# Harmonic Based Strategy for Location and Sizing of Distributed Generation Insertion

## استراتيجية لتحديد مكان وحجم ادراج التوليد الموزع بناء على التوافقيات

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## ملخص البحث:

لقد ادت زيادة التقدم التقني وهيكلة نظم القوى الكهربائية إلى التزايد المستمر في أحجام مصادر التوليد الموزع التى يتم دمجها مع شبكات التوزيع، ولربط وحدات التوليد الموزع بشبكات التوزيع فإن هناك العديد من العوامل المختلفة التى يجب أخذها فى الاعتبار ومن ضمنها المتطلبات التقنية التي تفرضها الشبكات للتأكد من أن هذه الوحدات لا يؤثر سلبا على تشغيل وجودة القدرة لهذه الشبكات. ويطرح استخدام الكترونيات القوى عند ربط كثير من مصادر التوليد الموزع بالشبكة متطلبات عديدة خاصة بالتحكم فى التوافقيات الناتجة عن ادماجها مع الشبكة، حيث يتركز الاهتمام على التوافقيات التى تبثها هذه المصادر.

ويقدم هذا البحث استراتيجية مرتكزه على تأثير التوافقيات لحساب (لتحديد) أفضل موقع وأفضل حجم لمصادر التوليد الموزع التى يمكن ادماجها مع شبكة توزيع. كما يقدم البحث مؤشر جديد يسمى مؤشر التوافقيات الموحد مبنى على كل من تشوه موجة الجهد، تشوه موجة التيار، والقدرة على الاستضافة (قدرة الشبكة على استضافة وحدات التوليد الموزع). وتقوم المنهجية المقترحة على اساس ترتيب المواقع المتاحة لربط مصادر التوليد الموزع بالشبكة، ومن ثم تحديد القيم المثلى لأحجام هذه المصادر، ثم ترتيبها طبقا لكل من مؤشر التوافقيات الموحد والحدود القصوى للتوافقيات التى حددتها المعاييرالعالمية (معيار IEEE-519).

وقد تم تطبيق هذه الاستراتيجية على أحد المغذيات بشبكة التوزيع المصرية لتحديد أفضل موقع وأفضل حجم يمكن ادخاله على هذا المغذى.

## Abstract

Technical advances and institutional changes in the electric power industry have resulted in a constantly increasing penetration of distributed generation (DG) integrated with distribution networks. For the connection of new DG installations to the networks a variety of factors have to be taken into account, including technical requirements imposed by utilities to ensure that the DG doesn't adversely affect the operation and power quality of the networks. The use of power electronics at the front end of many DG types poses harmonic control requirements for their insertion into the grid. The attention is focused on the harmonic emissions. This paper introduces a harmonic based strategy for the best location and size of DG sources integrated with distribution network. Also, this paper introduces a new index called unified harmonic index (UHI) that is based on the values of voltage harmonic distortion, current harmonic distortion, and hosting capacity. The procedure is used to rank the available locations of DG and then examined optimum capacities of DGs in the ranked sites based on both the UHI and harmonic limit consideration in IEEE-519. The strategy is applied to an actual Egyptian feeder to indicate the best location and size of DG connected to the feeder as a preliminary study for the distribution network in Egypt for the near future as planned to allow the DG to be inserted.

## Keywords:

*Distributed Generation, Harmonic Distortion, IEEE 519-1992 Standards, Power Quality.*

## 1. Introduction

Electric power consumption has been growing steadily due to the expansion of industries, the elevation of living standards, and so on. However, building a large conventional power station is a time-consuming and complicated process, and often causes enormous environmental concerns [1]. Distributed generation systems can deliver premium electric power of high quality and reliability, as clean natural energy generation and cogeneration system of high thermal efficiency has increased due to the problems of global warming and exhaustion of fossil fuels [2-3]. By 2010, about 25% of new generation will be distributed generation [4]. Many of distributed generations are set up in the

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vicinity of the customer, with the advantage that this decreases transmission losses [5-6]. By integrating these new generation technologies through power electronic converters, they will inject harmonic currents which lead to voltage harmonic distortion, harmonic resonance, and result in serious deterioration of power quality.

Harmonics have bad effects of increasing equipment copper, iron, and dielectric losses, and thus the thermal stress. These losses are resulting in heating in transformers, rotating machines, and breaking down the electronic equipments [7].

The optimum size and location of DG that is placed in radial system is defined by an analytical method so as to minimize total power loss [8] for the uniformly, centrally and increasingly distributed system profile and to minimize the distribution utility's cost [9].

In [10] optimal placement is determined by sensitivity analysis of power flow equations, the sizing method for a set of loading conditions and generation penetration level. Optimal placement of DG in DPS was investigated with an emphasis on active power losses and allocation for minimizing the cost of losses and capacity investment costs simultaneously in [4]. An adequate DG placement for steady-state operation of distribution systems so as to minimize electrical network losses and to keep the acceptable reliability levels and voltage profile was presented in [11]. Optimal locations and capacities of DG as a means of ensuring that the maximum amount of DG can be connected to existing and future networks due to optimal power flow was introduced in [12].

