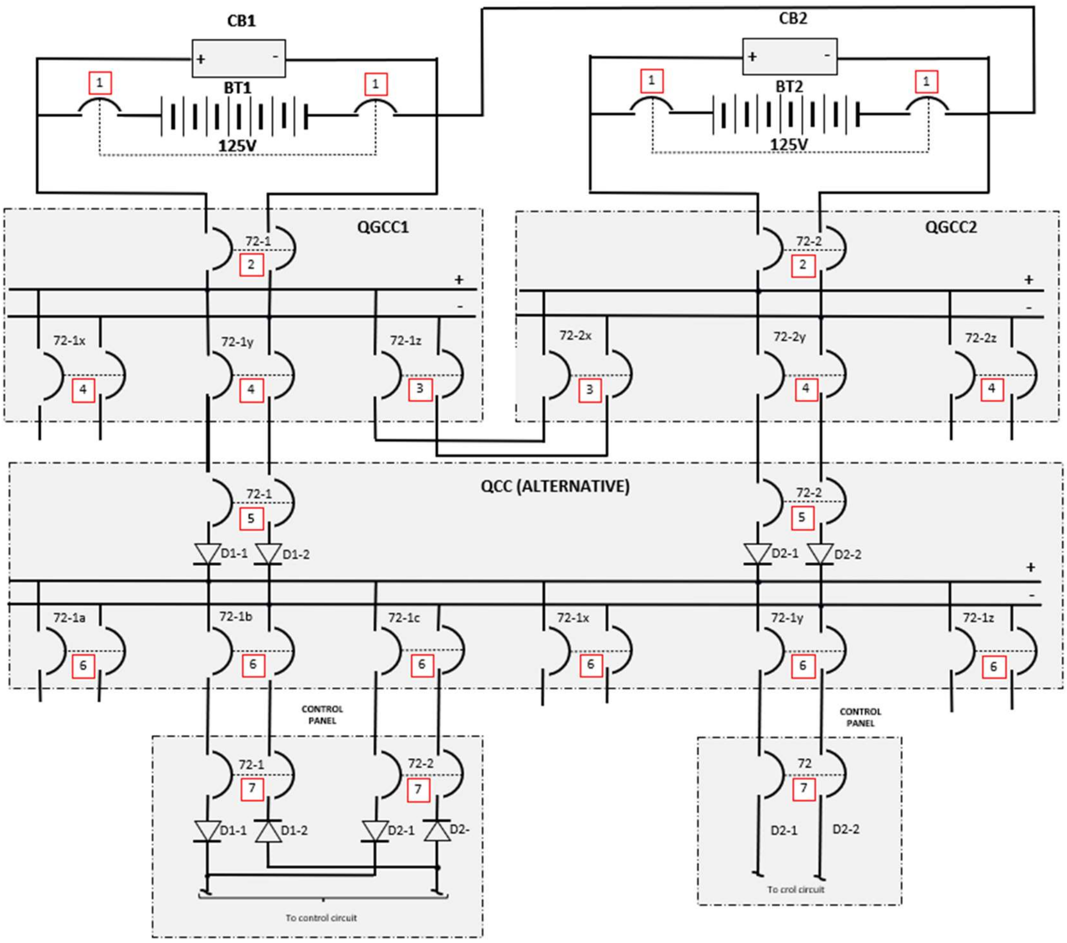
The coordination and selectivity of the protections of the circuits involved is an activity that must be well studied to ensure the continuity of the operation of the direct current system and, consequently, of the installation. All available resources must be used, among which we mention the large amount of information provided by the manufacturers of mini circuit breakers, molded case circuit breakers and, if necessary, combined with fuses. The calculations of the short circuit currents, maximum and minimum at all points, should also serve as a subsidy to define the protections and their integration and, with this information, to define the most appropriate type of coordination. Selectivity among all the protections of a facility should always be the purpose of any study.

In the following diagrams are indicated numbers, next to the protections, that indicate the level of selectivity of the protection. Different numbers indicate selectivity between protections; same numbers indicate same level of selectivity.

The diagram below indicates selectivity at all levels of the basic configuration, i.e., the best of possibilities:



The diagram below indicates selectivity at all levels of the alternate configuration:

