

OPTIMAL PROTECTION COORDINATION FOR MICRO GRIDS WITH GRID CONNECTED AND ISLANDED CAPABILITY

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Abstract- System behavior would change at the presence of scattered production units in electric distribution networks, where the most important effects of these units are on the protection of distribution networks. One of the methods to confront the influence of scattered production resources on the protection of distribution networks is the re-coordination of protective tools and substitution of fuses and breakers with ones that are more powerful. In order to decrease the economic cost, one can apply some changes to the FCLs of network (FCL does not normally make any changes in the operation of the network and only limits the current of scattered production resource while errors happen in the network). In this article, the protection tools and protective coordination are reviewed and then the network tools of annular sample are simulated by DIgSILENT. Next, an algorithm obtains the optimal protective coordination in presence of DG using FCL [1].

Keywords: Scattered Productions, Fault Current Limiter, Optimal Protective Coordination, Distribution System of Electric Energy.

I. INTRODUCTION

Scattered productions are resources of electric energy production connected to distribution networks and have less production capacity and establishment costs compared to power stations. During the installation of scattered production resources, fault current is increased in system. Thus, some components of protective system must be realigned after installation of production resources. Generally, problems made by scattered production resources in protection of distribution networks are wrong feeder cuttings, production units wrong cutting, increase, or decrease of short-circuit level, unwanted islanding, avoidance of automatic recloser and asynchrony recloser.

One of the methods to confront the influence of scattered production resources on the protection of distribution networks is the re-coordination of protective tools and the exchange of fuses and breakers with more powerful fuses and breakers, which is highly costly. In order to avoid such costs one can make some changes in the network to minimize the effect of scattered production resources while errors happen.

Of course, this change suggests a Fault Current Limiter (FCL). FCL normally does not make any changes in the network operation and just limits the scattered production current under fault conditions. In this article, the network tools of annular sample are simulated by DIgSILENT and after that, an algorithm in the presence of DG would provide the optimal protective coordination using FCL [1].

II. PROTECTIVE TOOLS CHARACTERISTIC

The protective tools such as fuse, recloser, and breakers are used in the distribution networks. Breakers and recloser and used in the main feeders and fuses are used in minor feeders. Breakers and reclosers are normally equipped with high inversed time. The general characteristic of these relays are:

$$T(I) = \frac{A}{(M^P - 1)} + B \quad (1)$$

where, A , B , and P are constants for the characteristics of selected curve. T is the operation time of high inversed current, M is ratio of I / I_{pickup} , which I_{pickup} and I are the domain of settlement current and the domain of fault current in relay respectively.

Fuses also have the inversed time current characteristics. The general equation for fuses includes:

$$\log(t) = a \log(I) + b \log(I) + b \quad (2)$$

where, t is time and I notes to current, a , b are coefficients to moderate the curve.

A. The Methods of Fault Current Limiters Utilization

Fault current limiter is an element located in series with system and normally has a negligible impedance but whenever a fault occurs, it limits the fault current by increasing the impedance and reduces the negative effects of scattered production on protective system [3]. The first generation of fault current limiters was of passive type, which was made from a self or high impedance transistor.

However, as normally they were not available in network, could cause the instability of voltage, increase of wastes and improper operation of tap changer transformers. Therefore, in order to solve the problems of next generation of these limiters, being parallel reactors with magnetic mechanic key, it was proposed to avoid the

influence of limitation reactors in normal conditions. The drawback of this limiter is the slow response and decrease of network reliability.

Another type of passive limiters is the Conductor Limiter (SFCL). This type of limiter does not need any control circuit and limits the fault current in less than half a cycle. Application of this type of limiter requires more investigations due to issues such as long return ability (5 seconds) and it is not economic in high voltage levels [2]. In recent decades according to the development of semiconductors in voltage level and power system ability, the fault current limiters have been empowered based on the electric tools. The passive elements such as reactors and transformers along with the Thyristor keys are used in the structure of this type of limiter. This type of FCL is known as Solid Station Fault Current Limiter (SSFCL).

