Protection and Automation Devices Testing Using the Modeling Features of EUROSTAG

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Abstract: **The paper presents out-of-step protection device testing methodology under close-to-real power system operation conditions. The power system stability modeling software is used as a source of test signals. The accurate modeling of power system in conjunction with dynamical modeling features allows the correct choice of the most reliable OOS protection scheme. Methodology was applied for out-of-step relay "AGNA" testing and device settings verification.**

Key words: **power system stability, out-of-step relay, power system modelling software, relay testing, COMTRADE format.**

I. Introduction

The power system is a subject to a wide range of small or larger disturbances which occur during steady state condition. 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. Large disturbances such as faults, loss of generation, excessive overload or lines switching can cause some part of power system to become unstable and the loss of 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 out-of-step (OOS) protection implementation principles are well - known [2, 5] 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 that should be studied. Power system regimes simulation is a typical way to evaluate the behavior of protection and automation devices under complex or non-standard operating conditions. Power system electromagnetic process simulation programs are widely used for protection relay testing purposes, but, when power system stability is under consideration, electromechanical processes should be simulated. The great advantage of EUROSTAG simulation program is that the program covers full range of transient processes, mid and long-term power system stability could be studied and appropriate signals could be simulated. Despite the fact that EUROSTAG simulated signals are not intended for real device testing, some efforts can be taken to overcome this shortage and implement EUROSTAG simulation results for real OOS relay testing. The paper presents the methods and tools which allow OOS protection to be evaluated using EUROSTAG modeling capabilities.

II. Out-of-step protection modeling objectives and deficiencies

To get all the information needed for successful 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 made 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 out-of-step 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 [3]. 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 precise technical information about all elements the power system is composed of (transformers, generators, lines) is required;
2. Software with an 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 a 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 build 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 to 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 the 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 is a 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 [4] (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 faults (hardware or software). Another 20% are marked as “reason unknown” – sometimes 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 conditions.

Taking into account all the above said 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.

III. Power system stability simulation

Practical realization of this concept is shown in Fig. 2. The EUROSTAG is used as a power system regime simulator. Power system model is represented with two generation areas which are interconnected with two HV links: one link is 330kV transmission line and the second one (the weak link) is 110kV transmission line (Fig.2).

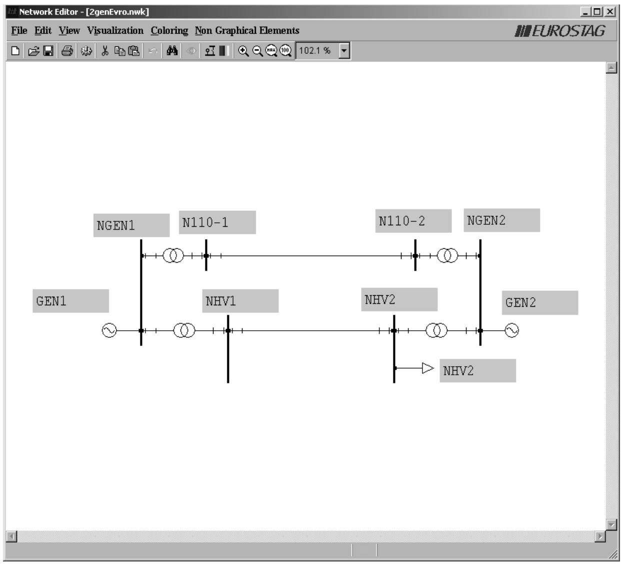

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Fig. 2. Power system model used in stability study

