IMPACT OF DISTRIBUTED GENERATION ON UNBALANCED DISTRIBUTION NETWORKS

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ABSTRACT

Unbalanced active distribution network (UADN) is the combination of unbalance distribution network (UDN) and distributed generations (DGs) such as gas generator, wind turbines, fuel cell, photovoltaic system, etc. Regarding to unbalance structure, different kinds of DGs models and bidirectional power flow, some network parameters such as amplitude voltage, voltage unbalance Factor (VUF), and power losses of network will alter accordingly. A suitable power flow analysis will provide a platform to analyse these behaviours in steady state condition. This paper offers appropriate method for handling DGs in a Power flow program which is developed using MATLAB® for practical unbalanced distribution network at Iran and investigate the impact of DG location and DG control mode (as PV and PQ mode) on voltage profile, reducing power loss and VUF.

I. INTRODUCTION

Active Distribution Networks (ADNs) are defined as a distribution network combined with distributed generations (DGs). DGs are included from green energy resources such as wind turbines, PV, etc and non-green energy resources like Diesel/Gas generators, micro turbine, etc. Energy efficiency, reduction of the power loss, reduced and deferral distribution investments, network (voltage) support, quality of supply improvement are some of the expected benefits of using DGs. Though, there are lot of advantageous of using DGs, but some concerned issues can be put to using DGs such as network protecting, load shedding, DG discarding, voltage supporting and bidirectional power flowing[1,5]. In order to development of ADN, appropriate operation and control, It should be concerned both DG operation and distribution network structures in power flow analysis which is an unavoidable tool for power system analysis. Radial network structure, an extremely large number of branches/nodes, an unbalanced distribution load, unbalanced operation and high penetration of DGs, a suitable method three- phase unbalanced radial power flow solution has to be addressed. Some works have been proposed to satisfy some of these features [2]. Handling DGs as PV and PQ models in power flow study are discussed in [4].

Unbalanced Voltage that is one of power quality index of distribution networks. An unbalanced voltage can cause increased losses in motor loads and abnormal operation of sensitive equipment’s. unbalance voltage problem will be improved when DG operate as PV mode. In [5] the authors proposed a definition on unbalance voltage and some effects of it on utilities. Juanuwattanakul et. al [6] investigate the effect of a voltage regulator and DG unit location in improving voltage profile, reducing power loss and increasing voltage stability margin.

As discussed above, DGs in UADN have significant effect on power flow analysis and may improve parameters of network such as unbalanced voltage, system losses and so on. Although, various researches have been done in this field, there are less examination to study the interaction of power between DGs and unbalanced distribution network that is named UDN.

This Study is structured in several sections. In sections I and II provide prepared models and an unbalance radial load flow based of forward-backward sweep method. In section III, a definition of percentage unbalance voltage is explained. In section IV, numerical results of power flow analysis with handling DGs as PQ and PV nodes on one practical unbalanced radial distribution systems and the behavior of these models on UADN are presented and discussed. Finally in the last section is the conclusion.

II. UNBALANCED ACTIVE DISTRIBUTION NETWORK MODELING

structure of UDN

The important step in modeling unbalance distribution network is line modeling. A precise model of line (both overhead and underground) in three-phase unbalance distribution network, which is shown in Fig.1, is developed by Kersing [7].

In distribution system, loads can be modeled as: constant real and reactive power (constant PQ), constant current, constant impedance, and any combination of these which each of them maybe wye or delta connections with one, two or three-phase structure. A comprehensive description of all types of loads with mathematical modeling is taken into account in [7].
Delta-grounded wye, ungrounded Wye-delta, Grounded wye-grounded wye, delta-delta and open wye-open delta transformers used in unbalance distribution network are modeled in [7]. Capacitors in unbalance distribution network can be modeled as constant impedance loads.

![Diagram of Three-phase line segment model](Image)

