

RELIABILITY ENHANCEMENT IN DISTRIBUTION SYSTEMS VIA OPTIMUM NETWORK RECONFIGURATION BY USING GRAVITATIONAL SEARCH ALGORITHM

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ABSTRACT: - Power system reliability is considered as one of the important power system operation issues especially in distribution system sectors. Sometimes power quality problems may cause sensitive equipments, especially modern products to malfunction and a process interruption leads to poor system reliability. Reliability improvement can be judged through monitoring certain indices. To enhance utility side reliability, distribution network reconfiguration is commonly used for the purpose of network loss reduction and other benefits. The main objective of this work is to propose a method, to assess and enhance distribution system reliability under optimal network configuration. The binary version of the gravitational search algorithm is used as a heuristic optimization tool to determine optimal solutions for the network reconfiguration problem. A section of Diyala governorate distribution system is considered in this work for a system case study. That section in Baqubah district consists of four 11kV distribution feeders with 116-buses. Implementation of the proposed method in the Baqubah sample system shows a significant reliability improvement.

Keywords: Network Reconfiguration, Reliability, Distribution Systems, GSA

1. INTRODUCTION

The power system is designed to provide sufficient electrical power supply to the customers in its area with an acceptable level of the supply reliability. The necessities of modern living press steadily towards more and more electrical power consumption with total dependence on electricity supply. The increasing customers demand along with advancements in science and technology shaped the industry and the customers to realize and acquire a high level of safety, quality and reliability. Moreover, the realization of such features should be at the lowest possible cost. Power utilities are pushed towards developing planning and operating enhancement techniques in order to satisfy the above mentioned features⁽¹⁾.

Distribution Network Reconfiguration (DNR) is one of the significant operational control techniques at distribution system sectors, which is defined as altering the topological structure of the distribution feeders by changing the open/closed status of sectionalizing and tie-switches⁽²⁾. It is a well-known fact that distribution systems at the low voltage levels are always of radial structure. In order to maintain such operation constraint, along with system loss minimization, reconfiguration is used. The main aims of reconfiguration are: System stays operatively radial, all loads are served, minimum losses, load balancing, minimizing voltage drops, improve system reliability.

A number of simple and complex methods, heuristics based methods were proposed in the literature to solve the reconfiguration optimization problems. These problems were formulated by single or multi-objective constrained cost functions. The progress in communication techniques, computer science and computational intelligence techniques makes the enforcement of network reconfiguration algorithms easier than before (3, 4, 5, 6, 7, 8).

2. RELIABILITY ASSESSMENT INDICES

The reliability assessment indices of distribution systems can be grouped into three categories, namely, load-related indices, continued interruption indexes, and short-term indices. ASIFI, MAIFI, and SAIFI can indicate load-related, continued interruption, and short-term indices, respectively, in reliability assessment. These indices are defined in the following equations (9):

$$ASIFI = \frac{\text{sum of connected KVA of load interrupted [Li]}}{\text{total connected KVAserved [LT]}} \quad (1)$$

$$MAIFI = \frac{\text{sum of costomer short-term interruptions}}{\text{total number of customer served [NT]}} \quad (2)$$

$$SAIFI = \frac{\text{sum of all customer continued interruptions due to each event}}{\text{total number of customers served [NT]}} \quad (3)$$

ASIFI can be used to indicate the financial losses caused by load outages, whereas MAIFI can be used to represent customer disruption because of protection-device operations. SAIFI can be used to indicate sustained customer interruptions.

3. MATERIALS AND METHOD

The necessary components required to perform DNR for the reliability improvement of system in this section describes. These components include the system interruption calculation, formulation problem for optimization, proposed optimization method, and procedure.

