A Frame Work for Over Current Relay Protection Optimization

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Abstract: **Faults in electrical power systems are common and this affects the reliability and security of electrical power system. In view to address the above scenario, an optimized algorithm prototype (Differential Evolution) for relay operation was developed and implemented using non-linear integer programming. These program codes were written in MATHLAB/SIMULINK environment for proper coordination of the relay prototype. Numerical values gotten from the simulation shows that the proposed algorithm is of high precision and stability.**

Keywords: ***Power system protection, differential evolution, constraints handling, pickup current and interaction buffer.***

I. INTRODUCTION

Electrical energy system consists of equipment that generates, transmit and distribute electrical energy to the end users. The reliability of and security of electrical supply becomes an important factor in modern society [1]. However the expanding of the power system such as intense increase of transmission line capacity and increase of grids looping degree will increase the complexity of power system [1]. To improve the degree of operation of the electrical energy system, power system protection equipment is utilized for protection purposes. Power system protection equipment is used to protect power system and swiftly isolate abnormal conditions from the system [2].

Every protective system must possess the basic qualities of selectivity, reliability and dependability. Protective relay has these qualities and plays great impact in power system. Protective relays are used to detect abnormality in power system and isolate the faulty part of the system within the shortest time [1]. For the protective relay to achieve this, relay coordination study should be carried out [3]. coordination of protection is defined as the process of choosing settings or time delay characteristics of protective devices such that the operation of the device will occur in a specified order to minimize customer service interruption, reduce equipment damage or personal injury[3].

Numerical relays provide a wide range of protection functions such as over current, directional over current, under voltage and also other types of protection [1]. Over current relay are the most widely used protection system used to detect and isolate faults in power system [3]. Over current relay protection operates with or without an intended time delay and trips the associated circuit breaker whenever a set point for the current is exceeded. For the time delay over current relays, coordination involves setting the pickup current and time multiplier parameters [3]. For decades, over current protection has been using conventional methods for over current relay protection. However according to [4], automated over current relay coordination using computer program has been proposed and tested. Recently many other automated methods for over current relay coordination have been reviewed as below.

In an effort to optimize the coordination of over current relays, some researchers used non-linear programming to solve the coordination problem but this seems to be complex and time consuming [5]. In [6] relay coordination were formulated using mixed integer non-linear programming (MINLP) and was solved using General Algebraic Modeling system (GAMs) software. Results of which were appreciative. Application of Evolution Algorithms (EAs) such as Genetic Algorithms (Gas) has drawn much attention [7]. Although some authors have shown that GAs has limitations in its operation. Limitations like premature convergence, long time of processing data among others. Various versions of GAs have been introduced to cope with the above limitations. Some of the versions are Evolutionary programming [8], Differential evolution (DE) [9] etc.

In this paper, well known differential evolution was used to solve the coordination problem of an over current relay and implemented using mixed integer non-linear programming. The result of which shows a high level of improvement in the power system over current protection.

2. THE DIFFERENTIAL EVOLUTION (D.E) ALGORITHM

2.1 Scenario i: Population initialization

The initialization state of a differential evolution involves seeding of the algorithm with a population of N candidates or individuals of uniform random distribution. These candidates of particular population are the parent population and are retained within the boundary of upper and lower limits respectively.

2.2 Scenario ii: Reproduction of the D.E

An offspring population can be produced by perturbing the value of each control variable in each individual parent population. It produces an offspring of kth generation by the difference vector of the parent individuals, according to equation (1) below. The current evolution of the individuals is located X_i^t. Where i is the serial number of individuals in the population, t is the evolution generation of randomly selected three individuals from current population X_{r1}^t, X_{r2}^t and X_{r3}^t. The difference between two individual vectors (X_{r2}^t, X_{r3}^t), were added to the r1 individual vector X_{r1}^t after increased scaling factor F_w, yielding the updated individual as follows:

$$K^{t+1} = X_{ri}^t + F_w(X_{r2}^t - X_{r3}^t) \quad . \quad (1)$$

Where,

F_w is the zoom coefficient and is uniformly distributed in the range of [0, 1]. X_{ri}^t is the control variable of the best individual.

2.3 Scenario iii: *The evaluation of the individual:*

A fitness function is defined for evaluating the fitness of each individual as:

$$F(x_i(k)) = \frac{1 - f_v x \sum_{i=1}^{h} ci}{\sum t_i l} \quad . \quad (2)$$

Where,

F_v equals a penalty coefficient, h is the number of constants and ci is the penalty value which is equal to 1 (one) when it meets the constraints and 0 (zero) otherwise, $t_i l$ is the operating time.