B. Optimal Location of Fault Current Limiter

Finding the optimal location of FCL is studied in the following based on the Genetic Algorithm. In this method, it is possible to consider fault current limiter for different network points and with different values per point. With such limitations, the program simultaneously calculates suitable location of limiters and their optimal parameters.

C. Calculation of Short-Circuit

Calculation of fault current to select cutting capacity and facilities tolerance based on the three-phase short circuit fault is with zero impedance. This type of fault rarely happens but its results are used to choose the protective facilities. Because this fault usually causes bigger short circuit current. In order to determine the points of network with extra current, the three-phase short circuit fault is implemented on each bus of the network.

The buses, whose short circuit current exceeds the allowed capacity of their power keys, are determined and the optimal orientation of fault current limiter is imposed on the program. As mentioned before the calculations are performed in DiGSILENT software.

III. PROTECTIVE COORDINATION

Selection of high-current protective tools along with their current time alignment in distribution system to resolve the faults of other lines of the tools considering the predetermined operation order is called the protective tools coordination. While fault occurs, the protective tools which acts first and orders for cutting is known as main protection and is usually closer to the fault location. Other protective tools play the role of supporting protection, which operates only when fault operation or non-operation of main protection occurs.

The proposed method is applicable to meshed distribution systems with CSG. The FCL size and optimal directional OCR settings are optimally determined taking into account both grid-connected and islanded mode of operation. The problem is formulated as a constrained NLP problem and is analyzed using GA. The proposed approach was performed and tested on a radial and annular distribution system of IEEE 30-bus system.

IV. TARGET FUNCTION AND CONSTRAINTS OF PROTECTIVE RELAYS

The operation time of an OCR is an inverse function of the short-circuit current passing through it. This function is defined by two parameters, namely the Time Dial Settings (TDS) of the relay, a tuning parameter, and the pickup current (I_p), which has a current higher than which the relay starts to operate.

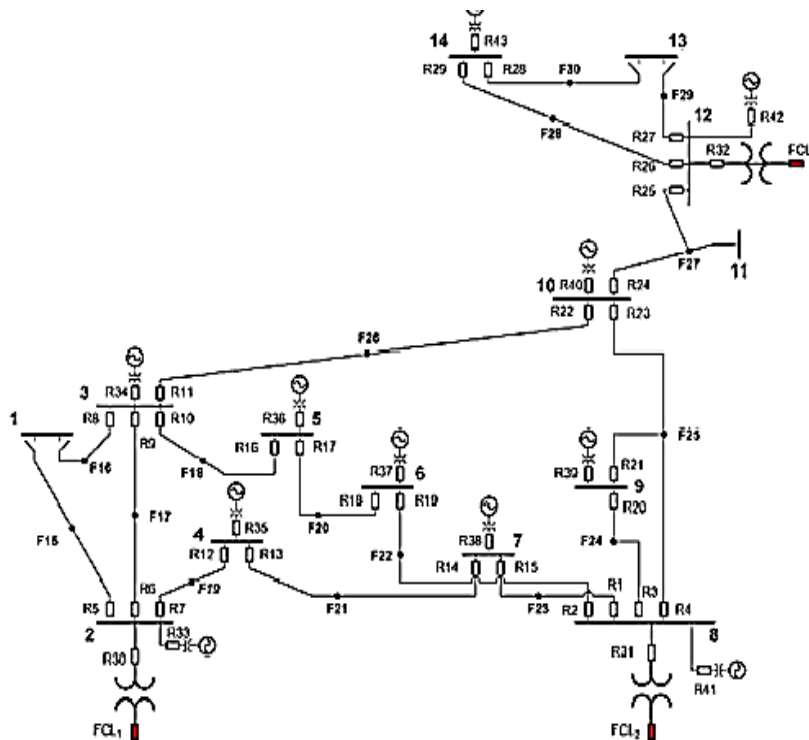


Figure 1. IEEE 30-bus test system

The inverse-time characteristic function that most commonly used is given by Equation (3).

$$t = TDS \frac{A}{\left(\frac{ISC}{I_p}\right)^B - 1} \quad (3)$$

where, the constants A, B vary according to the type of OCR used. It is assumed that the minimal and given time of OCR is applied and hence the constants of A, B are taken to be by 0.14 and 0.02 respectively.

