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INTERMITTENT GROUND-FAULT MODELING WITH EMTP/ATP

Розглянуто метод моделювання нестійких замикань, які використовуються для отримання кривих напруги та струму нульової послідовності і застосовується на стадіях дослідження і тестування автоматичних захисних пристроїв для електричних мереж середньої напруги. Наведено моделі замикань на землю для лабораторних досліджень і цифрового симулювання. Показано результати симулювання перехідних процесів і польових експериментів.

This paper describe intermittent fault modeling methods used to obtain zero-sequence voltage and current waves used at development stage and test stage of the electrical power automatics devices for medium voltage network protection. The models of the fault for the lab test and digital simulation are presented. The results of transient simulation and field tests are shown.

Introduction. Medium voltage networks are used for electrical energy distribution on large areas. There are two types of construction of the medium voltage lines: cable line and overhead line. Using each of those type of the line have an advantages and a disadvantages regarding of the utilization, safety and damage possibility. Due to construction issue power lines are threated by various kinds of damage. In Poland the overhead distribution lines are in majority located in rural areas and cable lines are commonly used in metropolitan power network. Causes of the damages that can occur in those lines are different for each line's type. In this paper the overhead lines are taken into consideration. The phase -to-ground faults exceed from 70 up to 80 % of all recorded faults. There are a many causes of those faults, but the common effect that make the protection system failure is high resistance of the fault loop. Examples of faults that can occur in the line and make trouble for protection devices are listed below:

- high resistance in fault loop $R_F>>0$ (in ex. fault trough high impedance element or high resistance of soil at fault spot),
- phase wire's breaks with phase-to-ground behind the break,
- intermittent phase-to-ground fault.

Good understanding of the phenomena concomitant to ground fault lets develop suitable methods and algorithms that can be used in power automatics devices and increase the power network reliability and safety. Modeling of the different kinds of network damages is the best way for this purpose. The research of the ground fault phenomena are conducted in Electric Power Institute at Poznan University of Technology long since. The effects of this work is a development of the methods and the criteria for detection different phase-to-ground faults, which are used in many types of protection systems and devices in Poland [1, 2]. Researches of the Institute solved problems with fault detection owning to good knowledge of the effects accompanying to specific fault type.

The experience acquired with fault modeling within a years effects in development of efficient criteria of the difficult to detect faults that can occur in overhead medium voltage lines. In farthest part of the paper the intermittent fault modeling will be presented.

Intermittent Fault Modeling. The research on intermittent faults was started over 15 year ago in the first research period the laboratory model was used. Intermittent earth-fault was switched on/off with thyristor device shown in figure 1. The controlled faults parameters are:

- duration of the fault state (N_F),
- duration of the non-fault state (N_B),
- starting angle of the fault (Φ_S),
- phase-to-ground fault's resistance (R_F).

Duration of the fault is a multiple of the basic period of the current wave (basic period time is equal to 20 ms). Starting angle of the fault is a angle of the current sinus wave.