3.1 Determine the number of interruption and voltage sag

Number of interruptions and voltage sag propagation is dependent on the fault position in a system. To estimate the number of interruptions which reduce bus voltages below a certain magnitude, it is important to define the exposed length of a line and cables. The resulting exposed length can be multiplied by the fault rate (faults per km per year of the line or cable) to obtain the number of interruptions per year for all possible fault events. The possible events may represent all fault occurrences on lines, cables, transformers and buses. The fault rate, is λ_L for the faulted line, λ_C for cable, λ_T for distribution transformer (faults per transformer per year) and λ_B for system buses (faults per bus per year), can be expressed as follows:

$$f_L = \sum_{K=1}^4 \sum_{i=1}^{N_L} L_i \lambda_L F D_K \quad (4)$$

$$f_C = \sum_{K=1}^4 \sum_{j=1}^{N_C} L_j \lambda_C F D_K \quad (5)$$

$$f_B = \sum_{K=1}^4 \sum_{m=1}^{N_B} B_m \lambda_B F D_K \quad (6)$$

$$f_T = \sum_{K=1}^4 \sum_{n=1}^{N_T} T_n \lambda_T F D_K \quad (4)$$

Where k represents the three-phase, line-to-ground, line-to-line, and line-to-line-to-ground faults; N_L is the total number of lines in the system, N_C is the total number of cable, N_B is the total number of buses and N_T is the total number of transformer. The integers i, j, m and n are the fault type index, line number index, cable number index, bus number index and transformer number index respectively. FD is fault type occurrence distribution percentages are given in Table (1).

3.2 Distribution Network Reconfiguration (DNR)

DNR can be defined as a change in the topological arrangement of distribution feeders by altering the open/closed status of tie and sectionalizing switches. A feeder may either be partially or fully fed by an alternate feeder by activating a tie switch that connects both feeders. The appropriate sectionalizing switch must be deactivated to preserve radial structures ⁽¹¹⁾. DNR is commonly used to reduce system losses, balance loads, and enhance voltage fluctuation in power distribution networks.

DNR can also be used to alleviate interruptions and voltage sag propagation in the system. Several system buses occasionally encounter voltage sag when the fault occurs at certain buses. Thus, reliability system may be affected by faults. DNR is mainly used to reduce number of interruptions and propagated sags ($N_{int\&vsag}$) as well as reliability indexes, such as ASIFI, MAIFI, and SAIFI. Optimization methods are necessary to determine a suitable configuration that can achieve minimum interruptions and voltage sag count.

3.4 Gravitational Search Algorithm (GSA)

Rashedi introduced GSA in 2009, and was intended to solve optimization problems in power system. In GSA algorithm, the searcher agents are a collection of masses which interact with each other based on the Newton's gravity and the laws of motion ⁽¹²⁾. The steps of implementing GSA are as follows:

- Initialization of agents: consider a system with N agent. The positions of agents are initialized arbitrarily by:

$$x_i = (x_i^1, \dots, x_i^d, \dots, x_i^n) \quad i=1, 2, \dots, N \quad (5)$$

Where x_i^d represents the position of i^{th} agent in the d^{th} dimension.

- Fitness calculation: in minimization or maximization problems, the evolution of fitness is performed by evaluating all agents at each iteration of the best and worst fitness. In a minimization problem (such as the cases in this work):

$$\text{best}(t) = \min_{j \in \{1, \dots, N\}} \text{fit}_j(t) \quad (6)$$

$$\text{worst}(t) = \max_{j \in \{1, \dots, N\}} \text{fit}_j(t) \quad (7)$$

Where, $\text{fit}_j(t)$ represents the value of tested fitness for the j^{th} agent at iteration t , meanwhile the $\text{best}(t)$ and the $\text{worst}(t)$ are the best fitness and worst fitness values at iteration t .

- Computation of the constant (G) of gravitational: constant (G) of gravitational is evaluated at iteration t as:

$$G(t) = G_0 e^{(-\alpha \frac{t}{T})} \quad (8)$$

Where;

G_0 and α are initialized at the start and will be reduced with iteration to control the search precision. T is the total number of iterations.

- Agent masses computation: gravitational and inertia masses for each agent are calculated at iteration t .

$$\text{Let } M_{ai} = M_{pi} = M_{ii} = M_i, \quad i = 1, 2, \dots, N$$

$$m_i(t) = \frac{\text{fit}_i(t) - \text{worst}(t)}{\text{best}(t) - \text{worst}(t)} \quad (9)$$

$$M_i(t) = \frac{m_i(t)}{\sum_{j=1}^N m_j(t)} \quad (10)$$

M_{ai} and M_{pi} are the active and passive gravitational masses respectively, while M_{ii} is the inertia mass of the i^{th} agent.

