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Phase Earth-Fault Short-Circuit Automatically Connecting and Detecting Device Solution to Enhance the Reliability of 6KV Grid Power Supply in Open-Pit Mines in Quang Ninh Area-Vietnam

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Abstract: **- Study on structural construction, designing a circuit of automatic detection and short circuit of fault phases when the ground fault intermittently occurs to increase the residual voltage on a busbar, reduce power failure time which will enhance the power supply quality, decrease the number of lines-fault interruption, reduce transient voltage and over-voltage in fault-free phases, ensure stable insulation as well as reduce fault current. When the intermittent earth-fault phenomenon is self-restoring, the power system returns to its normal state. If the fault does not disappear, the ground-fault protection system will operate and selectively disconnect the grid. This article presents the results of research on structural construction, selection of the principle of determining the earth-fault phase based on the absolute value of the leading phase and fault phase, designing an automatic fault-phase short circuit device, and simulation circuit of automatic detection and fault-phase short circuit. Simulation results yield fast, sensitive, and reliable performance according to requirements.**

Keywords- Single phase earth-fault, short-circuit fault, operating time, sensibility, reliability

1. INTRODUCTION

A single-phase earth fault is the main type of fault that often occurs in 6kV networks of open-pit mines in the Quang Ninh region, accounting for 70%÷80% of the total number of faults [1,2,3,5,6,16]. When the single-phase earth fault happens, especially the intermittent one, it causes an increased time of power failure and overvoltage in the fault-free phases, affecting the power quality and safe conditions of the network [1,2,4,9]. The asymmetry of the grid directly affects the insulation, service life, and working ability of the electrical system [6,7,8].

The solution to improve the safety conditions of the 6kV grid and the quality of power supply when a single-phase earth- fault occurs is to use a device that automatically detects and short-circuits the phase-to-ground to increase residual voltage and reduce the time of power failure, improve the quality of power supply, reduce transient voltages in the fault-free phases, ensure sustainable insulation without breakdown, decrease the fault current to critical safety [1,4,9,10]. When the intermittent ground fault phenomenon is self-resolved after a time (no more than 3 minutes), the short-circuiting device is disconnected from the network and the power system returns to the normal operation, otherwise, the earth-fault protection system will operate and cut selectively [9,15].

This proposed solution was first applied to open-pit mine grids in the Quang Ninh region of Vietnam, so it has scientific and practical significance, ensuring social insurance conditions when operating mine networks.

2. THE STRUCTURAL CONSTRUCTION AND SELECTION OF THE PRINCIPLE OF THE SHORT-CIRCUITING DEVICE FOR EARTH-FAULT PHASE OF THE 6KV GRID OF AN OPEN-PIT MINE IN THE QUANG NINH AREA

2.1. Structural build of the short-circuiting device of earth-fault phase

Requirements for the automatically protective device of short circuits for the fault-phase [9,10,16].

The automatically protective device of a short circuit includes A high voltage short-circuit switch and a fault-phase identification block.

The total operating time of short-circuit device including the operating time of the fault-phase identification block and the phase short-circuit switch does not exceed 15-20ms and meets this condition:

$$t_{T.B} \leq \frac{t_{bv}}{1{,}5 \div 2} \qquad (2.1)$$

The condition (2.1) ensures that the selective protection does not operate when the intermittent earth fault occurs with a subsequent tripping cycle when this fault is excluded and the symmetrical self-healing of phases as well as does not cause power interruption. The maintenance time in the shunt mode should not exceed 30-60s, depending on the ability to recover the insulation strength. When a stable earth fault occurs, after the short-circuit connector works (30-60 s), the earth-fault protective system will selectively disconnect in a definite order.

The sensitivity of the short-circuiting device according to the single-phase leakage resistance (R'r) should be suitable for an adjustment level of the selective earth-fault protection (R'cđ) and was selected in accordance with the condition:

International Journal of Engineering Research & Technology (IJERT)
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R'tb ≤ R'cđ.

