Paper accepted for presentation at 2009 IEEE Bucharest Power Tech Conference, June 28th - July 2nd, Bucharest, Romania

Automatic security measures foreseen in the Romanian Electrical Power System in case of major disturbances

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***Abstract* - In order to prevent the occurrence of major disturbances or to limit their consequAences in the Romanian Electric Power System (EPS) was implemented a Defense Plan that comprises a succession of hierarchical measures. These measures are chosen in relation with the nature and intensity of the disturbance and their action is to re-establish the normal operation.**

***Index Terms* - Transmission system, blackout prevention, observability, controllability, security, PMU.**

I. Introduction

IN order to prevent the occurrence of major disturbances or to limit their consequences in the Romanian EPS was implemented a Defence Plan that comprises a sequence of hierarchical measures. These measures are chosen in relation with the nature and intensity of the disturbance and their action is to re-establish the normal operation.

The disturbances taken into consideration are:

o major frequency disturbances

o voltage collapse

o cascade line trip

o asynchronous operation

o un-damped power swings

The automat measures included in the Defence Plan for each disturbance mentioned above are:

o selective, coherent and co-ordinated with the dispatch control actions

o in accordance with UCTE requirements.

Major unbalances between the generated active power and consumption, unbalances that are exceeding the action capacity of the automat control systems and/or planned power reserve lead to:

- fast and major frequency variations,
- significant changes of active (reactive) power flow on elements and/or on specific areas of the transmission network,
- deterioration of units regime of operation,
- disorder to some sensitive consumers,

Finally, following a cascade of events as transmission lines trip, generations trip etc. an area extended black out could happen.

It can be stated that in almost all black-out cases, independent of the initial disturbance, the process of operation regime degradation passed also a stage/ operational regime characterized by major frequency deviation from the normal rated frequency.

II. Measures To Overcome the Risc of Frequency Instability

As far as the frequency degradation process is not an extremely fast one it is possible to take automatic measures to stop the frequency drop mainly by load shedding.

The under-frequency load shedding is accepted as a necessity and it is carried out (in more or less sophisticated formula) in the majority of the EPS.

This automation has some advantages that derive from the supervised criterion – frequency:

- reflects clearly the electrical system regime of operation in each moment,
- can be precisely measured using digital devices quartz oscillator based,
- can be carried out with both centralized and/or distributed systems.

Frequently automatic under-frequency load shedding showed its efficiency in real time operation condition.

Further on it is presented a coordinate system on frequency criterion implemented in the Romanian EPS in which the under-frequency load shedding has the main role.

1. Short description of the automatic system on frequency criterion in operation in Romanian EPS

The Technical Code present governing the Romanian Transmission Network stated as admitted frequency range for operation:

47.0 ÷ 52 Hz for a time period 100% per year,

49.5 ÷ 50.5 Hz for a time period of 99.5% per year,

49.75 ÷ 50.25 Hz for a time period of 95% per week,

49.9 ÷ 50.10 Hz for a time period of 95% per week.

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The sequence of automatic actions foreseen in the Romanian EPS:

- frequency in the range 49.5 ÷ 50.5Hz. In this range it is developing automatic frequency control and/or the operational personnel control. The feature of this range is the permanent tendency to bring this parameter at the reference frequency and to minimize the existent net power exchange related to the scheduled one.
- increased frequency range: 50.5 ÷ 52 Hz. In this range the automatic frequency control continues to operate and in addition some severe actions are foreseen to take place such as switching off hydro units from the network.
- under-frequency range: 49.5 ÷ 49 Hz. In this range the automatic frequency control and/or personnel control continues to operate but additionally there are foreseen complex automatic measures such as: automatic starting and/or changing hydro units from synchronous compensator to generator.
- under-frequency range: 49.0 ÷ 48.0. In this range it is foreseen to take automatic under-frequency load-shedding actions,
- under-frequency range: 48.0 ÷ 47.0Hz. Hydro and thermal units separation from the network on auxiliary services in order to start a restoration program in case of black-out.

2. The automatic under-frequency load shedding represents the main action of the Defense Plan against major disturbances.

Principles applied for under-frequency load shedding calculation and organization

2.1. the only goal of the automatic under- frequency load shedding system is to stop the frequency drop; the frequency recovery until the initial (reference) value remains to be performed by the operational personnel.