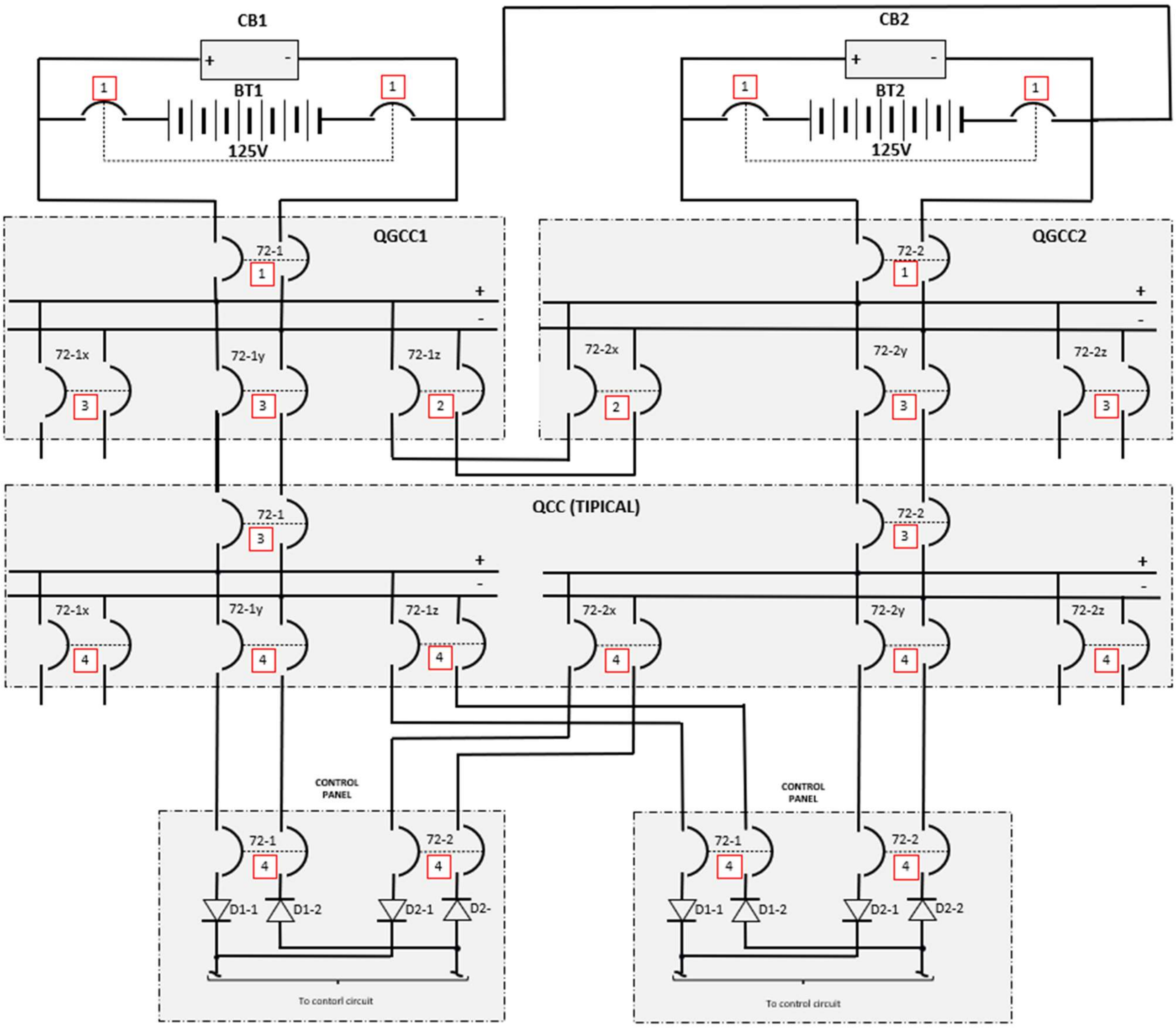


The protections of the local control circuits (Control Panel) are most often defined by the suppliers of the equipment, and, for this reason, it can be difficult to standardize their characteristics. However, whenever possible, it should be sought to optimize its integration into the plant system.

The diodes of the panels and control circuits have the function of ensuring the continuity of the supply of the loads when one of the sources is missing, which occurs even during a defect. When a defect occurs at any point downstream of the diodes, the protections involved will act.

As it is not always possible to obtain the total selectivity of a system, it is necessary to establish priorities to ensure the continuity of the operation of the installation. The following diagrams indicate a minimum level of selectivity between protections.

The following diagram indicates the minimum selectivity of the base configuration:



The selectivity between battery protection (1) and the input of the general QGCC frame (1) can be omitted. If a defect occurs in the QGCC bar the panel and battery input protections should act and lack of selectivity will not change the operating condition of the installation. If a defect occurs in the QGCC feeder, only the battery protection should act. The battery charger has its own protection that does not need to enter the study.

If the general frames QGCC1 and 2 are interconnected, the protections of the interconnect circuits may have the same level of selectivity (2). In case of defect in the bar of the fed frame the interconnection, protection will operate, but in case of defect in one of the outputs of the general board powered, only the defective circuit will be isolated, and the rest of the installation will continue to operate normally.

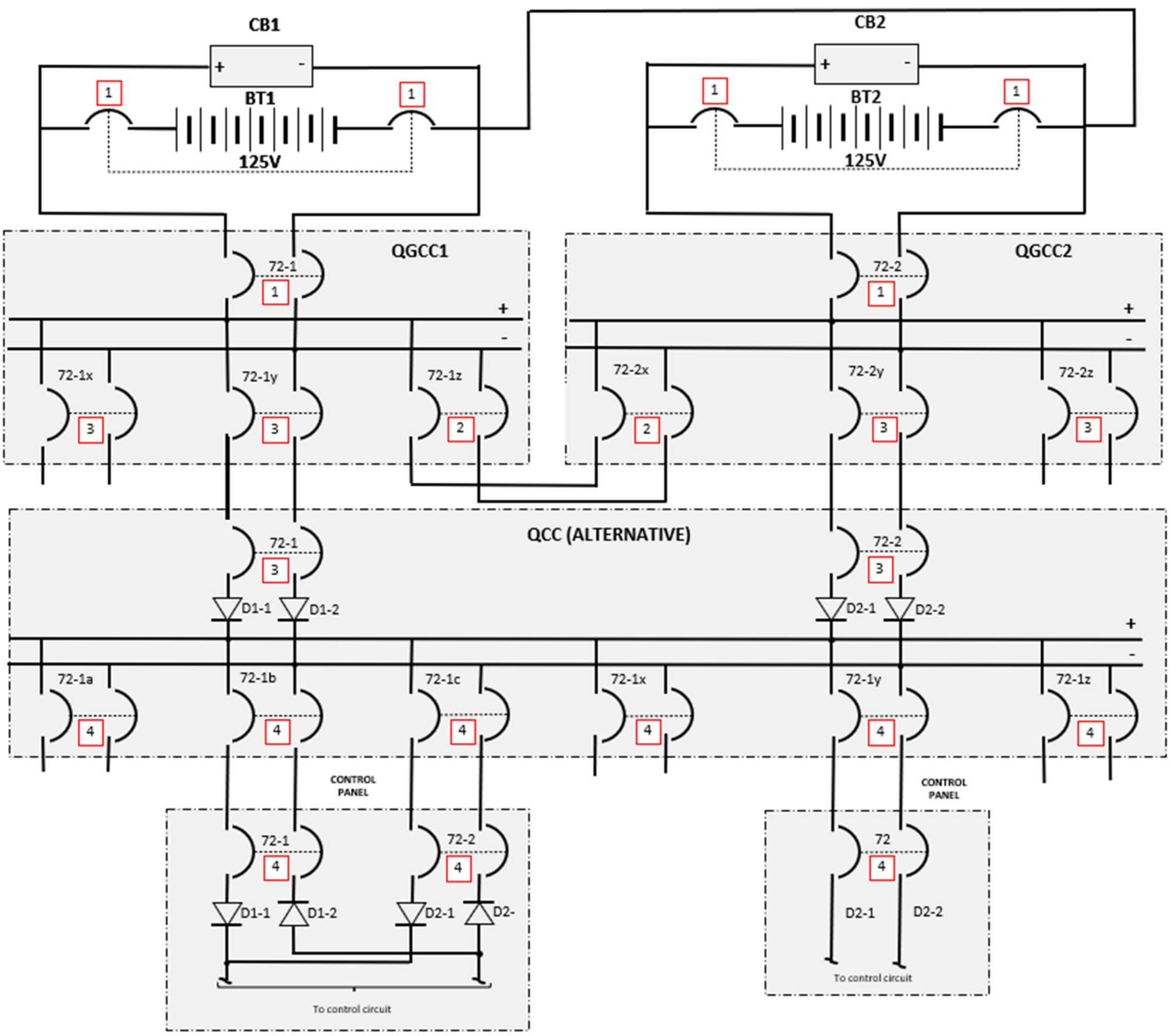
The selectivity between the protection of the input of the general framework QGCC (1) and protections of the output circuits (3) must be guaranteed, because if a defect occurs in any output the other outputs can continue to operate normally.