The objective is to minimize the coordination times of all relays, while maintaining the conditions of protection coordination. As was explained in previous section, two system configurations of grid-connected and islanded will be considered in one problem. The objective function is taken to be the sum, T , the coordination times of all relays should be minimized as follows:

$$T = \sum_{c=1}^C \sum_{i=1}^N \sum_{j=1}^M \left(t_{cij}^p + \sum_{k=1}^k t_{cij}^{bk} \right) \quad (4)$$

where, c is the system configuration identifier, with C being the number of configurations considered, i is the fault location identifier, with the total number of fault locations investigated being N , and j is the relay identifier, with the total number of relays being M . The superscript p refers to primary relays, while bk refers to backup relay k , with k being number of backup relays for each primary [4].

In addition, the coordination condition needs to be satisfied, which is that a minimum gap in time between the operation of primary and backup relays, known as the Coordination Time Interval (CTI). In this paper, CTI is

taken to be 0.2 sec. As we discussed in previous section, there may be more than one backup relay for each fault location, so some relays will have to satisfy several coordination constraints per fault. Therefore, we have:

$$t_{cij}^{bk} - t_{cij}^p \geq CTI \quad \forall c, i \in \{j, k\} \quad (5)$$

where, k is the backup relay identifier. Limits on the values that TDS and I_p can take must also be set. Practically, I_p will typically take only discrete values defined by the manufacturer, but this condition is usually relaxed for simplicity [5].

The value of $I_{pi, \min}$ is chosen such that it is larger than the rated load current by a significant margin. Therefore, the following constraints are further defined:

$$I_{pi, \min} \leq I_p \leq I_{pi, \max}, \quad \forall i \quad (6)$$

$$TDS_{i, \min} \leq TDS_i \leq TDS_{i, \max}, \quad \forall i \quad (7)$$

The adjusted and modified problem will involve the use of an FCL installed at the grid side. This is the component that will help reduce amount of short-circuit current. FCLs can be either resistive or inductive. In this paper, FCLs of the inductive type are used. The FCLs have fixed ratings once they are installed into the system. Hence, the following constraint is introduced:

$$0 \leq X_{FCL} \leq X_{FCL, \max} \quad (8)$$

In this way, the problem is set sometimes for TDS_i and sometimes for I_p in order to find the value of relay i , as well as the value of the fault-current limiting inductance X_{FCL} that would minimize the total operating time T for all considered system configurations simultaneously. Also, these settings will be applicable irrespective of the micro grid mode of operation.

