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RESEARCH ON SOLUTIONS ENHANCE POWER SUPPLY RELIABILITY WHEN SINGLE- PHASE EARTH-FAULTS OCCUR IN 6KV NETWORKS OF OPEN- PIT MINES IN QUANG NINH AREA

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SUMMARY OF THE DOCTORAL THESIS OF ELECTRICAL ENGINEERING

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INTRODUCTION

1. Reasons for choosing the topic

A single-phase earth-fault is the main type of fault that often occurs in 6kV networks of open-pit mines in Quang Ninh area, accounting for 70%÷80% of the total number of faults. According to statistical results show that, in open-pit mines, the probability of single-phase 6kV ground -faults fluctuates about 60-70 times/month or 700-800 times/year [3].

When the single-phase earth- fault happens on the grid, there will emerge the transient phenomenon and the overvoltage in the unfaulted phases, considerable influencing on power supply reliability, working ability, lifetime of electrical equipments as well as causing grid asymmetry.

Therefore, the research and construction of a device which automatically detects and connects a phase-to-earth short circuit to improve the reliability of power supply and reduce the time of power outage when a single-phase earth fault occurs in 6kV networks of open-pit mines in Quang Ninh has significant scientific, reality and urgent.

2. The aim of the thesis

Research and build an equipment which automatically detects and connects short-circuit phase to ground to improve power supply reliability, reduce the time of power supply interruption when the single phase earth-faults occur in 6kV networks of open-pit mines in Quang Ninh area.

3. The scientific significance and reality of the thesis

- The scientific significance

+ Build the dependent relationship between the insulating capacitance and conductance of the network compared to the ground, base on the structural parameters of the grid and the mining environment in Quang Ninh region, as a basis for modeling the 6kV power grid in the open-pit mine.

+ Research and build a device that automatically detects and connects a phase-to-earth short circuit to improve the reliability of power supply and reduce the time of power outage when a single-phase earth fault occurs as well as ensure the safety of people and equipments when operating the 6kV power network of open-pit mines in Quang Ninh operates.

- The practical significance

The construction of a device which automatically detects and connects a phase-to-earth short circuit in a laboratary ensures the sensitivity, reliability and quick action when a single-phase earth fault for 6kV networks of open - pit mines in Quang Ninh area.

4. The research object

The 6kV isolated networks of open-pit mines in Quang Ninh area

5. The scope of a study

- Open-pit mines in Quang Ninh area
- The reliability of power supply when single phase earth-fault happens: to reduce the time of power outage.
- Research and build an equipment which automatically detects and connects short-circuit phase to ground to improve power supply reliability, reduce the time of power supply interruption when the single phase earth-faults occur in 6kV networks of open-pit mines in Quang Ninh area

6. The method of study)

Theoretical research combined with experimental one.

Apply modern techniques and simulated software to solve real problems.

7. The expected (new) results of the project

Build the dependent relationship between the insulating capacitance and conductance of the network compared to the ground, base on the structural parameters of the grid and the mining environment in open-pit mines, Quang Ninh region.

Research and select solutions to automatically detect ground fault phase; build a structure diagram and simulate a device that automatically detects and connects short-circuit to the ground phase to ensure safety, reduce fault currents and arcing at the point of intermittent earth-fault; increase power supply reliability, reduce power failure time, increase residual voltage in the ground-fault phase, reduce overvoltage in unfault phases and increase insulation resistance and reduce switching times.

Research and build an equipment for automatic detection and short-circuit connection of phase-to-earth in the laboratory applied to open-pit mines in Quang Ninh region.

8. Outline of thesis

The thesis includes an introduction, a conclusion, 04 chapters in 122 pages and an appendix)

Chapter 1
AN OVERVIEW OF SOLUTIONS TO IMPROVE RELIABILITY, REDUCE POWER FAILURE TIME WHEN THE SINGLE PHASE EARTH-FAULTS OCCUR

1.1. The reliability of the grid

1.1.1. Causes of the power failure and damages by power failure

1.1.2. The effect of reliability on the structure of power grids and power systems

1.1.3. The reliability of the grid elements

1.1.4. The reliable criteria of the power grid [3, 20].

Research on the reliability of the power grid, the main reliable criteria are often used such as:

- The average number of power outages for a load in one year (in the case of using the short-circuit connection equipment when earth-fault occurs, the average number of power outages in 1 year will be significantly reduced; the results will be statistically if a ground-phase short-circuit connection device is used);
- The average power outage time for a load in 1 year (similar to power outage time in 1 year will be significantly reduced if a earth-fault phase short- circuit device is used);
- Electrical energy breakout due to power outage (similar to electrical energy breakout due to power outage will be reduced when a short-circuit connection equipment is used);
- Economical loss due to power outage.

1.1.5. Main factors affect the grid’s reliability, solutions to reliable improvement

- The grid structure is Well organized, grid diagrams which have high-redundancy are able to flexibly remotely control or automatically.

- Well organized planning, operation control and management system. In the planning, it is necessary to choose the optimal structure of the power grid, not only choosing the diagram and force devices, but also choosing the control system, applying scientific and technical progress on building the structure of power grid in the future. In operation, it must be solved quickly when a fault occurs: for example, when an intermittent earth-fault occurs, it must be handled in time: using a device to short- circuit the fault phase in order to increase residual voltage, reduce power outage time power. After 60 seconds, if the fault runs out, the system will return to normal work, cut off when the fault cannot be ruled out

- Improve the skills of operators and create conditions for them to work well to avoid errors in operating controls.

- Accurately forecast loads and weather to give solutions adaptively operating to reduce the risk of faults and power outages.

