



Research Article

Power Quality and Harmonics Study of IEEE 33 Bus Test Power Distribution System Using Digsilent

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ABSTRACT

A renewable or nonrenewable power source connected to power system at distribution system level is called distributed generation (DG). DGs with optimal location and size are integrated in to power system to mitigate the problems associated with centralized generation of power system, however, as a result of the power electronics devices associated with some of the DGs, the power quality of the system is jeopardized. Herein, Whale optimization algorithms was deployed for optimal sizing and siting of PV DG in an IEEE 33 Bus test system and DigSILENT software was used to create a model of the system to study its impact on the power quality and harmonics in the system. The results showed that the power loss of the system reduces to 89kW from 120kW and voltage profile of 9 out of the 33 buses which were below the recommended tolerance of $\pm 5\%$ fall within the tolerance. At the initial stage, there was harmonics as a result of the types of loads on the network which in turn affects both the voltage and frequency of the system, this parameter and the total harmonics distortion and harmonics voltage content in the system were increased significantly as a result of the presence of PV DG in the system. Furthermore, the frequency deviation of 10 buses in the power system with PV DG do not satisfy the recommended tolerance of $\pm 0.2\text{Hz}$, these deviations are due to non-linear loads and power electronics devices associated with the DG. This study has confirmed that integration of PV DG in to power system affects the power quality and increase the harmonics content.

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INTRODUCTION

A Power source connected to power systems at distribution level is called distributed generation (DG). It can be renewable or nonrenewable energy source but renewable energy sources are preferred because of the advantages associated with them (Akagi *et al.*, 1984; Akagi *et al.*, 1994). Renewable energy skill do not need transportation of primary energy sources as a result solar energy technologies which exploit solar energy from the sun and convert it into acceptable form of energy namely heat and electricity are leading candidates for distributed energy generation (Akagi *et al.*, 1996). In addition, other instances of renewable energy skills applied in DG technologies are wind turbine, small hydro, biogas and geothermal systems etc. As a results of the harmful effect on the environment associated with the usage of fossil fuel, there has been a substantial increase in the application of renewable energy technologies.

Though DGs are integrated in to power system to mitigate the problems associated with However, maintaining a good power quality is paramount and difficult to achieved. In most cases when there is fault in a power system, electrical equipment malfunction leading to Sometimes prematurely failure or shut down unexpectedly. This scenario may lead to high economic lost on the customer side. To mitigate these negative effects, there is need to study the consequences of these power quality issues on the system. (Tobali *et al.*, 2014)

centralized generation of power, vacillating nature of some of the DGs solar and other renewable energy resources constitute some technical threats on the system like feeder overloading, harmonic pollution and etc. On the other hand, high capital expenditure, low dependability and low efficiency limit the considerable applications of these technologies. As a result of variant nature of solar radiation, power fluctuations and voltage flickers are the catastrophic consequences of power system with high penetration of PV system (Cheng *et al.*, 2014; Bhim, *et al.*, 2010)

However, to derive maximum benefits from DG, the generators must be appropriately sized and located within the power distribution network (Chen *et al.*, 2013).

Power quality is a term that has different meaning to different people. In this study, power quality is a concept that defines efficient electrical energy. If an equipment is performing correctly as a result of the power it is receiving, the quality of the power is termed good otherwise is bad.

DG installation problem formulation

For coherent operation of power system operation, it is paramount to reduce the real power loss in the system. (Sang, 2010); (Ding *et al.*, 2013). The aim of the integration of DG approach is to reduce the total real power loss and enhanced voltage profile. Analytically, the approach can be formulated as in Equation (1).

$$\text{Minimize } P_L = \sum_{i=1}^{N_L} |I_i|^2 R_i \quad (1)$$

Subject to the following constraints.

$$\sum_{i=1}^{N_{DG}} P_{DG_i} = \sum_{i=1}^{N_D} P_{D_i} + P_L \quad (2)$$

$$|V_i|^{min} \leq |V_i| \leq |V_i|^{max} \quad (3)$$

$$\text{Currents Limits: } |I_{ij}| \leq |I_{ij}|^{max} \tag{4}$$

$$0 \leq P_{DG} \leq 0.4 \sum_{i=1}^{N_L} P_{LOAD} \tag{5}$$

Where;

N_L is the number of buses

N_D is the load bus at L

N_{DG} is the Bus with DG

P_L is the real power loss

P_{DG_i} is the MW generated

P_{D_i} is the MW required

I_{ij} is the flow from bus i to j

R_i is the line resistance

Problem Formulation of Power quality Issues Harmonics

Presence of harmonics in power systems is characterized by the numerous fundamental frequencies of operation. The deviation of sinewave from its original waveshape indicates presence of harmonics in the system which

$$v(t) = \sqrt{2}V \sin(\omega t + \Phi) \tag{6}$$

Where,

V is the system voltage

Φ is the voltage phase angle

ω is the angular frequency

f is the frequency of operation

T is time

Rationally, effective value is used to quantify current and voltage value, for example, the

$$I = \sqrt{\frac{1}{T} \int_0^T i^2(t) dt} \tag{7}$$

The momentary values of non-sine wave current and voltage, can be expressed using as follows:

$$v(t) = V_o + \sum_{n=1}^{\infty} \sqrt{2}V_n \sin(n\omega_1 t + \Phi_n) \tag{8}$$

$$i(t) = I_o + \sum_{n=1}^{\infty} \sqrt{2}I_n \sin(n\omega_1 t + \alpha_n) \tag{9}$$

Where n is the order of harmonics

To demonstrate the level of divergence of the wave form from typical sine wave, we can use the following harmonics related characteristics, such as harmonic content, total harmonic distortion and Nth harmonic content.

