Enhancement of Reliability and Loss Reduction with Distribution Switches Upgrade by Network Reconfiguration

A.Jyothirmaye[1], A.Sowjanya[2]

[1] Assistant professor, Dept of EEE, KKR & KSR Institute of technology and science, Andhra Pradesh, India.
[2] Assistant professor, Dept of EEE, Guntur Engineering College, Andhra Pradesh, India.

Abstract - *This paper presents an economic study to find loss reduction technique on the switches that should participate in a switch upgrade plan, based on the results of reconfiguration. The general reconfiguration problem trend considers only one loading condition (mostly maximum demand), in order to find the optimum reconfiguration. However, as the distribution loading condition has hourly and daily fluctuations, the optimum configuration continuously changes. More overly, considering only one loading condition might lead to inefficiency of the results. In this paper, daily load curves of different types of distribution consumers, during various types of days (weekdays and holidays) and seasons (summer and winter), are used to obtain the best reconfiguration hours during a day. Then, genetic algorithm (GA) is used to obtain the optimum configuration during each time interval. The objective function applied to GA consists of loss and energy not supplied. The switches that contribute to reconfiguration should be remotely controlled in order to have the capability of immediate mode alteration. In order to evaluate the feasibility of automated switch installation, the benefit-to-cost ratio is calculated. The entire procedure is applied to a test distribution system, and the results are evaluated and discussed in this paper.*

Key Words: **Benefit-to-cost ratio, daily load curve, distribution reconfiguration, reliability assessment, remotely controlled switches.**

1.INTRODUCTION

As a high proportion of electrical energy is dissipated in distribution systems, the reduction of distribution loss has always been one of the primary issues for economical operation of these systems. One of the solutions, which has been pro-posed in order to decrease distribution loss, is feeder reconfiguration, which is implemented by closing a number of normally open switches and opening the same number of normally closed switches, so that the radial structure of the system is preserved. Since distribution feeders are composed of different types of consumers and the daily load patterns of these types of consumers are different from each other, system reconfiguration is capable of loss reduction by transferring the load from heavily loaded feeders to other feeders and balancing feeders' load.

The electric power distribution systems consists of groups of interconnected radial circuits and have a number of constraints like radial configuration, all loads served, coordinated operation of over current protective devices, and voltage drop within limits etc. Each feeder in the distribution system has a different combination of commercial and industrial type of loads, with daily load variations. Due to uncertainty of system loads on different feeders, which vary from time to time, the operation and control of distribution systems is more complex particularly in areas where the load density is high. Power loss in distribution network will not be minimum for a fixed network configuration for all cases of varying loads.

Most of the literature on distribution reconfiguration has ignored load variations in its studies. However, this issue seems to be important, as distribution loads experience daily and seasonal variations. The authors of [1] have considered load variations in their annual recon figuration scheme. Their proposed method is composed of two steps. In the first step, the best configuration for each day of the year is found, by means of the harmony search algorithm and graph theory. Since the optimization is run for different loading conditions, a number of efficient system configurations are found in this step. In the next step, the year is divided into a number of periods with equal length. The dynamic programming algorithm is then applied in order to find the optimum configuration for each period. The candidate configurations, which are needed to run dynamic programming in each period, are chosen from the con figurations which were found in the previous step for different days. Bouhouras and Labridis have considered the available load data for their test system as the mean values and modeled load variations using uniform distribution [2]. They concluded that the difference between the configurations obtained for different loading conditions lies in switches that are not far from each other. In other words, there are groups of adjacent branches, so that for each loading condition, one branch in each group should be open. These results have been applied in [3] in order to select the switches that should become automatic. The authors of [4] have considered three cases: 1) hourly reconfiguration; 2) keeping a fixed con-figuration for the system based on the recon figuration results for peak loads; and 3) keeping the optimum configuration for average loads as the fixed configuration. They have concluded that the second and third cases are preferred to the first one, since it avoids the disadvantages of frequent switchings. The results of [5] reveal the efficiency of assuming load variation over time, during the optimization process; but keeping the best configuration throughout the whole planning period and, thus, preventing switching actions. In [6], short -term reconfiguration is performed, using daily load curves. For long-term reconfiguration, the authors have used an equivalent loading condition for each day. This equivalent loading, which is one of the 24 -hourly loadings of the day, is calculated so that the difference of loss obtained using the equivalent loading and actual hourly feeder loading over 24 h is minimized.

The tie switches are used not only for loss reduction purposes, but also for power restoration after fault occurrences. Hence, the location of these switches could have substantial effects on reliability indices, which led us to consider loss and reliability indices in this paper. A number of previous studies have considered loss and reliability in reconfigurations. For instance, in [7], a multi-objective optimization is performed considering switching cost, loss, and reliability cost to determine the best configuration of the system. The reliability cost is simply modeled by omitting the effect of tie switches. Binary particle swarm optimization is used in [8] to solve the distribution system reconfiguration problem as a multi-objective problem, where the power losses are minimized and reliability at load points is maximized. The reliability assessment is done by using probabilistic reliability models of components and implementing the minimal cutset method. A reliability oriented reconfiguration is done in [9], where the system average interruption frequency index (SAIFI) and system average interruption duration index (SAIDI) are used. The authors of [10] have considered reconfiguration for loss minimization aims. Though their objective does not include reliability improvement, they have shown that the system reliability improved due to reconfiguration.