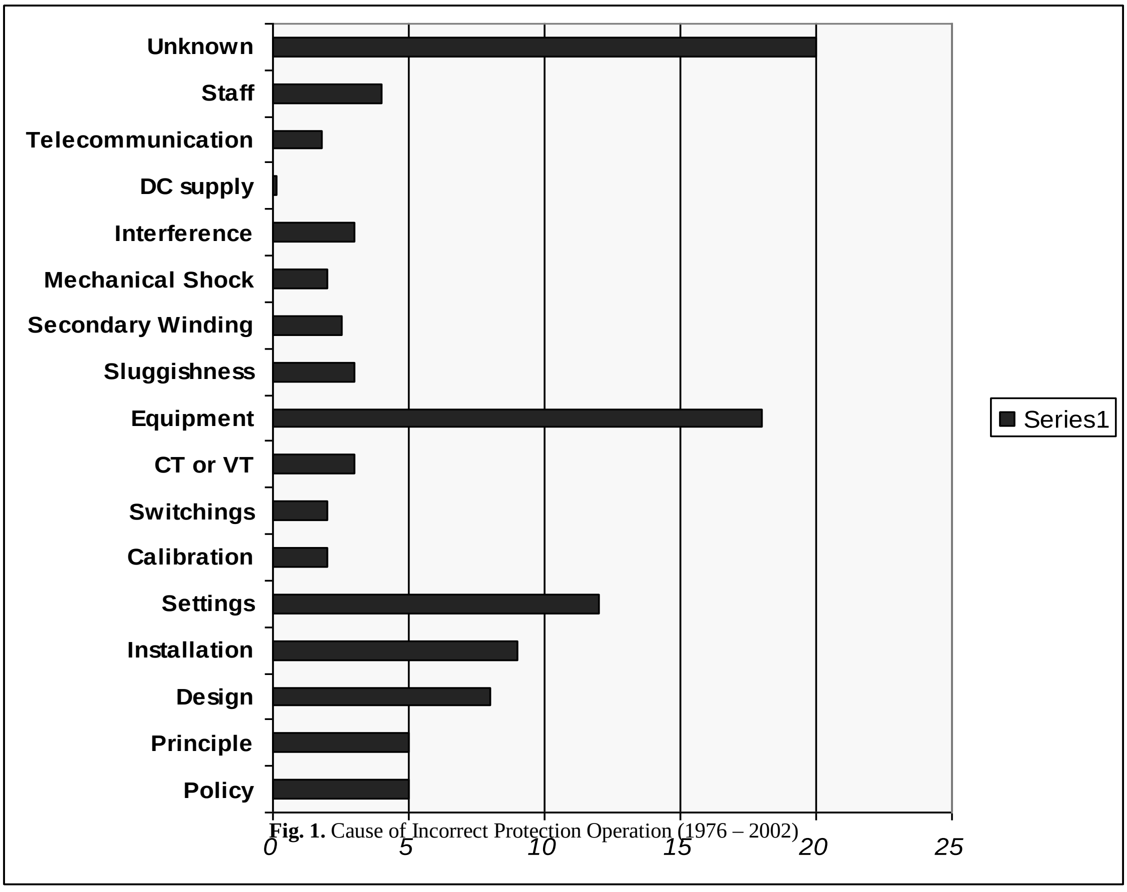

Fig. 1. Cause of Incorrect Protection Operation (1976 – 2002)

The power system can become unstable when short term loss of 330kV transmission link occurs. This condition can arise as a result of short circuit on 330kV 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 behavior of the power angles for both generation areas of the power system is presented in Fig. 3. Depending on the selected scenario, the cases from stable power swing toward the loss of synchronism and out-of-step condition can be simulated.

