

Real Time Monitoring of the State of Smart Grid

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Introduction

Reliability and economic - costs of the distributive network depends upon the quality of the maintenance like: fast and expeditiously elimination of faults or systematic network renovation. In the isolated network, where are full untreated trees, could be multifold repetitive earth – faults and they could call two or three – phase short – circuit. Such places of the power line could be found by the fast processes analysis monitoring device, mounted in the substation of this power line. In the compensated power line conventional relay devices often faulty shows which feeder is short – grounded. Having such unreliable information there are chance to disconnect healthy feeder with multiple actuation. They are very dangerous commutations, which could affect great overvoltage.

Technology of the fast process recognition allows avoid such harmful and faulty operations. For the fast fault localization after the one phase to ground fault, it is good to know in which place of the network it has happened. The analysis of the steady – state modes let us know only the distance till the one phase to ground fault place. A distributive network has specific asymmetric voltage and higher level harmonics. In fully computer – assisted power network, before any commutation, monitoring system has to perform analysis of stationary modes possible plan, which could arise after commutations and to find optimal switching variation [10].

Monitoring terminal system

In Lithuanian distributive networks, terminals for the fast process registration have 40 μ s steps. Voltage and current are measured in the zero sequence and phases. There are registered and stationary values by the enlarged step. Registered values processed by specialized DPDF and DSDF filters. DPDF filtering is used to cancel out influence of the pre-switched network. DSDF filtering is applied to highlight moments when function of the transient changes its character. Terminal programs perform: feeder, in which one phase to ground fault occur, recognition, fault place location, fault character

determination, result filling and sending to dispatcher center. Structure of the monitoring system is constantly refinement and updated by the internet: revising power net maintenance parameters, handling net adaptation system at the existing condition.

Model of the fast electromagnetic transients

Model of the fast electromagnetic processes, which shows initial processes after fault excess, is linear. After excess transient electromagnetic process in the power line fades during a few ten - milliseconds time. By nature linearity, registered process part of the first ten milliseconds till ~ 0.1 ms is most efficient with information about changes in the power network. This time segment is characteristically, because current and voltage transient component forms in linear part of the electric system. The biggest non-linearity in the model has a magnetic flow mathematical expression of the transformer steel core. Distribution network transformer core magnetic current in time ($i_{L\mu}$, Fig. 1) till ~ 0.1 ms concludes only 1.5 % of total inductive current component, then at the same time terminal and internal capacity current reduces till value, which is 1.5 time bigger that inductive current. Process linearity enables model of the fast electromagnetic processes use to find phase to grounding place.

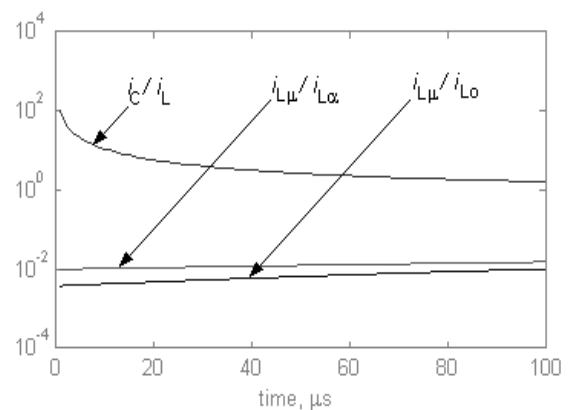


Fig. 1. Distribution network transformer core magnetic current

Linearity of the process violates only faults of lightning overvoltage or isolation corrosion in the lightning strike places. Processes loose linearity due to coronal discharge in the line, then voltage of the line reaches and exceeds primary voltage of the corona. Only registered process front part, which reaches primary coronal voltage, can be used for recognition of the fast process electromagnetic model. Model operates only for one phase fault to ground feeder finding and distance till fault place, because of the very limited process registering time. Linearity of the process composes proper conditions for the model adaptation.