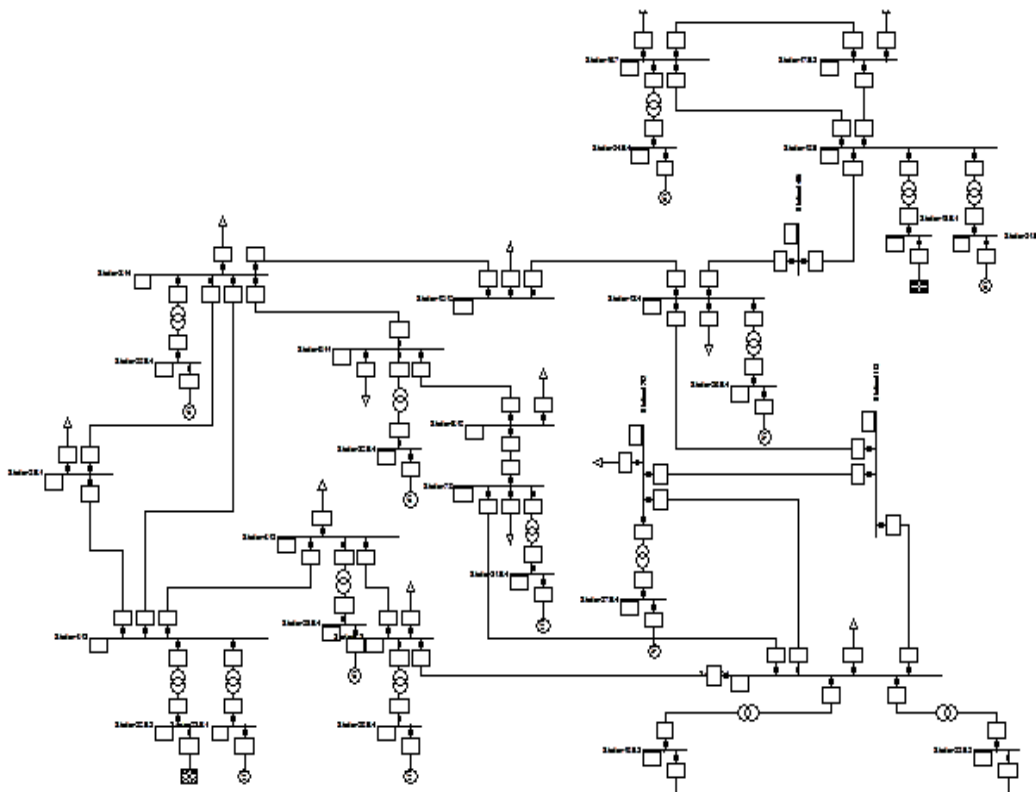


Figure 2. IEEE 30-bus test system schematic in DlgSILENT

It must be noted, however that because of their potentially high values, FCLs cannot be present in the system during normal operation since this can cause large voltage drops. For this reason, it is proposed to use FCL of the active type. Active FCLs are switched into the system in the event of a fault and have negligible impedance during normal operation. The inclusion of X_{FCL} will affect the admittance of matrix Y_{bus} , in the system and the magnitudes of the short-circuit currents as well. This will affect the optimal values of TDS and I_p (needed to achieve relay coordination) [6].

Hence, the relay time response is a function of X_{FCL} because X_{FCL} will propagate into the Z_{bus} matrix and especially when Y_{bus} is inverted, it becomes very difficult and complex to formulate equations and constraints in terms of X_{FCL} . For this reason, heuristic techniques such as the GA are often chosen in such a task due to their ease of implementation.