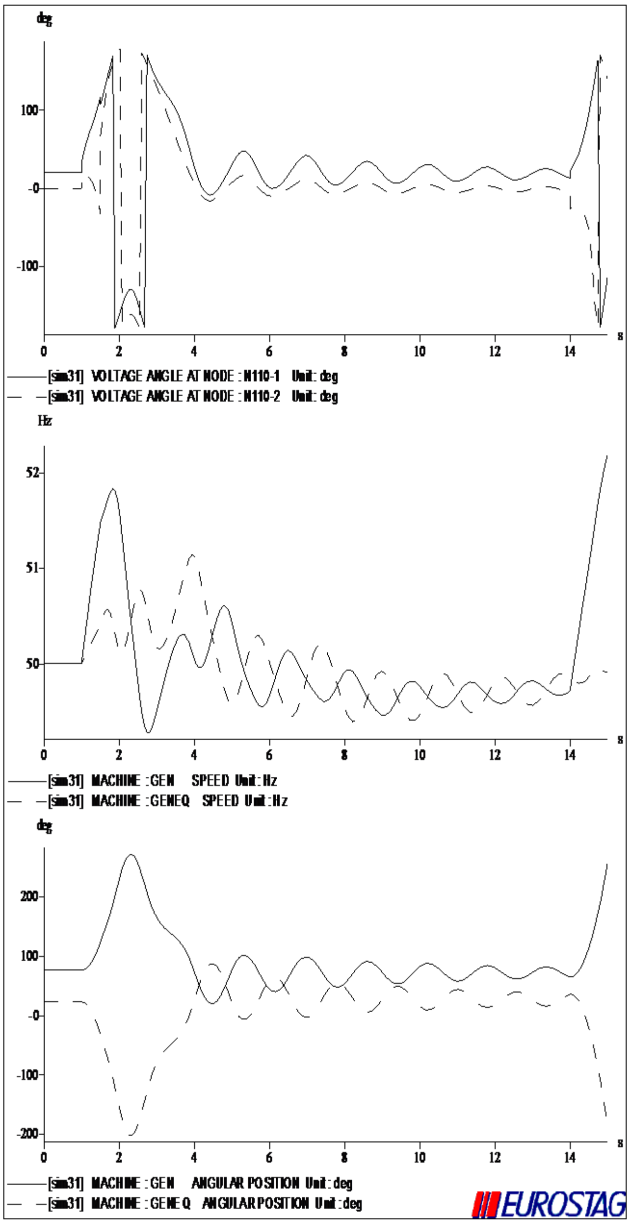

Fig. 3. Angular positions and voltage angles of GEN1, GEN2 generation area in the case of short circuit

IV. OOS RELAY "AGNA" OPERATION PRINCIPLES

The OOS relay should be used to protect the modeled power system from out-of-step condition. For power swing condition detection and OOS relaying "AGNA" protection is supposed to 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 in the first swing cycle. The second algorithm allows pole slip and device to operate after some 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 $\underline{U}_2$ [6]. To simulate these voltages two-machine circuit - an equivalent of the real system - is used (Fig. 4).

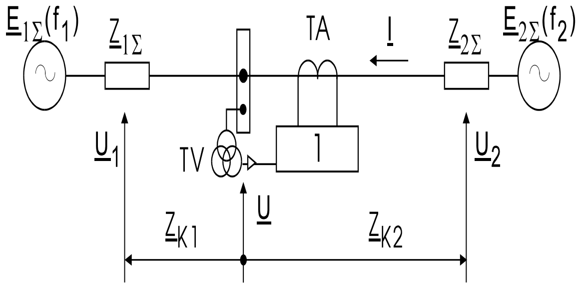

Fig. 4. Equivalent circuit of the power system

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

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 (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°).

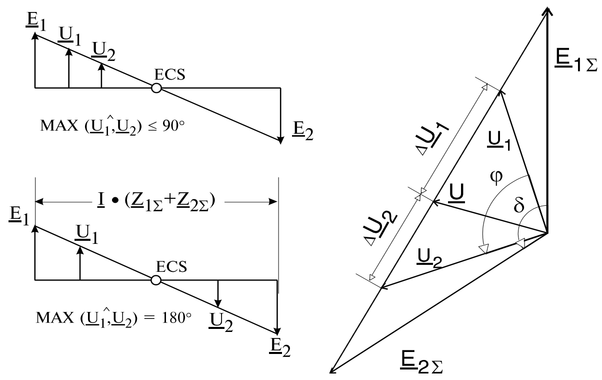

Fig. 5. Characteristic diagrams of device operation

The protection operates when the following requirements are met:

1. angle φ has reached its limit value;
2. angle changes at a sufficiently high rate (dφ/dt);
3. currents and voltages are symmetrical.

