# Directional Over-Current Relay Coordination Using Improved Mathematical Formulation and Soft Computing Technique.

**Major Project Report (Part-2)**

*Submitted in partial fulfillment of the requirements*

for Semester-IV of

Master of Technology in Electrical Engineering

(Electrical Power Systems)


Submitted By

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# CERTIFICATE

This is to certify that the Major Project Report (Part-2) entitled "Directional Overcurrent relay coordination using improved mathematical formulation and soft computing technique" submitted by Mr. Shubham Kashyap (17MEEE12), towards the partial fulfillment of the requirements for Semester-IV of Master of Technology (Electrical Engineering) in the field of Electrical Power Systems of Nirma University is the record of work carried out by him under our supervision and guidance. The work submitted has in our opinion reached a level required for being accepted for examination. The results embodied in this project work to the best of our knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

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# Undertaking for originality of work

**I,Shubham Kashyap, Roll . No. 17MEEE12 , give undertaking that the Major Project entitled Directional 0ver-current relay coordination using improved mathematical formulation and soft computing technique submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology in Electrical Engineering of Nirma University, Ahmedabad, is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.**

**Signature of Student**
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# Abstract

**Relay coordination is one of the most crucial process in the field of protection for power systems.In order to ensure a proper and healthy system protection for a particular system should be done carefully.In this the optimum coordination for directional over-current relay has been done. The objective is to minimize the value for relay settings along with maintaining the coordination constraints in the system. For the above five objective functions have been developed and being compared on the basis of their operating time for the relay settings with certain weight assigned to each objective function in order obtain optimum relay coordination. These objective functions are evaluated and then a new objective function i.e. a proposed objective function (POF) is being developed in order to improve the previous objective functions. Finally the coordination has been formulated by the use of soft computing technique and the outcome is compared with all the objective functions on the basis of operating time for both primary as well as back-up relay along with maintaining the value of discrimination time up-to a prescribed followed by satisfying the coordination constraints of the system.**

# Abbreviations

| | |
|---|---|
| **OCR** | **Over Current Relay** |
| **MINLP** | **Mixed-integer Non-linear Programming** |
| **SQP** | **Sequential Quadratic Programming** |
| **DOCR** | **Directional Over Current Relay** |
| **PSO** | **Particle Swarm Optimization** |
| **GA** | **Genetic Algorithm** |
| **KKT** | **Karush-Kuhn-Tucker** |
| **DOCR** | **Directional Over-current Relay** |
| **DG** | **Distributed Generation** |
| **SCs** | **Standard Characteristics** |
| **NSCs** | **Non-Standard Characteristics** |
| **CTI** | **Coordination Time Interval** |
| **WPP** | **Wind Power Plants** |
| **OT** | **Operating Time** |

# Contents

# List of Figures

# Chapter 1

# Introduction

## 1.1 General

For the most part, a power framework contains numerous segments and each area must be secured against over flows. So as to guarantee ideal supply unwavering quality, it is essential to acquire selectivity, for example to turn off the piece of the power framework where a deficiency happens and to abstain from turning off the pieces of the framework where no flaw happens. On the off chance that a rst over-current gadget comes up short (in spite of the fact that an over-current happens, the over-current gadget does not intrude on this issue current), a second over-current gadget will distinguish the over-current and interfere with the flaw current. Because of this back-up rule, a sheltered framework circumstance stays even in the event that an over-current gadget falls flat. While considering an outspread framework with one bolstering point and one directional power ow, it is somewhat simple to acquire the ideal selectivity utilizing over-current transfers having fitting time delays.

For outspread framework with multi-source focuses and for framework with shut ring topology when there is bidirectional power ow, it is insufcient to use over-current transfers having a fitting deferral to acquire the ideal selectivity property. In these cases, the directional over-current transfers (DOCRs) must be utilized, which can distinguish the extremity of the over-current. The DOCRs are generally utilized for the security of sub transmission and dissemination framework or as an optional insurance of transmission framework. The coordination of DOCRs in power frameworks comprises of choosing their appropriate settings with the end goal that their major defensive capacity is met under the prerequisites of affectability, selectivity, unwavering quality and speed. These prerequisites can be converted into conditions, for example, (I) a transfer must get sufcient opportunity to work, if a deficiency happens inside the hand-off purview, (ii) if an essential hand-off comes up short, a reinforcement hand-off ought to work, (iii) the grouping of essential and reinforcement (P/B) transfers activities ought to be with sufcient coordination edges, without over the top time delays. The objective in coordination of DOCRs is to nd the suitable time dial setting (TDS) and get current setting (PCS) of relay consider in different requirements, for example, coordination and limit limits. The coordination of DOCRs has been detailed as an enhancement issue and illuminated with various advancement strategies, including customary and heuristic methods. In ideal coordination has been gotten thinking about the free advancement of transfer settings.

A diagnostic way to deal with ideal coordination of DOCRs was proposed. It has been demonstrated that the customary streamlining strategies, for example, direct programming (LP), consecutive quadratic programming (SQP), quadratically compelled quadratic programming, angle based strategy and parallel number programming can be connected to upgrade DOCR settings. In any case, regular streamlining techniques have a downside, some time they may trap to neighborhood minima and neglects to give worldwide ideal arrangement. Furthermore, as the measure of framework builds the assembly is likewise powerless. It ends up fundamental to create enhancement techniques ready to beat these downsides and handle such difculties. As of late, numerous populace based techniques have been utilized to take care of complex obliged improvement issues. By and large, accomplishing ideal or close ideal answer for a specic issue will require numerous preliminaries just as proper tuning of related parameters. A wide assortment of populace based procedures, for example, versatile differential advancement (ADE), educational differential development (IDE), hereditary calculation (GA), non-overwhelmed arrang-

**ing hereditary calculation II, articial honey bee state, showing learning based improvement (TLBO), molecule swarm enhancement (PSO), searcher calculation have been connected in tackling the ideal coordination of DOCRs.**

# Chapter 2

# Literature review

## 2.1 Contribution

**Any directional over-current coordination technique ought to fulfill the accompanying requirements.**
**1) R1: The all out working occasions of essential transfers ought to be limited while keeping up coordination among all relays.**
**2) R2: The pickup and time dial settings ought to be hearty under all conceivable topological and operational scenarios.**
**3) R3: The advancement method ought to be equipped for finding the close worldwide ideal settings.**
**The hole that this paper means to fill is the improvement of the third necessities notwithstanding different prerequisites. As to issue, the coordination issue is defined as an advancement issue and is then comprehended by another searcher calculation.**

## 2.2 Paper Organization

**The rest of this paper is organized as follows. In Section II, the structure and formulation of the directional over-current coordination problem are described.**

## 2.3 Problem Formulation

**The coordination of directional over-current relays in a multi-loop system is formulated as an optimization problem. The coordination problem, including objective function and constraints, should satisfy all three aforementioned requirements.**

## 2.4 Objective Function

**The coordination of directional over-current relays in a muti-loop system is formulated as an optimization problem. The coordination problem, including objective function and constraints, should satisfy all three aforementioned requirements.**

**Where $I_{ik}$ is the short-circuit current seen by the th relay for the fault at location. It should be noted that the goal of the coordination problem is to minimize the total weighted sum of the operating times of primary relays for faults at their associated zones. Therefore, the objective function is written as follows:**

**Inverse time inverse definite minimum time (IDMT) characteristics are selected from a choice of some IEC/IEEE curves conforming to the following formula:**

**Assume L=0, alfa=0.02, k=0.14**
**formulation has been proposed to approximate the relay characteristic called the Sachdev nonlinear model.**
**Where,**

**Where $b_j$ and $a_j$ are constants. Tap settings is used to adjust the minimum current in the relay for which the relay will just pick up. This provides great flexibility in the relay application and permits the same relay to be used at many locations. The concept of relay pickup tap setting could be formulated by**

## 2.5 Paper Organization

**There are basically two types of constraints namely the characteristic of relay and coordination constraints in which the relay constraints encompass limitation to operating time as well as settings. Coordination constraints are those constraints which are allied to the coordination of primary and secondary i.e. back-up relays.**
***1) Relay constraint depending on the value of the operating time*: With the help of analytic formula and by the standard inverse curves the operating time of the relay is decided and operating time is the time of operation which is seen by the relay.**

***2) Constraint depending on the value of current and time***

**For phase relays, determining the maximum load current and minimum fault current considering engineering experiences and planning studies for different network topologies is required. The pickup current should be greater than the largest possible load currents and lower than the minimum fault current with a reasonable security margin. This is the trade-off between the security and dependability features of the relay.**

***3) Constraint of Coordination*: The operating time of a backup relay should be selected to be greater than the operating time of the related primary relay. An intentional time margin called the coordination time interval (CTI) is added to the operating time of the first backup relays.**

**For transient topologies where one relay of a zone has operated, the coordination constraint should be satisfied without considering the tripping sequence.**

# Chapter 3

# Literature Survey

## 3.1 Introduction

**Over-current transfers (OCRs) and Directional over-current transfers (DOCRs) are generally utilized for the insurance of outspread and ring sub transmission frameworks, and conveyance frameworks. Directional over-current transferring is for the most part utilized for the essential security of ring circulation frameworks as a similar extent of shortcoming current can stream in either course. They are likewise utilized for optional assurance in transmission frameworks. Transfers in various areas will distinguish incredibly unique flows amid a similar shortcoming. The hand-off coordination issue is to decide the arrangement of transfer tasks for every conceivable shortcoming area so the blamed segment is detached to give adequate coordination edges immediately. A definitive target being improved power framework unwavering quality; this paper is an endeavor to incorporate the majority of the noteworthy advancements in the zone of hand-off coordination utilizing distinctive strategies and methodologies.**

**The interconnected power transmission frameworks are ensured by directional over-current transfers, which are remain solitary gadgets and deliberately set all through the framework. Primary issue emerges in playing out the hand-off coordination with this kind of security in interconnected, multi-**

**circle control frameworks, where it is hard to set and arrange the transfers. The fundamental trouble emerges in setting the last hand-off of a shut circle with appropriate and fulfilling coordination with the transfer set at first in that circle. On the off chance that it doesn't, one should continue again for coordination, around the circle. Further, a given hand-off as a rule partakes in more than one circle. Appropriate ID of grouping of transfers to be considered for coordination is additionally vital. On the off chance that a subjective request is accepted, changing the parameters of one transfer for getting coordination for all the significant essential/reinforcement deficiency current sets can irritate the best possible coordination of a portion of the hand-off sets officially checked. Prior, the coordination of directional transfers was performed by tedious and enthusiastic manual counts. The utilization of PCs in the coordination procedure has diminished architects from these relentless counts. This could be conceivable just when scientific displaying of over-current transfers for PC portrayal was exhibited. Presently, advanced calculations are accessible, which permit dynamic cooperation between the client and the PC. Essentially, two kinds of methodologies are utilized for finding legitimate coordination, regular rationality, and the parameter enhancement strategies. The premise of the customary security logic is the idea of pre-determinism for example examination all things considered, unusual working conditions and framework possibilities are foreordained. Disadvantage of this strategy being failure to decide hand-off reaction for a condition not recently incorporated into the examination, since it is essentially all the working states of worry ahead of time. "Breakpoints" (BPs) are the ideal areas of the beginning transfers in the coordination method. The breakpoints are utilized to diminish the quantity of cycles in a coordination procedure. The succession for setting the transfers is shown by a "relative grouping lattice" (RSM). To set a transfer, it must be known, to which transfers this hand-off is reinforcement. This hand-off is then set in like manner for attractive reinforcement assurance on all flaw flows. The arrangement of all essential/reinforcement hand-off sets arranged by reinforcement transfers is the "arrangement of choice sets" (SSP). Intricate and complex topological**

investigation programs have been set up to decide the breakpoints set, the relative succession grid, the arrangement of determination sets and so forth, and the office for information the board.

