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Original Article

Feeder Board Design with GCHK-100 Protection Relay with Ground Wire Verification, Ground Fault Protection and Frame Voltage for Protection of Human Personnel

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Abstract **-** *Nowadays, in the formal mining industry, there are failures due to ground or casing discharges when mobile drilling equipment is used, which causes damages to the operating personnel of this equipment. This work proposes a solution by designing a power supply board with a relay that senses the casing voltage of the ground fault current. It verifies the ground wire, which circulates in the power supply of the drilling rigs. At the end of the design, laboratory tests were made to the relay, where the response times of the relay were verified; being in the ground fault injected a current of 0.25Amp and giving a time of 17.20mS of response, the voltage in the casing triggered instantaneously in 38V, and the resistance of the cable beginning instantaneously with a resistance of 20ohms.*

Keywords **-** *Protection relay, GCHK-100, Feeder board, Human protection, Grounding wire.*

1. Introduction

In Peruvian mining, whether in small, medium or large mining, there are occupational accidents in the different work environments, which affect the workers who work in this sector. Among these accidents, the one related to the electrical issue in the mining sector has fundamental importance since a current of 30mA causes respiratory paralysis, and the amount of current that a person can withstand and have control of his body is around 10mA [1]. In these cases, these current values are facially exceeded in most cases within the handling of electrical equipment [9].

For these cases of electrical accidents in Peru in formal mining, a percentage per year is documented by the Ministry of Energy and Mines (MINEM) of Peru. According to the statistical bulletin of the mining supervision management of the Supervisory Agency for Investment in Energy and Mining (Osinerming) [2] in (medium and large mining) in 2019, accidents related to electric shocks reached 6%, on the other hand, on the website of the Ministry of Energy and Mines (MINEM) [3] in its 2017 electric shock accidents report there were four deaths due to exposure or contact with electric current out of a total of 40 this would be equivalent to 10% of the deaths.

On the other hand, Peru's mining and hydrocarbon sector grew by 9.34% in December 2022, according to what is observed in [10]. Unfortunately, however, as a result, electrical accidents have continued to occur even though the formal mining company are improving their safety standards and raising the rigour of the protocols before performing the work, during the work and after the outcome, despite the severity and constant improvement of safety standards and occupational health that applies in mining, there are still some vulnerable points of potential electrical risk that have not been fully covered, or in some cases the standards to protect personnel are presented to a limited extent because for specific points they are perhaps considered unlikely events.

[14], An example of this can start from the basics, such as carelessness in not using Personal Protective Equipment (PPE) since safety is primarily part of each person. One has to be aware of when it is time to renew the safety equipment or if it has suffered any damage or physical wear, and often carelessness is not given due importance; another example may be the failure of PPE due to manufacturing failure that can also lead to a tragedy if the loss is not noticeable [17, 18].

To address the general problem of electric shock accidents, the following measures were taken as the case of the Bender brand that details in its document electrical safety solutions in mining [5]; it uses a system that allows monitoring of the grounding conductor cable [11] and ground fault detection. However, this system does not measure the voltage in the casing; unlike the proposed solution, the proposed solution does have the voltage in the case, which generates additional protection for the personnel.

Something of similar characteristics is the ground fault relay and pilot wire verification SE-135 of the Littelfuse brand. This system allows protection in case of a ground fault and supervision of the ground wire cable, but with the disadvantage that it also does not allow verification of the voltage in the housing [7, 16].

Finally, there is another Starco relay, model SE 107, which also uses a fault protection system in a more limited way as it cannot configure the opening times of the ground faults and ground wire monitoring, but with the same problem as the previous cases of not being able to census the voltage in the casing [8, 14].

The proposal in this article is the design of a feeder board with a mining relay GCHK-100 of the I-GARD brand for detecting ground faults, ground wire status and voltage in the casing, and defects that can occur in the equipment operated in the mine. The objective is to be able to have a design of optimum characteristics and verified that allows a next step to be implemented and, therefore, can avoid such ground faults causing electrical accidents to personnel; for this, the operation of the proposed design is verified with the use of a test case., to make this design will be used aboard and equipment that is prepared to meet the American standard Nema [20] for mining for its robustness and safety it provides, also for control and power equipment that will be used will be taken into account that has certification Underwriters Laboratories (UL) which is a safety standard that certifies electrical appliances and components.

2. Materials and Methods

The methodology is divided into two parts, first, the planning and then the design.

2.1. Planning

It determined the voltage level of the network, the work environment place and for which machines will be designed; the protection system, for the case, will be inside the mine, temperature 30ºC, operating voltage 460Vac and for the machinery will be for excavators.

2.2. Design

First, it is necessary to calculate the capacity of the main circuit breaker to be used in the proposed switchboard. This is obtained based on the load to be consumed by the machine. For this specific case, a 250A thermomagnetic switch will be used for equipment with 150HP motors; this will be the feeder switch that will give the power supply to the equipment. The formula shown in (1) will be used for the calculation.

$$I = \frac{P*746}{V*\sqrt{3}*\cos\Phi} \quad (1)$$

Where: P=Power, V=Voltage, I=Root Current, (three-phase system), 746 default value according to [4].

