

doi:10.15199/48.2016.04.37

An Overcurrent Relay Model to Adaptive Protection Applications

Abstract. Models are important tools to analyse performance of the components of power electric system (PES). Some researchers have been proposing relay models for a lot of analysis on the PES. However, when adaptive protection is analysed, there is not a defined model on technical literature. In this paper, a complete model for an adaptive instantaneous overcurrent relay is shown. Proposed relay allows protective settings will be send to it and update with a short time delay.

Streszczenie. Przy analizie systemów energetycznych często jest używany model przekaźnika. Tak nie jest w przypadku systemów adaptacyjnych. W artykule zaproponowano przetężeniowy model przekaźnika do analizy systemów adaptacyjnych. Model umożliwia ustawianie zabezpieczeń z bardzo małymi opóźnieniami. **Przetężeniowy przekaźnikowy model sieci energetycznych z adaptacyjnymi zabezpieczeniami.**

Keywords: Relay model, adaptive protection, instantaneous overcurrent.

Słowa kluczowe: model przekaźnikowy, zabezpieczenia adaptacyjne, sieci energetyczne.

Introduction

Development of digital relay includes on the power protection system (PPS) a large number of facilities and improvements [1, 2]. Recently, some researchers have been proposing relay models for study on several areas [3, 4, 5].

Distribution generation (DG) has been including on the PES and changing PPS architecture [6, 7, 8]. Furthermore, DG connection should be provide several problems on relay coordination. In distribution systems, others events may chance PPS coordination, as: the input or output of lines and modification on load profile. In [9], a complete review of protection system applied to coordination relay in distributions system with presence of DG is presented.

A methodology to maintain coordination of PPS relays even when modifications on network occur has been studied for a large number of researchers [10, 11, 12]. This method, called adaptive protection system (APS), should be developed splitting PPS in layers with the following tasks: monitor the PES, identifies modifications, and determine and share new relays settings. Even though APS task are basically defined, there is not a uniformity among researchers about how many layer APS may be formed. However, the most important layer as in APS, as in traditional PPS, has been continues the relay.

Modern commercial relays have been including APS characteristics in its hardware/software. However, in mostly of these devices a long time delay to permute among different settings is necessary. In some cases, these delay may be upper than one minute [13].

In [14], an adaptive relay model was proposed. However, proposed device, concentrates all APS tasks in only one device. This model has the disadvantage of need a high process power performance. In [15], a DSP based system was used to implement APS architecture layers, expect the intelligent electric device (IED).

Above cited relay models have a problem in common: the time delay to permute among settings. So, in adaptive protection approach a relay model that provide all adaptive functions and include the possibility of permute among settings in a short time delay, will be an important contribution.

On this paper, a relay model with above characteristics will be proposed, i.e., proposed device may be permute among settings in a short time delay, in attempt to an APS system. The method is based on technical literature proposed models, and in a divided architecture of APS. Proposed adaptive relay model shows a very time delay to

permute among settings, and act correctly in all simulated cases.

Adaptive Protection System

As mentioned above, APS maintenance PPS coordination ever when challenges occurs on the PES, i. e., a mix of traditional PPS techniques with control process, provides characteristics of APS.

Some researchers have been proposing models to APS implementation. Regarding to the system architecture, [16] propose divide it in five areas with free access to each other's information. Proposed APS operates in a transmission network system with a strong presence of DG. Following the some line of thought, [17] uses a multi agent strategies (MAS) technique with a PPS composed for three layers. In [17], only instantaneous overcurrent units are controlled by adaptive protection system. The necessary parameters to calculate instantaneous overcurrent reach must be obtained using [18].

In [17, 14], APS is formed by three layers:

1. Substation Control Center (SCC) - monitors and identifies when a modification occurs on the PES;
2. Control Operation Center (COC) - calculates the new relay settings ever when a modification occurs;
3. Intelligent Electronic Device (IED) - receives relay settings of COC and analyses electrical variables.

In [14], details were discussed about SCC and COC center. In this paper, only third center will be discussed with details. An overview of APS architecture is shown on Fig. 1.

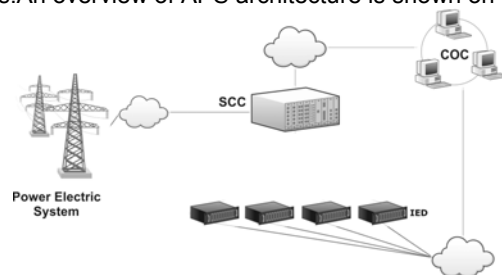


Fig.1. Adaptive protection system architecture.

