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OPTIMIZED DUAL-SETTING DIRECTIONAL OVERCURRENT RELAY COORDINATION IN MESHED DISTRIBUTION SYSTEM

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Abstract

In power system network, a fast and efficient protection system is necessary so that system remains stable and continuously reliable. With improvement of technology, most of the networks are ring and meshed type distribution/ sub-transmission levels instead of radial system. The integration of distributed sources at different locations is also a requirement to fulfil the increased load requirements. Due to evolutions in power system topology and network, bidirectional power flow is the standard case. The conventional protection schemes with directional overcurrent relay have large total operating time. So, dual-setting directional over-current relays are proposed for protecting meshed distribution systems with distributed generations. In dual-setting, primary and back-up both the functionality is offered by a single unit of dual-settings. These settings in two directions are programmed in dual-setting directional overcurrent relay, which work independently. Thus, the total operating time of relays reduces, resulting into improved performance. This article compares between conventional and proposed dual-setting overcurrent relay schemes in IEEE 9-Bus distribution system. A Genetic Algorithm is utilized to minimize the objective function, which is the total operating time of relays. The total time of operation in both schemes are compared.

Keywords: Distribution system, Dual-Setting OCR, Relay Coordination, Genetic Algorithm, Distributed Generation.

1. INTRODUCTION

The entire power system consists of generation, transmission, sub-transmission, and distribution [1], [17]. In India, generating stations are situated at many places of the country that are interconnected by the transmission line networks and directly connected to the distribution stations. The distribution system is the medium between the distribution sub-station and the customer.

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A protective relay plays an essential role in the efficient operation of power system network [2], [18]. For ensuring the reliable operation of power system, isolating the faulted sections of the system, fast, secure, economical, and selective process, and coordination of relay is of major concern. Directional over-current relays (DOCRs) are most favourable technical and economical equipment which can protect the interconnected distribution and sub-transmission system [3]-[6]. Nowadays, the conventional radial network system is transformed into interconnected ring, meshed system due to increasing penetration of different types of other distributed generation sources. A distribution system with addition of distributed generation (DGs) has major influence on the protection systems. The kind of impact on the existing protection scheme depends on the type of the distribution system (meshed or radial) as well as nature of DG [7], [19].

Equipments associated with DG protection system are based on synchronous machine type DG, and DG-linked through inverter [2]. DGs based on inverter create less fault current levels as compared to synchronous-based DG (SBDG), and thus, it has more effect on the conventional protection Systems. DGs based on inverter (IBDG) have fault current 1 to 2 pu recloses, over-current relay (OCR) and fuses are important element for protection of radial distribution system. So IBDG has very less impacts on existing protection coordination. After fault isolation, DGs can supply power in a meshed distribution system (MDS) from other feeders [8]-[12], [20].

To improve DG fault ride through protective devices should provide fast and secure fault isolation. Because fault results voltage dip in system and low voltage period has to be shortened. The low voltage period remains short. DOCRs become a suitable option for meshed system due to flow of fault current in bi-directional. Relays are coordinated in such that they can optimally reduce the total OT of all relays [13], [21]. New optimal relay settings are taken into consideration to overcome the negative impacts of bidirectional power flow on existing protection scheme.

The main objectives of this paper are:

1) Study of numerous types of relays and coordination of relays in the sub-transmission/ distribution system
2) Learning the basic features of E–TAP and MATLAB® software and to simulate the system on E-TAP.
3) Analysis of short circuits (SC) in a network.
4) Modelling of IEEE 9-bus test system distribution network and protection schemes in E-TAP.
5) To analyze the coordination of OCR with various possible faults locations.
6) To perform dual setting operations in overcurrent relays to minimize the total OT of the relay.

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A. Different distribution networks in power system

Radial system: In radial system, the power flow is unidirectional. This system is used only when the substation is near to load center and the voltage level is low. This is the simplest and cheapest configuration. The major drawback is that if the particular feeder gets faulted then the all consumers will be affected irrespective of the feeder [14]. This system can only be used for short distances as the voltage fluctuation will be very high for long distance [16].

Ring system: In this test system, the feeder makes a loop starting from the substation connecting the load centers and then terminating at another substation. This system is more reliable as every feeder is connected to two substations; even in the case of a fault in one feeder, the supply to the consumers remains intact. Voltage fluctuation problem is also very less as compared to radial system.

Interconnected system: Any feeder ring system, which is energized by equal to two sub-stations or more than two substations, is called an interconnected system. The main advantage of this system is that it is highly reliable, and in the case of peak load hour at one substation, another substation can feed the load [15], [20]-[26]. This will help in increasing the system efficiency and reserve power capability.

Faults: Electrical faults are the deviation of voltages and currents from the normal values. The system must be protected from such deviation of currents and voltages. This is done by isolating the faulted part from rest of the system with the help of circuit breakers and relays.

There are majorly two types of faults occurring in power system:

(a) Symmetrical faults: These are the faults which involve all three phases and the ground. This leads to be the severe fault current which needs to be interrupted. These faults involve are all the three-phase to earth (LLLG), and all the three-phase short circuit. (LLL).

(b) Unsymmetrical faults: Faults involving one line to ground or two lines to ground or the faults between the lines are called as unsymmetrical faults [14], [26]. These are the most common types of faults and involve; single line to ground fault, line to line fault, and double line to ground fault.

There are various reasons because of which faults occur:

Weather conditions: It includes storms, heavy rain, lightning, snow fall, etc. These natural conditions interrupt the power flow and causes failure.

Equipment Failures: There are various types of electrical equipment, such as transformers, generators, switches, motors, etc., which due to aging effect or insulation failure, cause a large amount of current to flow and damage the system.

Human errors: Lack of maintenance and wrong switching or switching when live are the main reasons for failure of system.

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B. Over-current Protection system

When the current in a protection system surpasses a predetermined value, then overcurrent relay comes into play. When the system passes through abnormal conditions such as SC, overloading of system, corona discharge, and other faults, OC relay is utilised for protection of the electrical power system component from excessive current such as transformers, generators, transmission line, and motor. In transmission system fault, OC relay acts as a backup relay [17]-[23]. It is the primary protection in distribution network, which protect mostly the feeders. More than one OCR is required to protect the various sections of the feeder [11].

(i). Overcurrent Relay

If current in a power system exceed a particular defined value, then overcurrent relay comes into play. When system has passes through abnormal condition such as corona occurrence, system overload, different types of faults and short circuit. Function of OC relay is to prevent power system component from excessive current such as transformer, transmission line, alternators and motors. To protect the feeder OC relay act as primary protection and in case of transmission line fault it acts as a backup protection. For protection of several parts of feeder, we need more overcurrent relay.

To protect distribution feeder, over-current (OC) protection is used. The relays effect should be in entire protected zone, which is required to make sure the back-up protection. The utilization of relays with same operating characteristic (OP-CH) in series with each other, whenever possible. To ensure the relay farthest from the source have current settings less than or equal to the relays behind it. i.e., The primary current needed to activate the relay in opposite is always similar to or less than the necessary to operate the primary current to operate the relay behind it.

