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# Adaptive overcurrent relay coordination for off-peak loading in interconnected power system

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ABSTRACT

Due to the substation automation, the supervisory control and data acquisition (SCADA) system is spreading that the protective relay settings can be modified through the network automatically. This work presents an overcurrent relay coordination decision for switching the relay settings to adaptive the off-peak loading in interconnected power system. Overcurrent relays (OCR) including directional and non-directional protective relays are widely applied in power system as main protective devices as they are reliable, cost effective and selective. Usually, the OCR protective coordination is coordinated at the time of maximum load and normal power supply, which may not be adaptive, as generating and load power are decreased significantly during the off-peak period of time compare to peak load that insufficient currents caused cascade lagging to activate OCRs. An example of single-ring interconnected power system was tested to demonstrate the coordination and confirm that the proposed approach method is practical during the off-peak time.



## Introduction

The inverse definite minimum time (IDMT) OCR is activated by over currents through taps setting to get required characteristic curves. Normally OCR coordination for protecting power systems is to set the relay curves from the top backup relay to the next main relay, assuming the maximum short circuit capacity of the power system while the curve type, current tap and time dials are chosen to provide adaptive protection. Consequently, approach can be operated during maximum or normal load on the system in case of fault. In other words, the OCR will be activated on the specific fault current is reached and the time elapsed.

In interconnected power systems, due to power consumption change from peak to off-peak significantly such as noon and mid-night, hot summer and cold winter, the load and generating power are changed, as well as the system capacity and short circuit current are very different, specifically as in Taiwan at work days, summer peak load on year 2012 was 32,932 MW and winter off-peak load was 16,173 MW in the case of system generation decreased, the short circuit current will decrease that system fault current too small to activate OCR for protection promptly, the solution may either be uses differential relay or distance relay for instead which are much more cost than OCR, not only relay itself but also extra wiring and consideration, otherwise the OCR protection may need to be adaptive and adjustable for the settings on off-peak time. The conventional method is to get a compromise of relay coordination setting plan to deal with peak throughout off-peak loading and short circuit capacity to meet requirement of grading margin from 0.2 s through 0.4 s in all loading conditions without changing the settings which may not be adaptive during off-peak period of time.

Recently, multifunction numerical communicable relays are developed products whose design is based on microprocessor technology using Digital signal processor (DSP) as intelligent electronic device (IED), SCADA system implements adaptive protection being applicable by data link for telecontrol application. The SCADA protocol between master and remote terminal unit (RTU) forms a viable model for RTU to IED communications. There are several protocols in use, the most popular are International Electrotechnical Commission (IEC) 61850-6 and 60870-5 series, specifically IEC 60870-5-101 and Distributed Network Protocol version 3 (DNP3). IED's advanced inter-station communication facilities can also be applied for protection of ring-type and meshed distribution networks [1–5]. A typical large SCADA system network is shown on Fig. 1 [3]. The protocols as can also be applied to switch the relay settings of IED. The proposed method is to optimize each grading margin to as closer to 0.3 s as possible by performing the adaptive protection in IED and SCADA system during peak and off-peak conditions to get optimal protection.

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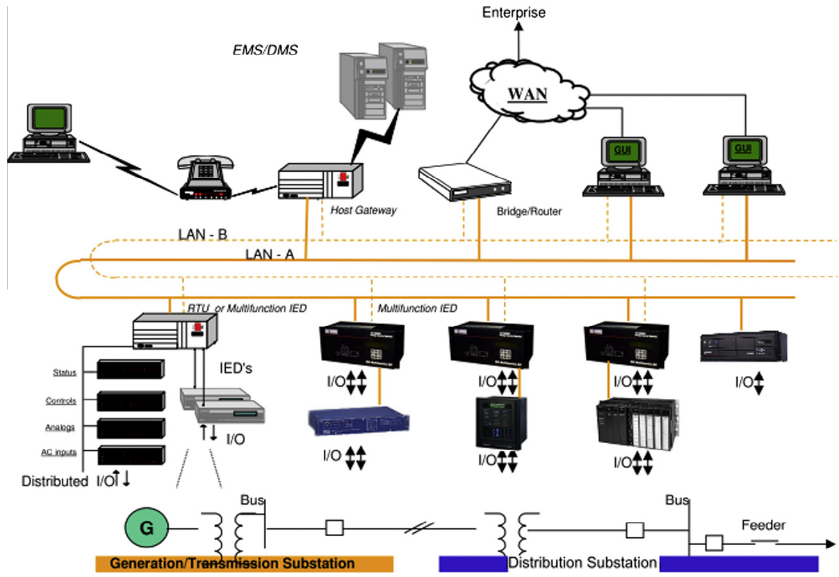