The reliability is an optimal problem, which means that there will be a reasonable level of confidence that reconciles factors related to reliability such as investment capital for the power grid, loss due to power failure…

1.2. Solutions to improve reliability, reduce power outage time when a single-phase earth fault occurs in countries around the world

1.2.1. The surveillance equipments for the insulation status of the network

1.2.2. Optimizing network neutral mode

1. Capacitance current compensation for single-phase ground fault

2. The neutral is grounded through the Peterson coil and the resistor in parallel

3. The neutral is connected to ground via a high resistor

4. The neutral is connected to ground via a low resistor

1.2.3. The automatical method shunts the ground fault phase

1. Theoretical basis for building a device used to detect ground – fault phases.

2. The device reacts to an absolute decrease in the phase-to-earth voltage (or an absolute increase in the non-earth two-phase voltage)[33,37,43, 48].

3. The device reacts to the sum (or subtract) of the reference voltage vector and the zero sequence voltage.

4. The device reacts to the rectifier voltage decrease of the ground-phase

5. The device reacts to the phase difference angle between the phase voltage and the zero sequence voltage

6. The earth-fault phase device reacts to the absolute difference between the over voltage phase and the combination of the remaining two phase voltages and the zero sequence voltage.

7. The device reacts to the absolute difference of the voltage: between the over phase and the ground -fault phase.

1.3. Solutions to improve reliability, reduce power outage time when a single-phase earth- fault occurs in Vietnam.

In 1986-1988, design, manufacture and installation of single-phase selective earth-fault relay system for 6kV terminals of 35/6 kV intermediate transmission substation of Mao Khe coal mine in Quang Ninh was carried out. In this work, the authors used the electromagnetic field theory method to calculate the capacitance of the grid to the ground (ignoring the conductive effect of the grid compared to the earth), and then combined it with experimental measurements to determine the earth-fault currents of the terminals and set up the protective relays.

In 1994÷1996 [6] capacitance C and inductance G of the network to the ground were determined, based on experimental measurement results were determined the rule of change of capacitance C and inductance G of the 6kV grid in Vietnamese mines, the results are described as follows:

$$C = a_0 + a_1.N + a_2.L_{dqđ} + a_3.L_{cqđ}$$

$$G = b_0 + b_1.N + b_2.L_{dqđ} + b_3.L_{cqđ}$$

Whereas: a_0, a_1, a_2; b_0, b_1, b_2 – ; $L_{dqđ}$, $L_{cqđ}$ –overhead- line length and cable length converted to cross-section $50mm^2$.

In 2015 [10] studied to ensure the safety of electric shock in 1140V underground mine electrical networks in Quang Ninh region according to the circuit diagram of automatic detection and short-circuit connection according to the reaction principle with absolute value difference. the ratio between the front phase voltage and the remaining two phase voltage combination and zero sequence voltage.

In 2016 [4], an experimental relationship was built which shows the dependent relationship between the insulation capacitance and the insulation conductance of the phase to the ground according to the structural parameters of the network of Cam Pha - Quang Ninh and provide the solution to connect low-voltage resistors to the open delta coil of the measuring transformer in order to reduce overvoltage when the single-phase earth-fault happens.

Recently, a number of works researching on single-phase earth fault have been carried out in the direction: Selecting a reasonable value and type of relay for earth- fault protection, improving sensitivity and selectivity [3-42] ; Building methods for determining the insulation parameters of the isolated neutral -network[4].

1.4. Comment on chapter 1

- In Vietnam, especially open-pit mines in Quang Ninh region, there has not been any intensive research on improving the reliability of power supply when a single-phase earth- fault occurs in an 6kV isolated neutral grid.

- There has not been any research focusing on predicting the insulation status of isolated neutral networks in open-pit mines of Quang Ninh region in accordance with different working states of the load when temperature and humidity change annual year.

- A number of domestic and foreign works (from 2016 and earlier) have used experimental measurement methods to build the dependent relationship between the insulation parameters of the network (capacitance and inductance) with the structure of grid.

- Currently, because climate change, mining production, geological conditions and modern techniques have changed a lot, the above research results are no longer suitable.

- The works on the solution of automatic shunt in single-phase ground fault are calculated in the condition of ideal insulation resistance, considering only the capacitance of the network, are not satisfactory in the actual conditions of open-pit mines Quang Ninh region

- Identify dependent relationship based on reality in the moment according to actual structure and environment (temperature, humidity) with development needs of society.

- The solution to automatically connect short –circuit in the fault -phase is considered as a basic solution to improve the reliability of power supply when a single-phase earth -fault occurs in a 6kV isolated neutral network.

- Research on building the structure of short-circuit connection device to phase-to-earth network of 6kV open-pit mine in Quang Ninh region according to the absolute value coefficient between the voltage of the over phase and the fault phase with a simple structure, the minimum number of elements that still ensure high sensitivity, fast action time, urgent, scientific and practical significance.

Chapter 2
DETERMINATION OF DEPENDENT RELATIONSHIP BETWEEN INSULATION PARAMETERS WITH NETWORK STRUCTURAL ONES AND ENVIRONMENTAL OF OPEN - PIT MINES OF QUANG NINH AREA

2.1. Determination of insulation parameters of 6kV electric network of open- pit mines in Quang Ninh region

2.1.1. Select measurement method

2.1.2. Determine the number of essential measurements

2.1.3. Theoretical basis defining C and G

2.1.4. Experimental measurements

2.2. Building the dependent relationship between the insulation capacitance Cf and the insulation conductance Gf of the network to the ground according to the structural parameters of the

network and the environment.

