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# STABILITY ENHANCEMENT BASED ON DISTRIBUTED GENERATION UNITS IN AL-NAJAF AL-ASHRAF ELECTRICAL NETWORK

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## ABSTRACT

The operation and structure of distribution system are changing with the integration of Distributed Generation (DG) units, where these units may have effect on power losses, stability, voltage profile, power quality and other quantities. Therefore the optimum location, size and number of DG units are necessary to avoid the negative impacts on electric power system. In this work, the Particle Swarm Optimization (PSO) technique is used to find the optimal number and locations of DG in order to minimize the active power losses. The thermal limit of transmission lines and transformers was studied to detect the lines or transformers which exceed the limit in order to process it. The voltage stability of distribution network has been investigated, using L index method.

**KEYWORDS:** Distributed generation (DG), Thermal limit, Voltage stability, Particle Swarm Optimization (PSO).

# تحسين الاستقرارية باستخدام التوليد الموزع في شبكة النجف الاشرف الكهربائية

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**الخلاصة**

ان عمل وتركيب نظام التوزيع يتغير مع اضافة وحدات التوليد الموزع (DG )، حيث انها تؤثر على خسائر القدرة ، الاستقرارية ، الفولطية ، جودة الطاقة وكميات اخرى، لذلك فان اختيار الموقع الامثل والحجم وعدد وحدات التوليد الموزع (DG ) ضروري لتجنب التأثيرات السلبية على نظام الطاقة الكهربائية. في هذا البحث استخدمت تقنية (PSO ) لإيجاد العدد والموقع الامثلان لوحدات التوليد الموزع (DG ) لتقليل خسائر القدرة الفعالة. بعد ذلك تم دراسة الحد الحراري لخطوط نقل الطاقة الكهربائية والمحولات لتحديد الخطوط والمحولات التي تجاوزت الحد ومعالجتها. كذلك تم دراسة استقرارية الفولطية لشبكة التوزيع باستخدام طريقة ( L INDEX).

## 1. INTRODUCTION

Traditionally, electric power is produced at central station power plants and delivered to consumers using transmission and distribution networks. Most of the distribution networks are radial in nature with high R / X ratios causing high power loss. As a result most of the distribution buses are operated with poor voltage profiles which may lead to voltage collapse and gradually total black out of system [1]. However, recently there has been a considerable revival of interest in accommodating generating units to distribution networks which may be called Distributed Generation (DG). Connection of DG units can fundamentally alter the operation of the network, therefore new connections of DG must be evaluated to identify and quantify any adverse impact on the security and quality of local electricity supplies [2]. The presence of distributed generation can have a number of significant impacts on the operation of the distribution network [2]. They include:

- Bi-directional power flow and the potential to exceed equipment thermal ratings.
- Reduced voltage regulation and violation of statutory limits on supply quality.
- Increased short circuit contribution and fault levels.
- Altered transient stability.
- Degraded protection operation and co-ordination.

Many researchers focused on the distributed generation because of its importance. Partha Kayal et al. [1] presented a methodology to determine both maximum and minimum sizes of DG connected to distribution system satisfying voltage level constraint. The PSO technique has been applied to deal with this optimization problem for determination of the optimal size of the required DG. A Voltage Stability Factor (VSF) was calculated. Gholamreza areiegovar et al. [3] used basic load flow equations، algorithm of load flow with DG and constraints presented to find the optimal location and size of DG. The real power losses, the voltage stability and the voltage profile of distribution network are formulated as objective function to consider in the optimization problem. A 69 bus distribution network is applied as a case study. The optimization problem of case study is solved using PSO algorithm. L.D. Arya et al. [4] presented a DG planning exercise with respect to the predicted peak loading. It employs an incremental voltage criteria effectively to locate buses for DG interconnection in sub-transmission system. Further differential evolution (DE) is employed for optimal DG capacity determination for minimum total system real power losses while economic aspects were not considered. Wind turbine along with induction generator has been considered for the study. The developed algorithms have been implemented on the standard 6-bus and 30-bus test systems. Nguyen Cong Hien et al. [5] presented effect of DG type, size, and location on the loadability and voltage profile of a distribution system investigated.