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

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.

V. 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 accepts signals in COMTRADE format (instantaneous values), the converter program is needed.

Such conversion program was developed 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 complete picture is similar to 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 the Relay Test System. The Relay Test System playbacks 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 relays “2st_trip” trip when the angle between simulated voltages U1 and U2 overreaches the appropriate setting value. The waveform analyses and device reaction for the particular experiment are made using the relay operation analyzing software “SMOKY”.

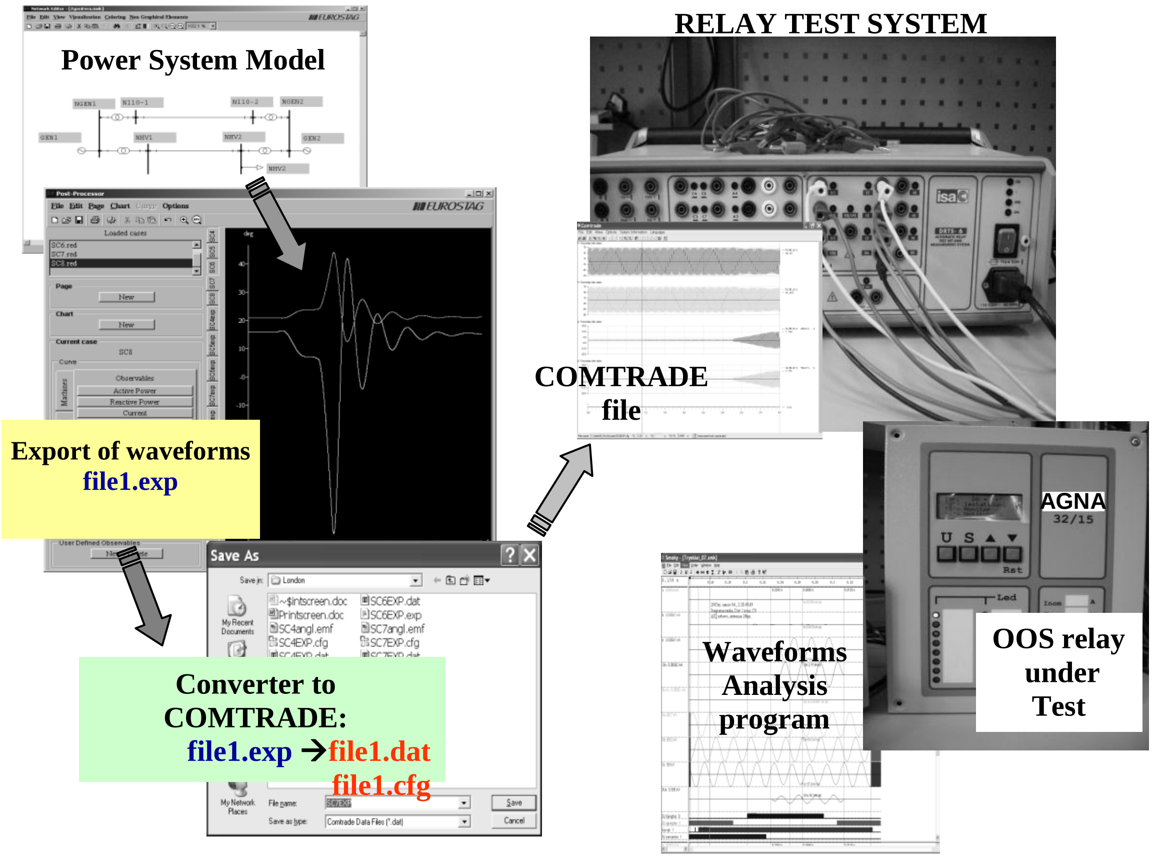

Fig. 6. OOS relay testing using simulation features of EUROSTAG

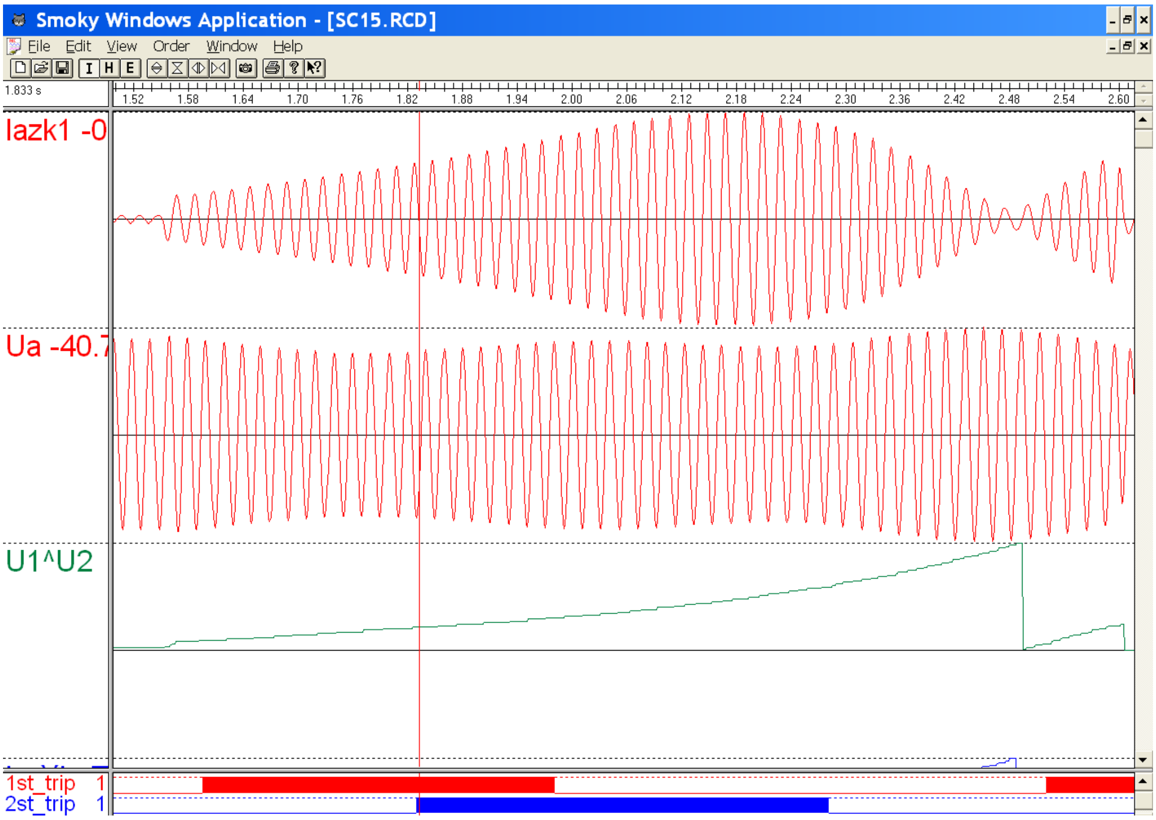

Fig. 7. Out-of-step regime simulation and OOS relay operation (2st_trip)

VI. Conclusions

1. Large disturbances may cause loss of synchronism between some parts of the power system and, if this condition is ignored, can lead to widespread power outages and blackouts.
2. The extreme importance of OOS condition liquidation dictates that all possible efforts must be taken to guarantee the correct OOS relay operation.
3. The settings for OOS relay could be difficult to calculate because of the power system complexity and parameter 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 dynamics modeling program EUROSTAG is used for power swing and out-of-step processes simulation.
4. Specially created program allows converting simulated signals into COMTRADE format and then real currents and voltages waveforms can be recreated by means of any modern relay test system.
5. Power system process modeling technique was successfully implemented for protection and automation device testing. Testing methodology allows the OOS relay to be tested in close-to-real conditions.

