Designing Predictive Diagnose Method for Insulation Resistance Degradation of the Electrical Power Cables from Neutral Insulated Power Networks

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Abstract. This paper describe some possibilities to minimize voltages switching-off risks from the mining power networks, in case of insulated resistance faults by using a predictive diagnose method. The cables from the neutral insulated power networks (underground mining) are designed to provide a flexible electrical connection between portable or mobile equipment and a point of supply, including main feeder cable for continuous miners, pump cable, and power supply cable. An electronic protection for insulated resistance of mining power cables can be made using this predictive strategy. The main role of electronic relays for insulation resistance degradation of the electrical power cables, from neutral insulated power networks, is to provide a permanent measurement of the insulated resistance between phases and ground, in order to switch-off voltage when the resistance value is below a standard value. The automat system of protection is able to signalize the failure and the human operator will be early informed about the switch-off power and will have time to take proper measures to fix the failure. This logic for fast and automat switch-off voltage without aprioristic announcement is suitable for the electrical installations, realizing so a protection against fires and explosion. It is presented an algorithm and an anticipative relay for insulated resistance control from three-phase low voltage installations with insulated neutral connection.

1. Introduction

In underground mining are found different cable needs for both fixed and mobile installations in mines where electrification is the main source of power. A primary goal in the development of different compounds for cable insulations is to obtain physical and electrical characteristics that are stable at elevated temperatures in either wet or dry environments. From an engineering and design viewpoint, high temperature resistance is highly desirable and increases the safety factor during periods of emergency. Insulation stability during an emergency overload is of extreme importance [1].
Operating temperatures must be kept in the standard range because if the current load increases the degradation of insulations and coverings will accelerate. Thermal environment can affect the degradation of insulation at elevated levels since the speed of a chemical reaction is doubled with a 10°C rise in temperature [2]. The continuous exposure of cable to heavy environmental conditions is a major concern for cable engineers. All polymer-type coverings undergo degradation over time. Environment, installation and chemical composition of the polymer significantly influence longevity. Figure 1 shows a type of underground mining cables and what are the materials of which it is built.

![Cable Composition Diagram](image)

**Figure 1.** Materials composition of the electrical power cables from neutral insulated power networks.

Many cable failures are the direct result of excessive tension. A cable that has been “stretched” no longer has the balanced construction. Tension on the conductors subjects the individual wires in the strand to compression and shear. These thin wires are damaged and will break more easily when bent or flexed. In some cases of mechanical damage, the failure is instant, and the cause can be assigned on the spot. Many times, however, the cable components are only “injured” and become latent failures [3]. For the electrical systems (regarding the increase of their reliability and particularly for the increase of the safety in their usage) solid improvements of protection subsystems are needed, for the classical type with contacts and switches, as well as for the second generation type, with discrete components, semiconductors and integrated logical or analogical circuits [4].

There are two possible ways of achieving these conceptual improvements in the field of electric and electronic protection, by using micro programmable, dedicated electronic circuits, such as microprocessors, micro controllers, etc and by implicating the electronic computer, hence the control and command virtual systems.

2. **Anticipative Strategy for Insulation Resistance Degradation**

There are electronic protection devices against resistance degradation of the electrical power cables from neutral insulated power networks and they are realized for normal electrical atmosphere, but also for hazardous electrical areas. This are destined to be used in tree-phase electrical network with insulated neutral connection.

The control of insulated resistance is made as fallow:
- **Preventive**, is made when the network is not supplied with voltage and act before the principal circuit breaker therefore the relay realized a blocking command to the switchgear when the value of the insulation resistance is under impose limit.
- **Permanent**, is made when the network is supplied with voltage and act after closing the principal switchgear therefore if insulation resistance is diminished the relay signalized and give automate disconnect command respectively.

The functionality principle of this device consist of applied a continuous voltage cu minus polarity for the controlled electrical installation and the resulting current is measured because this current is dependent on the insulated resistance value.