- Agent Acceleration computation: acceleration of the i^{th} agents at iteration t is computed.

$$a_i^d(t) = \frac{F_i^d(t)}{M_{ii}(t)} \quad (11)$$

$F_i^d(t)$ Represents overall acting force on i^{th} agent, it is calculated as:

$$F_i^d(t) = \sum_{j=1, j \neq i}^N \text{rand}_j F_{ij}^d(t) \quad (12)$$

The k best is the first k agents set with the best value of the fitness and biggest mass. During iteration, k best will decrease linearly; where obtained results at the final will present only one agent can stratify force to the another. $F_{ij}^d(t)$ is calculated as the

$$F_{ij}^d(t) = G(t) \frac{M_{aj}(t)M_{pi}(t)}{R_{ij}(t) + \epsilon} (x_j^d(t) - x_i^d(t)) \quad (13)$$

F_{ij}^d is the force effective on agent i from agent j at d^{th} dimension and t^{th} iteration. $R_{ij}(t)$ is the distance of Euclidian between any two agents such as i and j at t degree of iteration. $G(t)$ is the calculation constant of gravitational at the same t degree of iteration, while ϵ is very small constant.

- Velocity agents and positions: In the binary of GSA which is the similarity as that of PSO,

$$v_i^d(t+1) = \text{rand}_i \times v_i^d(t) + a_i^d(t)$$

$$x_i^d(t+1) = x_i^d(t) + v_i^d(t+1)$$

a normalized function referred to as sigmoid function $S(v_i^d)$ is used to transfer v_i^d into a prospect function. The function $S(v_i^d)$ which is in the interval of $(0, 1)$ is given by,

$$S(v_i^d(t)) = 1 / (1 + e^{-v_i^d(t)}) \quad (14)$$

Once $S(v_i^d(t))$ is computed, the new next positions of the agents will be reached according to the following rule,

$$x_i^d = \begin{cases} \text{comp}(x_i^d(t)) \rightarrow \text{rand} < S(v_i^d(t+1)) \\ x_i^d(t) \rightarrow \text{els} \end{cases} \quad (15)$$

3.5 Objective functions and constraints

The purpose of the optimization is to determine a suitable DNR that can reduce $N_{\text{int\&vsag}}$ and reliability indexes. The cost function to be minimized can be mathematically expressed as: $\text{Min}(C = N_{\text{int\&vsag}})$

Optimization solution is subjected to the operation constraints for distribution network; the distribution network should be in a radial structure, all the load points and system buses must be in connection state. The buses voltages magnitudes should be within standard nominal limits, the lines loading of flowing currents must be within the standard thermal limits of the lines, system line loss must be within acceptable limits.

3.6 GSA implementation for optimal DNR

On the basis of the objective functions and constraints indicated in Section 3.4, reconfiguration can be performed by changing the predefined status of the tie and sectionalizing switches in the distribution network. $N_{int\&vsag}$, ASIFI, MAIFI, SAIFI, are calculated by using the short circuit analysis and steady state load flow algorithm in MATLAB environment for every modification in network configuration. An encoding and decoding technique presented by Salman et al.⁽¹³⁾ is used to avoid generating unfeasible solutions as a result of system constraints on the initial random population during optimization. Only feasible configurations are generated by radial structures in the encoding technique. The main binary string is deconstructed into the original substrings in the decoding technique, and the binary number of each substring is changed to a decimal number that represents the open switch location in the corresponding loop⁽¹³⁾. Additional details regarding the encoding and decoding process are provided in the mentioned reference. The implementation of the overall optimum DNR algorithm is detailed in the flowchart shown in Figure. 1.