To study the characteristics of a power system with respect to the harmonic distortion levels, a

cause power quality issues which in turn give rise to heating in the equipment and conductors and misfiring in variable speed drives etc. (Fujita *et al.*, 1998)

The waveform of steady-state voltage in a system is a sine wave, mathematically formulated as in equation (18).

effective value of i(t) is mathematically expressed: (Kung-Ping and Min-Hoon, 1998)

guide has been conceptualized. These guides are estimates of the functional value of a waveform and can be estimated for both the current and the voltage. There are limits set by the IEEE-519 document on the extent of permitted harmonics (IEEE Standard 519-1992, 1992). Diverse guides are accessible for harmonic study; however, the most regularly put to practice is the

total harmonic distortion (THD). Mathematical formulations of (THD) for voltage and current and harmonics voltage content are given in The harmonic voltage content is:

$$V_H = \sqrt{\sum_{n=2}^{\infty} V_N^2} \tag{10}$$

The connotation HR (Harmonic Ratio) can be expressed the size of one harmonic component. For instance, the ith harmonic ratio of voltage (*HRV_i*) is

$$HRV = \frac{V_h}{V_1} \times 100 \% \tag{11}$$

Where,

V₁ and *I₁* are the Root Mean Square value of the fundamental voltage and current

V_h and *I_h* are the Root Mean Square value of the h-order harmonic component.

$$THD_V = \frac{\sqrt{\sum_{h=2}^{\infty} V_h^2}}{V_1} \tag{12}$$

$$THD_I = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_1} \tag{13}$$

Voltage imbalance

Negative sequence is used to evaluate the severity of voltage imbalance. The ratio of negative sequence voltage U-1 to positive sequence voltage U+1 expressed as a percentage is called the negative sequence (Lavopa *et al.*, 2009):

$$K_d = \frac{U_{-1}}{U_{+1}} \times 100 \% \tag{14}$$

Occasionally, distribution companies use the variance linking the maximal and minimal of the stable state voltage or line voltage to evaluate the unstable voltage

MATERIALS AND METHODS

Whale optimization algorithm

Whales’ optimization Algorithm (WOA) was established by Miraj Alli and Lewis as meta heuristic algorithms in 2020. Whales are found to exist as smart and moving animals and they select microscopic fish that lives close to the surface of the water as prey. Humpback whales’ unusual hunting etiquettes encouraged the WOA algorithm. They adopt a specific hunting technique called gusting net feeding. This approach is called bubble net feeding because the fish move around the prey and gusting in a sphere or a 9-shape model (Wang and Wang, 2016; Adeseye *et al.*, 2021)

equations (23), (24) and (25) respectively: (Garcia *et al.*, 2003; Han and Wang, 2015)

The mathematical model of WOA is as presented in the three stages below.

- i. Encircling the prey stage
- ii. Attacking using a bubble net stage
- iii. Search for the prey stage

Encircling the target

The selected fish is presupposed as the best solution at the time by the optimization algorithm. The remaining candidates struggle to go ahead to increase their position in order to become the leading candidate. The following equations are used to represent the behaviour. (Hari, *et al.*, 2023)

$$p[k + 1] = [p \times (k) - h \times g] \tag{15}$$

$$g = |q \times p(k) - p(k)| \tag{16}$$

$$h = 2(H \times rand) - H \tag{17}$$

$$m = 2 \times rand \tag{18}$$

$p \times (k)$ is the current good position, which can be adjusted if a better solution is achieved.

Where,

p is the position

k is the current iteration

m, q are coefficients

H is decreased linearly in the range (2, 0) and $rand$ is an arbitrary vector between 0 and 1

Attacking using a Sparkle net approach

This phenomenon has two approaches. (Sang, 2010; Liu *et al.*, 2009)

i) Encircling the prey shrinking

ii) Updating the position using the coiled model

In this research, updating the position spirally was adopted. They hunt by swimming in a

shrinking circle encompassing their target and also following a coiled model. Both of the models are placed at Fifty percent probability to keep route of movements of the candidates. The graphical representation of the phenomenon as is shown in figure 1 below (Xu, 2012)