2.2. automatic under-frequency load shedding system is organized as distributed automation (about 800 independent under-frequency devices). This distribution offers a mainly statistic and not deterministic checking possibility of the load shedding stages, selective action and their action efficiency in the process of stopping the frequency decrease; the probability of action failure or erroneous action is limited at one device implying only an insignificant volume of shed load.

2.3. it was decided that the calculation for dimensioning the under-frequency load shedding were no longer necessary from the following reasons:

- the principle that any consumption should be possible to be disconnected by one of the automatic load shedding stages in case of major frequency decrease, exception: auxiliary services of power plants and substations. Consumption with special needs should be ensured from special supply sources (not interruptible), other than the EPS the task and the responsibility for the realization of the supply solution should be the task of the interested part.
- the dimensioning calculation based on "scenarios" is not relevant; real life developments proved that it does not matter the number and diversity of analyzed scenarios/simulations because real frequency disturbances (especially in large interconnected systems as UCTE) are different. Another reason is that in the Romanian EPS there are insufficient and not very accurate data concerning the load characteristic. Usually, the dimensioning calculation results that treat "possible disturbances scenarios", especially in case of interconnected systems operation, lead to "optimistic solutions" (small amount of load to be disconnected by under-frequency load shedding stages).

2.4. implementation of the devices operating on the frequency (f) and frequency rate of change (df/dt) offers:

- an increased accuracy (pick-up, validation, operation, drop-off)
- a fast evaluation (due to the df/dt criterion) of the power unbalance and the acceleration of the load shedding action (faster action means higher success probability)
- reduced frequency selectivity step: 0.2 Hz

2.5. last but not least a co-coordinated and efficient under frequency load shedding system does not imply important financial efforts for the EPS participants but could save the EPS from a collapse that produces consequences difficult to be measured and appreciated.

As a result, in the Romanian EPS was carried out an automatic under-frequency load shedding plan prepared to switch off 60% of the load consumed in the Romanian EPS in the disturbance moment. There are 5 under frequency stages with a frequency selectivity step of 0.2Hz.

a) in case of the first two stages the frequency rate of change criterion is used
b) the first two stages (15% and 10%) are foreseen to operate while the system is still interconnected with the neighboring EPSs for mutual support
c) the last three stages are foreseen to operate after the Romanian EPS separated from the interconnection
d) the under frequency automation foreseen to separate Romanian EPS from the interconnected systems by switching off the tie lines are agreed, from the settings point of view with interconnection partners and set to f= 48.7 Hz, t = 0.5s.

III. Measures to Overcome the Voltage Instability

Voltage collapse, preventive/corrective measures:

- The voltage level and the reactive power flow are permanently supervised by the dispatch personal using SCADA system that is supposed to take the necessary measures in order to avoid the voltage collapse.
- In case of voltage drop it is foreseen an automatic measure to switch off the 100 MVAr shunt reactor 400kV/220 kV circuit breaker. The total amount of disconnected reactive power is about 1500 MVAr

The same shunt reactors ensure the primary equipment automatic over-voltage protection. For this purpose an automation to switch on the 100 MVAr shunt reactor 400kV/220 kV circuit breaker in case of voltage increase was foreseen. The total amount of connected reactive power is abot 1500MVAr.

IV. Cascade Line Trip

In the Romanian transmission grid there are no overload installed protections on the 220 and 400kV OHLs.
The maximum transferred power on an element value then the maximum thermal capacity of the element and also a higher value then the steady state power limit on that element.
The occurrence of overload on an EPS element is alarmed in the SCADA system and the regime is corrected by operational personal.

V. Measures to Overcome the Risk of transient instability

In the Romanian EPS are installed and in operation pole-slip (out-of-step) detection protection functions based on the rate of change of the measured impedance principle.

One of the phenomena that could initiate a major disturbance: significant changes of load or generation or/and uncontrolled cascade trip of transmission lines and/or units due to delayed short-circuits clearance time that are leading to unstable amplified oscillation between areas. In this moment the EPS or interconnection integrity is no longer possible to be maintained due to the high operational risk of severe electric and mechanic stress for the units (power plants). One large risk for the interconnection/system integrity is that in case the areas that are oscillating are not rapidly separated the units uncontrolled trip could not be avoided and that will determine a power deficit or an increase of the already existing one.

