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Optimal Switch Placement in Radial Distribution System Using PSO

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***Abstract*—This paper proposes an optimization method for planning adequate number and location of automatic switches in a radial distribution system. The purpose is to maximize the profit of that service reliability indices achieve the required level. First, a network equivalent technique is introduced to calculate the reliability indices. Second, by using the equivalent method, system reliability indices and profit on various switches configuration cases can be deduced. Then a mixed-integer particle swarm optimization (MIPSO) is proposed to determine the optimal switch number and location.**

Keywords— ***Distribution system, Particle swarm optimization, Reliability.***

I. Introduction

The percentage of system faults in a distribution network is more compared than that in other parts of a power grid system [1]. The reduction of momentary and sustained outages reacting more quickly to system disturbances can be achieved by protection schemes and leading-edge equipment, such as modern remote-controlled switches, breakers, reclosers, and fault indicators. In order to achieve a high level of reliability, more investment should be accomplished by the utilities and the best locations for installing these switches should be found so that the most possible benefit is gained. Determination of the best switch location is an optimization problem.

The selection of an adequate number of switches and their locations is a difficult task in distribution system planning. Utilities use their past experience, customer data and other considerations in selecting a suitable number of switches. Reference [8] provides four rules to locate protective devices in order to improve reliability. The reliability index used in [8] is the average number of minutes per customer year (SAIDI) [2].

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To improve system reliability for distribution systems under fault conditions, switch placement schemes are proposed by various algorithms such as genetic algorithm (GA) [3], particle swarm optimization (PSO) [4]. Kennedy and Eberhart [4] introduced the idea of continuous particle swarm optimizer in 1995 and many researchers have been developing and modifying different versions of the PSO in different disciplines.

The discrete binary version of PSO for discrete optimization problems has been introduced in 2001. In addition, researchers frequently model continuous domain problems in binary terms, and they solve those problems in discrete high dimensional spaces, featuring qualitative distinctions. In recent years, PSO with fast convergence has opened up a big opportunity to be employed in power systems [5].

In [6] PSO algorithm is used for Determine the optimum number and location of switches in distribution system and results on 13 bus test system shows this method is valid with this problem.

II. Reliability Indices

The reliability evaluation method used in this paper is based on common method named failure mode and effect analysis (FMEA) [13]. The first step of this method is to calculate the reliability indices of each load point. The load point reliability indices include:

Average failure rate $$\lambda_s = \sum_{i=1}^{n} \lambda_i \qquad (1)$$

Average annual outage time $$U_s = \sum_{i=1}^{n} \lambda_i r_i \qquad (2)$$

Average energy not supplied $$ENS = P_L U_s \qquad (3)$$

Where n is the set of components whose failure results is an outage of the given load point; λ_i and r_i are the failure rate and repair rate of component i; P_L is the average demand at the given load point.

The second step of the method is to evaluate system indices. The system indices include:

SAIDI (hrs/customer/year): system average interruption duration index

$$SAIDI = \frac{\sum U_i N_i}{\sum N_i} \qquad (4)$$

CAIDI (hrs/int): customer average interruption duration index

$$CAIDI = \frac{\sum U_i N_i}{\sum \lambda_i N_i} \quad (5)$$

SAIFI (int/customer/year): system average interruption frequency index

III. Problem formulation

The flow of power is always from the substation transformer downstream to the individual customers for the typical radial feeder. For a fault anywhere on the feeder, only one recloser operates, which is the closet to the fault typically, to minimize the number of affected customers. As an example, a radial feeder with a substation breaker, three reclosers is shown in Fig. 1. Assuming there are no distributed generators, the first recloser upstream the fault will operate in the presence of a fault anywhere on the line. Then the customers located downstream the recloser will lose service. However, if fault occurs between bus2 and bus 3 then substation breaker will trip first after that recloser 2 will operate allowing the portion of the feeder downstream from it to operate as an island so that we can continue supply up to bus 2.

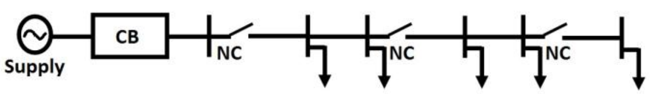

Figure 1. Radial feeder with three reclosers.

