

Using Genetic Algorithm for Overcurrent Relay Coordination in Industrial Power System

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Abstract-- In this paper a modified genetic algorithm is used to perform the IDMT overcurrent relay coordination applied in an industrial plant radial power distribution system for quickly getting the result of the best coordination comparing with the computer-aided software of traditional method. The result shows that it is fast and adoptable compared to the traditional method by verifying with an existing power system settings.

Index Terms—Genetic Algorithm, Inverse Definite Minimum Time, Industrial Power Distribution, Overcurrent Relay, Protective Relay Coordination.

I. INTRODUCTION

The Inverse Definite Minimum Time (IDMT) Overcurrent Relay (OCR) coordination need to be operated by qualified engineers with spending a lot of time, costs and the result may not easy to be validated. Overcurrent relays including ANSI device number 51, 67, 51N/G/V, 67N/G protective relays are widely applied for industrial plant power system as main protective devices as they are reliable, cost effective and selective. Good OCR coordination is very important for industrial plant, poor coordination may spread fault zones wider caused unnecessary power blackout or damage equipment which are avoidable, or even more affect back up utility substations.

The GA or particle swarm optimization (PSO) have been applied on IDMT OCR coordination in [6] - [7] but limited in directional ring-fed circuit power system which only one category of IDMT OCR curves were considered, there are different between ring-fed and radial system, the former usually uses normal inverse (NI) curves, the later uses not only NI but also very inverse (VI) or even more steeper curve like extremely inverse curve (EI) for adapting the variety loads and protective devices such as static capacitors, large induction motors and power fuses, damage curves and inrush point of transformer...etc.

The conventional method of OCR coordination for industrial plant power system is to set the relay curves from top one to the next with choosing curve type, current tap and time dials by qualified engineer. A grading margin of 0.3 sec. should be used which take relay idle time 0.1sec. + CB interrupting time 0.083 sec. (60Hz, 5 cycles) + safety factor 0.12 sec. into

considering; each point should keep at least but the closer the better of 0.3 sec. with upper curve. Engineer shall check the constraints of the coordination with system, including maximum fault current, load current, fault clearance time carefully to get correct curves, many commercial computer-aided software do not support these requirements. The genetic algorithm (GA) has been applied in OCR coordination in ring-fed power distribution system in [6], demonstrated its advantages. However the OCR coordination of industry plants are complicated as they have various objects to be protected and coordinated with such as large motor starting curves, load banks, transformers in which protection condition of inrush current, damaging curves... etc., need to be coordinated that not only one type of OCR curve can be adoptive but also various type of curves like very inverse (VI) or extremely inverse (EI) curves should be taken into consideration for getting the better coordination, the traditional method usually operated by qualified engineer step by step and the results are not easy to be checked as each curve should be checked point by point which are impracticable. In this paper, the genetic algorithm is used for locating the OCR setting, using its global optimal searching capability to get the time dial setting (TDS) and current setting multiple (CSM) and checking the constraints at one time for the whole OCRs of industrial plant protective system to get the best solution for not only using the normal inverse but also very inverse curves as they are required. The results to be compared with existing OCRs setting which has been serving the industrial plant for years.

II. RELAY COORDINATION

The induction disc IDMT OCR its operating principle is similar to the KWH-meter, operated by torque, derived from the interreaction of fluxes produced by an electromagnet with induced currents in the plane of a rotatable aluminum disc, the current setting multiplier for pickup the current sensitivity level, the time dial for control the setting of relay contact speed, each OCR can adjust operating time and current range to get required operating curve, different type of OCR has different operating slope for using in different protection which known as CO-2 normal inverse, CO-8 very inverse and extremely inverse CO-11...etc. The present technologies of OCR relay applying solid-state or microprocessor is to simulate the current-time characteristic under the requirements to get all slopes of relays in one. The commercial OCR curves shall be simulated in accordance with the equation defined by IEEE standard C37.112-1996 and IEC 255-3 as shown in (1).

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$$t(I) = \frac{A * TM}{I^p - 1} \quad (1)$$

where

$t(I)$ is the relay operating time based on a constant current I ,
 TM is relay time dial setting

$$A = \frac{K_d \theta}{\tau_s},$$

K_d is the drag magnet damping factor,

θ is the disk travel,

τ_s is the initial spring torque,

p is a constant,

I is constant while the relay is operating,

For Normal IDMT $A = 0.14$, $p = 0.02$.

For Very Inverse IDMT $A = 13.5$, $p = 1$.

For Extremely Inverse IDMT $A = 80$, $p = 2$.