To avoid these uncontrolled losses and to restrict as much as possible the area operating with disturbed parameters we have decided to implement in the Romanian EPS dedicated protection functions for pole-slip detection. Argument: disconnection of subsystems in points as close as possible to the electrical center of oscillation (ECO) proved to prevent in the best way the collapse of a complete system.
Historically this type of protection was used in the Romanian EPS as a generator protection and we have it in operation for the nuclear power generator (2x 700 MW in Cernavoda Nuclear Power Plant), for hydro generators (with Pn ≥ 150 MW) and for thermal generators (with Pn ≥ 200 MW).
We have decided to extend the application of this protection function to the interconnection OHLs (all 400 kV voltage level).
Reasons: historically, from the EPSs evolution point of view these are the easiest to be monitored sections and represent the most probable location for the ECOs in case of an asynchronous operation between systems.

The dedicated pole-slip function included in line protection terminals provide the following features:

- impedance measurement on all three phases
- oscillation detection principle based on impedance rate of change
- possibility to set the impedance rate of change
- the detection of oscillation performed with special logic “two-of- three” phases with blocking in case of zero-sequence current detection
- detection of the oscillation electrical center locus that crosses the reactance axis within two separate domains of the impedance plane:
  - 1st domain on the protected OHL, forward
  - 2nd domain outside the protected OHL, with 2 zones one situated forward and the other one reverse
- each domain has associated a counter to register the slip numbers
- possibility to dissociate impedance rate of change in the first slip cycle from the next slip cycles
- detection of the trajectory of apparent impedance direction that enters the operation characteristic
- possibility to chose the OHL CB trip moment in order to reduce the electrical and mechanical equipment stress.

The calculation cases presented below offered the possibility to prove the existence of operation scenarios in which it is possible to occur an asynchronous operation on the 400 kV OHL Nadab(RO) - Bekescsaba(HU) with the ECO positioned inside the line impedance.

Concrete case: the implementation of the pole-slip protection function on the 400 kV OHL Nadab(RO)-Bekescsaba (HU) is shown in fig 1÷ 4.

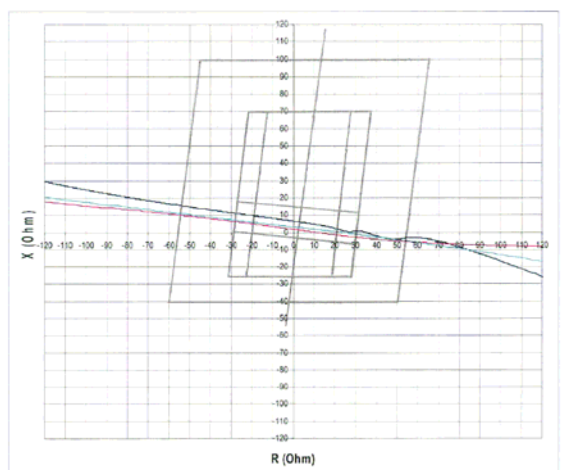

Fig.1. Pole-slip detection on the 400 kV OHL Nadab – Bekescsaba, 1400 MW export on Nădab-Bekecsaba, 3ph fault on 400 kV OHL Porțile de Fier - Djerdap

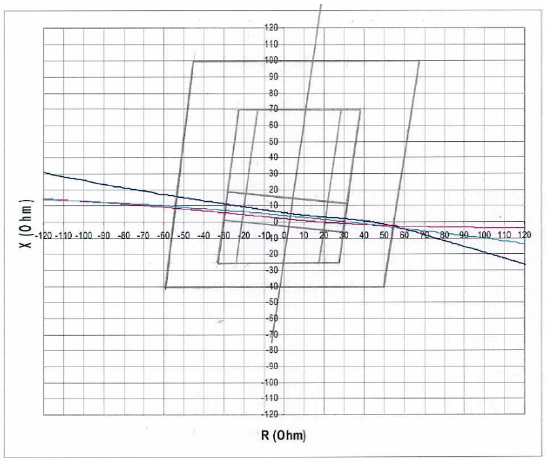

Fig.2. Pole-slip detection on 400 kV OHL Nadab – Bekescsaba, 1900 MW export on Nădab-Bekecsaba, 3ph fault on 400 kV OHL Porțile de Fier - Djerdap