A PSO algorithm to find proper size and location of DG unit to minimize reactive power losses in the systems is also proposed where DG units are classified into four types based on the DG technology and the terminal characteristics, DG injects active power (P) only (photovoltaic), DG injects reactive power (Q) only (synchronous compensators), DG injects active power but absorbs reactive power (induction generator) and DG injects both active and reactive power (synchronous generator). Three test distribution systems, 33-bus, 69-bus radial distribution system, and 173-bus distribution system have been used. Qian Ai et al. 2014, [6] studied the static stability effect of DG on the power grid and analyzed the power flow models of Double Fed Induction Generator (DFIG), Photovoltaic (PV) and battery storage, then IEEE 30-bus system was considered as an example and an improved continuous flow method is used to obtain voltage stability limit point of the power gird with or without DG respectively. In this paper, the optimal number and location of the Distributed Generation (DG) penetrated in part of Iraqi distribution network (Al-Najaf Al-Ashraf distribution network) was

found to minimize the active power losses، where DG was contributed significantly to reducing the power losses by about 96% achieved when the number of DG is four with size 125 MW at buses 14, 15, 16 and 18. Also the impact of the thermal limit of transmission lines and transformers on distribution network was studied, the DG changed the power flow in the network causing reduction TLF Led to many of the transmission lines and transformers operate within normal limits.
The voltage stability of buses was improved greatly, further the critical clearing time of circuit breaker of all lines through rotor angle stability was calculated.

## 2. OPTIMIZATION OF DG USING PSO

Planning of the electric system with the presence of DG requires the definition of several factors such as, best technology to be used, number and capacity of the units, best location, type of network connection etc. In this work the optimal number and location of DGs will be performed by using Particle Swarm Optimization technique (PSO) [7].
The PSO algorithm was motivated by social behavior of organisms such as fish schooling and bird flocking. PSO provides a population-based search procedure, in which individuals called particles change their positions (state) with time. In a PSO, particles fly around a multidimensional search space. During this process, each particle adjusts its position according to its own experience, and the experience of neighboring particles, making use of the best position encountered by itself and its neighbors. The swarm direction of a particle is defined by the set of particles neighboring the particle and its history experience. Assuming that $s$ and $v$ are the position and velocity of a particle in a search space, respectively. Therefore, the $i$th particle is presented as $s_i = (s_{i1}, s_{i2}, \dots, s_{id})$ where the d is dimensional space. The best previous position of the $i$th particle is recorded and presented as $pbest_i = (pbest_{i1}, pbest_{i2}, \dots, pbest_{id})$. The best particle among all the particles in the group is presented by $gbest_d$. The velocity for particle $i$ is presented as $v_i = (v_{i1}, v_{i2}, \dots, v_{id})$. The current velocity and position of each particle can be calculated by using current velocity, previous velocity, and previous position of that particle, as shown in

$$v_{id}^{k+1} = w * v_{id}^{k} + c_1 * rand() * \left(pbest_{id} - v_{id}^{k}\right) + c_2 * rand() * \left(gbest_d - v_{id}^{k}\right) \quad (1)$$

$$s_{id}^{k+1} = s_{id}^{k} + v_{id}^{k+1}, i = 1,2, \dots, n, d = 1,2, \dots, m \quad (2)$$

Where:
$n$ : number of particles in a group;
$m$ : number of members in a particle;
$k$ : iteration kth;
$w$ : inertia weight factor;
$c_1$, $c_2$ : acceleration constants;
$rand()$ : uniform random value in the range [0, 1];
$v_i^k$ : velocity of particle $i$ at iteration $k$;
$s_i^k$ : position of particle $i$ at iteration $k$.
The PSO-based approach to find the optimal number and location of DG units to minimize active power loss takes the following flow chart in Fig. 1 [8].