Then, as a second step, proceed with the definition of the control components to be used inside the board; the control voltage will be 120V for the components.

Depending on the control components, the power of the transformer, to be low consumption, is chosen to feed the control equipment with a transformer 250VA 460/120VAC).

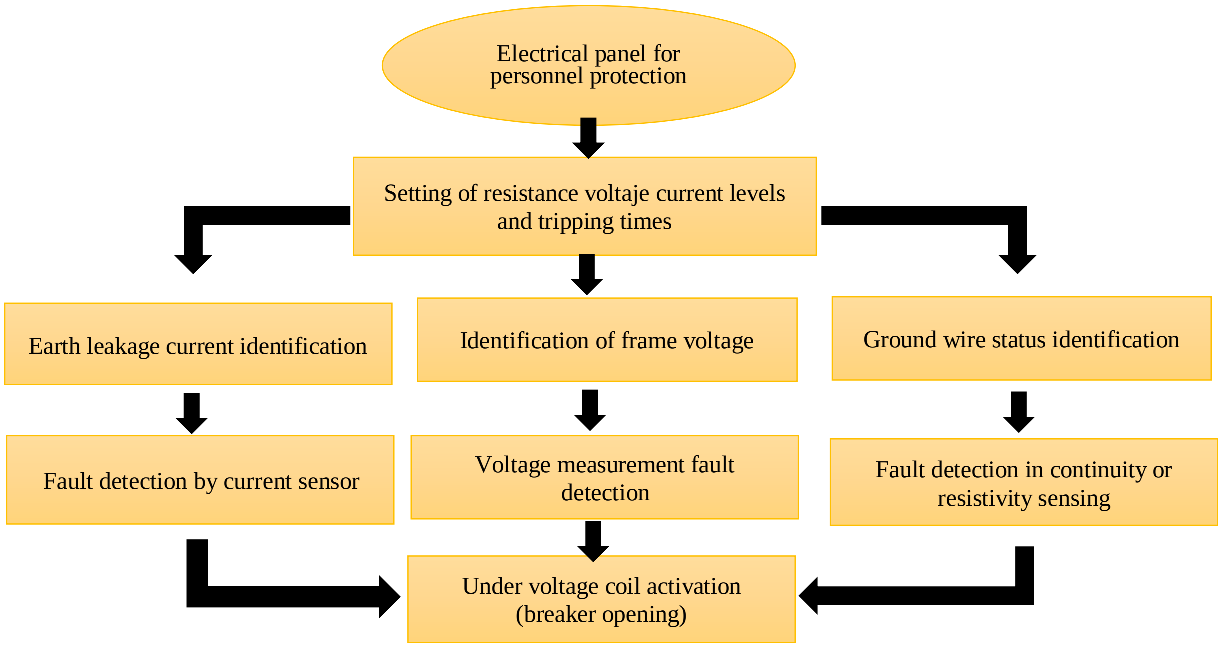

Fig. 1 Block diagram of electrical panel operation

This block diagram shows the board's operation in broad strokes where the GCHK-100 relay, which will perform the protection functions, is observed.

First, it will be sensed employing a current transformer, the leakage currents to the ground that can be caused in the power supply line; these current values can be set in the relay to tune the sensitivity of the equipment; in this case, it will be the most sensitive value possible which is 250mA and a time that can also be set, which in this application will be 20 ms.

Then, for protection from the voltage in the housing, a Zener diode is strung between the terminals of the G.C. pilot wireline and the ground line G of the relay; when a voltage discharge occurs in the housing of the load, this will return through the Zener diode which will pass the voltage to be censored by the G.C. terminal of the relay, which is set for the opening of the switch to 40V.

Then, finally, there is the ground wire sensing. This is achieved utilizing the zener die that closes the loop between the pilot wire and the ground, in which the impedance value of the conductor cable will be continuously censored; this is set to 20ohm for system purposes. This fault will be activated if the diode is disconnected or the line's resistance rises.

All the censored data exceeding the error setting values will command the main switch to open, thus cutting off the power to protect the operator.

