2021 International Conference on Intelligent Technologies (CONIT)
Karnataka, India. June 25-27, 2021

Application of Linear Programming for Overcurrent Protection

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2021 International Conference on Intelligent Technologies (CONIT) | 978-1-7281-8583-5/21/$31.00 ©2021 IEEE | DOI: 10.1109/CONIT51480.2021.9498330

Abstract **- Power system without proper protective scheme is similar to an unstable system, it is more prone to fault and unwanted tripping. In major distribution system overcurrent protection is used for protection. Hence a proper coordination should be done for overcurrent protection scheme. A protective scheme should operate as fast as possible, but when it operates a lesser area must be isolated, so that less blackout should occur. The two main parameter of overcurrent protection scheme are Time setting and current setting. The setting of relay should be such that, the desired operation should occur. This paper discusses the different Linear programming techniques implemented on a proposed system. Dual Simplex method is faster as compared to other methods of Linear programming.**

Keywords -Overcurrent Protection, TMS, Plug setting, Linear Programming

I. INTRODUCTION

Power systems consist of various element such as generators, transformers, transmission and distribution lines, loads and compensating devices. Every part as its role in power system. This interconnection of the power system forms a grid. As every element has its own role, at the same time they have their limitations. The power or the current flowing in the system can be categorized as normal (healthy) and abnormal (Unhealthy /faulty) conditions. In case of normal system current depends on the various parameters such as starting instant and conditions, types of loads, line charging components etc., on the other hand for the unhealthy system the most the significant parameter that decides the current flowing in the system is the nature, type and location of the fault occurring in the system.

Every system is designed to carry a definite amount of current. Under normal conditions system is designed to carry the normal current for an infinite (maximum) time, but under faulty the system can carry the current for a definite time interval only Beyond which the system generates it consequences in the whole system. To avoid such consequences it becomes the part and parcel of system-designer to design a system of zero fault tolerance or accept the possibility of fault occurrence and should provide a mechanism to separate the defective part from the system. Such a phenomenon of practice is called as the protection of the system. Table 1[1] below shows the Fault statistics occurring on different power system elements.

TABLE I. FAULT STATISTICS

System components	Possibility of accountabilities (%)
Transmission & Distribution Lines	50
Switchgear	12
Measurement and Protective equipment's	12
Transformers	10
Cables	9
Alternators	7
Total	**100**

Table 1 gives a clear picture of fault statistics, looking at the statistics the most faults occurring in the system are on overhead lines which is a combination of transmission and distribution lines. Among which distribution line are more prone to fault. The transmission lines are physically isolated from the generators and distribution lines by means of transformers. Transformers are the used to step down and step up the voltage levels. If either side of transformer consists of delta type of winding, then the zero sequence and 3rd order harmonics are isolated from the rest of the system. Also, zero sequence currents exist only in case of ground fault, so delta connection can provide isolation for the same.

In case of shunt fault, the major parameter which changes abruptly is the current and voltages. Current at the fault location increases suddenly whereas voltage at that location drops more, depending on the fault impedances [2]. Table II shows the equipment's and the protection used [1].

TABLE II. POWER SYSTEM PROTECTION

Apparatus \ Type of Primary Protection	Non-directional Overcurrent	Directional Overcurrent	Differential	Distance
Generator		√	√	√
Transformer			√	
Transmission Line	√	√		√
Distribution Line	√	√		
Loads	√			

However, in recent advances shows the use of differential protection to transmission line too [3]. As major of the equipment's (% wise) uses overcurrent protection schemes. This paper focuses on the overcurrent protection scheme of distribution line protection. The major factors which influences the overcurrent protection scheme are the type of system i.e. radial and ring main system[4] on which the major factors of the overcurrent protection are based are Plug setting (PS) and Time Multiplier setting (TMS) or Time Dial setting (TDS). [4] While designing the overcurrent protection scheme, above parameters should be taken into account along with the type of faults. The protective scheme should operate for least and most severe fault current. Table III shows the fault statistics and its severity [1].