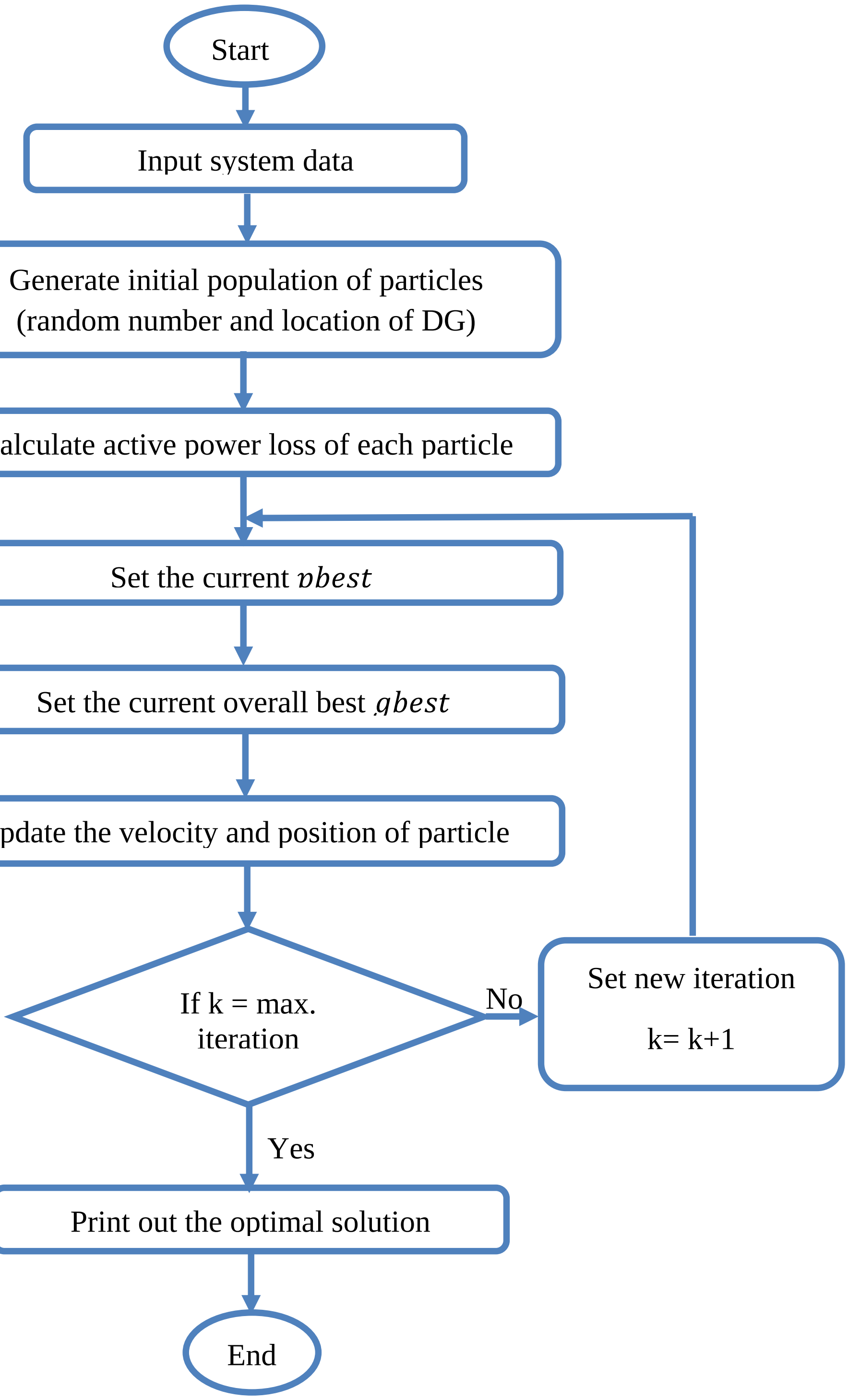


**Fig. 1. Flow chart of PSO algorithm based optimal number and location of DG units**

## 3. THERMAL LIMIT

The power handling ability of a line is limited by thermal loading limit and the stability limit. The increase in the conductor temperature, due to the real power loss, stretches the conductors. This will increase the sag between transmission towers. At higher temperatures this may result in irreversible stretching. The thermal limit is specified by the current-carrying capacity of the conductor and is available in the manufacturer's data. If the current-carrying capacity is denoted by $I_{thermal}$ the thermal loading limit of a line is [9].

$$S^{L}_{thermal} = 3 * V_{\phi rated} * I_{thermal} \quad (3)$$

In this work the thermal limit factor (*TLF*) will be defined to monitoring a transmission lines in case it exceeds the thermal limit where

$$TLF = \frac{line\ flow\ (S_{ij})}{S^{L}_{thermal}} \quad (4)$$

$S_{ij}$ is calculated by using power flow algorithm, then $TLF$ gives a percentage of each line if this ratio exceeds (1) it means the line is out of limit. Also this factor can be used as a limit indicator of transformers when the transformer exceeds its rating capacity, where $S^{T}_{thermal}$ equal to the rate of transformer which is found on nameplate. $S^{L}_{thermal}$ for transmission lines in (4) will be replaced by $S^{T}_{thermal}$ for transformers. The procedures of the thermal limit is shown in Fig. 2.

