OPTIMAL NETWORK RECONFIGURATION OF DISTRIBUTION SYSTEMS FOR IMPROVING THE PERFORMANCE IN TERM OF POWER QUALITY USING BAT ALGORITHM

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ABSTRACT:- Power quality is considered as one of the most important issue in power distribution systems. Voltage sag is considered as one of the most common power quality problems. It may cause sensitive equipment to malfunction and process interruption. In this work a method of optimal network reconfiguration is proposed to mitigate voltage sag problem in power distribution networks. It is applied to a distribution network in a specified period (usually one year) to minimize the number of propagated voltage sags (N_{sag}) index. To find the optimal reconfigured network, Bat algorithm (BA) as optimization technique is used. To validate the proposed method, a practical distribution system (section of Malaysian grid) is used. The simulation results show that it is effective to apply the proposed technique in mitigating voltage sag problem in practical power distribution systems.
Key words: Network Reconfiguration, Power Quality, Optimization, BA, Power Distribution systems

1- INTRODUCTION

It is almost impossible to avoid electrical faults in distribution systems. Power quality disturbances are usually caused due to some events of abnormal activities such as insulation failure, lightning or a fault on an adjacent feeder or even bird's contact, tree falling. These disturbances may be in the form of voltage imbalances, interruptions, voltage sag, swells, transients, and harmonics which can cause problems to the industries ranging from malfunctioning of equipment to complete plant shutdowns. occurring of such disturbances on high voltage end in distribution feeder will propagate downstream to the low voltage ends to affect the connected sensitive loads [1].

The recent high technology level of customer equipment has given rise to growing interest concerning electric power quality. The recent widespread use of power-electronic devices has increased the degree of reliability to be expected of the electric utilities. Voltage sags of even low magnitude and short duration can cause particularly malfunctioning in industrial processes to result financial losses to customers. The cost of interruption may be quite large compared with the apparent severity of the cause. Therefore electric service interruptions have a profound impact on customers. Particularly in the era of utility deregulation, it is critical that utilities keep their major customers satisfied [2].

The problem of power quality motivates the engineers and researchers to conduct this problem. Many solutions are achieved in this trend; the most of solutions have been taken in customer side. Voltage sags have been mainly associated with short circuit events [3]. Distribution network reconfiguration (DNR) is already employed for loss reduction [4].

However it was proposed as a voltage sag mitigation method by using feeder transfer switches (tie or sectionalizing switches) in power distribution networks [5].Although the reconfiguring optimization process involves just a change in switches status, it mitigates majority of the voltage sag propagation problems [6-8].

Heuristic optimization techniques are usually used in leading the optimal reconfiguration process such as genetic algorithm (GA), gravitational search algorithm (GSA) and firefly algorithm, where many researchers conducted optimal DNR by these mentioned techniques [7, 9-10]. Particle swarm optimization (PSO) and many of its variants have also been extensively used for solving DNR problem for different objectives such as loss reduction voltage profile and system reliability enhancement [11-12].

In this paper, a method for improving quality performance by reducing the number of propagated voltage sags experienced at each node in a distribution system. It is achieved by using optimal DNR. The binary version of bat algorithm (BA) is proposed to determine the optimal solution.

3-POWER QUALITY ASSESSMENT INDEX

System PQ performance can be assigned by using SARFI (System Average RMS Frequency Index), which represents the average number of RMS variations over the assessment period per customer served. SARFI-90 calculates all voltage sags with remaining voltages of less than 90% regardless of sag duration. Therefore, the sum of the expected number of sags N_{sag} caused by every registered fault event can be used to obtain the SARFI of the entire system [13]. N_{sag} represents the number of customers affected by all possible fault events during the assessment period. The customers served in the assessment area are considered the customers supplied by all system buses N_{bus}. SARFI can be defined as follows[13]:

$$SARFI = \frac{\sum N_i}{N_T} \qquad [1]$$

N_i= number of customers experiencing short-duration voltage deviations with magnitudes below 90% of nominal magnitude during assessment period.

N_T= number of customers served from the section of the system to be assessed.