2.2.1. Frequency of capacitance C and inductance G of phase-earth insulation

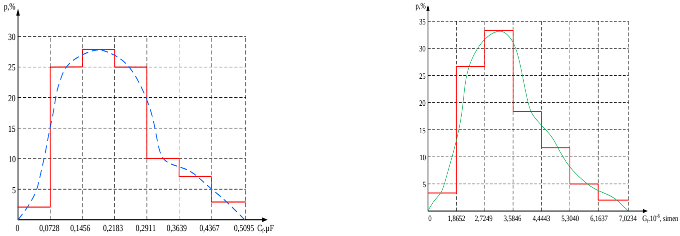


Figure 2.4 Graph of frequency of capacitance Cf and inductance Gf insulated- phase from earth

2.2.2. Check the standard distribution of insulation capacitance and inductance

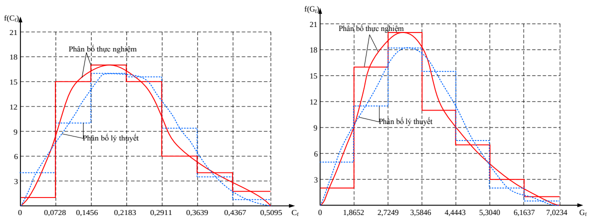


Figure 2.5. Graph of the standard distribution of insulation capacitance and inductance in the open-pit mines in Quang Ninh region

2.2.3. Convert cross - section of overhead lines and cables to standard one

2.2.4. Summary of calculation results

2.2.5. Building the dependent relationship between the insulation capacitance Cf and the insulation conductance Gf with the environment and structural parameters of the 6kV open-pit mine networks

a) Equation describing the relationship of insulation capacitance C_f

$$C_f = -0{,}45706 + 0{,}00555.D_a - 0{,}0005.T_d + 0{,}00594.N_{BA} + 0{,}01839.N_{đc} + 7{,}95.10^{-6}.L_{Tk.qđ} + 0{,}00015L_{C.qđ},\ \mu F \quad (2.23)$$

b) Equation describing the relationship of insulation conductance Gf

$$G_f = 0{,}5298 + 0{,}006064.D_a - 0{,}0042.T_d + 0{,}05288.N_{BA} +$$

$$0{,}064474.N_{đc} + 0{,}000144.L_{Tk.qđ} + 0{,}001686.L_{C.qđ}, S \quad (2.24)$$

Based on the obtained regression equation, it is shown that:

- If the number of motors $N_{ĐC}$, temperature Td, humidity Da, overhead line length L_{Tk}.qd and cable L_{C}.qd do not change, a transformer N_{BA} increase will make the insulation capacitance and inductance of network increase (Cf will increase by 0.00594 μF; Gf will increase by 0.05288. 10^{-6} Simen).

- If the number of transformers NBA, temperature Td, humidity Da, overhead line length LTk.qd and LC.qd cable do not change, an electric motor 1 NDC increase will make the capacitance and inductance the phase insulation of the network increase (Cf will increase by 0.01839 μF; Gf will increase by 0.064474. 10^{-6} Simen).

- If the number of motors NDC, temperature Td, humidity Da, transformer NBA and cable length LC.qd do not change, every 1km of overhead line which is not converted LTk.qd is increased ,capacitance and conductance of the network increase (Cf will increase by 7.95. 10^{-6} μF; Gf will increase by 0.000144. 10^{-6} Simen).

- If the number of motors NDC, temperature Td, humidity Da, transformer NBA and the length of the overhead line LTk.qd do not change, every 1km of the cable converted to LC.qd is increased capacitance and inductance of the network increase (Cf will increase by 0.00015 μF);

- The starting point of the model a0= -0.45706 shows that other factors affecting insulation capacitance of the phase Cf network are 0.45706 μF

- The starting point of the model b0= -0.45706 shows that other factors affecting insulation inductance of network Gf are 0,529854.10^{-6} Simen

- Multiple C_f (R =0,908382) và Multiple G_f (R =0,999701077) show that the relationship among the variables is very close.

- R^2 = 0.825157 shows that in 100% of the insulation capacitance value, 82,5157% is due to the number of transformers, temperature Td, humidity Da, motors, overhead lines and cables. remaining random factors and others negligibly influence.

- R^2 = 0,996182 shows that in 100% of the insulation inductance value, 0,991515% is due to the number of transformers, temperature Td, humidity Da, overhead lines and cables. remaining random factors and others negligibly influence.

- Cf: F = 41.68819306 with probability Significance F = 2.30721E-18 is less than 0.02 significance probability, so the linear regression equation is accepted.

- G_f: F = 1150,044 with probability Significance F = $2,9.10^{-54}$ is less than 0.02 significance probability, so the linear regression equation is accepted.

2.3. Comment of chapter 2

- Selecting a measurement method using 3 Voltmeters has many outstanding advantages which is analyzed above to determine the capacitance C and inductance of the network to earth.

- Build the experimental relationship between the capacitance Cf and the inductance Gf to the ground depends on the environmental parameters (temperature, humidity) and the open-pit mine network structure in Quang NInh region:

$$C_f = -0{,}45706 + 0{,}00555.D_a - 0{,}0005.T_d + 0{,}00594.N_{BA} + 0{,}01839.N_{đc} + 7{,}95.10^{-6}.L_{Tk.qđ} + 0{,}00015L_{C.qđ}, \mu F \quad (2.23)$$

$$G_f = 0{,}5298 + 0{,}006064.D_a - 0{,}0042.T_d + 0{,}05288.N_{BA} + 0{,}064474.N_{đc} + 0{,}000144.L_{Tk.qđ} + 0{,}001686.L_{C.qđ}, S \quad (2.24)$$

Chapter 3

RESEARCH ON MAKING A PHASE EARTH-FAULT SHORT- CIRCUIT AUTOMATICALLY CONNECTING AND DETECTING DEVICE TO ASSURE SAFETY AND ENHANCE RELIABILITY OF 6kV GRID POWER SUPPLY IN OPEN-PIT MINES IN QUANG NINH AREA

3.1. Residual voltage and earth-fault current of 6kV grid in open-pit mine when short-circuiting phase earth-fault

3.1.1. Theoretical basis

3.1.2. Simulation of the dependent relationship between residual voltage (before contact) on phase earth-fault with load current, conductor length and short-circuit resistance change in 6kV grid.