Prime fast processes numerous impacts feeder terminal cable and other cables on the net. During adaptive process successfully revises parameters of the line: surge impedance, electromagnetic wave spread constant and line length. The main feature of the fast electromagnetic process model is that linearity lets widely use algebraic differential equation and algebraic digital filters and to use superposition and proportional principles. All those things expedite modelling and let us to use model in the on-line applications.

Recognition of one phase to ground faulted feeder

In the isolated or compensated distribution network one phase fault to ground in the stationary mode generates voltage rise till the linear voltage value on the healthy phases. If at the same time in the net overvoltage are activated (atmospheric, induced direct lightning to power line or non-direct, commutative or resonate character at higher level frequencies and infra-frequencies), then isolation on the other feeders could be impacted also. Seeking to increase reliability of the network it is essential to perform fast operative switching. Fast electromagnetic process model with minimal time period lets us to find faulted feeder with high reliability. Reliable feeder recognition determines numerous primary charge and strong transient current in the zero – sequence and phase, which is one phase to ground faulted. At the case of the especially responsibly line fast phase disconnection could be used. This generally means the inserting of network interrupters (special fuses, fast circuit breakers, solid state interruption devices).

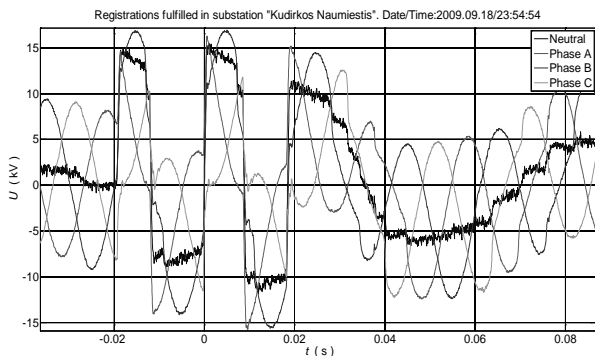


Fig. 2. Multifold one phase to ground process in phase C

If electronic switches were used to reconfigure a distribution system, the 16.7 ms objective is readily

realized. Fig. 2, 3, 4, 5 shows registered voltage process in the isolated 10 kV distributive power network, when during wind whiff any one of the side phases reaches a tree branch. It is shown, that between tree branch and the phase time to time processes multiple short – circuit with time period equal to half of period of the industrial frequency. Process escorts numerous overvoltages, which at he last ends in two-phase short circuit at the end of the power line in the consumer’s substation. Fast faulty line disconnection with network reconfiguration could let us to avoid two-phase short circuit.

