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Power System Dynamical Simulation Application for Out-of-Step Relay Testing

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Abstract: OOS (out-of-step) condition prevention becomes an imperative task to avoid possible power system blackout and collapses. To be confident in correct OOS relaying, the OOS protection device behavior under the vast majority of power system abnormal regimes should be tested. Comprehensive testing procedure becomes especially important for complex power systems when power system parameters and consequently device settings are not clearly defined or may vary in time. For such complex systems the real OOS protection device testing may become a problem because of specific waveforms of signals persisting during OOS condition. The goal of the methodology, presented in the paper, is to achieve the possibility of out-of-step protection device testing under close-to-real power system operation conditions. The power system stability modelling software is used as a source of test signals. The accurate model of power system in conjunction with dynamical modelling features allows to verify the reliability of OOS protection scheme under consideration as also allows the device settings correction, if necessary. The methodology allows to test the real device with signals waveforms which are hardly obtainable using traditional testing technique.

Key words: Out-of-step relay, modelling software EUROSTAG, relay testing, COMTRADE format.

1. Introduction

Power system is a subject to a wide range of small or large disturbances which occurs during steady state condition. The small disturbances such as load variation persist in power continually and power systems adjust to these changing conditions and continue to operate with nominal voltages and frequency. The large disturbances such as faults, loss of generation, excessive overload or lines switching can cause some parts of power system to become unstable and the loss of the synchronism with remaining parts. When two areas of a power system lose synchronism, the areas must be separated from each other as quickly as possible to avoid equipment damage and possible power blackouts [1, 2]. The power system should be separated in predetermined locations to maintain a load-generation balance in each of the separated areas. The task of power system separation is accomplished with the out-of-step protection. The significance of the research is determinate by necessity to ensure of proper OOS (out-of-step) protection operation for reduce probability of huge amount of economics and social losses as a result of blackouts [3-6]. The OOS protection implementation principles are well-known [2, 7-9] and OOS protection devices are in use in the power system utility. While the out-of-step relaying philosophy is simple, it is often difficult to implement for a large power system because of its complexity and large variety of different operating conditions to be studied.

2. Out-of-Step Protection Modeling Objectives and Deficiencies

To get all the information needed for successful

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OOS protection scheme realization several studies are to be carried out [2]:

(1) The selection of network locations for placement of OOS protection systems can best be obtained through transient stability studies covering many possible operating conditions;

(2) The maximum rate of slip is typically estimated from angular change versus time plots from stability studies;

(3) Determination of the optimal place of power system sectioning during an OOS condition is necessary. This will typically depend on the impedance between islands, the potential to attain a good load/generation balance, and the ability to establish stable operating condition of separated areas.

All these studies can be successfully accomplished simulating a variety of power system conditions which can affect the system stability [10]. The power system modeling software EUROSTAG enables the power system processes to be simulated with high precision and is especially effective when power system stability study is needed.

Thus, the following information and tools are needed:

(1) To build an accurate power system model, the precise technical information about all elements of the power system that is composed (transformers, generators, lines) is required;

(2) Software with ability to simulate a variety of conditions which can affect power system stability;

(3) To verify the correct application of out-of-step protection scheme, an appropriate mathematical model of the OOS relay should be included in the stability simulation program;

(4) A set of simulations is required in order to analyze the efficiency of the selected out-of-step protection scheme.

The accurate model of the OOS protection in conjunction with the power system dynamical modeling determines the choice of the most reliable OOS protection scheme and makes it possible to calculate appropriate OOS relay settings.

