THE USE OF WAP APPLICATIONS TO PREVENT LARGE BLACKOUTS IN THE NORTH-EAST ROMANIAN POWER GRID

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REZUMAT. Defectul în cascadă este un mecanism uzual prin care se propagă defectele ce cauzează intreruperi mari ale sistemelor de transport al energiei electrice. Pentru detectarea şi eliminarea rapidă a acestor perturbaţii astfel încât să se evite propagarea intreruperilor în cacadă in intreaga rețea de transport, se utilizează dispozitivele de măsură sincrofazoriala în timp real (PMU), care pot fi inglobate in diferite tipuri de sisteme de protecţii pe arii extinse (WAP), sisteme de optimizare si control de urgenţă, in vederea obtinerii unui management mai bun al securităţii sistemului prin strategii avansate de comandă şi protecţie. Obiectivul acestei lucrări este de a scoate in relief beneficiile aplicaţiilor WAP in vederea prevenirii blackout-urilor in sistemul de transport din nord-estul României utilizând infrastructura de fibră optică a CNTEE Transelectrica SA.

Cuvinte cheie: defect în cascadă, intrerupere, unitate de măsura sincrofazoriala, protecţii pentru arii extinse

ABSTRACT. Cascading fault is one common mechanism that causes large blackouts of electric power transmission systems. To detect rapidly and clear these disturbances so that to avoid the propagation of the fast-cascading outages in overall grid, it is used wide area real-time synchrophasor measurement system based on Phasor Measurement Units (PMUs), which can implemented in different types of Wide Area Protection, emergency control and optimization systems for better management of the system security through advanced control and protection strategies. The objective of this paper is to point out benefits of WAP applications to prevent of blackouts in the North-East Romanian power grid using optical fiber infrastructure of CNTEE Transelectrica SA

Keywords: Cascading fault, blackout, Phasor Measurement Unit, Wide Area Protection

1. INTRODUCTION

Cascading failure in electric power transmission systems is the usual mechanism by which failures propagate to cause large blackouts of electric power transmission systems. Most blackouts are caused during stressed power system conditions followed by a sequence of low-probability outages. These failures led to major blackouts with large economic penalties on a society that depends heavily on the availability of high quality electric power [1], [2]. The August 14, 2003, major system blackout in the Midwest and Northeast U.S. and Ontario, Canada, affected approximately 50 million people in eight states and two Canadian provinces. During the blackout, over 400 transmission lines and 531 generating units at 263 power plants tripped. Power to New York City and other affected areas was restored approximately 30 hours later [2], [3].

A study of significant disturbances reported by NERC(North American Electric Reliability Council) show that protective relays are involved in one way or another in 75 percent of major disturbances. A common scenario is that the relay has an undetected (hidden) defect that was exposed due to the conditions created by other disturbances. For example, nearby faults, overloads, or reverse power flows expose the defective relay and cause a false trip, which exacerbates the situation [4].

In recent years, it has become evident that precise measurements of power systems' state in real time is a very important tool for managing the operation of power systems, as well as mitigating some of the effects of catastrophic failures. Therefore, many techniques have been developed to make the power system survives during disturbances and continue to operate. One recent developed technique that may be used is Wide Area Protection (WAP) based on the Synchronized Phasor Measurement Units [5], [6].

Synchronized phasor measurement units (PMUs) were first introduced in early 1980s, and since then have become a mature technology with many applications which are currently under development around the world. This technology obtained with modern PMUs (Phasor Measurement Units) have become an important component of wide area measurements on most power systems [7]

2. RISK OF FAULTS AND DEFENCE PLAN TO MITIGATION OF BLACKOUTS

Risk of faults:

Major blackouts in electric power systems, seldom happen, requiring a sequence of low probability events to occur. Accurate sequence of events is difficult to predict, as there is practically an infinite number of operating contingencies. As system changes (load growth, independent power producers selling power to remote regions, new equipment installations), these contingencies may significantly differ from the expectations of the system designers. As a chain of events at various locations in the connected grid happens, operators cannot act quickly enough to address fast developing disturbances [8].

Security of the network has to be improved because of the large number of risks of faults or regimes which can degenerate in blackouts:

- the operating of the system out of the limits;
- the difficulty to predict accurately the low probability events,
- the difficulty for operators to act quickly enough in relation to the rate of occurrence of network events,
- a very great number of operating contingencies difficult to be predicted from system designer network,
- difficult to have lines and generators enough in backyard,
- uncertain power flows caused by transactions of the market,
- large number of maneuvers caused by maintenance works, faults or new entry depending ago works investment,
- competitive environment concerning new players of the network.