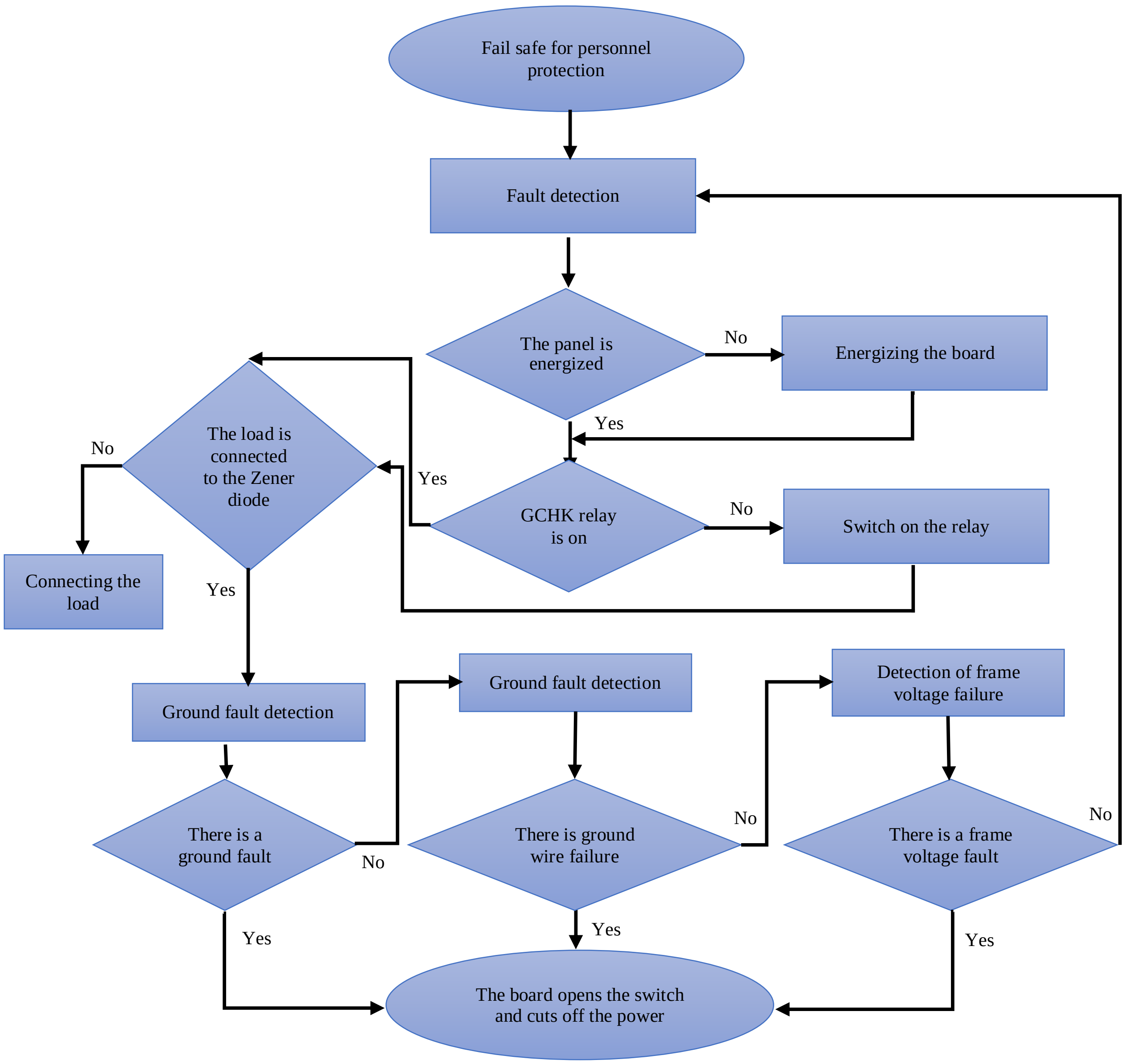

Fig. 2 Flowchart of relay protection activation due to system failures

In the flowchart in Figure 2, the conditions for the board to operate, the first condition is to energize the board; this is done by activating the main switch. Once this is done, it is verified that the relay is activated. If it is not activated, the control switch is checked, and the key is lifted to energize the relay. Then, as a last filter, it must be verified that the load is connected to the board; this mediates the pentapolar cable [15] linked to the pentapolar connector and, in turn, must have the zener diode installed on the motor to close the loop of the pilot wire cable, with this the board with the relay and can work properly and census the different values of protection for which it is programmed.

For the types of protection which the relay will be sensing are:

Ground fault detections will be sensed utilizing the toroid model T3A, which will feel the current imbalance that can be generated in the system.

Detection of ground fault cable: which will be censored by the pilot wire cable by the zener diode. This will allow us to verify that the loop is closed in the system and allow us to confirm the resistance level of the cable to see its status.

Detection of failure by voltage in housing: This will be censored through the pilot wire and the zener diode, which will detect any voltage in the equipment's chassis.

Table 1. Table of materials of the components used

QTY	Components	Manufacturer
1	Circuit Breaker 250AF/250AT	SQUARE D
1	Variable Depth Mechanism	SQUARE D
1	Handle Mechanism	SQUARE D
2	ITM de 3x16 Amp. 10kA	SCHNEIDER
1	ITM de 2x10 Amp. 10kA	SCHNEIDER
1	I.D. de 2x25A 30mA	SCHNEIDER
1	Transformer 100VA	MICRON
1	Undervoltage Release	SCHNEIDER
1	Rele GCHK-100	I-GARD
1	Zener Termination 6 Volts	I-GARD
1	Current Sensor T3A"	I-GARD
2	Mini Contactor, 60Hz	C3CONTROL

Table 1 shows the most relevant equipment of the protection panel design. For the power part, the 250A SQUARE D brand thermo-magnetic switch is shown, which will pass the current to feed the load, see drawing (Figure 8) also, the 2 Newark brand voltage indicators, which are used to visualize the input voltage of the switch and the output voltage of the button to the motor (Figure 8).

