Investigation of Power Flow Analysis in Networked Microgrids

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***Abstract*—In this paper, the power flow analysis of the Networked Microgrids (NMGs) is analyzed for different case studies of benchmark test systems. Multiple Microgrids (MGs) operating in combination enable high penetration of Distributed Energy Resources (DERs), which lowers electricity costs and improves the resilience and stability of the power network. This article's benchmark test system for networked MGs connects and manages four separate MGs. An important technique for operational and planning studies of NMGs is power flow analysis (PFA). Each MG uses tie lines to work alone after initially operating as a group employing all of the MGs. The bus voltages, phase angles, active power loss, reactive power loss, iterations and computational time for NMGs were analyzed.**

***Index Terms*—NMGs (Networked Microgrids), DERs (Distributed Energy Resources), SGs (Synchronous Generators), PFA (Power Flow Analysis)**

I. Introduction

A microgrid is a small-scale power grid that can function autonomously or in collaboration with other small power grids. Due to the enormous benefits for both power grid operators and electricity customers, microgrids have received a lot of attention recently. Microgrids can be divided into various categories according to their type (such as industrial, commercial, residential), size (such as large, medium, and small scale), application (such as expensive power, resilience-oriented, and loss reduction), and connectivity (such as isolated or grid-connected). One of the essential tools for the management, operation, and control of distribution grid/ Microgrid is a power flow study. Power flow analysis must be carried out in both fault conditions, such as a short circuit, and normal operating conditions in order to evaluate the performance of power flow study on test systems.

IEEE standard 1547.4 states [1] that dividing a network into several microgrids can enhance the performance and dependability of a distribution system. When a fault exists in the system that is in self-healing mode, the distribution system is divided into self-sufficient microgrids as discussed in [2]. The study in [3] uses a microgrid planning model to estimate the optimal size, generation mix, and type of microgrid, i.e., ac or dc, for distributed energy resources (DERs). Distribution systems' many load flow strategies, including deterministic, probabilistic, and evolutionary methods, have been discussed in detail in [4]. In [5], an extensive review of the most recent research on networked MGs is presented, along with a full explanation of the architecture, taking into account different control strategies, communication technologies, and energy management techniques employed in the operation of networked MGs. An offline EOPF-based hierarchical scheme for islanded AC microgrids uses a new type of bus to model the power flow and incorporates both primary and secondary control to better capture the steady-state dynamics of the system [6]. A list of the most important power flow algorithms developed during the past decade using optimization, Jacobian, and non-Jacobian techniques are presented in [7]. The Modified Newton Raphson (MNR) method, which considers an absence of a slack bus and formulates the generator bus as a droop bus, is used in [8] to solve the power flow for an islanded microgrid. A modified form of the Backward Forward Substitution approach is taken [9] into account when there is no slack bus. This can create the voltage reference to be used in the algorithm for updating bus voltages and the distribution of power (summation of load and losses) by droop-controlled DGs to improve the convergence of power flow problem in islanded microgrids. The solution of the load flow of isolated microgrids with droop control was explored in [10] as an extension of the traditional fast decoupling algorithm. The investigation of quick and effective power flow solutions for the radial distribution systems was covered in [11], leading to a comparison of distribution load flow algorithms. The research in this paper investigates quick and efficient power flow solutions for Networked Microgrids using a network topology-based load flow algorithm to decrease both active and reactive power losses and improve voltage profile.

The remainder of the paper is structured as follows. The architecture of networked microgrids is explored in Section II. The networked microgrid power flow is analyzed in Section III. Results of the power flow analysis and discussions for three case studies combining networked microgrids and islanded microgrids are presented in Section IV. Section V contains the conclusions.

II. Networked Microgrids

To provide the best infrastructure in electrical network by utilizing distributed energy resources and to provide ancillary services in energy market the networked microgrid is a highly explored research area. Several researchers are planning the use of NMGs for operational and planning studies. The Benchmark Test system for NMGs were developed by the authors in [12]. The line data (44 lines) of Networked Microgrid is given

TABLE I
LINE DATA OF NETWORKED MICROGRIDS [12]