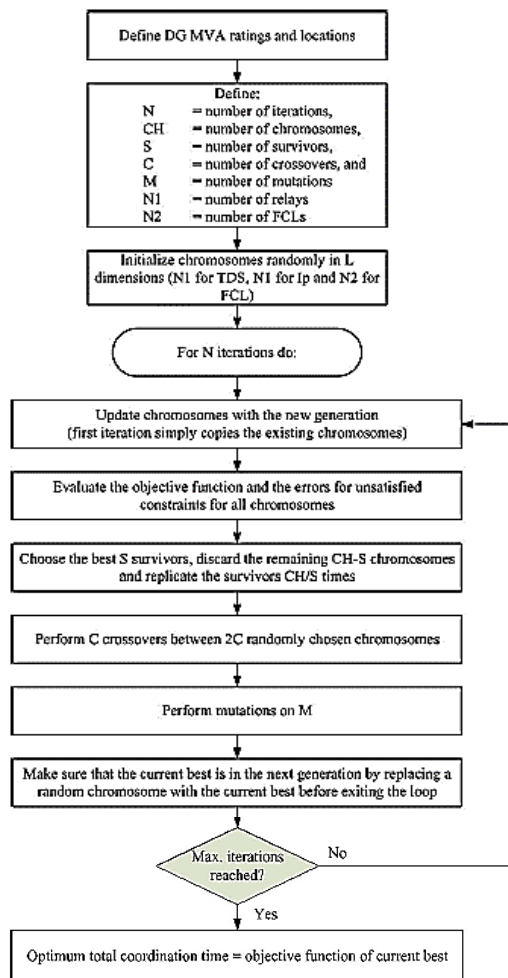


Figure 3. Flowchart of GA implementation

V. SIMULATION OF SAMPLE GRID

Current distribution grids have many complications. Among 30 standard annular distribution grids IEEE, 30-bus testing grid has suitable bus numbers and complications which is why it is used in this article. However, as the objective is to study in distribution level, only distribution level parts (33 kV) are studied.

The modified grid obtained from 30-bus grid has 11 buses and 43 relays presented in Figure 1. All the steps required are simulated through MATLAB and DiGSILENT and implemented on the presented distribution grid. In order to do these studies, DiGSILENT software is used to simulate the sample grid of Figure 2 and calculations of load distribution and short circuit and MATLAB to simulate, implement the algorithm and solve the mathematical solutions.

Table 1. Genetic optimization of important parameters

Parameter	Value
Pop-size	100
Number of generations	50
Stopping criteria	5 generations unchanged

A. IEEE 30-Bus System

IEEE 30-bus distribution system is illustrated in Figure 1. The distribution system is fed through converters (50 MVA 132 kV/33 kV) connected to 12, 2, and 8, buses of generators settled in different buses (see Figure 1). Each of DGs scaled in 10 MVA act with coefficient of one unit and the system is fed through converter 480 V/33 kV. It is noteworthy that this system is equipped with direct current OCR 43.

Table 2. Optimal TMS of 30-bus problem

Relay	TMS	Time	ΔT
1-4	0.60	0.50	0.85
5-8	0.55	0.80	0.65
9-12	0.20	0.80	0.75
13-16	0.95	0.15	0.70
17-20	0.35	0.40	0.80
21-24	0.80	0.45	0.50
25-28	0.55	0.75	0.80
29-32	0.10	0.20	0.40
33-36	0.75	0.90	0.50
37-40	0.60	0.65	0.40
41-44	0.15	0.75	0.85
45-48	0.60	0.15	0.50
49-52	0.20	0.15	0.80
53-56	0.90	0.30	0.45
57-60	0.05	0.60	0.35
61-64	0.65	0.40	0.80
65-68	0.85	0.50	0.75
69-72	0.25	0.80	0.95
73-76	0.85	0.90	0.50
77-80	0.65	1.0	0.05
81-84	0.60	0.20	0.05
85-86	0.75	0.40	

B. GA Implementation

Figures 3 and 4 show the implementation of GA used in this paper. For each relay and enforcement stations, two settings need to be determined, namely TDS and I_p . If each system has N_1 relays and (N_2) FCLs, then the total numbers is $L = 2N_1 + N_2$. Each chromosome will therefore be composed of L entries. The general implementation is explained in Figure 3. Figure 4 explains the procedure for evaluating the fitness function of each chromosome. Every chromosome will need to satisfy two sets of constraints especially when the utility is feeding the grid-connected configuration and islanded configuration [9]. Only the earlier of those must involve FCL.

In the single-configuration and the grid-connected part of the dual configuration, every chromosome will use a different X_{FCL} . Therefore, an Y_{bus} available in each chromosome must be calculated. For each fault progress and direct, all primary and backup short-circuit current components are calculated. Each of these currents is then mapped to its corresponding relays, and the objective function is updated with the operation times of primary and backup relays using the TDS , I_p and I_{sc} , and considering constraint values.