The maintenance time between the operation of the short-circuiting device during the on/off cycle when the intermittent earth-fault occurs is usually no more than 3 minutes.

The short-circuit device requires interlocking with protective relays in the substation and functional elements such as a non-selective reserve earth-fault protective interlock; a repetitive operation interlock of short-circuit device and fault-phase disconnection signal when the protection refuses operation; a fault-free phase interlock avoid mistaken operation; Transmission of the command to trip the short-circuit switch when a two phases short - circuit to ground occurs or the short-circuit switch refuses to trip.

Selection of a short-circuit switch should be given to the non-contact thyristor type. The number of thyristors connected in series in each of the counter-parallel branches depends on the nominal voltage of the network and is selected according to this expression (2.2).

$$N = \frac{k.U_{XP}}{U_{KLL}} \qquad (2.2)$$

Where as: K= 1,1-1,15 - reserve factor

U_{XP} - pulse voltage of a lightning discharge equipment

U_{KLL} - nominal voltage of thyristo.

Structure of the fault-phase short-circuit protective device [9,10,16].

Figure 1 shows the structure of the fault-phase short-circuit protective device.

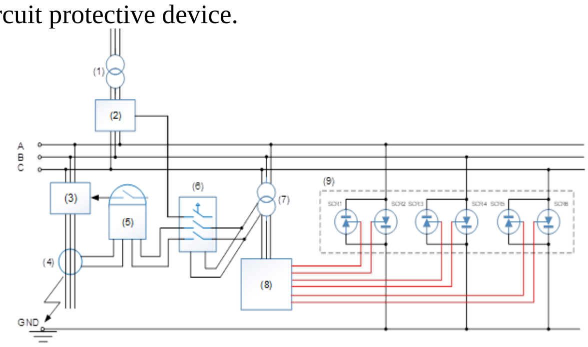

Figure 1. Structure of the fault-phase short-circuit protective device

(1- Transformer; 2-cutter; 3- protection cutter; 4- current transformer; 5- selective earth-fault protective device; 6- non-selective reserve protection;7- measuring transformer;8- control circuit including fault-phase detection block; 9- block of thyristors connected to the fault-phase short-circuit.)

When a single-phase flickering earth-fault occurs, the fault-phase identifiable device will operate. The short-circuiting switch on the fault phase will operate quickly, the shunt in the ground position to rapidly reduce the earth-fault current. After the 30-60s maintenance time, the short-circuit switch is tripped. If the earth-fault does not disappear by itself and continues to exist, the selective earth-fault protection will trip the fault departure. The reserve protection has locked the duration of the shunt.

2.2. Principle for determining 6kV grid earth-fault phase [9,10,16].

The content of principle is:

$$U_V(A) = |U_C| - |U_A| \qquad (2.3)$$

$$U_V(B) = |U_A| - |U_B| \qquad (2.4)$$

$$U_V(C) = |U_B| - |U_C| \qquad (2.5)$$

Figure 2 is the block diagram of the device according to the expressions (2.3), (2.4), (2.5). This device consists of rectifier bridges 1, 2, dc amplifier 3 containing RL relays, and 4,5 phase splitters separating into three-phase difference voltages in block 6. Blocks 7,8 are also similar.

In the normal operating, the inputs of rectifier bridges 1 and 2 (phase A) are symmetrical voltages, rectified and compared in absolute value, the input voltage $U_v(A) = U_C - U_A = 0$. Blocks 7 and 8 are also similar $U_v(B) = U_A - U_B = 0$, $U_v(C) = U_B - U_C = 0$.