4-DETERMINING NUMBER OF PROPAGATED VOLTAGE SAGS

The affected load buses in the exposed area of each fault location can be assigned from the results of the fault analysis test. The problem is in determining which component in the system causes significant voltage sag propagation during a fault, and the probability of its fault occurrence. The voltage sag magnitude depends on fault location in the system. However, every possible fault in the system must be evaluated, including faults at all buses and lines. In estimating the number of sags that reduce bus voltages below a certain magnitude, the exposed length of the faulted line or portion of the line must be defined. Thus, the resulting exposed length can be multiplied by the fault rate in faults per kilometer per year of the line to obtain the number of sags per year [14]. The evaluation can be performed for all possible fault events. The possible events may represent all fault occurrences on lines, buses, and transformers. If the fault rate of the lines is δ_L for the faulted line of length L, the expected number of voltage sags F_L, sag, or interruptions, due to all the four types of faults, namely, three phase, line to ground, line to line, and line to line to ground faults on all distribution lines, N_L, can be expressed as follows [9]:

$$F_L = \sum_{k=1}^{4} \sum_{i=1}^{N_L} L_i . \delta_{L_i} \qquad [2]$$

where k is the fault type index and i is the line index, respectively. In the same manner, the number of sags due to the faulted buses,   and faulted transformers, can be calculated by

using the fault rate of system buses (faults per bus per year, δ_B) and the fault rate of distribution transformer (faults per transformer per year, δ_T) and expressed as follows:

$$F_B = \sum_{k=1}^{4} \sum_{b=1}^{N_{bus}} B_b . \delta_B \qquad [3]$$

$$F_T = \sum_{k=1}^{4} \sum_{j=1}^{N_T} T_j . \delta_T \qquad [4]$$

where b is the bus (B) index and j is the transformer (T) index, respectively.
Then, the total expected number of sags and interruptions, N_{sag} due to all fault events occurring in the system can be expressed as:

$$N_{sag} = F_B + F_L + F_T \qquad [5]$$

The N_{sag} obtained from (5) represents the number of customers affected by all possible fault events during the assessment period. The obtained number of sags, N_{sag} can be used to calculate the voltage sag index known as the system average RMS variation frequency index (SARFI) for the whole system, by using (1), where the customers served in the area of assessment are represented as N_T and N_i corresponding to N_{sag} [9].

5-DISTRIBUTION NETWORK RECONFIGURATION (DNR)

Network reconfiguration is a process of altering the topological structures of distribution feeders by changing the open/closed status of the sectionalizing and tie switches. A whole feeder or a part of a feeder may be served from another feeder by closing a tie switch linking the two while an appropriate sectionalizing switch must be opened to maintain radial structures [15]. It is generally used for loss reduction, load balancing and voltage profile improvement in distribution systems. However, it may also be used to reinforce the distribution network against voltage sag propagation by increasing the line impedance towards fault current during short circuit events [16-17]. The procedure of DNR explained in [16] is adopted in this work completely.

6-PROPOSED BA FOR OPTIMUM DNR

BA is a population based evolutionary optimization algorithm that imitates the behavior of bat animals to take their prey. It is a population based metaheuristic optimization technique like PSO and GA. It was developed by Xin-She Yang in 2010. The algorithm mimics the echolocation behavior most prominent in bats [18]. The author developed the bat algorithm with the following three idealized rules:

1. All bats use echolocation to sense distance, and they also 'know' the difference between food/prey and background barriers in some magical way;
2. Bats fly randomly with velocity *vi* at position *xi* with a frequency f_{min}, varying wavelength λ and loudness A_0 to search for prey. They can automatically adjust the wavelength (or frequency) of their emitted pulses and adjust the rate of pulse emission r ∈ [0, 1], depending on the proximity of their target;
3. Although the loudness can vary in many ways, we assume that the loudness varies from a large (positive) A_0 to a minimum constant value A_{min}.