For the control part, the relay GCH-100 of the brand i-GARD is the system's brain. This works with the toroid of 3 inches T3A, which will censor the current and the zener termination of the brand I-Gard, allowing the census of the tension in the casing and verifying the state of the cable with the pilot wire. The line with the pilot wire needs a special connector of 5 poles, which would be for the 3 phases: the ground and the pilot wire (R+S+T +GND+ pilot wire); this, according to the table, would be the female connector of 225A of the BURREL brand. The table also shows the components for the fault visualization part; there are three pilots of the c3 control brand and the sound beacon with strobe light of the c3 control brand; this beacon will turn on in case the relay detects any of the three faults, see drawing (Figure 8). The most relevant component for the control power supply is the 120V transformer of the Micron brand and its 10A Schneider brand protection circuit breaker.

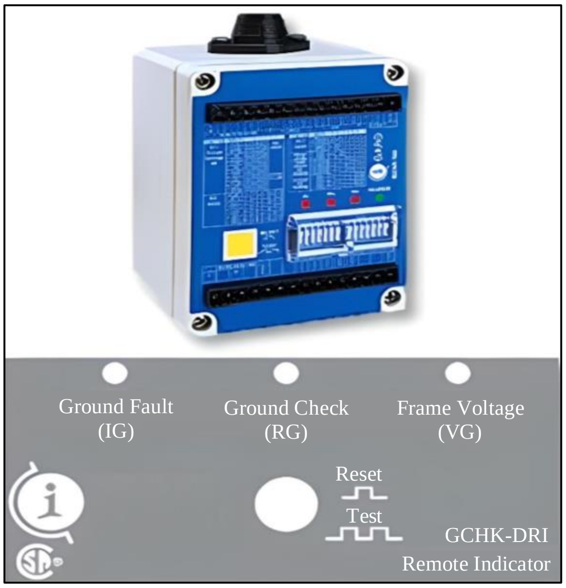

Fig. 3 GCHK-100 mining relay [6]

- It is a protection device with fault indicators.
- It contains three LEDs and a reset/test button.
  - The Ground Check Led - RG (Ground Check)
- It stays on in a normal state.
- It remains off when there is a ground check fault.
  - Ground Fault - IG (Ground Fault) and Frame
  - Voltage - VG (Frame Voltage) LEDs
- Remains off in a normal state.
- Remains on when the fault occurs.
  - To reset, press the button once.
  - To perform a test, press the button twice Quickly on the button.

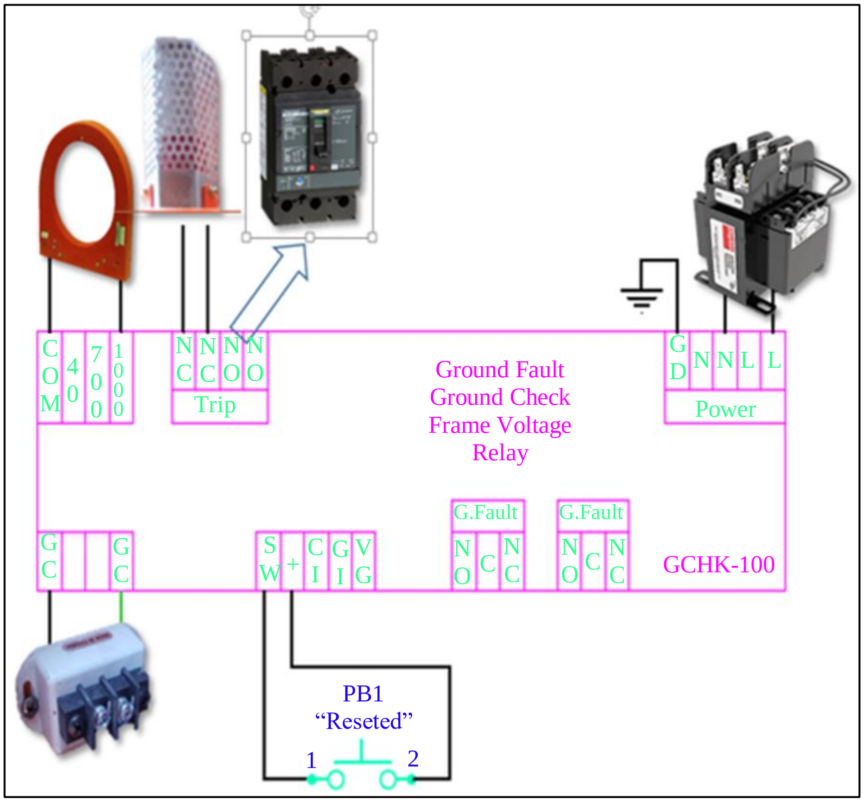

Fig. 4 Schematic diagram of basic operating connections

2.3. Mobile Equipment Connection Considerations

All equipment to use the protection board with the GCHK (ground check, ground fault and shelf voltage) relay must comply with the following components installed before energization.