2.4 Scenario iv: Selection:

Selection strategy of the differential evolution can be described as one on one search, where an offspring individual $X_j^i(k)$ is compared with its parent. After the comparison, better won and was updated for the next generation as described
below.

$$X_i(k+1) = \begin{cases} x_j^{(i)'}(K), & \text{if } f\left(x_j^{(i)'}(K)\right) > f\left(x_j^{(i)}(K)\right) \\ x_j^{(i)}(K) & \text{Otherwise} \end{cases} \quad (3)$$

2.5 Scenario v: Termination.

The procedure terminates if it meets a set point or after a number of specified generations. Figure 1.0 depicts the flow chart of the differential evolution.

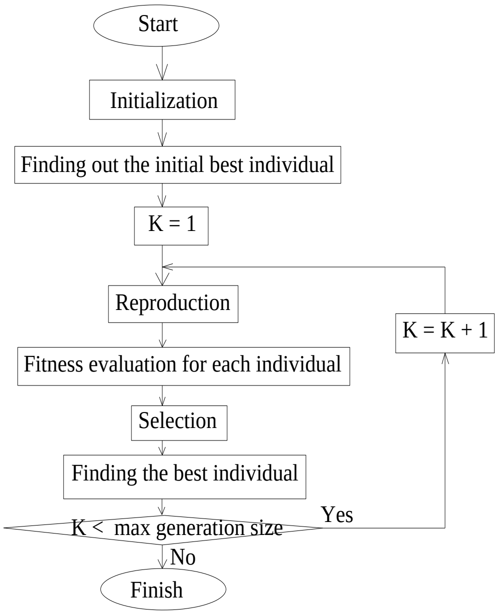

Figure 1.0 The flow chart of the D.E Algorithm

2.6 Constraints handling of the optimized model of the relay.

To minimize the total operating time of a protective relay system under different fault zones, its operating time is taken as the objective function for the optimal coordination of the relay.

The optimal coordination determines three parameters; the pickup current setting, the time setting multiplier and the time coordination interval of the protective relay as the major constraints.

The objective function can thus be expressed as:

$$_{\min}J = \sum_{i=1}^{Np} w_i t i l \quad . \quad . \quad (4)$$

Where,

NP is the number of primary and back up relays, W_i is the coefficient representing the ability of recurrence of a fault and could be set to 1 (one) for all possible faults if reliable data are available. t_i is the operating time of the ith relay when a fault occurs in zone L. The current/time characteristics of a directional over current relay under the institute of Electrical and Electronic Engineering (IEEE) standard C37.112-1996 and IEC255-3 can be expressed as [10].

$$t_{il} = \frac{T_{mi} \ x \ \lambda}{(\frac{I_{iL}}{I_{pi}})^{y-1}} \quad . \quad . \quad . \quad (5)$$

Where,

T_{mi} is the time setting multiplier, I_iL is the short circuit current passing through the relay when faults occurs in zone L. I_{pi} is the pickup current setting of the ith relays and λ and y are all constants. The constraints on the time setting multiplier and the operating time in this model are described as

$$T_{mi\,min} \leq T_{mi} \leq T_{mi} \max \quad . \quad . \quad (6)$$

$$t_{i\,min} \leq t_i \leq t_{i\,max} \quad . \quad . \quad . \quad (7)$$

Where,
T_{mi} is in the range of 0.01 to 1.

2.7 Constraints on the pickup current setting:
The pickup current setting of each protective relay is discrete, a 0 – 1 variable of y_{mi}. The setting were expressed as the product of the pickup current and the specified binary variable, thus

$$I_{pi} = y_{mi} . P_{ai} \quad . \quad . \quad . \qquad (8)$$

Where, P_{ai} are the available pickup current specified values.
Generally,

$$I_{pi} = \sum Y_{mi} P_{ai} \; \forall i \quad . \quad . \qquad (9)$$

Where, i = 1, 2, . . . , n

$$Y_{mi} = \begin{cases} 1, & I_{pi} = I_{pam} \\ 0, & otherwise \end{cases} \quad . \qquad (10)$$

In addition, the pickup current setting (I_{pi}) of each current relay meet the following conditions.

$$I_{pi\,min} \leq I_{pi} \leq I_{pi\,max} \quad . \qquad (11)$$

2.8 Constraints on the coordination interval of the protective relay:
For the constraints on the coordination interval of the protective relay,

$$T_{bl} - t_{il} \geq CT_i \quad . \quad . \qquad (12)$$

Where, T_{bl} is the operating time of the backup relay R_i when a fault occur in zone L and CT_i is the coordination time interval usually specified between 0.2 seconds to 0.5 seconds.