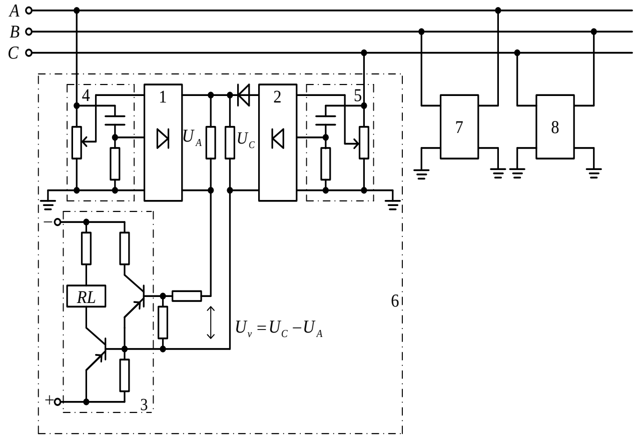

Figure 2. The block diagram of the device for determining fault- phase based on absolute difference between the ahead phase and the fault phase

When a single-phase earth -fault happens, for example, in phase A, the symmetry of the phase voltages is broken, the voltage into rectifier bridge 1 will decrease while the voltage into rectifier 2 will increase, as a result, $U_v(A) = U_C - U_A > 0$, if enough voltage is true, it will cause the relay (RL) to operate while the DC amplifier inputs of blocks 7 and 8 (for two phases B and C, respectively) will have negative values due to UB>UA, UC>UB, so the corresponding relays do not operate.

3. Design a circuit of automatic detection and earth -fault phase short-circuit

3.1. Simulation of a circuit of automatic detection and earth -fault phase short-circuit

With the parameters selected for the diagram:

Application of the formula to determine the resistance and capacitance with: Rcd = 1/G = 365kΩ (G = 2,74 µS)/phase; Ra = 1kΩ; C = 0.263µF/phase [5].

The low-voltage transformer with K_{ba} = 300 generates a voltage of 20VAC per phase. Voltage A_1 and C_2 are the input ones for the voltage generating block Uv(A); Voltage B1 and A2 are input ones for voltage generating block Uv(B); Voltage C1 and B2 are the input ones for the voltage generating block Uv(C).

The voltages Uv(A), Uv(B), Uv(C) through the motive circuit consisting of 2 PNP transistors transfer the signal to close the relay (block 3 on the block diagram).

Simulation diagram of the 6kV network is shown in figure 3, figure 4.

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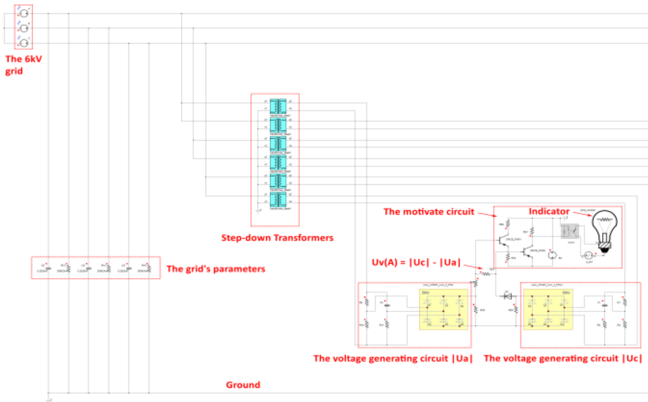

Figure 3: Circuit diagram of voltage generating circuit Uv(A)

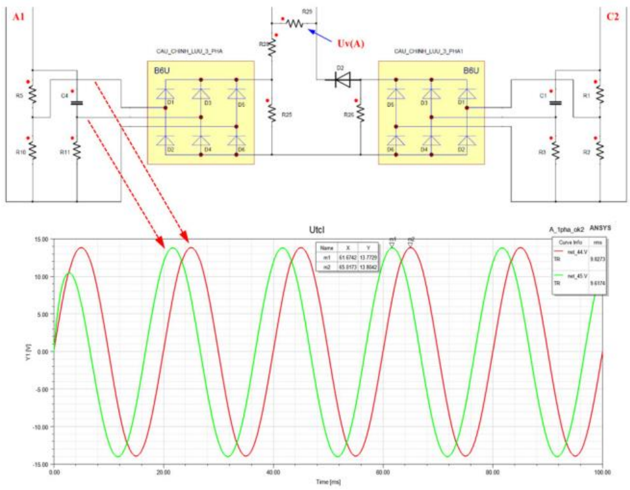

Figure 4: Diagram of voltage generating circuit UV(A) = UC-UA

1) In the normal working state

The simulated findings of line voltage on the phases of the 6kV grid and the low-voltage voltage after the transformer are shown in Fig 5, Fig 6.