In this paper, we considered daily load curves of different types of consumers in order to find reconfiguration hours during a day. Moreover, different types of days, that is, summer week-days, summer holidays, winter weekdays, and winter holidays are studied in order to find the switches that contribute to recon-figuration during each of these typical days. The objective function for finding the best configuration is composed of loss and energy not supplied (ENS). Based on the results of reconfiguration, the switches that should contribute to reconfiguration are found. Finally, a cost - benefit analysis is run in order to find out whether the benefits of installing remotely controlled switches can justify its cost or not. It is assumed that the system is not automated and the study is to survey the feasibility of automating some of the switches. Furthermore, in this study, the calculations are based on an offline procedure.

This paper is organized as follows: the next section explains the time-varying load model and the proposed technique for finding reconfiguration hours. Section III presents the objective function for reconfiguration, including loss and reliability. Section IV explains the genetic algorithm (GA) and benefit-cost analysis. In Section V, the method is applied to a distribution test system and the results are discussed. Finally, the last section presents the concluding remarks.

2 TIME-VARYING LOAD MODEL

In this study, different types of distribution consumer loads (i.e., residential, commercial, and industrial) were considered. Furthermore, the days of the year were divided into four categories: a) summer weekday; b) summer holiday; c) winter weekday; and d) winter holiday.

Since the daily load curves of distribution loads have time variations, the optimum configuration of the system constantly changes. However, reconfiguring the system based on an hourly schedule might not be logical, since:

- it needs quite a large number of switches to be remotely controlled, which is not economical;
- every switch has a maximum number of permissible switching operations during its lifetime, and frequent switching actions will decrease the switch's life expectancy.

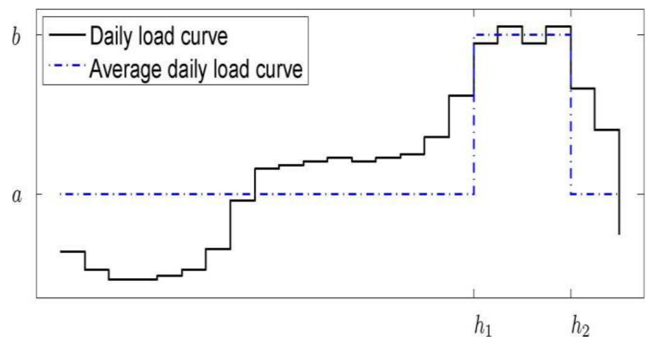


Fig. 1. Typical scaled daily load curve.

- every reconfiguration might lead to load interruption for a short period; this short interruption is negligible for most distribution loads; however, some industrial loads might not tolerate it in case it repeats a lot;

- it might lead to transient problems [5].

On the other hand, the systems that experience unfrequented reconfigurations mainly work far from their optimum state. For determining the best time of reconfiguration during a day, imagine that the scaled daily load curve of a distribution system is as shown by the solid lines in Fig. 1. In order to reconfigure the system less than 24 times a day, the 24 -h period is divided into a couple of intervals. The number of intervals is a tradeoff between the optimum reconfiguration and the number of switchings, and can be modified after benefit- cost analysis is executed. Let us divide the 24-h period into two intervals as illustrated in the figure. Hours h_1 and h_2 are calculated so that the term $|a - b|$ is maximized, where a and b are the average of load values during the first and second time interval, respectively. This technique is expected to reconfigure the system when the daily load curve of the system has its maximum changes. It is worth mentioning that in this study, the average of the load values is only used for obtaining the reconfiguration hours. To obtain the best configuration during each time interval, the exact load curve values are used.

3. PROPOSED ALGORITHM

3.1 Objective Function

Let time interval d of typical day i be divided into a set of 1-h periods, shown as $\{h_{i,d} h_{i,d} \ldots h_{i,d}\}$. In order to obtain the best configuration during this time interval, the following objective function is calculated for different radial configurations of the system and the configuration with minimum objective function is chosen:

$$f^{i,d} = \sum_{h \in \{h_1^{i,d},\ldots,h_n^{i,d}\}} \{W_L.\mathrm{ELoss}^h.E^h + W_R.\mathrm{ENS}^h.VOLL\}, \quad (1)$$

where ELoss_h is the total distribution energy loss through lines during hour h; E_h is the energy price during this hour; n_d is the number of time intervals during a day, which is calculated using the technique previously presented; and VOLL is the average value of lost load. W_L and W_R are the weighting factors given to energy loss and reliability index, which make it possible to give preference to one of them over the other. In case the loss optimization is more important than the reliability improvement to the system operator, W_R should be larger than W_L. Otherwise, W_L should be bigger. They could be obtained using methods, such as the analytical hierarchy process [11]. ENS_h is the energy not supplied, which is obtained as

$$\mathrm{ENS}^h = \sum_D U_D^h P_D^h, \qquad \forall D \in \{\text{load points}\} \quad (2)$$

This optimization is explicitly done for all of the typical day types (i.e., summer weekday, summer holiday, etc.).

Since the search space for finding the network configuration that minimizes the mentioned objective function is large and the problem is nonlinear and non-convex, heuristic methods should be applied. In this study, binary GA(genetic algorithm) is used, which is further explained in Section4-A.