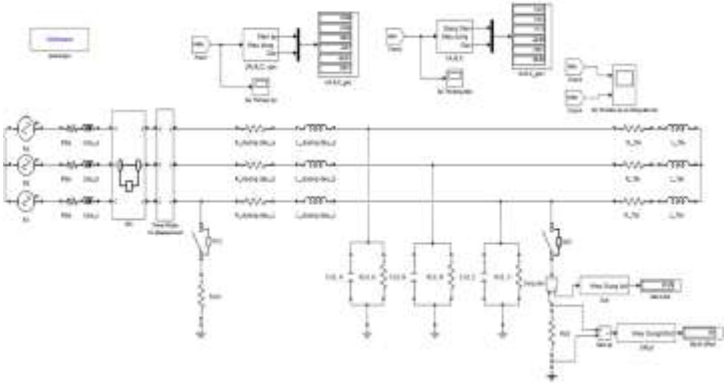


Figure 3.3. Simulation diagram of 6kV grid with 1-phase earth-fault and when closing short-circuit resistor R_{nm}

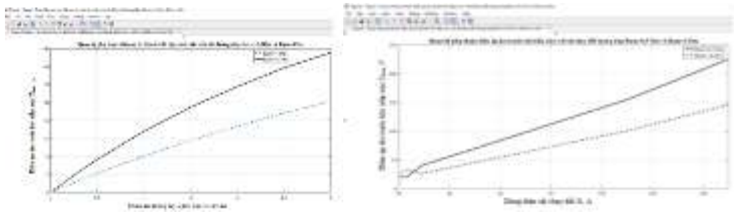


Figure 3.4. Dependent relationship between residual voltage (before contact) on fault phase with lead length and load current corresponding to short circuit resistance R_{nm} =0,5Ω and 4Ω and l=3km [3].

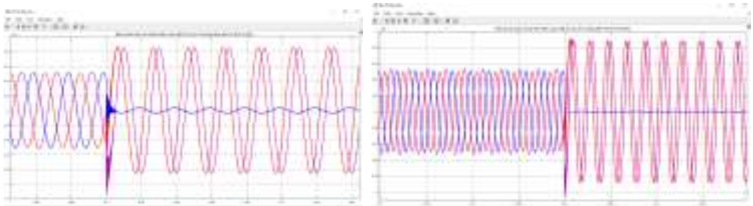


Figure 3.5 a- Voltage on the busbar at the time of earth-fault t=0.3s when not closed Rn.m ; b- Voltage on busbar at the time of earth-fault t=0.3s when closed R_{nm} =0,5Ω với R_{cd} =4Ω.

3.1.3. Comments

The actual length of the grid and the distance from the point of placing the automatic closing device to the point of earth-fault can be increased by 2÷3 times than the allowable limit length under safety conditions without disconnecting the grid. Then, the induced touch voltage can reach 100÷155V - when the grid length changes 0÷3km; 145÷225V - when the load changes 20÷150A. Using a multi-position automatic ..... solution in combination with a protective disconnection solution complicates the protection system and loses the superiority of the short-circuit connecting device to ensure continuity in the power supply.

The automatic short-circuit protection device is used as a means of improving the reliability of power supply in the event of an earth-fault instead of the automatic backup device. Although the residual voltage at the earth-fault position can fluctuate in the range of 20 - 225V, the application of a quick-acting automatic protection device is to limit the fault current, ensure quick recovery of voltage on the fault phase, not break the insulation in the remaining phases, reduce the overvoltage at the time of earth-faulth (from 3-4 times to 2,08 times), extinguish sparks at the fault locations, and not interrupt the power supply.

3.2. Research on making a phase earth-fault short-ciruit automatically connecting and detecting device of 6kV grid in open-pit mines in Quang Ninh area

3.2.1. Requirements for a phase earth-fault short-ciruit automatically connecting and detecting device [33][37][51][66]

3.2.2. Structure of a phase earth-fault short-ciruit automatically connecting and detecting device [48, 52, 76]

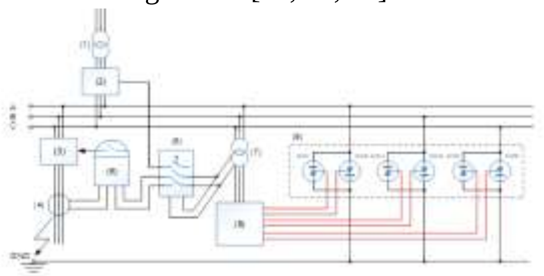


Figure 3.6. Structure of a phase earth-fault short-ciruit automatically connecting and detecting device

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

3.2.3. Basis for making a phase earth - fault determining device [48,50, 79]

3.2.3.1. Phase voltage and zero sequence voltage when a single-phase earth-ault occurs;

3.2.3.2. Principles of making a phase earth-fault determining device;

a) According to the decrease in the phase earth-fault voltage (while the two-phase non-earth-fault voltage increases);

b) According to the phase difference angle between the phase earth-fault voltage and the zero sequence voltage;

c) According to the absolute value difference between two electrical quantities, one is the leading phase voltage, the other component is the voltage combination of the behind phase voltage and the zero sequence voltage.

d) According to the absolute value difference of the leading phase and the phase earth-fault.

From the analysis of the abovementioned principles, it can be seen that, principle a) has the disadvantage that the sensitivity is not high (1÷2kΩ/phase in a grid with C=1μF). Principles b and c allow to select the phase earth-fault with higher sensitivity but complex structure. The principle d has a simpler structure with the least number of elements which still ensures high sensitivity. The content of principle d is as follows [36]:

$$U_V(A) = |U_C| - |U_A| \quad (3.21)$$

$$U_V(B) = |U_A| - |U_B| \quad (3.22)$$

$$U_V(C) = |U_B| - |U_C| \quad (3.23)$$

3.2.3.3. Block diagram of the device determines the phase earth-fault based on the absolute value difference between the voltage of the leading phase voltage and the phase earth-fault