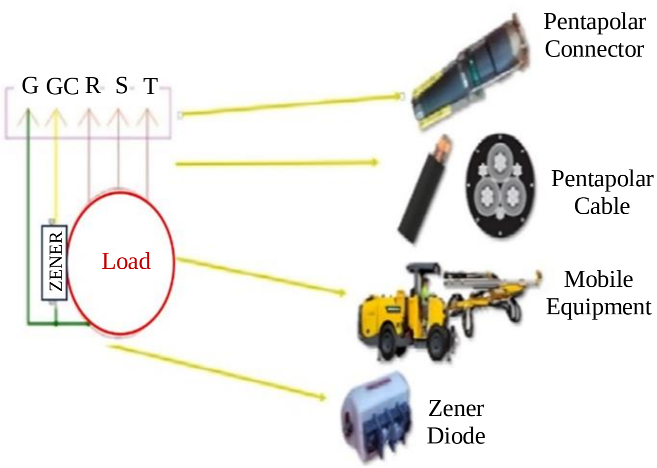

Fig. 5 Illustration of components for the connection

3. Results

Finally, after making the conceptual design and the choice of the devices to be used in the panel. It was possible to obtain a final circuit that protects human personnel from ground faults, the voltage in the casing and the detection of the state of the ground wire utilizing the monitoring pilot wire. The panel size was 680mm high x 420mm wide x 348mm deep. For the door, stainless steel hinges with a gooseneck design and a crescent-shaped gasket were chosen to achieve NEMA 4 tightness; see Figures 6 and 7.These mechanical details are essential because the place where this mobile equipment (the load) operates is inside the mine shaft, which is a highly polluted environment of the severe climate which affects the electronic equipment very quickly, for the reset button and fault and voltage display equipment of the door has a door with additional window to reinforce the protection of the equipment and thus are not exposed to environmental contaminants agents and possible blows or damage by explosions by blasting that occurs inside the mine, See Figure 6.

A P.G. 29 nickel-plated cable gland was chosen for the hermeticity of the cable entry. This is to avoid using foam or silicone sealants in the field. However, it is a quick alternative; it is filthy and being a movable board makes it difficult to change the conductor; apart from the cable exit to the portable equipment, a 225A female pentapolar connector of the BURREL brand hermetically mounted on the board, this will be used to attach a male connector with its respective power cable, This is to avoid the need to open the panel and to contribute to the hermeticity of the panel by minimizing the need to open the panel once it is inside the undercut, See Figure 6.