At present, seven types of overcurrent relay are verified by different protection engineers, on the basis of relay characteristics types of OCR. They are instantaneous OCR, definite-time OCR, inverse-time OCR, inverse-definite minimum-time (IDMT) relay, very-inverse (VI) relay, extremely-inverse (EI) relay, and DOCR.

(ii). Directional overcurrent relays

Directional overcurrent relays are that type of relays which sense the current of a particular direction. In distribution and transmission system these types of relays are commonly used as they are economically suitable. This is the only protection which is provided in power lines.

(iii). Time Multiplier Setting (TMS)/ Plug Setting Multiplier (PSM)

Pick-up setting for every relay is obtained by multiplying the full load current by a constant that is greater than one. Here, we have used the value of constant as 1.25. The value of plug setting multiplier is obtained by calculating the value of fault current. PSM is the ratio of fault current (If) to pick-up current (Ip). The value of PSM determines the number of times relay current is higher than current setting. We can obtain the OT from the time-current characteristic of the relays. [5], [21]-[24].

The minimum value of the operating current of an OCR is called the relay current setting. This setting should be taken such that the relay will not operate for a current equal to or less than the minimum fault current. The relay near the source must have a higher value of the current setting than relay far from the source. The relays with current settings higher than any current should flow through the relays under a normal state, i.e., 110% of the rated current. Microprocessor-based and electronic relays have a current setting step change of 5% [6].

To deploy the relay in the power system, it is necessary to modify the time scale of the time-current characteristic. The optimal value of TMS is chosen to get the lowest OT. It is also to be kept in mind that the operation of primary and backup relays have proper coordination time interval (CTI) between them. So, the time multiplier setting should be chosen such that there is a proper time interval gap.

The TMS of the relay plays a crucial role in the power system

(a) It determines the circuit breaker opening time.

(b) The TMS for the primary relay (PR) should be less than that of the back-up relay.

(iv). Operating time (OT) of overcurrent relay

The OT of OCRs mainly depends on two parameters: TMS, and the other is pick-up current value of relay. The coordination between different relays in the system and reducing the total OT, both the things can be achieved by selecting the optimum pick-up setting and time multiplier/ dial setting (TMS/ TDS) of overcurrent relays [1].

$$T_{op} = \frac{A\,(\mathrm{TDS})}{(I_{relay} / (PS \times CT_{sec\,rated}))^{B} - 1} \tag{1}$$

Table 1: Standard table for characteristics of relays

IEC standard table for characteristics of relays		
Type of characteristics	**A**	**B**
Normal-inverse (IDMT)	0.14	0.02
Very-inverse (VI)	13.5	1
Extremely-inverse (EI)	80	2
Long-time-inverse	120	1
Short time-inverse	0.05	0.04
Inverse (I)	9.4	0.7

C. Coordination in protecting devices

For each and every relay, a primary zone is defined and that relay must have to operate if some fault occurred in that zone. If, in any case primary protection won't be able to clear the fault, then the relay which is acting as back-up should operate and send signal to the circuit breaker for clearing the fault. Maloperation occur if primary and back-up protections are not coordinated in well manner. So, coordination of overcurrent relay is always a major concern in protection of power system [15].

As in a power system numbers of protecting devices are large in numbers. So, for optimum coordination between different relays, the function which is defined for total OT formulated as a linear function. Linear function because pick-up current value is taken as constant value which is 1.25 times of full load current and, TMS of each relay is taken as the variable. Different optimization algorithms can be used for solving the objective function (OF). So, coordination between relays can be maintained and OT can also be reduced by selecting the optimum TMS value [12]. By selecting optimum TMS and I_p value, optimum coordination of relays is achieved, and also the OT of relay is minimized. But still, fast protection scheme is needed so that total OT of relay can be minimized significantly. Reliability of system increases with fast operation.

D. Load flow analysis

Load flow analysis is done under steady-state conditions to determine the amount of voltages, currents, and power in the power system network on the different buses and on lines. Losses in line, voltage profile, and loading of line and transformer can also be analysed by load flow. Pick-up value for the relays has also been obtained from load flow. It also helps for power factor correction by determining the size and suitable location of capacitors. [13], [17].

Features of the load flow analysis are as follows:

1. It solves the nonlinear power equations.
2. We obtained the magnitude and phase angle of voltages at each bus.
3. It helps to plan for any foreseen or hypothetical situation in the system.

The information from load flow analysis is helpful for the future planning such as increased load demand.

E. Short Circuit Analysis

A short circuit occurs when a huge amount of energy is released in the form of heat. Due to very low impedance leads to the flow of large amount of current in the system which may cause failure of power supply. Basically, we design a power system to protect it from any short circuit but sometimes the fault occurs and system gets disturbed. Various power system quantities such as voltage, configuration, compensating devices, relays, and breakers settings give us the idea about the fault level.

Short circuit analysis is required to identify the rating of various switching devices. If the fault current is very much higher such that it exceeds the equipment rating, then the equipment will be burnt and this will result in huge economical loss. It helps to increase the reliability of the system and also tells us about the problems in power system and their applicable solutions. Short circuit analysis can be done on any type of system whether it is single phase or three phase. By studying the short circuit analysis, we can

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highlight the overloaded equipment's such as transformers and breakers. Hence, it is advisable to gather the information about the fault level before installing any electrical equipment.

2. OPTIMIZATION

Optimization is defined as the technique of evaluating the best possible solution of real problems which is defined mathematically. It can also be stated as the processes which continuously find out the solution for defined OF and simultaneously satisfy the given constraints. “Search for optimality" is the basic principle of algorithm of optimization. By using optimization technique, either maximization or minimization of the OF can be performed. Optimization adjusts the characteristics variables or inputs and mathematical expression of get optimized using those variables.

The existing optimization algorithms are as follows; ant colony optimization (ACO), particle swarm optimization (PSO), artificial colony optimization (ACO), and Genetic Algorithms (GA) etc. In this article we have discussed only about Genetic Algorithm

A. Genetic Algorithm (GA)

This algorithm is based on evolution theory of Charles Darwin who explained the principle of natural selection "Survival of Fittest". GA follows the natural selection process. John Holland invented the GAs in 1975. GA is a mathematical procedure which generates a set of population of mathematical objects each with an associated fitness value, into a new generation or new set of population of mathematical object [11].

The characteristics of operation of genetic algorithms are:

1) Instead of single point, it works with population of points and capture optimum solution easily.
2) GA can handle discontinuous functions, nonlinear functions and multimodal functions with great ease and works with information of fitness function.
3) GA operator does not work deterministically; it works with probabilistic approach.

B. Fitness Function

Defining an objective function (OF) which can modelled the problem accurately while incorporating all required constraints is the main part of optimization process [24]. Fitness function of genetic algorithm corresponds to OF of an optimization technique. Fitness function is the basis for selection and generation of population and helps in improvements in forthcoming generations. Depending on the problem to be solved fitness function is expressed mathematically for either minimizing or maximizing the OF [11].