Failure mode analysis (FMA) is an effective way to evaluate a simple network reliability level. But if network involves a large number of components, the failure events that lead to load point outage will become too much to be calculated by directly using FMA.

In distribution system probability of failure is function of length. Longer is the length higher is the failure probability of segment.

Let,

q_1 = probability that segment 1 may fail
q_2 = probability that segment 2 may fail
q_3 = probability that segment 3 may fail

The failure probability that load 3 may fail will be given as

$R_3 = p_1.p_2.p_3$; probability that load will serve

So failure of load = Q_3 = 1- R_3

For load 2

Q_2 = 1-R_3; because load2 will serve if all segment will serve similarly for load 1.

For the calculation of reliability we assume that one fault occurs at a time I.e. single outage.

When any fault occurs then first C.B. will operate, all load disconnected. Now recloser of faulted segment will operate to isolate the fault then close C.B. and resume the supply to healthy segment. Once repair are over then close the recloser and resume the supply to all system.

Here customers at the end of radial feeder have lower reliability. Now on the basis of above method we find a matrix between load point and segment. This matrix is helpful to calculate the reliability indices of the system. When fault occur in load point 1 then C.B. will trip first and all the load point will interrupted till load point 1 is not repaired. Hence the failure rate of all load point is same as λ_1 and repair rate is r_1. When fault occur in branch 2 then C.B. will trip at the source end and the failure rate of all load point will be same as λ_2. Now isolator 2 will operate so we can resume supply up to branch 1 within riso time but the repair rate of branch 2 and 3 will be same r_2, similarly for branch 3 and 4 and so on. Here λ is failure rate and r is repair rate.

riso= Additional time required to locate the fault and open the recloser of faulted segment and reclose the circuit breaker to resume the supply is known as riso

TABLE 1. The Equivalent failure rate and Repair rate of the system

	L_1(load point 1)			L_2 (load point 2)			L_3 (load point 3)		
Seg/load	λ	r	U	λ	r	U	λ	r	U
1	λ_1	r_1	$\lambda_1 * r_1$	λ_1	r_1	$\lambda_1 * r_1$	λ_1	r_1	$\lambda_1 * r_1$
2	λ_2	riso	λ_2*riso	λ_2	r_2	$\lambda_2 * r_2$	λ_2	r_2	$\lambda_2 * r_2$
3	λ_3	riso	λ_3*riso	λ_3	r_3	$\lambda_3 * r_3$	λ_3	r_3	$\lambda_3 * r_3$
	λ_{equ1}	r_{equ1}	U_{s1}	λ_{equ2}	r_{equ2}	U_{s2}	λ_{equ3}	r_{equ3}	U_{s3}

The basic system shown in Figure 1 has switching devices. This system has reasonably high reliability as interruption durations and energy losses are minimized due to the installed sectionalizing switches. Reliability indices such as the system average interruption frequency index (SAIFI), system average interruption duration index (SAIDI), system unsupplied energy due to power outages (ENS) can be calculated [10, 11] for this system. The reliability indices, ENS, SAIDI can be calculated [10,11], using Equations 3 and 4.

The objective function for this problem is as follows:

$$\text{Min } SAIDI = \frac{\sum_{i=1}^{n} U_i N_i}{\sum_{i=1}^{n} N_i} \quad (6)$$

Subject to,

Switch position>=1;

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Switch position<= n—1;

Where N_i is the number of customer connected at load point i. After calculating the indices we get the idea about ENS without switch and with switch using these data we calculate the profit.

Max profit= (ENSwsw-ENSws)*tariff -Ns*switchcost (7)

ENSwsw = ENS without any switch in radial distribution system

ENSsw = ENS considering switches in system

Ns= number of switches placed in system

n is total number of bus.

A. *Particle Swarm Optimization (PSO)*

PSO is an optimization method inspired by the collective behaviour patterns of birds flocks and fish schools or of human communities that evolve by information exchange among particles in a group.[12]. In this paper mixed-integer PSO (MIPSO) method, composing both the original version and discrete version of PSO, can simultaneously deal with the continuous/discrete control variables in the problem space.