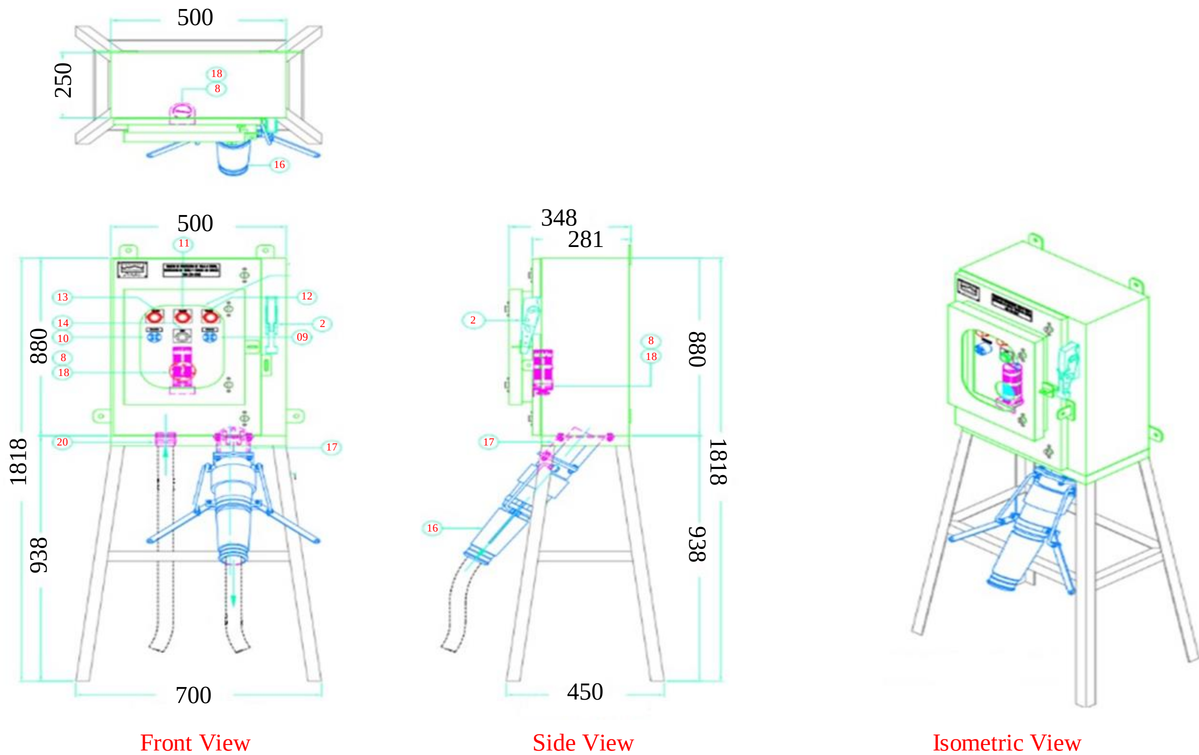

Fig. 6 General mechanical board arrangement diagrams

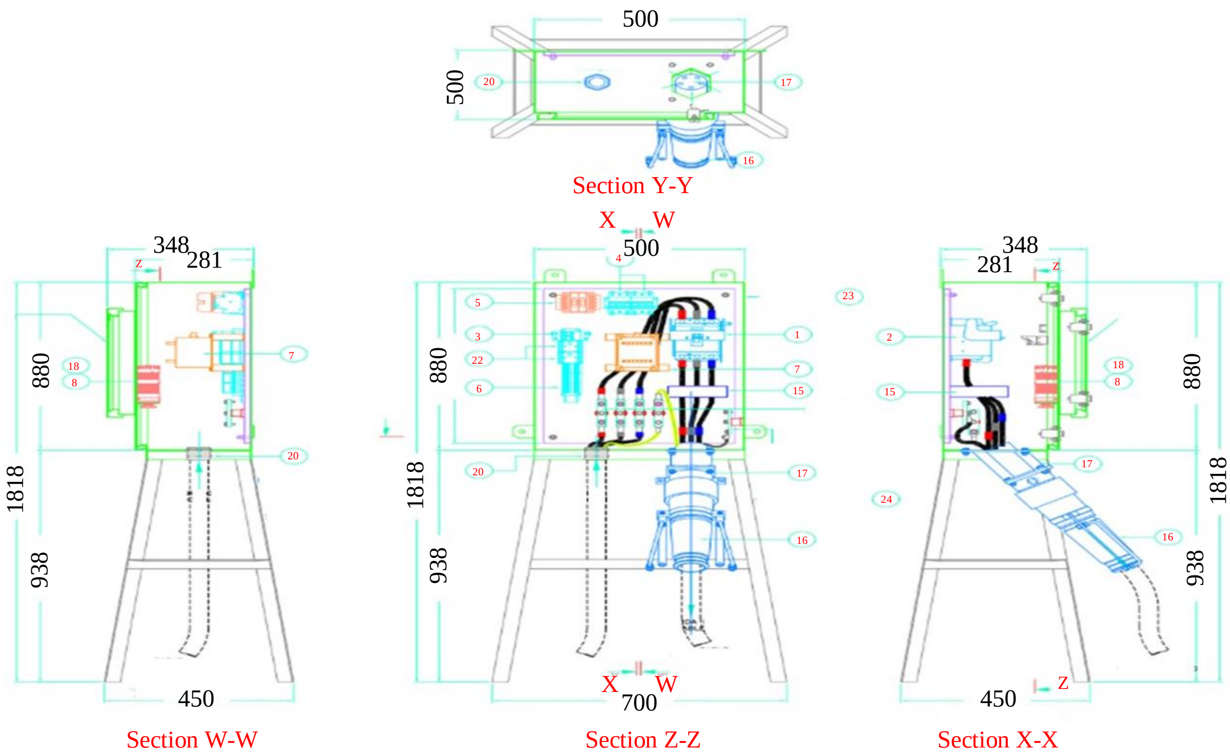

Fig. 7 Internal panel detail diagrams

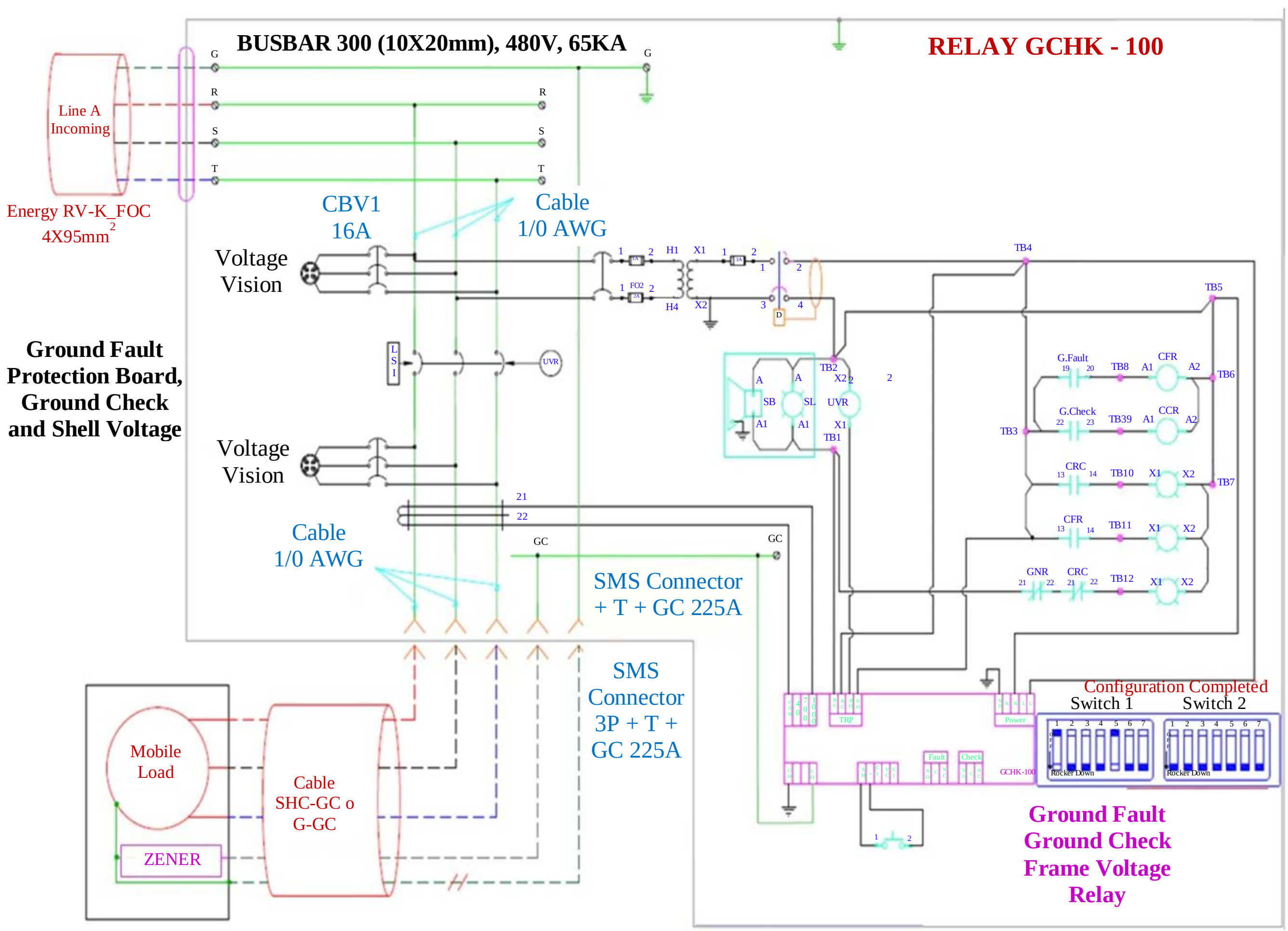

Fig. 8 Electrical diagram of control and power schematic of the board

Regarding the representation of the electrical schematic diagram, electrical symbols from the NEMA standard were used; the GCHK 100 protection relay trigger signal is connected to the Under-Voltage coil of the switch, as seen in Figure 8. In turn, it will cut the power to any of the three fault options that can be, by ground fault by measuring a current of 250mA, this will act in a time of 20ms all this previously configured in the equipment, by voltage in housing by sensing a voltage of 40V will work immediately and by sensing the state of the ground head if it is detected that the ohmic value rises above the 20ohms will serve immediately.

The requirement and planning of the connection for tests of the grounding checkboard proceeded to verify the performance of the GCHK-100 relay.

Equipment to be used:

- Three-phase 460 VAC power supply (Omicron CMC 356).
- Current source and trip check (Omicron CMC 356).
- Single-phase variable voltage 0 V - 100 V (Variac).