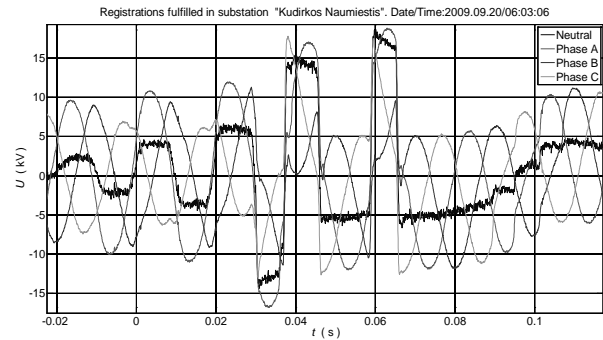


Fig. 3. Multifold one phase to ground process in phase B

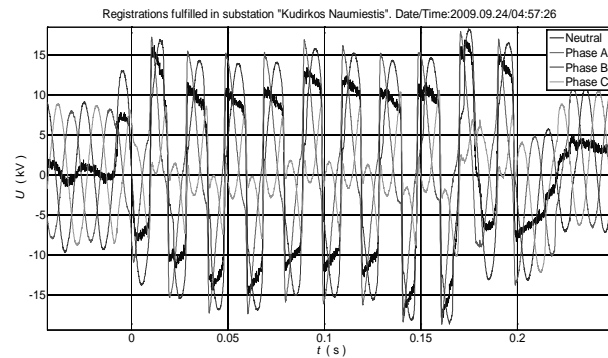


Fig. 4. Multifold (20 times) one phase to ground process in phase C

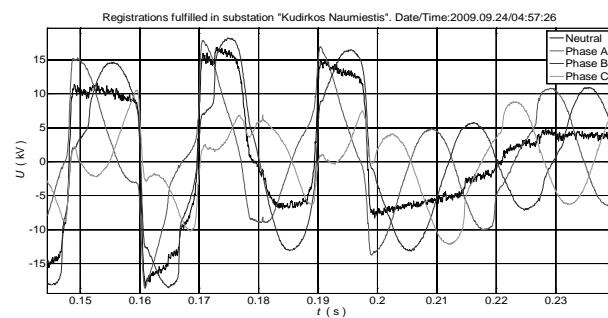


Fig. 5. End of the multifold (20 times) one phase to ground process in phase C

Fig. 6, 7, 8 shows a case then lightning strikes to the power tower with several current impulses in the leader channel. Lightning overvoltage in a whole distribution network lasts about 0.4 second. Fast reconfiguration of the network would let to avoid harmful overvoltage impact to the commutation equipment.

Registrations fulfilled in substation "Kudirkos Naumiestis". Date/Time:2009.09.17/06:28:04