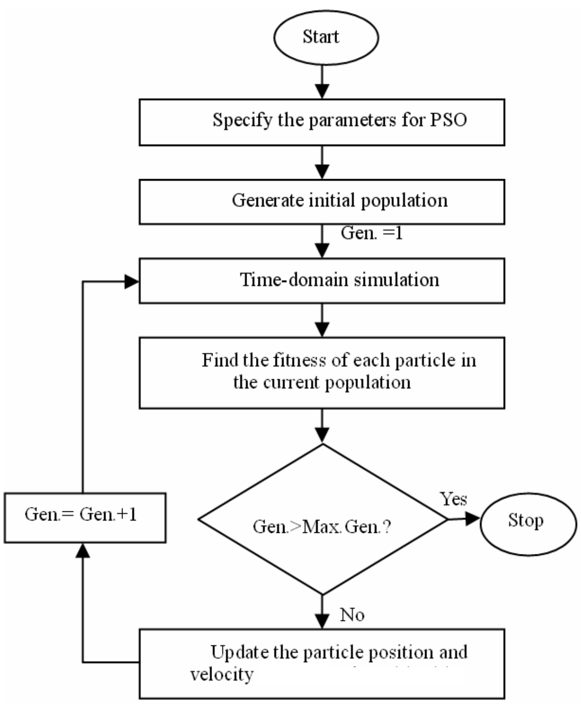

Figure 2. Flow Chart of PSO

Therefore, the MIPSO method can be used to solve mixed-integer optimization problems. In discrete binary PSO [13], the relevant variables are interpreted in terms of changes of probabilities. A particle flies in a search space restricted to zero and one in each direction and each v_{id} represents the probability of member x_{id} taking value 1. The update rule governing the particle flight speed can be modified accordingly by introducing a logistic sigmoid transformation function:

$$S(v_{id}) = 1/(1 - \exp(-v_{id})) \quad (8)$$

The velocity can be updated according to this rule: If rand() < $S(v_{id})$, then $x_{id} = 1$; or else $x_{id} = 0$. The maximum allowable velocity V_{max} is desired to limit the probability that member x_{id} will take a one or zero value. The smaller the V_{max} is, the higher the chance of mutation is for the new individual.

IV. Numerical Example and Result

In this section, 13 bus systems are used to test the proposed method. The data used in the program are listed in table. Tariff and riso are 7.0 and 0.5 respectively. C_1 and C_2 are chosen as 2.05 and maximum number of iteration is 200.

TABLE 2. Line Data for 13 Bus System

Line no	Failure rate (failure per year)	Repair rate (hrs)
1	0.10	2.0
2	0.15	2.5
3	0.20	3.0
4	0.20	3.0
5	0.15	2.25
6	0.10	2.0
7	0.10	2.0
8	0.15	2.35
9	0.20	3.25
10	0.20	3.0
11	0.15	2.25
12	0.10	2.0

TABLE 3. Load Data for 13 Bus System

Load points	No. of customers	Demand(Kw)
2	100	1000
3	200	2000
4	300	3000
5	200	4000
6	300	5000
7	100	2000
8	400	3000
9	100	1000
10	200	4000
11	300	1000
12	100	2000
13	400	1000

A. *Conclusion for 13-bus system*

From *Fig. 3* after 7 switches the variation in SAIDI is negligible. From Fig 4 after 7 switches profit is comparatively less and we can also conclude that seven switches in this

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system give best result. So for 13-bus system seven switches can be placed to get maximum reliable supply and more profit. Table 4 shows the result obtained using PSO. From graph it is clear that SAIDI decreases as switch increases but after 7 switches variation in SAIDI is very less. The profit also decreases after 7 switches and no more rapid variation in profit. Reliability of system is also good. There is very little variation of profit with swarm size as shown in fig. 6.