The energy loss considered in (1) is solely the proportional technical distribution energy loss, which is due to distribution lines. Hence, it is calculated as

$$\mathrm{ELoss}^h = \sum_{b \in B} r_b \left|I_b^h\right|^2, \quad (3)$$

here r_b is the resistance of branch b; I_h is the rms value of the current through the branch during hour h obtained running power flow; and B is the set of all of the distribution system branches.

3.2 Reliability Assessment

A wide variety of reliability evaluation methods has been developed so far [12]–[15], such as state and path enumeration methods, failure -mode-and- effect analysis (FMEA), minimal cut -set method, and Monte Carlo, to name a few. In this paper, a combination of the minimal cutset method and FMEA is used for reliability assessment of radial distribution systems, which gives us the opportunity to simply model the behavior of the tie switches, when faults occur, and considers the stuck probability of switches as well. The following three steps illustrate the reliability evaluation method used in this paper.

1) Minimal Cutset Determination: Starting from load points, searching the upstream node will give us the minimal path of the source node to the load points. The radial configuration of the distribution system guarantees that each node has only one upstream node. As a result, a recursive graph search algorithm can be used to obtain the minimal paths. For simplicity, each minimal path is identified by its switches. This procedure will specify the load points that will be interrupted due to the operation of a switch, which are the load points that have the switch in their minimal path.

After finding the minimal paths, minimal cutsets can be identified. Each minimal cutset is a set of system components, which has the following two specifications:

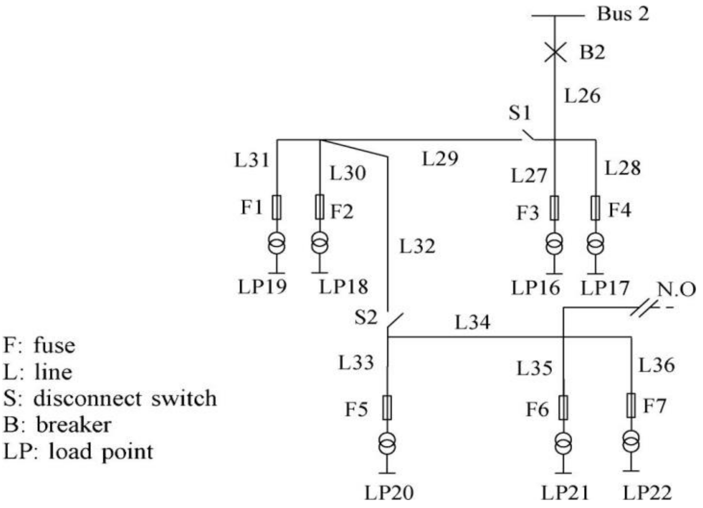


Fig. 2. One of the feeders of bus 2 of the RBTS test system and the minimal path of LP20 and the island corresponding to S1.

- a load point failure, when all of the components of the cutset are in outage;
- load point failure does not occur, in the case where at least one of the cutset components is operating.

In order to find the recoverable loads in case of each fault, a similar technique is used to find the shortest path between each tie switch and load point. Each load point can be restored by any tie switch, provided that the shortest path between the load point and the tie switch does not contain any normally closed switches or faulty elements.

For more clarity, this algorithm is applied to one of the feeders of bus 2 of the Roy Billinton Test System (RBTS) [16], which is shown in Fig. 2. In this figure, the minimal path of load point LP20 is B2, S1, S2, and F5. Considering S2 as a normally closed switch, the maneuverable load points by this tie switch will be LP20, LP21, and LP22, which are determined by finding the shortest path between S2 and the load points.

2) Finding Reliability-Network-Equivalent: In this step, the number of system components is reduced, by transforming a proportion of the system to an equivalent component. A similar method can be found in [14]. The elements, whose outage causes the operation of the same protection devices, are called an island. The elements of an island are considered as an equivalent element, and their equivalent reliability parameters are obtained. Finding system islands reduces the calculation time of the next step, that is, FMEA, due to decreasing the size of the system. In Fig. 2, L29, L30, L31, and L32 make an island, since the outage of any of them results in opening S1.

3) FMEA: FMEA is based on examining all possible failure modes and their effects on the system. Minimal cutsets make it possible to survey the effect of each failure mode. Three types of outages are considered for static components, which are: 1) active; 2) outage for preventive maintenance; and 3) transient. The active and transient failure of elements causes the operation of the primary protection system, whereas the other type of outage does not affect the protection system. The failure of switching elements is modeled based on the IEEE-493 standard [17], where the switches are assumed to have seven failure types. Four of these failure types are associated with the steady-state mode of switch operation, which are: 1) active; 2) transient; 3) outage for preventive maintenance; and 4) passive.

TABLE 1: Reliability indices of maneuverable an damaged load points

	Failure Rate		Average Annual Outage Time	
	due to fault isolation	due to system restoration	due to fault isolation	due to system restoration
maneuverable points	λ_{eq}	λ_{eq}	$\lambda_{eq} t_{aM}$	$\lambda_{eq} t_{aR}$
damaged points	λ_{eq}	0	U_{eq}	0

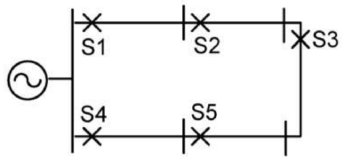


Fig. 3 Sample feeder

TABLE 2: Different chromosome structure and the Assigned States

Chromosome Structure	State Number
001	2
010	3
011	4
100	5
101	1
110	2
111	3

The passive failure is very similar to maintenance outage and models the cases when the normally closed switches open with no reason. Three other failure types are associated with the switches, which are modeled by their probability: 1) probability of failure to close on command; 2) probability of failure to open on command; and 3) probability of false operation.