Problem Formulation: Relay coordination problem can be solved optimally by using heuristic and meta heuristic optimization techniques. It can also be solved by trial and error optimization techniques. The optimization techniques define the objective function for relay coordination by the following equation:

$$\min z = \sum_{i=1}^{m} W_i t_{i,k}$$

where, m is the number of relays, t is the operating i,k time of relay R for the fault in zone k and W is their weight assigned for operating time of relay.

# Constraints

## Coordination Criteria:

$$t_{i,k} - t_{j,k} \geq \Delta t$$

Bound on Relay Setting and Operating Time:

$$TMS_{i,min} \leq TMS_i \leq TMS_{i,max}$$

$$t_{i,min} \leq t_{i,k} \leq t_{i,max}$$

where, t and t are the minimum and maximum i,min i,max operating time of relay R for any fault while TMS and i i,min, TMS are minimum and maximum time multiplier setting i,max for relay R.

# Relay characteristic:

$$t_{op} = \frac{(\lambda) * (TMS)}{(PMS)^{\gamma - 1}}$$

Deterministic Techniques: Deterministic strategies, for example, Linear Programming (LP). Non-direct Programming (NLP), Mixed Integer Programming (MIP) Mixed Integer Non-straight programming (MINLP), Dynamic programming (DP), Branch and Bound technique have been generally used to ideally take care of transfer coordination issue. The primary downside of these techniques is their high dimensionality. High computational time and expansive PC memory are expected to take care of the hand-off coordination issue by these procedures. Along these lines distinctive heuristic methodologies such as modified DP, Langrangian unwinding and Adaptive Dynamic programming have been presented in transfer coordination issue answer for decrease the computational time just as the pursuit space. X. Yan, et al introduced new graphical calculation for least or close to minimum break point look (BPS) and proposes back track cycle system to quickly reach towards least BPS.

## Meta Heuristic and Hybrid Optimization Technique:

Selection strategy. Deserting criteria is utilized to The arrangement got from Deterministic systems is far from worldwide ideal arrangement. Meta-heuristic methods accordingly have been created to get a worldwide ideal arrangement in sensible computational time and most generally utilized in hand-off coordination. Molecule Swarm streamlining (PSO), Artificial Bee Colony (ABC) Algorithm, Evolutionary Programming (EP), Tabu pursuit and Genetic calculation (GA) are arbitrary inquiry method that produce increasingly practical and close ideal arrangements. Half and half systems that are the blend of deterministic and meta-heuristic methodologies and are additionally broadly used to take care of hand-off coordination issue. These methods use focal points of the two methodologies.

### Trial and Error Methods:

**The PC helped coordination procedure is utilized to take care of transfer coordination issue in complex power framework with graphical UI. These papers further recommend that in the event that insight innovation is connected to the product, at that point it can make illation and completion all the work self-rulingly without human intrusion and improves the effectiveness of hand-off coordination. The "Power System Simulator Siemens Network Calculation (PSS SINCAL)" programming is additionally used to complete coordination thinks about. The creators carryout Coordination thinks about by methods for "PC Aided Protection Engineering (CAPE)". There for ring system, is effectively executed and distinctive kinds of issues, for example, single line to ground flaw, line to line shortcoming and twofold line to ground deficiency are embedded on feeder.**

## 3.2 Methodologies Used to Achieve Coordination

**As has just been expressed, in the time preceding approach of computerized PCs, one of the issues related with coordination of directional overcurrent transfers was the monotonous and tedious errand of manual settings of defensive transfers. The issue was progressively intricate in multi-circle, multi-source systems. The accessibility of computerized PCs prompted quick progressions in transfer coordination process. In the early stage, just disconnected PC transfer coordination was accounted for. First huge endeavor for the hand-off coordination utilizing computerized PCs was accounted for in 1964. In this work a hand-off coordination program zusing a "cluster" disconnected methodology was presented. A contextual investigation applying this program to an utility's transmission framework was accounted for in. A consequent report pursued a comparable bunch approach enumerating different coordination foundations to be received. In all these bunch approaches, the insurance engineer does not associate with the PC amid the coordination procedure. least arrangement of break.Hence,effective utiliza-**

tion of specialist's skill and information about the grouping before they were considered for coordination. One more methodology continued along this line of thought to acquire ideal beginning stages and an ideal transfer arrangement utilizing diagram hypothesis ideas. These two methodologies gave the essential foundation to deliberately examining the topology of the framework yet did exclude any of the transfer coordination strategies. In the underlying stage, the breakpoints set and relative succession grids were found to do the hand-off coordination technique. The advancement of a strategy for deciding the focuses was accounted for. This technique has been therefore improved in further work. A generally better strategy has likewise been accounted for in which just the essential circuits of the framework diagram are utilized. Expanding the ideas presented by, methodical calculations for deciding RSM and a relating SSP have been proposed. These have likewise proposed real coordination calculations utilizing the RSM and SSP for the given transmission network.Algorithms utilizing distinctive philosophies have been accounted for coordination of directional over-current transfers in interconnected and mechanical systems. In any case, these calculations did not yield the ideal outcomes.

## 3.3 Adaptive Coordination Philosophy

Adaptive assurance was characterized by and large terms and explicit applications were featured which could be executed utilizing this logic. The versatile transfer setting is depicted as a conceivable application for executing the coordination reasoning in the general system of versatile assurance. In the meantime another paper introduced thoughts regarding versatile handing-off. Their treatment of the subject is likewise theoretical and general. One of the fundamental contrasts between the two papers is that the later paper perceives the convenient human intercession as a major aspect of the generally versatile insurance rationality. Customarily, the directional over-current transfers comprised of simple sort electro-mechanical or strong state

**transfers, until their computerized proportional, chip based transfers came. It made conceivable to actualize Finding the breakpoints for example the beginning stages of wanted areas for setting the transfers is the extremely significant point to start the coordination procedure. Advancement methods wipe out the need to locate the arrangement of breakpoints. Nonlinear ideal programming procedures are perplexing. In all direct programming systems like simplex, two-stage simplex and double simplex techniques, the assistant factors are presented. These ought to be equivalent to the quantity of imperatives. Thus, the utilization of these techniques has impediments regarding low number of imperatives. Further, the customary advancement methods depend on an underlying supposition and might be caught in the nearby least. Since the issue of coordination has multi-ideal focuses, standard scientific based improvement procedure will fall flat. New streamlining strategies other than traditional, for example, transformative programming (EP) and hereditary calculation (GA) have come up which can be utilized to alter the settings of transfers. By the developmental programming method, the transfer settings might be enhanced. Developmental writing computer programs is a stochastic multi-point looking enhancement calculation and is equipped for break from neighborhood ideal issues. Hereditary calculation is an advancement technique to beaten the issues of traditional streamlining strategies. Hereditary calculation may end up being a trustworthy instrument to locate the ideal transfer settings. In streamlining techniques, the target esteem is delicate to one parameter while vast changes are required in different parameters to impact calculable changes, hereditary calculation is no exemption. Nonetheless, bigger number of ages and populace estimate produce better outcomes while utilizing hereditary calculation.**

# Chapter 4

# Summary of Research Papers

1 **A New Nonlinear Directional Over current Relay Coordination Technique, and Banes and Boons of Near-End Faults Based Approach, Dinesh Birla, Rudra Prakash Maheshwari, and H. O. Gupta, Senior Member, IEEE**

**This paper enlightens about the fact that consideration of weight factors and far end faults in directional over current relay coordination formulation does not affect the optimal solution but coordination quality gets affected upto some extent. This study is done by optimizing all settings in non linear environment by sequential quadratic programming method in MATLAB. By solving DOCR coordination problem based on near end faults does not loose objective function optimal value but coordination gets affected due to some of the constraints.**

**For a small system problem based on near end fault is acceptable for both optimal value and coordination quality but for a large interconnected system it is difficult to find which pair is critical pair. When the problem is solved by changing the objective function to running sum of all valid constraints , then coordination quality is improved, security and dependability of protective system increases.**

**2 An Approach to Tackle the Threat of Sympathy Trips in Directional Over current Relay Coordination, Dinesh Birla, Rudra Prakash Maheshwari, and H. O. Gupta, Senior Member, IEEE**

**This paper proposes to introduce additional constraints in the directional over-current relay coordination problem to tackle the sympathy trips. The solution of relay coordination problem is solved in two phases. From the solution obtained in the first phase, sympathy trips occurring before the primary relays corresponding to each fault location were detected.**

**In phase II, it was possible to reduce the sympathy trips detected in phase I. It was attempted in phase II by three approaches.**

**By the help of phase III it was possible to tackle all the sympathy trips before the primary relays. third approach can tackle the ominous threat posed by sympathy trips to the optimum performance of the system.**

**3 An Adaptive Multi-agent Approach to Protection Relay Coordination With Distributed Generators in Industrial Power Distribution System, Hui Wan, Member, IEEE, K. K. Li, Senior Member, IEEE, and K. P. Wong, Fellow, IEEE**

**This paper presents new explorations into the use of agent technology applied to the protection coordination of power systems. In the proposed system communication will play a important role to provide more information other than relay settings.**

**In this paper, a multi-agent approach to power system protection coordination has been proposed. The proposed multi-agent system consists of a number of relay, DG, and equipment agents.**

The communication simulation shows that the successful information communication between agents has been achieved indicating that the proposed multi-agent system is a feasible approach in protection coordination.

4 Study on Wind-Turbine Generator System Sizing Considering Voltage Regulation and Over current Relay Coordination, Hee-Jin Lee, Student Member, IEEE, GumTae Son, Student Member, IEEE, and Jung-Wook Park, Senior Member, IEEE

In this paper an algorithm has been proposed in order to select the optimal size of WTGS which is based on power flow analysis by treating WTGS as regulated voltage source which is added to the utility substation.

It considers the coordination time interval (CTI) of existing relays to maintain their present settings, and therefore provides an efficient solution in power system restructuring process by connecting the WTGS with its optimal size.

The CTI between the primary and back-up OCRs was used to evaluate the effect of WTGS with the optimal size on existing protective coordination.

5 Relay Protection Coordination Integrated Optimal Placement and Sizing of Distributed Generation Sources in Distribution Networks, Hongxia Zhan, Member, IEEE, Caisheng Wang, Senior Member, IEEE, Yang Wang, Senior Member, IEEE,Xiaohua Yang, Xi Zhang, Changjiang Wu,

and Yihuai Chen

This paper presents an optimal DG placement method to maximize the penetration level of DG in distribution networks without changing the original relay protection schemes.

Genetic algorithm is used to find the optimal locations and sizes of DG in distribution networks.

This paper proposed a relay protection integrated optimal DG placement and sizing method to maximize the penetration level of DG without changing the original relay protection system. A systematic approach was taken to formulate the optimization problem while the requirements imposed by the original relay system on allowable short circuit currents are treated as the constraints in the optimization process to avoid false tripping and failure to trip. GA-based program has been implemented to solve the optimization problem.

6 A Novel Quadratically Constrained Quadratic Programming Method for Optimal Coordination of Directional Overcurrent Relays, Vasileios A. Papaspiliotopoulos, Student Member, IEEE, George N. Korres, Senior Member, IEEE, and Nicholas G. Maratos

In this paper DOCR coordination NLP is reformulated as an equivalent quadratically constrained quadratic programming (QCQP) model which lead to reduction in problem complexity. This method is applied to three different meshed power system which involve state of art optimization software.