Basic steps in Genetic Algorithm (GA) are:

1) [Start] According to the definition of problem, defining the fitness function f(x).

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2) [Initialize] generation of random population which is the potential solution of fitness function.
3) [Fitness] evolution of objective function for each set of solution.
4) [New population] new population of solution generated.
5) [Convergence check] If maximum number of generation convergences, then stop.
6) [Loop] Go to step 3.

C. Protection coordination of directional over current relay in 9-bus system using dual setting

A protective relay plays an essential role in the efficient operation of the power network. For ensuring the reliable operation of power system, isolating the faulted sections of system, fast, secure, economical and selective operation, and co-ordination of relay is of major concern. DOCRs are most favourable technical and economical equipment which can protect the interconnected distribution and sub transmission system. Now a days conventional radial network systems are transformed into interconnected ring mesh system due to increasing penetration of different type of other distributed generation sources.

Distribution systems with the addition of DGs have major impact on the protection system in MDS. The kind of impact on the existing protection arrangement depends on the nature of the distribution system (radial or meshed) as well as nature of DG. Equipments associated with DG protections system is based on synchronous machine type DG and DG linked through inverter. DGs based on inverter create less fault current levels as compared to synchronous-based DG (SBDG) and furthermore, it has more effect on the conventional protection Systems [3], [18]. DGs based on inverter have faulted current 1 to 2 pu. Recloser, over-current relay and fuses are important element for protection of radial distribution system. So IBDGs have very less impacts on existing protection coordination. After fault isolation DG can supply power in a meshed distribution system from other feeders. To improve DG fault ride through protective devices should provide fast and secure fault isolation. Because fault results voltage dip in system and low voltage period has to be shortened than the low voltage period remains short. DOCRs become a suitable option for MDS due to the flow of fault current in bi-directional. Relays are coordinated so that they can optimally reduce the total OT of all relays. New optimal relay settings are taken into consideration to overcome the negative impacts of bidirectional power flow on the existing protection scheme.

3. DUAL SETTING RELAY AND PROTECTION COORDINATION SCHEME

In case of dual setting primary and back-up both the functionality is offered by single unit of dual-settings. Settings in two directions; one in forward and second in reverse that is programmed in dual setting directional overcurrent relay. Both the directions work independently to each other. Thus, the total OT of relay reduces, and results improved performance [3].

In first attempt, these types of relays were introduced in radial distribution network. But in DG mixed networks, due to having bidirectional current flow, operation time is long, and coordination is also complex. So, dual setting overcurrent relays are deployed on mesh networks too. Dual setting overcurrent relay and DOCRs are also used in micro grid protection for operation in both islanded and grid connected mode. The relay TDS and the pickup current setting state the profile of any relay characteristic. The overall OT of relay with the constraints is reduced, using concerned protection scheme with relay settings. The relays will operate as a backup for other relays in the system using a protection coordination scheme.

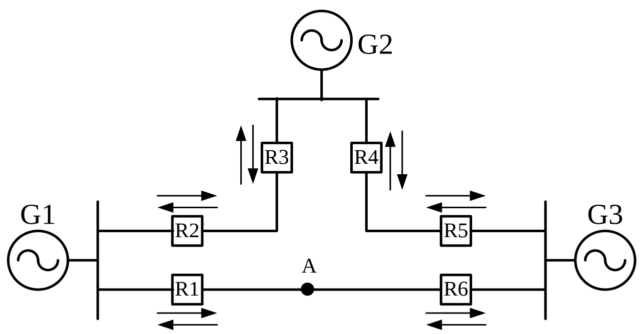

Figure 1. Protection with Dual-Setting Directional OC Relays

Figure 1 shows six dual-setting DOCRs in a mesh system with the optimal relay operating characteristics. Each relay has operated in the two directions of fault current flow, denoted by two arrows one is in forward, and the other is backward. Dual-setting DOCR protection coordination scheme is shown in Table 2. For a fault at point A shown in Figure 1, R3 acts as the back-up relay for PR R1 while R4 acts as back-up relay for PR R2. In that condition, back-up relay R3 uses the settings associated with the reverse direction (TDSrv3 and Iprv3) similarly PR R1 uses the settings related with the forward direction (TDSfw1 and IPfw1) [2], [5].

Table 2. PR and BR pairs based on conventional and proposed coordination arrangements for a 3-bus system

PR	BR (with Traditional)	BR (with DSDOCR)
R1	R3, R5	R2, R6
R2	R6, R4	R1, R3
R3	R5, R1	R2, R4
R4	R2, R6	R3, R5
R5	R1, R3	R4, R6
R6	R4, R2	R1, R5

R1 acts as the primary relay and R5 acts as back up relay if fault occurs at point A. Similarly, at the same point fault location R2 act as the PR responsible for isolating the

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fault and R6 acts as backup if primary relay fails to operate. A table has been shown for various relay as a primary and back up relays. In the time-current characteristic of the dual setting DOCRs, if fault current flows in forward direction, then relay act as primary protection and if fault current flows in the reverse direction, then relay act as BR. The relay for primary protection has two settings; TDS_{Fm}, Ip_{Fm} and similarly for Backup Protection (reverse) as TDS_{Rm}, Ip_{Rm}.

4. FORMULATION OF PROTECTION COORDINATION PROBLEM WITH DUAL SETTING DOCR

For a DOCR, Short circuit current of a relay is inversely proportional to OT, i.e., represented in (2).

$$T_{Omn} = \frac{TDS_m \times A}{\left(I_{fcmn} / I_{pkm} \right)^B - 1} \quad (2)$$

Where, ‘n’ as relay identifier and ‘m’ as fault location identifier. Constant parameters A and B depend on the type of OCR. For normal inverse characteristics value of A and B are 0.14 and 0.02, respectively [5]. The term I_{fcmn} is the fault current value and I_{pkm} is the pick-up value of current. Basic objective is to minimize the total time of operation of all primary and backup relays while aware of the constraints required for optimal protection coordination. Now the objective function (OF) is denoted as T_{OP}, as given below in (3).

$$T_{OP} = \sum_{m=1}^{K} T_{OFmn} + \sum_{n=1}^{K} T_{ORln}; \;\; \forall (\mathrm{m}, \mathrm{l}) \in \mu \quad (3)$$

Where µ shows the backup/primary relays, K is the total number of relays, and m is the number of fault locations in system. The variables t_{ORln} and t_{OFmn} represents the operation time of mth and nth relay for a fault at point ‘1’ during reverse (backup) and forward (primary) operation respectively.

$$T_{ORln} = \frac{TDS_{Rl} \times A}{\left(I_{fcRln} / I_{pkRl} \right)^B - 1} \quad (4)$$

$$T_{OFmn} = \frac{TDS_{Fm} \times A}{\left(I_{fcFmn} / I_{pkFm} \right)^B - 1} \quad (5)$$