Line number	From bus	To bus	length (km)	Resistance (Ohm)	Reactance (Ohm)	Normal rating (A)	SCCR (kA)
1	1	2	3	0.0927	0.1431	1000	114.4
2	1	3	2.4	0.09336	0.11988	890	83.8
3	1	4	3	0.0927	0.1431	1000	114.4
4	1	5	1.6	0.06224	0.07992	890	83.8
5	1	6	1.6	0.06224	0.07992	890	83.8
6	2	3	2	0.0778	0.0999	890	83.8
7	2	5	1.5	0.05835	0.07493	890	83.8
9	3	5	1.2	0.04668	0.05994	890	83.8
10	3	6	1.2	0.04668	0.05994	890	83.8
11	3	4	2	0.0778	0.0999	890	83.8
12	4	6	1.5	0.05835	0.07493	890	83.8
14	7	8	1.4	0.05835	0.07493	890	83.8
15	8	9	1.6	0.06224	0.07992	890	83.8
16	9	10	2.2	0.08558	0.10989	890	83.8
17	10	11	1.8	0.07002	0.08991	890	83.8
18	8	12	1.5	0.2385	0.162	310	21.4
19	9	13	1.4	0.2226	0.1512	310	21.4
20	10	14	1.2	0.04668	0.05994	890	83.8
21	14	15	0.8	0.1272	0.0864	310	21.4
24	16	17	1.2	0.04668	0.05994	890	83.8
25	17	18	1.8	0.07002	0.08991	890	83.8
26	18	19	1.2	0.04668	0.05994	890	83.8
27	19	20	1.4	0.05446	0.06993	890	83.8
28	20	21	1.6	0.06224	0.07992	890	83.8
29	21	22	1.5	0.05835	0.07493	890	83.8
30	22	23	1.5	0.2385	0.162	310	21.4
31	17	24	1.5	0.05835	0.07493	890	83.8
32	24	25	1.5	0.05835	0.07493	890	83.8
33	17	26	1.4	0.226	0.1512	310	21.4
34	26	27	1.2	0.1908	0.1296	310	21.4
35	18	28	1.5	0.2385	0.162	310	21.4
36	19	29	1.4	0.2226	0.1512	310	21.4
37	20	21	1.4	0.2226	0.1512	310	21.4
38	30	31	1.2	0.1908	0.1296	310	21.4
39	21	32	1.4	0.2226	0.1512	310	21.4
40	22	33	1.7	0.06613	0.08492	890	83.8
42	34	35	0.6	0.0381	0.0315	700	52.9
43	34	38	1	0.0635	0.0525	700	52.9
44	34	39	1.8	0.1143	0.0945	700	52.9
45	35	36	2	0.127	0.105	700	52.9
46	36	37	0.6	0.0381	0.0315	700	52.9
47	37	40	1	0.0635	0.0525	700	52.9
48	38	39	1.5	0.09525	0.07875	700	52.9
49	39	40	1.5	0.09525	0.07875	700	52.9

in Table I. The Tie line / Point of Common Coupling (PCC) data (5 lines) is given in Table II. The load data of Networked Microgrid is given in Table III. Distributed Energy Resources (DERs) such as PV (Photo Voltaic) and Wind Turbine (WT) installed capacities with their network area details are given in Table IV. The standby synchronous generator (SG) placed at each microgrid first bus and the capacities of SGs are given in Table V. The benchmark NMGs are suitable for several power system problems like power flow analysis, control strategies, system stability, protection and energy management studies. The benchmark NMGs has four different MGs with different sizes and topologies. Interconnection of MGs is done using point of common couplings (PCCs) which can be switched ”on/off” during the operation as per requirement. The single line diagram of Networked Microgrid is given in Figure 1.

TABLE II
TIE LINE/ PCC LINE DATA OF NETWORKED MICROGRIDS [12]

Tie line	From bus	To bus	length (km)	Resistance (Ohm)	Reactance (Ohm)	Normal rating (A)	SCCR (kA)
8	2	7	1	0.0309	0.0477	1000	114.4
13	4	23	1.5	0.04635	0.07155	1000	114.4
22	14	16	2	0.0778	0.0999	890	83.8
23	11	32	2.5	0.09725	0.12488	890	83.8
41	19	40	1	0.0389	0.04995	890	83.8

TABLE III
LOAD DATA OF NETWORKED MICROGRIDS [12]