The protective relay coordination problem is either as a linear, non-linear, or a mixed integer non-linear problem depending on the type of variables in the problem [3]. I^p is the variable that mainly the type of problem, if I^p is fixed the coordination problem becomes a linear problem, for continuous I^p values the problem becomes a nonlinear problem [5]. Whereas the genetic algorithm, the random generation of the initial population increases the probability of converging to the global optimal setting and overcomes the limitations of conventional rule base methods to solve the relay optimal settings [1].

A. CASE STUDY

An existing industrial plant single line diagram for relay coordination is shown as Fig. 1.

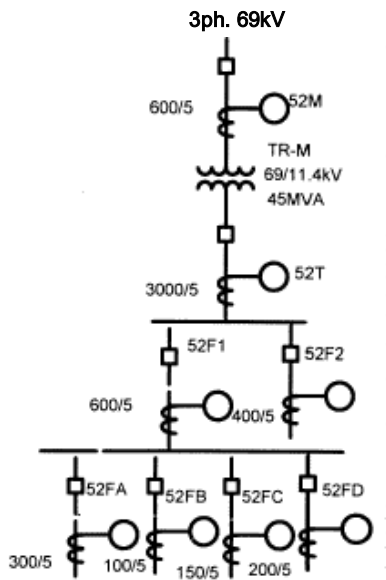


Fig. 1 Simplified Single Line Diagram

The system is located in a substation, the radial power system has 4 buses fed from power company 3ph. 69 kV step down to 11.4 kV by a 45 MVA, $Z=j10\%$ main transformer TR-M, there are 2 feeders below main feeder, 52F1 and 52F2, and 4 feeders 52FA/FB/FC/FD for supplying power to down stream subplants respectively. The short circuit current (SCC) from coupling point transfer to 11.4 kV is 22.8 kA; the system is solid grounded on the secondary Y connection neutral phase of the TR-M. All OCR settings have been done by conventional method as the settings listed on TABLE 1.

TABLE 1
OCR SETTINGS-CONVENTIONAL

Relay	CT Ratio(A)	Tap Setting (CMS)	Time Dial (TDS)
52M	600/5@69kV	1.0	0.5s
52T	3000/5	0.6	0.3s
52F1	600/5	1.0	0.3s
52F2	400/5	1.0	0.3s
52FA	300/5	1.0	0.25s
52FB	200/5	1.0	0.4s
52FC	150/5	1.0	0.3s
52FD	100/5	1.0	0.3s

The TIME-CURRENT CURVES are shown in Fig. 2, the standard (Normal) IDMT curve used for 52M as requested to be coordinated with upstream relay of 69 kV power distribution system. The very inverse curve VI relays are chosen for the others OCR, extremely inverse has not been considered as there are subplants on downstream, and this plant has been operating successfully for years under the settings.

