Smart Distribution System Design: Automation for Improved Reliability

Ahmed R. Abul Wafa[1]

[1] Ain Shams University

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Abstract

The objective of the study is to assess the reliability of distribution system and suggest solutions of reliability improvement in smart grid environment. A feeder, which has high rate of interruption, is selected as case study, for reliability improvement measures. This feeder, having two sectionalizing switches with calculated reliability indices: SAIDI of 0.23774 hr/customer/yr and SAIFI of 0.11887 int/customer/yr. The corresponding cost of energy not served plus discounted cost of sectionalizing switches is 698.581 US/*yr.Ageneticalgorithmoptimizationtechniqueisdevelopedtoimproveautomation*, *reclosingandswitchingcap*

Index terms— reliability, smart grid, sectionalizers, ACR, and sectionalizing switches, GA optimization.

1 I. Introduction

n utilities, achieving Power distribution reliability has been very challenging issue due to various shortcomings of legacy distribution network: Radial distribution system is vulnerable to faults, supply and demand imbalance occurs, aging of system equipment and time taking fault locating mechanism. Such vulnerability of the system to disturbance has caused frustration in daily activity of the customer. Unpredictable and non-programmed power outage, and long outage duration has affected customer electricity consumption patterns. Hence, the reliability issue is still the basic challenge for power utility to meet the customers need. Upgrading of the legacy distribution system to smart distribution system to alleviate existing problems is the proposed solution of this paper.

Being reliability one of the core advantages of smart grid system, its implementation makes visible change in the system's reliable power delivery and operation. Implementation of smart distribution is not one step work but continual improvement. The aim of this paper is to study some of the features of smart grid to step up the legacy distribution system with an incremental step towards the smart distribution.

2 a) Objective

A feeder, which has high rate of interruption, is selected as case study, for reliability improvement measures. This feeder, having two sectionalizing switches with calculated reliability indices: SAIDI of 0.23774 hr/customer/yr and SAIFI of 0.11887 int/ customer/yr. The corresponding cost of energy not served plus discounted cost of sectionalizing switches is 1698.581 US$/yr.

The study looks into the current system's reliability issues, challenges and possible effective improvement areas and explore the implementation of smart grid features for alleviating the existing distribution problems.

A genetic algorithm optimization technique is developed and used to improve automation, reclosing and switching capacity of the feeder. The optimization resulted in new design of a sectionalizer, an ACR, and three sectionalizing switches integrated with the existing two sectionalizing switches. SAIDI value of 0.25001hr/customer /yr and SAIFI of 0.12301int/customer/yr for the feeder have been achieved. The corresponding cost of energy not served plus discounted cost of automation, reclosing and switching is 4598.100 US$/yr. Reliability improvement by each new device is also calculated.

3 b) Methodology

For this particular problem in power distribution reliability, the study goes through literature survey on smart grid reliability solution and come up with ideas of mitigating the problems.

Reliability investigation of the feeder, selected as case study area highlighted a highly pronounced interruption problems. Then, the study identified reliability solutions in smart grid environment. Finally, simulation for the identified solutions is made in Matlab R2016a environment using genetic algorithm optimization.

4 c) Literature Review i. Smart Grid on Distribution System

The smart grid resources [1,2] such as renewable resources, storage devices, demand response and electric transportation have impact on the distribution network load profile. Ultimate use of these resources reduces peak demand but the system will be operated near to peak demands overtime. This?????????? = ? ?? ?? ?? ?? ? ?? ??**(1)**?????????? = ? ? ?? ?? ?? (2)

where, ? i is average failure rate of load point i U i average annual outage time of load point i N i number of customers connected to load point i CAIDI and ASAI are directly obtained from SAIDI and SAIFI as:?????????? = ?????????? ?????????? ?**(3)**

According to IEEE Standard 1366-1998 [8] the median value for North American utilities SAIFI is approximately 1.10 interruptions per customer, SAIDI is approximately 1.50 hours and CAIDI is approximately 1.36 hours per customer.

But the problem with such reliability measures is that the load loss during outage is neglected. Moreover, a calculation of these indices is inconsistent. They don't show particular reliability measure in a bus but the system. For same number of interruptions in two systems, the reliability of the systems is affected by the number of customers. The more the number of customers, the lesser the reliability numeric value is obtained. Reliability measurement is also conducted from customer point of view. iii. Reliability Improvement Methods Reliability of distribution system can be improved by increasing distribution system protection, decreasing equipment failure, system automation, installment of reclosing and switching devices and system configuration [9,10]. System automation shorten interruption duration. Restoration time of momentary outage event will be small [11,12,13]. Similarly system configuration [14] produces effective improvement in reliability. Additionally, reclosing and switching devices provide patterns to help to localize fault points and disconnect faulted lines. This achieves pushing a fault event affect fewer numbers of customers only. Sectionalizing devices also enable way of choosing supplying path during contingency. The study considers automation, installment of reclosing and switching devices for reliability improvement.