Bus Number	Active Power Load (P_d) (kW)	Reactive Power load (Q_d) (kVAR)	Critical Active Powerload (P_d^c) (kW)	Critical Reactive Power load (Q_d^c) (kVAR)	% of $\frac{P_d}{\sum P_d}$
1	0	0	0	0	0.00
2	2125	336	450	68	6.90
3	3329	1023	650	124	10.81
4	2050	555	200	50	6.66
5	1257	310	200	35	4.08
6	1056	240	200	35	3.43
7	600	100	0	0	1.95
8	1250	487	500	80	4.06
9	1203	410	500	80	3.91
10	1366	443	650	138	4.43
11	764	36	0	0	2.48
12	503	21	0	0	1.63
13	345	11	0	0	1.12
14	629	8	0	0	2.04
15	642	12	100	25	2.08
16	580	150	0	0	1.88
17	650	85	250	50	2.11
18	673	96	0	0	2.18
19	439	135	0	0	1.43
20	600	128	250	50	1.95
21	560	112	0	0	1.82
22	851	145	385	50	2.76
23	420	25	0	0	1.36
24	500	45	0	0	1.62
25	637	33	0	0	2.07
26	788	95	350	83	2.56
27	125	50	0	0	0.41
28	169	20	0	0	0.55
29	200	43	0	0	0.65
30	250	32	125	25	0.81
31	213	12	0	0	0.69
32	133	25	0	0	0.43
33	200	38	0	0	0.65
34	426	80	0	0	1.38
35	318	78	125	20	1.03
36	356	81	125	20	1.16
37	459	88	0	0	1.49
38	820	91	0	0	2.66
39	2500	635	850	150	8.12
40	816	60	250	44	2.65
Total load	30802	6374	6160	1127	100.0

III. POWER FLOW ANALYSIS OF NETWORKED MICROGRIDS

A power flow study’s goal is to determine the voltages (in terms of magnitude and angle) for a particular load, generation, and network condition. Line flows and losses which can be computed after the voltages for each bus are known. The Networked Microgrids are a combination of both radial and meshed type of networks so that the Current Inection Method (CIM) load flow algorithm [11] is most suitable and is used in the present study. The mathematical expressions for CIM are