3. THE POWER SYSTEM MODEL

For the evaluation of the protection system, the model of the power system is required. The generator model, voltage transformer model, current transformer model are realized using the MATLAB/SIMU-LINK SIM power system TOOL box. This was done in MATLAB/ SIMU-LINK environment as shown in figure 2.0 below.

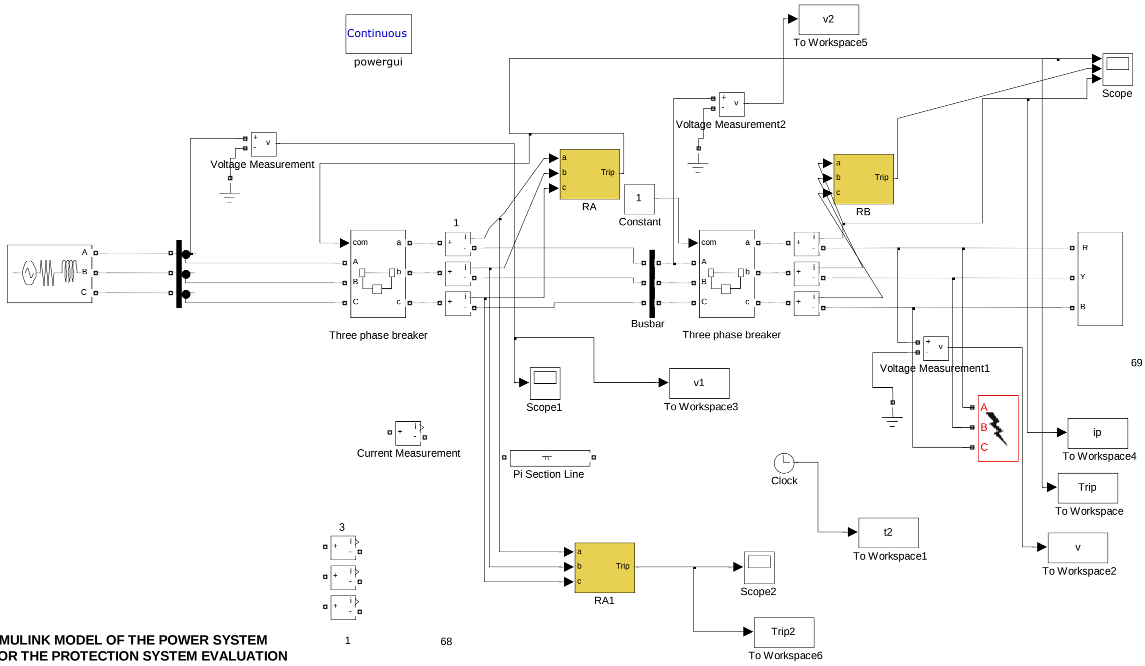

Figure:2.0 SIMULINK MODEL OF THE POWER SYSTEM FOR THE PROTECTION SYSTEM EVALUATION

The transmission line parameters were calculated by MATLAB power system transient solvers. The power system network under study consists of one three phase power supply as a power station supplying 400km transmission line. The bus bars are equipped with current measurement and voltage measurement devices. At the sending end and receiving end are circuit breakers. The relay model developed in SIMU-LINK is integrated with the power system model in the MATLAB/SIMU-LINK environment.
The mixed integer optimization model for the protection performance evaluation is coded in the MATLAB m-file, using the MATLAB workspace to integrate it with the power system model. The interaction buffer in the MATLAB workspace is coded to structure data exchanges between the power system model, relay model and optimization evaluation model.

4. SIMULATION AND RESULTS.

Simulation studies were carried out to test and evaluate the performance of the protection evaluation model. Two different events tests, optimized and un-optimized, were carried out to ascertain the performance of the proposed frame work. For un-optimized event, evaluation of the signal profile of the system and the transition of the relay trip signal when a 3- phase fault was triggered at time 5.0 seconds from the start of simulation was captured, figure 3.0 and 4.0. The rise in current at the start up of simulation was as a result of current inrush and harmonics in the transformer which settled within 3.0 seconds. At 5th seconds, a three face ground fault was introduced evidenced by the rise in current up to 800A and was cleared at 8.8659 seconds.