One of the methods of reliability enhancement is increase in level of protection of distribution system. Increase in protection device gives option of selective protection system; thus, any failure in some part of distribution network may not affect other part of distribution portion [6]. Selective automation of distribution system can also improve the reliability of? ?? ?? ???????? = 1 ? ?????????? 8760 ?**(4)**

increases system's failure susceptibility. The congestion in grid interconnection with large number of line transfers reduces reliability margins. During failure, the system will be subjected to high tensions as it is almost operating at peak demand. At the peak demand, the fault correction time and tolerable error margins are very small leading to volatility of the system. Moreover, storage system, distributed resources are coordinated to achieve flat load profile almost near to the peak load demand which push maximum asset utilization [3,4]. Though such kinds of effects occur, the reliability of distribution system is improved for sure with implementation of smart distribution system [5]. Reliability modeling and analysis of the system can reveal how power exchange between utility and customer side is enhanced. Modeling of distribution system helps to undergo reliability analysis, risk analysis, contingency analysis and sensitivity analysis. Only reliability analysis [5] is the concern of this study.

5 ii. Reliability Analysis

Reliability of distribution system can be expressed numerically using reliability indices: System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), Customer Average Interruption Duration Index (CAIDI) and Average System Availability Index (ASAI).These quantities reveal the sustained interruption frequency and duration of interruption on monthly basis or annual calculations. Moreover, reliability analysis can also be conducted using failure rates and outage duration of system components [6,7]. The reliability data can be illustrated using geographical maps and histograms to have better visualization of distribution portions with good or bad outage experience.

SAIDI and SAIFI are the best known reliability measures [6]. They are calculated to display general reliability characteristics of a distribution system. distribution system by more than half by placing automatically controlled switch mid-way in the distribution system; any downstream fault away from the switch cannot affect customers in the upstream [15].

For momentary faults occurring in distribution system, installation of ACR in overhead lines can avoid sustained interruption by reconnecting outage line after self-clearing of the fault [12,6], and if the fault persists, it ensures power delivery to upstream part of the feeder. The reclosing device helps faults to self-clear before affecting upstream customers.

As explained above, network reconfiguration capability of a system enables customers' power access and reduction in un served energy of the system. Sectionalizing and tie switch system option create power path searching alternative with the existing laterals. This improves supply reliability and power availability. It's also related to fault searching mechanism with remote control capability to identify which line to connect and disconnect. The resulting reconfigured network can have multi-objective function such as achieving maximized reliability and reduced power loss [14].

6 iv. Reliability Analysis Methods and Optimization

Depending on the complexity of distribution system, reliability can be analyzed using various methods. Fault tree analysis and Markov analysis [16] method are two examples that have been used in reliability analysis for many years. The preference of one with respect to the other depends on how complex and time consuming the analysis could be [6,16]. In this study the reliability is evaluated in cut set level, based on Markov analysis.

7 a. Genetic Algorithm

The optimization Genetic Algorithm (GA) is used in this study to locate optimal placement of new automating, reclosing and sectionalizing devices for reliability improvement. GA is a technique of optimization based on natural selection of Darwin's theory of evolution. The theory lies in that selected initial random population with member individuals (chromosomes) can give new population with better fitness and selectivity. These individuals (chromosomes) are represented with binary string [17,18,19]. GA has the following main components: Representation, Selection, Recombination (Crossover and Mutation), and Fitness function.

The algorithm searches a location of automating devices (sectionalizing switches, ACR and sectionalizers) where reliability of distribution network can be improved. It carries out such optimization under reliability constraints targets. Every line segment in the distribution line is treated as candidate for placement of automating device. By evaluating the reliability of the system for different locations, an optimal point is obtained.

v. Contribution For reliability improvement, optimized locations for new switches installment are achieved under reliability constraint. Simulation results for the effect of the new devices are tested for reliability improvement. Reliability indices of the identified reliability improvement are be evaluated. Sectionalizer, automatic circuit recloser (ACR), and sectionalizing switches are integrated in the new design combined with existing sectionalizing switches. Objective function is composed of the combined cost of energy not served (ECOST) plus discounted cost of automation devices.

8 II. Current State of Study Distribution System

A site substation having five outgoing feeders at 15kV voltage level is selected. Out of these, the study feeder has the highest installed capacity as shown Table **??**. The whole distribution system has a minimum power factor of 0.8 and the outgoing line are drawn as uniformly sized conductors for analysis convenience. It is connected to other feeder in the substation and to feeders in neighboring substations through open tie switches.