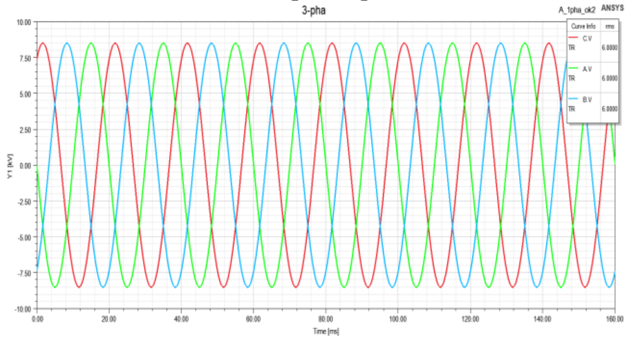

Figure 5. line voltage U_{ab}, U_{bc}, U_{ca} of the 6kV grid

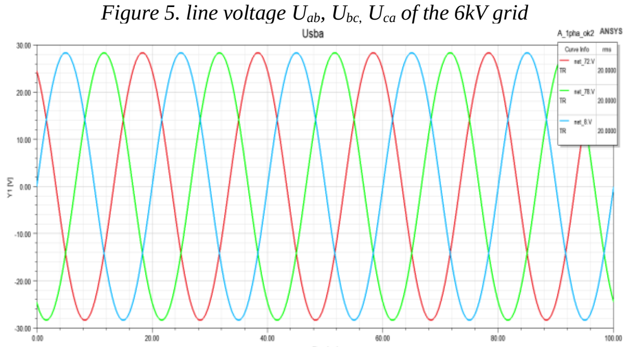

Figure 6. three- phase voltage after low-voltage transformer

Voltage waveform after three-phase bridge rectifier of phases UA, UB, UC và $U_v(A)$, $U_v(B)$, $U_v(C)$, shown in Figures 7, 8 and 9.

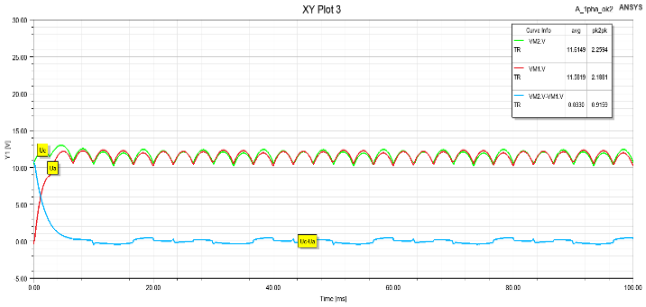

Figure 7. Voltage waveform U_C, U_A và $U_v(A) = U_C - U_A$ after three-phase bridge rectifier

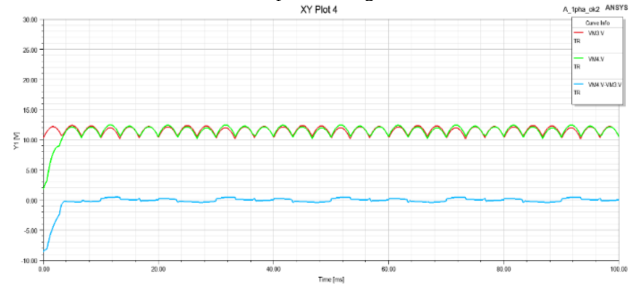

Figure 8. Voltage waveform U_A, U_B và $U_v(B) = U_A - U_B$ after three-phase bridge rectifier