- 0 ohm - 100 ohm Variable Resistance (Potentiometer).

3.1. Considerations

Table 2. Adjustment of relay GCHK-100

Function Switch 2		**1**	**2**	**3**	**4**	**5**	**6**	**7**
G.F. Pickup Setting Ig	0.25Amp.	o	o	o	o			
G.F. Delay	0.20 sec					o	o	o

Table 3. Protection settings of relay GCHK-100

Function Switch 1		**1**	**2**	**3**	**4**	**5**	**6**	**7**
Relay Mode	Fail safe	U	o					
Reset Mode	Normal			o				
GND Check R.G. Setting	20 ohms				o	U		
Voltage V.G. Setting	40 V						o	o

3.2. Testing Procedure

3.2.1. Ground Check Test

- By an open circuit between the pilot wire (GC) and the ground point (G).
- By a variable resistance exceeding the GCHK-100 relay setting between the pilot wire (GC) and a ground point (G) (Simulation of wire impedance).

3.2.2. Ground Fault Test

- Pickup verification by current flow through the ZSCS T3A (current sensor) exceeding the GCHK-100 relay setting.
- Verification of trip time by current flow through the ZSCS (current sensor) exceeding the GCHK-100 relay setting and monitored by the Omicron CMC 356 case via relay output signals.

3.2.3. Frame Voltage Test

- By a voltage variation (variac) exceeding the GCHK-100 relay setting between the pilot wire (GC) and a ground point (G).