Where TDS_{Rl} and TDS_{Fm} are TDS setting of the mth relay and nth relay TDS setting in reverse and forward directions, respectively. And the variables I_{fcRin} and I_{pkFm} denote mth relay and nth pick-up setting for both reverse and forward operation [2]. Fault at a point m, fault current passing through nth relay in the forward direction is marked as I_{fcFmn}. Similarly, fault point m, fault current passing through mth relay in the reverse direction is

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denoted as I_{fcRln}. To solve protection coordination problem following coordination constraints must be satisfied as (6):

$$T_{ORln} - T_{OFmn} \geq CTI; \ \forall \ m, l, n \tag{6}$$

Where CTI is the minimum operation time between the backup and the primary relay. Values of CTI range from 0.2s to 0.5s. Relay settings have upper and lower limits on the relay settings and shown below in (7) and (8).

$$I_{pk\_\min} \leq I_{pkFm}, \ I_{pkRl} \leq \mathrm{I}_{pk\_max} \tag{7}$$

$$TDS_{m\_\min} \leq TDS_{Rl}, \ TDS_{Fm} \leq TDS_{n\_max} \tag{8}$$

Where, I_{pk_max} and I_{pk_min} are the upper and lower bounds of m^{th} relay pickup current setting, respectively. The parameters TDS_{m_max} and TDS_{m_min} is the upper and lower limit of m^{th} relay, respectively.

1. Ip> 1.25 times of the maximum value of load current through any relay Ri
2. Ip< 0.67 times of the minimum value of fault current through any relay Ri [5].

5. SIMULATIONS AND RESULT

A. System Case Study

System information: Three distribution substation first 177MVA, 0.85 pf lag 18KV/230 KV; second 117 MVA, 0.85pf 13.8KV/230 KV; third 177 MVA, 0.85pf 16.5KV/230 KV all having power factor 0.85 lagging, 3 loads of 40MW,50MW,60MW unity power factor. All the impedance values of line and transformers are typical values.

Selection of System Parameters: All the parameters of CBs, CTs, and Buses are designed to bear continuously and without any damage for maximum faults and in normal currents, while carrying in numerous topologies. The SC level depends on MVA SC of source, as mentioned in the introduction section.

Selection of CTs: The saturation of CT is avoided. Due to saturation of CTs, the secondary relay current will be less than it should be, and the relay performs more sluggishly. In cases of severe saturation, the secondary output current might approach nearer to zero in one or more phases. The above-mentioned problem is avoided by keeping the secondary current of CT within 3-4 A for 5A secondary current of CT (IEEE Std 242, 2001). Based on system condition, CTs are selected and models of the CTs are given. CTs turn ratio is selected as 500/1, 100/1, and 800/1 according to the fault limit current (FLC).

CBs Selection: MVCB frame size is designed such that the first available standard rate which is higher than 125% of max FLA seen by CB is selected, and the interrupting capacity is selected to be the first available standard rate higher than max fault seen by CB.

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Ip and TMS: Pick-up current value is taken as constant which is equal to 1.25 times of the full load current. TDS value for forward and reverse direction have been determined through Genetic Algorithm by minimizing the OF while satisfying different constraints.

B. Modelling and result:

Modelling of the system is describing the system parameters and locations that are used in the proposed work.

(i). Distribution system model: 9 Bus model

Figure 2 depicts all the buses, transmission lines, loads, and DGs, i.e., IEEE 9-bus System. Fault locations F1, F2, F3, F4, F5, and F6 are detected through different dual setting backup and primary relay. Primary and back-up relay combination in conventional and dual setting compression with relying upon number and fault locations have to be done. Table 3 shows the coordination of dual setting DOCR and conventional relay with the primary relay through different fault locations.

Figure 2. IEEE 9 Bus System Model

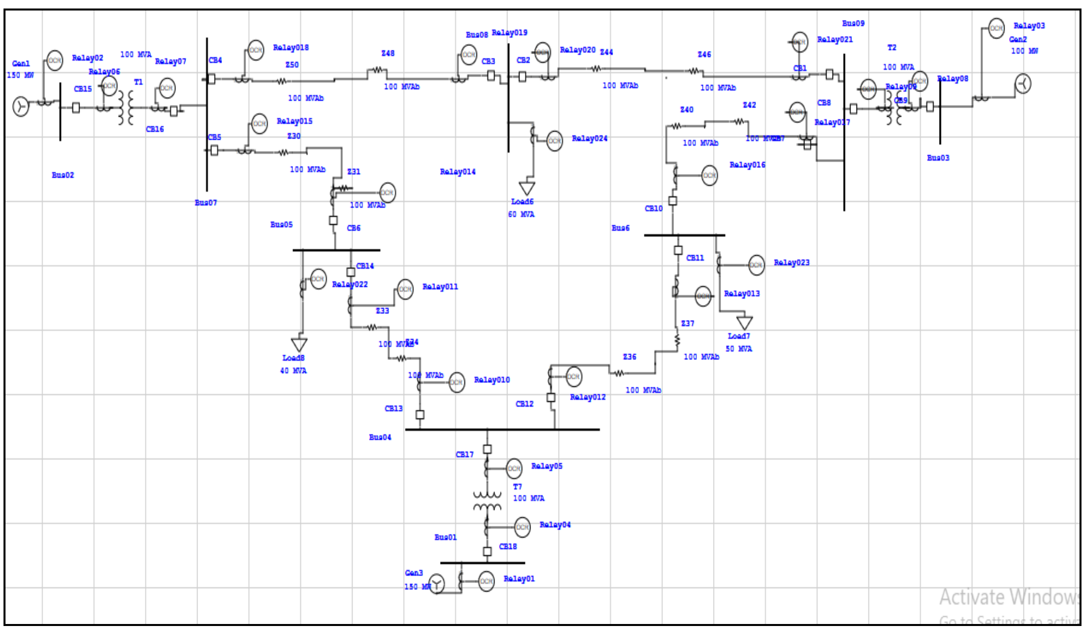

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Table 3. Primary and backup relay combination in conventional and dual setting case

Fault location	Primary relay (PR)	Back-up relay (BR)	
		Conventional system	Dual system
F1	R18	R6, R14	R7, R15
	R19	R21	R20
F2	R20	R18	R19
	R21	R16, R8	R17, R9
F3	R14	R10	R11
	R15	R6, R19	R7, R18
F4	R10	R4, R13	R5, R12
	R11	R15	R14
F5	R16	R4, R13	R5, R12
	R17	R8, R20	R9, R21
F6	R12	R4, R11	R5, R10
	R13	R7	R16

(ii). Load flow study of the system:

Figure 3 depicts the load flow study for the 9-bus MDS with all parameters of the transformer, transmission line, DGs, and bus values shown in the related place in the proposed MDS. This load flow analysis of the 9-bus system plays an important role in the protection coordination of the proposed methodology. Table 4 shows the load flow results, i.e., determined in the load flow analysis of the proposed system. The determined values are MW, MVAR, and current flow through the system.