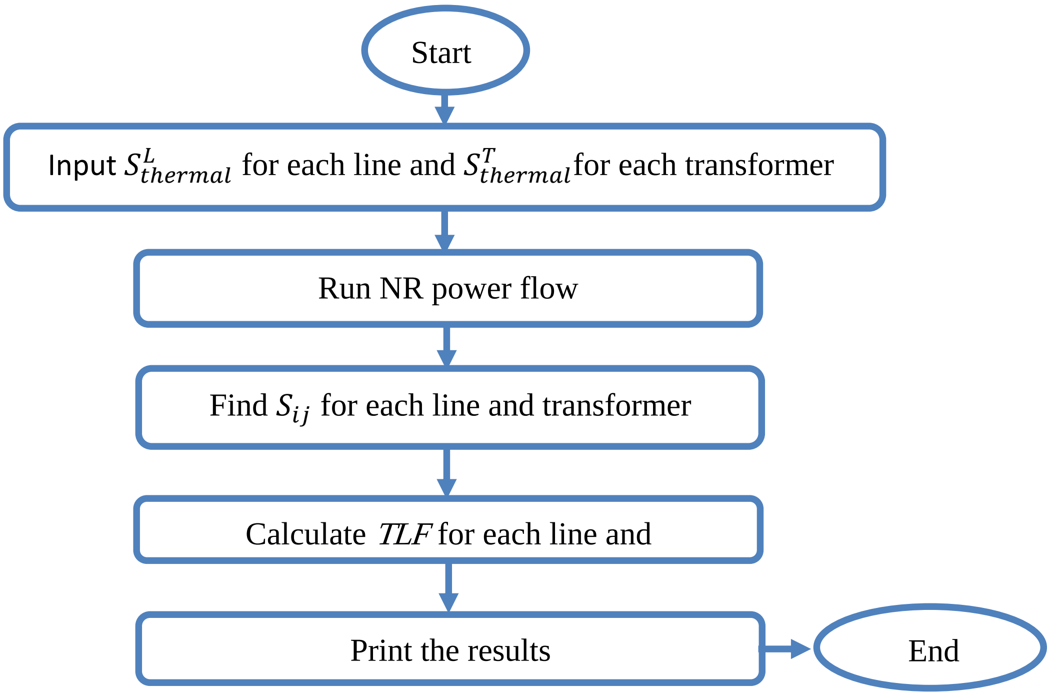


**Fig. 2. Flow chart of the thermal limit**

## 4. VOLTAGE STABILITY ASSESSMENT USING L INDEX

Voltage stability refers to the ability of a power system to maintain steady and acceptable voltages at all buses in the system after being subjected to a disturbance from a given initial operating condition. The main factor causing voltage instability is inability to meet the reactive power demand. Voltage stability can be classified as small or large based on the disturbance type. Small voltage stability refers to the ability of the system to control the voltage when small perturbations occur, such as changes in the loads. Large voltage stability refers to the ability of the system to control the voltage after being subjected to large disturbances such as load outages, faults, and large-step changes in the loads [4].

In this section the voltage stability using L index method which was proposed by P. Kessel and H.Glavitsch in [10] varies in the range between zero (no load) and one (voltage collapse) and uses information about a normal load flow. The advantage of the method is the simplicity of the numerical calculation and the expressiveness of the result. The procedure for voltage stability L index programming is summarized in Fig. 3.