It can occurs disturbances in the power systems caused by the following phenomena: angle instability, small single angle instability, frequency instability, short-term voltage instability, long-term voltage instability and cascading outages. These phenomena have to be counteracted [9].

Defence plan:

A plan defence is a list of measures in order to counteract the phenomena which can degenerate in blackouts, concerning coordinated wide area protection, monitoring and control application, enabling a cost-effective solution to mitigate disturbances [10]. The plan includes various coordinated actions to prevent disturbance propagation. The concept of defence plan is based on some criteria such as:

- understanding the causes of the blackouts produced in different points of the world in the last years;
- have to put emphasis on security versus dependability,
- prediction of scenarios of disturbances and the establishment measures with the purpose to reduce the time restoration.
- finding the measures in order to arrest the propagation of blackouts;
- balance among performance, risk and costs;
- maximizing use of opportunities offered by the fiber optic backbone,
- a extremely high level of the reliability of the telecommunication system and for rest of components including cyber security, self supervision, auto diagnostics, tolerance of the faults.
- Improve monitoring, diagnostics, and control center performance (e.g. availability of critical functions needs to increase to 99.99%);
- Secure real-time operating limits on daily basis (e.g. dynamic line ratings);
- Implement Special Protection Schemes and Adaptive Protection;
- Perform protection coordination studies on a regular basis as system conditions change;
- Test not only individual relays but system protection applications;
- Perform dynamic voltage and transient stability studies on a regular basis as system conditions change;
- Condition assessment of aging infrastructure and improved maintenance;
- Operator training, including a coordinated approach among control areas.

3. OVERVIEW OF THE PHASOR MEASUREMENT SYSTEMS

Synchronized measurements have become a common feature in modern electric power systems. Time-synchronized samples are used to calculate a variety of quantities such as voltage and current phasors or power. Due to their relationship to power flows, the relative voltage phase angles among substations are some of the most important measurements. The implementation of PMUs facilitates the relative phase angle measurement.

Figure 1 shows a typical block diagram of a PMU. The power system voltages and currents are converted to standard secondary levels by the voltage and current transformers, and properly isolated and filtered by signal processing units.

Synchronization can be achieved with equal results by two methods: (a) the sampling pulses are synchronized to a GPS (Global Positioning System) receiver and samples are taken at the same time in all devices with an error dictated by the ability of the sampling clock to phase lock and (b) the samples are time stamped precisely with respect to the GPS receiver time tag followed by the correct processing of the data samples and time tagging of the output data.

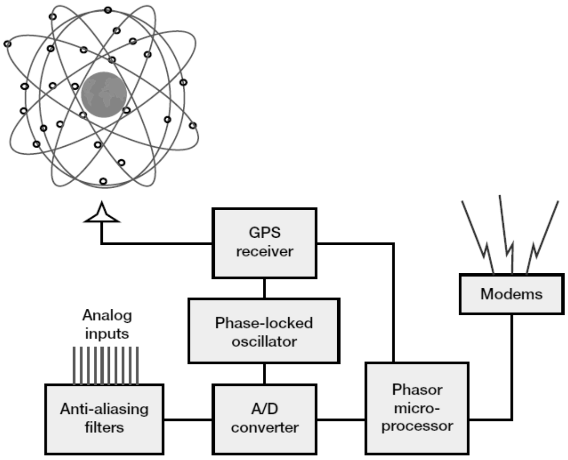

Fig. 1. PMU block-diagram

In figure 2 are depicted the connections of the PMU in the bay level.

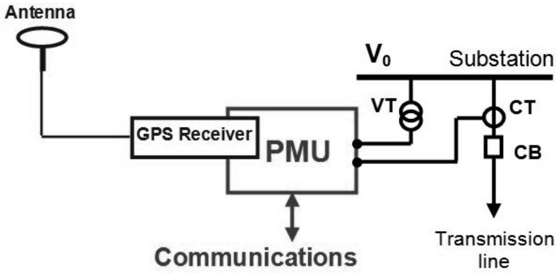

Fig. 2. The connections of the PMU

While most of relays still only use magnitudes of voltage and current measurements, a new technology is available for accurately measuring voltage phase angles (phasors). These measurements could offer new information that can be used to improve the functional logic of protective relays. In [11] it is presented a phasor estimation algorithm which starts from the classic full-period Fourier algorithm and adaptively suppresses an exponentially decaying dc component.