The selectivity between the protections of the outputs of the QGCC (3) and the inputs of the QCC panels (3), can be omitted, because if a defect occurs in the bar of one of the QCC panels, both protections must operate; if the defect occurs in the QCC panel feeder, only the output protection of the QGCC switchboard shall operate.

The selectivity between the protection of the input of the QCC panel (3) and protections of the output circuits (4) must be guaranteed, because if a defect occurs in any output the other outputs can continue to operate normally.

The selectivity between the protections of the outputs of the QCC panel (4) and the inputs of the control panels (4), can be omitted, because if a defect occurs in the control circuit of the panel, the two protections must operate; if the defect occurs in the control panel feeder, only the QCC frame output protection should operate. Note that if a defect occurs in the control panel circuit, the protections of the two power supplies will operate, because the faulty control circuit will be powered by the other source, in the absence of the first.

The following diagram indicates the minimum selectivity of the alternate configuration:



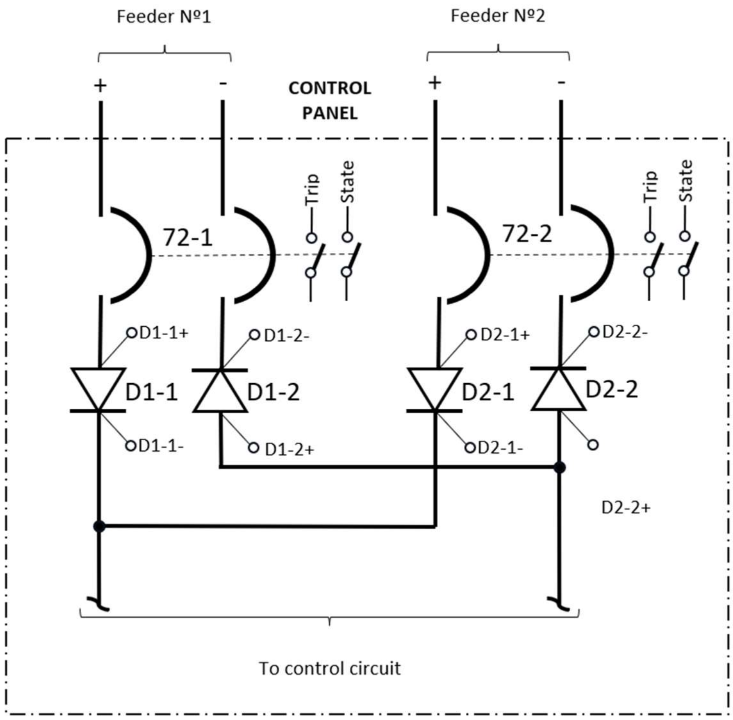
5.2 - Location of Earth Fault

The location of ground fault in direct current circuits is not a simple task to be performed, because it always involves risks of interruption of the power supply of some circuit, which can compromise the continuity of the operation of systems and even of the installation. However, as there are instruments that allow you to locate the defective points of a circuit, this informative will be limited to analyzing some alternatives and safety measures to turn off the direct current feeder circuits.

In the basic configuration of the direct current system, with the interconnection of the positive or negative poles, the circuits up to the load, where the parallelism between the sources is made, are more subject to ground defects than the alternative configuration, because it has, practically, twice as many load feeder circuits than the alternative configuration, where the parallelism of sources is done in the distribution panels.

Shutting down feeders on dual-feed control panels is also an operation that must be done with caution as there are risks of interrupting the power. Some of these risks will be described later.