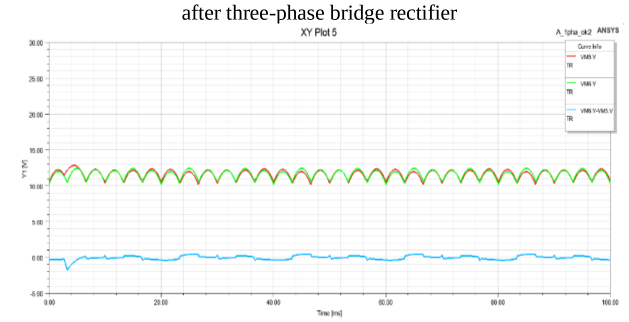

Figure 9. Voltage waveform U_B, U_C và $U_v(C) = U_B - U_C$ after three-phase bridge rectifier

2) When a phase A earth- fault occurs

The 3-phase voltage after the low-voltage transformer when the A-phase earth- fault occurs shown in Figure 10.

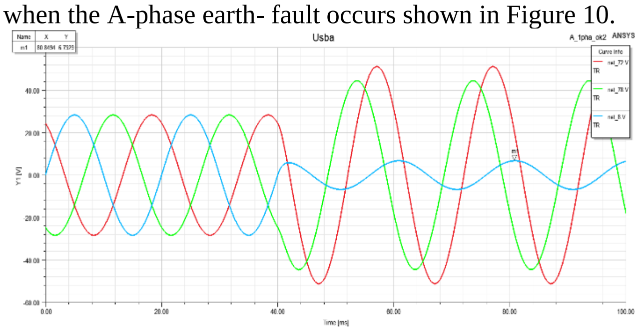

Figure 10. The 3-phase voltage after the low-voltage transformer when the A-phase earth fault occurs (Urms of phase A decreases from 20V to 4.7V)

Simulations are in the following cases:

a) Changing the end phase angle of the grid voltage (ψ)

The variable scan $\psi = 0 \div 180^o$ is performed with a scan step of 10^o. The graph of ahead phase and phase-to-earth voltage difference corresponds to the end phase angle and the detectable time, shown in Figures 11, 12 and 13.

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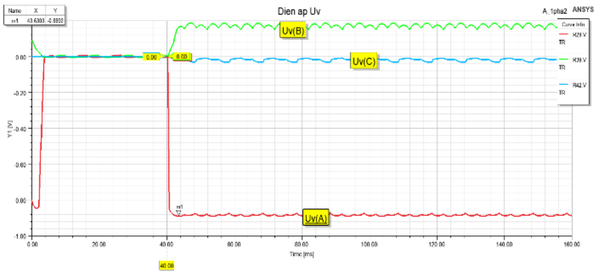

Figure 11. The graph of ahead phase and phase-to-earth voltage difference (ψ = 0°, t < 3ms)

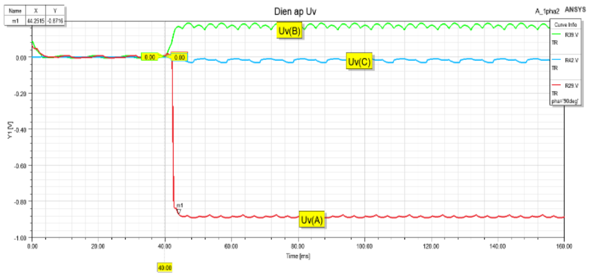

Figure 12. The graph of ahead phase and phase-to-earth voltage difference (ψ = 90°, t< 4 ms)

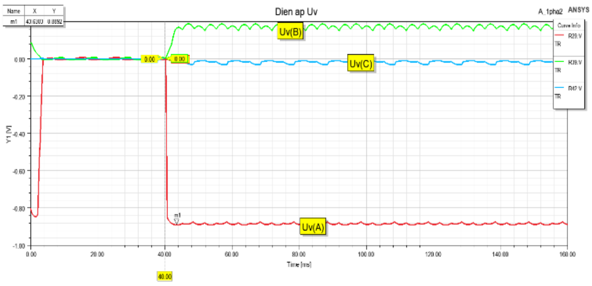

Figure 13. The graph of ahead phase and phase-to-earth voltage difference (ψ = 180°, t < 2 ms)

b) Changing leakage resistance (Rro).