A new optimization method is proposed to establish the optimal coordination between the directional over-current relay. Here relay coordina-

**tion is formulated as quadratically constrained quadratic programming (QCQP) model by employing graph theory principles. Simulation conducted in three different systems demonstrate its superiority, enhanced performance over the studied NLP model.**

**7 Resolving the impact of distributed renewable generation on directional overcurrent relay coordination, W. El-khattam T.S. Sidhu**

**This paper introduces two approaches, based on the existing protection systems capability, for regaining the directional over-current relay coordination status in an interconnected power delivery system (IPDS) equipped with multi-DRGs without disconnecting DRGs during faults.**

**For an existing adaptive protection system, the first approach was able to obtain the optimal minimum number of relays and their locations and settings for an existing adaptive protection system but this approach is not applicable when the no. of distributed renewable generation (DRG) increases. In the second approach, for an existing non-adaptive protection system, FCL was introduced to locally limit the DRG drawn current during fault and obtain new relay coordination status without altering the original relay setting.**

**The proposed two approaches were individually implemented to make use of the existing relay devices and protective schemes.**

**8 A Study on Wind-Turbine Generator System Sizing Considering Overcurrent Relay Coordination With SFCL, Hee-Jin Lee, Student Member, IEEE, GumTae Son, Student Member, IEEE, and Jung-Wook Park, Senior Member, IEEE**

**This paper analyzes the effect of a superconducting fault current limiter (SFCL) on the optimal sizing of a wind-turbine generator system (WTGS), which is a representative renewable energy source. The SFCL can limit the fault current in the WTGS, and thus restore the original relay coordination.**

**This paper described the effects of a resistive superconducting fault current limiter (SFCL) in determining the optimal size of the wind-turbine generator system (WTGS) in a practical distribution system. The coordination time interval (CTI) between the primary and back-up overcurrent relays (OCRs) has been used to evaluate the effects of the WTGS and SFCL with its optimal size.**

**The simulation shows that SFCL provides an effective solution for installing a large WTGS (wind turbine generator system) under a tightly constrained conditions resulting in protective relay coordination. SFCL helps to improve the dynamic performance of WTGS.**

**9 Adaptive differential evolution algorithm for solving non-linear coordination problem of directional over-current relays, Joymala Moirangthem, Krishnanand K.R., Subhransu Sekhar Dash, Ramas Ramaswami**

**In this paper the relay coordination problem is formulated as a non linear problem which take discrete time nature of time dial settings and the pickup current settings. In this adaptive differential evolution (ADE) algorithm is used for coordination problem.**

**The problem has been formulated as a non-linear problem taking into account, both types of parameters, that is, TDS(time dial setting ) of relay and Ip, as discrete. ADE algorithm gives better optimal operating**

time of relay without miscoordination when compared with other algorithms.

10 An analytic approach for optimal coordination of over-current relays, Arash Mahari, Heresh Seyedi

This paper presents a new analytic method for optimal coordination of over-current relays. The approach is based on various factors such as optimum pick up current, time dial setting on order to obtain minimum operating time satisfying boundary and coordination constraints.

In this paper a new method has been introduced for optimal coordination of over-current problem. This coordination problem is solved by using new proposed algorithm. This method is based on new setting mechanism which is based on minimum operating time of over-current relays. The algorithm is applied to three benchmark systems.

The results depict that this method produces the best solution compared to the previous solution other than this it has many advantages such as : fast convergence, small run time, initial values independence, insensitiveness to coordination order and capability of finding the global optimum.

11 A combined adaptive network and fuzzy inference system (ANFIS) an approach for over-current relay system, M. Geethanjali,S. Mary Raja Slochanal

In this paper a new method for modelling OC relay characteristics curves based on a combined adaptive network and fuzzy inference system (AN-

**FIS) is proposed. OC relay modelling is done using ANFIS for two types of OC relays (RSA20 and CRP9 with different types and various numbers of membership functions.**

**In this paper, for two different OC relays, namely RSA20 and CRP9 ANFIS model is designed and developed with various types of member functions (MFs). Operating time of over-current relays for different time dial setting are calculated. it is inferred that the ANFIS model using seven numbers of Gaussian-type MFs gave more accurate results (i.e. mean average error percentage is 0.15). The ANFIS model using five numbers of triangular-type MFs gave more accurate results (i.e. mean average error percentage is 0.61).**

**12 Optimal coordination of directional over-current relays using Teaching Learning-Based Optimization (TLBO) algorithm, Manohar Singh, B.K. Panigrahi , A.R. Abhyankar**

**This paper discusses the application of Teaching Learning Based Optimization (TLBO) algorithm for optimal coordination of DOCR relays in a looped power system. Combination of primary and backup relay is chosen by using Far vector of LINKNET structure, to avoid miscoordination of relays. Coordination of DOCR is tested for IEEE 3, 4 and 6 bus systems using the TLBO.**

**The performance of proposed algorithm is satisfactory in terms of reliable coordination margin and summation of total operating time of all the primary relays. Mal-operation of relay coordination pairs is also eliminated. Coordination time margin between primary and backup pairs also get modified.**

**13 Optimal coordination of directional over-current relays using informative differential evolution algorithm, Manohar Singh, B.K. Panigrahi,, A.R. Abhyankar, Swagatam Das**

**This paper discusses the application of informative differential evolution algorithm with self adaptive re-clustering technique for selection of TDS and PSM for optimal coordination of directional over-current relays.**

**IDA with self adaptive re-clustering technique is used for optimization of relay coordination problem and gives optimal value of objective function which is comparable with value obtained from hybrid GANLP. Proposed relay coordination algorithm eliminates the mis-coordination among the relay pairs and gives the optimal value of CTI between 0.2 and 0.8 s using both continuous and discrete version of relay settings.**

**14 Detecting and solving the coordination curve intersection problem of over-current relays in sub-transmission systems with a new method, Ying Lu, Jarm-Long Chung**

**This study presents a practical and effective method for inspecting and repairing curve intersection situations that occur in upstream and downstream coordinated over-current relay pairs in sub-transmission networks. The proposed method is based on the IEEE and IEC standard characteristic curve equations of digital over-current relays and a customized curve equation for electromechanical over-current relays.**

**This paper proposes a practical and effective approach for detecting and solving the coordination curve intersection problem of over-current relays in sub-transmission systems. The advantages of this method include substantial performance improvements and cost reduction compared to**

**the traditional manual calculation method. The proposed approach can be used for both digital and electromechanical over-current relays.**

**15 Optimal coordination of directional over-current relays using a modified electromagnetic field optimization algorithm, H.R.E.H. Bouchekara, M. Zellagui, M.A. Abido**

**The main objective of this paper is to develop a modified version of the Electromagnetic Field Optimization (EFO) algorithm referred to as MEFO for the optimal coordination of DOCRs. The proposed algorithm has been applied to three test systems including the 8-bus, the 9-bus and the 15-bus test systems.**

**The DOCRs optimal coordination problem has been formulated as a nonlinear programming problem and as a mixed integer non linear programming problem according to the nature of the optimized parameters. The obtained results demonstrate that the proposed MEFO algorithm is an efficient and reliable tool for the coordination of directional over-current relays.**

**16 Optimal coordination of distance and over-current relays considering a non-standard tripping characteristic for distance relays, Yaser Damchi, Javad Sadeh , Habib Rajabi Mashhadi**

**In this study, a new operating characteristic (OPC) for distance relays is proposed which decreases TZ2s. In the proposed OPC, the common characteristic for the second zone is divided into two sections: the first section protects the main line beyond the first zone with delay time TZ2n1 and the second one protects 50 percent of the adjacent line with**

**delay time TZ2n2. The presented method is tested on three test systems: namely, the 8-bus, the IEEE 14-bus, and the IEEE 30-bus test systems.**

**In this paper, a new non-standard characteristic is proposed for distance relays. Moreover, a new formulation is presented for the nonlinear DDOCRs coordination problem based on the proposed OPC, and HGA-LP is used to solve the problem. the operating times of distance relays (for the adjacent lines protection) and DOCRs are decreased in overall. Therefore, the proposed OPC for distance relays is very effective in achieving faster selective protection systems.**

**17 Advanced Coordination Method for Over-current Protection Relays Using Nonstandard Tripping Characteristics, Timo Keil and Johann Jger, Member, IEEE**

**This paper describes an advanced coordination method for an optimized protection time grading based on a new non standard tripping characteristic for over-current protection relays. The optimization is solved by the method of Lagrange generalized with the KarushKuhnTucker conditions and is aimed at selective fault tripping with shorter tripping times as standard characteristics and conventional coordination methods.**

**This method results in a noticeable reduction of the maximum and effective average tripping time in relation to the conventional DTOC and IDTM grading.**

**18 Considering Different Network Topologies in Optimal Over-current Relay Coordination Using a Hybrid GA, Abbas Saberi Noghabi, Javad Sadeh, Member, IEEE, and Habib Rajabi Mashhadi, Member, IEEE**

**The aim of this paper is to study DOCRs coordination considering the effects of the different network topologies in the optimization problem. In this paper, in order to improve the convergence of the GA, a new hybrid method is introduced.**

**The aim is to find an optimal solution for the coordination problem such that large number of coordination constraints corresponding to a set of network topologies are simultaneously satisfied. Due to decreasing the search space of GA and using LP as an efficient local optimizer, computational efficiency of the new proposed hybrid GA is significantly improved.**

**19 Optimal Coordination of Directional Over-current Relays Considering Different Network Topologies Using Interval Linear Programming, Abbas Saberi Noghabi, Habib Rajabi Mashhadi, Member, IEEE, and Javad Sadeh, Member, IEEE**

**In this paper, a new approach based on the interval analysis is introduced to solve the DOCRs coordination problem considering uncertainty in the network topology. The DOCR coordination problem is formulated as an interval linear programming (ILP) problem.**

**The relay coordination problem can be formulated as a linear programming problem with a large number of inequality constraints when different network topologies are considered. The results shows that the number of coordination constraints is drastically reduced when the proposed method is applied to the 14-bus and 30-bus IEEE test systems.**

**20 Optimum Coordination of Directional Over-current Relays Using the Hybrid GA-NLP Approach, Prashant Prabhakar Bedekar and Sudhir Ramkrishna Bhide**

**This paper presents hybrid genetic algorithm (GA)nonlinear programming (NLP) approach for determination of optimum values of TMS and PS of OCRs. This paper proposes a hybrid method to overcome the drawback of GA and NLP method, and determine the optimum settings of OCRs.**

**GA has been applied to find the initial solution of this problem, which was then used by NLP method to find the global optimum solution. This algorithm was tested for various system configurations including multi-loop system , it can be applied to a system having a combination of electromechanical relays and combination of over-current relays.**

# Chapter 5

# Implementation of digital over-current relays in power system protection

## 5.1 Recent changes in power system in distribution system

**Protection of power system is related with the identification of the fault and its clearance under unstable conditions as quickly as possible and hence the equipment used for protection must be have possess sensitivity that means it must be able to measure system parameters and must able to differentiate abnormal conditions immediately. For example, in Fig. 1a, the relay R1 or R2 is used to clear the fault at fault F1 but in order to maintain continuity at bus B, the relay R1 should be chosen. In general, the primary relay refers to the first relay that should operate in order to clear the fault and the back-up relay refers the second relay that should operate for the same fault.**

**It is very much important to operate relay in harmony that means the back-up relay must wait for the primary relay to get operate and this time interval is referred as coordination time internal and generally it is taken between 0.2-0.5 s.**

**In general protection scheme comprises of various equipment namely over-current relays, fuses and sectionalizers. Over-current relays are most com-**

monly used equipment for protection because of its inverse time-current characteristics which allows this device to coordinate with the another equipment. For illustration purpose,let a simple radial line with two over-current relays which is in Fig. 1a.In this illustration R1 and R2 are considered as primary as well as back-up relays against the fault location F1.With reference to fig 1a, inverse time -current characteristics curves of these relays are coordinated with the downstream fault across the relay.By adjusting the value of TDS and pick up current setting the coordination can be achieved which is elaborated in Section 3. The changes in the characteristic curves due to different TDS values can be seen in Fig. 1b.