1. Result and discussion

A practical 116-bus distribution network is shown in Figure.2 the system consists of 116 buses and 120 branches supplied by a 132 kV transmission system, the first bus is at 132kV, the 2nd and 3rd buses are at 33kV, and the rest 113 buses are at 11kV levels. Bus 1 is the swing bus. The four tie switches (83-67), (60-9), (98-28), (116-20) use to change the topology of system. The fault distributions and fault rates of the system elements are obtained from Zhang⁽¹⁴⁾ and Aung et al.⁽¹⁵⁾. These data are listed in Tables 1 and 2. The main substations are excluded as a fault location, and each load point is considered as a group of customers in the reliability evaluation. All industrial loads are sensitive to the voltage sag problem in the reliability evaluation and the fault is always a solid short circuit.

4.1 Base case test results

The base case voltage profile of the test system under study show that most of magnitudes of the buses voltage are within acceptable standard limits. Fault analysis simulations were conducted on all buses except buses 1, 2, 3, 4, 5, 6, 32, 62 and 103 were excluded. That is because, the main source is bus 1, and buses 2, 3,4,5,6, 32, 62 and 103 are main substations. The base number of $N_{int\&vsag}$, SAIFI, ASIFI, MAIFI, are 8502, 6.80, 71.69, 60.43 respectively.