The acceptable level of DG capacities that can be connected to the grid without exceeding the distribution networks harmonic limits was determined in [13-14]. Alejandro and Carlos [13] summarizes the results of a power quality (harmonic distortion) study performed on a PV generator capacity in order to estimate the effects that inverter-interfaced PV dispersed generation might have upon the quality of electric power. The paper focuses on economical consideration rather than a technical issue. Whereas, Latheef et al [14] determines the acceptable penetration level of distributed generation due to harmonic voltage distortion of the MV system was found for several values of penetration level and a comparison was made to the recommended harmonic distortion limits. But this study does not include the analysis of the resulting acceptable penetration levels of low voltage level in power distribution network configurations consisting of common feeder types.

In this paper a proposed strategy for location and sizing of DG sources integrated with distribution network is presented. The strategy is based on satisfying (not violating) the IEEE-519 harmonic limits after connecting DG sources. The objective of these methodologies is to ensure harmonic constraints' satisfaction. Also, this paper introduces a new index called unified harmonic index (UHI) that is based on the values of voltage harmonic distortion, current harmonic distortion, and the short circuit ratio. The proposed unified harmonic index is an innovative in the sense that it considers the voltage harmonic, current harmonic and harmonic short circuit ratio using suitable weighting factors. The procedure is used to rank the available locations of DG and then examined optimum capacities of DGs in the ranked sites based on both the UHI and harmonic limit consideration in IEEE-519.

## 2. Harmonic Indices

Harmonics have always been presented in power systems. Recently, the wide spread use of power electronic components resulting in an increase in harmonic magnitude, it becomes a key issue in installations. The fluctuating nature of the WECS is expected to inject both voltage and current harmonics into power systems. This harmonic injection is obvious to increase by increasing the wind penetration in the system. However, the grid has to make sure that the injected harmonics doesn't exceed the permitted level.

The distorted waveform may be expressed as a sum of sinusoids with various frequencies and amplitudes, by application of the Fourier transform. The sinusoids with frequencies equal to an integer multiple of the fundamental frequency are denoted harmonics, whereas the others are denoted inter harmonics [7].

Harmonic voltages, $U_h$, where h denotes the harmonic order (i.e. an integer multiple of 60 Hz) can be evaluated individually by their relative amplitude as shown in Eq. (1).

$$U_h = \frac{V_h}{V_n} \quad (1)$$

While harmonic current, $I_h$ can be evaluated individually by their relative amplitude as shown in Eq. (2)

$$I_h = \frac{I_h}{I_n} \quad (2)$$

Further, the total harmonic distortion (THD) of the voltage, is calculated according to Eq. (3) , has to be less or equal 8%:

$$THD_v = \left[\sum_{h=2}^{\infty}(v_h)^2\right]^{1/2} \quad (3)$$

However, the current total harmonic distortion is calculated according to Eq. (4), has to be less or equal 6%:

$$THD_i = \left[\sum_{h=2}^{\infty}(I_h)^2\right]^{1/2} \quad (4)$$

The hosting-capacity approach has been developed to obtain a quantitative measure on the amount of generation that can be connected without impairing the performance of the system. The hosting-capacity approach requires a set of well-defined.

In this analysis, the harmonic distortion is taken as phenomena and a performance index. This index can be defined by calculated both total harmonic distortion of voltage ($THD_v$), total harmonic distortion of current ($THD_i$) and harmonic short-circuit ratio (SCR). These values can by computed as [13, 15-16]:

$$THD_v\% = \frac{1}{V_1}\sqrt{\sum_{h=2}^{\infty} V_h^2} * 100 \quad (5)$$

$$THD_i\% = \frac{1}{I_1}\sqrt{\sum_{h=2}^{\infty} I_h^2} * 100 \quad (6)$$

$$SCR_{actu.} = h\frac{I_h\%}{V_h\%} \quad (7)$$

$$SCR_{pu}\% = \frac{SCR_{actu.}}{SCR_{base}} * 100 \quad (8)$$

Where:

$SCR_{actu}$: actual harmonic short-circuit ratio

$SCR_{base}$: base harmonic short-circuit ratio.

$V_1$, $I_1$ : fundamental peak voltage and current respectively.

$V_h$, $I_h$ : harmonic component of voltage and current respectively of the order indicated by the subscript, h.

H : Order of harmonic

In this study the limits for these indices are taken according to IEEE-519 Standards [17, 18].

$$THD_v\% \leq 4\% \quad (9)$$

$$THD_i\% \leq 5\% \quad (10)$$

$$SCR_{actu} \leq 20 \quad (11)$$

A Unified Harmonic Index (UHI) will be used to reflect the impact of all the above indices and is defined as follows:

$$UHI = a_1THD_v\% + a_2THD_i\% + a_3SCR\% \quad (12)$$

Where: $a_1$, $a_2$, and $a_3$ are weighting factors, their values are taken according to the impact (importance) of each component and their summation equals to the unity.