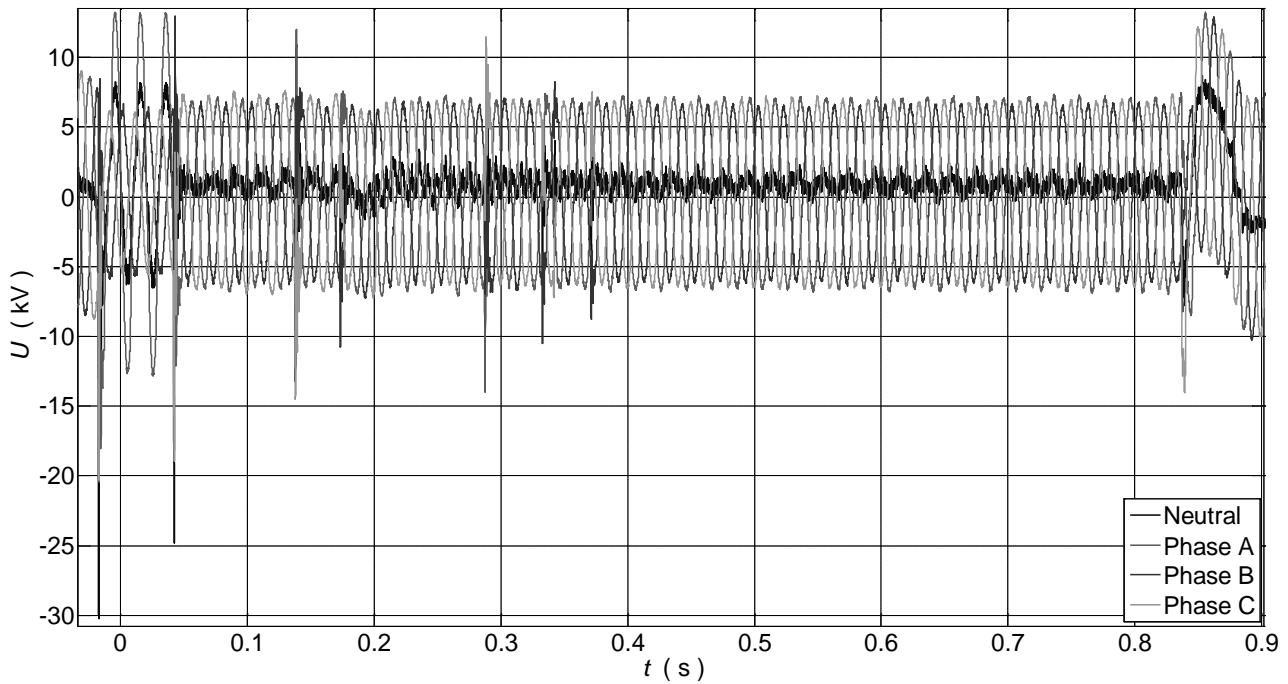


Fig. 6. Process of the overvoltages induced by lightning stroke

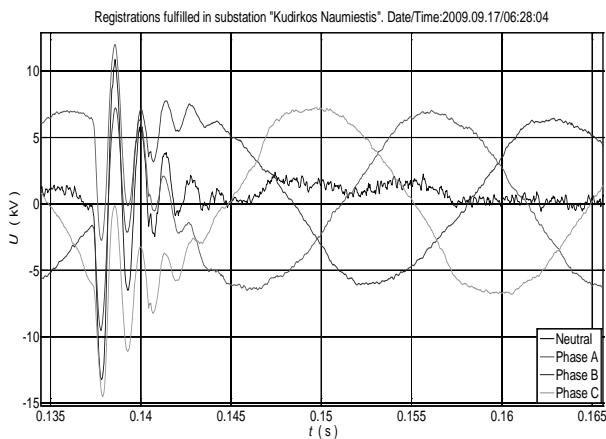


Fig. 7. Process of the overvoltage between first and second lightning stroke

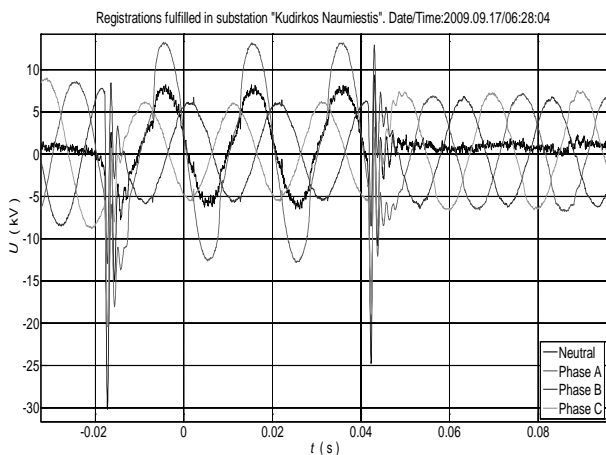


Fig. 8. Process of the overvoltage induced by third lightning stroke

The structure of on phase to ground place location

Numerous primary charge and strong primary one phase fault to ground stage transient current in the zero sequence and in phase creates beneficial conditions for the one phase fault to ground place recognition [11]. Regarding to the mathematical linearity of the primary process in the system fault place recognition task becomes invariant from primary conditions (phase angle and system electrical charge at the connection moment). Suitably adapted fast electromagnetic process model enables us to find such phase shortening to ground place, which best and more accurate repeats registered processes. A feature of task linearity allows us to fasten the recognition process till about 2 – 5 minutes. Such recognition time is acceptable for finding and localizing fault place. Table 1 shows successful and unsuccessful recognition results during man-made one phase fault to ground modelling in the 10 kV networks, in supervising of international experts committee. We can mention, that before testing there was accepted conditional, that parameters of the network will not be adapted anticipatory. A practice shows that adaptation of the parameters numerously increased recognition reliability. Satisfactory process recognition illustration (Fig. 9, Fig. 10) shows the curve of the primary transient current in the zero sequence, registered in the distribution network net and model simulated.

Task linearity specific can be used for adapting network parameters, when it is known exact one phase fault to ground in the network, and allows to find line parameters, soil specific resistance in the one phase fault to ground place and to correct line length in the feeder.

Table 1. Result of the one phase to ground fault spotting algorithm tests

Nr.	Estimated fault resistance, Ω	Test feeder	Estimation result of faulted feeder	Fault spot place/distance, km	Fault spot estimation result	Error, m
1.	11	L – 600 Leipalingis	Detected	LP – 610 / 17.79	Detected	-
2.	15	L – 600 Leipalingis	Detected	LP – 610 / 17.79	Detected with error	201
3.	10	L – 600 Leipalingis	Detected	LP – 624 / 4.7	Detected with error	140
4.	14	L – 600 Leipalingis	Detected	LP – 624 / 4.7	Detected	-
5.	15	L – 400 Leipalingis	Detected	LP – 404 / 11.17	Detected	-
6.	17	L – 400 Leipalingis	Detected	LP – 404 / 11.17	Detected with error	134
7.	20	L – 400 Leipalingis	Detected	LP – 401 / 5.15	Detected	-
8.	1174	L – 10 – 300 Nemencine	Detected	L – 10 – 303 / 3.2	Detected with error	259
9.	997	L – 10 – 300 Nemencine	Detected	L – 10 – 303 / 3.2	Detected with error	24
10.	1223	L – 10 – 300 Nemencine	Detected	L – 10 – 303 / 3.2	Detected	-

