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Implementation and Coordination Strategy of Overcurrent Protection

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Abstract: This work reports an adaptive overcurrent relay with new adaptive function. The target of the adaptation procedure is to enhance the sensitivity of time overcurrent relays. The adaptive relay has an enhanced sensitivity and decreased processing time. Various AN based algorithm for control strategy are discussed. The main objective of developing AN based algorithm is to eliminate miscoordination and improve sensitivity of OC protection. The control strategy varied according to the system topology and protection area covered. Adaptive function of the control strategy is available for connected or isolated system, thus providing more flexible system. The modification required for the proposed algorithm is minimal thus minor change in the relay's firmware and without an increase in cost.

Keywords: Overcurrent, OCR, Adaptive Protection, Sensitivity.

1. Introduction

The overcurrent relay has been commonly used in numerous protection applications in power system distribution. These devices exhibit fast operation when subjected to high currents if compared to their slower reaction to relatively lower currents. Therefore, the implementation of time overcurrent relays in power systems has serious limitations in terms of sensitivity [1]. Serious loadability issues for electrical networks are raised when load density undergoes disproportionate increase, especially if sub-transmission and distribution lines fail to keep up due to lack of upstanding. Conventionally, the overcurrent relay can be hardly adjusted due to the small fault current which makes precise fault detection a more tricky operation. Nevertheless in power system protection, the overcurrent tuning is done using maximum fault currents; approximately 3-5% of overall fault currents during maximum demand situations (a few minutes every day) because the curves of overcurrent relay are converged at high faults. Additionally, for the minimum fault currents, the curves diverge instead of concourse, which makes the back-up time much higher [2].

The operation time of the primary and backup protection is extended due to the demand for additional adjustment of the pickup current. This fragility is common in overcurrent protection and it was considered a challenging issue for conventional relays. Negative sequence approach, which reacts to unbalanced fault currents, was proposed to overcome this lack of sensitivity [3]. However, one downside of this method lays in the coordination itself, which require additional adjustment of the

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pickup current using readings from the primary relay. Another issue is that the identification of the balanced faults necessitate the presence of conventional protection.

A more recent scheme namely, adaptive current function, for overcurrent relays were introduced [4] and it can be useful for phase time overcurrent relays. This method resulted in increased minimum fault currents sensitivity even in situations where small load exists. In order to achieve such performance, the pickup current has to be dynamically altered. This is handled by some operational state of the electrical network.

The adaptive approach has been applied in some substations from which the relay can be configured using a centralized computer [5] [6] [7]. Other studies presented communication channels in order to refresh the adjustment values that are associated with relay coordination [8] [9]. However this method faced implementation challenges when it comes to applying it in rural places or in highly-connected networks due to high cost required to establish the communication channels. To overcome this issue, overcurrent adaptive relay is proposed in this paper. The proposed approach does not require communication channels to alter the relay parameters. Instead, it can be locally modified. The article explains the methodology of sensitivity improvement of overcurrent relays. The results of the proposed overcurrent relays is provided and their sensitivities are examined.

2. Methodology of Sensitivity Improvement

It is known for a fact that the maximum load current is only available for short period of time in a day. Conversely, the load current, Irk, which is less in value, dominates most of the rest of the time. Therefore in this study, it was chosen to calculate the pickup current, Ipickup, depending on the load current values [10].

$$I_{pickup} = \frac{1}{N}\sum_{j=0}^{N}(I_k^r)j + \Delta I \qquad \text{Eq.1}$$

where ΔI indicates a safety boundary that is about 15% of the maximum load current in this case, N is a number that is governed by the value of the integration time used in demand measures (*N*Δ*T*) which typically must be in between one and few minutes.

Equation (1), suggests there will always be minimum pickup current enough to overcome any improper operation that is caused by the load effect. This adds up extra sensitivity to the overcurrent relay.

The function *T=F(Z)* has been reported before for conventional relays [10]. On the other hand, the time-impedance plane, $T=F(Z, I_{pickup})$, is used to describe the tunability of the relay. What separates this formula from the conventional relay is the newly introduced parameter, I_{pickup} that is represented in form of a third-order vector.

The methodology of the pickup current is illustrated in Fig. 1. In this approach, the strategy is set to preserve certain stability of the pickup current such that it prevent high divergence in pickup setting when fault takes place. As the grid line is 'de-energized', i.e., $I_k^r < \epsilon$, the setting of the relay is set to the maximum pickup current, I_{pumax}, which is the same setting as that of conventional relays.

For full-cycle interval, the pickup current that is determined from (1) is then substituted after each interval. The methodology of the adaptive relay is demonstrated using the low-pass filter operation that is deep-rooted in the demand concept.