4.2 Optimal DNR Result

Figure (3) shows the voltage profile before and after the DNR. The improvement in the voltage profile after DNR is quite evident. Table (3) summarizes the system reliability results after the DNR process and including the base case results for comparison. Table (3) illustrates reduction in $N_{int\&vsag}$ (27%) and 23%, 49%, 63% in the SAIFI, ASIFI, and MAIFI indices respectively. Figure (4) show the optimization convergence by GSA.

CONCLUSIONS

The main objective of this work is achieved, where the reliability performance is improved. The improvement is evaluated throughout the significant reduction in the number of power interruptions per year as well as the reduction in values of the reliability indices SAIFI, MAIFI and ASIFI. Optimal DNR method also presented an observed improvement in voltage profile for the major system buses. From the obtained results, it can be concluded that the proposed method is very feasible and effective in enhancing distribution system operation performance.

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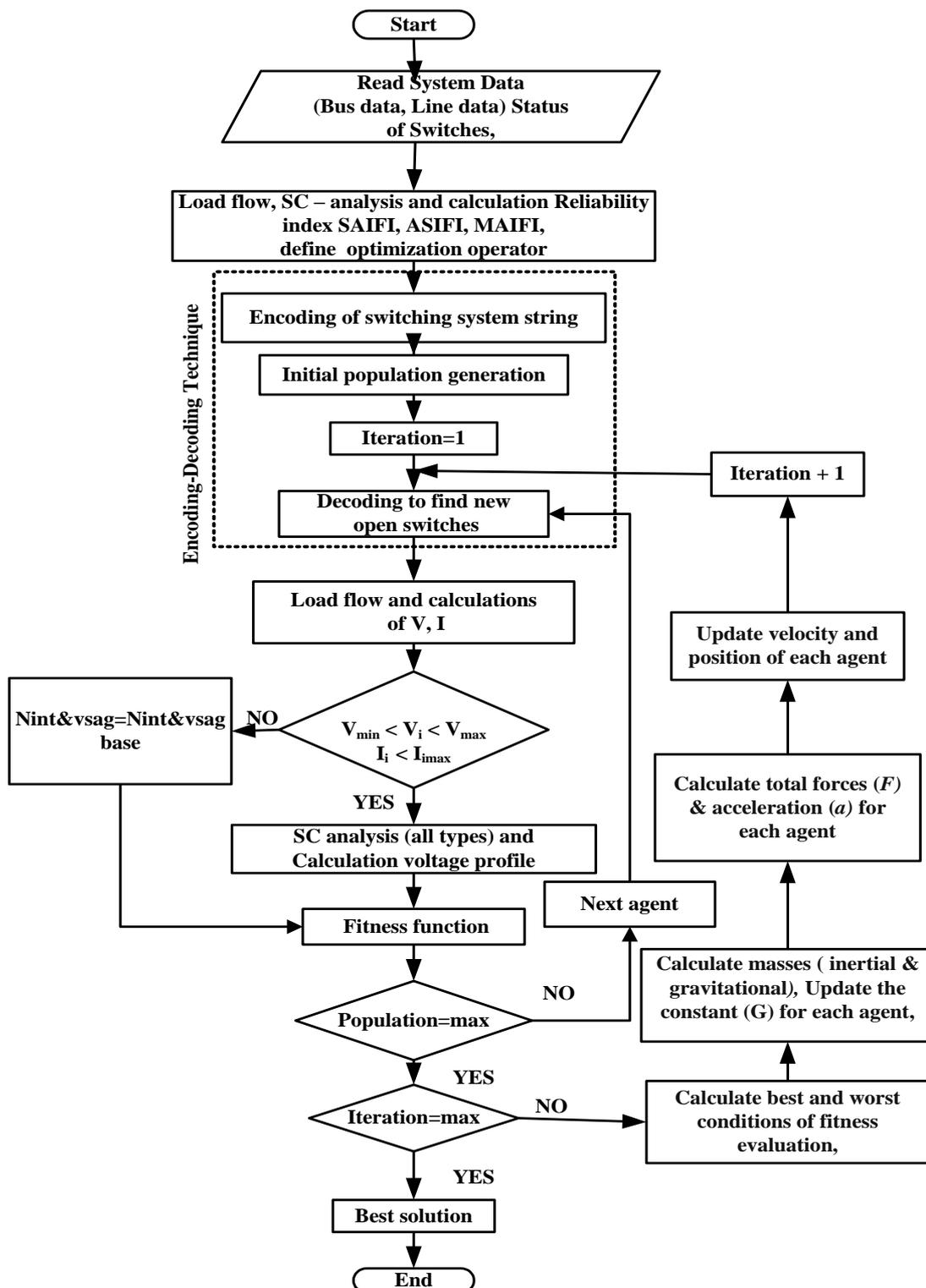