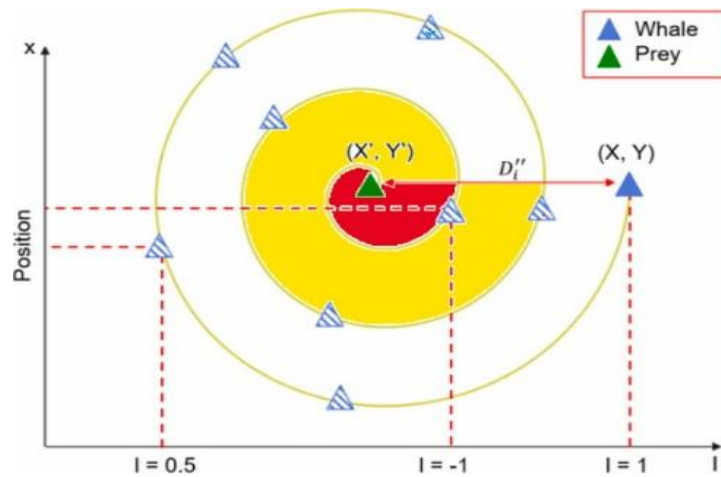


Figure 1: Spiral Updating Mechanism

To mimic the coiled movement between the positions of candidate and fish, the following helix equation was used.

$$p[k + 1] = [g \times e^{bl}(\cos(2\pi l))] + x1 \tag{19}$$

When the whale and the prey are separated by a significant distance (best solution)

$$g = |[x1 - x[n]]| \tag{20}$$

l is an arbitrary number from -1 and 1

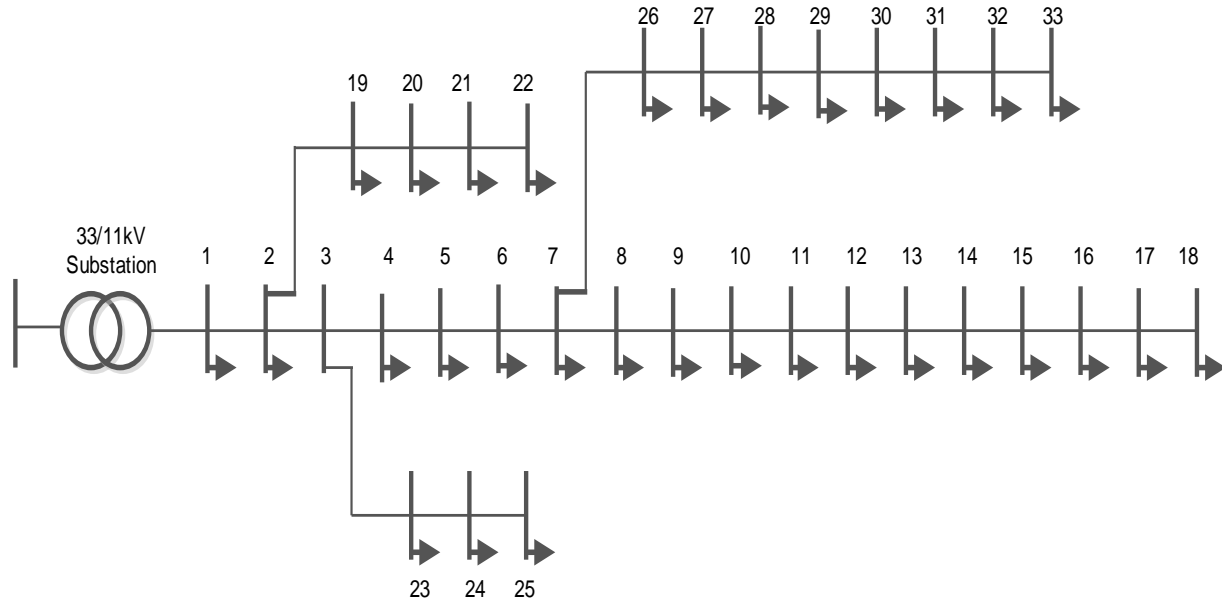


Figure 2: IEEE 33 Bus Single line Diagram (Modu, *et al.*, 2019)

b is a recurring number (Zhong *et al.*, 2012)

$$p[k + 1] = \begin{cases} x1[n] - h \times g & x < \frac{1}{2} \\ d \times e^{bl}, \cos(2\pi l) & x \geq \frac{1}{2} \end{cases} \quad (21)$$

x is randomized number in [0,1]

Search for the prey

Depending on the value of the search candidate, either greater than or less than one, the algorithm is updated according to an arbitrary search candidate rather than the prime search candidate.

$$p[k + 1] = [p \times (k) - h \times g] \quad (22)$$

$$g = |q \times p(k) - p(k)| \quad (23)$$

System Description

IEEE test system has 33 - Bus and 32 sections with the total load of 3.72 MW and 2.3 MVAR. Base MVA of 100, conductor type is All Aluminum Alloy Conductor (AAAC), Base

voltage is 12.66 kV, The line resistance and reactance are 0.550Ωper kilometer and reactance of 0.350Ωper kilometer respectively.

The single line diagram of the system is shown in Figure 2. (Zhong *et al.*, 2014)

DigSILENT

DigSILENT Stands for Digital simulation and electrical network analysis software. It is a superior power system study platform for use in analyzing generation, transmission, distribution and Manufacturing industries. It has wide range

of functionality ranging from normal to exceptionally modern and advanced practice which includes wind power, disperse generation, instantaneous study and monitoring, testing and supervision.