When the feeder receives huge load, there is a detection fault strategy that is embedded in the relay which is used to manage the pickup current. In this strategy, there exist a negative sequence confirmation and high current detection, both of which are gathered in an 'OR logic' operation. The settings that is used to detect the phase-to-phase faults has been adopted from the negative sequence previously proposed by [3]. The tendency of getting optimized settings are higher in networks with low voltage, since the maximum unbalanced negative sequence current is fewer than the negative sequence current of phase-to-phase faults. In this work, the three-phase faults identified is carried out using high-level detector. Additionally, the proposed method follows the same settings as those used in conventional overcurrent relay. Hence, distinguish between a fault and a huge load is practical.

On the other hand, the sensitivity of the relay can be calculated from (2),

$$Sensitivity = \frac{I_{minimum\ short\ circuit}}{I_{pickup}} \qquad \text{Eq.2}$$

There are different sensitivity calculations for each relay pickup. The methods of calculating the sensitivity from [11] [12] were used to calculate the pickup currents for negative sequence relays. However, for adaptive relay, the pickup current is calculated from (1).

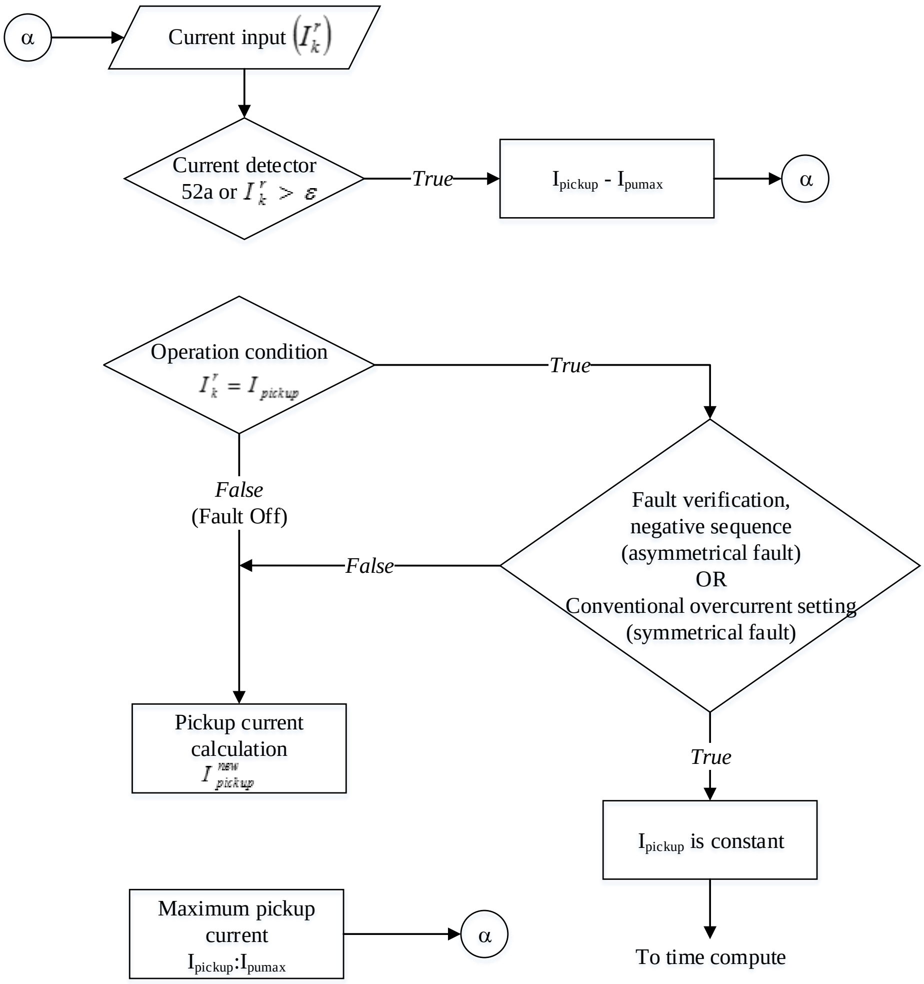

Figure 1: Control strategy for adaptive pickup current.

3. Discussion

Overcurrent (OC) relay is commonly located nearby current transformer in the distribution transformer secondary for ground fault protection [13] [14]. Integrated protection relay communicate with all neighbouring station through communication network and feed the related information to central protection and control system. The relay provide protection to all line connection to line section connected to the substation busbar and current transformer (CT) [15]. Coordination for fault isolation is can be done locally without the needs of communication network, which imply for remote substation or locally controlled substation.

Overcurrent protection covers various power system topology whether it is isolated or connected through the network, thus protection coordination varies with the specific location and optimisation method. The conventional method which require tedious calculation and sequencing will not be discuss here, rather use as a comparison.