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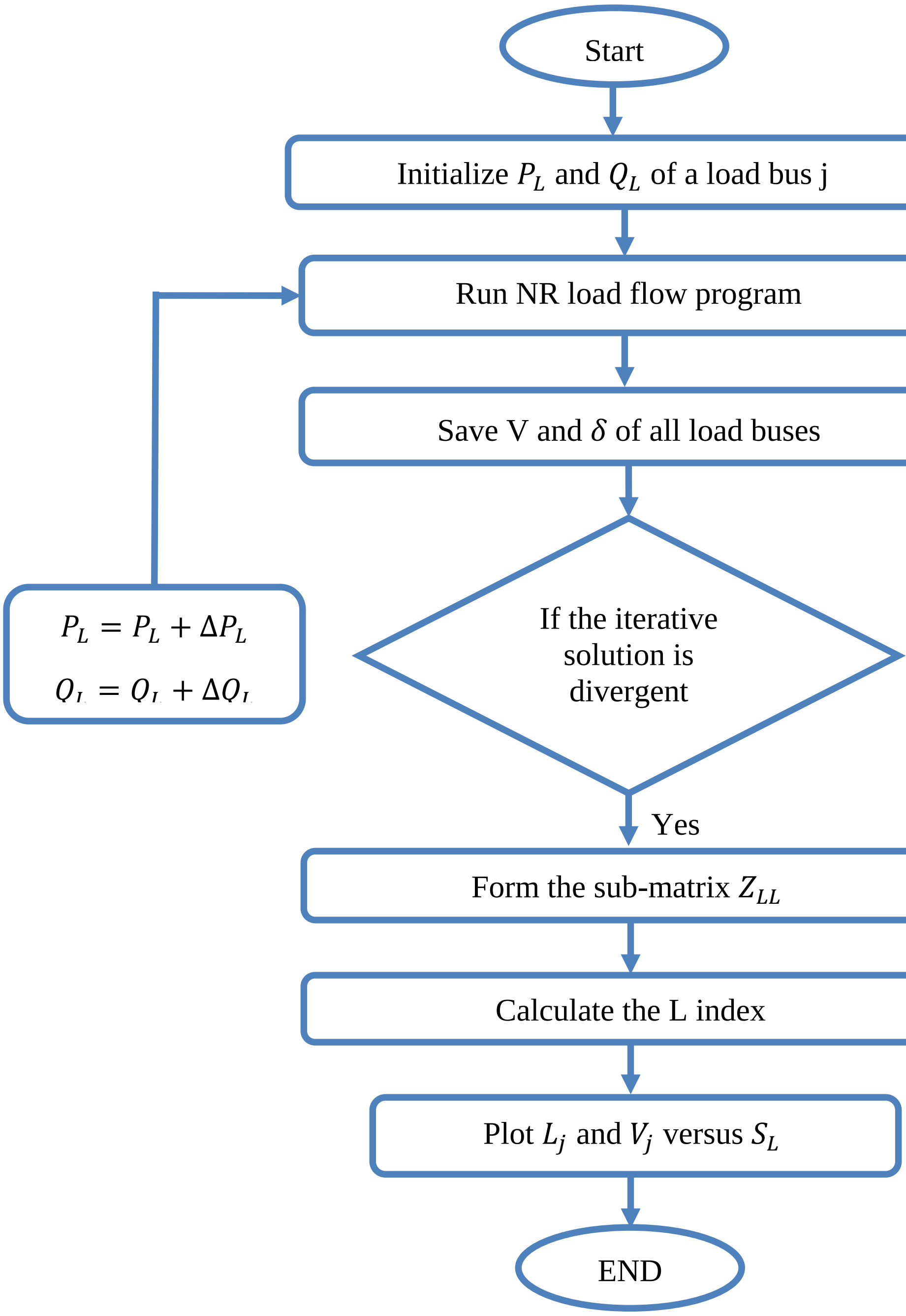



**Fig. 3. Flow chart of the L index calculation and plotting**

## 5. RESULTS AND DISCUSSION

### 5.1. Optimization of DG using PSO

A PSO based approach is proposed to find the optimal number and locations of distributed generation (DG) problem. In this study, the objective function has been considered to minimize the total active power losses .The proposed approach has been tested on IEEE 33-bus distribution system and then applied to part of Iraqi distribution networks (Al-Najaf Al-Ashraf distribution network). The IEEE 33-bus distribution system load data and line data are given in

[11]. The algorithm is implemented using Matlab 2013 Ra. Table 1 presents the results obtained without DG units and with PSO for one, two and three DG units. The size of DG units is selected as in the reference [12] to compare the results.

**Table 1. Optimal location of DG units for IEEE 33 bus distribution system**

| case | Size of each DG unit (KW) | Number of DG | Locations | Power losses (KW) |
|---|---|---|---|---|
| 1 | Without DG | | | 210.8 |
| 2 | 1100 | 1 | 31 | 86 |
| 3 | 1100<br>850 | 2 | 30 , 13 | 29 |
| 4 | 750<br>600<br>750 | 3 | 27,32,13 | 27 |