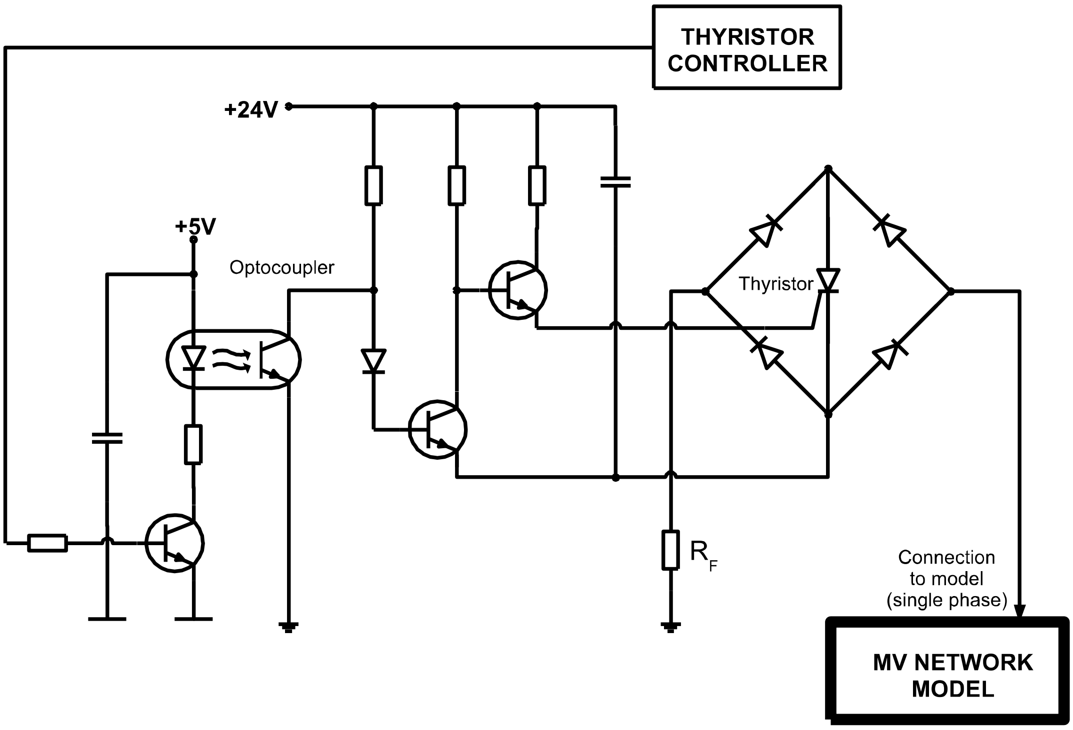

Fig. 1. Thyristor controlled device for intermittent fault modeling

Input of the fault modeling device is connected to phase wire of the lab model. Output terminal is connected to ground through resistor R_F. Modeling of the fault loop resistance was limited by the resistor parameters.

After certain period of time the transient calculation package was available and research of the intermittent fault phenomena can be taken into digital simulation. At first stage the model of the fault compatible to the physical device was made. Model was built in ATP/EMTP package using ATPDraw software (Fig. 2).

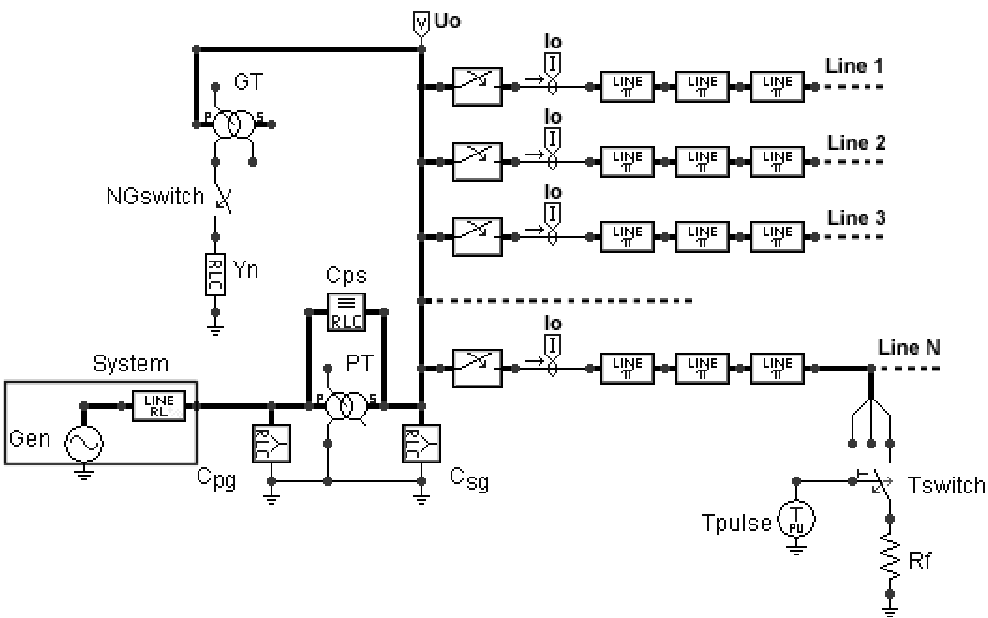

Fig. 2. Model of the network for intermittent fault modeling in ATPDraw

Model of the network was built with major components such as:

- power transformer (PT),
- grounding transformer (PT),
- transformer capacitance: primary side-to-ground (C_{pg}), secondary side-to-ground (C_{sg}), primary-to-secondary side (C_{ps}),
- system represented by source with equivalent impedance,
- neutral point grounding switch (NGswitch),
- neutral point grounding adnitance (Y_N),
- TACS controlled switch (Tswitch),
- TACS source (Tpulse),
- fault loop resistance (R_F).