**Fig 1: Three-phase line segment model. [7]**

### Structures of DGs

Structures of DGs are introduced by PQ and PV models in power flow study. Designating real and reactive power constrains PQ model at DG nodes which will prepare a Constant power factor and specifying real power- voltage (PV) will make fixed voltage at DG nodes within limited reactive power. In the same way, constant PQ-load with current injecting into node is substituted by PQ model and since in radial power flow handling PV model cannot be in the direct manner and need some supplementary procedures, PV model is represented by a compensation current injected by the DG that is a function of the terminal voltages. It should be noted that identifying the appropriate PQ and PV models for each DG in power flow study need to be recognized its connection to network (direct or indirect) beside of its operation. DGs can be connected to network by means of induction generators or synchronous generator or static power converter interfaces. Induction generators which are connected to network without power electronic interfaces (directly) can be modeled as PQ nodes. Some induction engines and wind turbines are in this group. Synchronous machines which depend on either regulating excitation voltage type or fixed excitation voltage type may be modeled by PV and PQ node respectively. Gas turbine and some internal combustion engines, which are connected directly to network, are located in this category. Fuel cells, photovoltaic systems, micro-turbines and more wind turbines use a mixture of both power electronic utility and electrical machine or only by means of power electronic utility to inject power into the network. Power electronic interface, which are inverters, rectifiers or AC/AC converters, use both independent P, Q control and independent P, V control interface. Based on the control strategy which is used in converter it can be defined as PQ and PV nodes. Flexible and high speed control active and reactive interaction power between DGs and network is significant feature of power electronic interface that improve power quality in ADNs. Fig. 2 shows a combination of DGs in distribution network.

![Combination of micro sources in distribution network](Image)

**Fig.2: Combination of micro sources in distribution network [5]**

### UADN Load-Flow Procedure

The procedure to study load flow for UADN needs to follow several steps. Before starting the main power-flow steps, the networks should be recognized. Reading network data, identifying all nodes beyond all the branches, constructing PV node sensitivity matrix Zv are some of these cases which were introduced by Shirmohammadi and Gosh in [4,5]. DGs as PQ operation are modeled constant PQ-load. After this, load-flow study without considering PV node will be done. These steps within kth interaction for mth node are shown as follow:

1. **Step 1: Nodal Current Calculation**
2. **Step2: Backward Sweep**
3. **Step3: Forward Sweep**
4. **Step4: Handling DGs as PV Node**

At PV node, it is considered to hold voltage node at specific value. For this purpose, appropriate reactive current will be injected to node by DGs and it means DGs should prepare a proper reactive power according to this reactive current injection. A compensation-based method can be used for this purpose, as described in literatures [2,7]. Voltage convergence criterion, after updating reactive power which has been described in step 4, return to step 1, 2 & 3. This algorithm will continue till the convergence of all PV nodes reach. Fig. 3 shows the flowchart of UADN load flow procedure with considering DGs as PV and PQ operation.

### III. UNBALANCE VOLTAGE MODELING

The uneven distribution of single-phase loads, asymmetrical transformer winding impedances, open wye and open delta transformer banks, asymmetrical transmission impedances many other causes may make a voltage unbalance in ADN. The voltage unbalance Factor (VUF) in percent is defined by the National Electrical Manufacturers Association (NEMA) in Standards Publication no. MG 1-1993:

\[
VUF = \frac{\text{Maximum Deviation From Average}}{\text{Average of Three Phase-to-Phase Voltage}} \times 100 \tag{1}
\]

NEMA standard defines that induction machine and utilities may be derated when the voltage unbalance Factor goes...
As can be seen in Fig. 5, with missing phase b at bus 62, VUF at some buses increase more than 1 percent (more than NEMA standard margin). The maximum VUF is about 1.048% at Bus 62. Total real losses leads to 256 KW.

**Network analysis with DG as PQ and PV Operation**

Because of limited land, 4 locations are chosen to install DG (bus number 16, 38, 56 and 74). The result of load-flow analysis for unexpected condition after connecting 2MW DG (at buses 16, 38, 56 and 74) as PV and PQ control mode are shown in Table. 1.

**Connect DG at Bus 16:**

With connecting DG at bus 16, VUF Reduced to less than 1% in PV mode operation but the maximum voltage deviation for PV and PQ modes exceed from standard margin (5%). The minimum power losses for this installation is 119 KW for PV operation mode.

**Connect DG at bus 38:**

With connecting DG at bus 38, voltage deviation at all buses for PV and PQ mode operation put to standard margin, while VUF at PQ mode exceed from 1%. Total power loss for PV mode reduced to 105 KW.

**Connect DG at bus 56:**

When connecting DG to bus 56, voltage deviation and VUF at all Bus for PV and PQ mode reach to standard margin. Voltage deviation at all buses is less than 4.9%. As can be seen in Table. 1, Total power loss for PQ and PV mode reduced to 106 KW and 101KW, respectively.

**Connect DG at bus 74:**

When connecting DG to bus 74, maximum voltage deviation for PV and PQ mode exceed than standard margin (5%) and total power loss is 117 KW for PQ operation mode and 112 KW for PV operation mode.