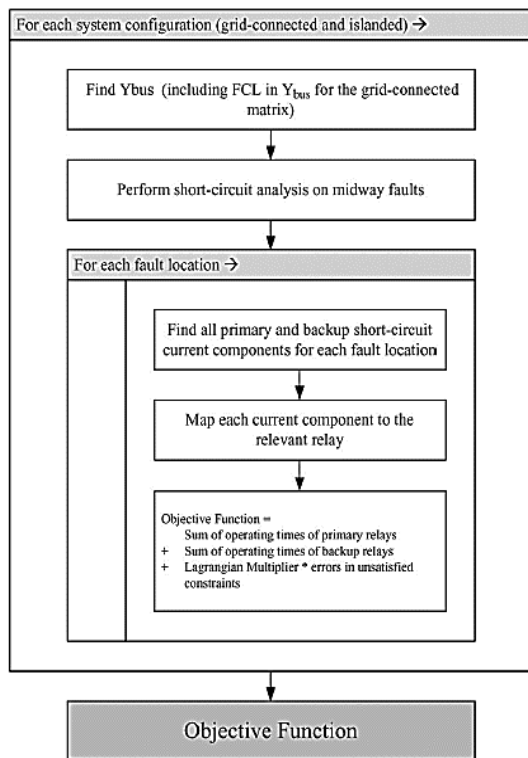


Figure 4. Flowchart of method for finding the fitness function

C. Implementation and Optimal Coordination Results

In order to implement the optimal coordination program in MATLAB, genetic optimization has been used. Since there are suitable tools in MATLAB to implement the genetic algorithm, there is no need to direct genetic programming and only definition of optimization and acceptance functions is required. For example, the coordination constraints between primary and back-up pair of relays of 1 and 19 is:

$$C(1, [1, 2, 3]) = 119t_{op}(x(1), I_p(1), I_{sc}(1,1), m_p) - t_{op}(x(19), I_p(19), I_{sc}(19,1), m_p) + 0.3 \quad (9)$$

which is the implementation of coordination relation of primary and back-up pair of relays:

$$T_{nk} - T_{ik} \geq \Delta T \quad (10)$$

where, t_{op} is the function of operation time calculation of relays, $X(19)$ and $X(1)$ TDS relays of 1 and 19, $I_{sc}(1,1)$ is short current in primary location of (1) for fault in the primary relay location (1), $I_p(1)$, $I_p(19)$ short circuit current in the backup relay location (19) for the fault in the primary relay location (1) and $I_p(1)$ and $I_p(19)$ to the pickup relays currents (1), (19). The received time based on the heuristic

optimization, is 35.03 seconds. The primary parameters of genetic optimization are in Table 1.

D. Coordination of High-Current Relays

As we described in introduction, high current relays have two primary values of TSM and PSM and constant values of K , B obtained from standard equation of IEC for high current relays. As mentioned, the values of K and B are constant and are proportional to high current relay type and its physical characteristic, but TSM and PSM values (or its equivalent fault threshold) are regulatory values which must be calculated for a system requiring some coordinated relays. Coordination calculations for the network are presented as follows:

Table 3. Optimal X_{FCL} of IEEE 30-bus problem

Relay	Z	X	R	I
X_{FCL} 1-4	0.1342	0.1499	0.1382	0.48
X_{FCL} 5-8	0.045	0.7185	0.7162	0.0381
X_{FCL} 9-12	0.4355	0.2632	0.7	0.4224
X_{FCL} 12-16	0.3907	0.7032	0.46	0.6981
X_{FCL} 17-20	0.0369	0.8869	0.9	0.4098
X_{FCL} 21-24	0.743	0.4934	0.5384	0.3745
X_{FCL} 25-28	0.7964	0.3975	0.0215	0.0426
X_{FCL} 29-32	0.993	0.9199	0.6518	0.9596
X_{FCL} 33-36	0.8869	0.9086	0.6713	0.9016
X_{FCL} 37-40	0.8863	0.7662	0.95	0.7199
X_{FCL} 41-44	0.7868	0.8571	0.9457	0.2242
X_{FCL} 45-48	0.0296	0.0779	0.001	0.0308
X_{FCL} 49-52	0.0742	0.0147	0.1201	0.0152
X_{FCL} 52-54	0.0587	0.1313	-	-