Substation Control Center (SCC)

The SCC has as main function the monitoring and detection topological changes on electrical grid. In Fig. 2 contains a detailed flow chart of SCC.

SCC performance is divided into two parts: (1) circuit breaker status monitoring on the network - it indicates if the circuit breakers on the grid are open or closed; and (2) detection of operational modification on the PES - it monitors input or output of generation or load unit, as well as, modification on these profiles.

In order to detect a new topological condition, SCC uses the follow algorithm: to each time step SCC receives digital data about circuit breakers status. Using a shift method, the *BD1* buffer stores only one digital word that provides complete identification about system topology. On the next step time, information stores on *BD1* will transfer to *BD2* and the new circuit breakers status will be saved on *BD1*. With *BD1* and *BD2* information, a binary subtraction operation is carried and the presence of bits with high logical value will indicate a topological modification.

Modifications on the load or generation profiles are obtained through a method similar of the one used to detect operational changes. It is important to observe that voltage and current values used by SCC consist in a set of local information, which are the same information used by relays.

To make a correct identification of an operational change, it is necessary distinguish this event of a fault scenario. To do it, SCC architecture provides a communication channel to receive fault detection of relays. So, an operational modification only will be indicate if the event do not represent a fault.

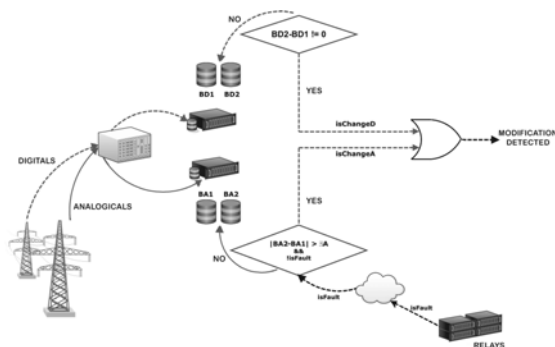


Fig.2. Substation Control Center (SCC).

Control Operational Center (COC)

The COC is the center in which all mathematical processes for automatic determination of protection devices adjustments are made. Strictly, an uninterrupted transfer of voltage and current phasor measurements from relays to COC is required. However, this transfer results in the need of a very fast communication channel. Because of this, it was decided to reproduce a similar architecture relay such as reported in [5], i.e., all functions responsible for the tasks until the phasor estimation process are presented as available in both relays and COC. Fig. 3 shows the COC operation architecture.

The scheme on Fig. 3 shows that the system must be able to operate with voltage and current signals on more than one electrical network point. With this, only local voltage and current are required on COC analysis. Again, no robust communication channels are need. Despite it has the same structure of digital relays, COC does not need a phasor estimation for all samples.

As COC will only be required when a topological or operational modification is detected, the windowing process continues to be done without interruption. However, phasor estimation, calculation of the equivalent network and adjustments on protective devices settings are only performed if the SCC detects any change in the electrical network. The setting adjustments of adaptive protection devices are extremely dependent on phasor estimation routine and network equivalents. Fourier full cycle algorithm and adaptive decaying DC offset elimination were used [20].

Thévenin equivalent circuit must be obtained as mentioned in [12]. Basically, equivalent determination must be obtained using probabilistic relationships between

voltage and current seen by COC. Through routines oriented tests, small error values of equivalent networks routines are verified when a minimum of 40 samples are used. As IED and COC use 16 samples/cycle, equivalent network determinations routine are set to use the triple samples rate value, i.e., mathematical calculations are performed as soon three complete cycles of samples on phasor estimation are counted.

Adaptive relay model

As early mentioned, an adaptive relay should have protects the power system and, when required, permute its settings without break monitoring of power system. In this paper, relay model is based on the proposed of [5, 14].

Fig. 4 shows the flowchart of proposed relay model. Traditional blocks continues present on device, i.e., anti-aliasing filter, analogic/digital converter, phasor estimation, etc. Observe that relay model has also for two communication channels: (i) connects protective device to SCC center and has as main function identification of when a fault have been identified and send this flag to SCC and, (ii) that receives the newest relay settings from COC.

In following subsections each block of Fig. 4 will be discussed and proposed modification indicate. For simply, auxiliary transducers will not explained.

Phasor estimation

A lot of methods have been proposed in literature to do phasor estimation [19, 20]. However, preliminary steps are required as: anti-aliasing filter, sample and hold and analogic/digital converter.