As a result, the outage of each load point should be evaluated for all the three failure types of each static component, as well as all seven failure types of each switch, separately, which could take a lot of time.

When a fault occurs, the protection system isolates the faulty part by means of circuit breakers (CBs) or fuses. In a radial distribution system, the opening of CBs results in the interruption of all the downstream users. The faulted component is then isolated by opening the disconnectors on both sides. By closing the CBs and some of the normally open switches, the supply is restored to the unfaulty parts. Let us assume the entire process takes t_M . After the fault clears, the tie switches are opened, the disconnectors of the faulty part are closed, and the system returns to its normal mode. Let us assume the activities that are done after fault clearance, takes the time t_R. Consequently, in case a fault occurs in each of the islands detected in the previous step, the load points can be classified as one of the following three categories:

- Healthy points: The load points that are not affected by the fault. These points are the upstream nodes of a protection device. For instance, in Fig. 2, for a fault in the island

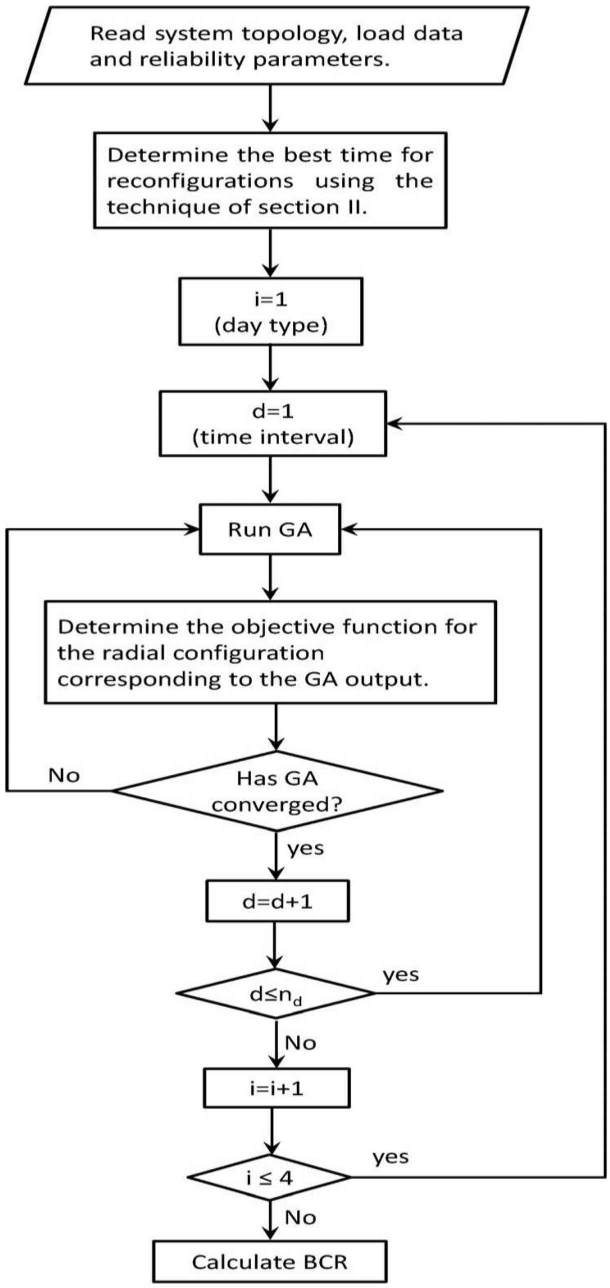


Fig. 4. Procedure for choosing the switches

Fig. 5. Single-line diagram of the test system

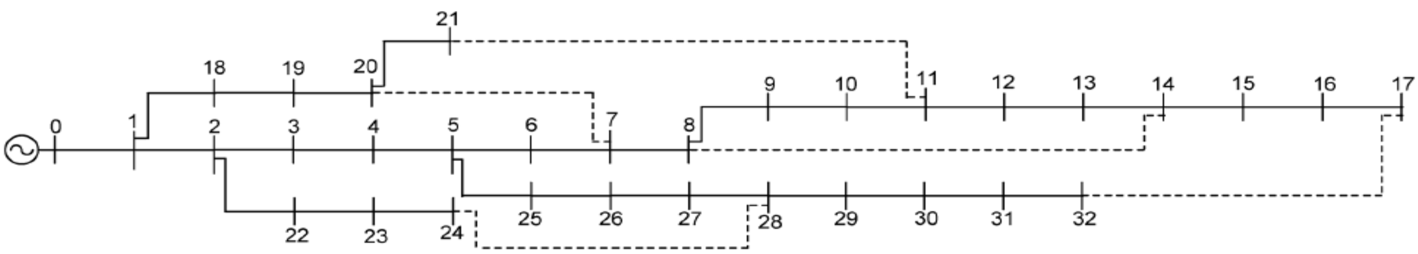


TABLE 3

Maximum Active and Reactive Power And The Percentage Of Different Load Types At Each Node