## 3. Proposed Strategy

The objective of this strategy is to identify, based on harmonic constraints, the best site and size of DG sources to be connected with a conventional distribution system. Integration of DG with a distribution network has to satisfy many operational and economical constraints. The proposed procedure identifies all the buses satisfying the harmonic constraints and then ranks them according to the value of the Unified Harmonic Index. These candidate sites are then examined to find the optimum DG capacity based on harmonic limit consideration in the IEEE-519 standard. Beside the harmonic constraints, the amount of added DG power per bus must be within a certain specified power range of this bus [19]:

$$P_{DG(j)} \leq MaxP_{(i)} \quad (13)$$

Where:

$P_{DG(j)}$ : injected power from DG in kW.
$MaxP_i$ : maximum rating power of bus ($B_i$) in kW .
j : number of DG units, j=1, 2, 3,...m
M : number of available DG units.
i : bus number, i= 1, 2, 3,.....n.
n : number of best selected buses.

Some other practical and experience constraints are desirable to be considered such as :

- DG is preferred to be at the end of the feeders or close to branch points,
- DG is preferred to be close to the critical loads,
- DG is preferred to be at the buses of the worst case of load percentage,
- Avoid installing a new transmission lines in the feeders,

The procedure for finding optimal location and size of a DG in distribution networks is shown in Figure 1.

## 4. Description of the Studied System

The proposed strategy is applied to an actual feeder in Egypt (Meet-Ali Feeder) as a one step ahead of ministry of electricity screening efforts to identify the best location and capacity of DG that could be allowed to be inserted in the distribution network in the near future.

### 4.1 Studied Feeder Data

The procedure is applied to (Meet Ali Feeder [20]). The main feeder is 30 Km long supplied by the 66/11 KV substation. The feeder supplies eleven secondary mains through distributed transformers each of 11/0.4 KV. All loads are considered to be linear. The single line diagram of this feeder is shown in Figure 2, and the main feeder data is given in Appendix (A).

### 4.2 System Description

For photovoltaic power system, like many other DG technologies, a power electronic interface is used to connect the DG system to the utility grid, with the main function of adapting the characteristics of the active and reactive power supplied from the DG to the grid. This power electronic interface usually comprises a current-controlled voltage source converter (VSC) based on IGBT valves, which can be controlled with pulse width modulation (PWM) techniques with high switching frequencies to achieve high controllability and power quality. Capability of distributed generation to achieve limitation of current and voltage quality limit, this is done by improving current quality through passive filters and current control circuit. Improving current quality leads to improve the voltage quality. In order to limit the complexity of the model, the power source is modeled as a DC voltage source connected with controlled three phase inverter voltage source interfaced with distribution systems through LCL-filter. The designed DGs units are 400 volt rms, at frequency 50 HZ, and switching frequency 10 kHz. In this study the rating power of the DG units will be taken as 40, 60, 80, 120, 160 and 200 kW. The detailed DGs data are given in Appendix (B).

## 5. Numerical Analysis

A Matlab/Simulink program Version 7.4 is used to simulate the distribution network (utility grid source, transformers, transmission lines, buses, and loads) and the distributed generation components (DC-link, IGBT inverter, current control circuit, and LCL-filter). The current and voltage waves are analyzed using FFT to record $THD_v$%, $THD_i$%, $V_h$%, and $I_h$%. According to the practical constraints, the candidates' locations at Meet-Ali feeder are the buses 14, 17, 20 and 23 because they are the heaviest loaded buses. The DG units are taken as 40, 60 and 120 kW. The following sub-items present the output results of the program simulation for different case studies.