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Antans Sauhats, Andrejs Utāns, Jevgēnijs Kucājevs, Grigorijs Pašņins, Dmitrijs Antonovs, Edīte Bieļa. Aizsardzības un automatizācijas ierīces testēšana, izmantojot modelēšanas iespējas ar EUROSTAG programmu.
Asinhronās gaitas novēršanas automātikas iestatījumu izvēle var kļūt par ļoti sarežģītu uzdevumu, ņemot vērā energosistēmas parametru neprecizitāti un to izmaiņas laikā. Automātikas darbības efektivitāti un iestatījumu pareizību jāpārbauda pie dažādiem energosistēmas darbības režīmiem. Lai izpētītu automātikas ierīci realitātei tuvos apstākļos, tiek izmantota energosistēmas modelēšanas programma EUROSTAG. Izmantojot EUROSTAG programmas modelēšanas iespējas var veikt paplašinātu energosistēmas stabilitātes izpēti un modelēt signālus, kuri nevar būt sintezēti izmantojot tradicionālo releju testēšanas metodiku.
EUROSTAG programmas modelējamie signāli pārstāvēti ar moduļiem un leņķiem, tāpēc tos nevar tieši izmantot reālo relejaizsardzības un automātikas ierīces pārbaudei.
Speciali izstrādāta programmatūra ļauj konvertēt EUROSTAG modelējamos signālus uz COMTRADE formātu, pēc kā reālas strāvas un spriegumus var iegūt izmantojot moderno releja testēšanas iekārtu.
Energosistēmas procesu modelēšanas tehnoloģija bija veiksmīgi pielāgota relejaizsardzības un automātikas ierīces pārbaudei. Asinhronās gaitas novēršanas automātika AGNA bija izmantota kā testējamā ierīce. AGNA ierīces pareizā darbība ir krietni atkarīga no pareizas uzstādīšanas vietas izvēlnes un no iestatījumu precizitātes. Testēšanas gaitā, AGNA ierīces darbspēja bija pārbaudīta un apstiprināta pie noteiktiem iestatījumiem un pie dažādiem energosistēmas darbības režīmiem. Testēšanas metodika ļauj izpētīt asinhronās gaitas novēršanas automātiku apstākļos, kas tuvi realitātei un šo metodiku var izmantot arī citu relejaizsardzības un automātikas ierīču pārbaudei.

Антанс Саухатс, Андрей Утанс, Евгений Куцаев, Григорий Пашнин, Дмитрий Антонов, Эдите Биеля. Защита и автоматизация устройств тестирования при использовании возможностей моделирования EUROSTAG.
Расчёт уставок устройства ликвидации асинхронного режима может быть сложным вследствие непостоянства параметров энергосистемы, поэтому эффективность действия автоматики и корректность уставок должна быть подтверждена опытным путём при различных режимах работы энергосистемы. Для асинхронного режима характерны сигналы, форму которых трудно воссоздать, используя традиционную технику проверки реле, поэтому тестовые сигналы получают путём моделирования процессов энергосистемы в различных режимах её работы. Для моделирования процессов используется программное обеспечение EUROSTAG.
Сигналы, рассчитанные программой EUROSTAG в результате моделирования асинхронного режима в энергосистеме, представлены в виде модулей и углов и не могут быть напрямую использованы с целью проверки реальных устройств зашиты и автоматики. Разработана специальная программа, которая позволяет конвертировать моделируемые сигналы в формат COMTRADE, после чего сигналы преобразуются в реальные токи и напряжения и используются для тестирования устройства.
Программа моделирования динамических процессов энергосистемы EUROSTAG была с успехом применена для тестирования устройств автоматики. В качестве тестируемого устройства использовалось устройство ликвидации асинхронного режима энергосистемы AGNA. В результате тестирования была подтверждена работоспособность реле AGNA при заданных уставках устройства и в различных моделируемых режимах работы энергосистемы. Методология тестирования устройств с помощью моделируемых сигналов позволяет проверить работоспособность устройства предотвращения асинхронного режима в условиях, близких к реальным и может быть применена для проверок других устройств релейной защиты и автоматики.