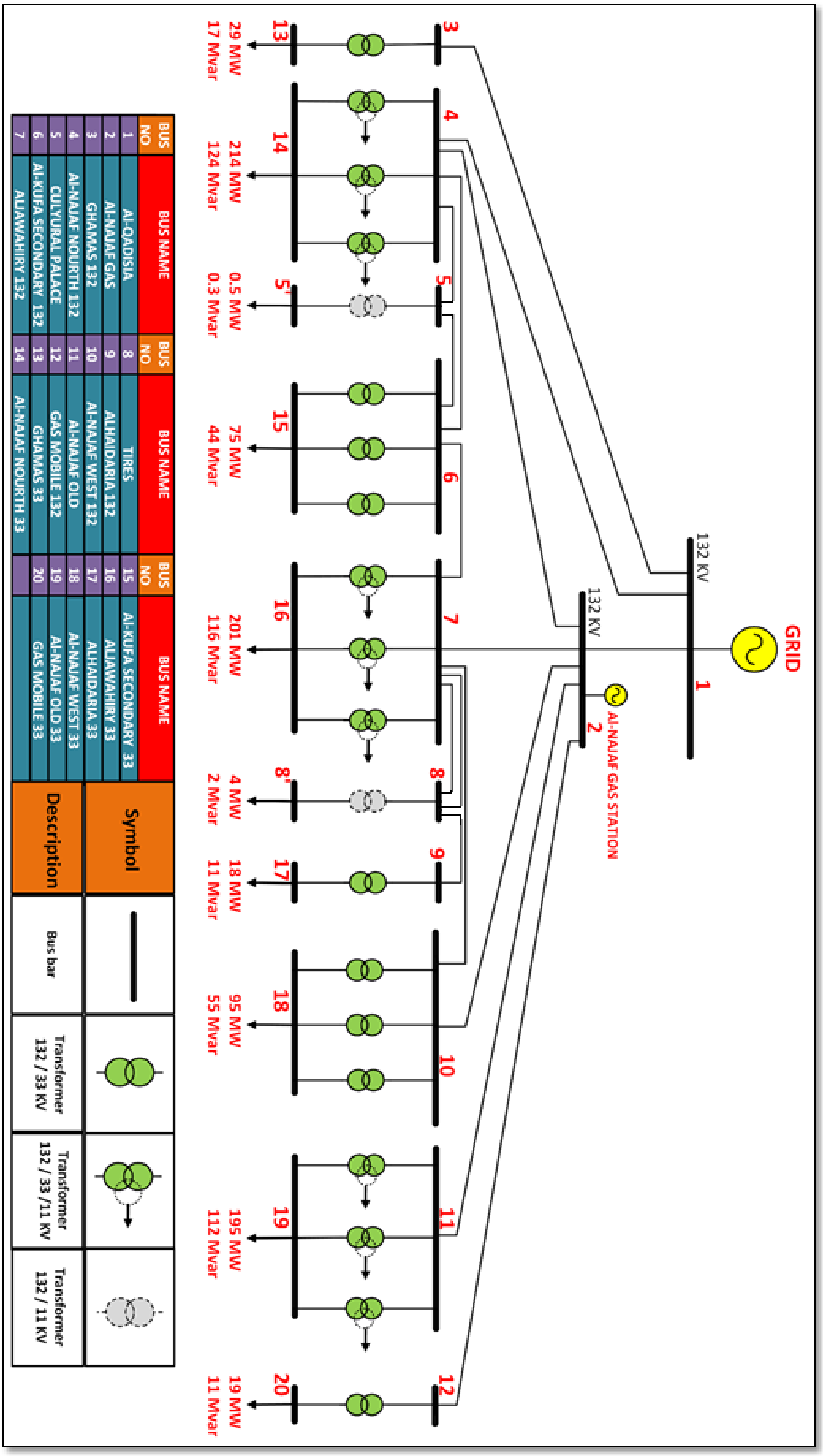
Al-Najaf Al-Ashraf distribution network is connected to the Iraqi power grid at Al-Qadisia bus bar to the southeast of Al-Najaf Al-Ashraf city, there is another connection at Al-Najaf gas station (generating station) which is connected to Al-Qadisia bus bar too. Al-Najaf Al-Ashraf distribution network consists of ten transformers substations transform the high voltage (132 KV) to the medium voltage (33 and 11 KV). Table 2 presents the results of optimal number and locations of DG units and the power losses (KW) for Al-Najaf Al-Ashraf distribution network (Fig. 4).

**Table 2. Optimal number and location of DG units for Al-Najaf Al-Ashraf distribution network**

| case | Size of each DG unit (MW) | Number of DG | Locations | Power losses (KW) |
|---|---|---|---|---|
| 1 | Without DG | | | 68433.9 |
| 2 | 50 | 7 | 13,14,15,16,17,18,20 | 11253.8 |
| 3 | 75 | 5 | 14,15,16, 18,20 | 6223.9 |
| 4 | 100 | 5 | 14,15,16,18,20 | 3274.2 |
| 5 | 125 | 4 | 14,15,16,18 | 2623.1 |
| 6 | 150 | 3 | 14,15,16 | 3056.1 |

### 5.2. Thermal limit

Power World Simulator 15 software was used to find the power flow and compare it with thermal limit that is calculated for each transmission line or the rated value of each transformer to detect the factor *TLF*. The results are summarized in Table 3.