Bat Motion

A given frequency is intrinsically linked to a wavelength. For example, a frequency range of [20kHz, 500kHz] corresponds to a range of wavelengths from 0.7mm to 17mm in the air. Therefore, we can describe the change either in terms of frequency f or wavelength λ to suit different applications, depending on the ease of implementation and other factors. To implement the motion, each bat is associated with a velocity v_i^t ti and a location, x_i^t, at iteration t, in a *d*-dimensional search or solution space. Among all the bats, there exists a

current best solution x_*. Therefore, the above three rules can be translated into the updating equations for x_i^t and velocities v_i^t:

$$f_i = f_{min} + (f_{max} - f_{min})\beta \qquad [6]$$

$$v_i^t = v_i^{t-1} + (x_i^{t-1} - x_*)f_i \qquad [7]$$

$$x_i^t = x_i^{t-1} + v_i^t \qquad [8]$$

Where, $\beta \in [0, 1]$ is a random vector drawn from a uniform distribution.

As mentioned earlier, we can either use wavelengths or frequencies for implementation, we will use $f_{min} = 0$ and $f_{max} = 0$ (1), depending on the domain size of the problem of interest. Initially, each bat is randomly assigned a frequency which is drawn uniformly from [f_{min}, f_{max}]. For this reason, bat algorithm can be considered as a frequency-tuning algorithm to provide a balanced combination of exploration and exploitation. The loudness and pulse emission rates essentially provide a mechanism for automatic control and auto zooming into the region with promising solutions[18].

Variations of Loudness and Pulse Rates

In order to provide an effective mechanism to control the exploration and exploitation and switch to exploitation stage when necessary, we have to vary the loudness A_i and the rate r_i of pulse emission during the iterations. Since the loudness usually decreases once a bat has found its prey, while the rate of pulse emission increases, the loudness can be chosen as any value of convenience, between A_{min} and A_{max}, assuming $A_{min} = 0$ means that a bat has just found the prey and temporarily stop emitting any sound. With these assumptions, we have:

$$A_i^{t+1} = \alpha A_i^t, \ r_i^{t+1} = r_i^0 [1 - \exp(\gamma t)] \qquad [9]$$

Where α and γ are constants. In essence, here α is similar to the cooling factor of a cooling schedule in simulated annealing algorithm [19]. For any $0 < \alpha < 1$ and $> \gamma$ 0, we have

$$A_i^t \to 0, \ r_i^t \to r_i^0 \ as \ t \to \infty \qquad [10]$$

To implement BA for DNR process, minimum N_{sag} obtained by equation (5) is defined as the objective function (fitness) of optimization. Fig. 1 shows the flowchart of the BA optimization for optimal DNR.

7-RESULTS AND DISCUSSIONS

The 47-bus practical distribution system shown in Fig.2 comprises 47 nodes and 42 lines supplied by a 132 kV sub-transmission system through four main substations that are connected at nodes 2, 17, 34, and 39. Substations 2 and 17 are fed by 132/11 kV, 30 MVA transformers, whereas substations 34 and 39 are fed by 132/33 kV and 45 MVA transformers. Bus 1 is the swing bus. The seven tie switches (SWs) between Buses 25 and 38, 29 and 38, 24 and 29, 16 and 18, 4 and 19, 20 and 23 and 4 and 14 may be used as alternatives to change the configuration of the system in case of unforeseen events or contingencies. The selected system comprises 132, 33, 11, 6.6, 3.3, and 0.433 kV multi-voltage levels. The voltage levels are fed through 15 transformers of different sizes. The system includes three large induction motors at 2000 KW, which are connected to Buses 9 (3.3 kV), 10 (0.433 kV), and 21 (3.3 kV). Capacitor banks of 2 MVar are also used in the system and are connected to Buses 42 (33 kV) and 38 (11 kV). Two mini-hydropower plants with capacities of 2000 kVA and 6.6 kV and 3000 kVA and 3.3 kV are also attached to Buses 32 and 8, respectively. The power plants in the system are considered as distributed generation units to control voltage magnitudes of the buses connected to them.[20].

The simulation procedure can be summarized by the following steps:

1) Perform load flow and fault analyses for all fault types at all possible fault locations of the system in order to determine the number of voltage sags propagated throughout the distribution system.
2) Use the equations (2 to 5) to calculate all possible propagated voltage sags and assess the base case power quality using SARFI index (1).
3) Apply BA to determine the optimal network reconfiguration.
4) Repeat steps 1 and 2 to assess the distribution system after optimal DNR.