9 Table 1: Feeder capacity

The paper assesses reliability improvement measure taken on the feeder, which can bring fair improvement in reliability of both to the feeder and to the substation. The feeder single line diagram with existing main CB and two sectionalizing switches is shown in Fig. 1 One line diagram of the study feeder Substation feeders have no standby networks through which alternative power supply mechanism can be reconfigured. If any fault occurs, loads downstream of the fault remain de-energized until fault is cleared. During fault occurrence, because absence of remote control mechanism and automated equipment, manual restoration is common practice which takes long time to reenergize disconnected lines. Additionally, the feeders has high frequency of interruption and it supplies the largest part of the energy from the substation. This is the reason why the reliability improvement study has focused on this feeder.

The interconnection with neighboring feeders has to be supported with adequacy and good reliability of the feeder, as any fault at it affects the other feeders as well. Making the feeder distribution mechanisms smart enhances power availability in the feeders, as neighboring feeders can share power with this feeder during contingency. This improves definitely the substations reliability.

10 III. Solution Options with Smart Grid Environment a) Objective

Smart grid uses technologies that have high performance in communication with control centers. They are remotely controlled. This feature has high importance in automation. The smart distribution is an evolution towards smarter power distribution with high flexibility towards controllability, monitoring and protection. The smart technology devices are superior in performance of communicating with system equipment, working reliably and making logical decisions in power system.

Examples of smart technology are Intelligent Electronic Device (IED), Phase Measurement Unit (PMU), Automatic Sectionalizer, Smart Re closer, and Sectionalizing and Tie Switches. IED, unlike the traditional devices such as remote control unit (RCU) and the general purpose programmable logic controller (PLC), they can adapt to the working environment [20].

11 b) Distribution Automation as Base Line for Smart Grid

Automation of distribution, reclosing and switching capabilities reduce the time duration an interruption lasts. If a fault persists for long time, autosectionalizing and auto-isolation of fault is carried out using switching and sectionalizing capabilities.

The automated switch avoids interruptions of customers due to faults in down streams of the switch. It being automated means momentary fault can't cause sustained outage and the switch can be operated from control centers. Installment of new devices for automation is important. Automation in distribution for this case is done either in the existing switch or placing new switch. Solution Options with Smart Grid Environment optimized location and connecting automating devices with it.

Placement of automating device is done using genetic algorithm assuming the line segments of the system as chromosomes of the algorithm. For each location, the feeder's reliability indices are evaluated to insure improvement in reliability. Reliability improvement in this section is assumed to be achieved by installment of suitable device from either of sectionalizer, ACR or sectionalizing switch. The reliability of candidates is Year 2016 **??**) and to equations (**??**), (6).F © 2016 Global Journals Inc. (US)

Fig. 2 is flow chart of algorithm solution. The algorithm starts by obtaining lines in mutual effect (cut sets). Mutual effect lines are segment of a feeder where any fault occurrence in some part the feeder affects customers of other mutually connected segments. Then, the algorithm puts devices in candidate segments. Reliability indices are calculated for the whole feeder with the new devices in the candidate segments. The resulting Reliability indices are compared to target reliability indices. The cost minimization process continues by placing either of sectionalizer, ACR or sectionalizing switch as long as SAIFI and SAIDI are within target limits. There are fifty candidate segments for device placement. Optimization of Reliability improvement with lower total cost of devices is simulated within reliability constraints. If the resulting SAIFI and SAIDI violate target limits, a new location for placement of devices and/or interchanging the type of devices is tested for better solution under the required reliability, the cost of installment is also minimized. In such a process, optimal solution of new device placement location is achieved. This flow chart algorithm is written into Matlab R2016a programming code and simulated. The objective of this simulation is to evaluate the redesigned distribution networks of the feeder for reliability improvement. It's to validate the design and test its implementation with software based analysis. Sectionalizers, ACR or sectionalizing switches placement optimization is simulated. The network design optimization and effectiveness is simulated subjected to reliability constraints. The simulation is implemented in Matlab R2016a version software using genetic algorithm.

12 a) Automation and Switching

In the existing network of the feeder, automation and switching capabilities are limited to substation circuit breaker and few (two) sectionalizing switches. The need for better reliability demands installment of recent technologies which can enhance system flexibility for quick restoration capability. In this section, placement of new devices is simulated to locate which line segments give best options to minimize the objective function subjected to reliability constraints. The target line segments are treated as candidate locations for reliability improvement test. Hence, any line segment resulting in system SAIFI and SAIDI indices that lies within the reliability target is chosen to placement of new device. Labeling of line segments starts from the substation and goes downstream. Line lengths of segments are measured from the smaller digit numbered node to the higher neighboring node. For instance, line segment L 2 is the length of line segment between nodes 2 and 3.