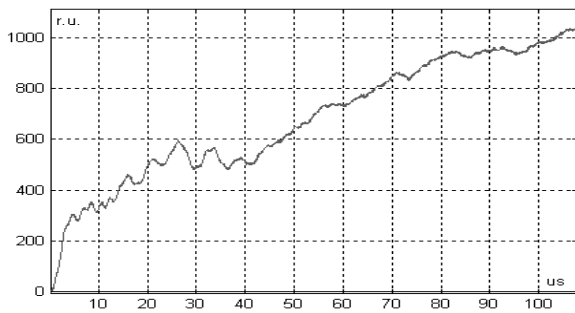


Fig. 9. Registered primary transient process zero sequence current

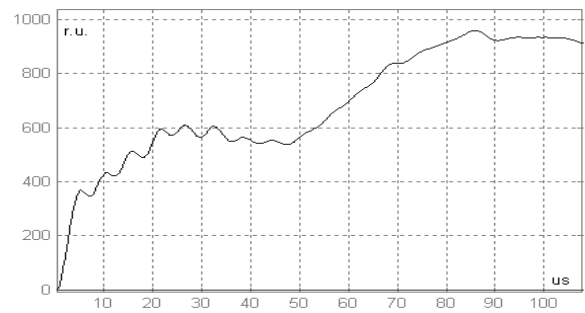


Fig. 10. Simulated primary transient process zero sequence current

Monitoring system of the faults in the network

Practice shows that distributive network, especially compensated network, often one phase fault to ground appears very short time. In the place of one phase fault to ground arcing slopes itself without line disconnection. However feeder terminal records such fault pass place which during long time period could become place for the

complicated network fault. Terminal registering and recording of such places allows to determinate and in fact of routine maintenance (trace cleaning) improve reliability indexes, i.e. the system average interruption frequency index (SAIFI) and the system average interruption duration index (SAIDI).