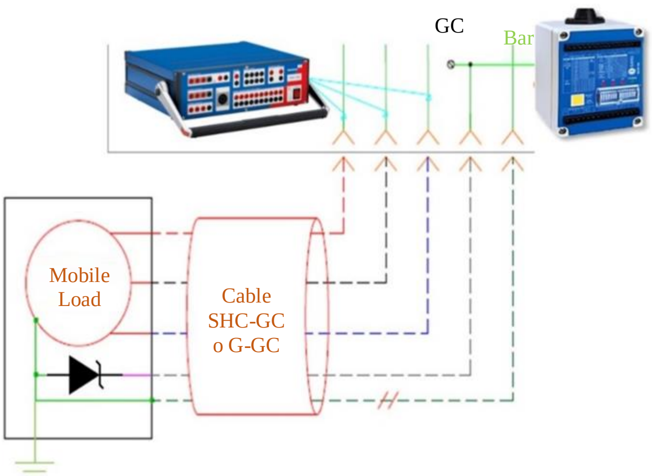

Fig. 9 Test case connection diagram

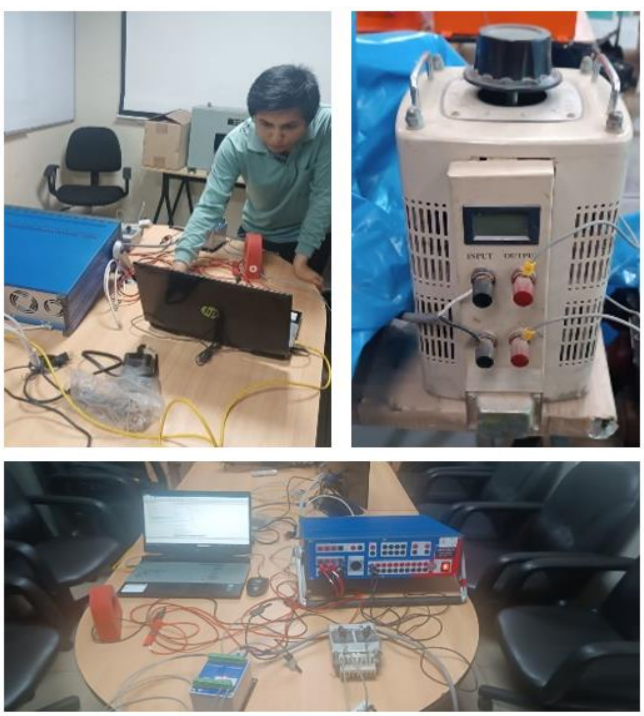

Fig. 10 gchk100 relay performing the trip tests of its protections

Table 4. Samples of voltage fault tripping in housing voltage, V.G. setting 40 V

Voltage VAC	Tripping Time
10	No TRIP
15	No TRIP
20	No TRIP
25	No TRIP
30	No TRIP
35	No TRIP
36	No TRIP
37	No TRIP
38	TRIP 100ms (instantaneous)
39	TRIP 100ms (instantaneous)
40	TRIP 100ms (instantaneous)

Table 5. Ground fault trip samples, G.F. pickup setting Ig. 0.25 Amp.

Current (mA) A.C.	Tripping Time
267	TRIP 17.20mS

3. Ground Fault Test

Ground Fault Note
Equipment to use:
-Power supply 480VAC
User Input:
Io: 267 mA
Test setting

State	Normal Operation	Trip Ground Fault
IL1	1.000 A 0.00* 60.000 Hz	1.800 A 0.00* 60.000 Hz
IL2	1.000 A -120.00* 60.000 Hz	1.000 A -120.00* 60.000 Hz
IL3	1.000 A 120.00* 60.000 Hz	1.000 A 120.00* 60.000 Hz

Test Results
Time Evalutaion

Name	Ignor. antes	Start	End	tnom.	tdesv-	tdesv+	treal	tdesv.	Eval
Ground Fault	Trip Ground Fault	Trip Ground Fault	Trip 0>1	20.00 ms	10.00 ms	10.00 ms	17.20 ms	-2.800 ms	+

Status of the Test:
Correct Test

Fig. 11 CMC 356 omicron case report, in ground fault current trip test

Table 6. GND pilot wire detection fault trip samples, check R.G. setting 20 ohm (resistance)

Resistance (Ohm)	Tripping Time
10	No Trip
15	No Trip
20	TRIP 150ms (instantaneous)

4. Discussions and Conclusion

From the tests performed on the protection relay, it can be corroborated that the trip time values by housing voltage fault (Table 3), ground current fault (Table 4), and pilot wire verification (Table 5) according to the preprogrammed setting, is thus evidenced that the system acts on housing voltage unlike [11] in which it is not included. Also, as mentioned, the relay system designed in this work makes it possible to correctly configure the opening times of ground faults and ground-wire monitoring, which was impossible in [14]. Verifying that the relay responded perfectly in the laboratory tests has been possible.

Still, it should be emphasized that all the external components must be in good condition, whether the connection cable, diode condition, etc. On the other hand, it is necessary to mention that in a certain way, the results obtained from the tests performed with the system could be improved and adjusted if it had the respective female and male output connectors since, in this way, it would also be possible to simulate a much more realistic environment and therefore perform more accurate tests, and also verify if there could be any failure in the connectors. It can be said that this design solution is better than using the RC48c relay made by Bender because it has three levels of protection in a single compact device. It has more protection modes, such as case voltage and pilot wire loop monitoring and more levels of resistance and case voltage sensing configuration in both additional protections. The main problem is electrical accidents in mining.

To contribute to the reduction of electrical accidents in the operation of mobile equipment in mines, this research aims to protect three essential points, which are the verification of the grounding cable that reaches the load, verification of the ground fault currents that are generated and verification of the voltage in the casing that circulates in the circuit.The i-Gard manufacturer's recommendations for connecting the protection circuit were taken as a basis. Based on that, the different improvements and protections were expanded according to the required application. In this case, it is for mobile equipment inside the mine.

It has been possible to make a robust design for the application. It has been theoretically corroborated that the circuit works according to the power calculations for the load, and in the control, the protection settings are safe to protect human personnel. It was also possible to realize a small wired circuit in the laboratory tests to measure the tripping response times. This circuit will protect against accidents in these three aspects of failures.

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