This simulation considers placement of sectionalizer, ACR or sectionalizing switch. Placement of Automating devices is made to either the newly placed switches or existing ones. Automation of switches helps to advance use of remote control capability by dispatch centers.

The problem of improving reliability by the use of reclosing and switching capability is subjected to cost of installation of new devices. The cost optimization is done under reliability target constraints to achieve reliability targets. The more devices used to reclosing and switching are placed in a feeder, the higher the reliability of the feeder will be, but the cost of installing new devices increases. ECOST is an item of optimization objective and cost of existing switches are deducted from the corresponding costs of the optimized solution.

13 b) Defined Genetic Algorithm Components

? Initial population: Fifty line segments are assumed as initial population for this optimization. These chromosomes are test points where new devices are placed randomely. 50x9 matrix of line segment make up the initial population. Line segment one is location of the circuit breaker. Therefore, other locations are in searching space of the optimization algorithm for placement of sectionalizers, ACR or sectionalizing switches. ? Representation of line segments: Line segments of the feeder are represented in binary string. Nine digits are used to number the location and the type of device that will be installed. The maximum line number is 50 and it can be represented in six binary digits. The whole string represents a chromosome of the population in the generation. Therefore, Single chromosome is made up of nine genes.?? 1 ?? 2 ?? 3 ?? 4 ?? 5 ?? 6 ?? 7 ?? 8 ?? 9 (**7**)

The six digits, B The way of combination of individuals in the population is based on one-point crossover. One portion genes of a chromosome are exchanged with another mate that gives rise to new chromosome. The combination assumes that variation in the last three genes can lead to the optimal solution. The crossover at this point enables alternative approach to installment of device at different location (chromosome).

Parent-1: 0 0 1 0 0 1 | 1 0 0 Parent-2: 0 0 1 0 1 0 | 0 0 0 Child-1: 0 0 1 0 0 1 | 0 0 0 Child-2: 0 0 1 0 1 0 | 1 0 0 Form of recombination:Child-1 = |geneparent1 geneparent2 | Child-2 = |geneparent2 geneparent1 |

where, the abbreviations stand for Geneparent1 -Genes from parent-1 Geneparent2 -Genes from parent-2

Six genes from parent one is placed in the first offspring and same from parent two in the second offspring. Gene exchange occurs after the sixth digit. The last three of the first parent is put into the second offspring and vice versa. Such combination is applied to consecutive chromosomes in the population. At first the initial population gives 50 new individuals and using selection function fittest ones are promoted to the next era. Matlab user defined function in m-file programming is developed for this recombination.

14 ? Mutation

In this optimization, a mutation probability of 0.08 is applied in the offspring. Alteration of genes brings about different placement location opportunity. This enables alternative way of checking reliability improvements due to installments of new devices. In each generation, the application of such mechanism develops chromosome fitness value to reach into the optimal locations of new candidate sections.

15 ? Fitness function

The objective of this optimization is to minimize the cost of installing new devices in the feeder. Cost optimization is done under reliability constraints. The objective function (8) for this optimization is taken for the cost values of installment of new devices stated as in [6] plus corresponding expected cost of interruption ECOST. The program analyzes the fitness value of only individuals whose B 7 =1 in their chromosomes. Sections having existing switch before this optimization are only provided to automating equipment installment. Hence for chromosome having B 7 =1, B 8 =0 and B 9 =0, for existing switch is deducted from the total sum of the optimized cost.???????????????? ?? = ?????? (?? ?? ?? ?? + ?? ?? ?? ?? + ?? ?? ?? ??) + ?????????? (8) Subjected to ?????????? ? 0.15 ??????/????????/????(**9**)

?????????? ? 0.25 ???/????????/???? (10) where, This optimization considers failure rate of lines, ACRs, sectionalizing switches and sectionalizers. For every generation, the reliability of the feeder is evaluated to see any improvement of the cost minimization process. Because of different individuals represent different line segments in a generation, it is the cumulative reliability of the system that corresponds to the cost minimization process. Hence by improving fitness values of chromosomes in a particular generation, the average reliability value of that generation can be improved. Therefore, a generation is considered instead of individuals. Reliability indices are evaluated for each generation to minimize the cost within the constraint.?????? = ??(1 + ??) ?? ((1 + ??) ?? ? 1) ?(**11**

To evaluate reliability of the system, the line failure and the portion of the feeder it affects is considered. Fig. 1 shows feeder line segments and labels of candidates for recruitment to new device installment.