Methodology

In order to study the impact of Solar PV DG on the power quality and harmonics in the system, first the optimal size and location of the DG were obtained using WOA.

Secondly, a model of the distribution system was created in the DigSILENT environment to study the power quality and harmonics in the system.

Thirdly, Solar PV DG of the optimal size (3MW) and location (Bus 18) as suggested by WOA was integrated in to the system to study the impact of the DG on the said parameters.

Finally, the results obtained were presented and discussed.

Modelling of the study System

Models of IEEE 33 Bus test system with and without DG created in DigSILENT environment are presented in figures 3 and 4.

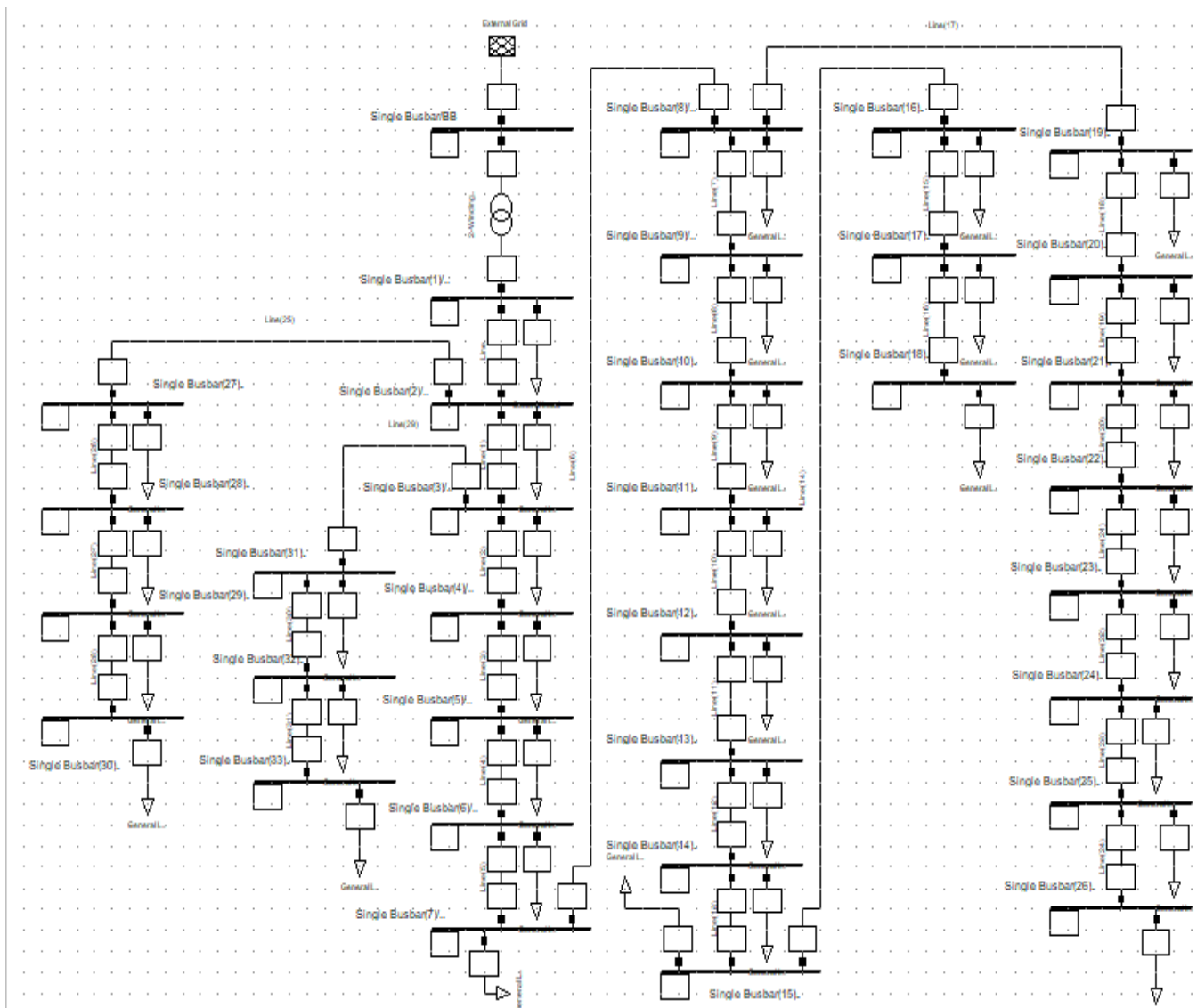


Figure 3: DigSILENT Model of IEEE 33 Bus Test Systems without DG

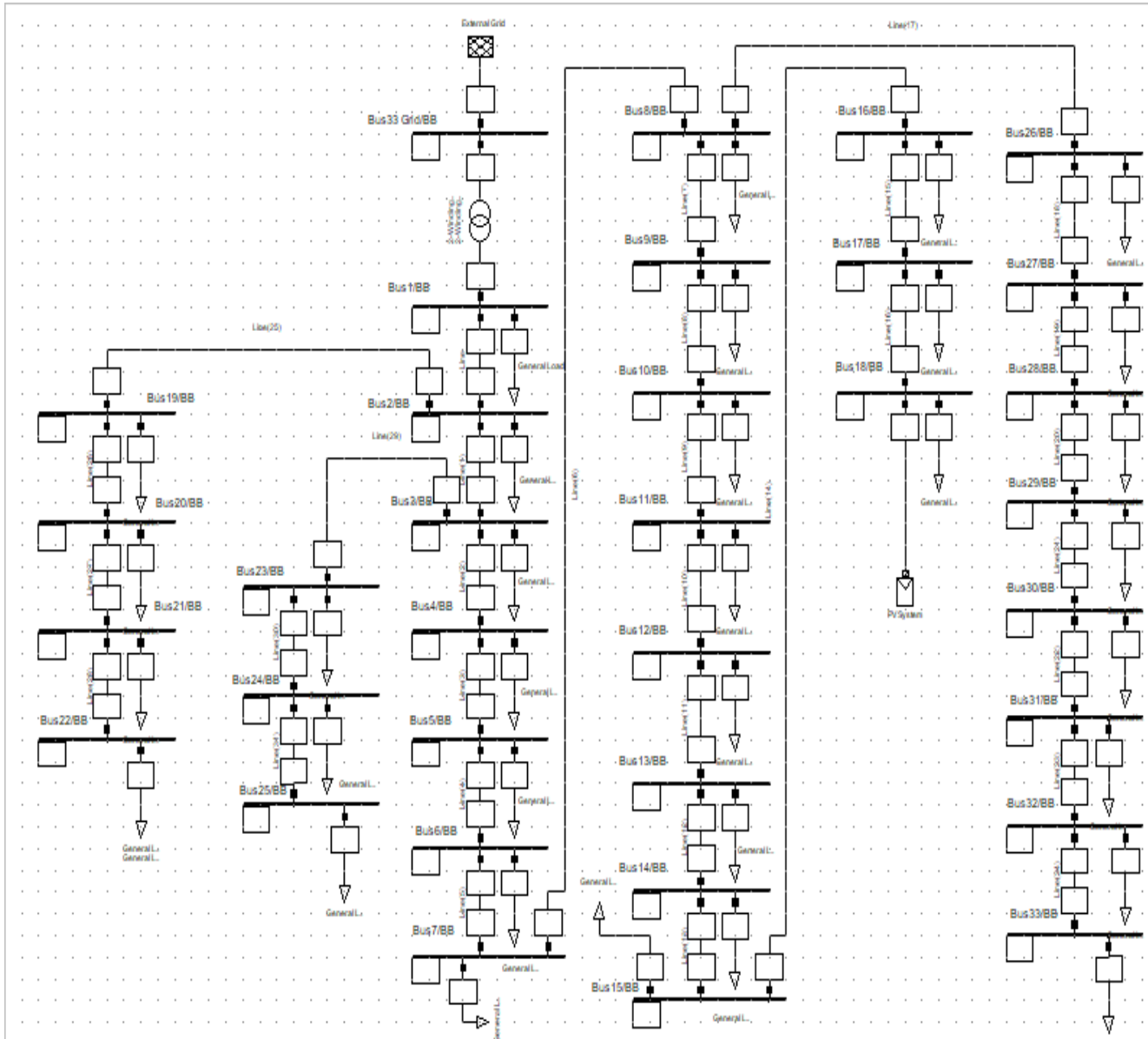


Figure 4: DigSILENT Model of IEEE 33 Bus Test System with Solar DG

RESULTS

The results obtained from the simulation of the model of IEEE 33 bus test system created in DigSILENT environment for Voltage profile, Power loss, Harmonics voltage content, total harmonics distortion, Voltage imbalance and

frequency deviation for all transformers in the system are presented in this section.

Voltage Profile and Power Loss

Voltage profile of the system with and without DG which was integrated according to the results suggested by WOA is presented in figure 5.

