NUMERICAL PROTECTIONS IMPACT ON THE SECURE OPERATION OF ELECTRIC POWER SYSTEMS

Felicia LAZAR[1], Mircea EREMIA[2]

The paper analyzes the impact of numerical protections on the electric power systems and their contribution to enhance the safety in operation. Starting from the performances offered by numerical protections, the paper presents a study of the contribution these systems have brought to the improvement of transient stability and frequency stability of the electric power systems operation.

Keywords: Intelligent Electronic Device, critical fault clearance time, multi terminal line differential protection, under-frequency load shedding

1. Introduction

The evolution of technologies used in power systems protection spans for more than 100 years, starting with electro-mechanical relays, to electronic and more recent, intelligent electronic devices (IED). The full potential offered by numerical protection devices can now be exploited using their new feature, i.e. communication capability. The use of IEDs and their communication paths between them enriches the numerical protection devices with a power that was not considered at the initial design stage of these equipments.

2. Requirements for the power system protections

The safe operation of an electrical power system (EPS) can be characterized by two main functional aspects: the adequacy and the security.

The adequacy can be defined as the EPS capacity to permanently satisfy the power and energy demand of the consumers taking into account both the scheduled and unexpected outages of the network elements [3].

The operational security of the EPS is the system capacity to cope with sudden disturbances such as short-circuits or unexpected tripping of network elements. The safe operation of EPS is ensured by the fact that the transmission network is designed and operated so that to comply with the (N-1) security criterion, with the steady state criterion and with the transient stability conditions.

When a power system operates in stressed conditions, a single low probability event, not planned by the system designers and not expected by system operators could lead to dangerous overloads, voltage instability, angle instability or frequency instability. Depending on the situation, these phenomena may generate a complete blackout.

[1] Eng., ELIA Engineering, Belgium Technical Gouvernance and eXpertize, Secondary Systems, e-mail: felicia.lazar@elia-engineering.com

[2] Prof. Emeritus, Department of Electrical Power Systems, University POLITEHNICA of Bucharest, Romania, eremia1@yahoo.com

The IEDs and transmission network elements offer significant improvements over the previous generations and technologies and represent a significant aid in coping with the above mentioned system conditions. The improvements in the protection performance are related to fault discrimination techniques and fast fault clearance time, protection selectivity, increased back-up principles, improved measuring algorithms and improved directional discrimination techniques [1].

SECURITY of a protection system is given by its characteristic not to operate for non-fault or out of zone fault conditions beyond the limit of the particular protection function strictly internal fault conditions. The security of a protection system is defined as the probability of its correct reaction when needed.

DEPENDABILITY of a protection system is defined as the characteristic to operate correctly for internal faults. The failure of a protection system to clear a fault that occurred inside its primary limits has the effect of exposing the system to longer fault durations that could lead to power plant tripping due to the operation of remote back-up protection.

AVAILABILITY represents the ability of the numerical protection to self monitor and to diagnose internal failures or discrepancies.

SENSITIVITY is the measure of the protection function ability to detect faults with low primary quantities or with small deviations from the healthy state.

SPEED of fault clearance is represented by short tripping delays in case of severe faults. The applications of high speed protection functions are contradictory to security requirements. Security may be compromised by increased speed of operation. Prolonged exposure to system voltage dips caused by slow fault clearance time represents a significant power quality issue. More important, for critical feeders, a slow clearance of the faults may impact the system stability.

3. Enhancing the transient stability of an EPS: A case study

The transient stability of a power system depends on its initial state and the disturbance severity. The capability of the power system to maintain the synchronism is related to the performances offered by protection and automatic control systems [2].

The digital protection systems had an important impact in reducing the fault clearance time due to the performances described in section 2, i.e.: increased operation speed, selectivity, sensitivity, and reliability. The critical criterion, i.e. "*the total fault clearance time < the fault critical time*", is easier to be achieved by means of digital protections. Their total time of less than 80 ms complies with the fault clearance time of 100 ms ÷ 120 ms declared as critical for transmission networks across Europe. This feature was one of the reasons to implement them at large scale for ensuring the protection of the special primary topologies required in order to allow integration of renewable energy sources (RES).

The secure integration of RES requires more flexible primary topologies of the electrical network. The new primary topologies proposed to be developed in the transmission network are: the teed connection of centralized generation (Fig. 1) and the connection with active three ends (Fig. 2). These proposed schemes have two major features: preserve the power system reliable operation at reduced costs [5].