Node No.	P (kW)	Q (kVAR)	Load Type R	C	I	Node No.	P (kW)	Q (kVAR)	Load Type R	C	I
1	100	60	0	0	100	17	90	40	100	0	0
2	90	40	0	0	100	18	90	40	0	0	100
3	120	80	0	0	100	19	90	40	0	0	100
4	60	30	0	0	100	20	90	40	0	0	100
5	60	20	0	100	0	21	90	40	0	0	100
6	200	100	0	100	0	22	90	50	0	0	100
7	200	100	0	100	0	23	420	200	0	0	100
8	60	20	0	100	0	24	420	200	0	0	100
9	60	20	50	50	0	25	60	25	0	100	0
10	45	30	50	50	0	26	60	25	0	100	0
11	60	35	100	0	0	27	60	20	0	100	0
12	60	35	100	0	0	28	120	70	100	0	0
13	120	80	100	0	0	29	200	600	100	0	0
14	60	10	100	0	0	30	150	70	100	0	0
15	60	20	100	0	0	31	210	100	100	0	0
16	60	20	100	0	0	32	60	40	100	0	0

R: percentage of the node load dedicated to residential consumers
C: percentage of the node load dedicated to commercial consumers
I : percentage of the node load dedicated to industrial consumers

- Damaged points: The load points that belong to the faulty island. These load points should be interrupted until the re-pair or replacement of the faulty element finishes. The load points that do not belong to the faulty island and cannot be restored through maneuver actions are categorized as this type of load point too.

For FMEA, all of the islands detected in the previous step are considered faulty, one by one. Then, for each of the faulty is-lands, the load points are classified as one of the aforementioned categories. After load points classification, the interruption rate and average outage time indices of maneuverable and damaged load points can be obtained as shown in Table I.

The table I, λ_{eq} and U_{eq} are respectively, the equivalent failure rate and outage time of the island. As previously de-fined, t_M is the average time spent on isolation of the faulty points and restoring the healthy and maneuverable points; and t_{aR} is the average time spent for opening the closed tie switches and closing the isolation switches to transfer the system into its normal mode, after repairing or replacing the faulty element.

4. SOLUTION METHOD

4.1. Genetic Algorithm (GA)

The number of radial configurations of real systems is large. Hence, GA is applied in order to find the optimum configuration during each time interval, since it is considered to be an efficient method for large-scale combinatorial optimization problems. Besides, it has the benefit of avoiding being trapped in local optimums [18]. The algorithm used in this paper is binary GA.

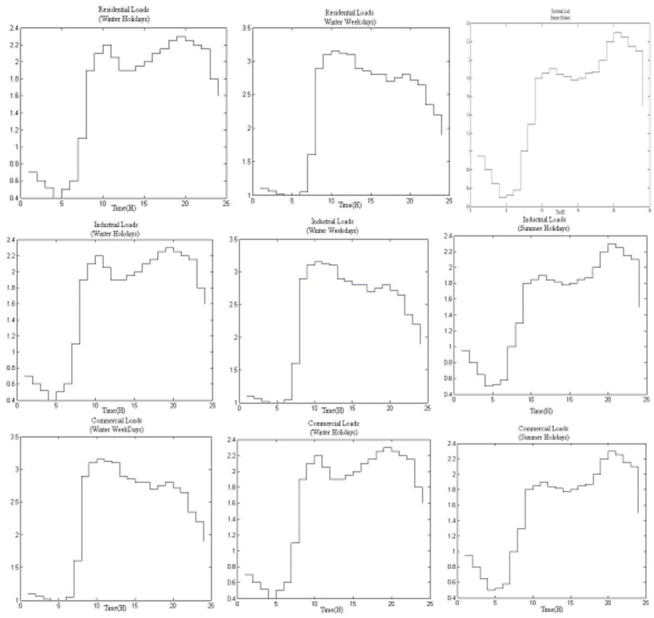


Fig. 6 Daily Load profile of different consumer types for different typical days of the year.

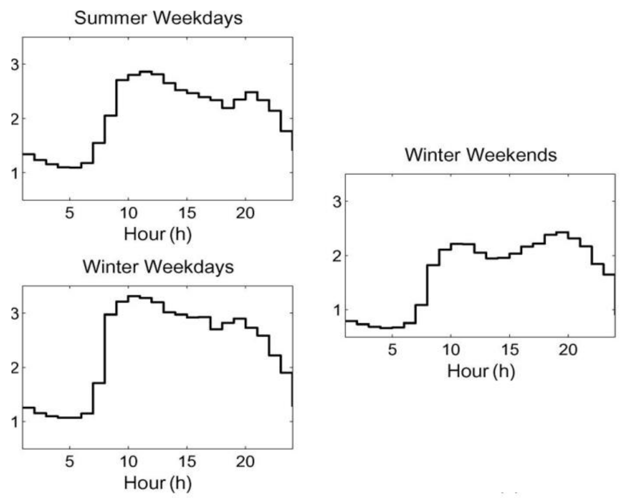


Fig. 7. Daily load curve of the main feeder during different seasons.