The fault analysis is performed for all possible fault locations on nodes rated below 11kV voltage level where, main substations and the nodes that are supplied through more than one feeder are excluded. It means the nodes 1, 2, 3, 17, 18, 33, 34, 35, 36, 39, 40, 41, 42, and 43 are excluded during simulation process. It can be explained as node 1 is the main source, nodes 2 and 17 are main substations, nodes 3 and 18 are supplied by more than one feeder, node 33 is a service supply for local loads meanwhile, the nodes 34, 35, 36, 39, 40 ,41, 42 and 43 are at 33kV voltage level. Fig. 3 shows the voltage sag distribution on all nodes of the system for three phase short circuit with zero fault resistance (Z_f=0). The darkness level in Fig.3 reveals voltage sag magnitude on each bus of the system corresponding to every fault location.

Optimal network reconfiguration is carried out by using BA, and objective function, minimizing the number of propagated sags (N_{sag}). The convergence characteristic of BA is shown in Fig. 5, where 70 iterations are used.

The results of the proposed method of power quality assessment for the distribution system are listed in Table 1. It is obvious from the obtained results there is a significant improvement in quality performance, there is a clear reduction in the number of propagated voltage sags (N_{sag}) and voltage sag index SARFI.

8-CONCLUSIONS

It can be concluded, the proposed optimal DNR method is efficient and feasible for improving the power quality performance bus voltage profile during voltage sags. Although DNR process involves just an altering the switching status, it solves majority of the voltage sag propagation problem. The proposed method may assist utility engineers in taking the right decision for network reconfiguration. The right decision can be taken after making a compromise between the obtained benefits from line loss reduction and the financial losses due to the load outages from power quality problems.