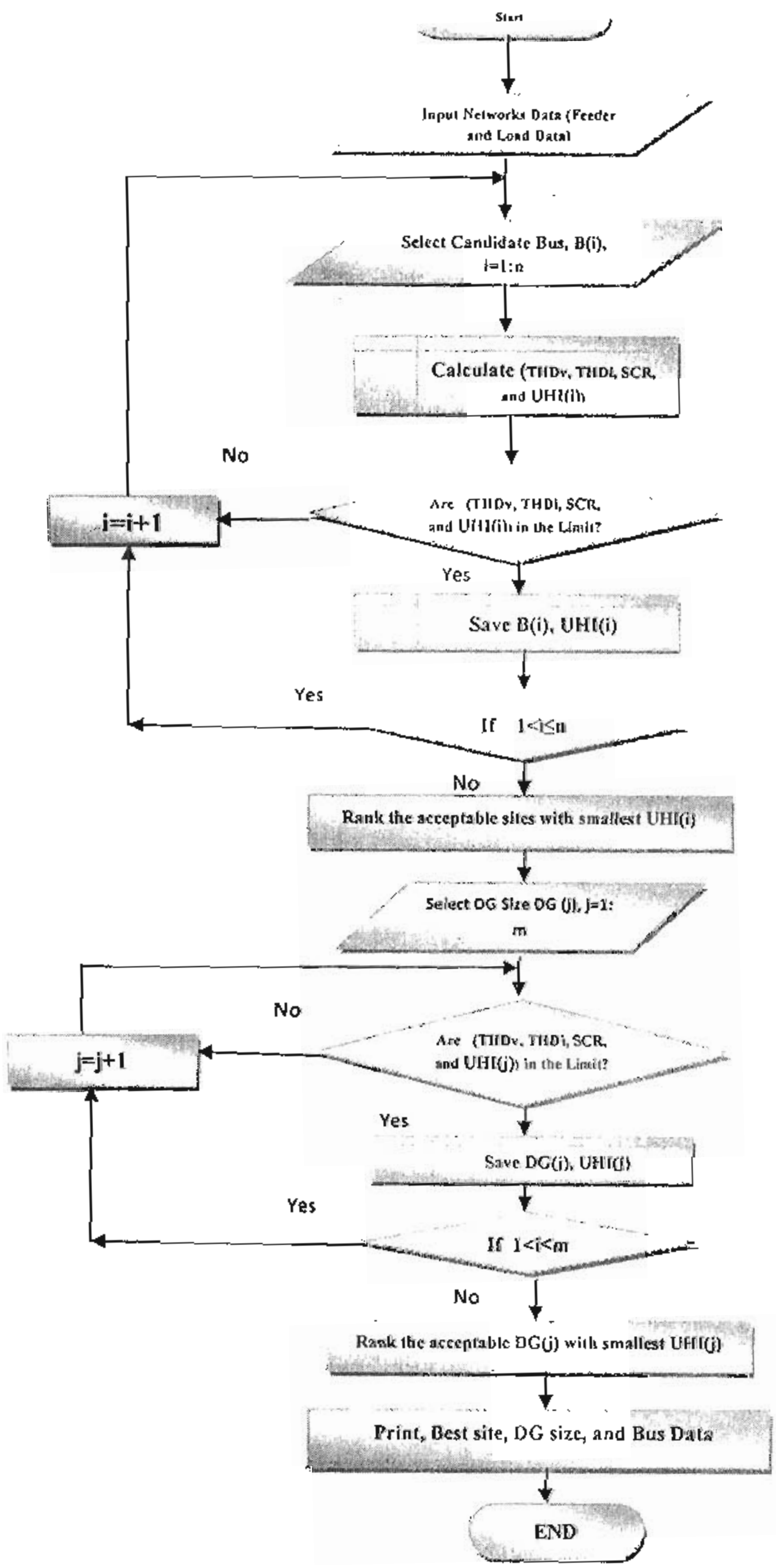


*Fig.(1): Procedure for finding optimal site and capacity of a DG in distribution networks.*

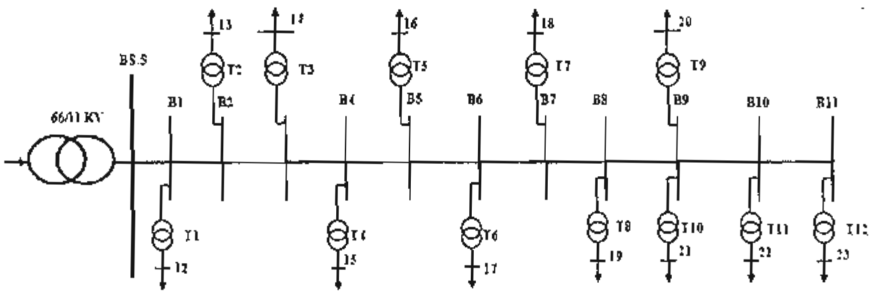

*Fig.(2): Single line diagram of Meet-Ali feeder*

### 5.1 60 kW DG Integrating to Bus #14

In this case, a DG unit of 60 kW is integrated at bus #14 of the Figure 2. The output active power of the DG is shown in Figure 3. The output voltage and current waves in time domain and their harmonic spectrum at frequency domain are shown in Figure 4.