Consider again a similar basic spiral line, and expect a DG associated with transport B as delineated in Fig. 2. For this situation, the current through hand-off R1 amid the flaw F1 increments while the current through transfer R2 does not change or diminishes contingent upon shortcoming type, which implies that the coordination between hand-off sets break down. Obviously, the defensive hardware must be fit for detecting and responding to these issue current dimensions. Notwithstanding that, when an issue happens at the utility side in the framework associated mode, the MG ought to have the capacity to change to islanded mode without losing sound DG units that are found inside the island. So also, it is normal from the assurance frameworks that in these of internal MG blames just the blamed part ought to be de-invigorated in a specific way. Concerning operational changes in power frameworks, traditional assurance structure theory ought to be overhauled so as to adjust new normal for power frameworks.

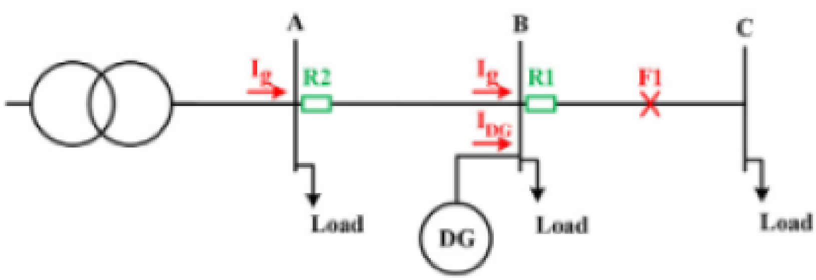



Figure 5.1: DG connection considering radial line

## 5.2 Characteristics based on standard

This section mainly comprises of different types of characteristics which is accepted generally and universally. The objective of this section emphasize on ensuring about the correct operation of This section contains information about generally accepted and used relay characteristics i.e. IEC and IEEE SCs. The objective of these studies was to ensure that the protection system should operate properly by accurate relay characteristic so that it could be coordinated with reclosers and fuses.

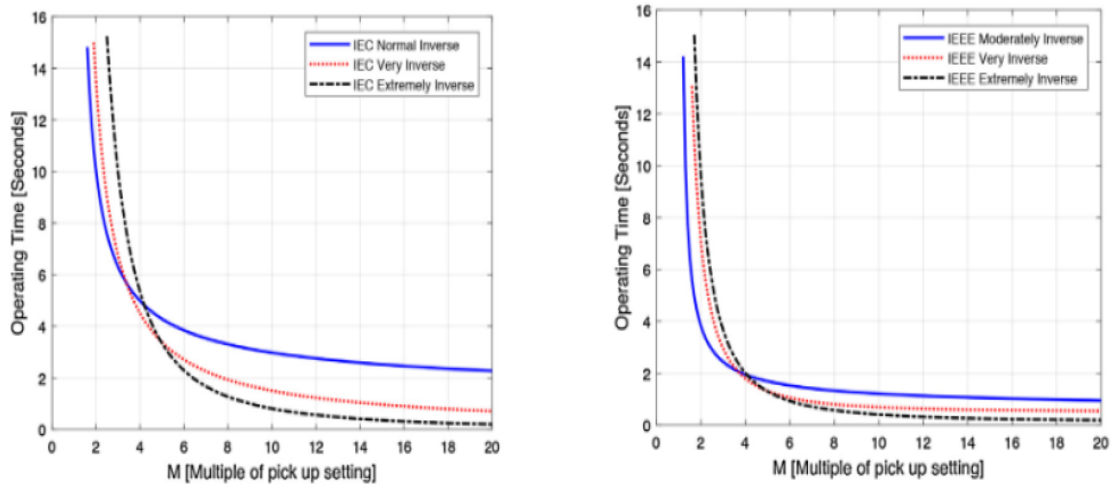
### 5.2.1 Characteristic based on IEC standard

By the help of graphical method or by using equation the type of shape of curve can be found out. Graphical portrayals of the IEC standard attributes for various issue current extents are outlined in Fig. 3a.

$$t = \frac{A}{(I_f/I_p)^B - 1} \cdot \mathrm{TDS} \qquad (1)$$

### 5.2.2 Characteristic based on IEEE

IEEE standard is also a type of standard which is generally accepted as well as universally accepted. This standard is different from IEC by just addition of an extra parameter C which is udes because of non linear relationship between the input and the core flux of the electro-mechanical relay. Thus, the condition of the IEEE standard qualities contains a C parameter so as to mirror the fixed stumbling time brought about by the inductance immersion which happens when the info current esteem is more noteworthy than a limit. For viable security applications, the IEEE advisory group characterized three distinct qualities which were like the IEC standard attributes. Table 2 outlines the required A, B, and C esteems so as to get the diverse IEEE standard hand-off attributes. The visual delineation of the reactions given by the three IEEE standard attributes to the diverse issue current extents can be found in Fig. 3b.




(a) Based on IEC SCs

(b) Based on IEEE SCs

Figure 5.2: OCR characteristics

$$t = \left[ \frac{A}{(I_f/I_p)^B - 1} + C \right] \cdot \text{TDS} \qquad (2)$$

## 5.3 Characteristics based on non-standard

This section gives the detail about the studies which aimed to construct NSCs in order to achieve protection coordination in the power system. This section is devoted to giving details about the studies which aimed to construct N-SCs in order to achieve protection coordination. These unconventional approaches are categorized as four groups: (1) approaches that include electrical magnitudes,

(2) approaches that use different coefficients apart from the SCs,

(3) mathematical approaches,

(4) other approaches.

### 5.3.1 NSCa based on electrical magnitude

Before, the transfers that were utilized to identify and clear an issue depended just on the shortcoming current esteem. In any case, today, the voltage esteem can likewise be utilized to analyze the defective piece of the power framework because of the way that directional over-current transfers (DOCRs) have commonly turned out to be progressively available and can gauge both current and voltage esteems on hold which they are associated with by means of current and voltage transformers. The past research demonstrated that this element of the DOCRs makes an open door for the use of N-SCs which are shaped by considering the ebb and flow as well as the voltage esteem . A few scientists have recommended utilizing voltage estimations by adding a voltage parameter to the SCs so as to moderate the impacts brought about by DG association, MG idea, and so on., while others have proposed utilizing induction based attributes gave that the converse time trademark is protected. In this area, the examination identified with accomplishing transfer coordination regarding utilizing different mixes of estimated current and voltage esteems is additionally checked on.

### 5.3.2 Characteristics based on the value of current

Non standard characteristics can be generated depending upon the value of current which is generally used in standard characteristics.It is quite evident from the eq (3) and (4) that the value of A is changing with respect to the measured value . Fig 4a depicted about the impact of change in the value of fault current which is The impact of changing fault current on N-SC characteristic. Fig. 4a.

**Table 2**
Coefficients indicated in the IEEE C37.112-1996 standard [47].

| | Moderately inverse | Very inverse | Extremely inverse |
|---|---|---|---|
| A | 0.0515 | 19.61 | 28.2 |
| B | 0.02 | 2 | 2 |
| C | 0.1140 | 0.491 | 0.1217 |

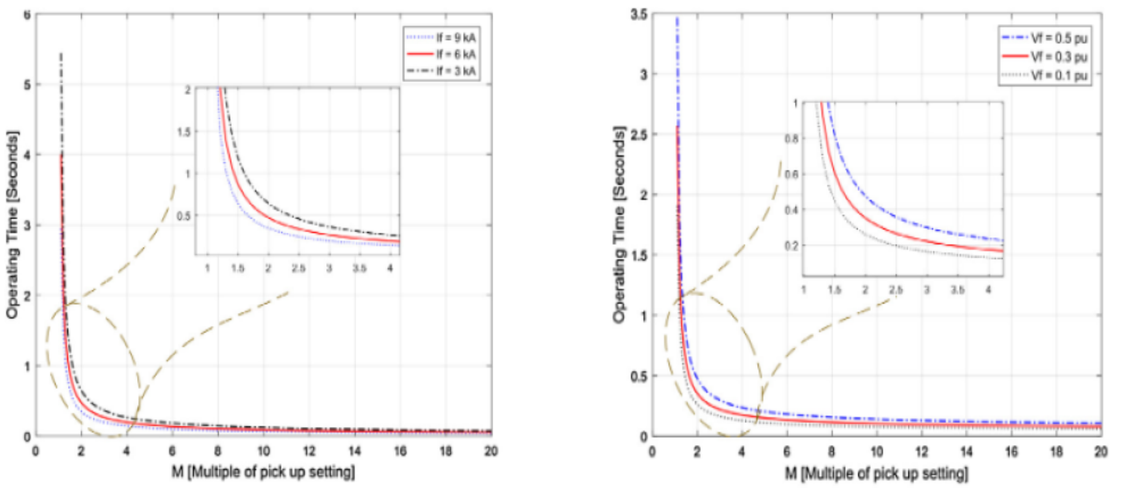
$$A(I_f) = A \cdot e^{-I_f/C} \quad (3)$$

$$t = \left[ \frac{A(I_f)}{(I_f/I_p)^B - 1} \right] \cdot \mathrm{TDS} \quad (4)$$

It is quite evident from the result that the decrease in the operating time of relays is basically obtained with the introduction of non standard characteristics into the industrial system. The presented results showed that a dramatic decrease in OT of the relays can be obtained by introducing the aforementioned N-SC in the industrial power systems.

### 5.3.3 Voltage based characteristics

In order to provide proper and reliable relay coordination under the impact of high pervasive of distributed generations the value of the voltage can be also taken into consideration. In this characteristics the value of Vf is used which used to signify the contribution of that voltage value in relay coordination. However, below in fig 4b depicted the impact of voltage on the proposed non standard characteristics.