Table 4. Load flow result on E-Tap

ID	Type	MW Flow	MVAR Flow	Amp Flow
T1	Transformer 2W	48.944	6.762	1585
T2	Transformer 2W	52.216	7.553	2207
T7	Transformer 2W	45.245	6.362	1599
Z30	Impedance	19.091	1.513	48.41
Z31	Impedance	19.066	0.762	48.41
Z33	Impedance	19.977	0.813	50.72
Z34	Impedance	20.004	1.638	50.72
Z36	Impedance	25.18	2.637	63.98
Z37	Impedance	25.136	1.326	63.98
Z40	Impedance	23.408	1.124	59.59
Z42	Impedance	23.446	2.262	59.59
Z44	Impedance	28.649	1.229	72.85
Z46	Impedance	28.689	2.508	72.85
Z48	Impedance	29.738	1.43	75.62
Z50	Impedance	29.781	2.809	75.62

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Figure 3. Load Flow Analysis of IEEE 9 Bus System

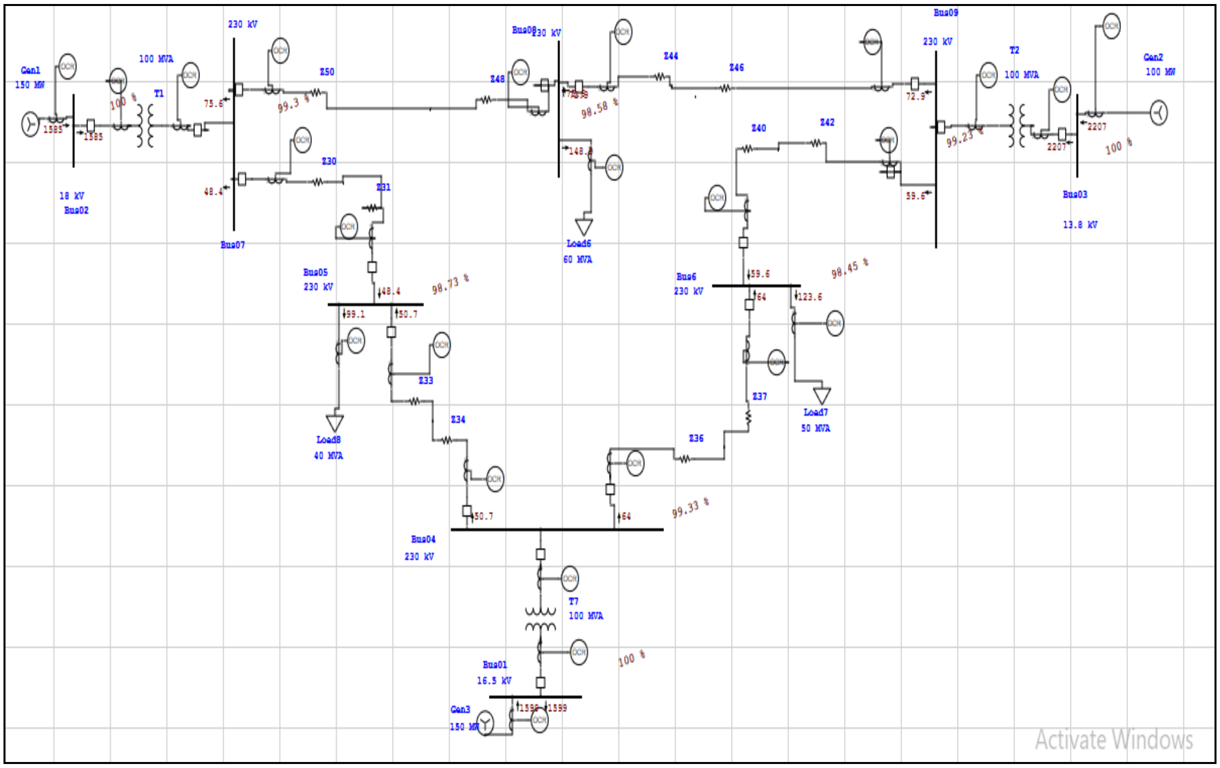

Table 5. Pick-up current value and CT ratio value for each relay

Relay	CTR	Ip=(1.25*FLC)/CTR
R4	500/1	3.9975
R5	100/1	1.43375
R6	500/1	3.9625
R7	100/1	1.55
R8	800/1	3.4484
R9	100/1	1.65625
R10	100/1	0.63375
R11	100/1	0.63375
R12	100/1	0.8
R13	100/1	0.8
R14	100/1	0.605
R15	100/1	0.605
R16	100/1	0.745

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R17	100/1	0.745
R18	100/1	0.945
R19	100/1	0.945
R20	100/1	0.91125
R21	100/1	0.91125

Table 5 depicts the relay Current transformer ratio (CTR) and pick-up current Ip for a particular relay number, i.e., coordinated for faulty section. Table 6 shows the short circuit analysis on E-Tap software with fault location, bus location, primary and backup, or forward and backward relay pairs for the related fault current in amperes.

(iii). Short circuit analysis:

Short circuit analysis has been done on E-Tap. The following observations are shown in Table 6:

Table 6. Short circuit result on E-Tap

Fault Location	Bus Location	Fault current (A) through relays		Fault Current (A)
		Primary relay (PR)	Backup relay (BR)	
F1	Bus07 - Bus08	R18=767	R6=8271 R14=119	1150
		R19=383	R21=383	
F2	Bus08 - Bus09	R20=391	R18=391	1129
		R21=738	R16=125 R8=10221	
F3	Bus05 - Bus07	R14=310	R10=310	987
		R15=677	R6=7022 R19=128	
F4	Bus04 - Bus05	R10=643	R4=7446 R13=108	962
		R11=319	R15=319	
F5	Bus06 - Bus09	R16=311	R12=311	969
		R17=658	R8=8695 R20=136	
F6	Bus04 - Bus06	R12=643	R4=7438 R11=110	957
		R13=314	R17=314	

Short circuit analysis of fault locations F1 and F2 are shown below in Figure 4 and Figure 5, respectively. Fault locations of F1 and F2 are depicted in Figure 4 and Figure 5 with red colour in 9-bus MDS. Fault F1 has been created between bus-07 and bus-08, while the fault F2 has been created between bus-08 and bus-09, respectively.