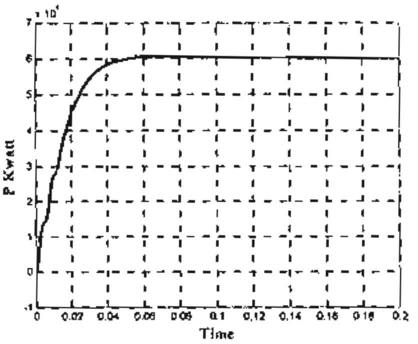


*Fig.(3): 60 kW output DG active power*

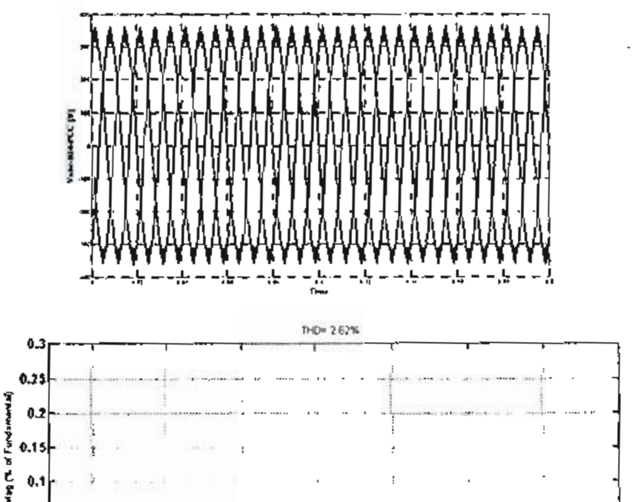

*Fig. 4 (a) Output Voltage and Harmonic Spectrum of 60 kW DG at Bus 14*

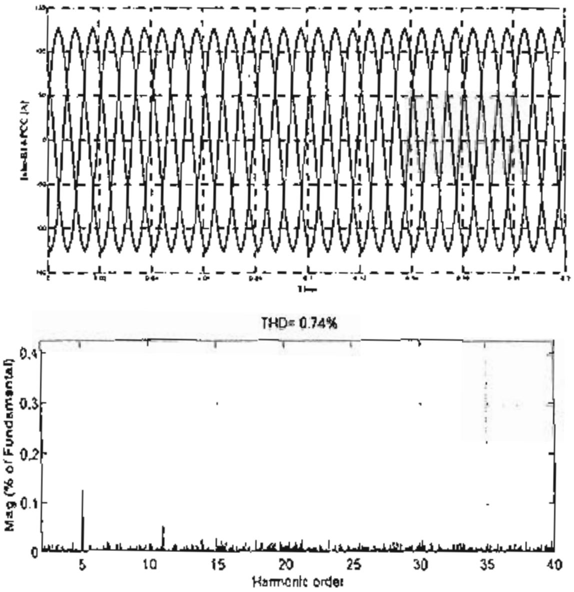


*Fig. 4 (b) Output Current and Harmonic Spectrum of 60 kW DG at Bus 14*

The obtained values of total harmonic distortion of voltage ($THD_v$), and current ($THD_i$), for all buses are shown in Table 1. Whereas, To evaluate the hosting capacity limit (Hosting capacity is a notation to the amount of DG (or size) that could be connected to the grid without breaking any limitation as for instance the allowed harmonics at a bus), the calculation of the $SCR_{sactu}$ using equation (3), for individual harmonics groups as in [17], to $37^{th}$ harmonic order are in Table 2.

*Table(1) $THD_v$%, and $THD_i$% for all buses in case of 60 kW DG, at Bus 14*

| Bus No. | THDv% | THDI% | Bus NO. | $THD_v$% | $THD_i$% |
|---|---|---|---|---|---|
| S.S | 0.01 | 0.02 | 12 | 0.01 | 0.01 |
| 1 | 0.01 | 0.05 | 13 | 0.01 | 0.01 |
| 2 | 0.01 | 0.25 | 14 | 2.62 | 0.74 |
| 3 | 0.01 | 0.67 | 15 | 0.01 | 0.01 |
| 4 | 0.01 | 0.07 | 16 | 0.001 | 0.001 |
| 5 | 0.01 | 0.02 | 17 | 0.01 | 0.01 |
| 6 | 0.01 | 0.05 | 18 | 0.001 | 0.001 |
| 7 | 0.01 | 0.02 | 19 | 0.01 | 0.01 |
| 8 | 0.01 | 0.07 | 20 | 0.01 | 0.01 |
| 9 | 0.01 | 0.18 | 21 | 0.01 | 0.01 |
| 10 | 0.01 | 0.1 | 22 | 0.001 | 0.001 |
| 11 | 0.01 | 0.46 | 23 | 0.01 | 0.01 |

*Table (2): Hosting capacity in case of 60 kW DG, at Bus 14*

| h | $V_h$% | $I_h$% | $SCR_{actu}$ |
|---|---|---|---|
| $5^{th}$ | 0.0306 | 0.12 | 19.61 |
| $13^{th}$ | 0.00587 | 0.00895 | 19.8 |
| $19^{th}$ | 0.0198 | 0.0201 | 19.19 |
| $25^{th}$ | 0.0102 | 0.0062 | 14.7 |
| $37^{th}$ | 0.0279 | 0.0108 | 14.32 |

As shown from Table 1, the percentage voltage total harmonic distortion, and the percentage current total harmonic distortion at bus #14 (2.62%, 0.74%) are the highest among the distribution network.

### 5.2. Ranking results for integrating 60 kW DG at Different Sites

The same procedure of inserting the 60 kW of DG at Bus #14 was repeated at Buses 17, 20 and 23 aiming at selecting the best site among them. Applying the proposed procedure to all candidate buses, the simulation results are listed in Table 3 for $THD_v$%, $THD_i$%, and SCR% at the selected buses.

