IMPACT OF DISTRIBUTED GENERATION ON UNBALANCED DISTRIBUTION NETWORKS

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ABSTRACT

Unbalance 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.

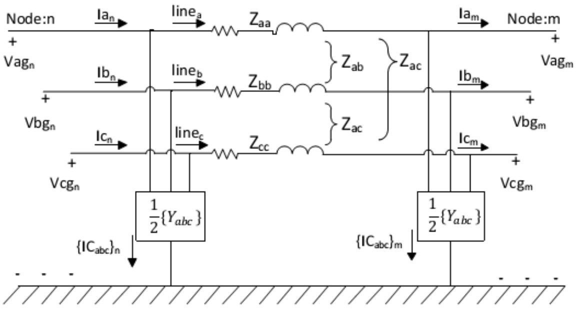

Fig 1: Three-phase line segment model. [7]

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.

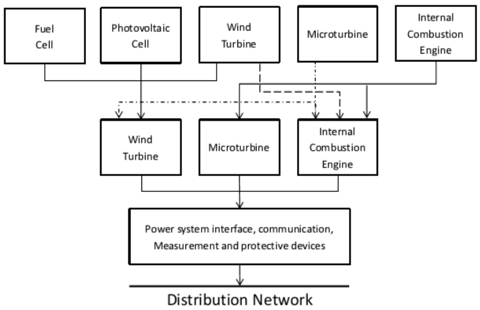

Fig.2: Combination of micro sources in distribution network [5]

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 Z_V 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 k_{th} interaction for m_{th} node are shown as follow:

Step 1: Nodal Current Calculation
Step2: Backward Sweep
Step3: Forward Sweep
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:

$$VUF = \frac{Maximum \quad Deviation \quad From \quad Average}{Average \quad of \quad Three \quad Phase-to-Phase \quad Voltage} \times 100 \quad (1)$$

NEMA standard defines that induction machine and utilities may be derated when the voltage unbalance Factor goes beyond 1.0%

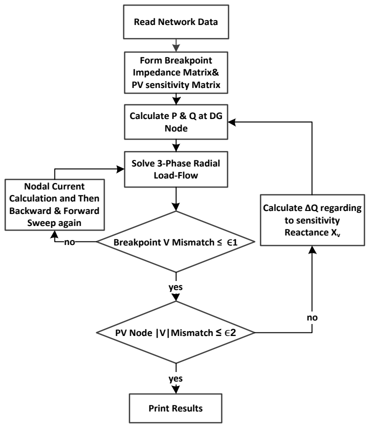

Fig.3 Load- flow solution algorithm for UADN

IV.CASE-SYUDYDESCRIPTION, SIMULATION AND ANALYSIS

To verify the unbalance radial load flow program, an 89-bus, 20KV practical unbalanced distribution network at Iran are used and developed in MATLAB®. The load and line data and single line diagram for case-study networks are given in APENDIX. The result of power flow analysis without DGs is show in Fig.4.

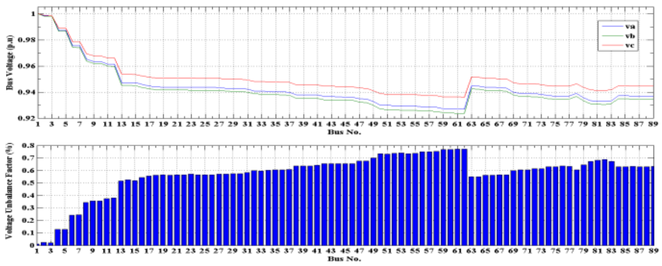

Fig.4 : voltage profile and VUF of case-study

Since the favorable voltage range is between 0.95 and 1.05 p.u, there is violation at many buses. The minimum voltage occurs at bus 62 with about 0.93 p.u. Total real losses for this case is 270 KW.

Unexpected condition

To study unbalance condition and show significant behaviour of DGs as PV&PQ models in UADN, phase (b) of load at bus 62 in case study is missed. The result of power flow analysis in this situation show in Fig.5.

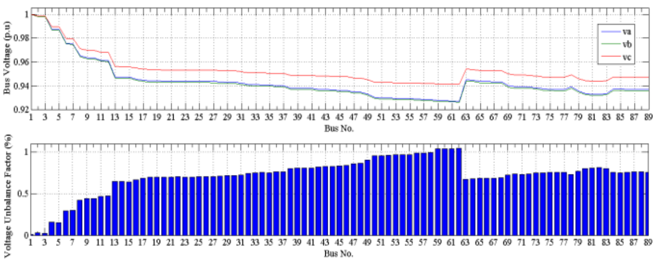

Fig.5 voltage profile and VUF after missing phase b at Bus 62

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.