One of the techniques for applying GA, is to assign each bit of the chromosomes (0 or 1) to the status of one of the system switches. Then, a large objective function is assigned to the chromosomes that result in non-radial topologies, and are in-feasible solutions. However, this technique might lead to a GA

TABLE 4
RELIABILITY DATA FOR THE CASE SYSTEM

Equipment	λ_A	λ_P	λ_M	λ_t	R	R_M	P_S	P_C	P_O
Switches	0.004	0.002	1	0.06	4	72	0.001	0.06	0.001
Buses	0.001	0	1	0.01	2	8	0	0	0
Lines	0.065	0	0	0	5	0	0	0	0
Distribution Transformers	0.015	0	1	0	200	120	0	0	0

λ_A: Active failure rate in (failure/yr) for all elements and in (failure/(yr.km)) for lines
λ_P: Passive failure rate in (failure/yr) for all elements and in (failure/(yr.km)) for lines
λ_M: Maintenance outage rate in (outage/yr) for all elements and in (outage/(yr.km)) for lines
λ_t: Transient failure rate in (failure/yr) for all elements and in (failure/(yr.km)) for lines
R: Repair time of active and passive failures in hr
R_M: Maintenance outage time in hr
P_S: Probability of failure to close on command
P_C: Probability of failure to open on command
P_O: Probability of false operation

convergence problem. In this paper, a lookup table is used to as-sign each chromosome to one of the radial configurations. The number of bits per chromosome should be selected so that the number of chromosomes covers all of the radial configurations of the system. Assume the number of radial configurations of the system is k. Each chromosome of binary GA should have n bits, where n is the minimum integer number that satisfies $2n \geq k$. Imagine the binary value of a chromosome is m. In the proposed GA, this chromosome is assigned to the configuration corresponding to $(mMOD2n)\_1$, where m $MOD2n$ is the residue of dividing m by $2n$. This technique avoids getting caught up in local extremums. As an example, consider the sample feeder shown in Fig. 3. The system has five radial configurations. Let the configuration in which S1 is open be state 1, , and the con-figuration in which S5 is open be state 5. Table II demonstrates the lookup table for assigning chromosomes to different con-figurations. As can be seen, in order to be able to demonstrate five states, 3 b are needed $(5<23)$. Consequently, three extra chromosomes are found (8-5). One can assign a large objective function to these extra chromosomes, which might lead to convergence problems. In order to prevent this problem, these three extra chromosomes are assigned to three of the states. Hence, there will be three states of the system, each of which is as-signed to two chromosome structures.

By generating new chromosomes and calculating (1) for each one, GA will find the best chromosome, which is equal to finding the optimum radial configuration. The configurations that violate buses voltages or line loading limits are assigned large objective functions and are ignored. This procedure is independently repeated for all of the time intervals obtained in Section II. Hence, all of the switches that contribute to reconfiguration during different days and hours of the year are identified. These are the switches willing to be replaced by automatic ones, in case the costs are justified by the resulting benefits, which are discussed in the following subsection.

4.2. Benefit-Cost Analysis

In order to reconfigure the system immediately, all of the switches that contribute to reconfiguration during different time intervals should be remotely controlled. This will offer the following benefit to the distribution operator, over N years:

$$\text{benefit} = \sum_{\text{year}=1}^{N} \left[\frac{\sum_i n_i \sum_d \left(f_{\text{base}}^{i,d} - f_{\text{opt}}^{i,d} \right)}{(1+IR)^{\text{year}}} \right]$$

$$i \in \{\text{summer weekday, summer holiday, winter weekday, winter holiday}\}$$
$$d \in \{1, 2, \ldots, n_d\} \quad (4)$$

Where n_i is the number of days of the typica i; $f_{\text{base}}^{i,d}$ of is the value of objective function in case no reconfiguration is performed, and W_L and $f_{\text{opt}}^{i,d}$ are equal to 1; is the value of the

Optimum objective function in case no reconfiguration is performed and W_L and W_R are equal to 1; and IR is the interest rate. The term $(1+ IR)^{year}$ is encompassed in (4), in order to discount annual benefits to the present value. The mentioned benefits should justify the cost of remotely controlled switches, which is equal to

$$\text{cost} = SC.N_S + \sum_{k=1}^{N_S} \sum_{\text{year}=1}^{N} \frac{MC_k}{(1+IR)^{\text{year}}}. \quad (5)$$

In (5), SC is the capital cost of a remotely controlled switch considering the communication and measurement devices; N_S is the number of remotely controlled switches; and MC_k is the yearly maintenance cost of switch k, which increases as the number of switchings of the switch increases and, hence, is not equal for different switches of the system.

The benefit-to-cost ratio is simply obtained by

$$\text{BCR} = \frac{\text{benefit}}{\text{cost}}. \quad (6)$$

Assume $n_{\max}$ is the maximum number of allowable switching operations during the lifetime of a remotely con-trolled switch; and n is the number of yearly switching of the switch, obtained based on GA results. The switch lifetime in years (S_{life}) can be calculated as

$$S_{\text{life}} = \frac{\max}{n_{\text{op}}}. \qquad (7)$$

In order to evaluate whether installing remotely controlled switches is economically justifiable or not, S_{life} is calculated for all switches. Furthermore, investment return time, that is, the time when BCR starts to become more than 1, is obtained. In case investment return time is less than the minimum value of S_{lif} , the project lacks economical justification.

Fig. 4 demonstrates the procedure for selecting the switches that should become remotely controlled and its economical evaluation.