The orthogonal components of the power frequency phasor computed with the phasor estimation algorithm are as:

$$X_R[n] = X_C[n] - \delta_c[n] \tag{1}$$

$$X_I[n] = X_S[n] - \delta_s[n] \tag{2}$$

where $X_C[n]$ and $X_S[n]$ are the orthogonal components computed with the classic full-period Fourier algorithm:

$$X_C[n] = \frac{2}{N}\sum_{i=1}^{N} x[n-i]\cos(\frac{i2\pi}{N}) \tag{3}$$

$$X_S[n] = -\frac{2}{N}\sum_{i=1}^{N} x[n-i]\sin(\frac{i2\pi}{N}) \tag{4}$$

and $\delta_c[n]$, $\delta_s[n]$ are the corrections functions:

$$\delta_c[n] = d_c[n]X_0[n],\ \delta_s[n] = d_s[n]X_0[n] \tag{5}$$

where $x[n]$ is a generic sample from the measured fault signal with $n = 1, 2,\ldots, M$ (M is the number of samples considered), N is the number of samples in a fundamental period, equal in this case with the number of samples in the data window of the full-period Fourier algorithm, and i is the i^{th} sample in the data window.

Regarding (5), $d_c[n]$ and $d_s[n]$ are obtained using the formulas:

$$d_c[n] = D\cos(\frac{2\pi}{N}n + \delta) \tag{6}$$

$$d_s[n] = D\sin(\frac{2\pi}{N}n + \delta) \tag{7}$$

Also from the measured fault signal $x[n]$ there is computed an exponentially decaying dc component:

$$X_0[n] = \frac{2}{N}\sum_{i=1}^{N} x[n-i] \tag{8}$$

Regarding (6), D and δ are computed as:

$$D = \frac{1 - \exp\frac{-T_1}{N\tau}}{\sqrt{\left(\cos\frac{2\pi}{N} - \exp\frac{-T_1}{N\tau}\right)^2 - \sin^2\frac{2\pi}{N}}} \tag{9}$$

$$\delta = \tan^{-1}\left(\frac{\sin\frac{2\pi}{N}}{\cos\frac{2\pi}{N} - \exp\frac{-T_1}{N\tau}}\right) \tag{10}$$

with $T1$ being the fundamental period of the power frequency. The term $r = \exp(-T1/N\tau)$ depends on the unknown value of the time constant τ of the exponentially decaying dc component and can be estimated from the measurements at each sample:

$$r = r[n] = \frac{X_0[n]}{X_0[n-1]} \tag{11}$$

Equation (11) was obtained taking into account (8) where $X_0[n]$ stands for a sum of N elements of geometric progression with multiplier r. For stabilizing the estimator (11) there may be defined apriori values for r as:

$$r_{\min} \leq r \leq r_{\min} \qquad (12)$$

where *rmin* and *rmax* are fixed values in accordance with the minimum and maximum assumed values of the time constant τ of the exponentially dc component.

In figure 3 and 4 there are shown some output results in the phasor computation taking into account the DFT algorithm and the adaptive presented algorithm

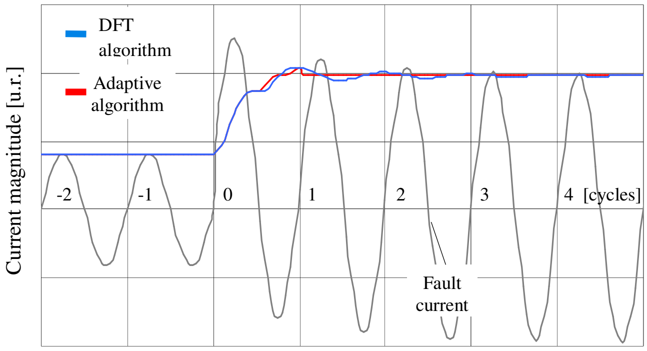

Fig. 3 The phasor magnitude computation of the fault current

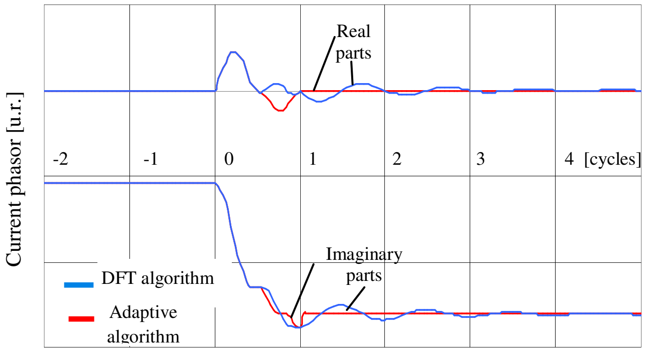

Fig. 4 The real and imaginary parts of the current phasor

Thus, obtaining the real and the imaginary parts of the phasor, it can be achieved very easy the magnitude as well as the phase angle of the phasor.