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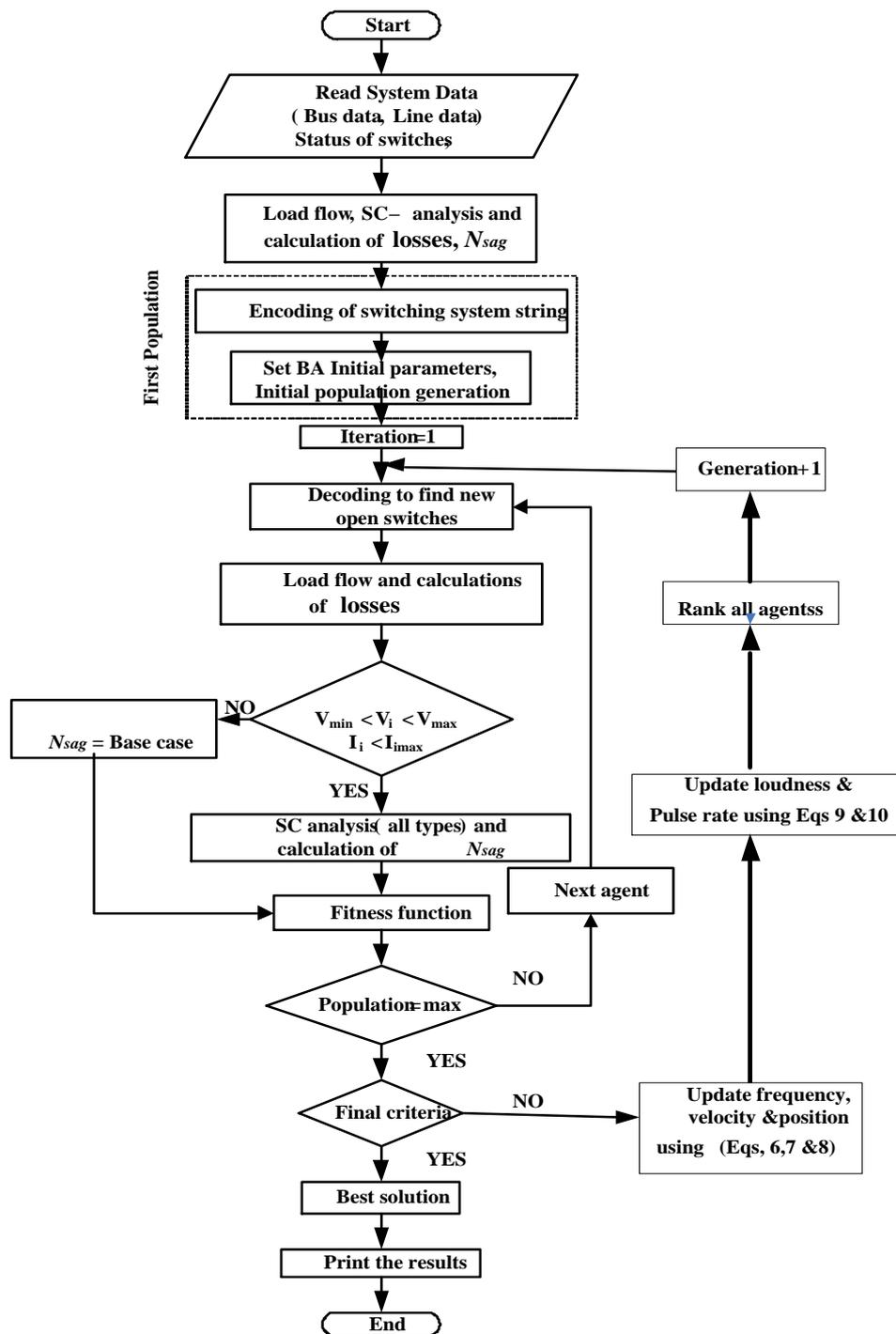
Fig. 1   Flowchart of BA implementation for optimal DNR
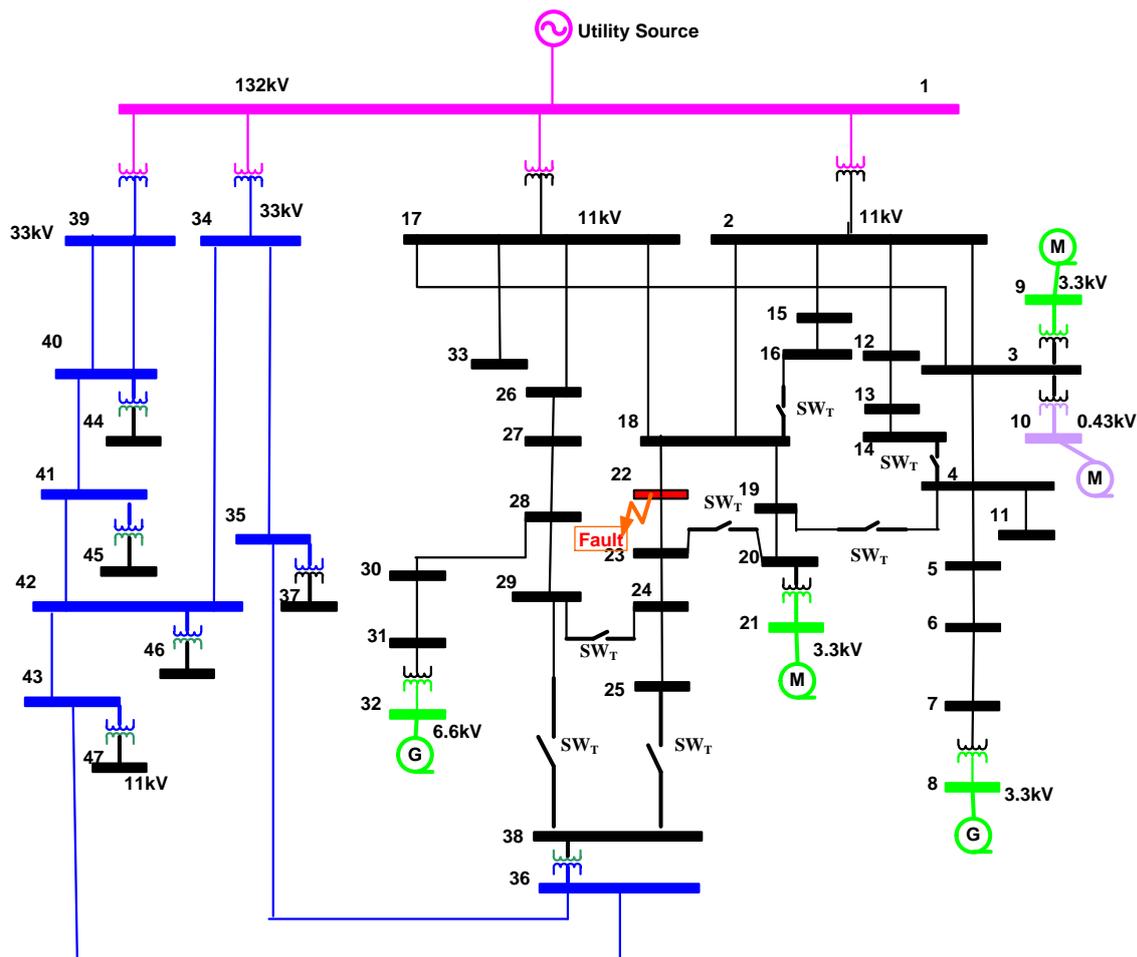
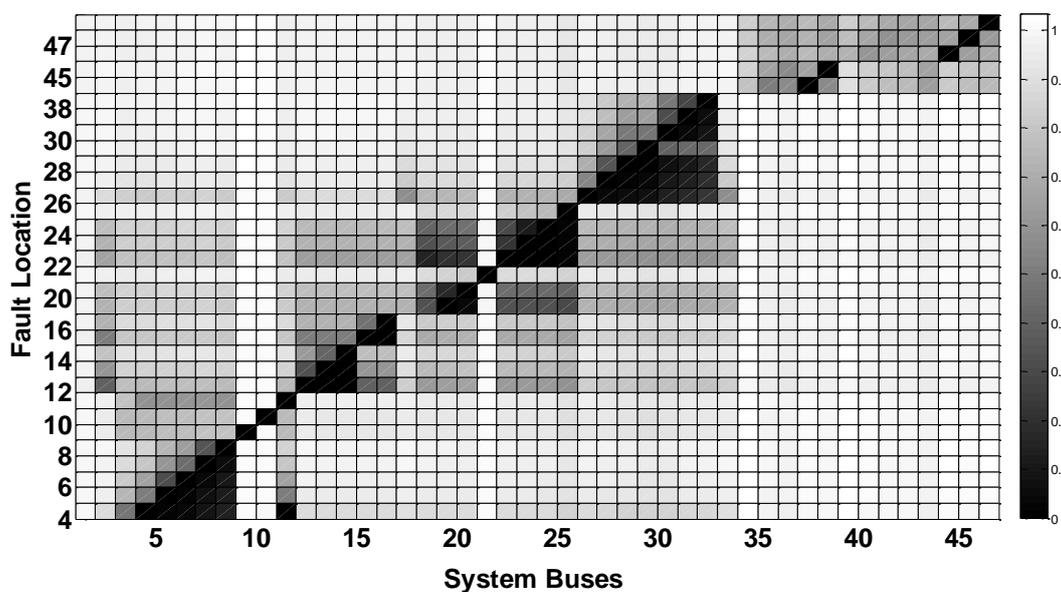Fig. 2   47-bus practical distribution system