The failure rates of newly installed devices are also assumed in each line segment. Failure rate data of new devices installed is assumed according to data values stated in [18]. Line sections and load points affected by upstream and downstream failure are exclusively and mutually grouped. First row of X 1 is the line segments in the feeder and the second row is load points (cut set) interrupted by any failure occurring in line segments. Because these load points are isolated using sectionalizing switch at line L 9 . It's to estimate the reliability of this portion according to how many customers are affected for each lines failure.

The same is true to node points between L9 and L21. Any failure in the upstream of these loads and within the section of L9 and L21 interrupts power to the section from substation to L21. Second row of X 2 is the load points (cut set) interrupted by any failure occurring in line sections in the first row. It shows failure in the upstream affects loads in the downstream but the reverse is not true. This optimization problem result shows line candidates for automation, reclosing and switching as shown in Table 2 Reliability improvement ideas are identified to reduce frequency of interruption and the time an interruption lasts. Utility reliability requirement is taken as bench mark to improvement, automation upgrade are designed using genetic algorithm as optimization tool. Reliability Improvements are designed under constraints of feeder reliability indices SAIDI and SAIFI. The study feeder is chosen for this implementation because of its high installed supply capacity and high record of interruption.

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The design considered cost minimization while improving reliability. A sectionalizar, an ACR and three sectionalizing switches are installed. The automation, reclosing and switching optimization simulation results are achieved at low annual extra cost. However resulted reduction in SAIFI and in SAIDI are not significant. This is because Substation feeders have no standby networks through which alternative power supply mechanism can be reconfigured. If any fault occurs, loads downstream of the fault remain de-energized until fault is cleared. This simulation took into consideration existing sectionalizing switches.

Genetic algorithm optimization is applied to search for optimal automation configuration for the network. The genetic algorithm is selected for this design because of its effective combinational searching and representation of potential candidates is easy. Type and location of automation devices (candidates) are represented only by binary coding. Besides, searching space of design candidates are improved through generations enabling rapid arrival to optimal targets using Matlab R2016a version software.

Genetic Algorithm can be implemented in reliability improvement of vast and complex distribution networks.

17 VI. Future Works

Distribution reliability improvement for the study feeder in smart grid environment is achieved by applying switching, automation and reclosing in the existing distribution system. Reliability data is analyzed Reliability improvement ideas are identified to reduce frequency of interruption and the time an interruption lasts. Utility reliability requirement is taken as bench mark to improvement, automation upgrade are designed using genetic algorithm as optimization tool. Reliability Improvements are designed under constraints of feeder reliability indices SAIDI and SAIFI. The study feeder is chosen for this implementation because of its high installed supply capacity and high record of interruption.

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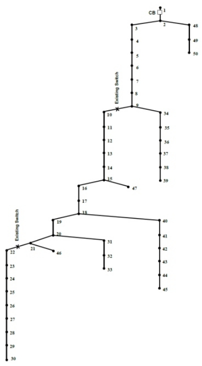
18 ACR



1

Figure 1: Fig. 1 :

[1] [2] [3]