Components NGswitch and Y_N are used for changing neutral point grounding conditions to select different mode of network grounding through Petersen's coil, resistor or insulated network. The key element of the intermittent fault modeling is a TACS source (Tpulse), what send signal to cyclically open and close TACS switch (Tswitch). Parameters controlled by Tpulse to fault modeling are: period of pulse train (T) and duration of each pulse (Width) both given in seconds (Fig. 3). Those parameters have similar meaning (Eq.1) to parameters used in laboratory fault model described above. Starting angle (Φ_S) of the beginning of the fault can be set by value of start time of source (T_sta).

$$\begin{aligned} N_F &= T \\ N_B &= \text{Width} - T \end{aligned} \quad (1)$$

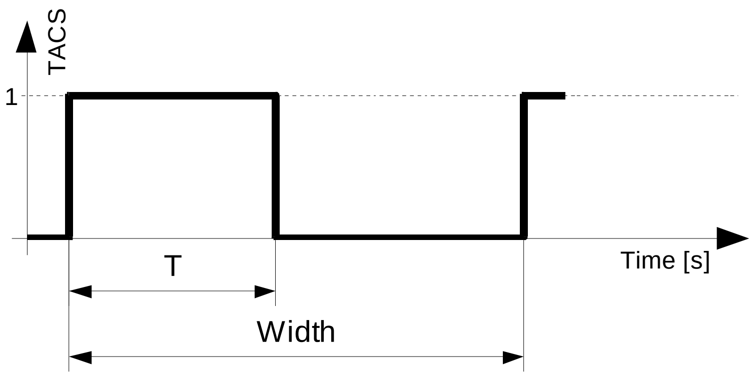

Fig. 3. TACS signal controlling fault switching operations

This simplified model does not include arc effect during the intermittent fault. To take into consideration the arc phenomena the suitable secondary arc model can be used. The high impedance phase-to-ground arc model in ATP/EMTP can be realized by Type-91 TACS/ MODEL [3–6]. Secondary arc models are based on differential equation of the conductance described by energy balance:

$$\frac{dg}{dt} = \frac{1}{\tau} \cdot \left(G - g\right) \quad (1)$$

where t – time constant of the arc; G – stationary arc conductance; g – instantaneous arc conductance.

The instantaneous arc conductance (g) depends on: arc length, arc voltage, arc resistance per length and last two parameters are characteristic parameters. The typical TACS/MODELS application of the intermittent phase-to-ground fault including arc model with time varying resistor in ATP/EMTP is shown in fig. 4.

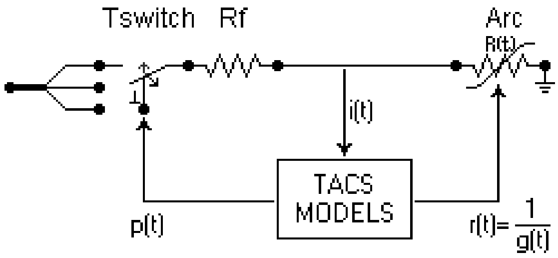

Fig. 4. TACS signal controlling fault switching operations

The Results. All results are obtained from digital simulation of the MV network model in ATP/EMTP for parameters given in Table 1. The results are for different neutral point grounding and duration of the intermittent phase-to-ground fault.

Table 1

Network model parameters

Network rated voltage	15 kV
Network capacity current	100 A
Fault line capacity current	10 A
Decompensation level	+15 %
Neutral grounding resistor	72 Ω
Fault resistance R_F	0 ÷ 25000 Ω

In figures below (5÷ 6) the sample results of the simulations are shown. The zero-sequence voltage and current waveforms are presented for each case.

Fig. 5. Zero-sequence voltage (top) and current (bottom) during intermittent phase-to-ground with neutral point grounded by resistor (R_F=0)

Fig. 6. Zero-sequence voltage (top) and current (bottom) during intermittent phase-to-ground with neutral point grounded by Petersen's coil with zero-sequence current forcing arrangement (R_F = 0)

Field tests were performed using the device called "spinner" shown in fig. 7. The core of device is spinning wheel with two wires. Rotating wires cyclically touching the ground and makes short-circuit. By controlling the rotation speed of the motor duration of the fault can be controlled. The results of the field tests in MV network with neutral point grounded by parallel connection inductor and resistor for different duration of the fault are shown in fig. 8.

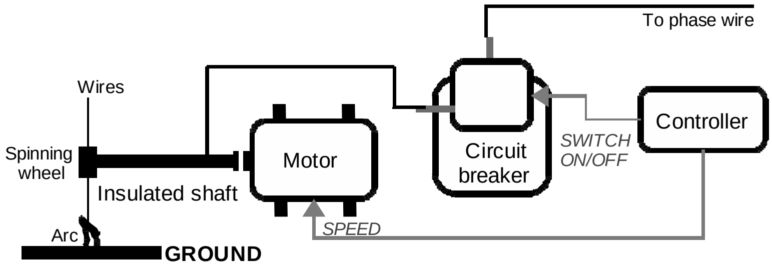

Fig. 7. Schematic of the "spinner" device

Signals obtained as the result of the simulation present behavior of the zero-sequence voltage and current during a fault in networks with different mode of neutral point grounding. Comparing the results of simulation with field test result full confirmation of intermittent fault model was succeed.