4. SIMULATION RESULTS

In order to obtain the simulated voltages and faults, the authors have modeled in Matlab the Romanian North-East power grid, which has the equivalent model in figure 5. The nominal voltage of the grid is 220 kV and the nominal frequency is 50 Hz. The power grid model contains three equivalent sources, with the parameters shown in table 1.

Table 1

Sources' parameters

Name	S_{SC} [MVA]	*Resist* [mΩ]	*Induct.* [mH]
Gutinas	3000	10	42,5
Filesti	1000	7	32,5
Stejaru	800	5	29

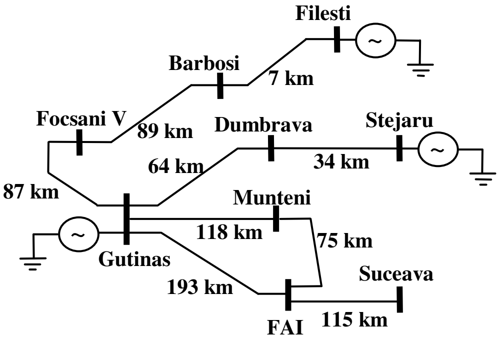

Fig. 5 The equivallent model of the power grid

Also, in the model depicted in figure 5, are shown the lengths of the considered lines. There were made the assumptions that all lines have the same type of conductor and that all circuits have the same type of tower. Taking into account these assumptions, in table 2 are shown the sequence parameters for 1 km of line.

Table 2

Sequence parameters of the line

Seq. param.	*R* [Ω]	*X* [Ω]	*B* [S]
Pos. / Neg.	0,038	0,331	$3{,}4 \cdot 10^{-6}$
Zero	0,180	1,131	$2{,}3 \cdot 10^{-6}$

In table 3 there are presented the real numbers of the unsuccessful re-closure cycles occured in the Romanian North-East power grid during the period 2007-2011.

Table 3

Unsuccessful re-closure cycles during 2007-2011

Considered 220 kV line	No. of unsuc. re-closure cycles
Focsani V - Barbosi	6
Gutinas - FAI	17
Gutinas - Dumbrava	14
Gutinas – Focsani V	8
Gutinas - Munteni	14
Suceava - FAI	14
Munteni- FAI	5
Stejaru-Gheroghieni	3
Gutinas - Stejaru	1

From table 3 and figure 5 results that the area of the grid delimited between Gutinas, Munteni, FAI and Suceava substations is the most affected by the unsuccessful re-closure cycles. Thus, in this area can take place a blackout if rapid measures of protection and control are not available.

In figure 6 there is shown an example of simulated voltage wave and in figure 7 is shown the sampled voltage, obtained at the PMU level. The sample frequency of the PMU is 1 kHz. It can be seen that in figure 6, the voltage wave has high frequency components.

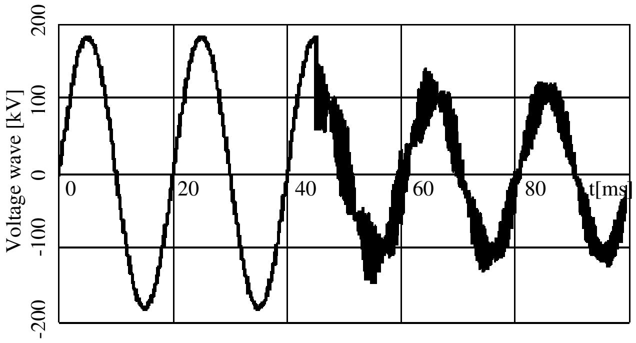

Fig. 6 Simulated voltage wave

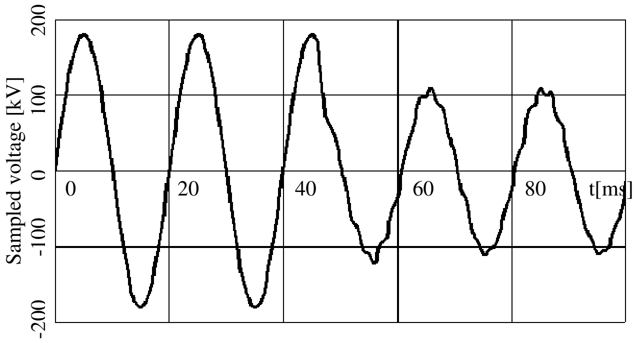

Fig. 7 Sampled voltage obtained at PMU level

Regarding table 3, the authors simulated many single-phased faults, especially in the area delimited by the Gutinas, Munteni, FAI and Suceava substations. Some graphic results regarding the sampled voltages obtained at the Gutinas and Suceava substations are given in the following draws.