### 2.1. Predictive diagnose method for insulation resistance degradation

In order to avoid unexpected switching-off voltage, when failure of electrical insulated resistance appear, is presented in figure 2 a predictive protection strategy for the insulated resistance control relay. If a degradation process of insulated resistance in taking place this function is like an integral temporal function and can be identify on the certain time interval with a temporal discreet value. The idea is to calculate the degradation speed \( \Delta R/\Delta t \) in the beginning degradation process of insulated resistance because the accepted limit value is known and so we can determine the time reserve.

![Figure 2. The predictive diagnose method for insulation resistance degradation.](image)

This reserve of time can help the energetic operator to maintain electrical installations supplied with voltage. This method is functional if the degradation characteristic is not changed very much.
2.2. Predictive flowchart for insulation resistance degradation

The relay functionality flowchart shown in picture 2 sequentially run through a few steps. At \( ET0 \) all the acquisition system ports are initialized in order to signalize the functionality of the relay, after this was voltage supplied.

\[
\text{START} \rightarrow \text{ET0} \rightarrow \text{Ports initializing} \rightarrow \text{YES} \rightarrow \text{NO} \rightarrow \text{start command?} \rightarrow \text{YES} \rightarrow \text{measure and display } R_{i,\text{nom}} \rightarrow \text{block command + signalizing} \rightarrow \text{NO} \rightarrow R_{i,\text{nom}} > R_{i,\text{prev}} \rightarrow \text{YES} \rightarrow \text{Accept the action command} \rightarrow \text{ET1} \rightarrow R_{i} > R_{i,\text{lim.all.}} \rightarrow \text{NO} \rightarrow \text{Instantaneous uncouple voltage} \rightarrow \text{YES}
\]

- Measure \( R_{i,(tx)} \)
- Measure \( R_{i,(tx-\Delta t)} \)
- Calculate \( \Delta R = R_{i,(tx-\Delta t)} - R_{i,(tx)} \)
- Calculate the degradation speed \( \frac{\Delta R}{\Delta t} \)
- Linear extrapolation of the insulated resistance characteristic intersection with \( R_{i,\text{lim.all.}} \)
- Determine \( t_d \)
- Display the calculated value of \( t_d \)
- Display \( R_{i,(tx-\Delta t)} \)

\[ \text{Figure 3. Predictive flowchart for insulated resistance control.} \]

Measure the voltage over resistance \( r \) realizing insulated resistance conversion, \( R_{iz} \), which is again measured and displayed.
The measured value of the nominal insulated resistance (Ri.nom.) in compared with the preventive insulated resistance (Ri.prev.) threshold value, which has a standardization value [5]:

- If the rated value of insulated resistance Ri.nom is greater than Ri.prev the relay allows the switching devices (K) to close and in this point the consumers (Zs) will receive electric voltage, jump to ET1;
- If Ri.nom is smaller than Ri.prev the relay obstructs a possible voltage supply command to consumers. The relay signalizes the deficiency and command an ET0 jump.
- If insulated resistance (Ri) is smaller then allowed limit insulated resistance (Ri.lim.all.) the relay give a command to switching devices (K) which instantaneous uncouple voltage. After that the relay give the signalizing signal command an ET1 jump;
- If Ri is greater than Ri.lim.all. then the resistance Ri(tx) is measured on the certain moment of time tx; after a certain time Δt the insulated resistance Ri(tx - Δt) is measure again; the next step is to calculate the difference ΔR = Ri(tx) - Ri(tx - Δt); the insulated resistance degradation speed is calculated; the insulated resistance characteristic is linear extrapolating and will be intersected with the insulated resistance characteristic which is standardization allowed Ri limit allowed; now the microcontroller can determine the time duration td which is the prevision time to safe voltage maintaining; the next step is to display the calculated value of the safety time duration td and also the microcontroller will display the last insulated resistance value Ri(tx - Δt); the last step of the algorithm is the jump command to ET1 and after that the cycle is repeating following the describe logic.

3. Predictive diagnose electronic protection

Technical realization is possible by implementing electronic systems like microcontrollers, microprocessors or using a PC. In order to understand more easily is synthesized an electronic insulated resistance relay with virtual anticipation of the insulated resistance and using a PC, a data acquisition board and an adequate program.