Fig.3 Voltage sag distribution on the system buses attributed to the LLL fault
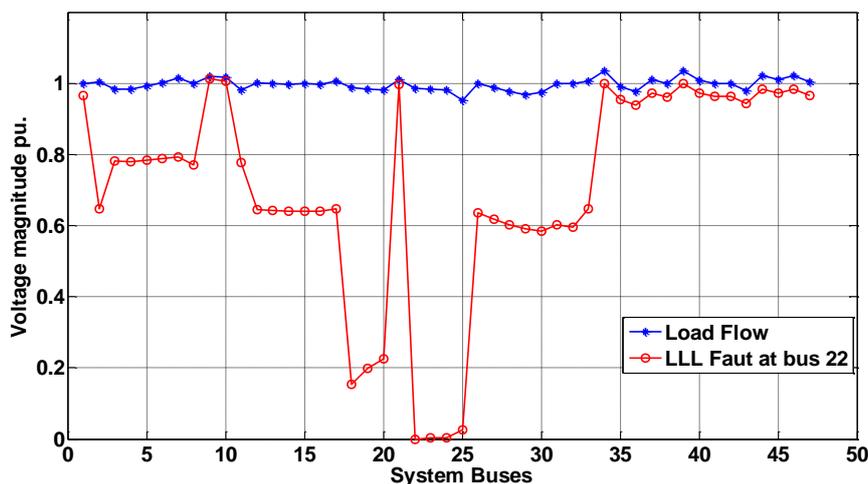
Fig.4 Bus voltage magnitudes before and after LLL fault in Bus 22