TABLE III. FAULT STATISTICS AND ITS SEVERITY

Fault	Chance of Existence (%)	Severity
Line to ground	85	Lowest
Line to line	8	
Double line to ground	5	
Three phase	2	Highest
Total	**100**	

A relay must detect fault under its zone. In case of failure of primary protection or in case of inoperative of primary protection due to maintenance purpose, the back-up protection should operate for the same. Due to lack of coordination in backup protections, maloperation can occur, resulting in major breakdown and other technical and economic issues and, therefore, Over Current relay synchronization is an alarm of power system protection [5,6]. Overcurrent protection is designed in such a way that it should coordinate with the relays protecting with the inline equipment's. As the power system is vast relay coordination is one of the major tasks for design engineers.

II. OPTIMAL RELAY COORDINATION PROBLEM

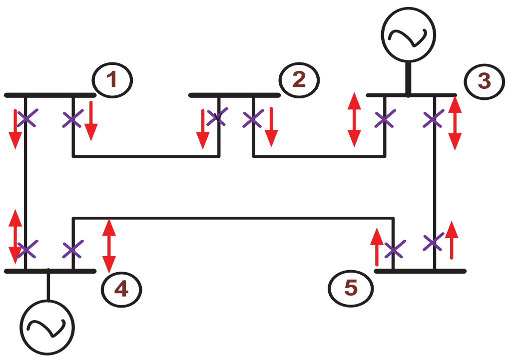

Fig. 1. Generalised directional and non-directional overcurrent protection scheme.

As it looks overcurrent coordination problem not only as a simple as only PS & TDS problem, but this PS & TDS depends on type of feeder i.e. ring main and radial feeder. In radial feeder the power / current flow is unidirectional, hence it doesn't require the directional relay property, but in case of ring main feeder or distributed generation (DG) system the power is flow is bi-directional hence this system requires a directional relay [7]. It It's a general Practice the directional relays are set to operate for a current more than a predefined value and direction is such a way that the directional overcurrent relay is set to operate always away from the bus except the generator bus as shown in fig (1).

Here the optimisation problem is discussed, based on PS & TDS. The pickup for each overcurrent relay is bounded by two current parameters of a bus adjacent to relay location, the lowest value of fault current and the highest value of load current refer at a bus refer to all parameters to either primary or secondary side of CTs i.e. $I_{f\,min} < PS < I_{f\,max}$ [1], [5]. However optimization technique is used as an objective function to optimize TDS calculation (setting), lower the TDS, less will be the time required for clearing the fault and vice versa.[8]

The function represented in equation 1, is nothing but the summation of entire operating time of all the overcurrent protective devices situated at different positions in a network.

$$A_{min} = \sum_{i=1}^{r} w_i * Y(I_p, I_{i,}) * TMS \quad (1)$$

$$B_{min} = \sum_{i=1}^{n} w_i * t_{(i,m)} \quad (2)$$

Where

r is the no. of relays,

$t_{(i,m)}$ is the relay (i_R) operating time, for fault in zone m,

w_i is weight allotted for working time of the relay i_R.

$w_i = 1$, for length of different feeders is same

The function represented in equation 1 is subjected to limitations for appropriate relay coordination.

TMS_i for relay R_i and $Y(I_p, I_{i,})$ term depends upon setting of relay, I_f and characteristic of relay used. As per Normal Standards, $Y(I_p, I_{i,})$ term is defined in "(3)"

$$Y(I_p, I_{i,}) = \frac{B}{PSM^{A-1}} + L \quad (3)$$

Where

PSM is plug setting multiplier

A is relay characteristic slope

The various parameters of standard overcurrent types of relay is given in Table IV.