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(a) Fault location F1:

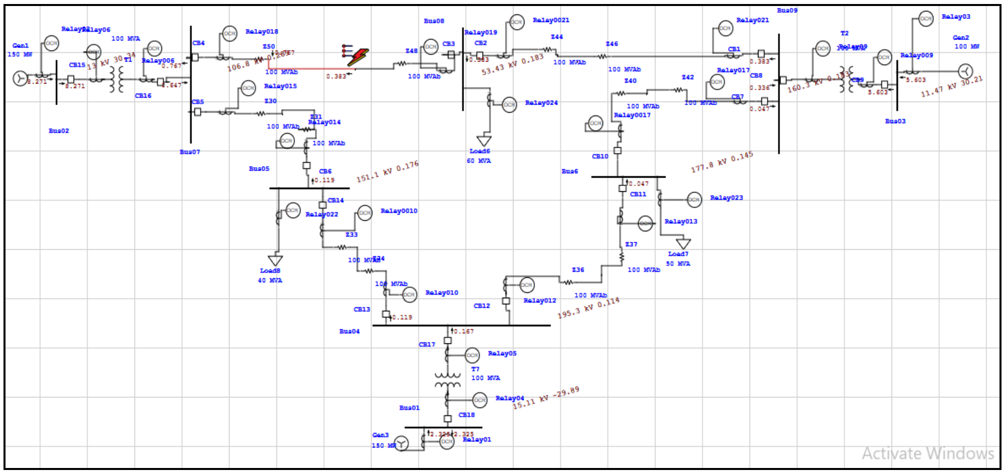

Figure 4. Short Circuit Analysis on E-Tap for F1

(b) Fault location 2:

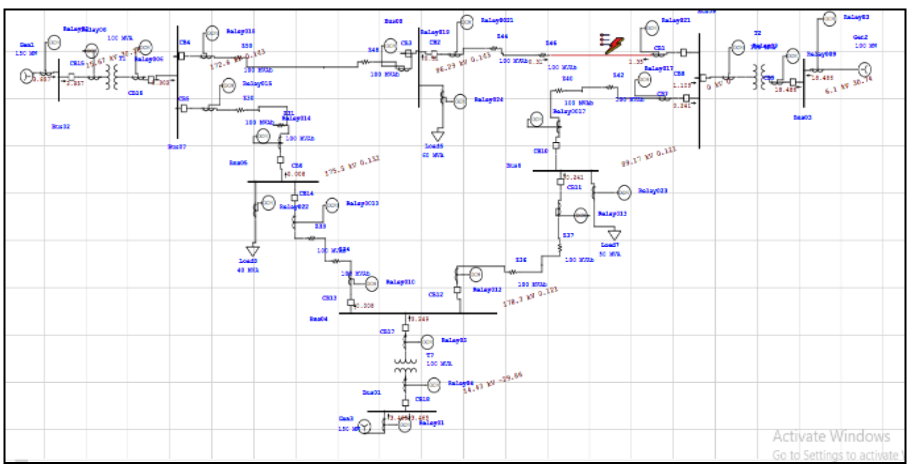

Figure 5. Short Circuit Analysis on E-Tap for F2

Objective function and its minimization using Genetic Algorithm:

Objective function for conventional settings in Genetic algorithm:

Minimize Z = ((x (1)*(3.27+4.859)) +(x (2)*(4.93+22.99)) +(x (3)*(4.73+17.41)) +(x (4)*(3.277+4.805)) +(x (5)* (4.214+10.277))

+(x(6)*(4.14+2.829))+(x(7)*(2.9516+4.3398))+(x(8)*(4.2617+12.6248))+(x(9)*(4.828+13.456))+(x(10)*(3.1438+4.796))+(x(11)*(3.289+5.0858))+(x(12)*(5.0496+23.255))+(x(13)*(4.8287))+(x(14)*(5.2514))+(x(15)*(5.2572))+8*max(A1)+8*max(A2)+8*max(A3)+8*max(A4)+8*max(A5)+8*max(A6)+8*max(A7)+8*max(A8)+8*max(A9)+8*max(A10)+8*max(A11)+8*max(A12)+8*max(A13)+8*max(A14)+8*max(A15)+8*max(A16)+8*max(A17)+8*max(A18))

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Lower bound on TMS: 0.05

Upper bound on TMS: 1.2

Number of iterations used: 428

Value of Z (optimal time): 18.0809 sec

(iv). Conventional setting forward TMS convergence curve:

Figure 6(a), 6(b), 6(c), and 6(d) are depicted the TMS convergence curve for different relay numbers along with related TMS values. These curves clearly show the given settings for the conventional setting forward TMS convergence curve.

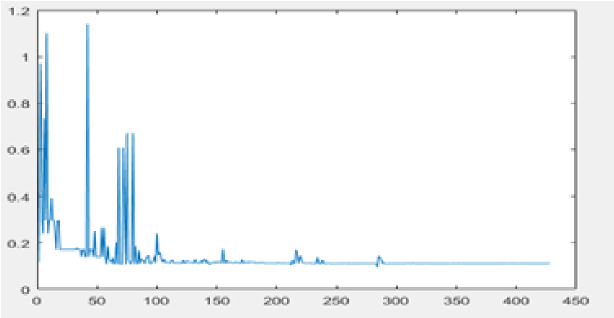

Figure 6(a). Forward TMS Convergence Curve for R14 [TMS=0.1106]

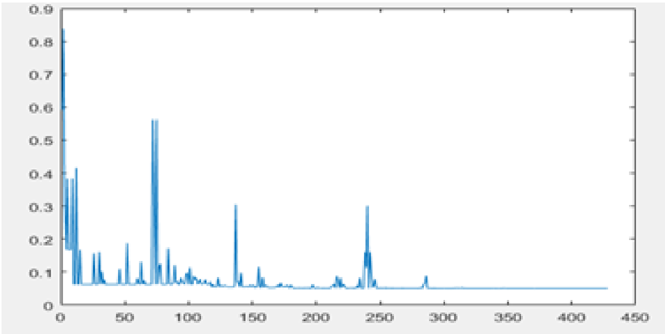

Figure 6(b). Forward TMS Convergence Curve for R16 [TMS=0.0533]

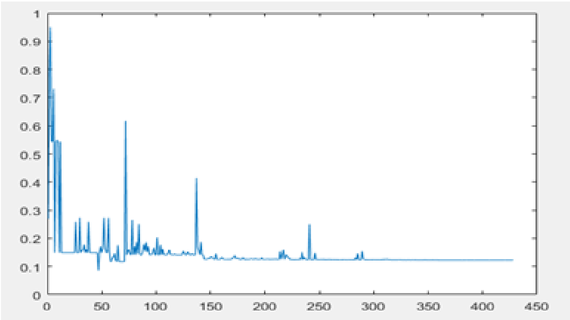

Figure 6(c). Forward TMS Convergence Curve for R20 [TMS=0.1219]

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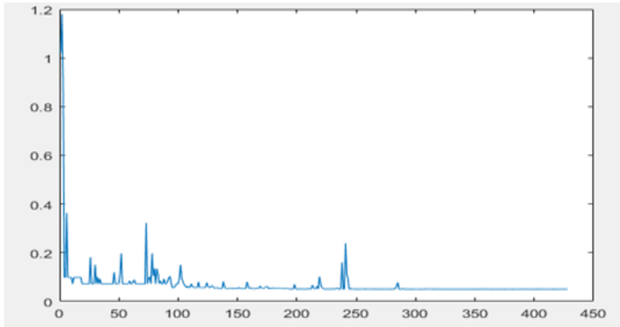

Figure 6(d). Forward TMS Convergence Curve for R21 [TMS=0.05]