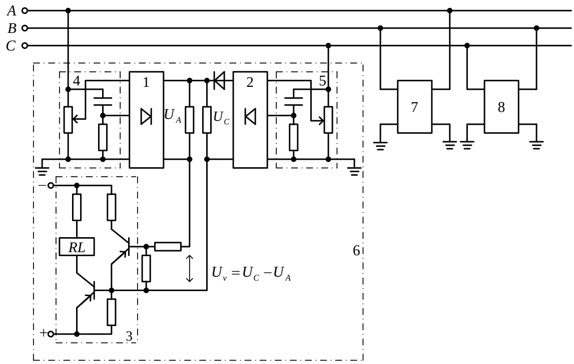


Figure 3.8. Block diagram of the device determines the phase earth-fault based on the absolute value difference between the voltage of the leading phase voltage and the phase earth-fault

3.3. Making a block diagram of phase earth-fault short-ciruit automatically connecting and detecting device

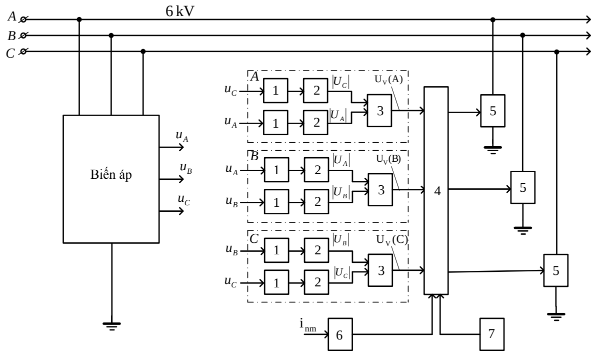


Figure 3.10. Block diagram of the phase earth-fault short-ciruit automatically connecting and detecting device

3.3.1. Principle diagram of the phase earth-fault detecting circuit (blocks 1,2,3)

Principle diagram of the phase earth-fault automatically detecting circuit shown in Figure 3.11.

The principle diagram of the signal taking module for the control circuit connected to the phase A short-circuit is shown in Figure 3.12.

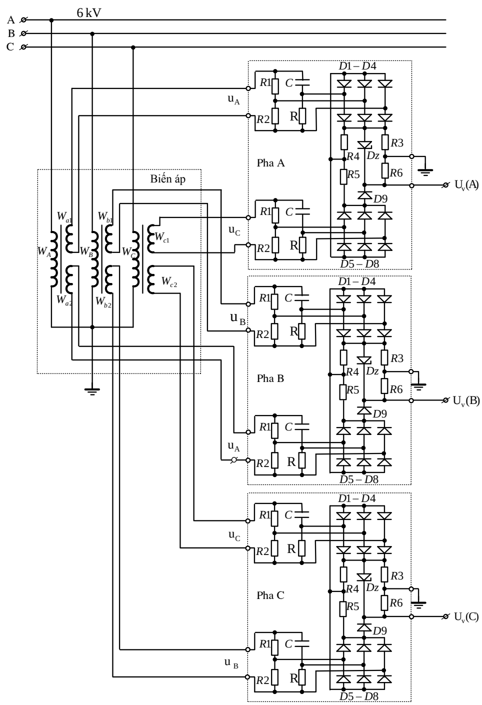


Figure 3.11. Principle diagram of phase earth-fault automatically detecting circuit

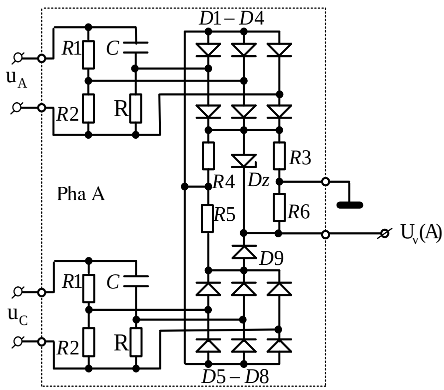


Figure 3.12. Principle diagram of the phase A short-circuit control signal taking module

3.3.2. Single phase to 3 phase converter with 60^0 out-of-phase

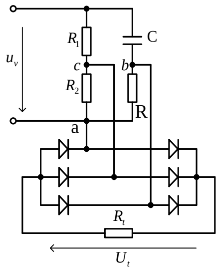


Figure 3.13. Single-phase to three-phase converter

3.3.3. Principle diagram of the interlock circuit between phases (block 4)

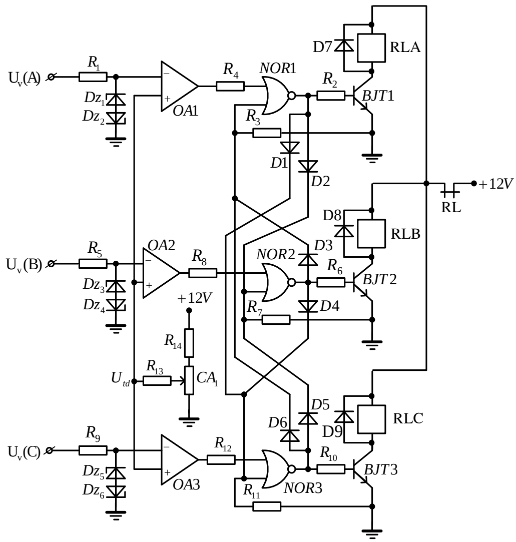


Figure 3.14. Principle diagram of the interlock circuit between phases

3.3.4. Principle diagram of automatic-shutoff control circuit after short-circuit connecting 30-60s (block 7)

The principle diagram of automatic-shutoff control circuit after phase short-circuit connecting shown in Figure 3.15.

Synthesization of the principle diagram of blocks 1, 2, 3, 4 and 7 of the phase earth-fault short-ciruit automatically connecting and detecting device is shown in Figure 3.16.