5. CASE STUDY

In this section, the proposed procedure is implemented on a 12.66-kV primary distribution system, whose single-line diagram is shown in Fig. 5. This system comprises 32 nodes,

TABLE 5: DAILY ENERGY LOSS REDUCTION AND ENS REDUCTION AND THE RESULTING BENEFIT

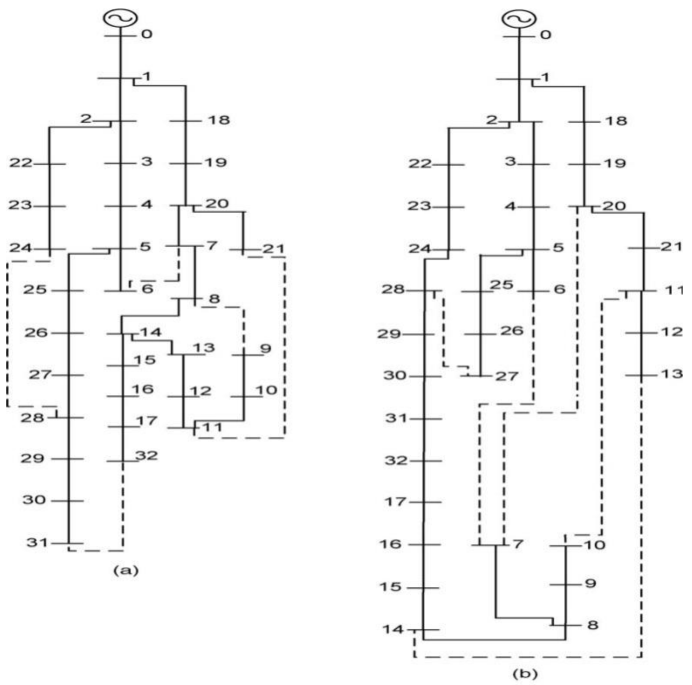
Type of Day		$W_L = 1$ $W_R = 0$	$W_L = 0$ $W_R = 1$	$W_L = 1$ $W_R = 1$
Summer Weekday	Loss (kWh)	817.12	-197.4	811.3
	ENS (kWh)	2.47×10^5	2.95×10^5	2.85×10^5
	Loss ($):	3.50×10^3	-3.03×10^3	2.02×10^3
	ENS ($):	1.66×10^5	1.98×10^5	1.92×10^5
Summer Holiday	Loss (kWh)	501.94	242.3	319.1
	ENS (kWh)	1.23×10^5	2.59×10^5	2.35×10^5
	Loss ($):	5.58×10^3	1.65×10^3	1.83×10^3
	ENS ($):	8.26×10^4	1.74×10^5	1.58×10^5
Winter Weekday	Loss (kWh)	1138.6	-677.9	-578.1
	ENS (kWh)	2.35×10^5	3.31×10^5	3.29×10^5
	Loss ($):	1.58×10^3	-2.91×10^3	-1.04×10^3
	ENS ($):	1.58×10^5	2.22×10^5	2.21×10^5
Winter Holiday	Loss (kWh)	619.3	554.7	568.2
	ENS (kWh)	2.02×10^5	2.56×10^5	2.46×10^5
	Loss ($):	1.66×10^4	2.51×10^3	5.97×10^3
	ENS ($):	1.36×10^5	1.72×10^5	1.65×10^5

5 tie switches, whose data can be found in [19], where it was initially presented by Baran and Wu. A CB is available on the line connecting nodes 0 and 1. Every line has a switch on its sending node.

Each load point of the system is assumed to be the combination of different consumer types, with the percentages shown in Table III. Typical load curves of different consumer types are as shown in Fig. 6. As illustrated in the figure, it is assumed that the loads profiles are not only different for weekdays and holidays, but also have seasonal variations. Consequently, four daily load curves are attributed to each consumer type.

The maximum value of the yearly active and reactive power demand of each node of the system is given in Table III. In order to obtain the active and reactive demand of each node at different hours of different seasons, the figures shown in Fig. 6 are multiplied by the values of Table III. In order to find the hours of reconfiguration, the load curves of the main feeder, which are shown in Fig. 7, are changed into the format described in Section II. The reliability data used for the test system are shown in Table IV [16] and VOLL is taken as U.S.$0.67/kWh [20].

In our case, four types of days and two time intervals for each of them were considered. Hence, the optimization problem had to be solved eight times, in order to obtain a yearly reconfiguration pattern. The MATLAB GA toolbox is used in order to obtain the switches that should be open to have an optimum objective function. Table V shows the result of optimization, when W_L and W_R are equal to 1. The generation and population size for GA are, respectively, set to 100 and 10. The stall generation of 70 is used as a stopping criterion, setting the objective function



(a): Considering only total loss improvement
(b): Considering only reliability improvement

TABLE 6

Hour	Open Branches in Summer Weekday	Hour	Open Branches in Summer Holiday	Hour	Open Branches in Winter Weekday	Hour	Open Branches in Winter Holiday
0–8	7–8, 13–14, 27–28, 29–30, 20–7	0–7	2–3, 6–7, 8–9, 11–12, 17–32	0–8	2–3, 8–9, 11–12, 20–7, 8–14	0–8	5–6, 8–9, 13–14, 2–22, 20–7
8–24	6–7, 9–10, 13–14, 27–28, 8–14	7–24	7–8, 12–13, 14–15, 1–18, 27–28	8–24	6–7, 11–12, 14–15, 27–28, 20–7	8–24	12–13, 27–28, 20–7, 8–14, 11–21

RECONFIGURATION HOUR AND OPEN BRANCHES FOR EACH TYPICAL DAY

tolerance to U.S.$1. Using a 2.63 GHz ($\times$ 2) Intel processor with 4 GB of memory, it takes about 3 h for the GA to find the optimum configuration. In each iteration, the average cumulative change in the value of the fitness function over generations becomes less than the objective function tolerance, which indicates the convergence of GA. The values of daily ENS and energy loss reduction and the benefit from ENS and loss reduction, for different values of weighting factors, are shown in Table VI.