The modeling of faults of different kinds can be used to improve efficiency of existing protection devices, gives an opportunity to make new one and can be used to test relays operation under short-circuit and line's damages [1, 2, 8, 9].

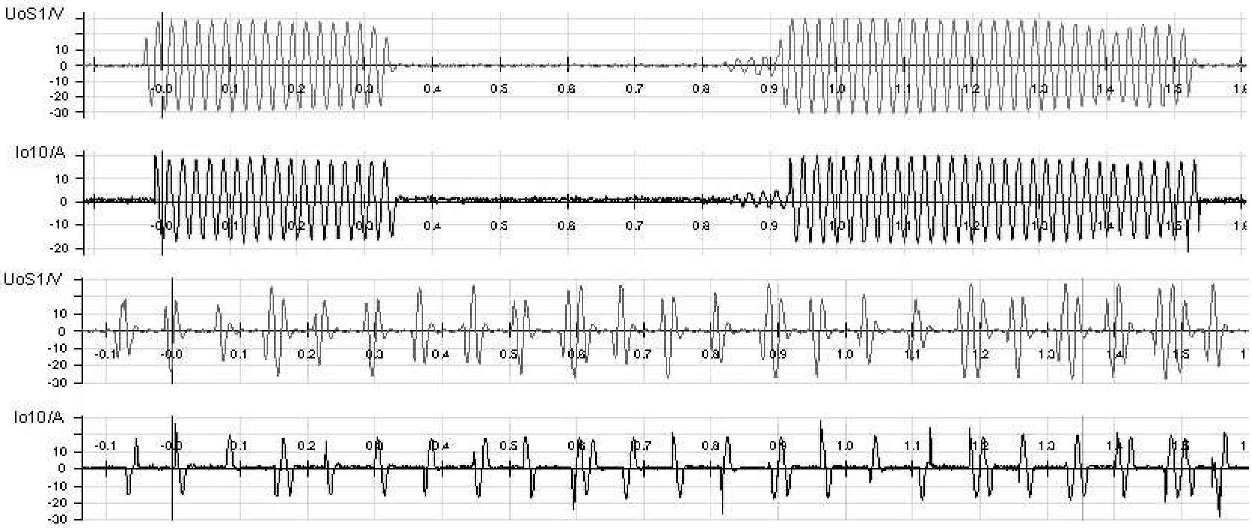

Fig. 8. Recorded waveforms of Io and Uo during intermittent phase-to-groud fault: slow switching fault (top), fast switching fault (bottom) [7]

Conclusion. In the paper methods of modeling of the intermittent phase-to-ground was presented including fault's complementary arc model. The results of digital simulation was fully confirmed by field test. Methods of short-circuit simulation in power networks gives an excellent approach to get knowledge about fault's accompanying phenomena. This knowledge can be used to improve safety of operation of the power network by development of the new methods of faults detection.

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FUZZY-LOGIC ALGORITHM FOR DETECTION OF INTERMITTENT EARTH FAULTS

У разі коротких замикань, які особливо важко визначити, ефективність роботи захистів можна покращити використанням нестійких замикань на землю. Нестійкі замикання в розподільних мережах середньої напруги часто не реєструються звичайними захистами від замикань на землю, і як наслідок, не можуть бути усунені. Під час таких замикань генеруються нестаціонарні періодичні сигнали вимірювання. Згладжування сигналу, наприклад, усередненням її в межах відповідного інтервалу, призводить до зниження величини нижче від значення уставки спрацювання і традиційна бінарна логіка (так/ні – замикання/відсутність замикання) для реєстрації замикання не є надійною. Нечітка логіка працює тут краще. В роботі запропоновано захист на основі нечіткої логіки.

In the case of faults which are especially ‘difficult’ to detect, the effectiveness of the operation of protections can be improved using fuzzy logic. It refers mainly to the intermittent earth faults. The intermittent faults in the MV distribution grids are often unnoticed by the conventional earth fault protections and, consequently, are not eliminated. In such faults, the periodically non-stationary measuring signals are generated. By smoothing the waveform, for example by averaging it within an appropriate interval, the criterion value falls below the start-up value and the fault discrimination using traditional binary logic (true/false – fault/ lack of fault) is not ensured. The fuzzy logic fits here better. In the work, the protection with fuzzy decision system is proposed.

Introduction. Effectiveness of elimination of disturbances by protections depends strongly on propriety of distinction between the normal operating conditions and the emergency conditions like a fault. It is lied with description of the position of the decision vector’s trajectory within one of two regions corresponding to these conditions. In this simple two-value (binary) logic, the position of decision vector must be unambiguously assigned to the one of two possible regions: the region of the object’s normal operation and the faulty operation’s one.