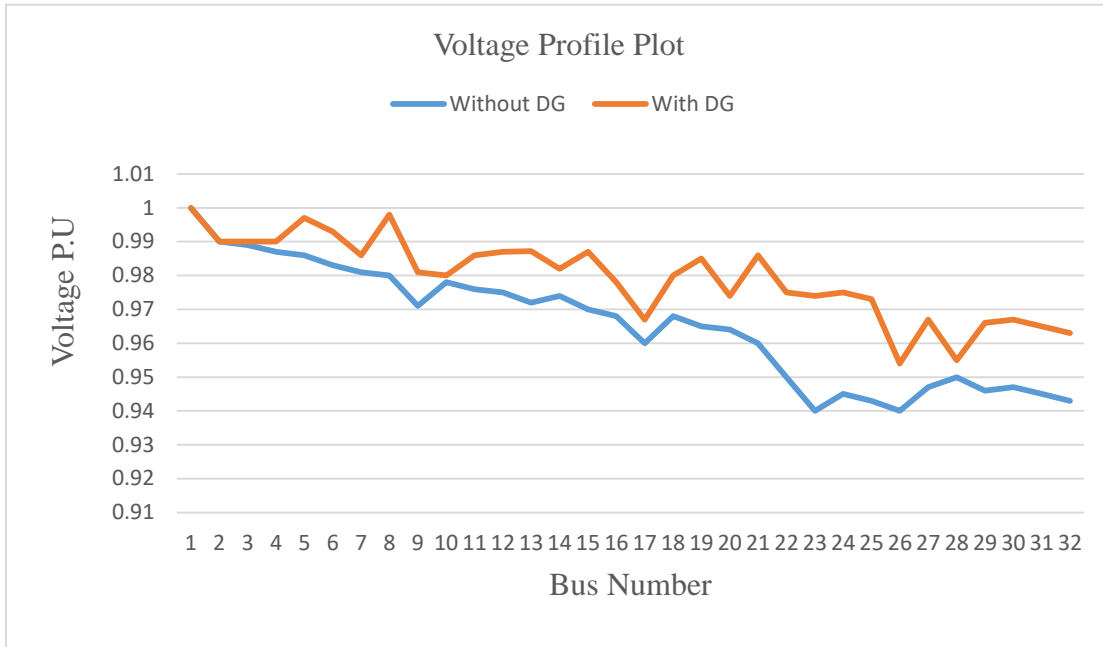


Figure 5: Voltage Profile Plot

Total Harmonics Distortion and Frequency

The Total Harmonics Distortion, Harmonics Voltage content and Frequency Deviation of the

system with and without DG are presented in Table 1.

Table 1: Total Harmonics Distortion, Harmonics Voltage content and Frequency Deviation

S/No.	Transformer Number & Capacity (kVA)	THD %		HRV %		Frequency (Hz)		Frequency Deviation	
		Without DG	With DG	Without DG	With DG	Without DG	With DG	Without DG	With DG
1.	TBus 1 - 500	2.65	2.32	2.22	1.89	50.03	50.02	0.03	0.11
2.	TBus 2 - 200	1.76	1.87	1.41	1.52	50.01	50.00	0.01	0.21
3.	TBus 3 - 300	2.39	2.42	2.32	1.81	49.89	49.79	0.14	0.19
4.	TBus 4 - 200	1.86	2.11	1.42	1.56	49.80	49.81	0.20	0.15
5.	TBus 5 - 500	2.76	2.19	2.15	1.82	49.87	49.85	0.13	0.50
6.	TBus 6 - 300	1.65	1.81	1.23	1.60	49.56	49.50	0.44	0.23
7.	TBus 7 - 200	3.12	2.99	1.12	1.09	49.70	49.77	0.30	0.22
8.	TBus 8 - 300	2.31	2.09	1.34	1.29	49.80	49.78	0.20	0.35
9.	TBus 9 - 300	1.98	1.45	1.45	1.72	49.67	49.65	0.33	0.21
10.	TBus 10 - 500	1.76	1.87	1.27	1.08	50.01	50.00	0.01	0.02
11.	TBus 11 - 100	1.25	1.43	1.51	1.24	50.00	50.02	0.09	0.08
12.	TBus 12 - 200	1.32	1.40	1.62	1.38	50.10	50.08	0.10	0.27
13.	TBus 13 - 300	3.01	2.81	2.24	2.11	49.75	49.73	0.25	0.05
14.	TBus 14 - 300	2.55	2.03	1.98	1.82	49.99	49.95	0.01	0.19
15.	TBus 15 - 200	2.31	2.23	1.92	1.56	49.80	49.81	0.20	0.13
16.	TBus 16 - 300	2.81	2.67	2.01	1.32	49.83	49.87	0.17	0.21
17.	TBus 17 - 500	2.67	2.23	2.12	1.45	49.76	49.79	0.24	0.01
18.	TBus 18 - 300	2.89	2.54	1.29	1.25	50.04	50.01	0.04	0.18
19.	TBus 19 - 300	1.95	1.43	1.15	1.51	50.02	50.00	0.02	0.12
20.	TBus 20 - 200	2.11	2.65	1.52	1.62	50.08	50.10	0.10	0.06
21.	TBus 21 - 300	3.12	2.70	1.32	2.21	49.96	49.94	0.04	0.41
22.	TBus 22 - 200	2.33	2.12	1.52	1.34	49.19	49.59	0.81	0.13
23.	TBus 23 - 300	2.09	1.90	1.41	1.47	49.82	49.87	0.18	0.08
24.	TBus 24 - 500	2.51	2.17	1.82	1.22	49.94	49.92	0.06	0.05
25.	TBus 25 - 200	1.90	1.56	1.31	1.56	49.93	49.95	0.07	0.29
26.	TBus 26 - 200	1.84	1.45	1.21	1.44	49.21	49.71	0.59	0.09
27.	TBus 27 - 500	1.98	1.76	1.54	1.45	50.01	49.91	0.01	0.02
28.	TBus 28 - 200	2.15	2.43	1.87	1.23	49.99	49.98	0.01	0.06
29.	TBus 29 - 100	2.81	2.39	2.12	1.51	49.92	49.94	0.08	0.03
30.	TBus 30 - 300	1.89	1.65	1.27	1.62	49.95	49.97	0.05	0.20
31.	TBus 31 - 100	1.25	1.11	1.36	2.24	49.75	49.80	0.25	0.40
32.	TBus 32 - 200	2.55	2.32	1.97	1.36	49.65	49.6	0.35	0.23