The leakage resistance (Rcđ = 0,65÷15kΩ) is changed with a scan step of 1kΩ. The graph of ahead phase and phase-to-earth voltage difference corresponds to the end phase angle and the detectable time, shown in Figures 14, 15, 16.

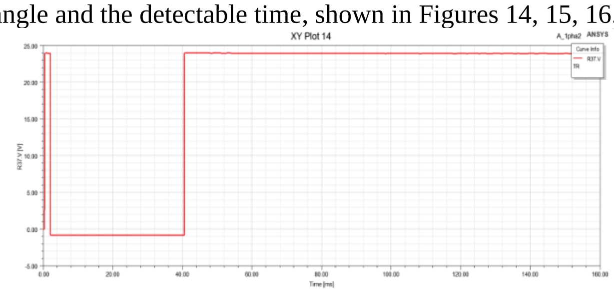

Figure 14. The graph of ahead phase and phase-to-earth voltage difference (R = 0.65 kΩ; t =0.61 ms)

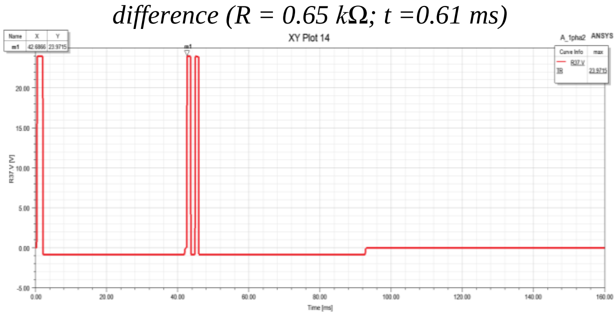

Figure 15. The graph of ahead phase and phase-to-earth voltage difference (R = 11.46 kΩ; t =2.68 ms)

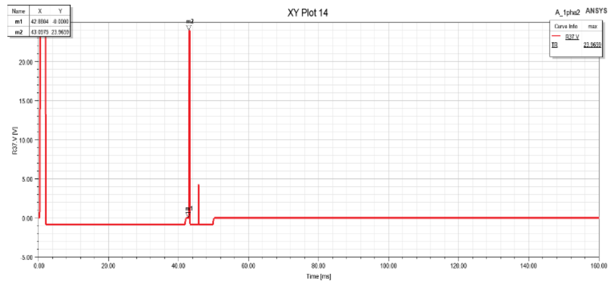

Figure 16. The graph of ahead phase and phase-to-earth voltage difference (R = 15 kΩ;t =3.1 ms)

c) Chaning the the grid capacitance (C).

The variable scan (C = 0.25, 0.5, 1, 2, 3μF) and Rcđ = 1kΩ is performed. The graph of output voltage on tải cực C of PNP2 when the grid capacitance changes and the graph of the relationship between the grid capacitance with the phase-to-earth detectable time shown in Figure 17.

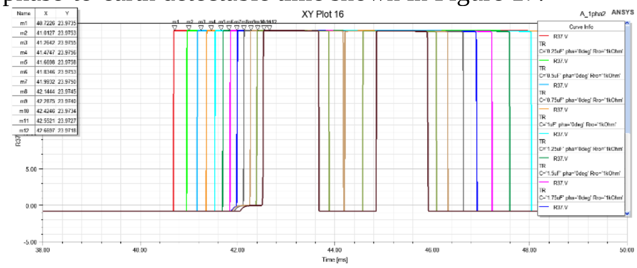

Figure 17. The graph of output voltage on tải cực C of PNP2 when the grid capacitance changes (from 0.25 to 3 μF/ 1 phase)

Remark: When the capacitance and insulation resistance of the network is C = 0,263μF/phase, R=364kΩ/phase, respectively, with an earth-fault resistance less than 11.46kΩ will ensure the essential sensitivity - the device will operate reliably.

Detectable time of earth-fault phase when the single-phase earth-fault through the resistor 1kΩ is t < 3ms. The operating time of short-circuit connection of the earth-fault phase is t < 10ms.