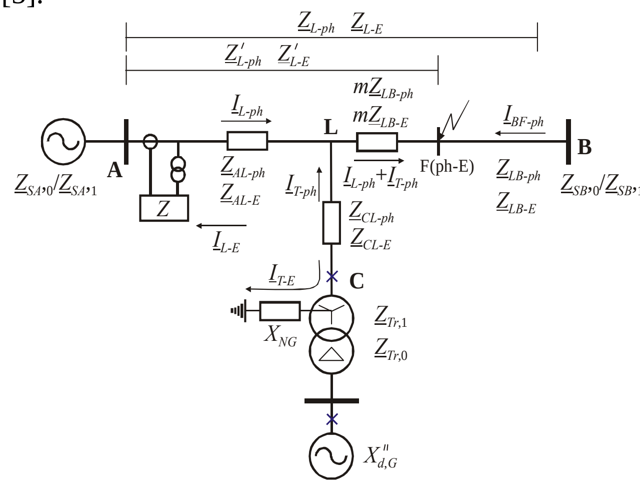

Fig. 1. Topology of a teed centralized generation connection: case study.

A study was performed on these two primary topologies in order to identify the most dependable, secure, fast, and sensitive protection solution. The 380 kV voltage level was chosen to better simulate a transmission network.

Three protection schemes can be applied for the primary topology in the case of teed connected generators:

Case 1: Distance Protection with POTT (Permissive Over-reach Transfer Trip) logic carried for all three line end.

Case 2: Distance Protection with POTT logic carried for two line ends with transfer trip commands sent from both these ends towards the third end.

Case 3: Three ends line differential protection with back-up protection, i.e. a distance protection with zones set for remote faults.

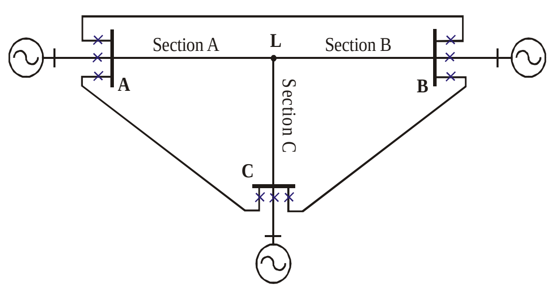

Fig. 2. Topology of an active three end connection.

For the second topology, with three active ends, the protection solutions Case 1 and Case 3 were studied.

The main comparison criterion: the reaction of these protection schemes with respect to fault critical clearing time presented above.

For the teed connected generators, 8 categories of variables are generally influencing the distance measurement. In our simulations, a number of 4 variables were considered [5]:

a) the characteristics of the in-feed network for the main existing ends, maximum and minimum values of the source impedance, and the Z_0/Z_1 ratio;
b) the location of the point of common coupling of the centralized generation on the initial OHL or cable;
c) the length of the new branch added;
d) the fault type and location.

For most of the studied cases an important error was obtained in the distance protection measurement which showed that the protection with POTT logic between the ends will not react. For the terminal A distance protection, presented in figure 1, the measurement of the phase-to-earth impedance is determined using the following expression:

$$\underline{Z}_R = \frac{\underline{U}_{A,ph-E}}{\underline{I}_{ph-L} + \underline{k}_e \cdot \underline{I}_{L-E}} \tag{1}$$

Let us denote by $\underline{k}_e$ the residual compensation factor, setting adapted to the OHL characteristics (2):

$$\underline{k}_e = \frac{\underline{Z}_{L,0} - \underline{Z}_{L,1}}{3\underline{Z}_{L,1}} \tag{2}$$

relation (1) can be written as:

$$\underline{Z}_R = \underline{Z}_{AL-ph} + m\underline{Z}_{LB-ph} + m\underline{Z}_{LB-ph}\frac{\underline{I}_{T-ph} + \underline{k}_e\underline{I}_{T-E}}{\underline{I}_{L-ph} + \underline{k}_e\underline{I}_{L-E}} \tag{3}$$

The measurement error (under-reach) for the case of single phase fault is:

$$\varepsilon_{1f} = m\underline{Z}_{LB-ph}\frac{\underline{I}_{T-ph} + \underline{k}_e\underline{I}_{T-E}}{\underline{I}_{L-ph} + \underline{k}_e\underline{I}_{L-E}} \tag{4}$$

For the case of a three phase fault, case in which the impedance is:

$$\underline{Z}_R = \underline{Z}_{AL-ph} + m\underline{Z}_{LB-ph}\left(1 + \underline{I}_{T,ph}/\underline{I}_{L,ph}\right) \tag{5}$$

the measurement error is:

$$\varepsilon_{3f} = m\underline{Z}_{LB-ph}\,\underline{I}_{T,ph}/\underline{I}_{L,ph} \tag{6}$$

where: $\underline{Z}_{n-ph}$ and $\underline{Z}_{n-E}$ are the phase impedance and the earth-fault impedance, respectively, of the element *n* (*n* is a portion of a OHL, transformer, etc.);
$\underline{I}_{n-Ph}$ and $\underline{I}_{n-E}$ are the faulty phase and the earth-fault current, respectively, flowing through element *n* (*n* is a portion of a OHL, transformer, etc.);
$\underline{I}_{L,1}$ and $\underline{I}_{L,0}$ are the positive- and zero-sequence impedances of the line.