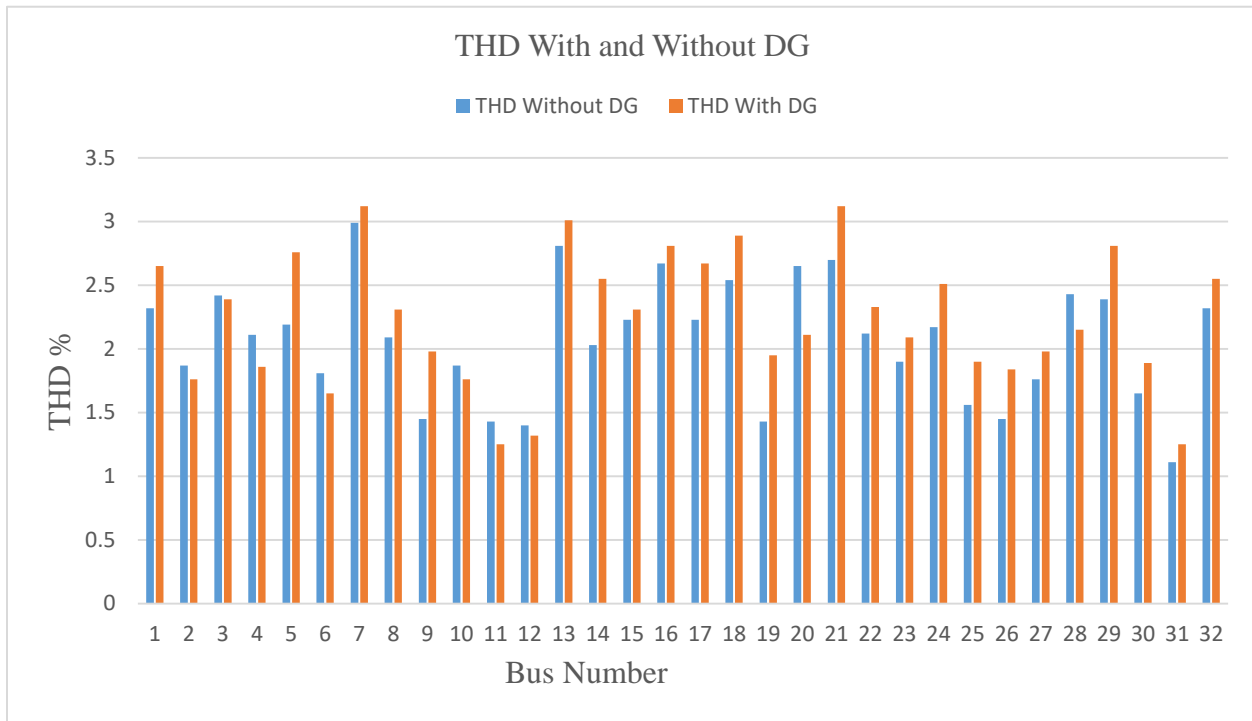


Figure 6: Plot of THD With and Without DG

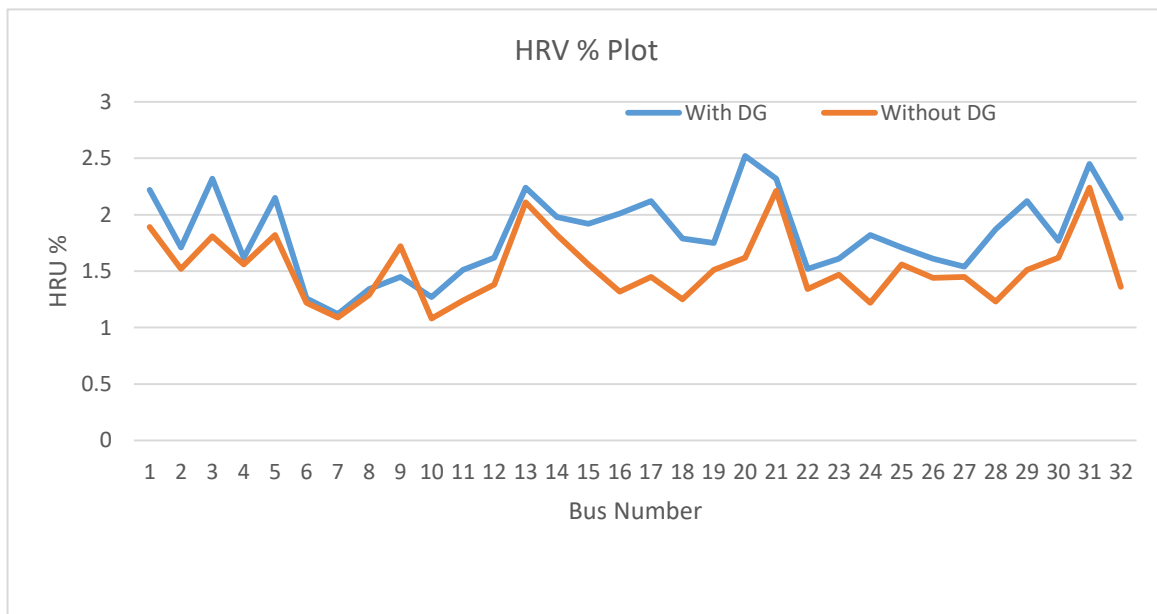


Figure 7: Plot of % HRV with and Without DG

Frequency Deviation

The results of frequency deviation with and without DG integrated in to the system are presented in figure 8.