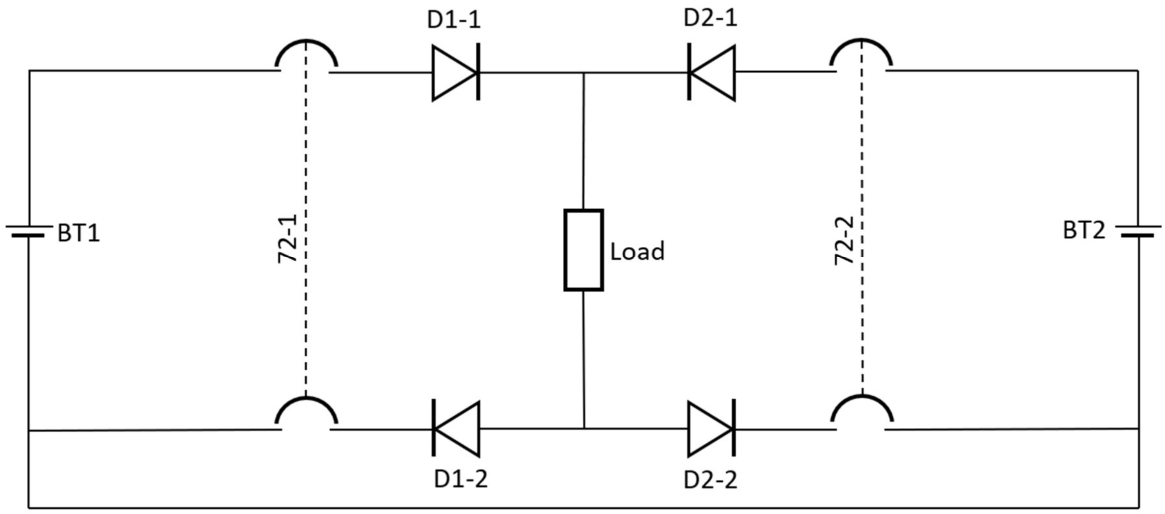
The following circuit is the basic configuration of a direct current control circuit feed, where terminals were introduced to perform measurements on the diodes. Access to the diodes, through terminal terminals, to allow measurements facilitates the maintenance services and evaluation of the condition of the circuits:



Regardless of whether it is necessary to disconnect one of the power supplies from a control circuit and keep it powered by the other source, checking the status of the diodes should be done routinely, because if they are in trouble, shutting down one of the sources may interrupt the power supply of the circuit. As the diodes can be open or short, the checks should provide for these possibilities. When the circuit is under maintenance these checks can be done easily, however, if the circuit is operating, any shutdowns should be done with all precautions.

Control circuits that are powered by two sources of direct current, through diodes, can have one of their feeds turned off, provided that the diodes are without defect because, inadvertently, it can cause a lack of voltage in the circuit. For example, if one of the diodes of one input is open, and the other power input is turned off, the direct current supply of the circuit will be interrupted. Therefore, before interrupting any power supply it is necessary to make sure that the diodes of the inputs are operative.

The following diagram represents, simply, the electrical circuit of the supply of a control of a direct current system with interconnected negatives (if they are the interconnected positives the situation will be the same):



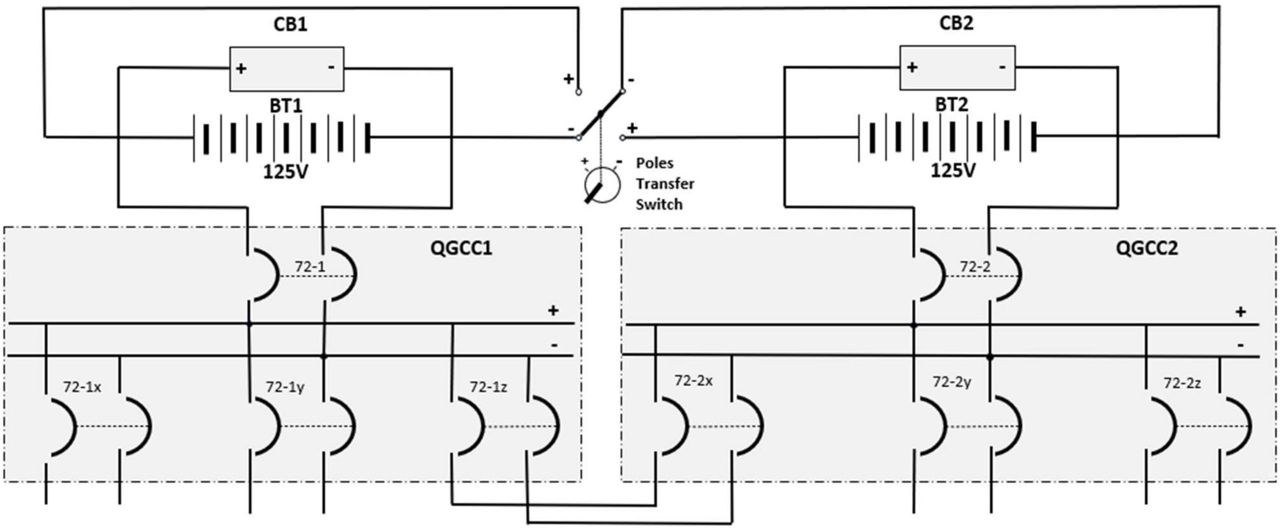
The voltage in the diodes that are feeding the control circuit should be approximately 0.7V. However, it should be noted that, as the paths and power circuits must be practically identical, if the control circuit is being fed through the diode D1-1 or D2-1, the return may not be by the diode D1-2 or D2-2, respectively. Thus, for example, if the two feeds are connected, if the power is being made by the D1-1 diode, if the D1-2 diode is open, the return of the power will necessarily occur by the D2-2 diode. Therefore, if in these conditions the circuit breaker 72-2 is opened for the power to occur by the circuit breaker 72-1, the power to the control circuit will be interrupted. The voltages of the diodes should be measured, and, in the mentioned situation, the diodes D2-1 and D2-2 should indicate the voltage of 0.7V.

The voltage at the input of the control power, before the diodes, must be approximately 1.4V higher than the voltage of the control circuit.

If all the diodes are operating correctly and it occurs that the power is being made by the diode D1-1 and the return by the diode D2-2, and if you open the circuit breaker 72-2, the return of the power will automatically be made by the diode D1-2, without causing any interruption in the power supply of the control.

In the case of the use of the configuration of the direct current system, with the interconnection of one of the poles of the same name, in case of defect to the earth in the circuit of interconnected poles, the sensors to the ground of the two systems will accuse the defect. If the ground defect occurs in a non-interconnected pole circuit, only the system in which the failure occurred will report the defect.