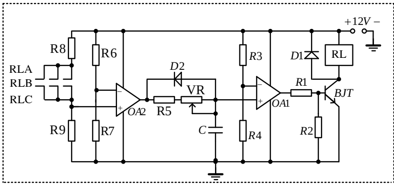


Figure 3.15. Principle diagram of automatic-shutoff control circuit after short-circuit connecting

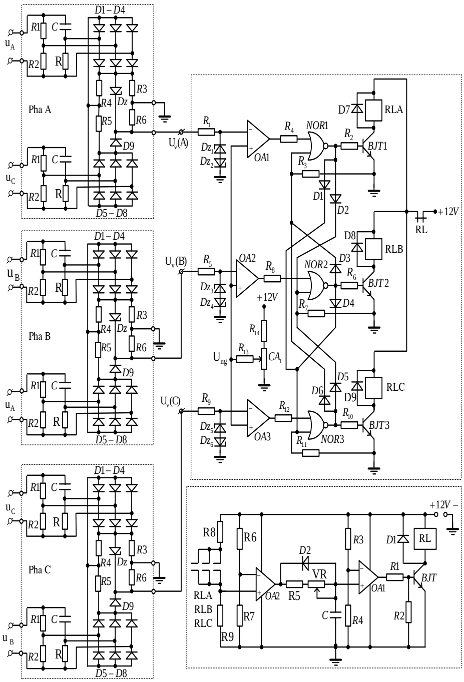


Figure 3.16. Principle diagram of blocks 1, 2, 3, 4 and 7 of the phase earth-fault short-ciruit automatically connecting and detecting device

3.4. Simulation of the phase earth-fault short-ciruit automatically connecting and detecting device

3.4.1. Before earth-fault occurrence

The principle diagram of the phase earth-fault detecting circuit is shown in Figure 3.17.

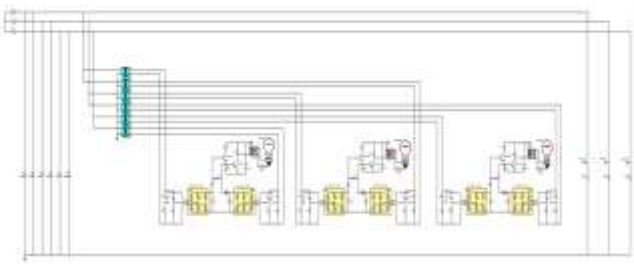


Figure 3.17. The phase earth-fault detecting circuit

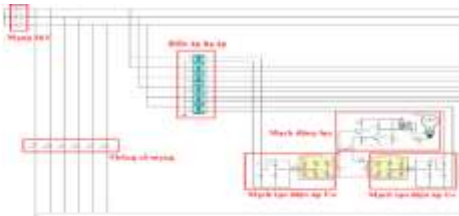


Figure 3.18. Voltage generator circuit Uv (A)

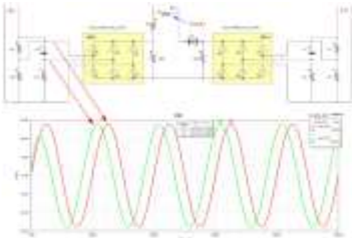


Figure 3.21. Diagram of voltage generator circuit
UV(A) = UC-UA

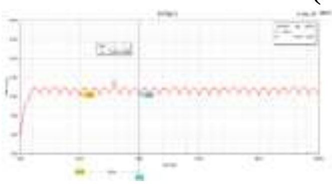


Figure 3.22. Phase voltage waveform UA after 3-phase bridge rectifying (*frequency 300Hz, amplitude:11.6V, amplitude of peak-to-peak voltage fluctuation: ~ 2.2V)*

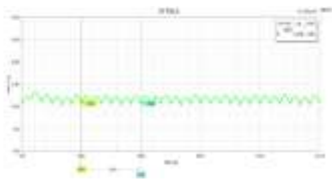


Figure 3.23. Phase voltage waveform UC after 3-phase bridge rectifying (*frequency 300Hz, amplitude:11.6V, amplitude of peak-to-peak voltage fluctuation: ~ 2.26V)*

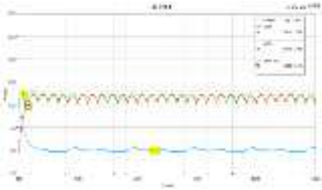


Figure 3.24. Voltage waveform U_C, U_A and $U_v(A) = U_C - U_A$ after 3-phase bridge rectifying

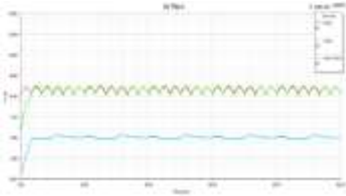


Figure 3.25. Electric waveform U_A, U_B and $U_v(B) = U_A - U_B$ after 3-phase bridge rectifying

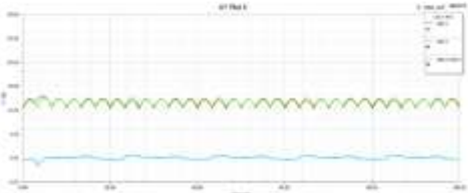


Figure 3.26. Voltage waveform U_B, U_C và $U_v(C) = U_B - U_C$ after 3-phase bridge rectifying

3.4.2. After phase A earth-fault occurs

Figure 3.27. 3-phase voltage after transforming when phase A earth-fault occurs *(Urms phase A reduces from 20V to 4.7V)*

1. The case of changing the first phase angle of the grid voltage:

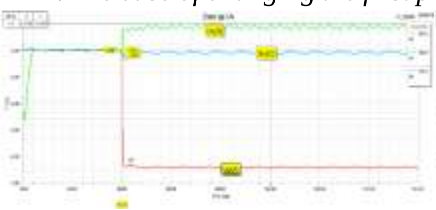


Figure 3.30. Graph of voltage difference of leading phase and phase earth-fault (ψ = 60^o, t < 2 ms)

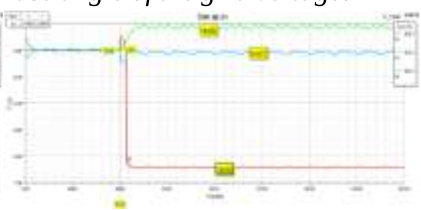


Figure 3.33. Graph of voltage difference of leading phase and phase earth-fault (ψ =120^o, t< 4ms)