TABLE IV. VALUES OF A, B AND L FOR DIFFERENT TYPES OF OCRS [9]

Reference	**Relay**	L	B	A
IEEE	NI	0.114	0.0515	0.02
	VI	0.491	19.61	2.0
	EI	12.17	28.2	2.0
IEC	SI	0.0	0.14	0.02
	VI	0.0	13.5	1.0

Following are the Normal Managing Restrictions

1) Limits on Delinquent Variable:

I) Boundaries on TMS of each relay

TMS should be between TMS_{min} and TMS_{max} (4)

i.e between 0.025 and 1.2 sec. (5)

II) Boundaries on pickup current (I_{pickup}) setting

$$PSM = \frac{I_f}{I_{pickup}} \quad (6)$$

Similar to TMS I_{pickup} should be between $I_{f\,min}$ and $I_{f\,max}$ (7)

For IEC-SI relay: B = 0.02, A = 0.14 (table iv)

2) Boundaries on Primary Operating Time

All the relay should follow the constraints agreeing to each probable fault location, the operating time should be less than a maximum delayed time interval but on the contrary it should be more than some lowest pre-decided time in view of momentary circumstances [5].

3) Selectivity Restriction:

With the occurrence of Fault all the forward relays through which the I_f is flowing, senses the fault simultaneously, i.e. both primary as well as backup relays. To avoid unwanted tripping by backup relay, backup relay should have enough time delay, it should only operate if primary relay fails to operate. For ex. If R_a is the primary relay for fault at P, and R_b is backup relay for the same fault location, then the coordination constraint can be stated as;

$$t_b - t_a = dt \quad (8)$$

where,

t_a is Primary relay R_a operating time, for fault at location P;

t_b is backup relay R_b operating time of the, for the same fault at location P,

dt is between operation of two relays, mostly taken as 0.3 sec.

III. LINEAR PROGRAMMING TECHNIQUES

There are various optimization techniques, among them Linear programming [LP] can be used for optimization. In this method problem is modelled and solved mathematically. By using LP desired accuracy is achieved among the various alternatives by choosing a sequence of action by economic allocation of limited resources. There exists a linear relationship among the different variables of a model in Linear programming problem [LPP]. Literature shows there are numerous unalike methods to solve the LPP. In this paper four methods are used. They are Revised Simplex Method [RSM], Dual Simplex Method [DSM], Two Phase Simplex Method [TPSM] and Big-M methods [BMM] have been used [10].

A. RSM

RSM is the modification of simplex method(regular). In RSM relevant information is computed and stored and therefore in means of computer facility it is more economical and faster [11]. In RSM Coefficients are calculated at each iteration, they are of [12] –

i) non-essential variables,

ii) variables to be used in basics set of constraints.

B. Dual Simplex Method

To solve LPP, Lemke has modified RSM a bit in another way. He started from infeasible solution to the primal. DSM is an iterative method, it tends the solution to become viable and best [11,12]. The features of DSM are

i) it doesn't require the phase I i.e initial calculations as that of the TPSM. As the phase current calculation may be not be optimal as in TPSM, DSM method is more useful

ii) solution can be obtain in less iterations as it works simultaneously on feasibility and optimality.

C. Two phase Simplex

In this methods, mock variables play a vital role. Logically Mock variables have no essence. They are only used for producing an initial basic possible solution. All the mock variables are removed earlier to final result, [12]. All the mock items made zero if they are found to be the basics in the solution 11]. In TPSM, initial part reduces mock variables from the second function. The second Phase practices the solution obtain best solution obtain by part one. Hence the name two phase method[11,12].

D. Big-M Methods

Charne's penalty method or Big-M method is used to remove mock variables from the initial phase i.e. phase one. Here a large unwanted coefficient is assigned to mock variables. A very big positive penalization is allocated to each mock item (M > 0), which in turn minimizes the relay coordination problem.