| BUS NO | BUS NAME | BUS NO | BUS NAME | BUS NO | BUS NAME |
|---|---|---|---|---|---|
| 1 | Al-QADISIA | 8 | TIRES | 15 | Al-KUFA SECONDARY 33 |
| 2 | Al-NAJAF GAS | 9 | ALHAIDARIA 132 | 16 | ALJAWAHIRY 33 |
| 3 | GHAMAS 132 | 10 | Al-NAJAF WEST 132 | 17 | ALHAIDARIA 33 |
| 4 | Al-NAJAF NOURTH 132 | 11 | Al-NAJAF OLD | 18 | Al-NAJAF WEST 33 |
| 5 | CULYURAL PALACE | 12 | GAS MOBILE 132 | 19 | Al-NAJAF OLD 33 |
| 6 | Al-KUFA SECONDARY 132 | 13 | GHAMAS 33 | 20 | GAS MOBILE 33 |
| 7 | ALJAWAHIRY 132 | 14 | Al-NAJAF NOURTH 33 | | |

**Fig. 4. Al-Najaf Al-Ashraf distribution network**

**Table 3. Thermal limit**

| | From bus | To bus | Power Flow MW | $S_{thermal}$ | TLF |
|---|---|---|---|---|---|
| TRANSFORMERS | 3 | 13 | 34 | 63 | 0.54 |
| | 4 | 14 | 29.7 | 63 | 0.472 |
| | 6 | 15 | 16.6 | 63 | 0.263 |
| | 7 | 16 | 25.5 | 63 | 0.404 |
| | 9 | 17 | 21.5 | 25 | 0.861 |
| | 10 | 18 | 10 | 63 | 0.158 |
| | 11 | 19 | 78.7 | 63 | **1.248** |
| | 12 | 20 | 22.4 | 15 | **1.493** |
| LINES | 1 | 2 | 2.6 | 332 | 0.008 |
| | 1 | 3 | 35.9 | 332 | 0.108 |
| | 1 | 4 | 0.9 | 332 | 0.003 |
| | 2 | 4 | 55.7 | 332 | 0.168 |
| | 2 | 7 | 54.7 | 332 | 0.165 |
| | 2 | 10 | 1.7 | 332 | 0.005 |
| | 2 | 11 | 238.9 | 332 | 0.72 |
| | 2 | 12 | 22.4 | 91 | 0.246 |
| | 4 | 5 | 16.3 | 91 | 0.179 |
| | 4 | 6 | 16.4 | 91 | 0.18 |
| | 5 | 6 | 16.8 | 91 | 0.184 |
| | 6 | 7 | 16.7 | 182 | 0.092 |
| | 7 | 8 | 26.4 | 91 | 0.29 |
| | 7 | 10 | 28.5 | 182 | 0.157 |
| | 8 | 9 | 21.6 | 91 | 0.237 |

### 5.3. Voltage Stability

The L index is used to find the system voltage stability and to detect the weakest load bus. The algorithm has been done with a MATLAB-based power flow program solution by using Newton-Raphson method (MATLAB R2013a) to study the steady state voltage collapse at the load buses and their respective L indexes. The algorithm was applied to Al-Najaf Al-Ashraf distribution network to show effect of lines outage on the L index and voltage stability when the DG is found. Table 4 summarized the results of voltage stability.

**Table 4. Voltage stability**

| | Line 2-4 | | Line 2-7 | | Line 4-5 | | Line 5-6 | |
|---|---|---|---|---|---|---|---|---|
| **bus** | **L index** | **Vm(P.U)** | **L index** | **Vm(P.U)** | **L index** | **Vm(P.U)** | **L index** | **Vm(P.U)** |
| 5 | 0.0003 | 0.9968 | 0.0005 | 0.9980 | 0.0004 | 1.0007 | 0.0003 | 0.9979 |
| 8 | 0.0101 | 0.9620 | 0.0102 | 0.9571 | 0.0101 | 0.9619 | 0.0101 | 0.9619 |
| 13 | 0.0461 | 0.9222 | 0.0461 | 0.9222 | 0.0461 | 0.9222 | 0.0461 | 0.9222 |
| 14 | PV bus | 1.0000 | PV bus | 1.0000 | PV bus | 1.0000 | PV bus | 1.0000 |
| 15 | PV bus | 1.0000 | PV bus | 1.0000 | PV bus | 1.0000 | PV bus | 1.0000 |
| 16 | PV bus | 1.0000 | PV bus | 1.0000 | PV bus | 1.0000 | PV bus | 1.0000 |
| 17 | 0.0311 | 0.9377 | 0.0315 | 0.9326 | 0.0311 | 0.9376 | 0.0311 | 0.9376 |
| 18 | PV bus | 1.0000 | PV bus | 1.0000 | PV bus | 1.0000 | PV bus | 1.0000 |
| 19 | 0.0923 | 0.9416 | 0.0923 | 0.9416 | 0.0923 | 0.9416 | 0.0923 | 0.9416 |
| 20 | 0.0254 | 0.9853 | 0.0254 | 0.9853 | 0.0254 | 0.9853 | 0.0254 | 0.9853 |