(a) Impact of current change on NSC (b) Impact of voltage change on NSC

Figure 5.3: Characteristics with impact of voltage and current

This study aimed about operation of wind power plants by adjusting the relay settings properly. The status of wind power plant is governed by determination of critical voltage .Different topologies has been tested by the help of eq (5). Eq (6) is developed by means of characteristic equation.

$$t = \frac{A}{(I_f/I_p)^B - 1}\left(\frac{V_f}{e^{k \cdot V_f}}\right) \cdot \text{TDS} \quad (6)$$

This includes the per unit voltage value along with the constant K. Fig 5a depicted the relation between the change in the voltage and the proposed characteristic. A comparative methodology regarding utilizing voltage sizes was displayed , which brought another viewpoint utilizing a logarithmic ca-

$$t = \mathrm{TDS}\cdot\frac{(V_f)^k}{e^{V_f}}\left[\frac{A}{(\ln(V_n\frac{I_f}{V_f}))^B - (\ln(V_n\frac{I_{set}}{V_{set}}))^B} + C\right] + D \qquad (7)$$

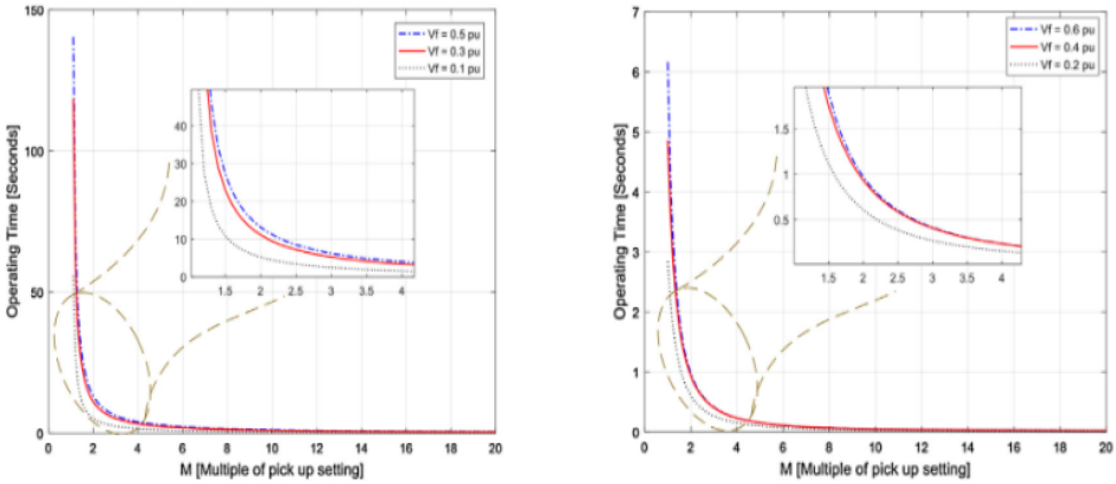
pacity in the denominator. One can consider the exhibited trademark in as a joined methodology since it incorporates both a "whimsical" numerical articulation and electrical extents, as given in (7). It very well may be seen from (7), when the voltage estimated by the hand-off is zero, OT of the transfer depends just on the steady D. Likewise, the explanation behind utilizing the common logarithm was to confine the high varieties in current and voltage.

$$A = V_f\cdot(1 - V_f) \qquad (8)$$

$$t = A\cdot\left[\frac{28.2}{(I_f/I_p)^2 - (1/e^{(1-V_f)})^2} + 0.1217\right]\cdot \mathrm{TDS} \qquad (9)$$

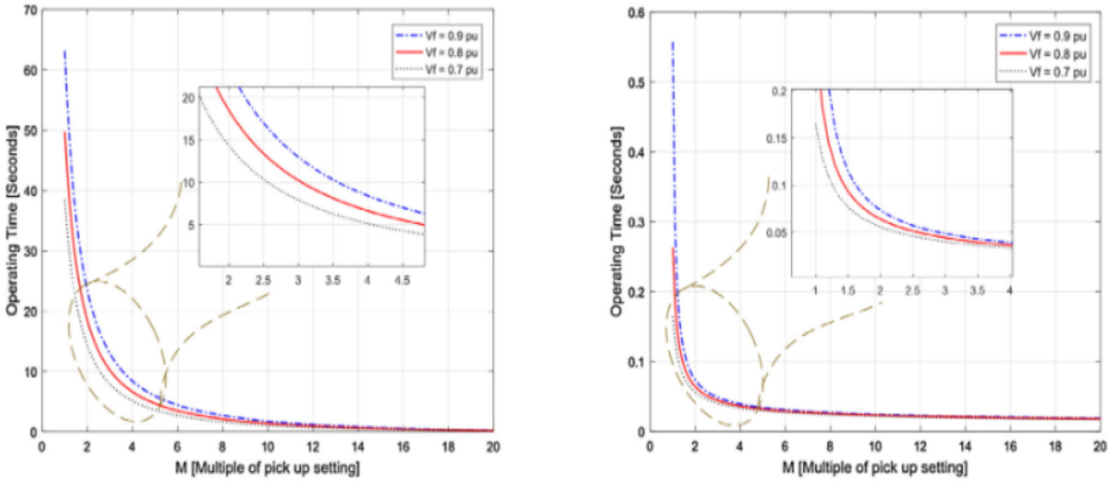
$$t = \left(\frac{1}{1-(\log\ V_f)^C}\right)^k \frac{A}{(I_f/I_p)^B - 1} \qquad (10)$$

A non standard characteristics which is based on the value of voltage is depicted bu (10). In fig 6a the response of non standard characteristic has been recorded in accordance with the variation the value of voltage.




(a) TDS=1 (b) TDS=0.5

Figure 5.4: Impact of voltage change on NSC




(a) Impact of voltage change on NSC (b) The voltage effect on admittance based NSC

Figure 5.5: Effect of various parameters on NSC

$$t = \frac{\log(V_f + A)}{M^B - 1} + C \quad (11)$$

### 5.3.4 Admittance value based characteristics

**By utilizing the value of admittance the features of recent power system can be mitigated.The aforesaid statement can be visualized in fig 6b. The struc-**

$$t = \frac{A}{Y_r^B - 1} + C \quad (12)$$

**ture of the equation is quite similar to standard characteristics except some changes in the parameter values as (If/Ip) can be replace with Yr and it should be noted that it is not involving settings of TDS. Here Ym signifies**

$$Y_r = \left|\frac{Y_m}{Y_t}\right| \quad (13)$$

**the deliberate induction amid the flaw and Yt is the set permission esteem for the hand-off. It very well may be closed from the conditions that the hand-off produces stumbling signal just when —Ym— ¿ —Yt —. As per the Yt esteem, the secured line was isolated into zones as though it was a separation transfer and afterward a backwards time trademark was doled out for each**

**zone. The thought is that keeping away from the TDS esteems gives a chance to avert high OTs for transfers which are near the source. Notwithstanding, setting extra zones with one of a kind estimations of A, B, and C for each hand-off could be a difficult undertaking for clients. Notwithstanding that, estimation and count of the induction esteem ought to be likewise painstakingly considered in light of the fact that dispersion frameworks have shorter lines than transmission frameworks. Additionally, recognizing the area of a profoundly resistive issue which is near end of the characterized zone can be a non-minor undertaking in this strategy.**

# Chapter 6

# Result

## 6.1 Introduction

In the optimum coordination of directional over-current relays the operating time of the relays is minimized while maintaining the coordination constraints. In this problem a range of objective functions is being developed including coordination constraints with various weights assigned to each objective function.Based on the performance of above objective function a new proposed objective function is also being developed in order to improve the previously objective function.

The Proposed objective function (POF) minimizes the operating time along with the descrimination time of the relays. The comparative analysis is being executed to find out the best objective function for the coordination of Directional over-current relays. The operating time of the relays and the relay settings will be optimized by means of various soft computing techniques such as: Particle Swarm Optimization (PSO), Genetic Algorithm (GA), Teaching learning based optimization (TLBO) etc.

## 6.2 Problem formulation

The DOCR coordination problem is formulated as a non constrained optimization problem.The purpose of objective is reduce the operating time of primary relay which is expressed as : In OF1, n is the no. of relays ,T is the

$$OF1 = min\left(\alpha_1 \sum_{i=1}^{n} T_{p,i}\right)$$

operating time of relay, a1 is the weight assigned to the objective function and is considered as 1 for the above objective function. The operating time of relay is formulated as:

$$T_i = \frac{0.14}{\left({}^{I_{R_i}}/_{PS_i}\right)^{0.02} - 1} \times TMS_i$$

The OF1 minimizes the operating time of primary relays only which causes higher operating time of back-up relays , this is the drawback of this objective and to overcome the above disadvantage another objective function has been developed and is expressed as: In OF2, n is the no. of primary relays, m is the

$$OF2 = min\left(\alpha_1 \sum_{i=1}^{n} T_{p,i} + \alpha_2 \sum_{j=1}^{m} T_{b,j}\right)$$

no. of back-up relays and a1 and a2 are the weights assigned to the objective function.The OF2 minimizes operating time of both primary relays as well as back-up relays but in a large inter-connected systems larger value of CTI still exists , this is main drawback of this objective function and to overcome this disadvantage, a new objective function is developed and is expressed as:

$$OF3 = min\left(\alpha_1 \sum_{i=1}^{n} {T_{p,i}}^2 + \alpha_2 \sum_{k=1}^{N} {\Delta T_k}^2\right)$$

where ACTI is expressed as:

$$ACTI = \Delta T_k + FCTI$$

where delta tk is expressed as:

$$\Delta T_k = T_{b,j} - T_{p,i} - FCTI$$

The OF3 minimizes the value of CTI hence the problem of larger value of CTI has been solved by the help of OF3 but the problem is operating time of both primary as well as back-up relays is not being minimized. Hence in order to overcome the drawback of the above OF, a new objective function is developed and it is expressed as: The OF4 minimizes the operating time of both

$$OF4 = min\left( \alpha_1 \sum_{i=1}^{n} {T_{p,i}}^2 + \alpha_2 \sum_{j=1}^{m} \left(T_{b,j} - FCTI\right)^2 \right)$$

primary and back-up relays and minimize the value of ACTI but the problem of this objective is that it does not satisfy the coordination constraints of directional over-current relays. In order to overcome this drawback a novel OF is developed and is expressed as:

$$OF5 = min\left( \alpha_1 \sum_{i=1}^{n} {T_{p,i}}^2 + \alpha_2 \sum_{k=1}^{N} (\Delta T_k - |\Delta T_k|)^2 \right)$$

Since the OF5 satisfies all the coordination constraints of DOCR but it only minimizes the operating time of primary and as OF5 value is negative so it leads to mis-coordination where the operating time of back-up relay is lesser than the primary relay which infers that the back-up relay will operate earlier than the primary . This the major drawback of this OF and so we can't take OF5 to solve the coordination problem.

As per the above discussion each OF suffers from mis-coordination or higher operating time of relay so a proposed objective function (POF) has been developed in order to overcome the difficulties faced by the aforementioned OFs. The POF is expressed as: The POF resolves the problem of

$$POF = a_1 \sum_{i=1}^{m} t_{i^2} + a_2 \sum_{k=1}^{n} \left( \left| \Delta t_{pbk} - |\Delta t_{pbk}| \right| \times \frac{\Delta t_{pk^2}}{\Delta t_{bk^2}} + \left( \Delta t_{pbk} + |\Delta t_{pbk}| \right) \times t_{bk^2} \right)$$

mis-coordination and at the same time minimizes the operating of primary relay in case of mis-coordination. This characteristic of POF minimizes the operating time of relay and along with maintaining the descrimination time at a prescribed limit.