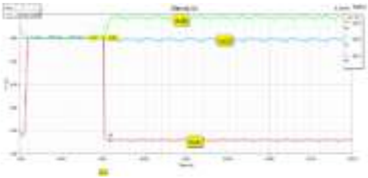


Figure 3.35. Graph of voltage difference of leading phase and phase earth-fault (ψ =180^o,t<2 ms)

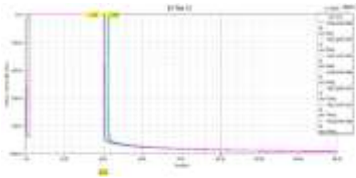


Figure 3.37. Ube voltage graph of PNP2 when earth-fault occurs

2. The case of changing the earth-fault resistance:

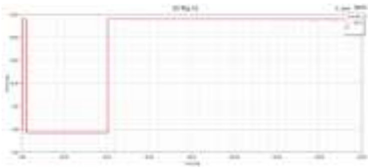


Figure 3.39. Graph of voltage difference of leading phase and phase earth-fault (R = 0.65k**Ω***;* t =0.61ms)

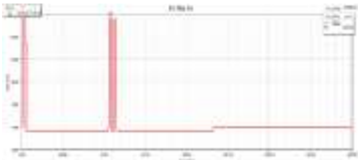


Figure 3.44. Graph of voltage difference of leading phase and phase earth-fault (R = 11.46k**Ω***;* t =2.68ms)

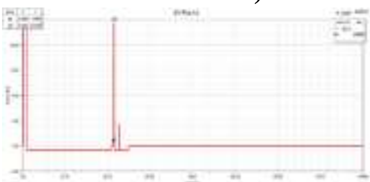


Figure 3.46. Graph of voltage difference of leading phase and phase earth-fault
(R = 15k**Ω***;* t =3.1ms)

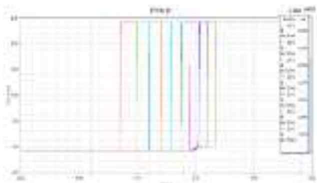


Figure 3.47. The graph shows the output voltage on the pole load C of PNP2 when the earth-fault resistance changes from 1 to 10k**Ω**

3. The case of changing the grid capacitance:

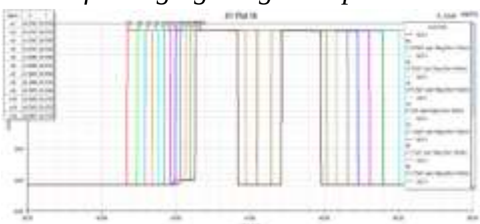


Figure 3.49. Output voltage graph of PNP2's pole load C when the grid capacitance changes from 0.25 to 3 µF/1 phase

Comments: When the capacitance and insulation resistance of the grid relative to the earth correspond to: R= 292kΩ/phase, C = 0.261μF/phase with the earth-fault resistance of less than 11.46kΩ will ensure the necessary sensitivity - the device will act reliably and reliably.

The time to detect the phase earth-fault at single phase earth-fault through the resistor $1k\Omega$ is t < 3ms.

The operating time of the phase earth-fault short-circuit connection is t < 10ms.

3.4. Comments for chapter 3

The short-circuit automatically protecting device is a means of improving the reliability of power supply in the event of an earth-fault instead of the backup automatic closing device. Although the residual voltage at the earth-fault position can fluctuate in the range of 20-225V, the application of a quick-acting automatic protection device is to limit the fault current, ensure quick recovery of voltage on the fault phase, not break the insulation in the remaining phases, reduce the overvoltage at the time of earth-faulth (from 3-4 times to 2,08 times), extinguish sparks at the fault locations, and not interrupt the power supply.

The simulation results show that phase earth-fault automatically detecting circuit meets the set requirements: Ensuring sensitivity, reliability and quick action.

Chapter 4
MAKING AN EXPERIMENTAL MODEL OF PHASE EARTH-FAULT SHORT-CIRCUIT AUTOMATICALLY CONNECTING AND DETECTING DEVICE IN THE LAB

4.1. Designing and simulating an experimental device model in the laboratory

4.1.1. Selecting the principle diagram

4.1.2. Simulation model

4.1.3. Designing and fabricating the phase earth-fault automatically detecting circuit

4.2. Experiment in the lab

4.2.1. Introduction to the experiment model

4.2.2. Experiment results

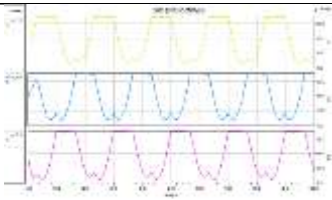
Simulation	Experiment
	

Figure 4.11. Signal before rectification

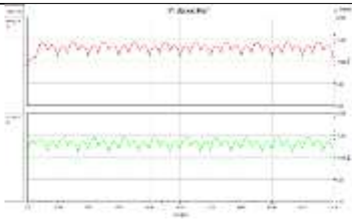
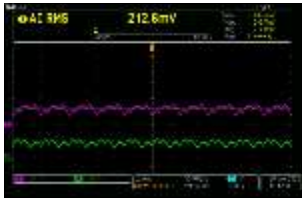
Simulation	Experiment
	

Figure 4.12. Signal after rectification of each phase

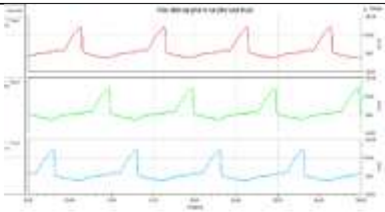
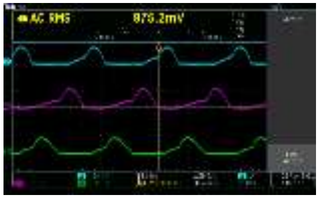
Simulation	Experiment
	