To assist in locating the fault to the ground, a switch, or other device, may be used to reverse the interconnected poles and, in this way, if the failure to the earth occurs in a circuit of the interconnected pole and the ground sensors of the two systems signal the defect, through the switch can be made the transfer of the interconnection of poles, That is, instead of keeping the negative or positive poles of the two systems interconnected, the positive or negative poles are interconnected, respectively, and the signals will only accuse the defect in the affected system.



When performing the transfer of poles, one must be careful because if two defects have occurred to earth, one in each system and in different poles, in interrupting the interconnection to transfer of the interconnected poles, the situation that causes the overvoltage that one wants to avoid may occur.

The probability of overvoltage occurring in the alternative configuration is much lower because the quantity and quality of circuits subject to cause this problem are few and boil down to feeders of distribution panels.

5.3 - Batteries

The following are some considerations about the batteries normally used in hydroelectric power plants.

5.3.1 - Type

The evolution of sealed batteries is undeniable, and their use is consolidated, as they have the same reliability, duration and guarantees that ventilated batteries offered, and the maintenance and operation need of sealed batteries are much lower. However, as many plants still have ventilated batteries, this type will also be considered in some evaluations.

For new installations and replacement of existing batteries, the use of sealed batteries should be considered preferred.

5.3.2 - Rated Capacity

The calculation of the capacity of the batteries depends on the information of the loads and the operating conditions considered. The momentary charges, lasting up to 1 minute, are affected by the voltage drop, but are not determinant for the definition of the battery capacity. Permanent and short-lived charges are what define battery capacity. Therefore, the actual values of consumption and operating conditions are the most important information to be obtained.

Often, those responsible for defining the consumptions, for convenience, inform the values of the powers of the sources as the values of the consumption of the loads. As the powers of the sources usually have powers much higher than the consumption of the loads, the nominal capacity of the batteries ends up being much higher than necessary. Therefore, it is necessary to be aware of this information. For example, the current of all direct current loads of a generating unit, excluding any motors in direct current, with a nominal voltage of 125V, is of the order of 10 to 15A.

The nominal capacity of the batteries is set to a final discharge voltage, discharge time and electrolyte temperature. Manufacturers provide the data needed to correctly size batteries based on other values of discharge currents, final voltage per element, and electrolyte or ambient temperature. Therefore, it is important to be aware of this information to avoid misconceptions in choosing the correct battery.

In hydroelectric plants, where the IEEE Std 485 recommendation is normally used, the nominal capacity of the batteries is defined in Ampère-Hour, referred to a discharge time of 10 hours, electrolyte temperature of 25ºC and final discharge voltage of 1.75V/element.

5.3.3 - Number of Elements

The number of elements of a battery is often defined as 60 elements for nominal 125V systems. Memories always assume that batteries will have 60 elements, which is an almost consecrated number of elements, and they find a way to get to that number. For example, a direct current system set to the nominal voltage of 125V (+10%, -20%), that is, between 100 and 137.5V and, arbitrating a voltage drop of 5V from the battery to the charge, the battery voltage at the end of discharge should be 105V. As the nominal capacities of the batteries are set to a discharge of 10 hours. with a final discharge voltage of 1.75V per element, it is considered that the number of elements should be, the magic number, 60:

$$Number\ of\ elements = \frac{105}{1{,}75} = 60$$

When the battery goes into discharge mode, in a short time the voltage of the elements drops from the fluctuation voltage to the nominal voltage of 2V/element. If the final discharge voltage of the battery is arbitrated at 105V, to allow a voltage drop of 5V, from the battery to the consumer, The initial voltage of the battery, when the discharge cycle begins, will depend on the number of elements.

If we consider extreme and absurd situations, to limit the system voltage to 137.5V and the final discharge voltage is 105V, the number of elements would be:

$$Maximun\ number\ of\ elements = \frac{137{,}5}{2{,}0} = 68$$

$$Minimum\ number\ of\ elements = \frac{105}{2{,}0} = 53$$

With the maximum number of elements, the fluctuation voltages, equalization, and deep charge would be extremely high and, with the minimum number, the battery in a few minutes of operation, would be at the final discharge voltage. Therefore, the choice of the number of elements must meet criteria that will be considered later.

5.3.3.1. Number of Elements of Ventilated Batteries

When ventilated batteries of 2V/element are used, the fluctuation voltage is approximately 2.2V/element, of equalization 2.4V/element can reach 2.8V/element for deep load.

For the maximum system voltage (137.5V) to be respected, the maximum number of elements for each situation will be:

$$Maximun\ number\ of\ elements\ (fluctuation) = \frac{137{,}5}{2{,}2} = 62$$

$$Maximun\ number\ of\ elements\ (equalization) = \frac{137{,}5}{2{,}4} = 57$$

$$Maximun\ number\ of\ elements\ (deep\ charge) = \frac{137{,}5}{2{,}8} = 49$$

Since the minimum number of elements must be 53, the alternative of 49 elements must be discarded.

With the number of 57 elements the fluctuation voltage will be, and the equalization voltage will be $57x2{,}2 = 125{,}4V57x2{,}4 = 136{,}8V$

With the number of 62 elements the fluctuation voltage will be, and the equalization voltage will be $62x2{,}2 = 136{,}4V62x2{,}4 = 148{,}8V$

The solution to be adopted should be to use a battery with 57 elements, because the direct current system will operate most of the time, which occurs with the battery in fluctuation, with the voltage of 125.4V, very close to the nominal voltage of 125V.

5.3.3.2. Number of Elements of Sealed Batteries

When 2V/element sealed batteries are used, the fluctuation voltage is approximately 2.25V/element and the equalization voltage can reach 2.35V/element.

For the maximum system voltage (137.5V) to be respected, the maximum number of elements for each situation will be:

$$Maximun\ number\ of\ elements\ (fluctuation) = \frac{137{,}5}{2{,}25} = 61$$

$$Maximun\ number\ of\ elements\ (equalization) = \frac{137{,}5}{2{,}35} = 58$$

Both solutions meet the minimum and maximum number of battery elements.