Table 1. Summarized results

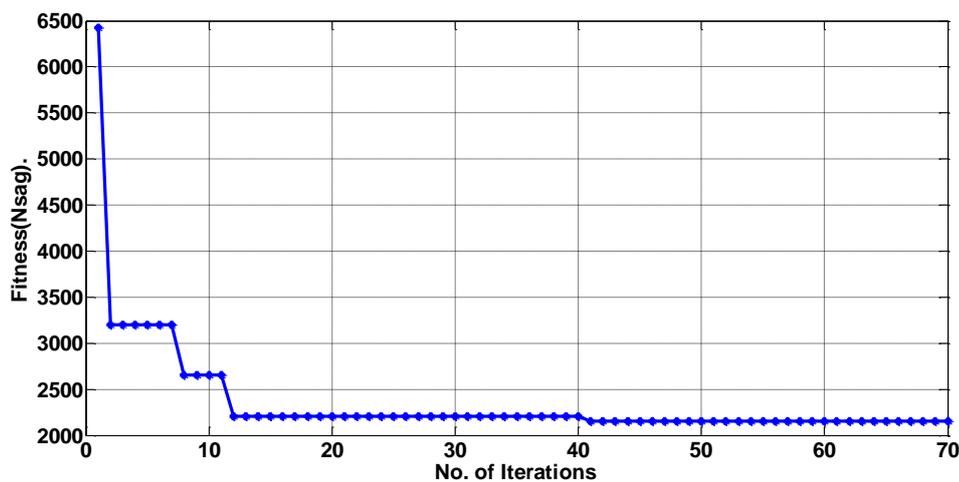| System cases	Losses MW	System Sag Indices	
		N_{sag}	Sag Index SARFI
Base case	2.089	6421	1.65
With optimal DNR by BA	2.163	2211	0.57
Overall performance	Increase little	Reduction 66.44%	Reduction 66.44%

Fig.5 BA convergence characteristics for optimal DNR, Fitness is N_{sag}

إعادة تشكيل شبكات التوزيع الكهربائية لتحسين جودة أداء القدرة وبإستخدام خوارزمية محاكاة الوطواط

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الخلاصة

تعتبر جودة القدرة الكهربائية كأحد أهم القضايا في أنظمة توزيع الطاقة الكهربائية. ويعتبر الجهد المفاجئ باعتباره واحدا من الأكثر شيوعا في مشاكل جودة القدرة. فإنه قد يسبب للمعدات الحساسة سوء الأداء او التوقف عن العمل. في هذا البحث تم اقتراح طريقة الأمثلية في إعادة تشكيل شبكة التوزيع للتخفيف من تأثير مشكلة انخفاض الجهد المفاجئ في شبكات توزيع الطاقة. حيث يتم تقييم اداء شبكة توزيع في فترة محددة (عادة سنة واحدة) وتقييمها من خلال تقليل مؤشر عدد انتشار حالات انخفاض الجهد (N_{sag}). ومن أجل العثور على شبكة التوزيع الأمثل تكوينا تم استخدام خوارزمية محاكاة الوطواط والتي تعتبر من تقنيات الأمثلية لهذا الغرض. ومن اجل التحقق من صحة الطريقة المقترحة تم تطبيقها باستخدام شبكة توزيع عملية (جزء من الشبكة الماليزية) حيث تبين من نتائج المحاكاة ان هذه الطريقة المقترحة فعالة في تخفيف تأثير مشكلة انخفاض الجهد المفاجئ في منظومات التوزيع الكهربائية.