The precise technical data about high voltage apparatus are available from power system utility. The EUROSTAG software can be used as powerful tool to build the complex power system models and to simulate the variety of scenarios for power system stability study. The OOS protection model can also be built using the EUROSTAG software if the OOS protection operation principle is known and a description of device operational algorithms is at hand. However, if the OOS protection model is built according with the protection operation manual, then it will be necessary to decide whether the model is equivalent to the real device or not. One can suppose that the device and its model are not absolutely the same things. This is just because the mathematical/logical description of the protection operation algorithms provided by manufacturer and software/hardware realization of the same algorithms makes the difference. The differences in measurement/calculation precision of the model and its real counterpart usually are tolerable, but there exists the probability of rare software errors as well as other irregularities which exist only in the real device and can affect the device proper operation. Observing the statistical information about the cause of incorrect protection operation [11] (Fig. 1), the following can be pointed out: more than 10% of all incorrect protection operations are due to incorrect device settings, about 20% are due to internal relay fault (hard- or software).

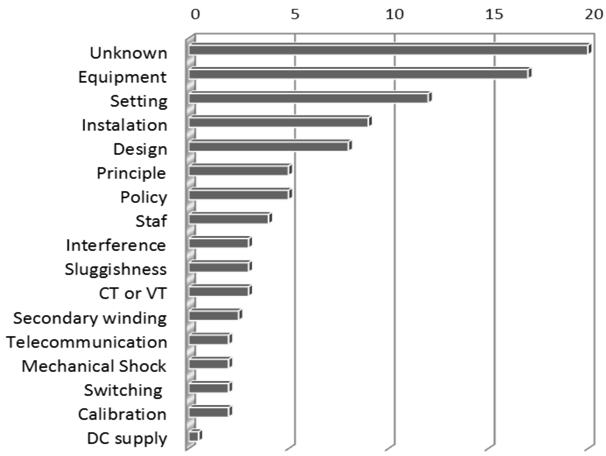

Fig. 1 Cause of incorrect protection operation (1976-2002) [12].

Another 20% are marked as "reason unknown"—sometimes the software error detection is nearly impossible because it is hard to reconstruct the situation when this error becomes visible and affects the device operation. This kind of errors can be fixed only when device operates with real signals under real or close to real operation condition.

Taking into account all the above saying as well as the extreme importance of the out-of-step relaying, the following conclusion can be made: the concept of OOS device testing in real or close to real conditions may become imperative for successful and confident relaying.

3. Power System Stability Simulation

Practical realization of this concept is shown in Fig. 2. The EUROSTAG is used as power system regime simulator. Power system model is represented with two generation areas interconnected with two HV links: one the power system can become unstable when short term loss of 330 kV transmission link occurs. This condition can arise as a result of a short circuit on 330 kV line with a subsequent successful auto reclosing. Varying the short circuit clearing time, automatic reclosing delay, the load, short circuit type and location, different scenarios can be simulated. The behaviour of the OOS regime is presented by simulated signals typical waveform as shown in Fig. 3.

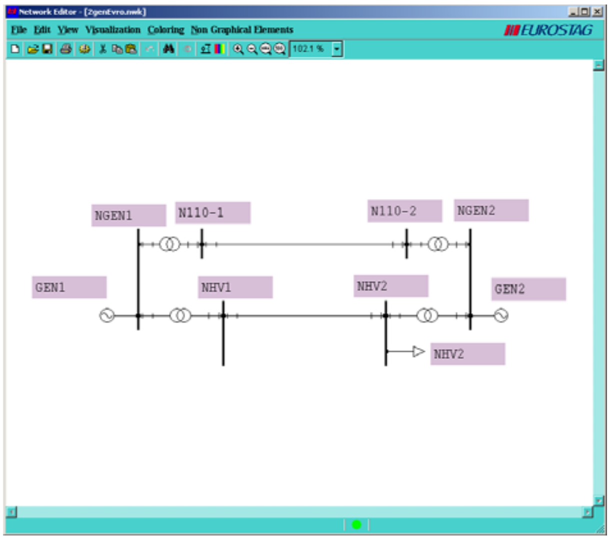

Fig. 2 Power system model used in stability study.