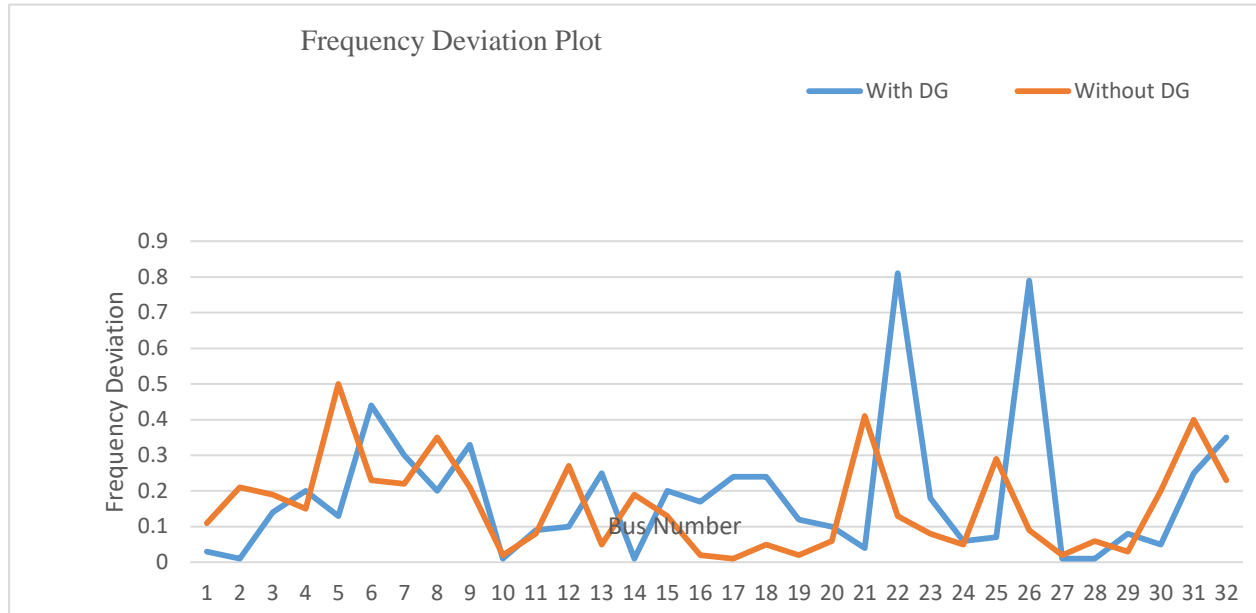


Figure 8: Plot of Frequency Deviation With and Without DG

DISCUSSION

DGs are integrated in to the system to improve the voltage profile by raising the voltage up which in turn reduces the power loss. The power loss of the system reduces to 89kW from 120kW and voltage profile of 9 out of the 33 buses were below the recommended tolerance of $\pm 5\%$ but integration of DG raises all the bus voltages to fall within the recommended tolerance as depicted in figure 5.

At the initial stage, there was harmonics as a result of the types of loads on the network which in turn affects both the voltage and frequency of the system. The results showed that as a results of integration of DG in to the system, both the total harmonics distortion and harmonics voltage content harmonics in the system significantly increases as presented in figures 6 and 7.

According to the requirement of GB/T 15943-2008 power quality and power system frequency deviation, frequency deviation of power system with DG should be less than $\pm 0.2\text{Hz}$, but the results obtained shows that some of the buses in the system does not satisfy the requirement as shown in figure 8. These deviations are as a

result of non-linear loads and power electronics devices associated with the DG.

CONCLUSION

In this research efforts have been made to integrate PV DG of optimal size and location using whale optimization algorithm in to IEEE 33 bus test system. A model of the system was created in DigSILENT environment to study the impact of PV DG on the power quality and harmonics in the system. Optimal sizing and location of the DG in the system reduces the power loss to 89kW from 120kW and voltage profile of 9 out of the 33 buses which were below the recommended tolerance of $\pm 5\%$ have fallen within the tolerance. At the initial stage, there was harmonics as a result of the types of loads on the network which in turn affects both the voltage and frequency of the system and integration of DG further increases the total harmonics distortion and harmonics voltage content in the system significantly. Furthermore, the frequency deviation of 10 buses in the power system with DG do not satisfy the recommended tolerance of $\pm 0.2\text{Hz}$, these deviations are as a result of non-linear loads and power electronics devices associated with the DG. The results

were presented and discussed. This study has confirmed that, integration of PV DG in to power system has negative impacts on the power quality and harmonics.

It is recommended that other types of DG like Wind turbine, Hydro, Fuel cell and etc should be integrated in to the power system to study their impacts on the power quality and harmonics.

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