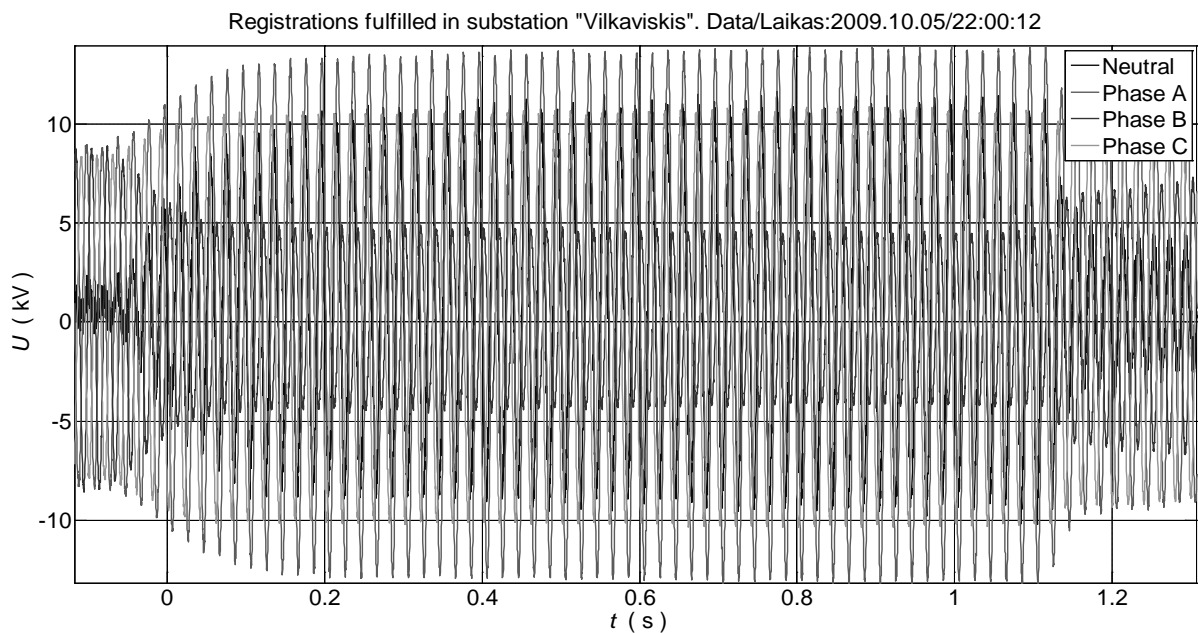


Fig. 11. Transient processes after short-term neutral

Registrations fulfilled in substation "Kudirkos Naumiestis". Date/Time:2009.09.28/06:08:11

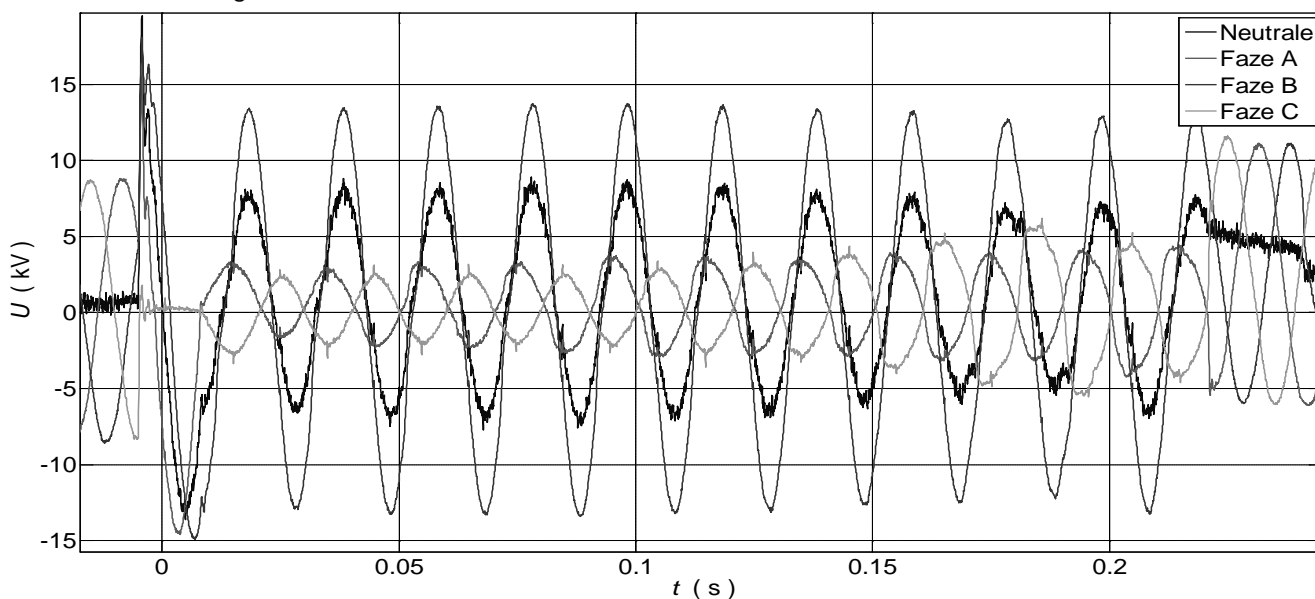


Fig. 12. Transient processes during fault switching off

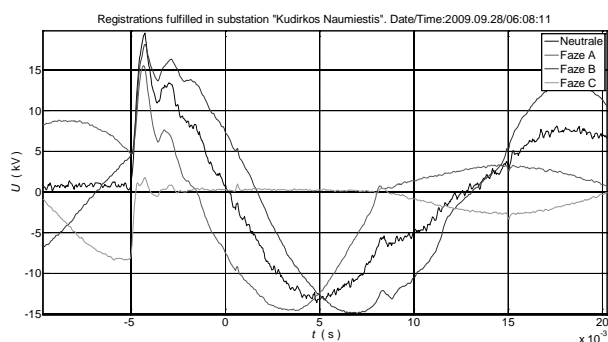


Fig. 13. Transient process of the one phase to ground fault passing to two phase fault