In general, with connecting DG at Bus 56, maximum voltage deviation, VUF and Total power loss reach to the lowest possible value and this place is best candidate for installing. The result of power flow analysis with connect DGs at bus 56 as PV mode are shown in Fig6.

Fig. 6 power flow analysis with connect DG at bus 56 as PV mode operation
Table 1: Result of load flow analysis

<table>
<thead>
<tr>
<th>DG Location (Bus No.)</th>
<th>Operation Mode</th>
<th>DG Status</th>
<th>Total Loss (kW)</th>
<th>Maximum Voltage Unbalance % at 62</th>
<th>Maximum Voltage Deviation @ Bus B (%)</th>
<th>Total Loss (kW)</th>
<th>Maximum Voltage Unbalance % at 62</th>
<th>Maximum Voltage Deviation @ Bus B (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>56</td>
<td>P-Q</td>
<td>Final</td>
<td>138</td>
<td>1.05 % at 62</td>
<td>0.17 % at 62</td>
<td>1.99</td>
<td>1.56 % at 62</td>
<td>0.17 % at 62</td>
</tr>
<tr>
<td>56</td>
<td>P-V</td>
<td>Final</td>
<td>139</td>
<td>0.99 % at 62</td>
<td>0.15 % at 62</td>
<td>1.99</td>
<td>1.56 % at 62</td>
<td>0.15 % at 62</td>
</tr>
<tr>
<td>38</td>
<td>P-Q</td>
<td>Final</td>
<td>115</td>
<td>1.00 % at 62</td>
<td>0.17 % at 62</td>
<td>1.99</td>
<td>1.56 % at 62</td>
<td>0.17 % at 62</td>
</tr>
<tr>
<td>38</td>
<td>P-V</td>
<td>Final</td>
<td>140</td>
<td>0.88 % at 62</td>
<td>0.17 % at 62</td>
<td>1.99</td>
<td>1.56 % at 62</td>
<td>0.17 % at 62</td>
</tr>
<tr>
<td>56</td>
<td>P-Q</td>
<td>Final</td>
<td>106</td>
<td>0.98 % at 62</td>
<td>0.17 % at 62</td>
<td>1.99</td>
<td>1.56 % at 62</td>
<td>0.17 % at 62</td>
</tr>
<tr>
<td>56</td>
<td>P-V</td>
<td>Final</td>
<td>110</td>
<td>0.80 % at 62</td>
<td>0.17 % at 62</td>
<td>1.99</td>
<td>1.56 % at 62</td>
<td>0.17 % at 62</td>
</tr>
<tr>
<td>34</td>
<td>P-Q</td>
<td>Final</td>
<td>117</td>
<td>1.03 % at 62</td>
<td>0.17 % at 62</td>
<td>1.99</td>
<td>1.56 % at 62</td>
<td>0.17 % at 62</td>
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<tr>
<td>34</td>
<td>P-V</td>
<td>Final</td>
<td>112</td>
<td>0.92 % at 62</td>
<td>0.17 % at 62</td>
<td>1.99</td>
<td>1.56 % at 62</td>
<td>0.17 % at 62</td>
</tr>
</tbody>
</table>

V. CONCLUSION

Analysis of simulation results and utilizes voltage deviation, unbalanced voltage factor and power loss can be used to validate the placement of DG units. For this study operation of DG as PV mode not only decrease VUF and voltage deviation but also decrease total power losses.

REFERENCES


APENDIX:

Table 2: Load and line data

<table>
<thead>
<tr>
<th>Name</th>
<th>Location</th>
<th>Power factor</th>
<th>Active Power (KW)</th>
<th>Voltage (p.u)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P:A</td>
<td>Location</td>
<td>0.88</td>
<td>0.88</td>
<td>0.88</td>
</tr>
<tr>
<td>P:B</td>
<td>Location</td>
<td>0.88</td>
<td>0.88</td>
<td>0.88</td>
</tr>
<tr>
<td>P:C</td>
<td>Location</td>
<td>0.88</td>
<td>0.88</td>
<td>0.88</td>
</tr>
<tr>
<td>P:D</td>
<td>Location</td>
<td>0.88</td>
<td>0.88</td>
<td>0.88</td>
</tr>
</tbody>
</table>

Table 3: Conductor’s Parameter

<table>
<thead>
<tr>
<th>Type</th>
<th>Impedance in ohm/km</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.511+0.857i</td>
</tr>
<tr>
<td>2</td>
<td>0.511+0.857i</td>
</tr>
<tr>
<td>3</td>
<td>0.511+0.857i</td>
</tr>
</tbody>
</table>

Fig. 7: Single line diagram