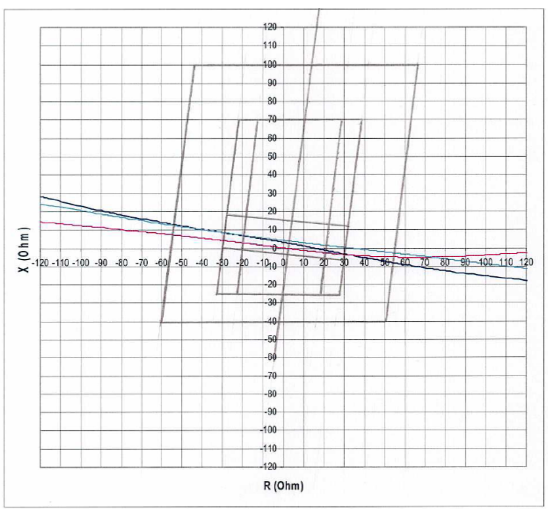

Fig.3. Pole-slip detection on 400 kV OHL Nadab – Bekescsaba, 2000MW export on Nădab-Bekecsaba, 3ph fault on 400 kV OHL Porțile de Fier - Djerdap

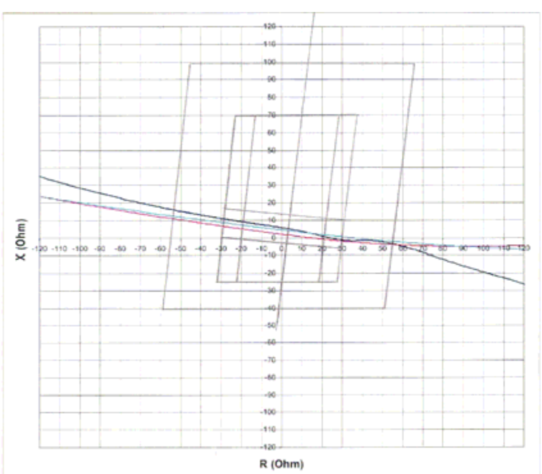

Fig.4. Pole-slip detection on 400 kV OHL Nadab – Bekescsaba, 2500MW export on Nădab-Bekecsaba, 3ph fault on 400 kV OHL Porțile de Fier - Djerdap

Legend: 1st slip 2nd slip 3rd slip

The calculation conditions:

- The Romanian EPS interconnected with UCTE and Burstin island
- Romanian EPS peak load = 7300 MW (summer conditions)
- Tie lines in operation:
  - ❖ for the first two examples Nadab-Bekescsaba & Portile de Fier (RO)-Djerdap (Yu)
  - ❖ for the last two examples Nadab-Bekescsaba, Isaccea (Ro)-Dobrudja (Bg) & Portile de Fier - Djerdap
- Fault scenario: 3 phase fault without earth on the 400 kV OHL Portile de Fier – Djerdap, correctly cleared by the line differential protection and CB correct operation

TABLE I
CALCULATION RESULTS PRESENTATION

Case	Entrance speed [Ω/s]	Exit speed [Ω/s]	Δt entrance [s]	Δt exit [s]
Case 1				
1st slip	22.32	357.14	1.12	0.07
2nd slip	416.67	526.32	0.06	0.0475
3rd slip	476.19	555.56	0.0525	0.045
Case 2				
1st slip	81.83	294.46	0.3055	0.0849
2nd slip	366.57	1101.32	0.0682	0.0227
3rd slip	611.25	2192.98	0.0409	0.0114
Case 3				
1st slip	71.65	450.45	0.3489	0.0555
2nd slip	392.46	550.66	0.0637	0.0454
3rd slip	611.25	733.14	0.0409	0.0341
Case 4				
1st slip	37.50	333.33	0.6666	0.075
2nd slip	405.19	625.00	0.0617	0.04
3rd slip	652.74	883.39	0.0383	0.0283

The calculation results presented in Tabel 1 offer data for:

- the slip impedance rate of change
- the tripping domains (areas)
- the associated counting of slips number
- the tripping characteristic
- the possibility to check the validity of the frequency of oscillation value
- the basic document for discussion and agreement of this function settings and acting logic with our partners.