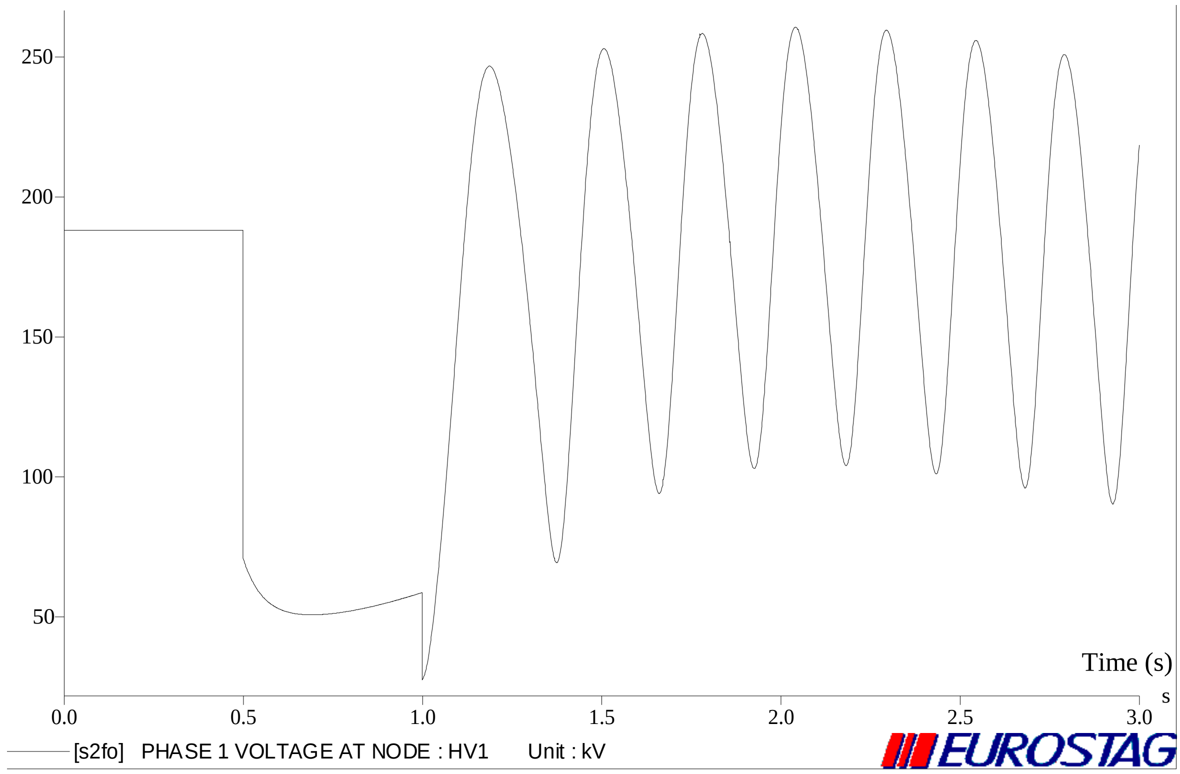

Fig. 3 Voltage waveform in out-of-step regime.

Depending on the selected scenario, the cases from stable power swing toward the loss of synchronism and out-of-step condition can be simulated.

4. OOS Relay "AGNA" Operation Principles

The OOS relay should be used to protect the modelled power system from out-of-step condition. For power swing condition detection and OOS relaying "AGNA" protection should be installed on N110-1–N110-2 HV line. The operation conditions of the OOS protection AGNA are determined by one of the two algorithms. The first operation algorithm does not allow generator angle to slip, and operation takes place within the first swing cycle.