IV. BEST VALUES OF PS AND TMS OF OCRS

The get the best values of PS and TMS of OCRs is expressed as a Nonlinear Programing Problem. If initial value of PS chosen, then the problem remains with only the value of TMS, thus it converts NLPP into a LPP. By using LPP a set of solutions are obtained. Hereafter the next set of PS is considered and again the LPP is applied to get a new set of solutions. These iterations are continued till all the possible sets of PS are considered. Among the various solutions obtained the solution set which optimizes the objective function is selected as the final solution for the universal minima. The flowchart shown in Fig. 2 explains the same [10].

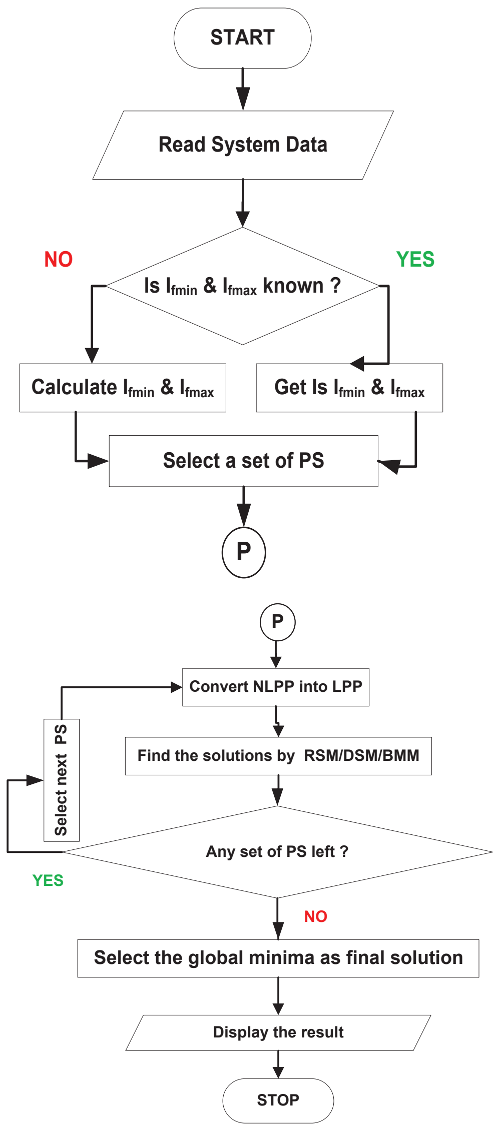

Fig. 2. Proposed LPP Flowchart

V. RESULTS AND DISCUSSION

The above flowchart was written in terms of a program. The program was verified for different case studies. proposed substation at YCCE. Fig. 3 shows a Ring main feeder with source at one bus is considered. It has 06 no. of overcurrent Relays, as shown in fig 3. Load currents and the shunt admittances can be neglected during fault, Table V and Table VI shows the data about the system and relays respectively. Operating time of relay R_E was taken as 0.05 s, and that for relay R_E was taken as 0.25s. Fault is assumed on each line as shown in fig. 3 (one fault is considered at one time). Whereas the primary and backup relays are mentioned in are given in Table V.

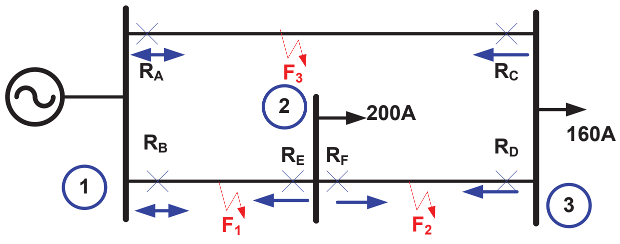

Fig. 3. A Proposed system at YCCE

TABLE V. SYSTEM INFORMATION

Bus Connection	Impedance (pu)
1-2	$0.3354<26.57^0$
2-3	$0.6708 <26.57^0$
1-3	$1.3416<26.57^0$
MVA Base = 25 ;kV Base = 11 $Z_{source} = (0.25<90^0)$ pu	