This strategy creates an advantage because the switching-off voltage events can be prevented. Basically, by applying this predictive strategy the time reserve of the safe functionality of the energetic system will be more easily to monitors because the insulated resistance remains in the safety limits that are technically accepted.

The insulating resistance protection type switch is created for automatic, permanent and preventive control of the status of isolation resistances in low voltage, triphased circuits, with an isolated null to the ground. This switch uses information about the operational current, injected in the controlled network, which proves to be a measure of the state of isolation resistances. The switch has the capacity to control isolation faults between each phase and ground, on the one hand, and between the null of the power transformer and ground on the other hand.

The state of the isolation resistance is an electro security global indicator, which can outline accidental touches of electric circuits at dangerous potentials.

The electronic protection switch is made to accomplish the following two specific functions:

- it does not allow tension connection on a certain part of the circuit, if the isolation resistance does not compel with the minimal legal values, for a certain guard tension of the network;
- it automatically and instantaneously cuts the tension, when the isolation resistance to the ground decreases under a legally imposed minimal value.

This virtual anticipation relay, presented in figure 4 and 5, is used for insulated resistance control and the currents absorbed by the consumers (1) who are supplied from a electrical transformer (2) with a isolated neutral connection to the ground through the impedance Z_{iso}. The anticipative insulated resistance relay is integrated inside a computer (3) hardware, which has a data acquisition board (4) on the PCI port (5) or on the USB (6) input. The connection between the anticipative relay and the measuring interface (7) is made trough an shielded cable (8) or a USB cable (9). The insulated resistance control is made by the current injection and the system unbalance. The continuous current is infected in the system trough a voltage operative source (10).
By developing the implementation principle of virtual protection systems in real electro energetic systems, we open new opportunities, only limited by the imagination of the application architect, in order to realize intelligent protection systems, with direct consequences over the increase of the viability of these systems and over their degree of security.

Figure 4. The predictive insulation resistance protection using a measuring interface.

Figure 5. The predictive insulation resistance protection using a data acquisition board.
3.1. Virtual instrumentation for simulating the insulating resistance degradation

In order to understand test the method is synthesized an electronic insulated resistance relay with virtual anticipation of the insulated resistance and using a PC, a data acquisition board and an adequate program. To express electrical insulating properties, volume resistivity or dielectric strength is widely used as an index. The volume resistivity is expressed in terms of electrical resistance calculated per unit volume of the test piece. The dielectric strength is expressed in terms of the magnitude of voltage withstood without destruction of the test piece when a specified amount of voltage is applied for a specified period of time. In both cases, a higher value means better electrical characteristics.

The virtual instrumentation for real time measurement and processing of various physical values is the result of the development of microelectronic technologies, implemented in the computer technology. Through the hardware and the software which are specific to the electronic computers – PC, using specific interfaces for data acquisitions, based on specific emulation programming of signal analysis and measurement instruments, a conceptual leap has been realized regarding the measurement, the control and the computerized command of processes. Practically, the electronic computer is becoming the virtual, like is presented in figure 6, universal instrument, which can be transformed into any kind of measurement, analysis, command and fine tuning equipment, through specific programming, called for by users.

In order for the shown system to become operational, it is necessary to install, in the process dedicated PC, a function driver of the data acquisition system and the software which is adapted to the application, meaning that to the graphic simulation programme we need to attach and set the graphic instrument for data acquisition, from the programmed application tool bar [6].

Figure 6. Predictive flowchart for insulated resistance control.

4. Conclusions

This paper presents a predictive strategy for insulated resistance control. Through this method, the control of the insulated resistance is made with monitoring of the safety functionality time reserve from the energetic system. In this case the insulated resistance parameter remains in the standardizations limits. Conceiving a relay based on this strategy shown in this paper we have the possibility to take anticipative measures that can prevent voltage uncoupling and all the events that come after this.
The implemented functionality algorithm consists on new conception and applications of a new strategy to control the insulated resistance from electrical network in the hazardous areas. The implemented algorithm creates a possibility to take some anticipative measures in order to prevent undesirable voltage disconnecting.

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