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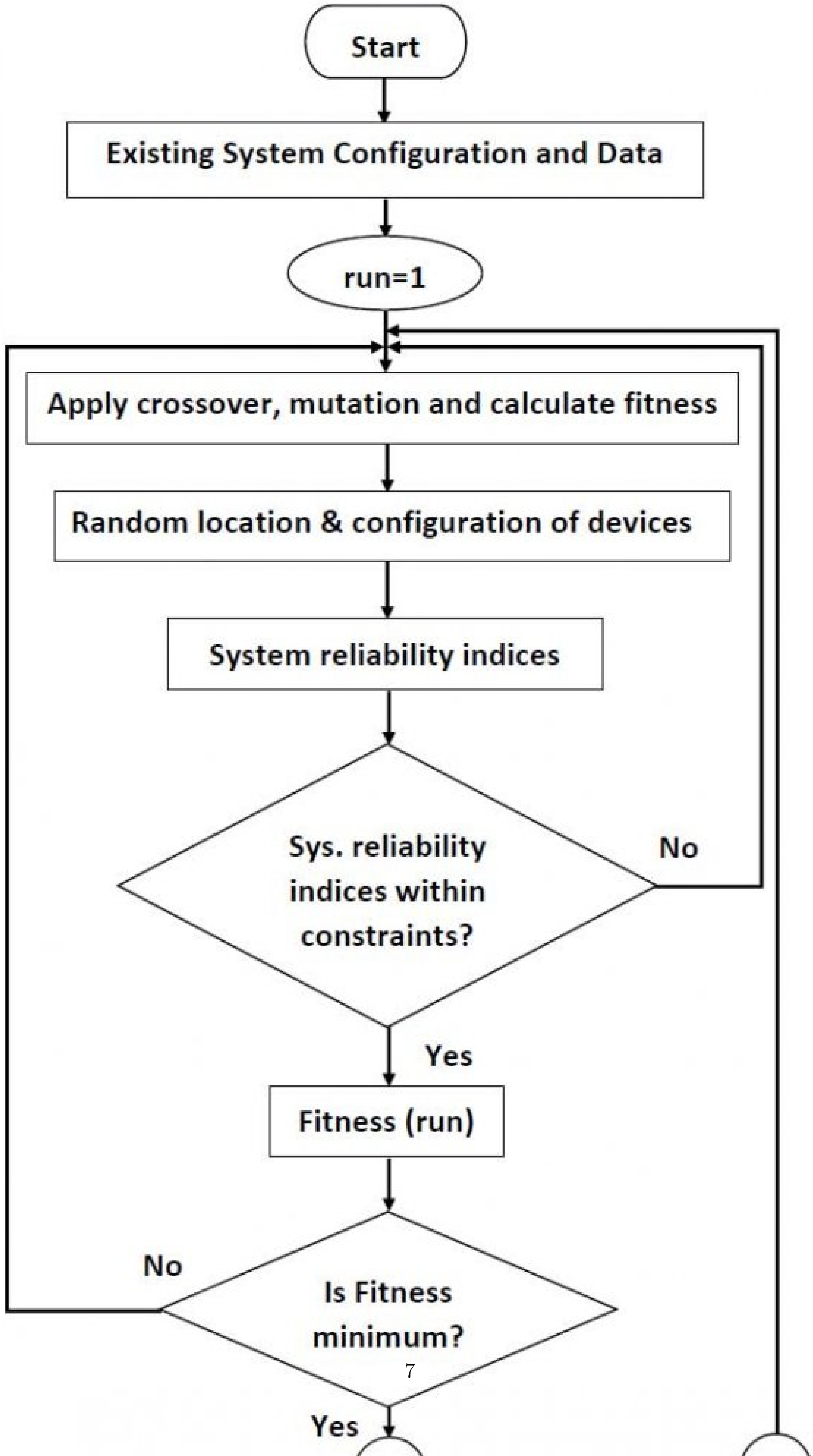
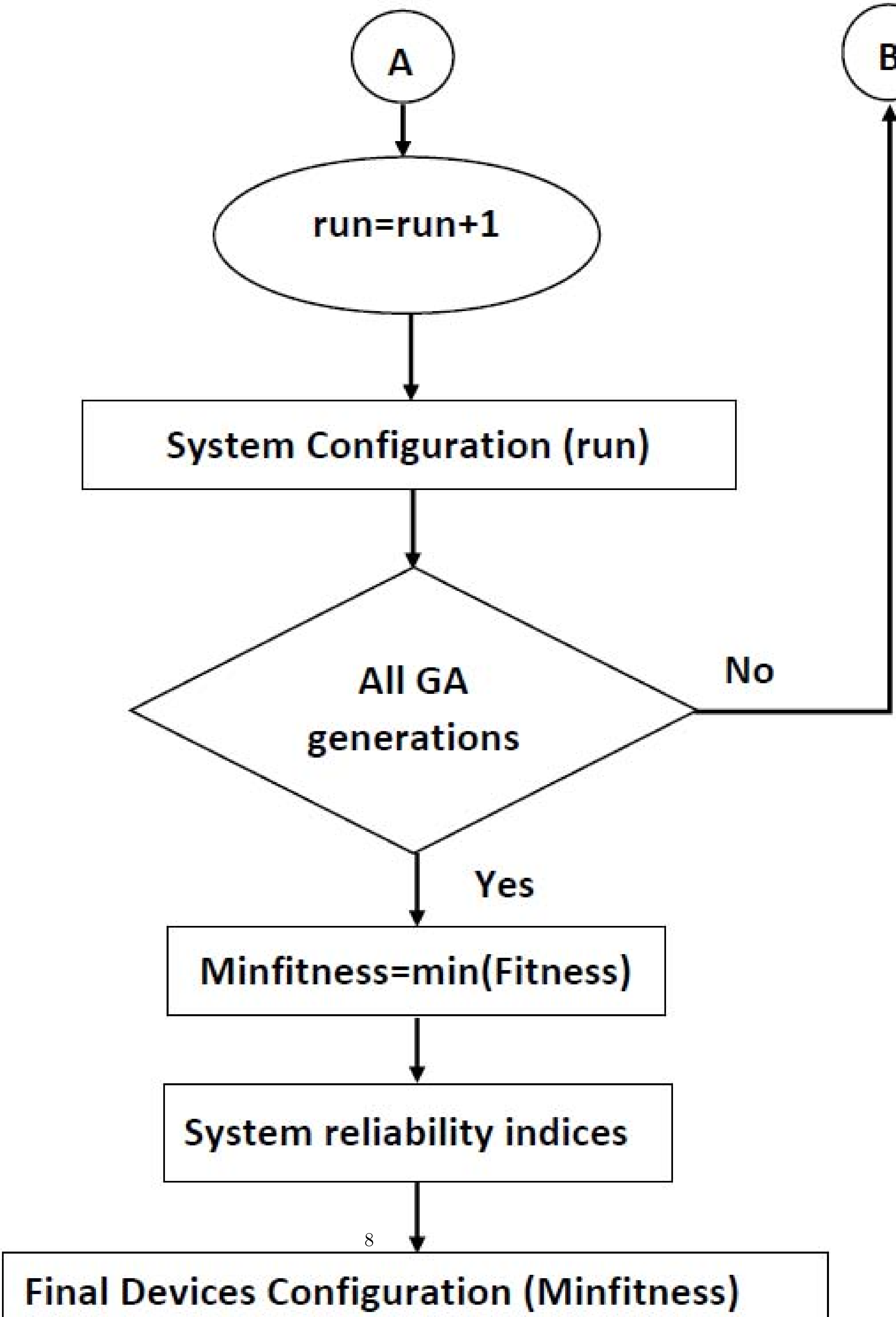
[2]Smart Distribution System Design: Automation for Improved Reliability © 2016 Global Journals Inc. (US)