Fig. 8 illustrates the effect of weighting factors alterations in the optimum system configuration. Configuration (a) is the optimum configuration when $W_L=$ 1 and $W_R=$ 0, and configuration (b) is the optimum system configuration for 0 and 1. In configuration (b), the tie switches are located so that the system is divided into three subsystems: 1) The first sub-system contains the lines from nodes 1 to 13; 2) the second one contains the lines from nodes 2 to 27; 3) the third one contains lines from nodes 2 to 14. As the figure shows, the tie switches are located in order to make a connection between different subsystems, and not the same subsystem. This will make the configuration more reliable in case of fault occurrences, since it gives the opportunity for the damaged load points to be supplied from an-other path. In configuration (b), the tie switches between nodes 10 and 11, nodes 13 and 14, and the one between nodes 7 and 20 connect subsystem III to subsystem I. The tie switches between nodes 27 and 28, and the one between nodes 6 and 7 connect subsystem III to II. In case a fault occurs in subsystem III, which contains a lot of nodes, this subsystem can be recovered through the tie switches, which makes configuration (b) a fairly reliable one. In contrast to configuration (b), configuration (a), in which only loss minimization has been considered, is not a reliable one. Confi- guration (a) is composed of three subsystems: 1) the lines from node 1 to node 32; 2) the lines from node 2 to 31; and 3) the lines from nodes 2 to 24. The tie switches between nodes 6 and 7 and the one between nodes 31 and 32 connect subsystems I and II, and the tie switch between nodes 23 and 28 connect subsystems II and III. However, the tie switches between nodes 8 and 9 and the one between nodes 11 and 21 connect the nodes inside subsystem I, which cannot help system restoration in the case of many fault occurrences. For instance, for a fault upstream node 8, the tie switch between nodes 8 and 9 cannot give us any reconfiguration opportunities for system restoration.

In order to calculate BCR, the energy price is assumed to vary as shown in Fig. 9, and the interest rate is considered to be 8%. Furthermore, it is assumed that the summation of the cost of an MV remotely controlled switch that can be operated 1000 times during its lifetime, and measurement and communication de-vices corresponding to that is U.S.$24 000 [3]. The base maintenance cost of the switches is assumed to be 0.05% of the switch cost and is considered to increase linearly as the switching frequency increases. Table VII shows the results of the economic study.

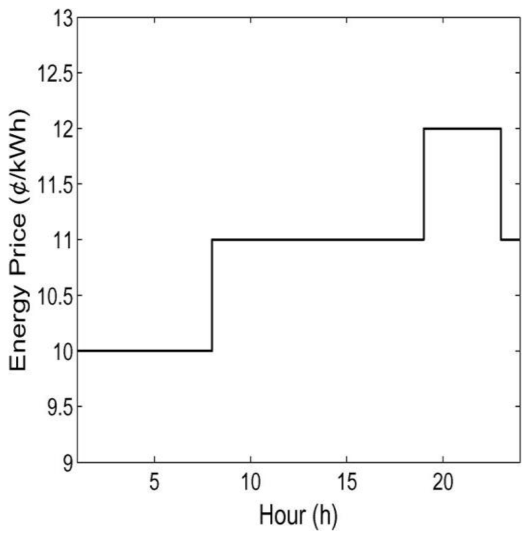


Fig. 9. Daily energy price curve.

TABLE 7
RESULTS OF THE ECONOMIC STUDY

	$W_L = 1$, $W_R = 0$	$W_L = 0$, $W_R = 1$	$W_L = 1$, $W_R = 1$
BCR for 1 Year	1.05	0.9881	0.9551
Total BCR During Lifetime	3.1282	3.9795	4.666
Lifetime	5.3763	4.2735	3.1847

6. CONCLUSION

In this paper, daily reconfiguration is assumed to be done for loss reduction and reliability improvement. GA was applied to find the optimum system configuration during each time interval. Based on the results of reconfiguration, the switches that need to become remotely controlled were found, in order to re-duce the switching time needed for daily reconfiguration. Finally, BCR analysis was implemented to investigate whether switch upgrade is profitable or not. The procedure is applied offline, based on load estimation results. Hence, there is no limitation on the calculation time. The successful implementation of the method on a test system was shown. The presented method could be extended to investigate the effect of uncertainty in load prediction.

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BIOGRAPHIES

Received M.Tech degree inPower system From RVR & JC college of engineering, in 2009. Currently working as Assistant professor, Dept of EEE, KKR & KSR Institute of technology and science, Andhra Pradesh, India.

Received M.Tech degree inPower system From VR e of engineering, in 2012. Currently orking as Assistant profesor, Dept of EEE, Guntur Engineering College, Andhra Pradesh, India.