Figure (1) GSA for optimal network reconfiguration

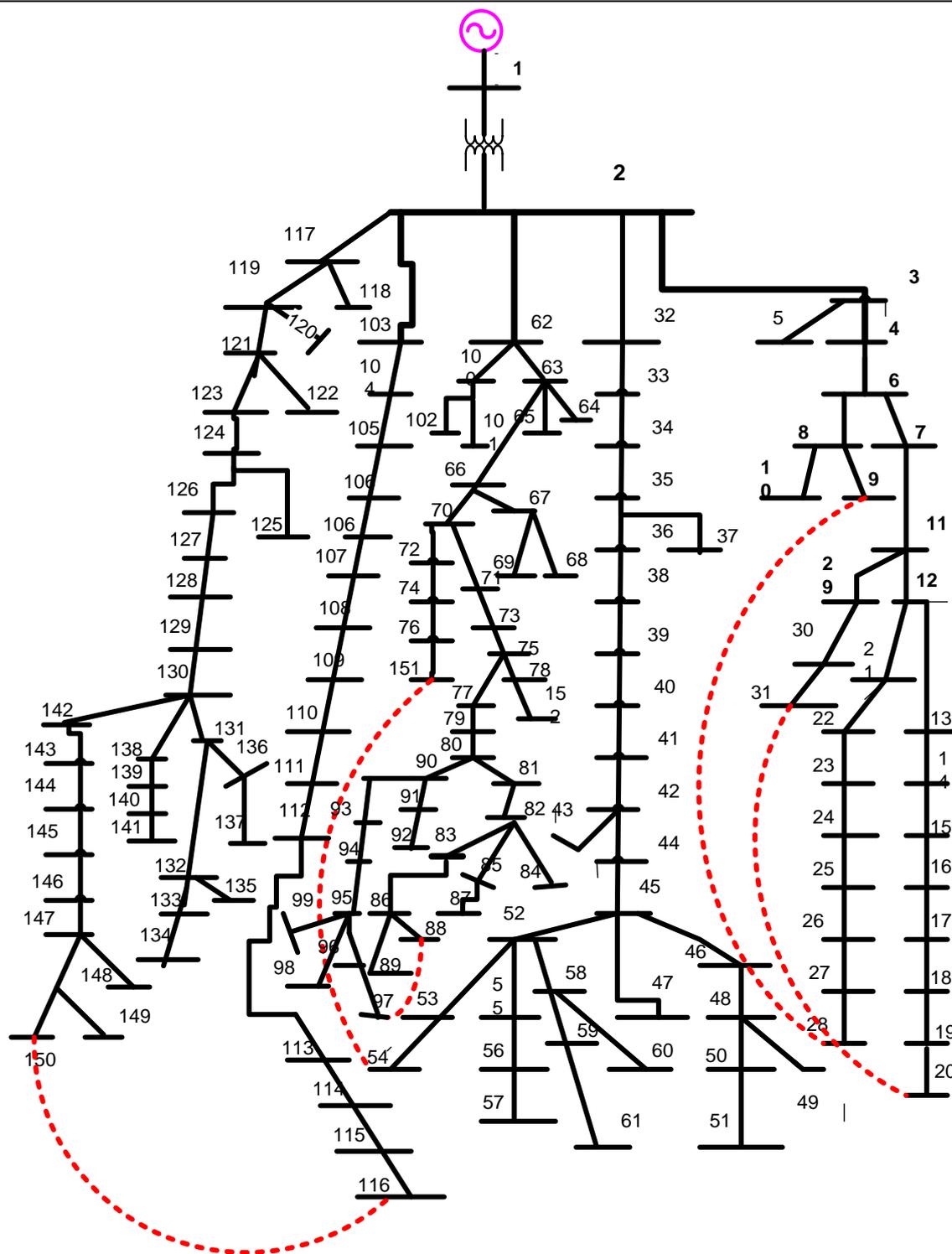


Figure (2) 116-Bus Diyala practical distribution system

Table 1 Fault rate of the distribution system elements ⁽¹⁴⁾.

	System element			
	Line (F/km/yr)	Cable (F/km/yr)	Bus (F/yr)	Transf. (F/yr)
Fault rate	8.7	4.6	0.08	0.015

Table 2 Fault distribution percentage of occurrence according to the fault types ⁽¹⁵⁾.

Fault Type	LG fault	LLG Fault	LL Fault	LLL Fault
Occurrence Percentage	73%	17%	6%	4%

Table (3) the system reliability results after and before the DNR process

System state	$N_{int\&vsag}$	SAIFI	ASIFI	MAIFI
Base case	8502	6.80	60.43	71.69
DNR by GSA	6198	5.22	30.74	26.35