With the number of 58 elements the fluctuation voltage will be, and the equalization voltage will be $58x2{,}25 = 130{,}5V58x2{,}35 = 136{,}3V$

If we adopt the solution of using batteries with 57 elements the fluctuation voltage will be and the equalization voltage will be $57x2{,}25 = 128{,}25V57x2{,}35 = 133{,}95V$

If we adopt the solution of using batteries with 56 elements the fluctuation voltage will be and the equalization voltage will be $56x2{,}25 = 126{,}0V56x2{,}35 = 131{,}6V$

The solutions of using batteries with 56, 57 or 58 elements can be adopted, and with 56 elements the direct current system will operate most of the time with the voltage of 126.0V, closer to the nominal 125V the equalization voltage well below the maximum voltage which is 137.5V.

5.3.4 - Calculation of the Final Voltage of the Elements

The calculation of the final voltage of the battery elements shall consider the characteristics of the installation, such as load currents, length of feeders and permissible voltage drops in the loads. This information can be defined through preliminary simulations, which allow to define the minimum voltage of the battery.

Considering that the final discharge voltage of the battery is 105V, for the calculation of the battery capacity, the final voltage of the elements will be given by the following formula:

$$Final\ Voltage\ by\ Element = \frac{Minimum\ Battery\ Voltage}{Number\ of\ Elements}$$

For 56 elements: 1.87V/e

For 57 elements: 1.84V/e

For 58 elements: 1.81V/e

5.3.5 - Maintenance

The maintenance of the batteries should be done according to the recommendations of the manufacturers and, at the defined times, perform the discharge tests to verify that the battery capacity still meets the capacity of 80% of the nominal capacity, because the calculation memories of the batteries consider the aging factor of 1.25, that is, if the calculated capacity of the battery is 80Ah one should specify one of 100Ah (80x1, 25).

After a discharge has occurred, the batteries must be charged to at least allow the system to operate safely in the event of a new occurrence.

What it turns out is that the above provisions are not fulfilled in many facilities.

5.3.6 - Conclusion

The definition of the number of elements of a battery should not be arbitrated but calculated based on the needs of the installation. Using fewer elements for a battery with the same discharge current, but higher final discharge voltage, will result an increase in the nominal capacity of the battery, as the initial discharge voltage of the battery will be lower. For example, the theoretical initial discharge voltage of a battery with 57 elements will be 114V instead of the 120V of the battery with 60 elements, and to meet the final discharge voltage of the battery of 105V, the final discharge voltage per element will be 1.84V/element for battery with 57 elements and 1.75V/element for battery with 60 elements.

The nominal capacity of a battery, defined for a discharge time of 10 hours and final voltage of 1.75V/element does not mean that it cannot be dimensioned for other discharge times and other final voltages per element, such as a discharge time of 5 hours and final discharge voltage of 1.70V/element.

Manufacturers provide the information to equalize the calculations of the nominal capacities, discharge times and final voltage per element of their batteries and refer them to the discharge time and final voltage per element calculated by the user.

The batteries dimensioned for a final voltage of 1.75V per element, will have their voltage gradually reduced in the discharge process, from the nominal voltage of 2.0V to 1.75V per element, passing through all the intermediate values. The difference is that if the final voltage per calculated element is 1.84V, when the battery voltage reaches this value, theoretically, the battery is considered discharged for the application that was calculated. Therefore, even intuitively, it can be deduced that the same battery can be considered discharged for one application and still charged for another. For example, for a discharge current of 40A for 10 hours and final discharge voltage of 1.75V per element, the nominal capacity of the battery will be 400Ah; the same battery, for the same discharge time, but final discharge voltage of 1.85V per element, will provide a current of 37.7A; yet the same battery, with final voltage per element of 1.80V, for a discharge time of 6 hours will provide a current of 48A.

5.4 - BATTERY CHARGERS

Because it is a vital system of an installation, the direct current system must be simple and safe. However, the inclusion of some expendable features and the omission of others make chargers more prone to failure. The most important items will be covered below.

5.4.1 - Falling Diode Unit

To operate with voltages above the maximum voltage (137.5V), battery chargers must be equipped with falling diode unit, to allow the equalization charge of the batteries without the need to isolate the battery packs from the system.

If the charger voltage is set at 144V, to reduce the voltage on the charge, the manufacturers of the battery chargers provide a falling diode unit to keep the system voltage at the maximum voltage, i.e., 137.5V, which is to say that the falling diode unit is equipped with approximately 10 diodes. In this example cited, the falling diode unit should reduce the voltage by 6.5V (144V-137.5V).

The use of falling diode unit, to limit the voltage in consumers to the maximum permissible values, can be dispensed with by reducing the number of battery elements. For example, in the case of sealed batteries with 57 elements, with a fluctuation voltage of 2.25V per element, in addition to limiting the voltage in the system during the loading or equalization operation, the operating voltages of the chargers under conditions of fluctuation and/or equalization will be:

$$Fluctuation\ Voltage = 57x2{,}25 = 128{,}25V$$

$$Equalization\ Voltage = 57x2{,}35 = 133{,}95V$$

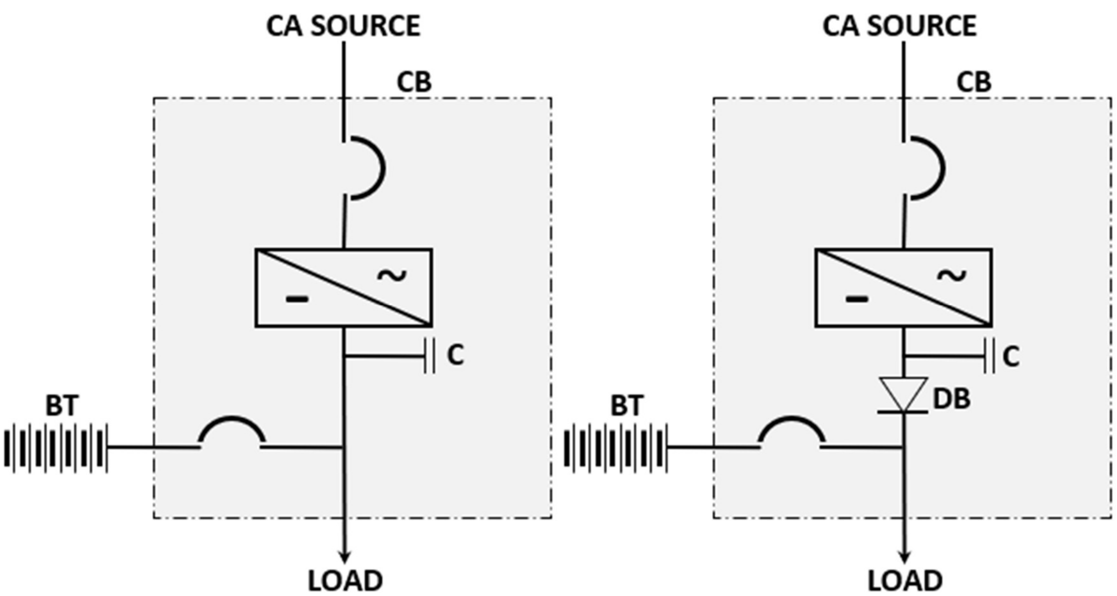
5.4.2 - Power Factor Correction

An unnecessary requirement is also, for direct current auxiliary systems of hydroelectric plants, the installation of capacitors for correction of power factor in the input of the chargers.

When supplied, the power factor correction considers the rated power of the charger, that is, that a single charger feeds all the loads of the plant and simultaneously charges the battery associated with it. However, the normal operating condition is to feed, at most, half of the calculated load of the plant, and this calculated half is greater than the actual load. Therefore, it makes no sense to correct the power factor of the charger, only more components will be installed that are subject to failure and will make the equipment more expensive.

5.4.3 - Blocking Diode

In the following figure are indicated the rectifiers without and with the blocking diode (DB):



In chargers that do not have the blocking diode, the energization sequence of the charger must, mandatorily, start by energizing the charger through the alternating current source, and it is not possible to power the charge by connecting the battery circuit breaker with the charger off.

As the rectifier has capacitors (C) in the output filters, if the battery circuit breaker is turned on with the rectifier off (without the AC voltage source) the peak charge current of the capacitors will cause the operation of the battery breaker protection (or burning of the fuses if they exist). To avoid this problem the installation of the blocking diode (DB) will allow the energization of the rectifier in any sequence, including the supply of the charge by the battery with the rectifier turned off.

5.4.4 - Resources for Poles Interconnections

Chargers must be provided with resources that allow the interconnection of their positive or negative poles. This feature is intended to allow the adoption of the basic configuration of the system to avoid overvoltage.

5.4.5 - Parallel Operation

Chargers must be suitable for parallel operation.

5.4.6 - Spare Parts

One problem that occurs when specifying battery chargers is not purchasing some spare parts along with the chargers.

Usually, the commercial area prefers to request the information of the spare parts costs to acquire them separately. However, as some charger spare parts are very specific and cannot be purchased on the market, what happens at best is that they are purchased from the charger manufacturer but are not available in the receiving and commissioning tests of the facilities.

When purchased separately, the spare parts may not be identical to those supplied in the chargers, and any changes to the circuit board configurations made during factory testing or during plant commissioning are not made in the spares. It is common for the manufacturer to make changes to the rectifier boards to correct a problem or improve their performance, but they do not replace the cards already supplied.

The spare parts recommended to be purchased with the chargers are usually only those that are not found on the market and are of exclusive supply of the manufacturer and, at a minimum, should be:

- Thyristor Bridge.

- A circuit board of each type supplied in the charger.

- One transformer of each special ratio

- One HMI, if it is not included in the supplied circuit board.

- One blocking diode.

5.5 - DIRECT CURRENT PANELS

Although this information is not a specification of the DC panels, the most relevant observations will be made about the local control panel and distribution panel of the alternative configuration.

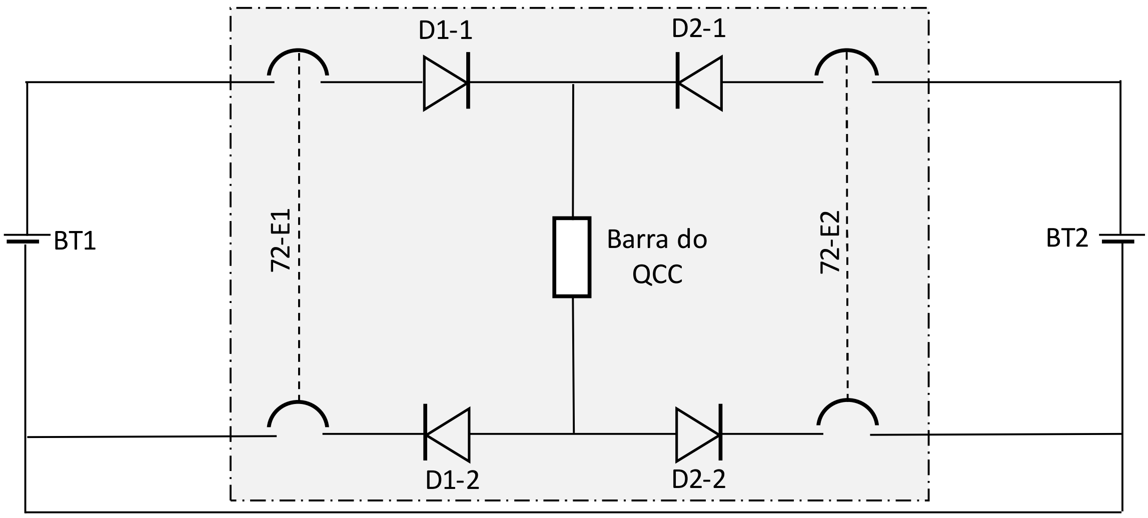
5.5.1 - Local Control Panel

Local control panels should have the inputs and outputs of all diodes taken to terminals to facilitate voltage measurements, continuity, and evaluation of their integrity.