TABLE VI. RELAY SELECTION

Relay	R_A	R_B	R_C
Type	IDMT	IDMT	EI
CT	300:01	300:01	100:01
I_{Lmax}	80	280	--
I_{fmin}	194.9	356.9	513.8
I_{fmax}	1483.3	2250.4	593.4

Relay	R_D	R_E	R_F
Type	DTOC	Inst	VI
CT	100:01	100:01	300:01
I_{Lmax}	--	--	80
I_{fmin}	194.9	779.6	513.8
I_{fmax}	593.4	900.2	1483.3

TABLE VII. PRIMARY-BACKUP RELATIONSHIP OF RELAYS

Location of fault	Primary	Backup
F1	R_B, R_E	R_A, R_D
F2	R_F, R_D	R_B, R_A
F3	R_A, R_C	R_B, R_F

The optimum values obtained by proposed LPP for TDS and PS obtained are as below

$TDS_{RA} = 0.01$ $PS_{RA} = 0.5$

$TDS_{RB} = 0.0850$ $PS_{RB} = 0.8563$

$TDS_{RC} = 0.0329$ $PS_{RC} = 1.5779$

$TDS_{RF} = 0.0494$ $PS_{RF} = 1.1409$

VI. CONCLUSION

The setting obtain are lowest possible TMS which will cause the relay operation as early as possible for any of the mentioned fault at any point in the system and the faulty part gets out-of-the-way as early as possible. At the same time backup relays will also operate properly, so that the malfunctioning will not occur over there. Although all methods require same number of iterations, but the dual simplex method has less calculation per iteration.

REFERENCES

[1] Y. G. Paithankar, and S. R. Bhide, “Fundamentals of Power System Protection, 2nd edition”, Prentice-Hall of India Pvt. Ltd., New Delhi, 2010.

[2] J. J. Blackburn, “Protective Relaying : Principles and Applications, 2nd edition”, Marcel Dekker, Inc., New York.

[3] B.Bahlja, R.P. Maheswаre, N.G. Chothani “Protection and Switchgear”, Oxford University Press, 2011.

[4] Dinesh Birla, Rudra Prakash Maheshwari, Hari Om Gupta, “Time-Overcurrent Relay Coordination: A Review”, IJEEPS, vol 2 issue 2, 2005.

[5] A.S. Noghabi, J. Sadeh, and H.R. Mashhadi, “Considering Different Network Topologies in Optimal Overcurrent Relay Coordination Using a Hybrid GA”, IEEE Trans. on Power Delivery, Vol 24, October 2009, pp. 1857-1863.

[6] B. Chattopadhyay, M.S. Sachdev, and T.S. Sidhu, “An Online Relay Coordination algorithm for Adaptive Protection using Linear Programming Technique”, IEEE Trans. on Power Delivery, Vol 11, Jan 1996, pp. 165-173.

[7] Piyush Patil, M.R. Ramteke “Impact of Distributed Generation on power distribution system: Over-current protection by phase angle estimation”, Power, Communication and Information Technology Conference (PCITC), 2015.

[8] Manohar Singh, B. K. Panigrahi, and A. R. Abhyankar “Optimal Overcurrent Relay Coordination in Distribution System”, 2011

[9] P.P. Bedekar, S.R. Bhide, and V.S. Kale, “Determining Optimum TMS and PS of Overcurrent Relays Using Big-M Method”, Joint International Conference on Power Electronics, Drives and Energy Systems & 2010 Power India (IEEE PEDES 2010) , New Delhi, 21-23 December 2010.

[10] Prashant P. Bedekar Sudhir R. Bhide Vijay S. Kale, “Determining Optimum TMS and PS of Overcurrent Relays Using Linear Programming Technique”, ECTI, 2011, pp. 700 -703.

[11] P. Sankara Iyer, “Operations Research”, Tata McGraw Hill Publishing Company Limited, New Delhi, 2009.

[12] J.K. Sharma, “Operations Research – Theory and Applications, Third edition”, Macmillan India Limited, New Delhi, 2009.