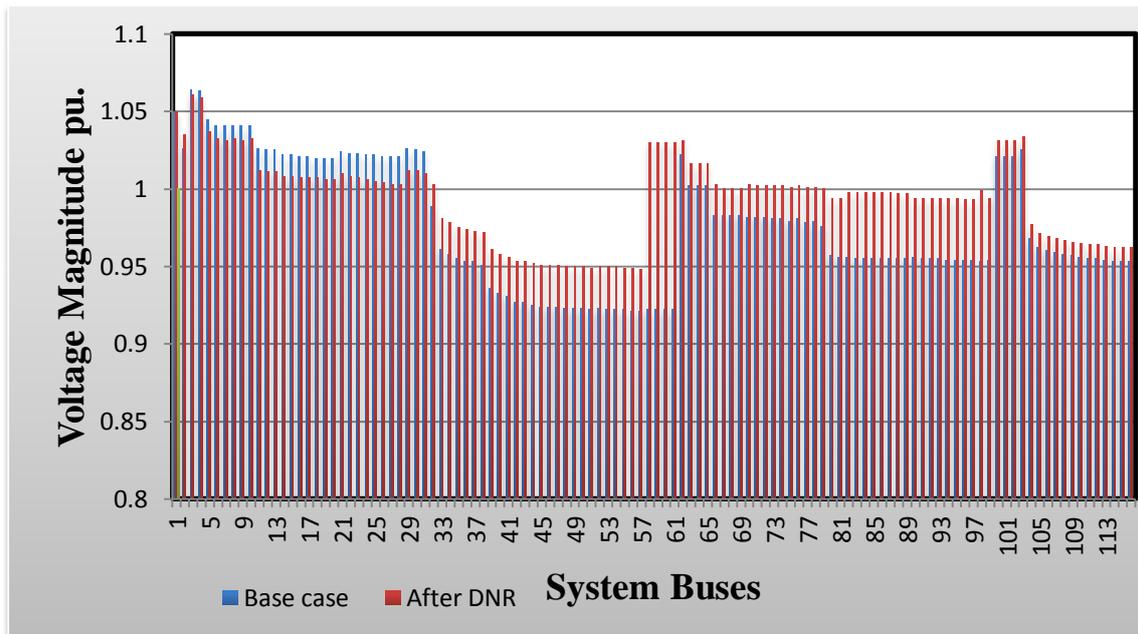


Figure (3) shows the voltage profile before and after the DNR

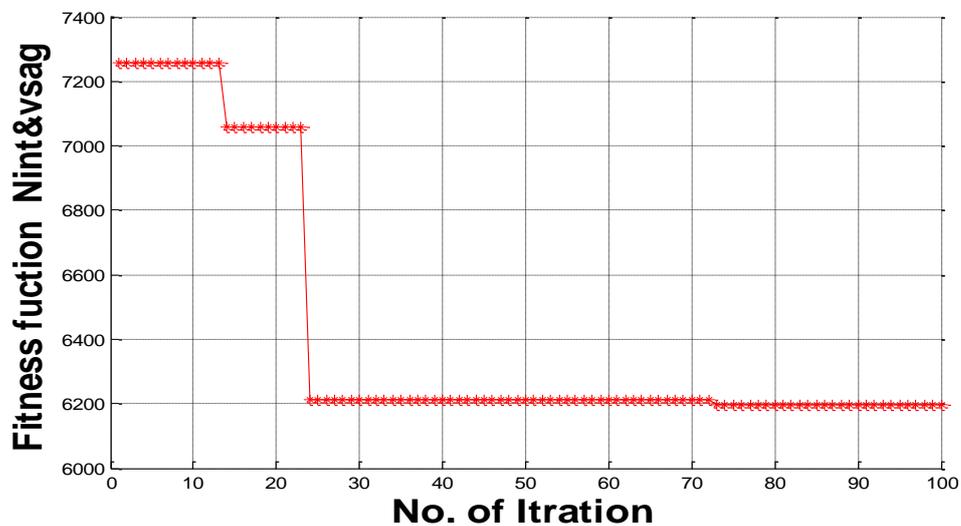


Figure (4) The optimization convergence by GSA

تقييم موثوقية منظومة توزيع بوجود توليد موزع وإعادة التشكيل

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الخلاصة

تعتبر موثوقية منظومة القدرة الكهربائية واحدة من أكثر الامور التي تخص عملية التشغيل وخاصة في قطاعات التوزيع. تؤخذ مشاكل جودة القدرة بعين الاعتبار والتي قد تتسبب في عدم انتظام الاشتغال لبعض المعدات الحساسة خاصة الحديثة منها أو توقفها تماما الأمر الذي يؤدي إلى ضعف موثوقية منظومة القدرة. بذلت الكثير من الجهود لتحسين الأداء والموثوقية وتناولها كثير من الباحثين. الهدف الرئيسي في هذا البحث هو تقييم الموثوقية وتحسينها بطريقة ايجاد افضل تشكيل لشبكة التوزيع. تم ايجاد أفضل تشكيل لشبكة التوزيع والذي يستخدم مفاتيح الربط بين المغذيات لتعزيز افضل قيم لفولتيات عقد التوزيع اثناء حدوث الأعطال الكهربائية. استخدمت خوارزمية بحث الجاذبية كأداة ارشادية لأيجاد الحلول المثلى في إعادة تشكيل الشبكة . استخدم جزء من منظومة التوزيع لمحافظة ديالى كحالة للدراسة وهذا الجزء من مدينة بعقوبة ويتكون من اربعة مغذيات (11kV) و 116 عقدة و اظهرت نتائج الطريقة المقترحة تحسنا كبيرا في أداء الشبكة وتحسين موثوقيتها . كما ظهر ايضا تحسنا في فولتيات معظم عقد الشبكة.