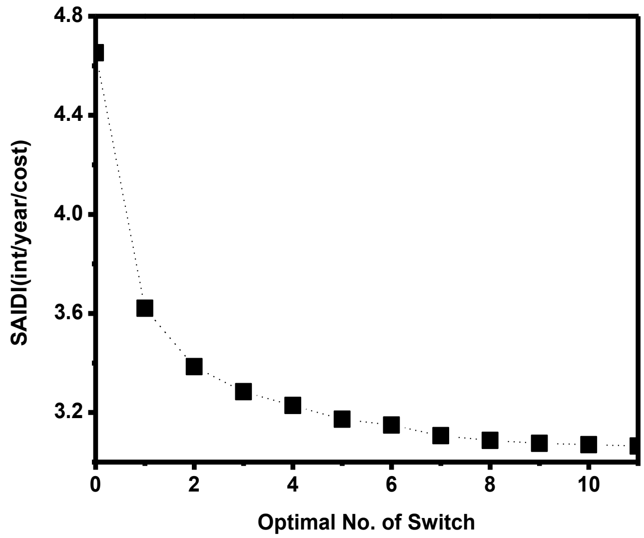

Figure 3. SAIDI vs Optimal Switch

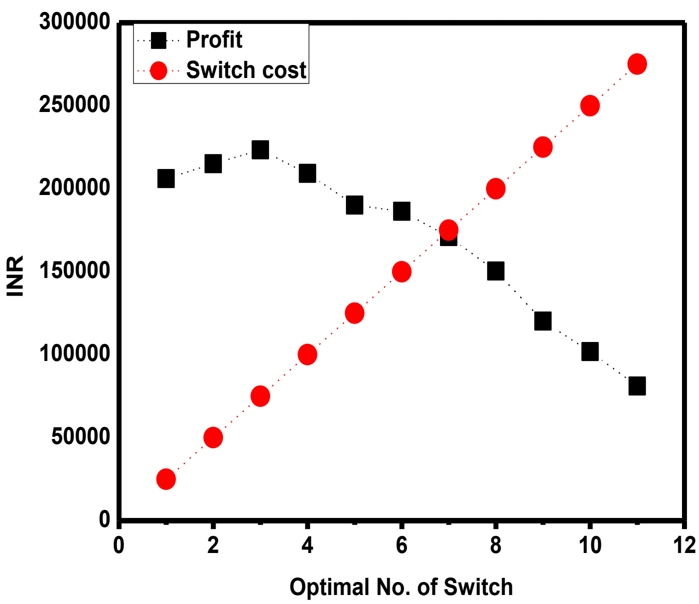

Figure 4. Variation of Profit vs Switch

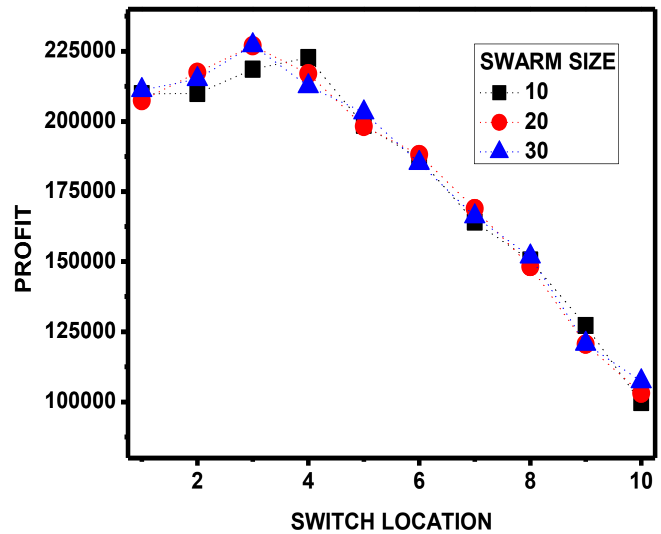

Figure 5. Variation of Profit with Swarm Size

TABLE 4. Result for 13 Bus System

No of switch	ENS	SAIDI	Profit (PSO)
0	122400	4.6525	0
1	91875	3.6213	209878
2	87150	3.3852	209994
3	85500	3.2838	218568
4	83500	3.2283	222731
5	81250	3.1727	198637
6	80875	3.1271	186882
7	79775	3.1065	164123
8	79437.5	3.0871	150528
9	79087.5	3.0815	1272220
10	78637.5	3.0760	99721
11	78337.5	3.0704	82761

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