## 6. CONCLUSIONS

The conclusions from this work can be summarized as follows:

1. The optimal number of DG units decreases whenever its size increases and the optimal locations of DG are near the buses that carry more load.
2. DG contributes significantly to the reduction in power losses, where there is a reduction by about 96% achieved when the number of DG is four with size 125 MW at buses 14, 15, 16 and 18 in Al-Najaf Al-Ashraf distribution network.
3. DG units reduce the system dependency on the centralized generation leading to reduction in the power flow through the transmission line which ensures its survival within thermal limit, furthermore, the load on transformers is reduced.
4. Also the DG units in Al-Najaf Al-Ashraf distribution network improve the voltage stability, because the L index value decreases and the voltage magnitude increases in several buses nearest the DG buses such as buses 5,8 and 17, in addition to the DG buses themselves.
5. The L index can detect the weakest load bus in the electrical network, where the weakest load buses are bus 16 without DG and bus 19 with DG in Al-Najaf Al-Ashraf distribution network.

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## APPENDIX A

### DATA BASE OF AL-NAJAF AL-ASHRAF DISTRIBUTION SYSTEM

**Table A.1. The input bus data for Al-Najaf Al-Ashraf distribution system**

| Bus NO. | **V P.U.** | **δ Degree** | **$P_L$ MW** | **$Q_L$ Mvar** | **$P_G$ MW** |
|---|---|---|---|---|---|
| 1 | 1 | 0 | 0 | 0 | - |
| 2 | 1 | - | 0 | 0 | 325 |
| 3 | - | - | 0 | 0 | 0 |
| 4 | - | - | 0 | 0 | 0 |
| 5 | - | - | 0.5 | 0.3 | 0 |
| 6 | - | - | 0 | 0 | 0 |
| 7 | - | - | 0 | 0 | 0 |
| 8 | - | - | 4 | 2.3 | 0 |
| 9 | - | - | 0 | 0 | 0 |
| 10 | - | - | 0 | 0 | 0 |
| 11 | - | - | 0 | 0 | 0 |
| 12 | - | - | 0 | 0 | 0 |
| 13 | - | - | 28.8 | 16.6 | 0 |
| 14 | - | - | 214.1 | 123.6 | 0 |
| 15 | - | - | 75.3 | 43.5 | 0 |
| 16 | - | - | 201.3 | 116.2 | 0 |
| 17 | - | - | 18.4 | 10.6 | 0 |
| 18 | - | - | 95.1 | 54.9 | 0 |
| 19 | - | - | 194.8 | 112.4 | 0 |
| 20 | - | - | 18.9 | 10.9 | 0 |

**Table A.2. The input branch data of Al-Najaf Al-Ashraf distribution system**

| From Bus | To Bus | R (P.U) | X (P.U) | From Bus | To Bus | R (P.U) | X (P.U) |
|---|---|---|---|---|---|---|---|
| 1 | 2 | 0.0369 | 0.2010 | 5 | 6 | 0.0041 | 0.0033 |
| 1 | 3 | 0.3084 | 0.2469 | 6 | 7 | 0.0082 | 0.0116 |
| 1 | 4 | 0.0377 | 0.2059 | 6 | 15 | 0.0000 | 0.0383 |
| 2 | 4 | 0.0022 | 0.0121 | 7 | 8 | 0.2474 | 0.0933 |
| 2 | 7 | 0.0022 | 0.0117 | 7 | 10 | 0.0168 | 0.0247 |
| 2 | 10 | 0.0004 | 0.0024 | 7 | 16 | 0.0000 | 0.0441 |
| 2 | 11 | 0.0013 | 0.007008 | 8 | 9 | 0.0907 | 0.0342 |
| 2 | 12 | 0.0165 | 0.0062 | 9 | 17 | 0.0000 | 0.1169 |
| 3 | 13 | 0.0000 | 0.1180 | 10 | 18 | 0.0000 | 0.0418 |
| 4 | 5 | 0.0137 | 0.0110 | 11 | 19 | 0.0000 | 0.0364 |
| 4 | 6 | 0.0178 | 0.0143 | 12 | 20 | 0.0000 | 0.1132 |
| 4 | 14 | 0.0000 | 0.0340 | | | | |