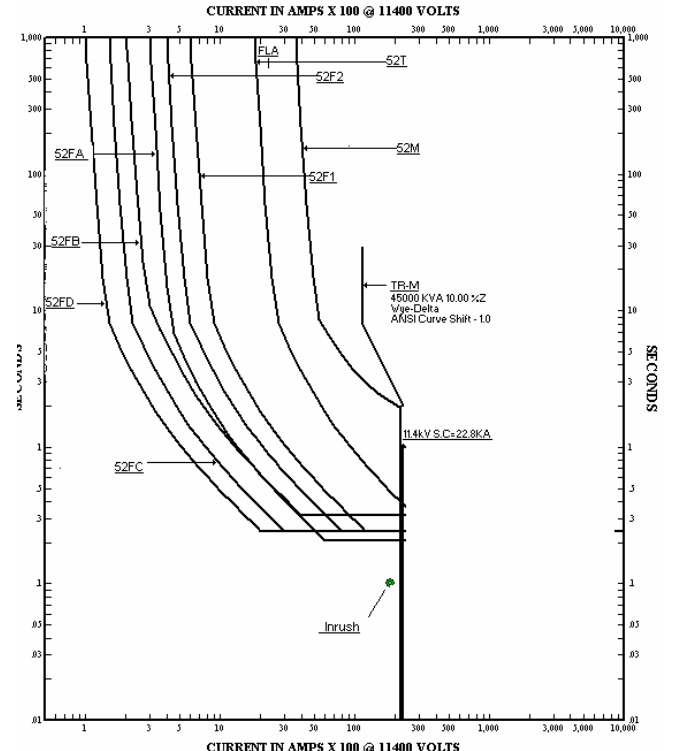


Fig. 2 Time-Current Curves-Traditional

B. SIMULATION

The upstream 3ph. 69kV system short circuit capacity MVA, OCR relay curve and settings should be given by power company for coordinating with the OCR of incoming CB 52M to protect main transformer TR-M, but 52M OCR should also coordinate with both damage curve, inrush point and grounding type of TR-M which are defined by IEEE C57.109-1985 Cat. IV, in considering the through-fault protection curve to protect the TR-M effectively, 52M shall also keep at least 0.3 sec. away from the curve. The 52M is also requested to coordinate with upstream OCR which usually uses Normal Inverse (NI) by a power company; therefore the NI curve type is adopted for 52M. The VI curves can be used for the downstream to get marginal protection. Every OCR connected to the current transformer (CT) to sense the load current which can be finely adjusted by setting Current Multiple Setting (CMS), and the trip time by Time Dial Setting (TDS) of OCR to get fixed curves by checking the coordination with upstream OCR. The CSM ranges are applicable from 50% through 200% in increments of 1%, and TMS ranges are from 0.1 through 1.2 in step of 0.05 of commercial solid-state or micro-processor OCR made in accordance with IEEE 37-117 1996 and IEC 255-3.

The CSM and TMS have been encoded to chromosome for all OCR and current transformer ranges. The flowchart of algorithm as described on Fig. 3, the current rating of each feeder should be able to carry the full load current that is around 100% rated current, to evaluate the effectiveness of each curve that every point on the curve is minimized by the objective value as defined as (2).

$$\text{Objective} = \min [\Sigma t(I) + \omega \Sigma (\text{tap} - 1.0)^2] \quad (2)$$

Where $t(I)$ is the relay operating time including the CB operating time at the particular system configuration, ω is coefficient governing the amount of contribution of current taps so as closer to 1.0 as possible, in this case 200 is used.

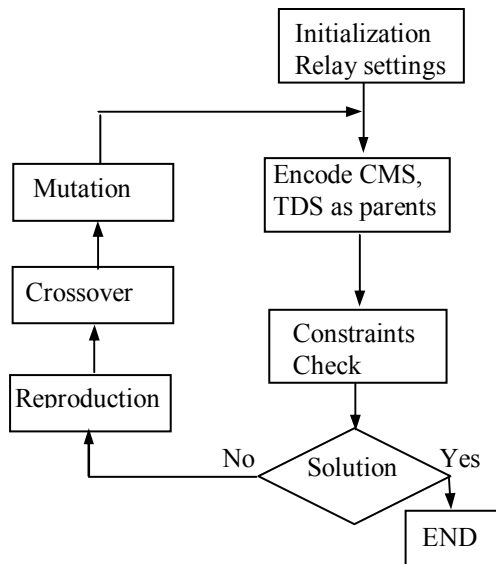


Fig. 3 Flow Chart of Algorithm

GA will minimize a function for using a simple genetic algorithm to find a maximum of the fitness function of IDMT OCR relay equation specified by revising the (1) as (3).

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

where

$t(I)$ is the same with (1)

td is time dial, (0.1 : 0.05 : 1.0)

k_1 is a constant for NI(0.14/2.97), VI(13.5/1.5) and EI(80/ 0.808) respectively

tap is current tap of relay, (0.5 : 0.1 : 1.2)

k_2 is a constant of transformer ratio

α is an OCR type constant, NI (0.02), VI (1), EI(2) respectively

I_n are fault currents, 600:500:24000

ct is the current transformer (CT) ratio, in this case,

$ct = [600, 3000, 400, 600, 300, 100, 150, 200]$

Each OCR curve will be described by using 40 points from the formula to get satisfied slope. The through-fault protection curve of TR-M main transformer is generated by curve plotting, as specified by IEEE C57-109 1985 the thermal and mechanical damage have been considered depending on the impedance and capacity of transformer as shown on the TABLE 2

TABLE 2
TRANSFORMER ANSI POINT

Total Fault		Mechanical Damage	
Time	If / I _s	Time	If / I _s
2 s	25	50 s	4.8
10 s	11.3	8 s	4.8
30 s	6.3	8 s	4.8
60 s	4.75	2 s	10
5 min	3.0		
30 min	2.0		

As the capacity of TR-M is 45 MVA, the recommended duration limit is based upon Category IV (above 30MVA) of IEEE C59.109 with impedance 10% for using in the coordination. The inrush point of TR-M during energizing is $8 \times I_s$ at 0.2 sec., where I_s is the full load current of TR-M, the 52M shall also coordinate with the points.

The duration of action of all protective relays + CBs shall be less than 1.0 sec. before the completion of worst fault case, that is the maximum system fault current, i.e. 22800 A at 11.4 kV, 1.0 sec. in the case of expired maximum fault time, an instantaneous trip at maximum current shall be set to meet the constraint.