VI. CONCLUSIONS

The concept of micro grid is quickly taking root not only in the research community, but also on the agendas of utilities, power system component manufacturers, and policy makers. Micro grids, by definition, should be operational both in grid-connected and islanded mode. This paper tackles this issue from the point of view of protection. In this paper, a micro grid protection scheme based on optimally sizing of FCLs and optimally setting of OCRs is proposed.

Inductive type FCLs are located at the main interconnection point of the micro grid to the main grid. Inserting the FCL as an optimal parameter in the protection coordination problem affects the system admittance matrix which allows for changes in the fault current levels. Thus, the results show that it is possible to have one optimal relay setting and enforcement station that satisfies both micro grid modes of operation of the grids.

In addition, without the FCL, it was found that it is difficult to set the relays and enforcement station and operational modes implementations. The proposed approach was tested on a typical radial distribution system of IEEE 30 equipped with CSG and the results confirm the effectiveness of the proposed method.

REFERENCES

- [1] A.J. Pansini, "Electrical Distribution Engineering", McGraw-Hill, 1989.
- [2] M.S. John, A. Borgrino, "Coordinating Overcurrent Protection Devices", IEEE Computer Applications in Power, July 1996.

- [3] W.J. Ruschel, A. Wayne Ashley, "Coordination of Relays, Reclosers, and Sectionalizing Fuses for Overhead Lines in the Oil Patch", IEEE Transactions on Industry Applications, Vol. 25, No. 6, November 1989.
- [4] "Applied Protective Relaying", Westinghouse Electric Corporation, Relay Instruments Division Coral Springs, , Chapter 10, Florida, 1982.
- [5] "IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power System", ANSI/IEEE Buff Book, Std 242-1986, 1986.
- [6] D. Birla, R.P. Maheshwari, H.O. Gupta, "Time Overcurrent Relay Coordination - A Review", International Journal of Emerging Electric Power Systems, Vol. 2, Issue 2, pp. 1-13, 2005.
- [7] D.E. Schultz, S.S. Waters, "Computer-Aided Protective Device Coordination - A Case Study", IEEE Transactions on Power Apparatus and Systems, Vol. PAS103, No. 11, pp. 3296-3301, November 1984.
- [8] M.J. Damborg, R. Ramaswami, S.S. Venkata, J.M. Postforoosh, "Computer Aided Transmission Protection System Design, Part I - Algorithms", IEEE Transactions on Power Apparatus and Systems, Vol. PAS103, No. 1, pp. 51-59, January 1984.
- [9] M.H. Dwarakanath, L. Nowitz, "An Application of Linear Graph Theory for Coordination of Directional Overcurrent Relays", Electric Power Problems, The Mathematical Challenge, SIAM Meeting, Seattle, WA, pp. 104-114, March 1980.
- [10] V.V. Bapesara, K.S. Rao, "Computer Aided Coordination of Directional Relays - Determination of Break Point", IEEE Trans. on Power Delivery, Vol. 3, No. 2, pp. 545-548, April 1988.
- [11] L. Jenkins, H.P. Khincha, S. Shivakumar, P.K. Dash, "An Application of Functional Dependencies to the Analysis of Protection Schemes", IEEE Trans. On Delivery, Vol. 7, No. 1, pp. 77-83, July 1992.

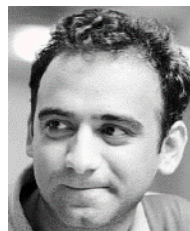
BIOGRAPHIES



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