Anti-aliasing filter is necessary to eliminate spectrum superposition of input voltage and current signals, especially, when high frequency harmonics provenders of fault scenario are present. So, anti-aliasing filter is a low pass filter of third order with brand pass from 150 Hz to 240 Hz. In this paper, a Butterworth filter was used and transfer function is show in (1).

$$(1) \quad H(s) = \frac{1,6.45 \times 10^9}{s^3 + 2.361s^2 + 2,787s + 1,6.45 \times 10^9}$$

Next block of relay model is analogic/digital converter. In this step, analogical signal of voltage and current are converted to digital signals.

Buffer block stores the digital signal of voltage and current necessary to windowing process of phasor estimation. As known, phasor estimation algorithms are based on specific group of values. For each time step, this data are shifted, including newest values and eliminating oldest, forming a group on the window. So, amplitude and phase are calculate for each window.

In this paper, phasors have been estimated using Full Cicle Discrete Fourier Transform (FCDFT) algorithm and exponential DC offset was eliminated using adaptive mimic filter algorithm proposed in [20].

Protection Algorithms

To detect a fault on power system, a short windowing algorithm was used. This method is based on second derivative proposed in [23]. A fast and careful estimation of disturbs on the PES is provided by proposed method, with a delay about two samples of the signal. According with authors, the peak value of a periodic signal for the h sample should be obtained with the following form:

$$(2) \quad A_h = \sqrt{\left(\frac{x_h''}{\omega^2}\right)^2 + \left(\frac{x_h'}{\omega}\right)^2}$$

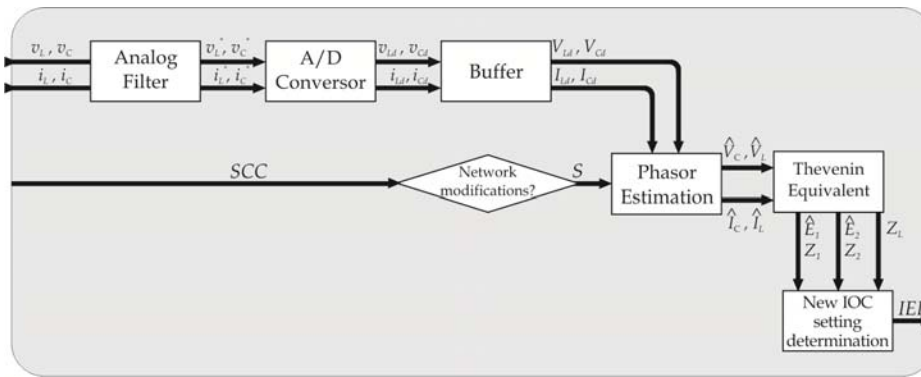


Fig.3. Internal architecture of Control Operational Center (COC).

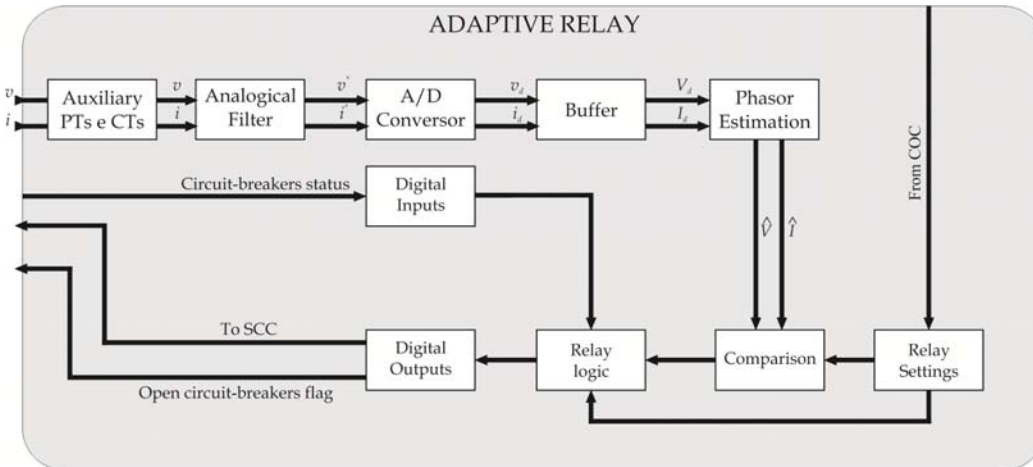


Fig.4. Proposed adaptive relay model.

where: x'_h and x''_h represents first and second derivatives of the signal.

Using finite derivative method, first and second derivatives should be calculated as:

$$(3) \quad x'_h = \frac{3x_h - 4x_{h-1} + x_{h-2}}{2\Delta t}$$

$$(4) \quad x''_h = \frac{x_h - 2x_{h-1} + x_{h-2}}{\Delta t^2}$$

Results and Analysis

In Fig. 5 a fault is identified using proposed method. A zoom on the fault start shows that in this case, a delay of just one sample was necessary to identify the fault.