This calculation shows that an in-feed between the distance protection location and the fault location will influence the impedance measurement; the impedance is apparently greater then the real one which leads protection trip in a superior time zone. In these cases with a non-reactive POTT, the fault is cleared by the delayed distance protection zones in a sequential cascade trip leading to fault clearances times higher than the critical one.

For the active three ends topology, another influence factor would be the existence of parallel paths. For this primary topology one particular behavior should be mentioned: the impedance measured by the protection device may also decrease due to “negative in-feed” or “out-feed” when the current flows out of the feeder during an internal fault. A reduction of the fault impedance occurs due to the existence of a parallel path in the short circuit loop.

The study reveals that the distance protection combined with communication logic is not dependable and not compliant with critical fault clearance time, therefore a risky solution for these particular primary topologies results.

The multi-terminal line differential protection possible to be fulfilled by digital technology only represents the best solution and offers the following advantages that contribute to the enhancement of transient stability[6]:

→ increased dependability;
→ suitable for heavy loaded links;
→ special communication algorithms and digital logic to provide fast trip, even when one communication path is unavailable;
→ immune to power swings phenomena.

The study briefly described above was developed for the 380kV transmission network. The aim of the study was to find out the performant protection scheme most suitable for the two new primary topologies presented above. The study was performed in order to check the behavior of the traditional protection scheme: distance protection completed with POTT communication logic. Based on the results of this study it was decided that the protection solution best suitable for these topologies will be represented for the transmission network by two multi-terminal line differential protections as main 1 and main 2.

4. Frequency stability related protection systems performances

The digital devices that include the under-frequency protection function combined with frequency rate of change detection offer the following performances [3]:

– increased accuracy (pick-up, validation, operation, drop-off);

- fast evaluation (due to the d*f*/d*t* criterion) of the power unbalance and the acceleration of the load shedding action (faster action means higher success probability);
- reduced frequency selectivity step, i.e. 0.2 Hz;
- avoidance of incorrect operation due to the under-voltage blocking

Based on the performances described above, a secure automatic under-frequency defence plan was developed in the Romanian power grid [4]. This is designed for automatic load shedding up to 60% of the load consumed in the Romanian EPS at the disturbance inception, and is additionally provided with islanding possibilities by disconnecting the interconnection lines in case of frequency problems.

5. Conclusions

The features of digital protections presented earlier are due to the performances of the IEDs implemented at large scale in the electrical power networks. Other important features such as the capability for more accurate parameters and setting selection, the incorporation of a complete autorecloser functionality, including secure and reliable faulty phase detection or the switch into fault protection, are limiting the impact of faults on the power system operational stability.

There is a strong need for new solutions of protection systems as the power grid topology is changing following the large developments of RES based power plants. These new solutions can be carried out in secure and reliable conditions with the functionality offered nowadays by the IEDs.

R E F E R E N C E S

[1] *** CIGRE Brochure 465, Modern Techniques for Protecting and Monitoring of Transmission Lines, 2011

[2] *D. Tziouvaras*, Relay Performance During Major System Disturbances, SEL, Inc 2006.

[3] *F. Balaşiu, F. M. Lazăr, R. Balaurescu, F. E. Ciausiu, L. Toma , M. Eremia*, Future Improvements in the Romanian EPS Defense Plan, IEEE PES GM Minneapolis, USA, 2010

[4] *F. Balasiu, F. Lazar, R. Balaurescu*: Automatic security measures foreseen in the Romanian EPS in case of major disturbances, IEEE Powertech Bucuresti, 2009

[5] *F. Lazăr, G. Huon, L. Uyttersprot,* Flexible grids protection schemes in ELIA vision: from traditional to intelligent ones**,** IEEE PES GM San Diego, USA 2012.

[6] *F. Lazăr, L. Uyttersprot;* Performance assessment of special protection schemes introduced by renewable energy network integration, IEEE Powertech Grenoble, France, 2013.