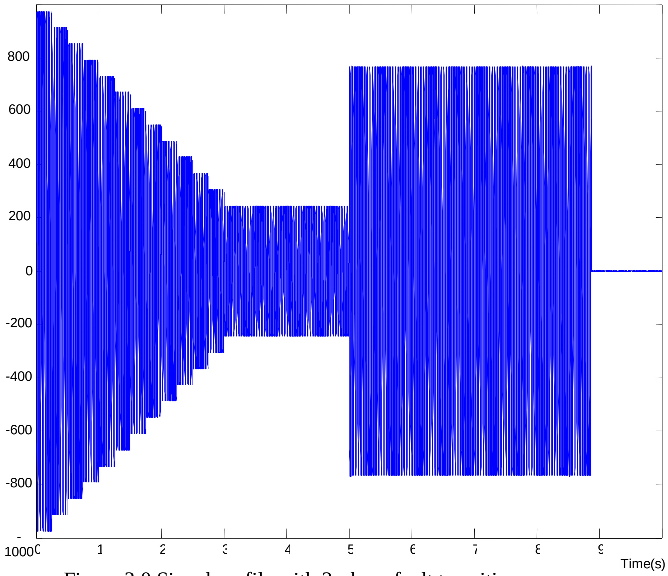

Figure 3.0 Signal profile with 3-phase fault transition time set to 5.0 seconds

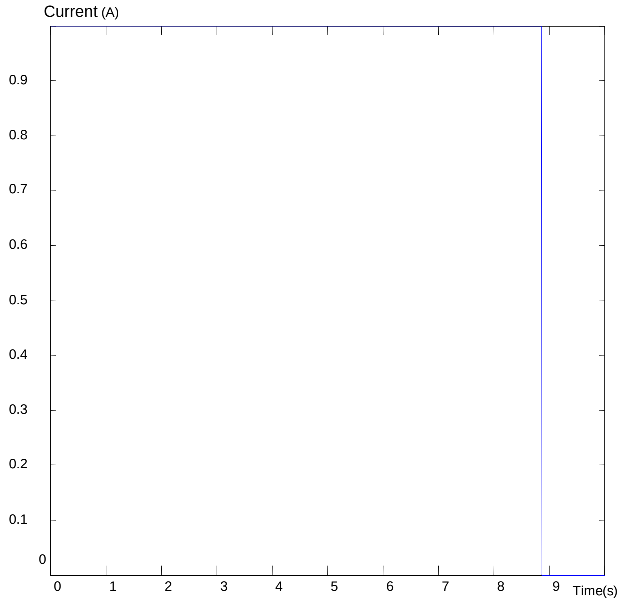

Figure 4.0: Trip transition of relay with 3-phase fault transition set at 5.0 seconds

For the evaluation purpose, based on the hypothetic evaluation of the optimization algorithm, the expected trip time of the relay was estimated at 8.5232 seconds, figure 5.0. However the relay tripped at 8.8659 that is a variance of 0.3427 seconds.

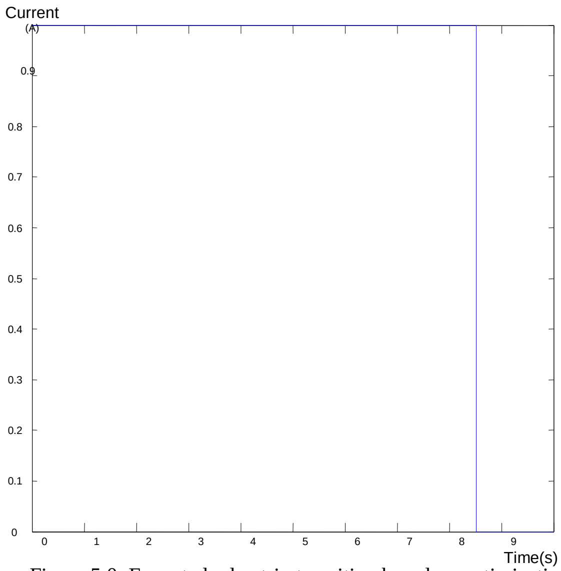

Figure 5.0: Expected relay trip transition based on optimization evaluation algorithm with fault transition set at 5.0 seconds

This shows that the relay action falls short of optimal response. The fault event was repeated at 5.25, 5.5, 5.75 and 6.0 seconds respectively. Results of which are shown in the table 1.0 below.