**Fig. 1.** A typical large SCADA network [3].

IDMT OCR can be adaptive by fine adjusting time and current settings as polynomial equation [6]. For the currents in solid-state or microprocessor-based relays are discrete and digital. The pick-up current setting is discrete; the relay coordination problem is therefore a mixed integer nonlinear programming problem (MINLP) [7–9]. The MINLP is thus easily locally optimized, and the genetic algorithm (GA) provides global optimal search to locate optimal solutions [10–12].

In the conventional method of relay coordination, the engineer carefully checks the power system constraints for deciding the current setting multiplier (CSM) and time setting multiplier (TSM), those constraints including the maximum fault current, the load current, the fault clearance time, the current transformer (CT) ratios and others to yield adaptive curves. Many commercial computer software packages do not support those checking. Artificial intelligence such as GA, Particle Swarm Optimization (PSO) have been employed to solve relay coordination problem in terms of a constrained objective function to optimize coordination [9–18], the GA has been applied in OCR coordination in interconnected or ring-fed power distribution systems, and its advantages have been demonstrated. However the difference between peak and off-peak loads for the optimal relay coordination need to be studied furthermore.

A ring type interconnected power distribution system thus has been tested for both peak and off-peak loading application of the study to show the proposed method is applicable in 'Proposed method' of the article.

## Problem formulation

The problem for adaptive relay coordination on peak and off-peak loadings is to locate the relay CSM and TSM optimal settings which can be coordinated on either peak or off-peak loads at same power system with the loadings, that is coordination time interval (CTI) for activating time of overcurrent relays in series with one another can be 0.30 s as marginal CTI, when adopting an eight cycle circuit breaker is used in a static relay, representing a conservative average of protection, as recommended in IEEE Std 242-2001 [19]. In the radial or ring type systems, the coordination criteria can be modified from Eq. (2) of [6] as the optimal coordination criteria:

$$T_{nk} - T_{ik} \geqslant \text{CTI} \tag{1}$$

where $T_{nk}$ represents the operating time of the first backup relay $R_n$ for fault zone $k$, and $T_{ik}$ is the operating time of relay $R_i$, CTI is the coordination time interval, The CTI of the primary and backup relay can be easily determined for each pair of relays for coordination.

The OCR curves are simulated in accordance with the equation that was defined by IEC 60255-3 1989 and similar to that associated with the IEEE standard C37.112-1996 [20,21] as presented in Eq. (2)

$$t(I) = \frac{A \cdot TM}{I^P - 1} \tag{2}$$

where $t(I)$ is the relay operating time based on a fault current $I$, $TM$ is the dial relay time setting, $P$ is a constant, and $I$ is fault current during the operation of the relay.

A simple genetic algorithm is adapted to maximum the fitness or objective function of IDMT OCR. The relay equation Eq. (2) is revised for use with various voltage levels, relay curves and load types of industrial power systems according to Eq. (3) [22,23] below:

$$t(I) = \frac{td \cdot k_1}{[(k_2 \cdot tap \cdot \frac{I_n}{ct})^{\alpha} - 1)]} \tag{3}$$

where $t(I)$ is the same as in Eq. (2), $td$ is the setting of time dial (0.1: 0.05: 1.0), $k_1$ is the relay type constant: for normal inverse (NI) it is 0.14, for very inverse (VI) it is 13.5, and for extreme inverse (EI) it is 80 respectively, $tap$ is current tap of the relay (0.5: 0.1: 1.2), $k_2$ is the constant of transformer ratio, $\alpha$ is the OCR type constant for NI it is 0.02, for VI it is 1 and for EI it is 2, $I_n$ is the fault current which ranges from $2I_R$ to $20I_R$ but should not exceed maximum fault current of the system, where $I_R$ is the primary rated current of each current transformer (CT), and $ct$ is the ratio of CT of each feeder.

The protective relay coordination problem is a linear, a non-linear, or a mixed integer non-linear problem depending on the variable of the pick-up setting $I$, which is a variable that mainly affects the problem, if $I$ is fixed, then the coordination problem becomes a linear problem. For continuously changing $I$ values, the problem becomes a nonlinear problem, if $I$ is discrete, the problem becomes a mixed integer nonlinear Problem (MINLP) [6]. In the genetic algorithm, the random generation and the initial