Transelectrica experts consider that the separation between areas detected as possible to operate asynchronously one related to the other is an efficient measure to prevent an area or extended black –out.

All distance protection installed on transmission grid (OHLs, autotransformers, transformers, couplers) have at least the distance protection first zone blocked in case of power swing detection.

On the OHLs were pole-slip protection is active the two protection functions power swing detection and pole-slip are independent and neither of them can be used as a replacement of the other through negation action due to sensitivity and selectivity reasons.

In this field, Transelectrica is in the process of implementing these devices (functionality) on internal transmission OHLs on critical sections of the Romanian EPS and we are now in the process of principle establishment for grading their settings. We are also in the process of introducing EPS monitoring using the phasor measuring units (PMUs) and the associated synchrophasors techniques.

Conclusions

The EPS operating closer to its stability limits imposes a more accurate monitoring to avoid system frequency or voltages instability because of system contingencies. The dynamic behaviour of the EPS depends on actual network topology, load balance, current flows in and out of the critical sections, and generation unit's location in the network and type and control systems of these units. To improve EPS monitoring an ongoing pilot project is foreseen that involves installing of twelve PMUs in key transmission substations and of a phasors data concentrator at the network control centre location. As a first approach cross-border lines as well as substations close to large scale generating units were chosen for phasor monitoring.

The automatic security measures foreseen in the Romanian EPS, schematically presented above, is the result of years of continuous improvement actions in power system reliability and stability. These measures were developed and carefully reviewed after each major system disturbance that occurred in our system and also taking into account the lessons learned from other systems incidents.

It is of high importance to be stressed that the process of assessing and developing the automatic security measures in the Romanian EPS is a continuous one:

- in the frequency domain we have developed an additional back-up under-frequency load shedding stage in case the above mentioned stages are insufficient or inefficient,
- the pole-slip tripping applied to large generators should be coordinated as settings and action logic with the TSO schemes introduced in the network and an interregional design philosophy to determine the proper moment of tripping a unit in case of pole-slip detection (if during first slip or after a number of slips) should be considered (considering also particular requirements of certain plants as the nuclear power plant),
- we are also interested in Wide Area Protection and Control schemes development and on reliable high speed communication technologies that could improve power system reliability.

- in the near future synchrophasor measurement units will be installed within twelve important transmission network substations to provide wide area monitoring and analysis in order to increase the system operator situational awareness. Future power system control based on these techniques will improve the EPS defense plan.

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VII. Biographies

Florin Balasiu

Director of the Protection and Automation Management Division of the Romanian Power Grid Company – Transelectrica.

He has an engineer diploma in Electrical Engineering from Polytechnic University Bucharest, Romania, 1979 and a Ph.D. diploma from Polytechnic University Timisoara, Romania, 1997.

He has almost 30 years of experience in the area of Transmission and Distribution protection and control systems engineering, commissioning and maintenance. He is an observer member of CIGRÈ, Study Committee B5 – protection and automation and has authored over 30 technical papers on protective relaying and is co-author of a Hand Book on Numerical Protection devices.

Felicia Mihaela Lazar

Chief Inspector for System Safety Romanian Power Grid Company –Transelectrica Bucharest – Romania.

Diplomat engineer from 1981 when graduating from Polytechnic University Bucharest – Electro energetic Department. From the beginning of 1984 activated as an engineer in the Protection and Automation Department from National Dispatch Center. In 1994 gained the Expert in Protection and Automation position in the above mentioned department. In March 2002 was appointed as Head of Protection & Automation Department in the Romanian National Power Grid Company - "Transelectrica" S.A. From January 2009 was appointed in the position of Chief Inspector for System Safety.

Rodica Balaurescu

Chief of diagram planning office Romanian Power Grid Company –Transelectrica Bucharest – Romania.

Diplomat engineer from 1978 when graduating from the Bucharest Polytechnic University – Electro energetic Department. She activated since graduation as an engineer at the National Dispatch Center. In 1991 she obtained the PhD title from the Bucharest Polytechnic University, Romania.