Table 1.0 Evaluation of expected and actual relay response.

Scenarios	II	III	IV	V	VI
Fault transition time (seconds)	5.00	5.25	5.50	5.75	6.00
Expected relay trip time based on optimizat-ion technique (seconds)	8.5232	8.7651	9.0272	9.2692	9.5212
Actual relay trip time (seconds)	8.5736	8.8165	9.0675	9.3196	9.5716
Expected fault clearing time (seconds)	3.5232	3.5151	3.5272	3.5192	3.5212
Actual fault clearing time (seconds)	3.5736	3.5655	3.5675	3.5696	3.5715
Variance (seconds)	0.0504	0.0504	0.0403	0.0504	0.0504

Adjustment was made in the relay settings based on the trend in the response expectations of the optimization evaluation technique. By giving the trend (either upwards or downwards) in the deviation of the actual relay response from that of the evaluation expectation, the proper adjustment in the relay zone settings was done. On the basis of evaluation, the expected relay trip times indicates lower values than the actual relay trip times (as can be inferred from table 1.0). This gives the indication of downward adjustment in the relay zone settings. Hence the expectation is downward adjustment of the setting based on the percentage variance (since zone setting is in percentage). The percentage value for downward adjustment in relay zone reach can be found as follows [49]:

$$\frac{Sum\ of\ variance\ in\ trip}{Sum\ of\ actual\ trip\ tir} \quad . \qquad (13)$$

= (1.7131/46.8196) x 100%
= 3.6602%
= 3.66%.

Hence, the relay zone setting is reduced by 3. 6602 %. The simulations are repeated based on the relay adjustable settings. The new protection system (optimized) response shows a reduction of fault clearing times and variances for the fault transition times of 5.0, 5.25, 5.50, 5.75 and 6.0 seconds, table 2.0 below. Figure 6.0 below shows the mean variances of the two fault events.

Table 2.0 Comparison of expected and actual relay responses after optimization.

Scenarios	II	III	IV	V	VI
Fault transition time (seconds)	5.00	5.25	5.50	5.75	6.00
Expected relay trip time based on optimizat-ion technique (seconds)	8.5232	8.7651	9.0272	9.2692	9.5212
Actual relay trip (seconds) time	8.8659	9.1079	9.3599	9.6119	9.8740
Expected fault clearing time (seconds)	3.5232	3.5151	3.5272	3.5192	3.5212
Actual fault clearing time (seconds)	3.8659	3.8579	3.8599	3.8619	3.8740
Variance (seconds)	0.3427	0.3428	0.3327	0.3427	0.3528

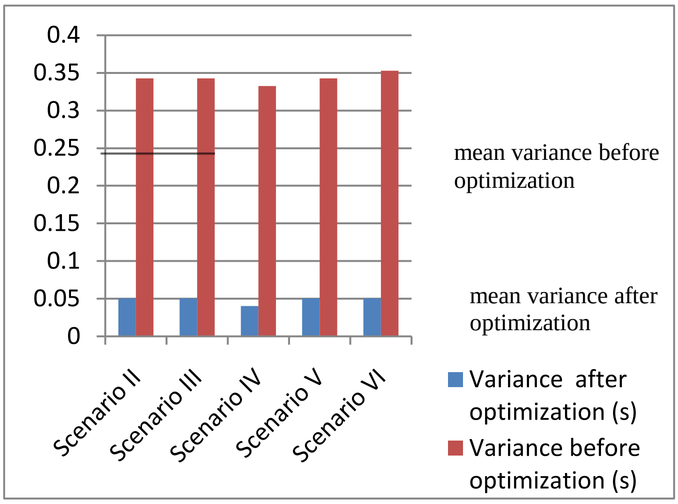

Figure 6.0 Comparison of variances of optimized and un-optimized trip time of the relay response.

5. CONCLUSION.

Different protection schemes have been reviewed. The review on relay coordination shows that there is always a mismatch between the actual and expected relay coordination time. In other words the actual trip time of a relay is never the real/expected time of tripping. Thus some adjustments are deemed necessary to overcome the mirage.

Implementation of Differential Evolution solved by mixed integer non-linear programming was able to reduce the mismatch in relay coordination interval between the actual and expected trip times. The extent to which the reduction was made was arrived at after evaluating the percentage variances in trip time as against the total actual trip time of a relay. The results of the evaluation were encouraging as it shows a reasonable improvement (7.6%) in the relay time coordination.

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