Fault zone can be classified using overcurrent protection relay or phasor measurement unit (PMU). PMU is used to measured transmission line, busses and equipment's associated with it. Measurement data of the system such as voltage, current, frequency and phase angle at designated location, is used to determine faulty or healthy zone. Although the system provide better decision comparative to the conventional overcurrent relay in isolating fault portion of the system, higher cost incur is the main drawback [16]. The following discussion focused on modelling, optimization solution of overcurrent protection relay with various approach depending on the protection coverage and optimization method used, with minimal changes in relay firmware and cost.

To provide better protection scheme, multiple overcurrent relay is installed. Instantaneous overcurrent unit which will provide ultra-speed fault clearing for primary protection. Secondary overcurrent relay is installed with to provide secondary protection with delayed time triggering to detect any possibilities of fault [13] [15]. Primary protection covers all associated line section and will send direction to remote relay using communication channel (for connected topology) or locally processed by central computer for isolated substation. Second stage function applied only if the relay do not trip at predefined OC setting. This directional comparison technique for inter tripping is applied when communication channel for the distribution system is available, otherwise accelerated tripping is applied [15]. Integrated Network Protection (INP) is implemented as the third stage protection for interconnected distribution system. INP received and processed fault information (directional information) within the network and decide the fault line section thus send command to associated relay at fault line section to trip. INP provide fast protection for individual line section as well as integrated network protection and determine the fault direction through overcurrent direction detection and trip according to the fault current setting. The information is channelled to central protection and control unit, to decide the direction of tripping [15].

Interconnected power network with adaptive protection scheme is adaptable to load, generation level or system topology changes. Periodical measurement for CT is channelled to central computer to estimates the system changes and decides the new setting before conveys it back to substation [9]. The optimized solution is controlled by linear programming, hence decide for any requirement of relay setting amendment thus classify the system to be safe. This implementation however, restrict on the usage of digital OCR and dependent upon communication network to monitor the changes in operational or topology of the system. Meanwhile, offline measurement can be used to determine Thevenin equivalent circuit using adaptive (least square) algorithm to improve relay tripping time by varying short-circuit level and profile. The uses of inverse time overcurrent adaptive relay is suggested to be implemented in isolated/rural substation, where communication strategy is not cost effective [17]. Relay parameter is set with local current information and from backup device. This adaptive relay, uses current demand concept in the calculation of pickup current [10]. The operating time of load current is adjusted in accordance to the operating response time from the back-up device. This adaptive relay does not require any coordination or any setting value as all the processed is automatically and independently processed by the same relay.

Connection to non-linear loads and smart grid resulted in the increment of harmonic level, the efficiency of overcurrent relay operating in fundamental frequency decreases, causing undesired tripping sequence thus effecting power system protection performance. CT saturation may occur due to the presence of harmonics, which may causing relay tripping under normal operation condition. Due to signal distortion in the presence of harmonics, electromechanical and negative-sequence overcurrent relay are the most venerable [18]. Due to the harmonic effect, overcurrent relay must be equipped with filters that purify the incoming signal to the relay. The implementation of adaptive filters, power passive or active filter offers solution for eliminating harmonics thus purifying the relay operational signal.

The implementation artificial neural network (AN), fuzzy logic and naturally inspired algorithm (NIA) such as genetic algorithm (GA) evolves the coordination of optimal solution for OC protection. The implementation of evolutionary programming using GA with multi point searching algorithm increases global optimizing relay. Relay grading coordination for this implementation rely upon the system configuration, fault condition and relay setting. The optimization solution generated by the program, shows the capability of handling all OC setting optimization and monitoring the rightful coordination for all system constraints and configuration [19]. The main objective for objective function (OF) in neural network is to minimize the OC operating time. The existing GA algorithm with newly introduced parameter and OF is able to overcome miscoordination, continuous or discrete time setting multiplier (TSM) and time dial setting (TDS) [20]. For directional overcurrent relay (DOCR), AN-based optimization coordination is modelled as non-linear function of relay setting TDS and plug setting (PS). TDS unsure relay operates when Ifault ≥ Ipick-up whereas PS define the pick-up current of the relay [21]. Fuzzy representation and AN implementation on modelled OC relay is used to calculate time dial setting or time multiplier setting (TDS/TMS). Fuzzy representation is based on mathematical model (linear Sachdev) whereas AN included nonlinearity feature. These combination is proven to be more efficient, flexible and produced accurate estimation time for TDS/TMS on the simulated model [22]. Optimization of overcurrent relay coordination using GA which involves transformer protection is considering current setting multiplier (CSM) as a variable. CSM is not commonly taken into consideration (low weightage in coordination), but variation of current setting due to various load current in the industry thus require specific CSM setting along with TSM for optimization. Using multiple curve fitting consideration such as very inverse (VI), moderate/normal inverse (NI) and transformer damage curve in determining accurate and fast coordination for overcurrent protection relay in single-ring power distribution system. Method of optimizing coordination (using GA fault clearence) is to minimize total relay operating time at maximum fault current. Using GA optimization method, CSM and TSM values are at nearly optimal application setting with faster relay operating time for maximum fault current in comparison with conventional method [23]. The implementation of fuzzy logic, artificial neural network and GA implementation [19] - [23] in real situation or simulation is suited by the requirement of the power system topology and improvement of specific situation.