*Table (3): Results of integrating 60 kW DG units to candidate buses*

| Bus No. | $THD_v$% | $THD_i$% | SCR% |
|---|---|---|---|
| *14* | 2.62 | 0.74 | 87.6 |
| *17* | 0.61 | 0.77 | [redacted] |
| *20* | 2.25 | 0.77 | 93.1 |
| *23* | 3.79 | 0.81 | 75.5 |

As shown from Table 3, $THD_i$% in this case of site algorithm approximately has the same value, because harmonic current is injected from the same DG unit of 60 KW has current controlled circuit, where the value of $THD_i$% is in per unit.

The distortion in voltage has different values due to different values of SCR%, and voltage drop along the feeder. Values of harmonic voltages are affected by the whole system impedance; the $THD_v$ % is in per unit.

SCR% at bus 14, and 20 are very close to each other because Isc is approximately the same (101%, 117%) respectively and using the same DG unit of 60 KW.

Values of $THD_v$ % vary for each case of analysis because $THD_v$% is directly affected by the SCR%, Now, it is logical if DG unit integrated at bus 17, which is apparently the load center, the most impact is occurred, so having the less $THD_v$%, because it is actually decreasing the total load at this bus as seen from the power system point of view (increasing the SCR%, while having the same parameters).

The value of SCR% at bus 17 is greater than100 % so this bus is refused from the harmonic point of view.

From the stability point of view, not harmonic distortion, the best allocation of DG is at load center at bus 17, as higher SCR means stronger system and then the operation of DG will not affected the system stability, moreover the system is not exposed to over voltages at light loads, a situation that could easily happen at an already light loaded bus.

The accepted buses are ranked according to the UHI index as defined by Equation 8, and the results are shown in Table (4).

*Table (4): Ranking Order after Integrating 60 kW DG Units to Different Buses*

| Bus NO. | UHI | Ranking |
|---|---|---|
| *14* | 2.056 | 2 |
| *20* | 1.8059 | 1 |
| *23* | 2.81 | 3 |

As shown from Table 4, the best location is bus # 20 from the harmonic distortion point of view, which has low value of UHI and it will be used to find optimum sizing of DG unit.

### 5.3. Optimal Sizing of DG

After indicating the candidate buses and examine their acceptability for DG integration, the next step is to investigate the amount of DG that can be added at these sites without violating harmonic and other constraints .

The proposed procedure, using the algorithm illustrated in Figure (1), to select the optimal DG allowed capacity at the best site depends on the geometric ranking site scheme as a selection mechanism of UHI in Table 4.

The process begins with first defining DG of 40, KW, 60 KW, 80 KW, 120 KW, 160 KW and 200 KW with different penetration level. The master plan (structure) process is illustrated in Figure (5) below.

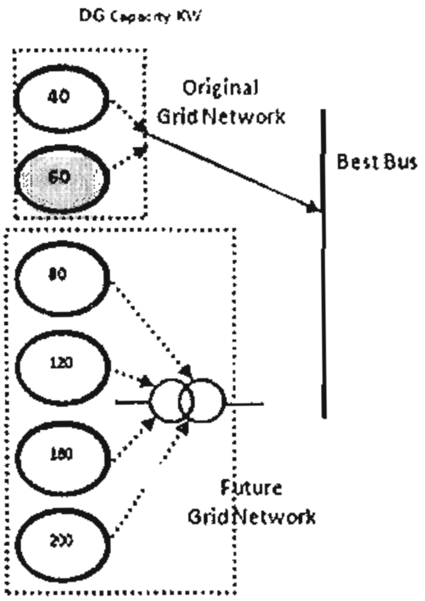


*Fig.(5): The master structure plan process*

### 5.3.1 Optimal sizing of DG in case of original distribution network

In this case two distributed generation units are used one of 40 KW, and the second with 60 KW as analyzed above.

For the case of integrating 40 kW this DG unit with Meet Ali Feeder at best bus 20. The penetration level of DG is 2.2% of the whole load. The active output power of this unit is shown in figure (6). Table 5 shows the hosting capacity *in Case of 40 KW DG at Bus 20 .While, table 6 lists the $THD_v$%, $THD_i$%, and SCR% Values in Case of 40 KW DG at Bus 20.*

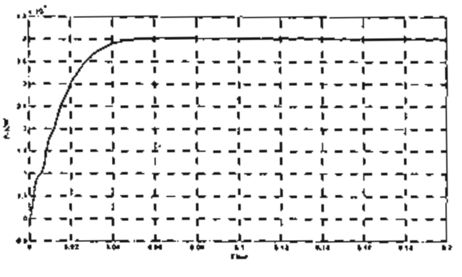

*Fig.(6): 40 KW (a) output DG active power*

*Table (5): Hosting Capacity in Case of DG 40 KW at Bus 20*

| $h$ | $V_h\%$ | $I_h\%$ | $SCR_{actu}$ |
|---|---|---|---|
| $5^{th}$ | 0.0221 | 0.126 | [redacted] |
| $13^{th}$ | 0.0119 | 0.0262 | [redacted] |
| $19^{th}$ | 0.00992 | 0.0153 | [redacted] |
| $25^{th}$ | 0.0168 | 0.0223 | [redacted] |
| $37^{th}$ | 0.04 | 0.0354 | [redacted] |

*Table (6): THDv%, THDi%, and SCR% Values in Case of DG 40 KW at Bus 20*

| Bus NO. | 20 |
|---|---|
| $THD_v$% | 2.32 |
| $THD_i$% | 1.15 |
| SCR% | [redacted] |

As shown from Table 6, The SCR% values is more than 100 when inserting 40 kW at bus 17 is greater than100 % so this case is rejected. So, the optimum allowed DG capacity in original distribution network is 60 KW at bus 20 with distribution transformer rating of 63 KVA, which has low value of UHI.