The generated TDS and CMS by GA are tabulated in TABLE 3 with considering above constraints and conditions.

TABLE 3 shows that the CMS and TDS of 52M and 52T are closer to upstream OCR setting margin for optimal application which were not considered by conventional method, the curves of 52F1 to 52FA/FB/FC/FD are up-right lifted on the Time-Current Curves plan so that more tripping time margin needed for reliable operation as compare to TABLE 1 conventional case.

Fig. 4 shows the OCR and TR-M curves generated by GA, for the curve type of 52M, Normal Inverse curve is different from other Very Inverse ones.

TABLE 3
RELAY SETTING- GA

Relay	CT Ratio(A)	Tap Setting (CMS)	Time Dial (TDS)
52M	600/5@69kV	0.6000	0.6500s
52T	3000/5	1.2000	0.7500s
52F1	600/5	1.0000	1.0000s
52F2	400/5	1.2000	1.0000s
52FA	300/5	1.0000	0.3500s
52FB	200/5	1.0000	0.3500s
52FC	150/5	0.9000	0.3500s
52FD	100/5	1.0000	0.3500s

A minimum number on each curve will be selected to compare with the upper one curve to check if the most close two points of curves satisfy $t_{up} - t_{down} \geq 0.3$ sec. as shown in TABLE 4, the result shows that the grading margins are satisfied with the constraints. As can be seen that the grading margins at the most close points of each relay pairs are very close to ≥ 0.3 sec. limit, which conventional one is unable to know precisely.

TABLE 4
RELAY GRADING MARGINS

Up	Down	Grading Margin (Minimum)
52M	52T	0.3010 sec.
52T	52F1	0.3040 sec.
52T	52F2	0.3040 sec.
52F1	52FA	0.3079 sec.
52F1	52FB	0.3079 sec.
52F1	52FC	0.3079 sec.
52F1	52FD	0.3079 sec.

III. CONCLUSIONS

The GA has been applied for using in OCR coordination of the industrial plant power system, the CMS and TDS of the overcurrent relays were generated successfully. Comparing with the results of the TABLE 1 by traditional method and TABLE 3 generated by GA. It can be found that 52T relay has more

margin to close the 52M either operating time or current so as to adjust the setting of 52F1/F2/FA/FB/FC/FD relays to the best locations on the Time-Current Curves Plan for marginal and reliable relay coordination, the grading margins are closed to 0.3 sec. the target on the most closed points among each pair of relays as shown on the TABLE 4.

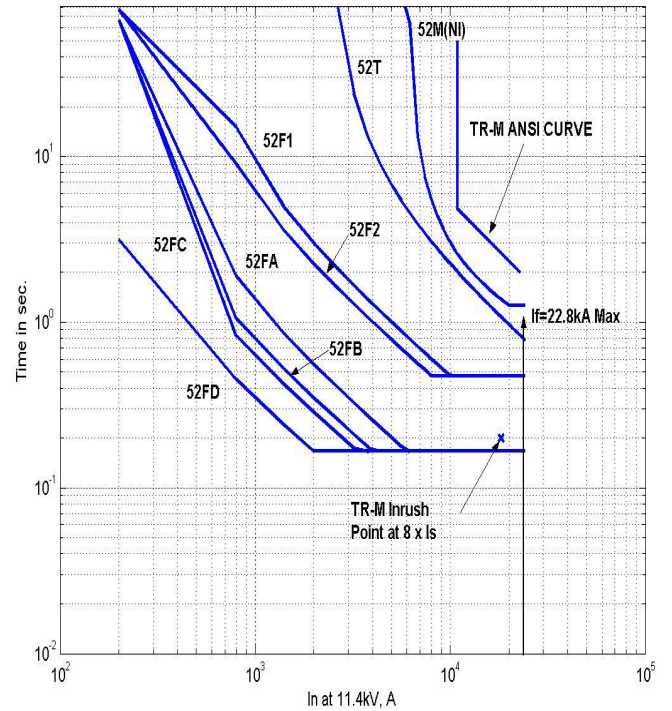


Fig. 4 Time-Current Curves-GA

The traditional OCR coordination is a highly professional work which needs engineer spending a lot of time to do it, and the result of grading accuracy is not easy to be verified, this paper proposes an intelligent, fast way for getting the correct and satisfied result.

The research demonstrated that it is possible for using GA to implement the overcurrent relays coordination in considering not only different type of relay curves but also the other components such as transformer curves, limitation of system short circuit current...etc. to complete the protective relay coordination instead of computer-aided manual operation by well trained engineer to save time and get better result.

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VI. BIOGRAPHIES

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