3.2. Design a circuit that automatically detects and phase-to-earth short-circuit based on simulation results

Using automatic circuit design software Altium Designer 18, according to the product manufacturing and design process, the results are shown in Figures 18, 19 and 20.

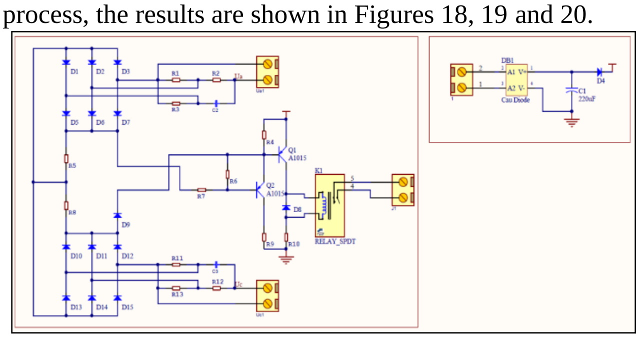

Figure 18. Circuit diagram of earth-fault phase detection

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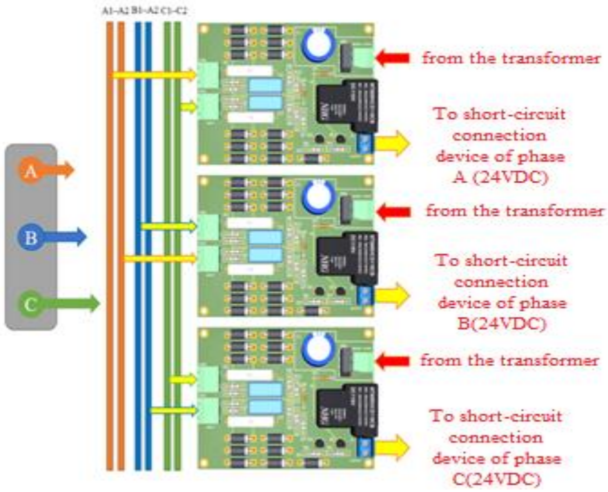

Figure 19. The diagram of device connection

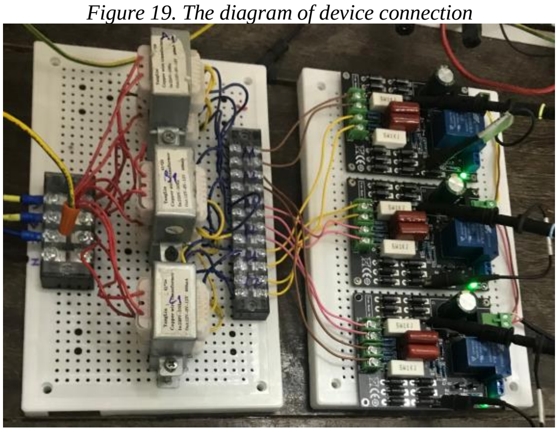

Figure 20. Actual image of the circuit that automatically detects and connects the phase earth-fault short-circuit

4. CONCLUSIONS

Based on the simulation results, the following conclusions can be drawn:

The 6kV ground fault detectable device based on the principle of the absolute difference between the ahead phase and fault phase has a simple structure, sensitive ensuring, reliability and quick action in accordance with the requirements.

- When the capacitance and insulation resistance of the network is C = 0.263μF/phase, R=364kΩ/phase, respectively, with an earth-fault resistance less than 11.46kΩ will ensure the essential sensitivity - the device will operate reliably.

- Phase-to-earth detectable time when single-phase ground fault occurs through a resistor $1k\Omega$ is t < 3ms

- The operating time of a phase-to-earth short-circuit device is t<10ms.

The device of automatic detection and short- circuit of the fault- phase ensures rapid recovery of residual voltage on the busbar without the power supply interruption and the breakdown of insulation as well as reducing the overvoltage in the remaining phases at the time of earth- fault (from 3-4 times to 2.08 times), reducing the fault current is the solution to restrict power supply downtime and improve power quality when a ground fault occurs.

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