5.5.2 - Direct Current Distribution Panels.

The direct current distribution panels of the alternative configuration have the following particularities:

- The following figure represents the circuit of the input diodes of the switchboards, whose operation is identical to those of the control circuits with two feeds:



The supply current of the panel can occur through the diodes D1-1 or D2-1, but the return may not necessarily occur by the diodes D1-2 or D2-2, respectively. Therefore, before opening an input circuit breaker one must be sure of the integrity of the diodes of the other source.

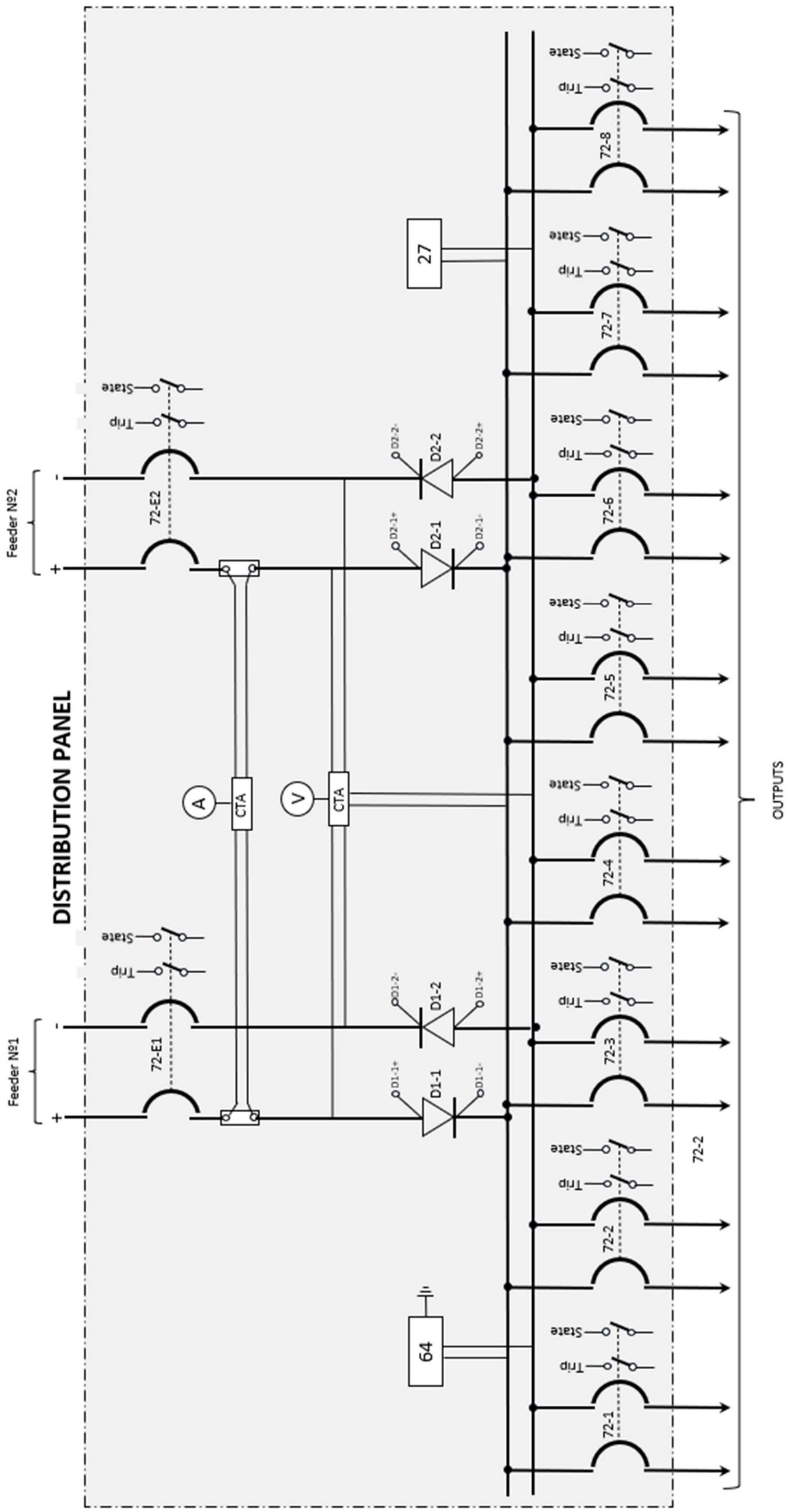
- The measurement of the voltages at the inputs and on the bar is done with the same voltmeter so that the same measurement standard can be used, and it can be assessed, by the measurements, if the diodes are having problems. For example, if in an input the voltmeter is indicating 125.0V, the voltage in the bar should indicate the voltage in the order of 123.6V, due to the voltage drop in the two diodes.

- The positive and negative poles of all diodes are taken to terminal terminals of the terminal ruler to allow, with ease, to make the voltage and continuity measurements of the diodes.

- Although fault to ground be signaled on the battery chargers, positive or negative earth signs and alarms are also signaled locally, to facilitate the operation and maintenance services of the facilities, in this case the location and elimination of faults to the ground.

- The representation of the number of outputs is only symbolic and should be defined in the specification.

The DC distribution panels of the alternative configuration are represented, in a simplified way, in the following figure:


DISTRIBUTION PANEL
Feeder Nº1
Feeder Nº2
72-E1
72-E2
D1-1
D1-2
D2-1
D2-2
D1-1+
D1-1-
D1-2-
D1-2+
D2-1+
D2-1-
D2-2-
D2-2+
A
V
CTA
CTA
27
64
Trip
State
72-1
72-2
72-3
72-4
72-5
72-6
72-7
72-8
72-2
OUTPUTS