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 into 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 ±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 ±0.2Hz, 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 centrally generated 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).

\[
\text{Minimize } P_L = \sum_{i=1}^{N_L} |I_i|^2 R_i
\]

Subject to the following constraints.

\[
\sum_{i=1}^{N_DG} P_{Di} = \sum_{i=1}^{N_D} P_{Di} + P_L
\]

\[
|V_i|^{min} \leq |V_i| \leq |V_i|^{max}
\]
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 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).

\[ v(t) = \sqrt{2}V \sin(\omega t + \Phi) \]  

(6)

Where,
- \( V \) is the system voltage
- \( \Phi \) is the voltage phase angle
- \( \omega \) 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 effective value of \( i(t) \) is mathematically expressed: (Kung-Ping and Min-Hoon, 1998)

\[ I = \sqrt{\frac{1}{T} \int_0^T i^2(t) dt} \]  

(7)

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

\[ v(t) = V_0 + \sum_{n=1}^{\infty} \sqrt{2}V_n \sin(n\omega_1 t + \Phi_n) \]  

(8)

\[ i(t) = I_0 + \sum_{n=1}^{\infty} \sqrt{2}I_n \sin(n\omega_1 t + \alpha_n) \]  

(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 \( N \)th harmonic content.

To study the characteristics of a power system with respect to the harmonic distortion levels, a 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 equations (23), (24) and (25) respectively: (Garcia et al., 2003; Han and Wang, 2015)

The harmonic voltage content is:

$$V_h = \sqrt{\sum_{n=2}^{\infty} V_n^2}$$ (10)

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

$$HRV = \frac{V_h}{V_l} \times 100 \%$$ (11)

Where, $V_1$ and $I_1$ 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.

$$THD_V = \frac{\sum_{h=2}^{\infty} V_h^2}{V_1}$$ (12)

$$THD_I = \frac{\sum_{h=2}^{\infty} I_h^2}{I_1}$$ (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):

$$K_d = \frac{U_{-1}}{U_{+1}} \times 100 \%$$ (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 Ali 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)

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)

$$p[k + 1] = [p \times (k) - h \times g]$$ (15)
\[ g = |q \times p(k) - p(k)| \]  
\[ h = 2(H \times rand) - H \]  
\[ m = 2 \times \text{rand} \]

(16)  
(17)  
(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 \( \text{rand} \) 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](image)

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

\[ p[k + 1] = [g \times e^{bl(\cos(2\pi l))} + x1] \]  
\[ g = [\|x1 - x[n]\|] \]

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

\[ l \] is an arbitrary number from -1 and 1
b is a recurring number (Zhong et al., 2012)

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

\(x\) 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.

\[
p[k + 1] = [p \times (k) - h \times g] \\
g = |q \times p(k) - p(k)|
\]

**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 0.550Ω per kilometer and reactance of 0.350Ω per 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
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

<table>
<thead>
<tr>
<th>S/No.</th>
<th>Transformer Number &amp; Capacity (kVA)</th>
<th>THD % Without DG</th>
<th>THD % With DG</th>
<th>HRV % Without DG</th>
<th>HRV % With DG</th>
<th>Frequency (Hz) Without DG</th>
<th>Frequency (Hz) With DG</th>
<th>Frequency Deviation Without DG</th>
<th>Frequency Deviation With DG</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>TBus 1 - 500</td>
<td>2.65</td>
<td>2.32</td>
<td>2.22</td>
<td>1.89</td>
<td>50.03</td>
<td>50.02</td>
<td>0.03</td>
<td>0.11</td>
</tr>
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<td>2.</td>
<td>TBus 2 - 200</td>
<td>1.76</td>
<td>1.87</td>
<td>1.41</td>
<td>1.52</td>
<td>50.01</td>
<td>50.00</td>
<td>0.01</td>
<td>0.21</td>
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<tr>
<td>3.</td>
<td>TBus 3 - 300</td>
<td>2.39</td>
<td>2.42</td>
<td>2.32</td>
<td>2.61</td>
<td>49.89</td>
<td>49.79</td>
<td>0.14</td>
<td>0.19</td>
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<td>49.80</td>
<td>49.81</td>
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<td>0.15</td>
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<td>49.85</td>
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<td>1.12</td>
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<td>49.77</td>
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<td>1.45</td>
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<td>49.67</td>
<td>49.65</td>
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<td>1.27</td>
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<td>50.00</td>
<td>0.01</td>
<td>0.02</td>
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<td>1.43</td>
<td>1.51</td>
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<td>0.08</td>
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<td>0.01</td>
<td>0.19</td>
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<td>49.81</td>
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<td>0.13</td>
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<td>49.79</td>
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<td>49.65</td>
<td>49.6</td>
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</table>
**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 into the system are presented in figure 8.
DISCUSSION

DGs are integrated into 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 ±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 result 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 ±0.2Hz, 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 ±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 ±0.2Hz, 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.

REFERENCES