Objective function used for dual setting in GA:

Minimize Z= x (1)*4.829+.0501*3.27+x (2)*10.277+0.0501*3.27+x (3)*4.8056+.1325*4.93+x (4)*4.859+0.1219*4.73+x (5)

*13.456+.05*3.277+x(6)*5.2793+.05*3.277+x(7)*4.3398+.1106*4.214+x(1)*4.829+.0606 *2.829+x(8)*22.99+.0606*2.829+x(9)*5.2537+.0532*2.9516+x(10)*23.255+.0532*2.951 6+x(11)*4.14+.1466*4.2617+x(12)*5.0858+.0533*4.828+x(6)*50.2793+.1013*3.1438+x(13)*17.41+.1013*3.1438+x(9)*5.2537+.0953*3.289+x(14)*12.6248+.0953*3.289+x(15)* 4.796+0.05*3.289+8*max(A2)+8*max(A3)+8*max(A4)+8*max(A5)+8*max(A6)+8*max(A 7)+8*max(A8)+8*max(A9)+8*max(A10)+8*max(A11)+8max(A12)+8*max(A13)+8*max(A 14)+8*max(A15)+8*max(A16)+8*max(A17)+8*max(A18)

Lower bound on TMS: 0.05

Upper bound on TMS: 1.2

Number of iterations used: 732

Value of Z (optimal time):13.87 sec

(v). Reverse TMS convergence curves

Figure 7(a) and Figure 7(b) show the reverse TMS convergence curve for different relay numbers along with related TMS values with the use of GA for the minimization objective function.

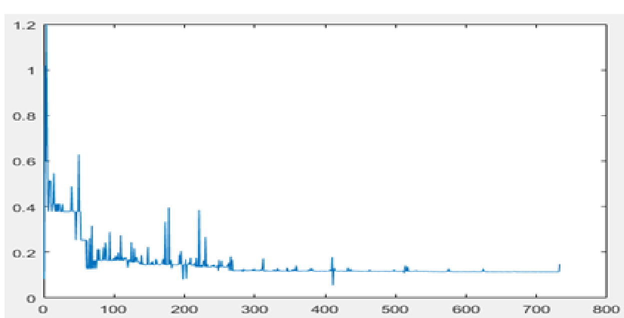

Figure 7(a). Reverse TMS Convergence Curve for R7 [TMS=0.1231]

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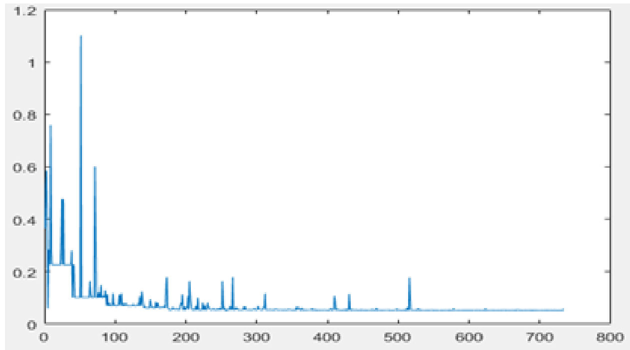

Figure 7(b). Reverse TMS Convergence Curve for R7 [TMS=0.1231]

Table 7, clearly depicts the forward TMS and reverse TMS with related relay numbers in 9-bus MDS. Meanwhile, Table 8 shows the OT of each relay for conventional and dual-setting with six different fault locations. Table 8 also depicts the comparison of the primary and backup relay OT in both the settings, above discussion clearly verified the dual setting coordination in 9-bus MDS.

Table 7. Forward and reverse TMS of each relay

Relay No.	Forward TMS	Reverse TMS
R4	0.1489	-
R5	-	0.1498
R6	0.1245	-
R7	-	0.1231
R8	0.1355	-
R9	-	0.1371
R10	0.0532	0.1328
R11	0.1466	0.0572
R12	0.0501	0.1074
R13	0.0953	0.05
R14	0.1106	0.0550
R15	0.0606	0.1136
R16	0.0533	0.1067
R17	.1013	0.0501
R18	0.0501	0.0911
R19	0.1325	0.0502
R20	0.1219	0.0501
R21	0.05	0.0987

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Table 8. Operating time (OT) of each relay for conventional and dual setting

Fault location			Conventional setting		Dual setting	
	Primary relay (PR)	OT	Backup relay (BR)	OT	Backup relay (BR)	OT
F1	R18	0.298	R6	0.485	R7	0.604
	R19	0.248	R14 R21	0.623 0.586	R15 R20	0.562 0.475
F2	R20	0.237	R18	0.646	R19	0.442
	R21	0.234	R16 R8	0.716 0.721	R17 R9	0.676 0.717
F3	R14	0.232	R10	0.636	R11	0.5763
	R15	0.321	R6 R19	0.6011 1.1500	R7 R18	0.594 1.150
F4	R10	0.392	R4 R13	0.787 1.060	R5 R12	0.782 1.060
	R11	0.248	R15	0.478	R14	0.450
F5	R16	0.257	R12	0.546	R13	0.485
	R17	0.318	R8 R20	0.723 0.872	R9 R21	0.711 0.870
F6	R12	0.353	R4 R11	0.787 1.670	R5 R10	0.783 0.722
	R13	0.253	R17	1.539	R16	0.511

6. CONCLUSION

The relay coordination has been performed on IEEE 9 bus meshed distribution system. Load flow analysis and short circuit analysis has been done using E-Tap. Objective function of total operating time is minimized using Genetic algorithm. Optimal value of TMS for forward and reverse settings has been determined by objective function minimization. The operating time of relays and their characteristics are determined through conventional overcurrent relays and with dual setting DOCRs. Relay coordination curves has been obtained during fault condition using both conventional and dual setting.

Total operating time through conventional settings came out 18.0809 sec and 13.87 sec when deployed dual settings. So, the total operating times of relays have been reduced by 23.28%.

REFERENCES

1) H. A. Patel, V. M. Sharma, A. Deshpande, "Relay coordination usin E-Tap,'' International Journal of Scientific & Engineering Research, Volume 6, Issue 5, pp.1583-1588, May 2015. ISSN 2229-5518

2) H. H. Zeineldin, H. M. Sharaf, D. K. Ibrahim, E. E. Abou El-Zahab, "Optimal protection coordination for meshed distribution systems with DG using dual setting directional over-current relays," IEEE transactions on smart grid, 6(1), pp.115-123, Sep. 2014. **doi:** 10.1109/TSG.2014.2357813

3) A. Yazdaninejadi, S. Golshannavaz, D. Nazarpour, S. Teimourzadeh, F. Aminifar, "Dual-setting directional overcurrent relays for protecting automated distribution networks," IEEE Transactions on Industrial Informatics, 15(2), pp.730-740, March 2018. **doi:** 10.1109/TII.2018.2821175