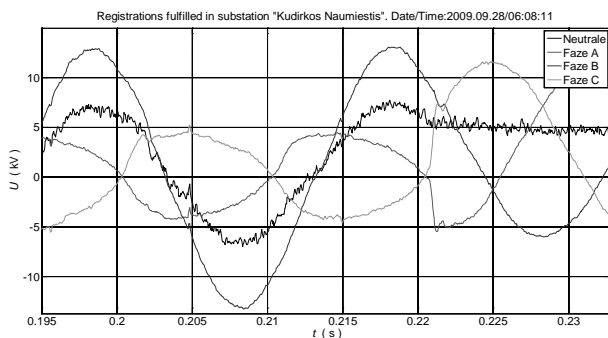


Fig. 14. Transient process after two phase fault switching off

Fault character recognition procedures groups registrations by the fault nature: insulation overlapping regarding to the lightning surge, shortenings by the tree branch, isolation surge by the overvoltage, system zero sequence voltage numerous changes (moisten isolator at the cleavage place, Fig. 11).

Model of the stationary processes

The model of stationary process for the substation network master feeder is prepared in fact to perform analysis of possible modes of the whole network. By the anticipatory reconfiguration schemes terminal regularly

should check their acceptance and electricity supply for the consumer's reliability indexes by the line loads, economical affect and voltage modes also. It should be formed proper interface and connection link protocols both with other feeder slave terminals, both with consumer's substations and distributed generation controllers and control – tower for the master terminal. It is creating stationary process model for power flow, voltage modes in the three – phase structure, static and dynamic stability analysis.

Conclusions

The initial transients of grounding current practically do not depend on instantaneous voltage in the spotting place and polarity.

Initial processes linearity specific can be used for adapting network parameters, when is known exact fault place and allows to find line parameters, soil specific resistance in the one phase fault to ground place and to correct line length in the feeder

When the processes identification algorithm is applied for electrical network with insulated and compensated neutral, the spotting place can be determined with span accuracy.

References

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The paper describes the mathematical models of fast electromagnetic processes analysis and its application principles for normal, fault, post-fault regimes identification of electricity distribution networks and fault place location. Algorithms based on fast electromagnetic processes identification models have been created and implemented in distribution network state identification terminals. Terminals have been mounted in six substations of Lithuanian electricity distribution utility and deliver real-time network state identification information to the dispatcher centre. The analysis of the results and algorithms application for the distribution network regimes identification is presented, and the further development perspectives based on fast electromagnetic transient analysis models are discussed. Ill. 14, bibl. 11, tabl. 1 (in English; abstracts in English and Lithuanian).

S. Gudzius, V. Gvozdaz, L. A. Markevičius, A. Morkvėnas. Sumaniojo elektros tinklo būklės stebėjimas realiu laiku // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2010. – Nr. 10(106). – P. 57–62.

Straipsnyje aprašytas elektromagnetinių procesų analizės matematinis modelis ir jo naudojimo principai normalaus, avarinio ir poavarinio elektros skirstomojo tinklo režimų analizei ir gedimo vietai nustatyti. Naudojant elektromagnetinių procesų identifikavimo modelius buvo sukurtas elektros skirstomojo tinklo būvio identifikavimo algoritmas. Šis algoritmas buvo panaudotas tinklo būvio identifikavimo terminaluose, kurie yra sumontuoti šešiose skirstomojo tinklo pastotėse įvairiuose Lietuvos regionuose. Tinklo identifikavimo rezultatai perduodami į elektros tinklų dispečerinio valdymo centrus. Straipsnyje pateikti elektromagnetinių procesų identifikavimo algoritmų naudojimo rezultatai, aptartos jų tolesnės plėtros perspektyvos. Il. 14, bibl. 11, lent. 1 (anglų kalba; santraukos anglų ir lietuvių k.).