The second algorithm allows pole slip, and the device operates after fewer swing cycles depending on the settings. The power swing detection is based on the control of angle φ between two simulated voltages $\underline{U}_1$ and $\underline{U}_2$ [12]. To simulate these voltages two-machine circuit, an equivalent of the real system is used (Fig. 4).

$$\left.\begin{aligned} \underline{U}_1 &= \underline{U} \pm \underline{Z}_{\Sigma 1} \cdot \underline{I} \\ \underline{U}_2 &= \underline{U} - \underline{Z}_{\Sigma 2} \cdot \underline{I} \end{aligned}\right\} \quad (1)$$

where $\underline{U}$ and $\underline{I}$ are local voltage and current, controlled by protection in the point of installation, $\underline{Z}_{\Sigma 1}$ and $\underline{Z}_{\Sigma 2}$ are the settings, which are chosen depending on the equivalent parameters of the power system. Depending on the location of ESC (electric swing center) (Fig. 5), the modeled voltages $\underline{U}_1$ and $\underline{U}_2$ can be located on the same side of ESC (the angle φ does not exceed 90°) or can be located on the opposite sides of ESC (angle φ increases until it reaches 180°).

The protection operates when the following requirements are met:

- Angle φ has reached its limit value;
- Angle changes with a sufficiently high rate ($d\varphi/dt$);
- Currents and voltages are symmetrical.

$$\left.\begin{aligned} &\varphi_1 < \varphi = \arg\left(\frac{\underline{U}_1}{\underline{U}_2}\right) < \pi \\ &C_1 > d\varphi / dt > C_2 \end{aligned}\right\} \quad (2)$$

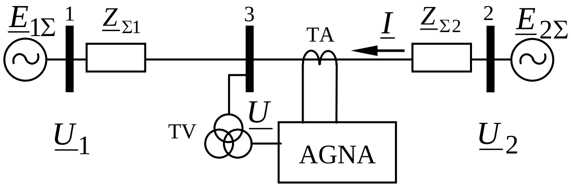

Fig. 4 Equivalent circuit of the power system.

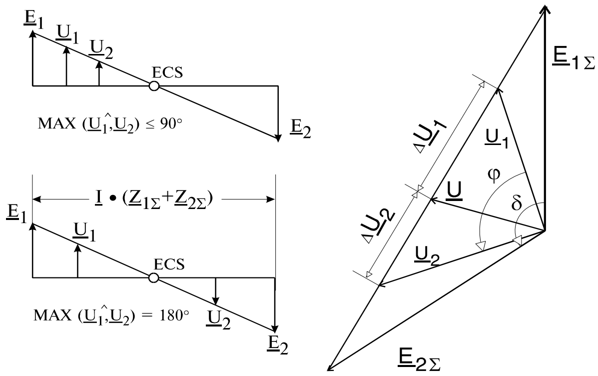

Fig. 5 Characteristic diagrams of device operation.

where φ_1, C_1 and C_2 are the appropriate device settings. The device settings are preliminary calculated and can be checked and corrected during simulation if necessary.

5. OOS Relay Testing with Power System Dynamics Simulation Signals

The EUROSTAG allows any signal of power system dynamics simulation to be exported in ASCI format. Thus, 3-phase currents and voltages, obtained during simulation, can be saved in external file and can be used (after conversion into real currents and voltages) for real device testing. The relay test system (ISA DRTS) is used for simulated signals playback.

Since the EUROSTAG output signals are represented with signal effective value and phase angle, but relay test system accept signals in COMTRADE format (instantaneous values), the converter program is needed.

Such conversion program was made and it converts the EUROSTAG output file into COMTRADE format.

As soon as the COMTRADE data file is obtained it can be used with any modern relay test equipment which allows the signal waveforms playback. The