### 5.3.2 Optimal sizing of DG in case of future distribution network

In this case four distributed generation units are used with 80KW, 120 KW, 160 KW, and 200 KW.

For the case of integrating, 80 kW DG unit with Meet Ali Feeder at the best location (bus 20). The penetration level of DG is 4.4% of the whole load. In this case, a new distribution transformer is used, at the line connecting bus 20 and bus 8, with a rated of 100 KVA. Figure (7) shows DG unit at the bus 20.

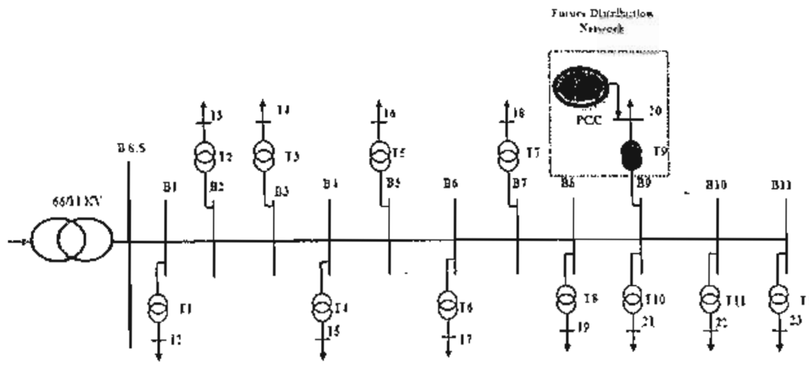


*Fig. (7): DG in bus 20 of future distribution network of Meet Ali Feeder*

The active output power of this unit is shown in figure (8). Table (7) summarizes the results of hosting capacity when inserting 8 KW DG at bus 20 for future network and Table (8) contains THDv%, THDi%, and SCR% for this case. The collected results and the ranking of cases are tabulated in table (9).

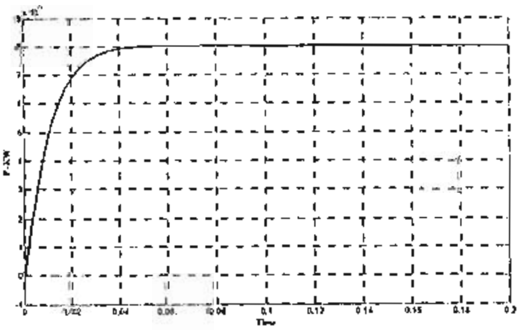

*Fig.(8): 80 KW output DG active power*

*Table (7): Hosting capacity in case of DG 80 KW at bus 20 for Future Network*

| $H$ | $V_h\%$ | $I_h\%$ | $SCR_{actu}$ |
|---|---|---|---|
| $5^{th}$ | 0.0688 | 0.203 | 14.75 |
| $13^{th}$ | 0.0426 | 0.0485 | 14.8 |
| $19^{th}$ | 0.0147 | 0.0117 | 15.122 |
| $25^{th}$ | 0.00605 | 0.0041 | 16.9 |
| $37^{th}$ | 0.0253 | 0.0115 | 16.82 |

*Table (8) :Harmonic Indices in case of DG 80 KW at bus 20 for Future Network*

| *Bus NO.* | 20 |
|---|---|
| $THD_v\%$ | 1.99 |
| $THD_i\%$ | 0.56 |
| *SCR%* | 78.4 |
| *UHI* | 1.561 |

As shown from table 9, the optimum allowed DG capacity in future distribution network is 160 KW at bus 20 with new distribution transformer rating from 63 KVA to 200 KVA which has low value of UHI. This case is refused due to the assumed practical constraints (To avoid install a new transmission lines in the feeders). The discrete DG units of 40 KW and 200 KW are out of selection because they don't achieve $SCR_{actu}$ constraint [2].