4) S. M. Brahma, A. A. Girgis, "Development of adaptive protection scheme for distribution systems with high penetration of distributed generation," IEEE Transactions on power delivery, 19(1), pp.56-63, Jan. 2004. **doi:** 10.1109/TPWRD.2003.820204

5) A. J. Urdaneta, R. Nadira, L. G. Perez Jimenez, "Optimal coordination of directional overcurrent relays in interconnected power systems," in IEEE Transactions on Power Delivery, vol. 3, no. 3, pp. 903-911, July 1988. doi: 10.1109/61.193867

6) M. Awaad, S. F. Mekhamer, A. Y. Abdelaziz, "Design of an adaptive overcurrent protection scheme for microgrids," International Journal of Engineering, Science and Technology, vol. 10, no. 1, pp.1-12, Feb. 2018. doi: 10.4314/ijest.v10i1.1

7) M. Dewadasa, A. Ghosh, G. Ledwich, "Protection of distributed generation connected networks with coordination of overcurrent relays," IECON 2011 - 37th Annual Conference of the IEEE Industrial Electronics Society, pp. 924-929, Nov. 2011. doi: 10.1109/IECON.2011.6119434

8) S. Saini, "Overcurrent relay coordination for phase and earth faults using ETAP," In Electrical and Electronics Department, Amity University (AUUP), Noida, India, Proceedings of IRF International Conference, pp. 57-60, 2018.

9) M. H. Hussain, S. R. Rahim, I. Musirin, "Optimal Overcurrent Relay Coordination: A Review," Procedia Engineering, vol. 53, pp.332-336, Jan. 2013. doi: https://doi.org/10.1016/j.proeng.2013.02.043

10) A. Yazdaninejadi, S. Golshannavaz, D. Nazarpour, S. Teimourzadeh, F. Aminifar, "Dual-Setting Directional Overcurrent Relays for Protecting Automated Distribution Networks," in IEEE Transactions on Industrial Informatics, vol. 15, no. 2, pp. 730-740, Feb. 2019. doi: 10.1109/TII.2018.2821175.

11) M. R. Asadi, H. Askarian Abyaneh, M. Mahmoodan, R. A. Naghizadeh, A. Koochaki, "Optimal Overcurrent relays coordination using genetic algorithm," 2008 11th International Conference on Optimization of Electrical and Electronic Equipment, pp. 197-202, Aug. 2008. doi: 10.1109/OPTIM.2008.4602366

12) V. N. Rajput and T. M. Vala, "Co-ordination of overcurrent relay for chemical industrial plant using ETAP", International Journal of Futuristic Trends in Engineering and Technology, pp. 1-5, vol. 1, 2014.

13) A. Elhaffar, N. El-Naily, K. El-Arroudi, "Management of distribution system protection with high penetration of DGs," In Energy Systems and Management Springer, Cham., pp. 279-291, 2015. doi: 10.1007/978-3-319-16024-5_27

14) M. R. Asadi, S. M. Kouhsari, "Optimal Overcurrent relays coordination using particle-swarm-optimization algorithm," 2009 IEEE/PES Power Systems Conference and Exposition, pp. 1-7, April 2009. doi: 10.1109/PSCE.2009.4839976

15) J. Havelka, R. Malarić, K. Frlan, "Staged-Fault Testing of Distance Protection Relay Settings," Measurement Science Review, vol. 12, Issue 3, pp. 111-120, 2012. doi:10.2478/v10048-012-0014-9

16) Onah, A.J. "Relay Coordination in The Protection of Radially-Connected Power System Network", Nigerian Journal of Technology, 31(1), pp.58-62, 2012.

17) D. K. Singh, S. Sarangi, A. K. Singh, S. R. Mohanty, "Coordination of Dual-Setting Overcurrent and Distance Relays for Meshed Distribution Networks with Distributed Generations and Dynamic Voltage Restorer," Smart Science, vol. **7**, pp. 1-9, March 2022. https://doi.org/10.1080/23080477.2022.2046943

18) A. Yazdaninejadi, D. Nazarpour, S. Golshannavaz, "Dual-setting directional over-current relays: An optimal coordination in multiple source meshed distribution networks," International Journal of

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 41 Issue: 11-2022
DOI 10.17605/OSF.IO/6CMVG

Electrical Power & Energy Systems, vol. 86, pp. 163-176, 2017. https://doi.org/10.1016/j.ijepes.2016.10.004

19) L. Hong, M. Rizwan, M. Wasif, S. Ahmad, M. Zaindin, M. Firdausi, "User-Defined Dual Setting Directional Overcurrent Relays with Hybrid Time Current-Voltage Characteristics-Based Protection Coordination for Active Distribution Network," in IEEE Access, vol. 9, pp. 62752-62769, 2021. doi: 10.1109/ACCESS.2021.3074426

20) A. A. Balyith, H. M. Sharaf, M. Shaaban, E. F. El-Saadany, H. H. Zeineldin, "Non-Communication Based Time-Current-Voltage Dual Setting Directional Overcurrent Protection for Radial Distribution Systems with DG," in IEEE Access, vol. 8, pp. 190572-190581, 2020. doi: 10.1109/ACCESS.2020.3029818

21) S. T. P. Srinivas, K. S. Swarup, "Optimal relay coordination and communication-based protection for microgrid," 2017 IEEE Region 10 Symposium (TENSYMP), pp. 1-5, 2017. doi: 10.1109/TENCONSpring.2017.8070034

22) D. K. Singh, A. K. Singh, S. R. Mohantv, N. K. Singh, "Novel Combined Coordination of Distance and Overcurrent Relay for a Radial Distribution System," 2018 5th IEEE Uttar Pradesh Section International Conference on Electrical, Electronics and Computer Engineering (UPCON), pp. 1-6, Nov. 2018. doi: 10.1109/UPCON.2018.8596946

23) H. H. Zeineldin, H. M. Sharaf, D. K. Ibrahim, E. E. Abou El-Zahab, "Closure to “Optimal Protection Coordination for Meshed Distribution Systems with DG Using Dual Setting Directional Over-Current Relays,” in IEEE Transactions on Smart Grid, vol. 7, no. 3, pp. 1757-1757, May 2016. doi: 10.1109/TSG.2016.2548879

24) C. Wang, and Y. Zhang, “Fault correspondence analysis in complex electric power systems”, Advances in Electrical and Computer Engineering, 15(1), pp.11-17, Feb. 2015. doi: 10.4316/AECE.2015.01002

25) H. Beder, B. Mohandes, M. S. E. Moursi, E. A. Badran, M. M. E. Saadawi, “A New Communication-Free Dual Setting Protection Coordination of Microgrid," in IEEE Transactions on Power Delivery, vol. 36, no. 4, pp. 2446-2458, Aug. 2021. doi: 10.1109/TPWRD.2020.3041753

26) M. Istrate, A. Miron, C. Istrate, M. Gusa, and D. Machidon, “Single-phased fault location on transmission lines using unsynchronized voltages”, Advances in Electrical and Computer Engineering, 9(3), pp.51-56. Oct. 2009. doi:10.4316/aece.2009.03010