To identify which are the cases where new relay settings should be determined, the logic showed on Table 1 is used.

A scenario with fault and modification on grid topological was used to analyse proposed relay model. A simply power electric system, shown on Fig. 6 was implemented on ATP [21] and APS on MODELS [22].

According with Table 1, a line output of power grid may be succeeded for an update on relay coordination settings. Fig. 7 shows logic values that represent relay identification and send the flag to COC center calculate new relay settings.

As can be see, *isFault* do not high value for a modification on grid topological.

Fig. 8, show that fault scenario was correctly identified and eliminate the fault. When a fault is eliminate, a topological modification is identified by APS and new relay settings may be calculated. This event is identified on Fig. 8 through the flag *isChange* at bottom of the Fig. 8.

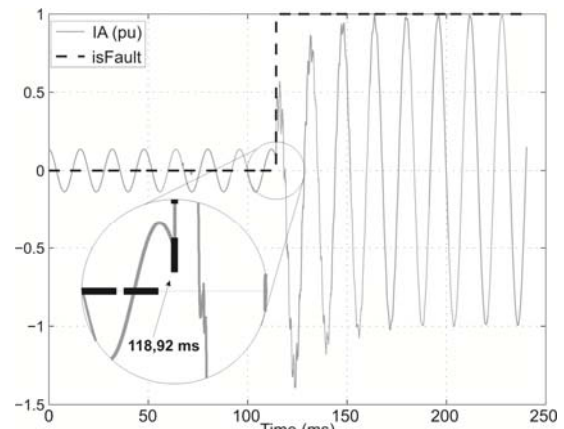


Fig.5. Fault identification algorithm.

Table 1. Actions of proposed adaptive relay.

<i>isFault</i>	<i>isChange</i>	Action
0	0	-
0	1	Calculates new setting
1	0	Sends trip signal
1	1	Sends trip signal and calculates new settings

In Fig. 8 a fault was applied on line between bus 4 and bus 5.

As can be seen in Fig. 7 and Fig. 8 the time delay necessary to permute among relay settings, is always lower than 10 ms, i.e., a delay shorter than actual commercial relay provides.

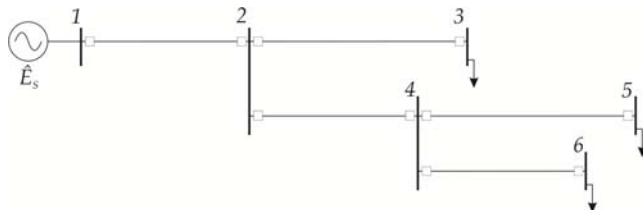


Fig.6. Distribution system used to evaluate adaptive relay proposed model.

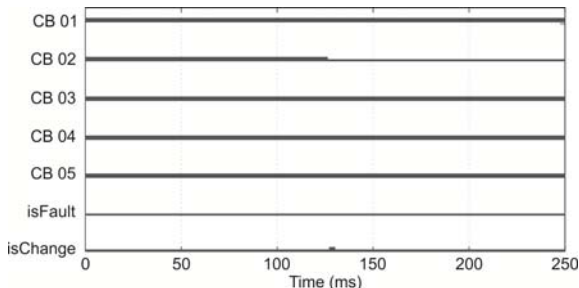


Fig.7. Status of circuit breakers and flags to identify a modification on grid topological.

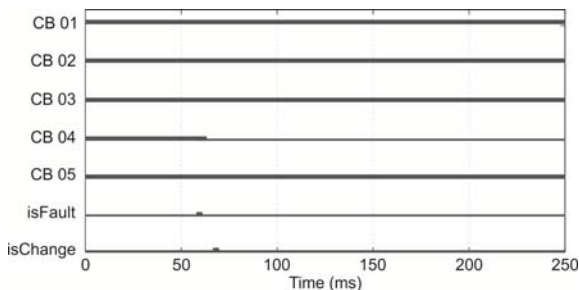


Fig. 8. Status of circuit breakers and flags to identify a faults on grid topological.

Conclusion

This paper present an adaptive instantaneous overcurrent relay model.

Results show that proposed relay model consists on appropriate device to contribute as with APS tasks, as traditional protection schemes.

The main advantage of proposed relay consists in the short time delay that is necessary to permute among relay settings. Reduction about 99% on time delay compared with commercial protective devices was verified. Future works should approach physical implementation of proposed relay model in platforms based on DSP and FPGA architectures.

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