*Table (9): Total results of optimum DG capacity at best site*

| DG Size (KW) | Description | Penetration% | $THD_v$% | $THD_i$% | SCR% | UHI | Ranking |
|---|---|---|---|---|---|---|---|
| 40 | Original Grid | 2.2 | 2.32 | 1.15 | 152.3 | Out | Out |
| 60 | Original Grid | 3.3 | 2.25 | 0.77 | 93.1 | 1.8059 | 4 |
| 80 | Future Grid | 4.4 | 1.99 | 0.56 | 78.4 | 1.561 | 3 |
| 120 | Future Grid | 6.6 | 1.65 | 0.3 | 54.3 | 1.245 | 2 |
| 160 | Future Grid | 8.8 | 1.36 | 0.21 | 82.2 | 1.0156 | 1 |
| 200 | Future Grid | 11 | 1.33 | 0.2 | 116 | Out | Out |

## 6. Conclusions

For the connection of new DG installations into the distribution networks a variety of factors have to be taken into account, among them comes the harmonic contents. Especially, using of power electronics at the front end of many DG types poses harmonic control requirements for their insertion into the grid. This paper presented the methodology for optimizing the placement and capacity of distributed generation in practical feeder in Egypt based on harmonic constraints.

In this study, harmonic constraints are constraints on voltage harmonic, current harmonic and hosting capacity. Also, this paper introduced a new index called unified harmonic index (UHI) that is based on the values of voltage harmonic distortion in terms of voltage total harmonic distortion, current harmonic distortion in terms of current total harmonic distortion, and hosting capacity in terms of harmonic short circuit ratio. The procedure is used to rank the available locations of DG and then examined optimum capacities of DGs in the ranked sites based on both the UHI and harmonic limit consideration in IEEE-519.

The proposed strategy was tested on MEET Ali Feeder, Egypt. The distributed generation capacity of 160 KW with penetration level 8.8% of whole load at buses 20 as it has the best UHI value in case of future distribution network. In case of original distribution network the unit 60 KW is selected because it has acceptable UHI value.

Integrated distributed generation in distribution systems take in consideration harmonic limit consideration lead to the positive impact of DG in power quality of distribution networks.

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# Appendices

## Appendix (A) Meet –Ali Feeder Data

*Table A-1 Feeder configurations*

| ASCR cross section area AL/ST $mm^2$ | Resistance AC of line ohm/Km at 20 $c^0$ | Inductive impedance of line ohm/Km |
|---|---|---|
| 150/25 | 0.239 | 0.344 |
| 70/12 | 0.514 | 0.365 |
| 35/6 | 1.0285 | 0.393 |
| 3*150 (underground cable) | 0.246 | 0.024 |
| 3*240 (underground cable) | 0.148 | 0.023 |

*Table A-2 Main feeder data*

| From Bus | To Bus | Feeder Type | Feeder Length Km |
|---|---|---|---|
| S.S | 1 | 3*240 | 3.9 |
| 1 | 2 | 150/25 | 3.2 |
| 2 | 3 | 70/12 | 1.6 |
| 3 | 4 | 70/12 | 2 |
| 4 | 5 | 70/12 | 2 |
| 5 | 6 | 3*150 | 3 |
| 6 | 7 | 35/6 | 2.3 |
| 7 | 8 | 70/12 | 3.7 |
| 8 | 9 | 70/12 | 4.6 |
| 9 | 10 | 70/12 | 2.4 |
| 10 | 11 | 70/12 | 1.3 |

*Table A-3 Transformers' Data*

| Trans. No. | Rating (KVA) | % age loading | Per unit impedance |
|---|---|---|---|
| 1 | 63 | 81 | 3.84 |
| 2 | 100 | 49 | 4.11 |
| 3 | 63 | 101 | 3.84 |
| 4 | 100 | 78 | 4.11 |
| 5 | 200 | 84 | 4 |
| 6 | 500 | 49 | 4 |
| 7 | 300 | 84 | 4 |
| 8 | 200 | 44 | 4 |
| 9 | 63 | 117 | 3.84 |
| 10 | 63 | 62 | 3.84 |
| 11 | 100 | 85 | 4.11 |
| 12 | 63 | 69 | 3.84 |

## Appendix (B) Distributed Generations Data

The designed distributed generation unit is at nominal voltage of 400 Volt, nominal grid frequency 50 Hz, and switching frequency 10 KH.

*Table B-1 Distributed Generations' Data*

| *Description* | *Symbol* | *Unit (1)* | *Unit (2)* | *Unit (3)* | *Unit (4)* | *Unit (5)* | *Unit (6)* |
|---|---|---|---|---|---|---|---|
| Nominal Power KW | $P_{Nom}$ | 40 | 60 | 80 | 120 | 160 | 200 |
| Nominal DC voltage Volt | $V_{dc}$ | 650 | 650 | 650 | 700 | 750 | 750 |
| DC-link capacitance μF | $C_{dc}$ | 550 | 550 | 550 | 600 | 650 | 650 |
| *LCL-filter* | | | | | | | |
| Inverter Side LCL-filter inductance mH | *L1* | 0.4 | 0.39 | 0.35 | 0.252 | 0.203 | 0.1623 |
| LCL-filter capacitance μF | *C* | 60 | 90 | 120 | 180 | 238 | 300 |
| Grid Side LCL-filter inductance mH | *L2* | 0.264 | 0.257 | 0.232 | 0.167 | 0.134 | 0.107 |