Overcurrent protection coordination is best classified using three technique. Mathematical model of relay characteristics which has the polynomial form will determine the fitness function (representing data) by using curve fitting technique. Whereas the second classification using graph theoretical technique analyse the respective information on minimum set of breakpoints, relay setting sequence, primary or backup relay settings and line directionality of directional relay. Optimization technique is develop to eliminate the needs of relay arrangement thus setting breakpoints is no longer required. Linear programming technique develop the fundamental of optimization method, later improved by AN based and NIA, will further improve the convergence problems. This lead to eliminating miscoordination problem and minimizing the operation time of the relay thus provide more reliable and faster protection coordination [24].

The difficulty to correctly detect fault due to comparative minimum fault current values and relay adjustment, leads to the study of sensitivity improvement at negative sequence. Fault under minimum demand represent less current contribution (high sensitivity is required) meanwhile adjustment of relay starting current is set using load current maximum value (require longer operation time for primary and back-up protection). Non alignment of both parameters, impaired the sensitivity and back-up operating time in overcurrent protection. The dynamic adjustment (OC adaptive relay) to pick up current will justify the operational state whether it operates in fault or normal condition. The adjustment requires communication strategy which modify relay setting through substation central computer [1]. The implementation of constant back-up time delay applied to simulation and lab test, is to calculate time element function for coordination process during current fault. The new time element function of overcurrent relay is proposed to overcome the limitation of sensitivity and high back-up times for minimum fault current thus enhanced overcurrent coordination system. To obtain analytical expression for dynamic equation of overcurrent relay, the time curve of primary device is required. The algorithm developed time overcurrent relay that are independent to the magnitude fault current thus require less back-up time [2].

In radial power system, during low demand the sensitivity of the relay is reduced, resulted in higher setting of pickup current thus giving impact in fault response. Three step approach is develop by using the differential phase to phase current to set the saturation effect of CT, symmetrical component for selectivity improvement and voltage overlapping signal for protection awareness improvement in radial distribution system [25]. Pickup current detect the fault condition and determine the time of operation of overcurrent relay. Function of fault detection and calculation of time operation should be separated as discriminating fault and overload condition is hardly obtain by pickup current alone.

By using breakpoints the number of variables and inequalities is reduced thus provide the optimal solution by avoiding inequality conflict in OC coordination. The removal of these conflicts is made possible by providing the starting point of coordination. Break point optimal method is more effective in larger network which reduces the number of constraints and effectively improve CPU time. Adaptive off peak loading is introduced to solve lagging in OCR activation time due to insufficient current during off-peak period. The existing communication between remote terminal unit (RTU) to intelligent electronic device (IED) in SCADA system can be used to adjust the protective relay setting during peak and off-peak condition for optimal protection [26]. Adjustment of time and current setting is adapted by using polynomial equation or mixed integer non-linear programming problem (MINLP), applied according to type of relay being used. Coordination of CSM and TSM during peak and off-peak loads is essential to develop the adaptive protection. The protective relay coordination is highly dependent on the variable pick-up setting which can be linear, nonlinear or mixed integer non-linear problem. Optimal relay setting during peak and off-peak loadings is represented in different values if CSM and TSM which generated by GA algorithm, later selected by SCADA system for adaptive protection [4].

4. Conclusion

Overcurrent protection system rely upon current to decide any fault location. Primary function of OC relay is to isolate fault from cascading through the network thus protecting the system as a whole. The recent study of OC protection focus on the optimisation solution (algorithm) for various power system topology to improve the sensitivity during peak and off-peak demand. Whether coordination of isolating fault occurs in interconnected or isolated system the setting adjustment require effective and adaptable algorithm according to load condition or system connectivity. The conventional method provide the fundamental guideline for engineers in order to sequence the coordination during fault. With complexity of existing system due to introduction of new system and equipment further increase the complexity of the coordination thus effected the sensitivity of OC protection. With the assistance of AN, GA and hybrid algorithm, the coordination is becoming more efficient, faster, adaptable and manageable thus increasing the sensitivity of the power system.

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