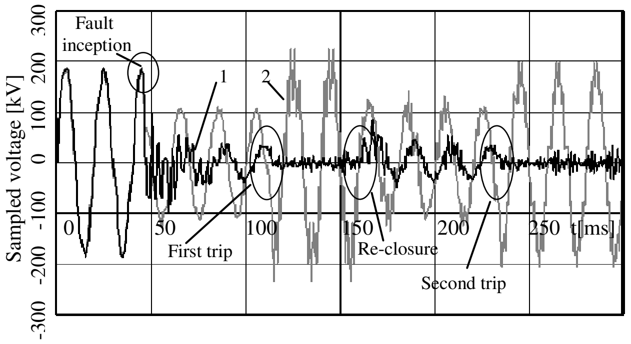

Fig. 8 Sampled faulty voltages obtained in 1-Gutinas and 2-Suceava substations

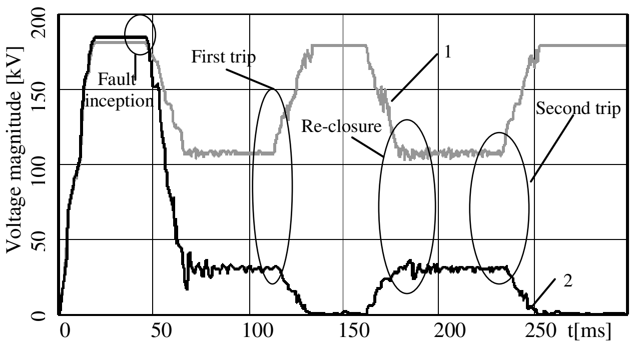

Fig. 9 Voltage magnitudes: 1-Gutinas, 2-Suceava

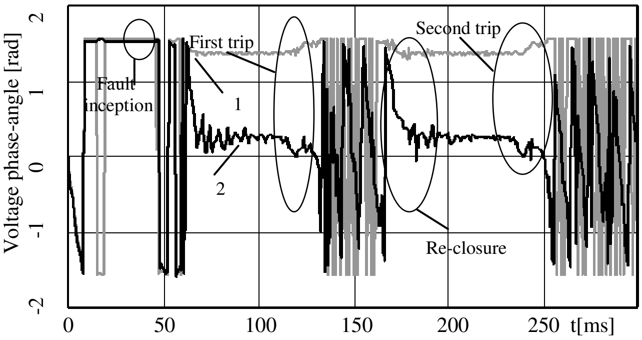

Fig. 10 Voltage phase-angles: 1-Gutinas, 2-Suceava

In figures 9 and 10 there are shown the magnitudes and phase angles of the voltage phasors on the faulty phases at Gutinas and Suceava substations. The magnitude computed values (figure 9) have stable values in normal as well as in the fault regime, but for the phase angles values this remark is not available (figure 10). It can be seen that after an unsuccessful re-closure cycle, the Suceava substation remains without power supply. Also, the FAI substation could remain without power supply, in the case of a fault on the line Gutinas-FAI.

In order to avoid possible blackouts in the Romanian North-East power grid, a possible way to improve protection and control is to implement two synchronized PMUs, one in Gutinas substation and one in Suceava substation. In this way, the entire area between Gutinas, Munteni, FAI and Suceava substations is covered.

5. CONCLUSIONS

In this paper there were pointed some advantages of using the PMU in order to improve the protection and control and to avoid the possible blackouts that can occure in the Romanian North-East power grid.

Also there was presented a phasor estimation algorithm, that can be implemented in the PMU.

Authors have modeled in Matlab a real network and simulated many single-phased fault. A part of the modeled network presented a higher interest due to the problems that arise in the real network.

It was shown that after an unsuccessful re-closure cycle, the monitored part of the modeled grid could remain without power supply. In order to avoid such situations, the authors proposed a possible way of the PMUs implementation.

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