## 6.3 Comparison of Objective functions

The various objective functions has been developed as above and the comparison of all the objective functions with respect to the relay settings are described as below:

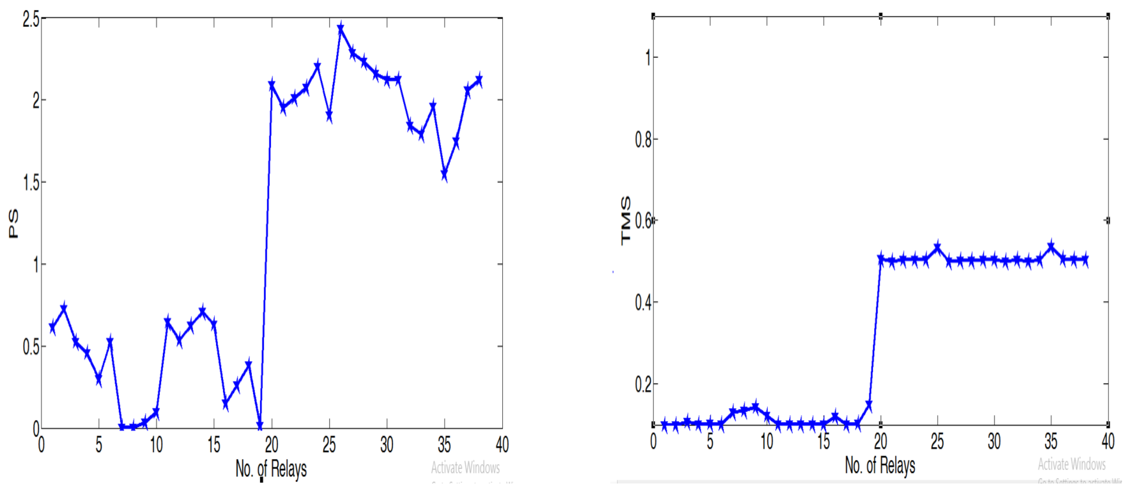



Figure 6.1: Objective function 1

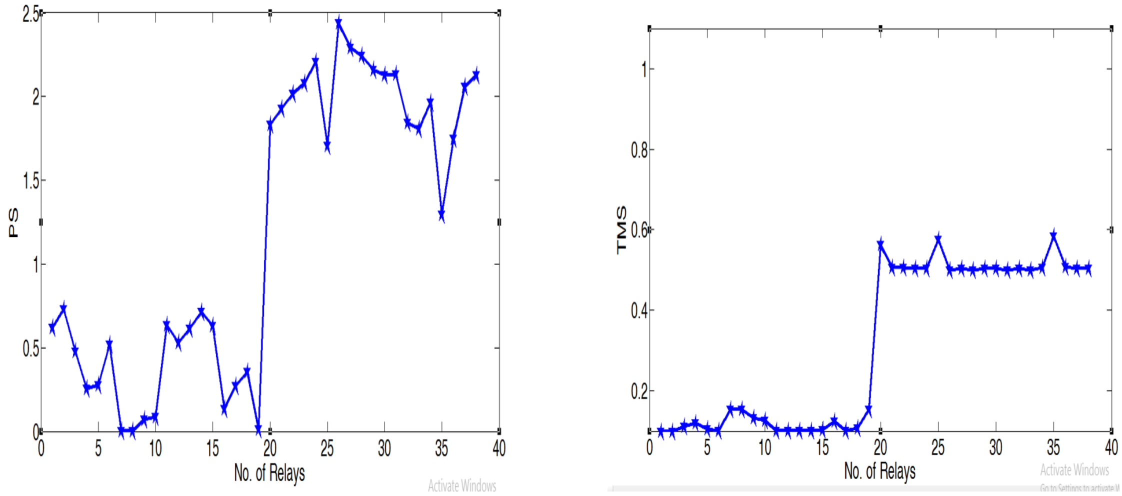



Figure 6.2: Objective function 2

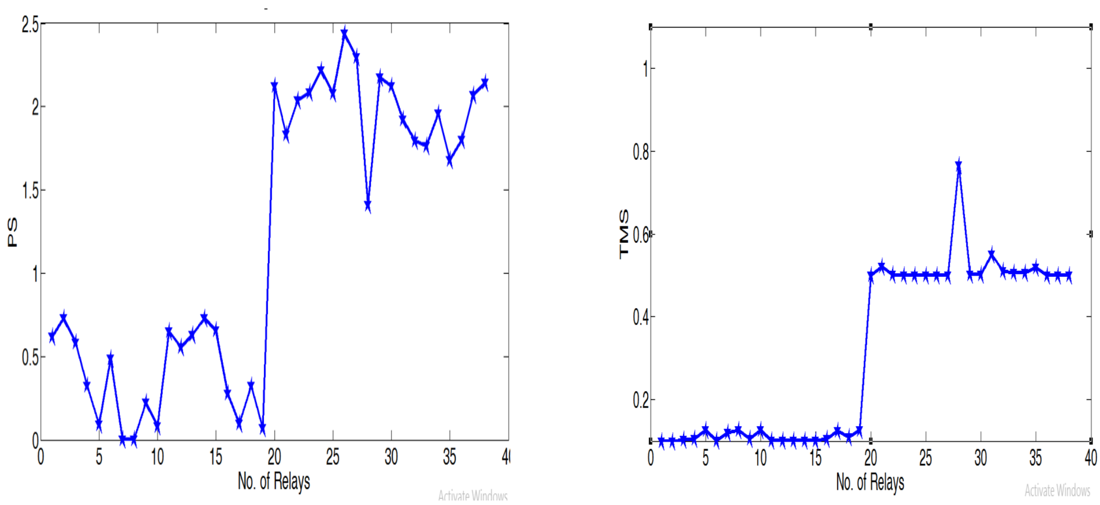



Figure 6.3: Objective function 3

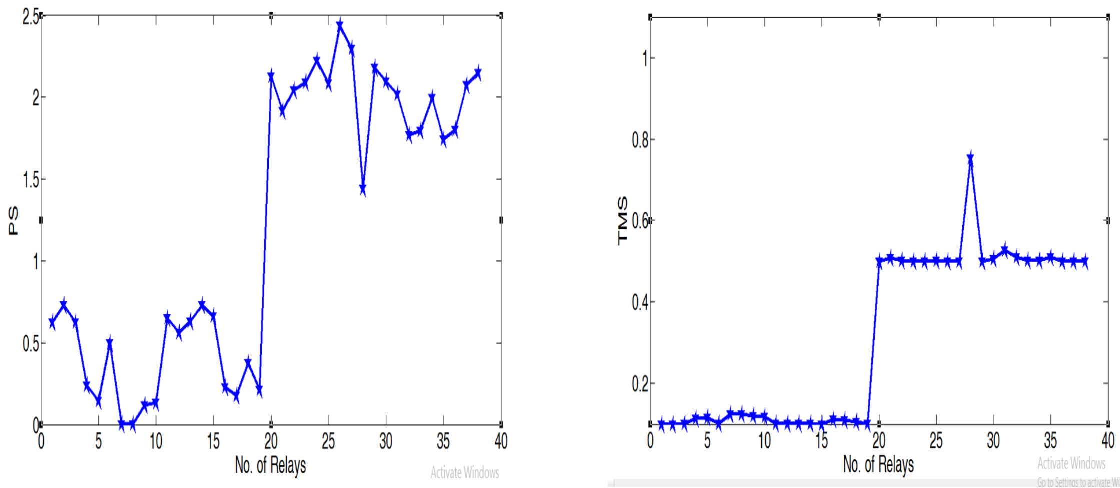



Figure 6.4: Objective function 4

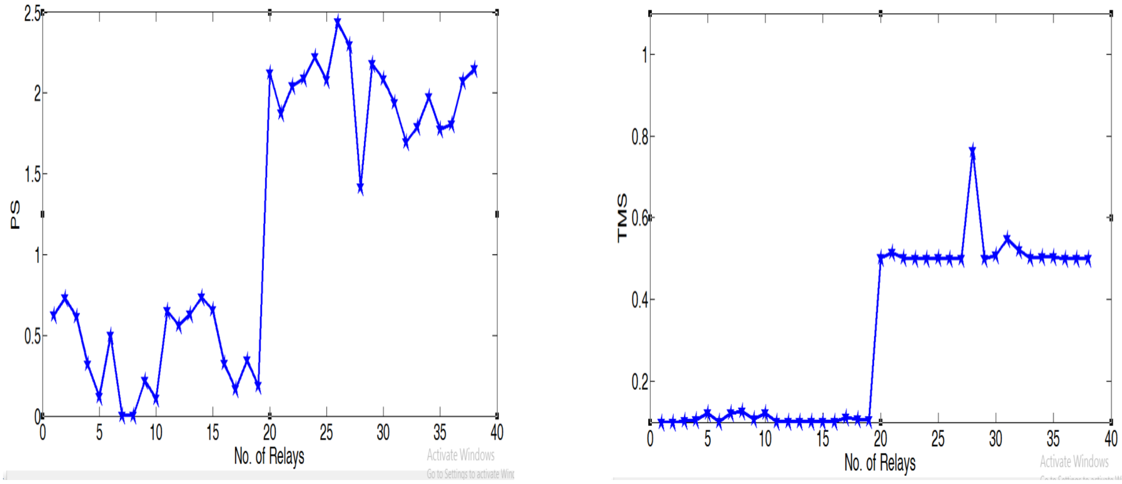



Figure 6.5: Objective function 5

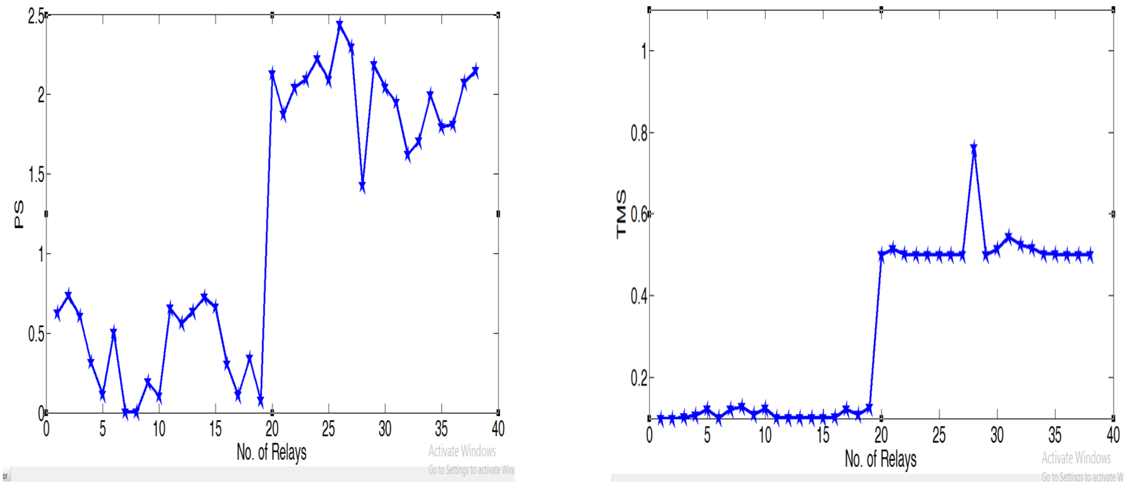



Figure 6.6: Proposed Objective function

**Apart from comparing objective functions on the basis of relay setting it can be also compared on the basis of value of coordination time interval (CTI) versus the no. of relay back- up pairs.**