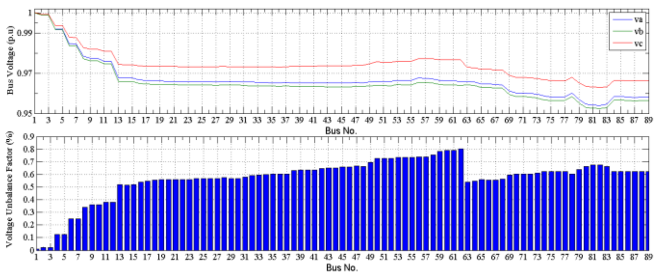

Fig.6 power flow analysis with connect DG at bus 56 as PV mode operation

Table.1: result of load-flow analysis

DG Location (Bus No.)	Operation Mode	DG Status		Total Loss (KW)	Maximum Voltage Unbalancing	Maximum Voltage Deviation @ Bus @ Phase	Feeder Input Active Power (MW)	Feeder Input Reactive Power(MWAR)
no DG		Normal Condition		270	0.77 % at 62	7.61% at 62 at phase B	6.28	3.63
no DG		Unexpected Condition		256	1.048 % at 62	7.33% at 62 at phase B	6.13	3.54
16	P-Q	P(kw)	2000	128	1.01 % at 62	5.5% at 62 at phase B	4	2.38
		Q(kwar)	970					
	P-V	P(kw)	2000	119	0.93 % at 62	5.1% at 62 at phase B	3.99	1.94
		Q(kwar)	1400					
		V (p.u)	0.97					
38	P-Q	P(kw)	2000	115	1.00 % at 62	4.9% at 62 at phase B	3.99	2.36
		Q(kwar)	970					
	P-V	P(kw)	2000	105	0.88 % at 62	4.5% at 62 at phase B	3.98	1.89
		Q(kwar)	1420					
		V (p.u)	0.97					
56	P-Q	P(kw)	2000	106	0.98 % at 62	4.9% at 82 at phase B	3.98	2.35
		Q(kwar)	970					
	P-V	P(kw)	2000	101	0.80 % at 62	4.7% at 82 at phase B	3.97	2.18
		Q(kwar)	1130					
		V (p.u)	0.97					
74	P-Q	P(kw)	2000	117	1.01 % at 62	5.4% at 62 at phase B	3.99	2.36
		Q(kwar)	970					
	P-V	P(kw)	2000	112	0.92 % at 62	5.2% at 62 at phase B	3.98	2.15
		Q(kwar)	1170					
		V (p.u)	0.97					

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.

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APENDIX:

Table.2: Load and line data

branch	sending bus	receiving bus	conductor type	length (m)	Receiving end load in KW					
					Pa	Qa	Pb	Qb	Pc	Qc
1	1	2	1	126	0	0	0	0	0	0
2	2	3	2	385	10	6	11	7	13	8
3	2	4	1	828	0	0	0	0	0	0
4	4	5	2	95	17	11	16	10	15	9
5	4	6	1	889	0	0	0	0	0	0
6	6	7	2	243	170	82	110	53	100	48
7	6	8	1	839	24	15	22	13	20	12
8	8	9	1	126	0	0	0	0	0	0
9	9	10	2	170	7	5	6	4	7	4
10	9	11	1	175	0	0	0	0	0	0
11	11	12	2	105	25	12	25	12	25	12
12	11	13	1	1156	0	0	0	0	0	0
13	13	14	2	75	67	42	85	53	57	35
14	14	15	2	164	43	27	65	40	30	19
15	13	16	1	150	0	0	0	0	0	0
16	16	17	1	140	6	3	6	3	5	3
17	17	18	1	114	0	0	0	0	0	0
18	18	19	2	39	7	4	6	4	8	5
19	19	20	2	122	0	0	0	0	0	0
20	20	21	2	139	13	8	6	3	11	7
21	20	22	3	120	0	0	0	0	0	0
22	22	23	2	109	0	0	0	0	0	0
23	23	24	2	180	20	10	15	8	19	9
24	23	25	2	182	0	0	0	0	0	0
25	25	26	2	104	2	1	2	1	2	1
26	25	27	2	147	63	39	20	12	43	21
27	18	28	1	105	63	31	40	19	40	19
28	28	29	1	39	0	0	0	0	0	0
29	29	30	2	18	21	13	19	12	24	15
30	29	31	1	110	21	13	18	12	25	16
31	31	32	1	207	0	0	0	0	0	0
32	32	33	2	477	31	19	41	25	29	18
33	32	34	1	80	0	0	0	0	0	0
34	34	35	2	398	24	15	17	11	30	19
35	35	36	2	452	30	19	15	7	25	15
36	34	37	1	85	20	13	10	5	16	8
37	37	38	1	443	0	0	0	0	0	0
38	38	39	1	192	0	0	0	0	0	0
39	39	40	1	41	11	7	25	13	20	12
40	39	41	1	312	14	9	8	5	14	9
41	38	42	1	225	0	0	0	0	0	0
42	42	43	2	214	17	11	10	6	15	9
43	42	44	1	54	80	50	30	19	40	19
44	44	45	1	62	0	0	0	0	0	0
45	45	46	2	94	42	20	30	15	25	12
46	45	47	1	320	0	0	0	0	0	0
47	47	48	2	492	25	12	14	7	24	15
48	47	49	1	520	30	19	15	7	27	17
49	49	50	1	713	0	0	0	0	0	0
50	50	51	2	95	165	107	135	84	145	70
51	51	52	2	452	30	15	15	7	17	8
52	50	53	1	227	0	0	0	0	0	0
53	53	54	2	28	165	77	141	68	120	60
54	54	55	2	24	49	29	40	25	67	34
55	53	56	1	394	0	0	0	0	0	0
56	56	57	2	240	49	31	43	28	55	34
57	56	58	1	165	25	12	15	9	10	5
58	58	59	1	726	38	24	15	8	32	20
59	59	60	1	77	0	0	0	0	0	0
60	60	61	1	482	63	31	40	19	30	15
61	60	62	2	238	180	112	0	0	130	63
62	16	63	1	160	30	15	20	10	60	29
63	63	64	1	68	9	5	4	3	6	4
64	64	65	1	210	0	0	0	0	0	0
65	65	66	2	42	135	65	120	58	80	39
66	65	67	1	67	5	2	5	2	5	2
67	67	68	1	56	13	6	6	3	14	7
68	68	69	1	840	13	8	15	7	11	8
69	69	70	1	263	0	0	0	0	0	0
70	70	71	2	67	2	1	2	1	2	1
71	70	72	1	85	9	4	11	6	9	4
72	72	73	1	107	2	1	2	1	2	1
73	73	74	1	271	0	0	0	0	0	0
74	74	75	1	136	0	0	0	0	0	0
75	75	76	1	175	5	2	5	2	5	2
76	76	77	1	302	45	28	40	25	30	18
77	75	78	1	529	0	0	0	0	0	0
78	78	79	2	103	160	78	125	55	112	52
79	78	80	2	1157	0	0	0	0	0	0
80	80	81	2	424	11	5	11	5	11	5
81	81	82	2	259	125	67	50	30	88	43
82	80	83	2	79	140	68	120	71	163	88
83	74	84	1	162	0	0	0	0	0	0
84	84	85	1	627	7	4	4	3	5	2
85	84	86	1	188	0	0	0	0	0	0
86	86	87	2	115	170	82	120	58	145	70
87	86	88	1	88	18	9	14	7	18	9
88	88	89	1	349	20	10	21	10	35	20

Table.3: Conductor's Parameter

Type	Impedance in ohm/km
1	0.3359+0.8975i 0.0593+0.4826i 0.0593+0.4826i 0.0593+0.4826i 0.3359+0.8975i 0.0593+0.4826i 0.0593+0.4826i 0.0593+0.4826i 0.3359+0.8975i
2	0.5225+0.952i 0.0593+0.4826i 0.0593+0.4826i 0.0593+0.4826i 0.5225+0.952i 0.0593+0.4826i 0.0593+0.4826i 0.0593+0.4826i 0.5225+0.952i
3	0.5112+0.8605i 0.0593+0.6917i 0.0593+0.6917i 0.0593+0.6917i 0.5112+0.8605i 0.0593+0.6917i 0.0593+0.6917i 0.0593+0.6917i 0.5112+0.8605i

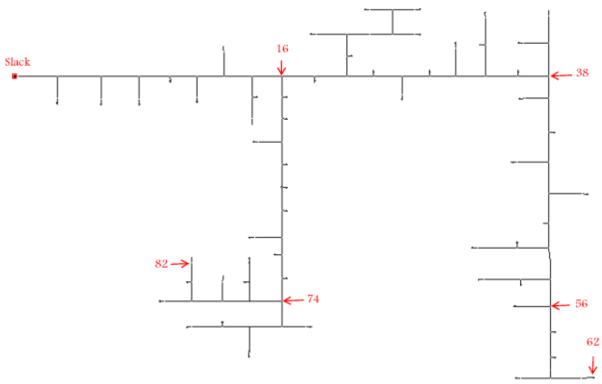

Fig.7 : single line diagram