[3]© 2016 Global Journals Inc. (US)


Start
Existing System Configuration and Data
run=1
Apply crossover, mutation and calculate fitness
Random location & configuration of devices
System reliability indices
Sys. reliability indices within constraints?
No
Yes
Fitness (run)
Is Fitness minimum?
No
Yes


A
B
run=run+1
System Configuration (run)
All GA generations
No
Yes
Minfitness=min(Fitness)
System reliability indices
Final Devices Configuration (Minfitness)

4

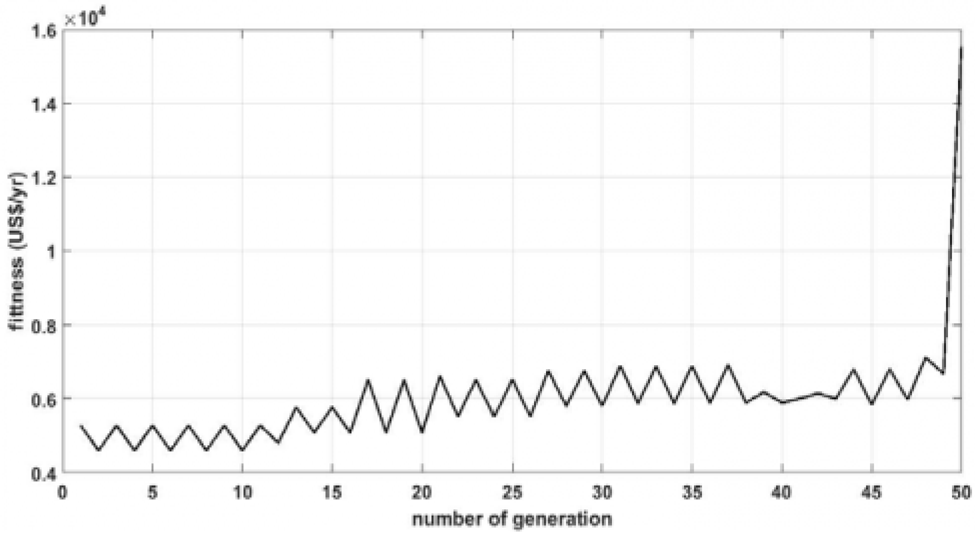
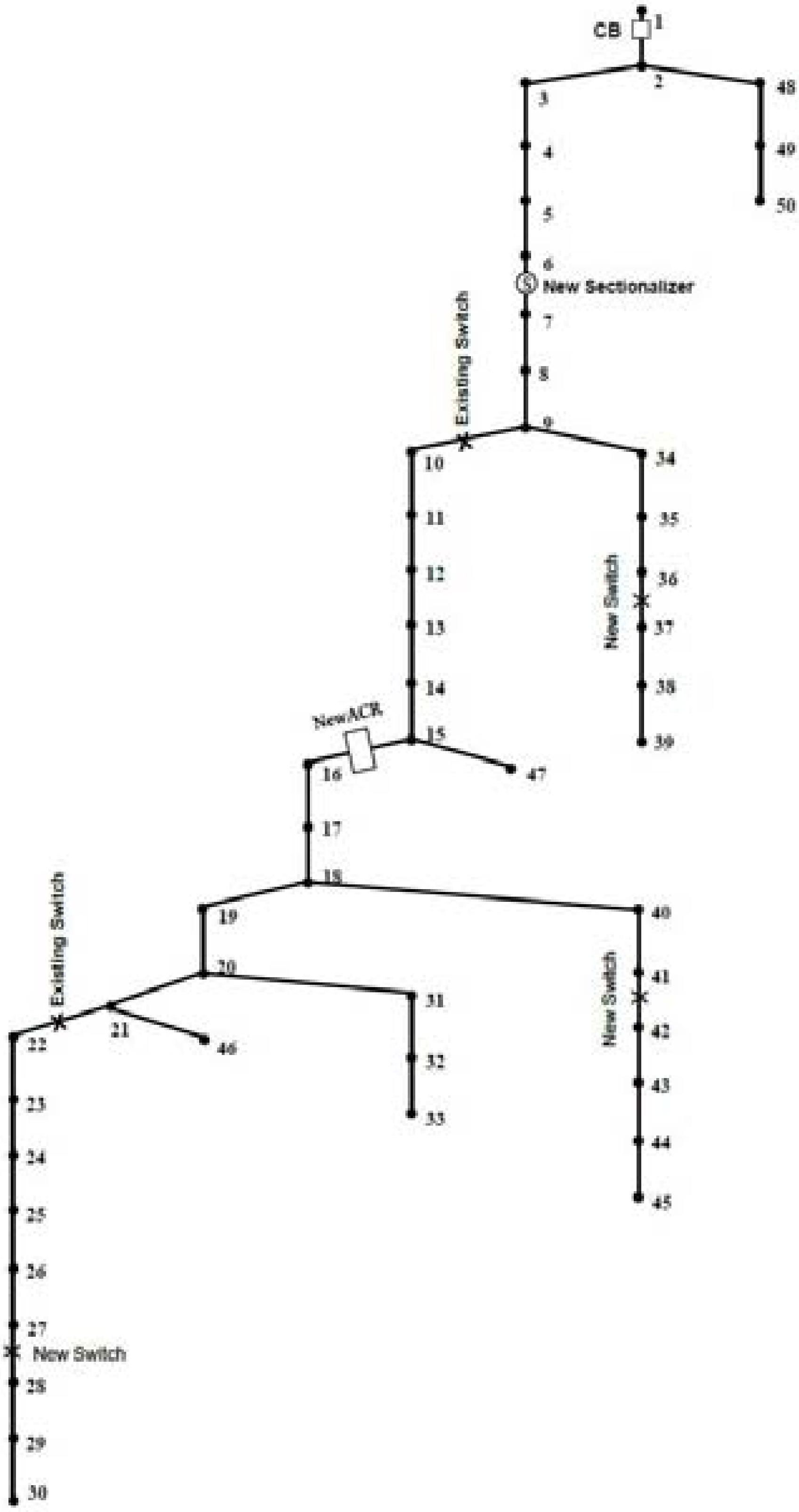


Figure 4: Fig. 4 :


CB
New Sectionalizer
Existing Switch
New Switch
NewACR
Existing Switch
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New Switch
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Figure 5: F

???????? = ? ? ?? ?? ?? ?? ?? ?? (5)

?? ??

(6)

?? ??

where

i	Outage source (line, transformer, switch, etc.)
k	Load point
L k	Average load at load point k
t i	Interruption duration by outage source i
?	

[Note: i Failure rate by outage source i]

Figure 6:

				F
Capacity (MVA)	Active power (MW)	Reactive power (MVAR)	No of transformers	No of customers
16.085	12.868	9.651	50	11235

Figure 7:

chromosome. B 9 =1 indicates automating device installment.

1. B 7 =1, B 8 =0, B 9 =1 represent the new device placed as sectionalizing switch that has automating equipment connected with it. If there is previously an existing switch, only automating equipment is required.

2. For B 7 =1, if B 8 =1, it represents new ACR is installed. B 9 , automating equipment, is required to enable remote-control capability of sectionalizing switches. It's not required if the installed device is an ACR. Therefore, in this case, the value of B 9 doesn't represent anything.

3. B 7 =0 shows that the status of B 8 and B 9 has no effect in the process. It means no device is installed. However, if an existing switch is there no matter the value of B 7 , the value of B 8 =0, B 9 =1 implies the existing switch is automated.

This way of representation is used for all of the fifty line segments. Line sections or chromosomes that have existing switch have initially B 7 =1 value. If no switch exists, B 7 =0. But after recombination, the value of B 7 can be changed, i.e., it can have value zero though a switch exists initially.

? Recombination

? Crossover combination

Figure 8:

2

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Figure 9: Table 2 :

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