**The results of all the objective functions compared on the basis of CTI value are shown as below :**

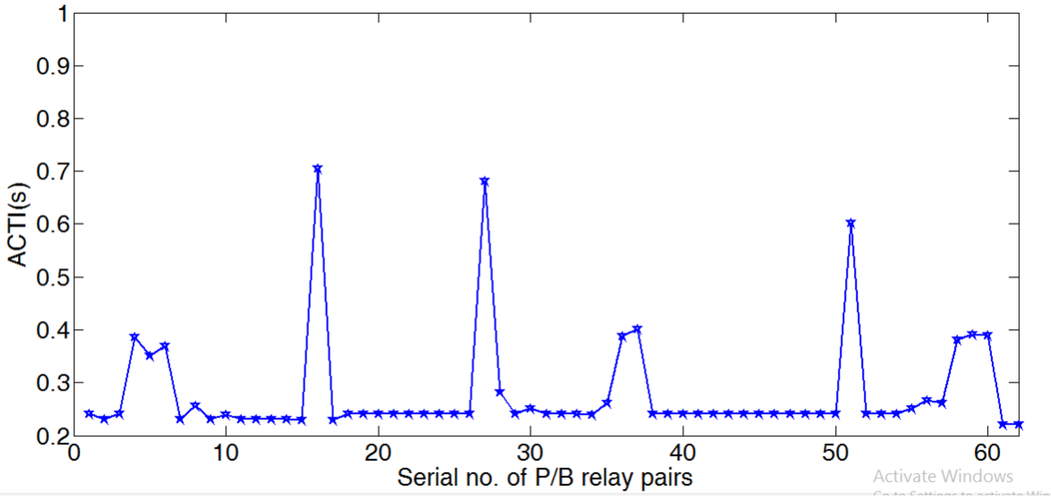



Figure 6.7: CTI values of OF1

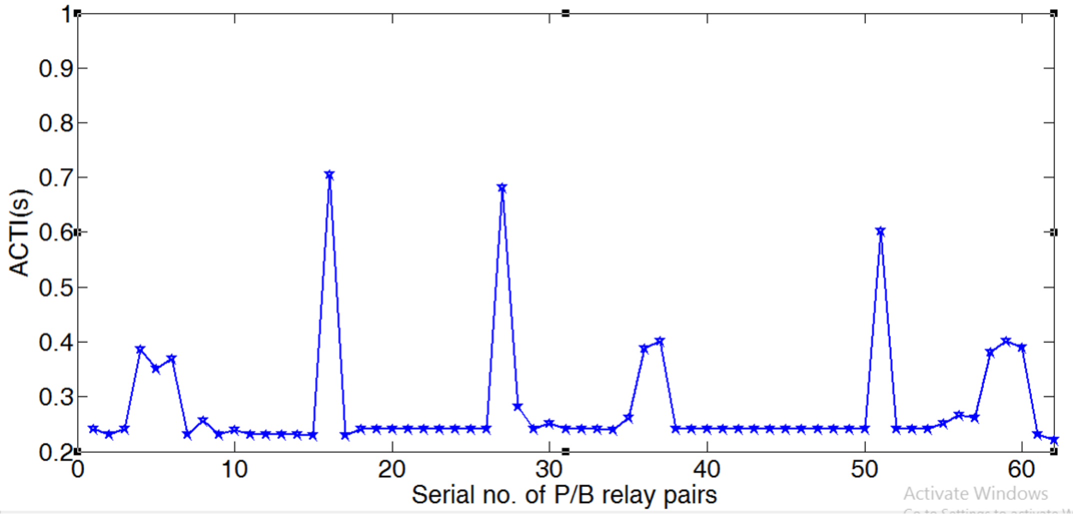



Figure 6.8: CTI values of OF2

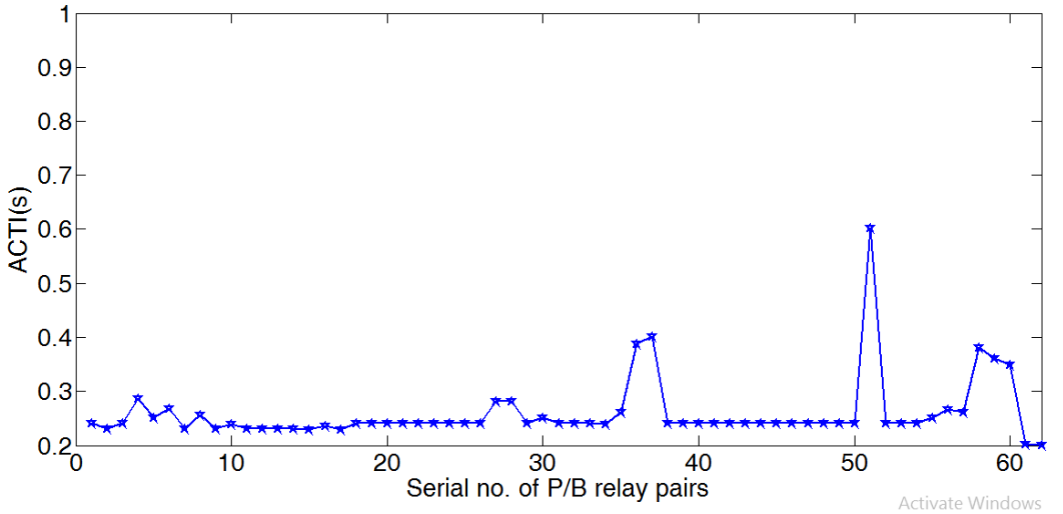



Figure 6.11: CTI values of OF5

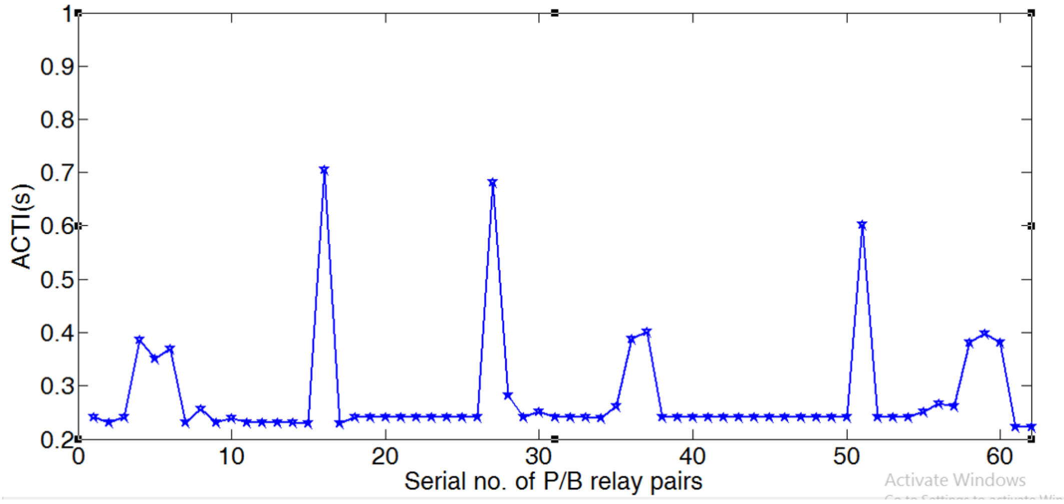



Figure 6.9: CTI values of OF3

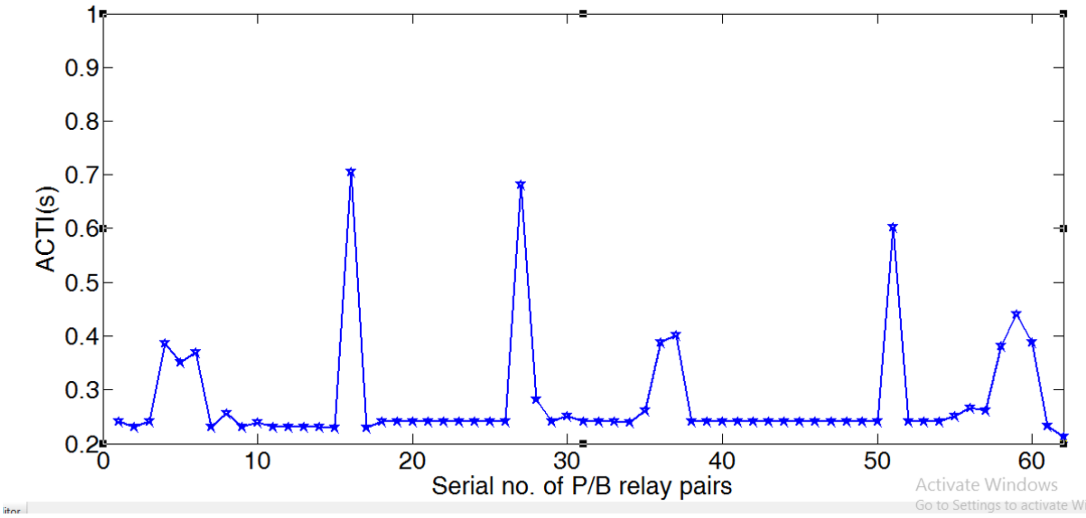



Figure 6.10: CTI values of OF4

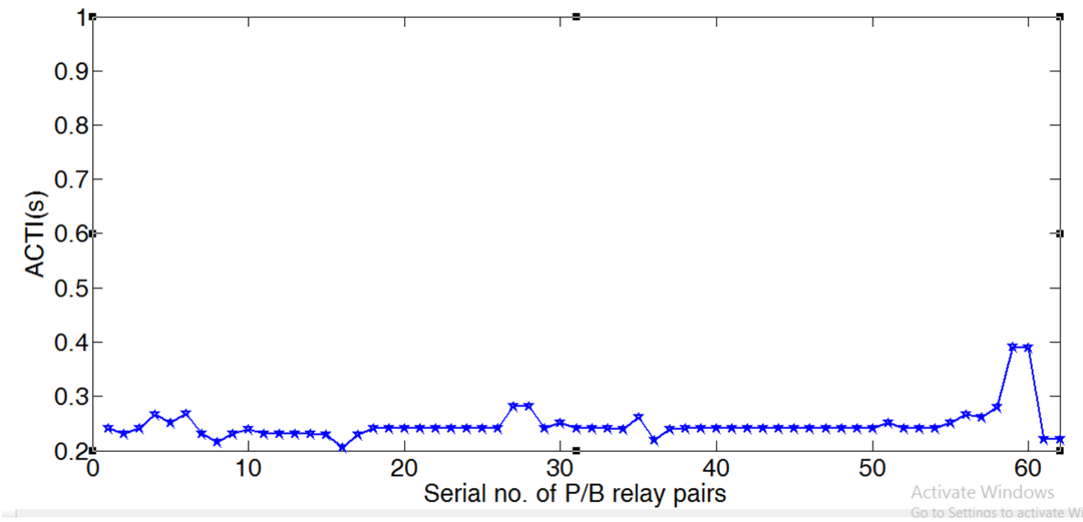



Figure 6.12: CTI values of POF

Hence from the above results it can be inferred that POF minimizes the total operating of primary relay as well as back-up relay with maintaining proper discrimination time within a prescribed limits. So it is quite evident from the above results that POF is the best objective function amongst the all and it should be taken for relay coordination of Directional over-current relays (DOCRs).

Further the relay coordination is carried out by using Particle Swarm Optimization (PSO) technique and all the objective functions are compared.