Figure 4.13. Voltage difference signal between phases when there is no fault

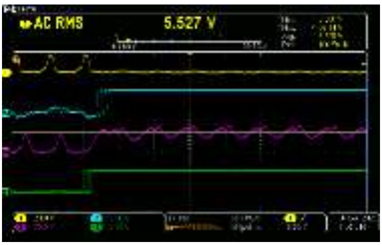


Figure 4.16. Waveform measured in phase A earth-fault experiment

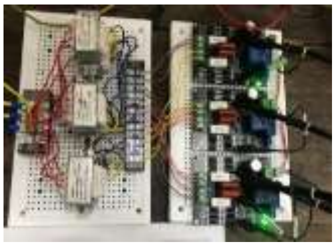
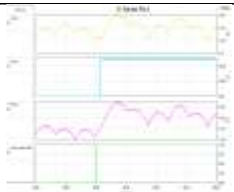
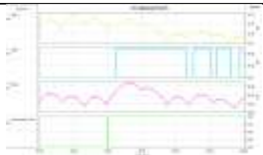
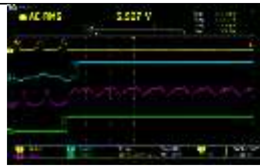
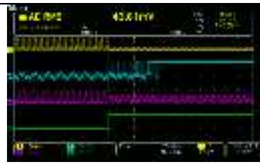


Figure 4.15. The image shows phase B earth-fault

Bảng 4.3. Experiment results determine the phase earth-fault detecting time.

No.	Leakage resistance (Ω)	Waveform graph: Simulation Operation time requirement ≤ 2ms because there is no relay element in simulation	Waveform graph: Experiment Relay operation time requirement ≤ 10ms	Detecting time (ms); conclusion
1	10			10 Passed
2	20			10 Passed
3	30			No earth-fault detected

4.3. Comments

- The simulated and experimental waveforms are similar. Deviation due to component error, real resistors and capacitors have ±5% error, while simulated components are ideal.

-The circuit is capable of detecting phase earth-fault

- For the grid converted from voltage 6kV to 400VAC, the circuit is capable of detecting leakage phase with a leakage resistance not exceeding 26.6Ω and affecting the relay with a total time not exceeding 10ms.

CONCLUSIONS AND PROPOSALS

I. Conclusion

The thesis is the first research in open-pit mines in Quang Ninh region in order to ensure safety conditions, improve the reliability of power supply and reduce the time of power outage when a single-phase earth -fault occurs, especially there are intermittent earth-faults in 6kV grids:

1. An overview of solutions to improve reliability – reduce time due to power outages in the event of a single-phase earth -fault.

2. The experimental relationship between the capacitance Cf and the inductance Gf of the phases to the ground is built, depending on the environmental parameters (temperature, humidity) and the structure of the open-pit mine network in Quang Ninh region (the number of transformers, high voltage motors, conversion lengths of overhead lines and cables):

$$C_f = -0{,}45706 + 0{,}00555.D_a - 0{,}0005.T_d + 0{,}00594.N_{BA} + 0{,}01839.N_{đc} + 7{,}95.10^{-6}.L_{Tk.qđ} + 0{,}00015L_{C.qđ}, \mu F$$

$$G_f = 0{,}5298 + 0{,}006064.D_a - 0{,}0042.T_d + 0{,}05288.N_{BA} + 0{,}064474.N_{đc} + 0{,}000144.L_{Tk.qđ} + 0{,}001686.L_{C.qđ}, S$$

Based on the obtained experimental relationships to simulate the actual working state of the network and take valid conclusions in order to improve reliability and reduce the time of power outage when grounding, when a single-phase earth -fault occurs, especially there are intermittent earth-faults in grids.

3. Research and select solutions to automatically detect ground -fault phase; build a structure diagram of the device that automatically detects and short-circuit to the ground phase to ensure safety, improve the reliability of power supply, and reduce the time of interruption of power supply when a ground fault occurs in the 6kV network of open-pit mines in Quang Ninh area.

4. Simulation of an equipment that automatically detects and short-circuit to ground phase to ensure safety, reduces fault currents, reduces arcing intermittent ground fault points: increases residual voltage at ground fault phase, reduces overvoltage at ground fault unfault phases; increase the insulation strength; reduce the time of power supply interruption, reduce the number of switching times, increase the reliability of power supply.

5. Research and build an equipment to automatically detect and short- circuit of earth-fault phase for open-pit mines in Quang Ninh in the laboratory.

II. Next research direction: complete the device so that it can be applied in practice and commercialize the product.

LIST OF PUBLICATIONS

1. Ho Viet Bun, Tran Quoc Hoan (2018), "Research on solutions enhance power supply reliability when single- phase earth- faults occur in 6kv networks of open- pit mines in Quang Ninh area". Collection of reports, XXVI National Mining Science and Technology Conference, August 2018, page (328-330).
2. Tran Quoc Hoan, Nguyen Anh Nghia, Ho Viet Bun (2019), Research on improving the reliability of power supply when a single-phase earth fault occurs in 6kV open-pit mine network, Mining Industry Journal, No. 2-2019, NS. 51-55.
3. Tran Quoc Hoan, Ho Viet Bun, Nguyen Anh Nghia (2020), "*Research on building for dependence of insulation parameters of the 6kV grid with the enviroment and structural parameters of open-pit mines in the Quang Ninh area".* International Journal of Engineering Technologies and Management Research, page (56-63).
4. Tran Quoc Hoan, Nguyen Anh Nghia, Ho Viet Bun (2021), "*Research on designing a detectable circuit of the earth- fault phase in order to enhance power supply reliability of the 6kv grid of open-pit mines, Quang Ninh area". National Conference on Mechanical, Electrical, Automation Engineering* (MEAE 2021), page 100-104.
5. Tran Quoc Hoan, Nguyen Anh Nghia, Ho Viet Bun (2022), "*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*". International Journal of Engineering Research & Technology (IJERT), page (208-212).