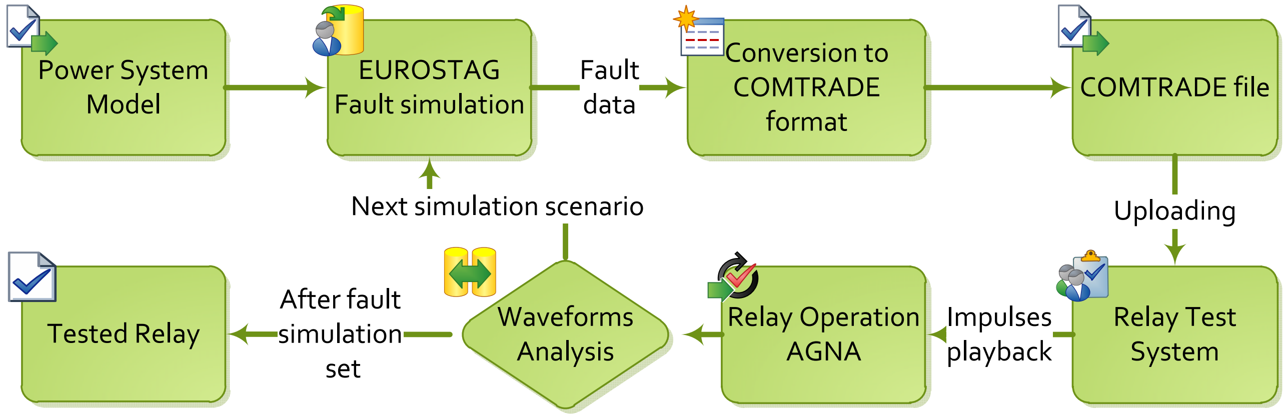

Fig. 6 OOS regime simulation and OOS relay operation testing.

complete picture is similar to the one in Fig. 6. The power system model and various regimes (short circuits, line loss, load variations) are simulated with the EUROSTAG software. With the help of special program, simulated signals are converted in COMTRADE format and uploaded in RTS (relay test system). The RTS playback the currents and voltages and the reaction of the OOS relay AGNA is observed. Simulated out-of-step condition and AGNA OOS relay correct operation is presented in Fig. 7. AGNA output relay "BO1 1" trip when the angle between simulated voltages $\underline{U}_1$ and $\underline{U}_2$ overreach the appropriate setting value. The waveforms analyses and device reaction for the particular experiment are made using the relay operation analyzing software "SMOKY".

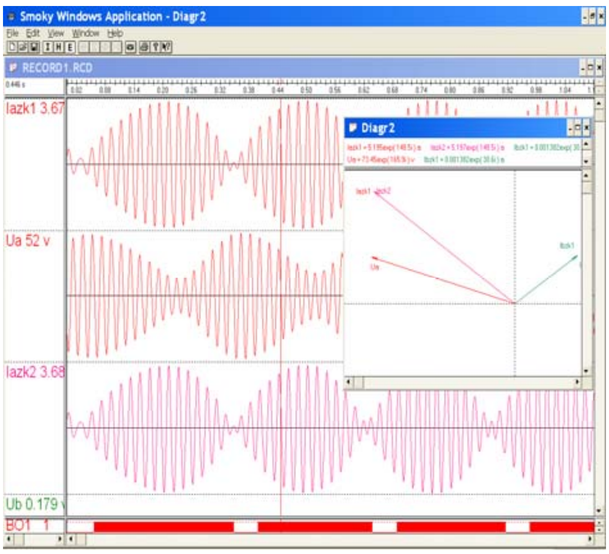

Fig. 7 OOS regime simulation and OOS relay operation.

6. Conclusions

Large disturbances may cause loss of synchronism between some parts of power system if this condition ignored can lead to widespread power outages and blackouts.

The extreme importance of OOS condition liquidation dictates that all possible efforts must be taken to guarantee the correct OOS relay operation.

The settings for OOS relay could be difficult to calculate because of the power system complexity and parameters variation in time. OOS relay operation should be verified in different power system regimes which can hardly be simulated using traditional relay testing technique. Power system dynamic modeling program EUROSTAG is used for power swing and out-of-step processes simulation.

Specially created program allows to convert simulated signals into the COMTRADE format and then real currents and voltage waveforms can be recreated by means of any modern relay test system.

The modeling technique of the power system processes was successfully implemented for protection and automation devices testing. Testing methodology allows to test the OOS relay in close-to-real conditions.

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