The input data and its output for particle swarm optimization has been shown below :

| Relay | CT ratio | OLFmax | OLFmax | LC | If | ∝ | β | Tdes | Sat limit | Tol | DT | PSMmin | PSMmax | StepPSM | MinTDS | MaxTDS | StepTDS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 200 | 1 | 1.25 | 200 | 5794 | 0.14 | 0.02 | 0.107 | 20 | 0.001 | 0 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 2 | 200 | 1 | 1.25 | 200 | 6223 | 0.14 | 0.02 | 0.108 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 3 | 200 | 1 | 1.25 | 200 | 3102 | 0.14 | 0.02 | 0.1 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 4 | 200 | 1 | 1.25 | 200 | 4679 | 0.14 | 0.02 | 0.1 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 5 | 200 | 1 | 1.25 | 200 | 4306 | 0.14 | 0.02 | 0.1 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 6 | 200 | 1 | 1.25 | 200 | 2251 | 0.14 | 0.02 | 0.112 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 7 | 200 | 1 | 1.25 | 200 | 4510 | 0.14 | 0.02 | 0.107 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 8 | 200 | 1 | 1.25 | 200 | 4510 | 0.14 | 0.02 | 0.108 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 9 | 200 | 1 | 1.25 | 200 | 5804 | 0.14 | 0.02 | 0.1 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 10 | 200 | 1 | 1.25 | 200 | 6061 | 0.14 | 0.02 | 0.1 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 11 | 200 | 1 | 1.25 | 200 | 3038 | 0.14 | 0.02 | 0.1 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 12 | 200 | 1 | 1.25 | 200 | 4233 | 0.14 | 0.02 | 0.112 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 13 | 200 | 1 | 1.25 | 200 | 2927 | 0.14 | 0.02 | 0.107 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 14 | 200 | 1 | 1.25 | 200 | 2556 | 0.14 | 0.02 | 0.108 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 15 | 200 | 1 | 1.25 | 200 | 2142 | 0.14 | 0.02 | 0.1 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 16 | 200 | 1 | 1.25 | 200 | 4656 | 0.14 | 0.02 | 0.1 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 17 | 200 | 1 | 1.25 | 200 | 5890 | 0.14 | 0.02 | 0.1 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 18 | 200 | 1 | 1.25 | 200 | 4120 | 0.14 | 0.02 | 0.112 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 19 | 200 | 1 | 1.25 | 200 | 4263 | 0.14 | 0.02 | 0.107 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 20 | 200 | 1 | 1.25 | 200 | 3328 | 0.14 | 0.02 | 0.108 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 21 | 200 | 1 | 1.25 | 200 | 4909 | 0.14 | 0.02 | 0.1 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |

Figure 6.13: Input data for 30 bus

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22 | 200 | 1 | 1.25 | 200 | 4069 | 0.14 | 0.02 | 0.1 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 23 | 200 | 1 | 1.25 | 200 | 3070 | 0.14 | 0.02 | 0.1 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 24 | 200 | 1 | 1.25 | 200 | 2060 | 0.14 | 0.02 | 0.112 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 25 | 200 | 1 | 1.25 | 200 | 2060 | 0.14 | 0.02 | 0.107 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 26 | 200 | 1 | 1.25 | 200 | 946 | 0.14 | 0.02 | 0.108 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 27 | 200 | 1 | 1.25 | 200 | 1310 | 0.14 | 0.02 | 0.1 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 28 | 200 | 1 | 1.25 | 200 | 1649 | 0.14 | 0.02 | 0.1 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 29 | 200 | 1 | 1.25 | 200 | 1897 | 0.14 | 0.02 | 0.1 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 30 | 200 | 1 | 1.25 | 200 | 2237 | 0.14 | 0.02 | 0.112 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 31 | 200 | 1 | 1.25 | 200 | 2666 | 0.14 | 0.02 | 0.107 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 32 | 200 | 1 | 1.25 | 200 | 2510 | 0.14 | 0.02 | 0.108 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 33 | 200 | 1 | 1.25 | 200 | 4866 | 0.14 | 0.02 | 0.1 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 34 | 200 | 1 | 1.25 | 200 | 4693 | 0.14 | 0.02 | 0.1 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 35 | 200 | 1 | 1.25 | 200 | 3473 | 0.14 | 0.02 | 0.1 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 36 | 200 | 1 | 1.25 | 200 | 5280 | 0.14 | 0.02 | 0.112 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 37 | 200 | 1 | 1.25 | 200 | 3099 | 0.14 | 0.02 | 0.107 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |
| 38 | 200 | 1 | 1.25 | 200 | 2689 | 0.14 | 0.02 | 0.108 | 20 | 0.001 | 0.3 | 0.5 | 2.5 | 0.01 | 0.1 | 1.1 | 0.01 |

Figure 6.14: Input data for 30 bus

| Relay | PSM | TDS | Ot | DT | OF1 | 0F2 | OF3 | 0F4 | OF5 | POF |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.14 | 0.05 | 0.131207 | 0 | 0.05 | 0.06 | 0.18 | 0.07 | 0.05 | 0.03 |
| 2 | 1.09 | 0.17 | 0.431486 | 0.30028 | 0.19 | 0.2 | 0.28 | 0.29 | 0.14 | 0.11 |
| 3 | 1.14 | 0.21 | 0.731709 | 0.300222 | 0.29 | 0.21 | 0.43 | 0.49 | 0.22 | 0.17 |
| 4 | 1 | 0.36 | 1.033121 | 0.301412 | 0.46 | 0.48 | 0.51 | 0.41 | 0.36 | 0.26 |
| 5 | 1.09 | 0.43 | 1.333115 | 0.299994 | 0.59 | 0.34 | 0.52 | 0.51 | 0.45 | 0.39 |
| 6 | 1.1 | 0.33 | 1.633048 | 0.299933 | 0.58 | 0.63 | 0.62 | 0.48 | 0.38 | 0.28 |
| 7 | 1.06 | 0.67 | 1.932464 | 0.299417 | 0.86 | 0.76 | 0.77 | 0.68 | 0.37 | 0.26 |
| 8 | 1.03 | 0.78 | 2.232646 | 0.300181 | 0.99 | 0.89 | 0.85 | 0.79 | 0.63 | 0.47 |
| 9 | 1.06 | 0.97 | 2.533601 | 0.300955 | 0.98 | 0.88 | 0.8 | 0.98 | 0.61 | 0.58 |
| 10 | 1.09 | 1.09 | 2.858782 | 0.325181 | 0.27 | 0.34 | 0.47 | 0.39 | 0.28 | 0.21 |
| 11 | 1.02 | 0.89 | 3.193493 | 0.334711 | 1.03 | 0.93 | 1.02 | 1.01 | 0.84 | 0.66 |
| 12 | 1.1 | 1.13 | 3.494119 | 0.300626 | 1.05 | 0.95 | 1.05 | 1.03 | 1.01 | 0.86 |
| 13 | 1.02 | 1.1 | 3.794903 | 0.300784 | 1.1 | 0.99 | 0.94 | 0.81 | 0.78 | 0.58 |
| 14 | 1.03 | 1.03 | 4.095065 | 0.300161 | 0.78 | 0.61 | 0.76 | 0.74 | 0.63 | 0.57 |
| 15 | 1.01 | 1.06 | 4.396041 | 0.300977 | 0.98 | 0.89 | 0.91 | 0.99 | 0.97 | 0.81 |
| 16 | 1.09 | 1.67 | 4.696535 | 0.300494 | 1.02 | 0.96 | 1.01 | 1.01 | 0.92 | 0.77 |
| 17 | 1.12 | 1.9 | 4.99605 | 0.299514 | 1.01 | 0.91 | 1.02 | 0.98 | 0.99 | 0.84 |
| 18 | 1.13 | 1.65 | 5.326945 | 0.330896 | 0.98 | 0.88 | 0.89 | 0.99 | 0.98 | 0.66 |
| 19 | 1.12 | 1.88 | 5.655243 | 0.328298 | 0.82 | 0.92 | 0.98 | 0.87 | 0.77 | 0.68 |
| 20 | 1.05 | 1.64 | 5.954614 | 0.299371 | 1.04 | 1.01 | 1.03 | 1.02 | 1.02 | 0.74 |

Figure 6.15: Output data for 30 bus

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 21 | 1.01 | 2.17 | 6.254176 | 0.299562 | 0.73 | 0.79 | 0.84 | 0.77 | 0.65 | 0.48 |
| 22 | 1.07 | 2 | 6.553941 | 0.299764 | 0.72 | 0.82 | 0.87 | 0.68 | 0.69 | 0.43 |
| 23 | 1.11 | 1.89 | 6.853226 | 0.299285 | 0.61 | 0.71 | 0.99 | 0.6 | 0.59 | 0.45 |
| 24 | 1.1 | 1.65 | 7.152759 | 0.299533 | 0.87 | 0.7 | 0.86 | 0.68 | 0.75 | 0.6 |
| 25 | 1.11 | 2.12 | 7.484875 | 0.332117 | 0.54 | 0.74 | 0.99 | 0.73 | 0.52 | 0.39 |
| 26 | 1.03 | 1.19 | 7.848736 | 0.36386 | 0.87 | 0.71 | 0.82 | 0.61 | 0.78 | 0.45 |
| 27 | 1.05 | 1.6 | 8.15209 | 0.303354 | 0.76 | 0.81 | 1.02 | 0.99 | 0.68 | 0.52 |
| 28 | 1.07 | 1.9 | 8.454129 | 0.302039 | 0.56 | 0.66 | 1.05 | 0.89 | 0.53 | 0.37 |
| 29 | 1.04 | 2.23 | 8.755281 | 0.301151 | 1.1 | 1.08 | 1.06 | 0.92 | 0.98 | 0.71 |
| 30 | 1.04 | 2.42 | 9.055335 | 0.300055 | 0.95 | 0.97 | 1.01 | 0.85 | 0.79 | 0.63 |
| 31 | 1.11 | 2.27 | 9.392468 | 0.337132 | 1.02 | 1.04 | 1.03 | 1.01 | 1.01 | 0.86 |
| 32 | 1.01 | 3.62 | 9.693 | 0.300532 | 1.06 | 1.05 | 1.03 | 1.01 | 1.02 | 0.88 |
| 33 | 1.08 | 3.47 | 9.993482 | 0.300482 | 1.06 | 1.08 | 1.06 | 1.03 | 1.04 | 0.9 |
| 34 | 1.01 | 3.19 | 10.29391 | 0.300428 | 1.04 | 1.09 | 1.07 | 1.01 | 1.06 | 0.91 |
| 35 | 1.06 | 3.88 | 10.6195 | 0.32559 | 1.03 | 1.09 | 1.08 | 1.08 | 1.03 | 1.01 |
| 36 | 1.06 | 3.99 | 10.92057 | 0.301068 | 1.01 | 1.08 | 1.08 | 1.07 | 1.07 | 1.02 |
| 37 | 1.07 | 3.2 | 11.22164 | 0.301073 | 1.09 | 1.09 | 1.09 | 1.09 | 1.09 | 1.05 |
| 38 | 1.04 | 3.01 | 11.52273 | 0.301084 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.08 |
| | | | | | 29.08 | 29.94 | 33.24 | 30.66 | 27.78 | 22.67 |

Figure 6.16: Output data for 30 bus

# Chapter 7

# Conclusion and Future Work

**The problem of relay coordination for directional over-current relays has been solved by the help of two techniques namely:**

1. **Improved mathematical formulation**

2. **Particle swarm optimization**

**In (1),five different objective functions has been developed and the performance of each objective function is determined and each objective function is having weights assigned to each objective function and in order to improve the performance of previously improved objective functions, a new proposed objective function i.e. POF has been developed. Thus the results of (1) has been compared with respect the relay settings and discrimination time within prescribed limits and the results have been formulated by the help of matlab optimization tool box.**

**In (2) the optimization technique for directional over-current relays has been carried out with the help of Particle Swarm Optimization (PSO) . In this all the objective functions are compared with respect to the relay settings and all other parameters.**

**Thus by using the improved mathematical formulation and soft computing technique , it is quite evident from the results obtained in Chapter 6 that amongst all the objective the proposed objective function i.e. POF gives the optimum relay settings along with maintaining the coordination constraints by having proper value of coordination time interval i.e. CTI . Hence in**

**order to perform relay coordination the proposed objective function should be considered because of the above stated reasons.**

**The future scope is that the coordination of relays can be improved for the aforesaid objective functions by enhancing the performance of the objective functions by applying suitable relay characteristics to each objective function in order to get more optimum results for the relay settings and to maintain the discrimination time and coordination time interval within a prescribed limits.**

# Chapter 8

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