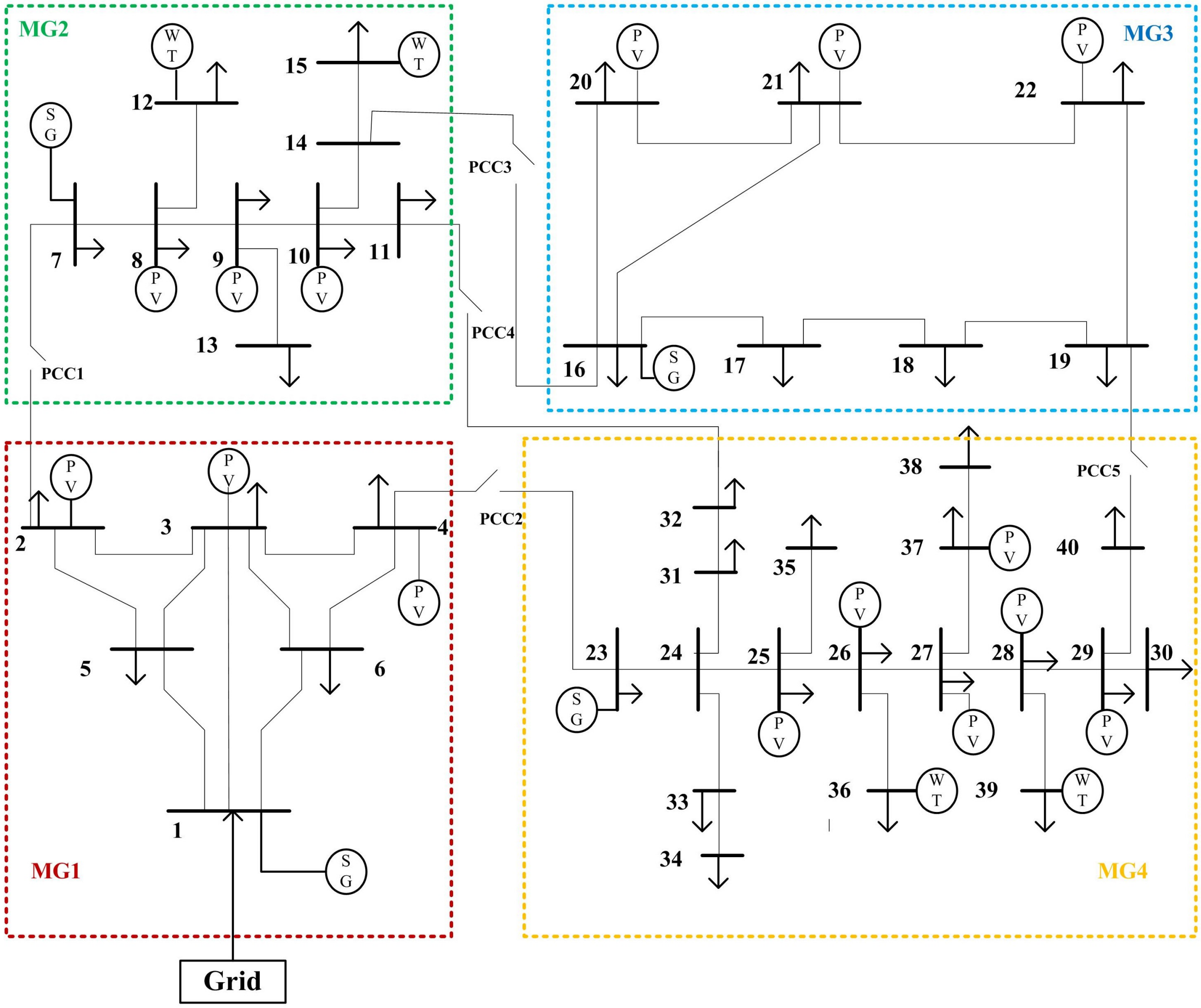

Fig. 1. Single line diagram of Benchmark Networked Microgrids

represented in equations (1)-(5). The current mismatch is given in equation (4). The equation (6) is non-linear and converges fast. It took 3 to 4 iterations for load flow computation. The step by step procedure of CIM based power flow solution is given in Algorithm 1.

$$[I_{bus}] = [Y_{bus}][E_{bus}] \tag{1}$$

$$I_p^{cal} = Y_{pp}E_p + \sum_{q=1\&q\neq p}^{n} Y_{pq}E_q \tag{2}$$

$$I_p^{sp} = (P_p^{sp} - jQ_p^{sp})/E_p^* \tag{3}$$

$$F_p = \Delta I = I_p^{sp} - I_p^{cal} \tag{4}$$

$$F_p = (P_p^{sp} - jQ_p^{sp})/E_p^* - Y_{pp}E_p - \sum_{q=1\&q\neq p}^{n} Y_{pq}E_q \tag{5}$$

$$\begin{aligned} F_p = {} & \frac{(P_p^{sp} - jQ_p^{sp})(e_p^2 - f_p^2 + j2e_pf_p)(e_p - jf_p)}{|E_p^4|} \\ & - Y_{pp}E_p - \sum_{q=1\&q\neq p} Y_{pq}E_q \end{aligned} \tag{6}$$

IV. Results and Discussions

In this work, current injection based load flow method was used for power flow analysis for bench mark networked microgrids under MATLAB environment [13] using a computer with an Intel (R) Core (TM) i7-3770 CPU running at 3.40GHz and 8GB of RAM. The test system of networked microgrids is shown in Figure 1 and the data pertaining to NMGs is taken from [12]. The whole network was first connected into the main grid, which can be used as a distribution network by closing all PCC lines without considering DERs and SGs.

TABLE IV
INSTALLED CAPACITY OF PV AND WT IN NETWORKED MICROGRIDS [12]

Bus Number	DG Type	PG (kW)	QGmin (kVAR)	QGmax (kVAR)	Network area
2	PV	2000	0	400	MG1
3	PV	2400	0	480	MG1
4	PV	2000	0	400	MG1
8	PV	1600	0	320	MG2
9	PV	1600	0	320	MG2
10	PV	2400	0	480	MG2
12	WT	800	-250	250	MG2
15	WT	500	-200	200	MG2
20	PV	1600	0	320	MG3
21	PV	2400	0	500	MG3
22	PV	1600	0	320	MG3
25	PV	2000	0	500	MG4
26	PV	400	0	100	MG4
27	PV	800	0	160	MG4
28	PV	800	0	160	MG4
29	PV	800	0	160	MG4
36	WT	500	-250	250	MG4
37	PV	800	0	160	MG4
39	WT	1200	-600	600	MG4

TABLE V
STANDBY SYNCHRONOUS GENERATOR DATA IN NETWORKED MICROGRIDS [12]

Bus Number	Unit capacity (kVA)	Number of units	QGmin (kVAR)	QGmax (kVAR)	Network area
1	5000	3	-3000	5000	MG1
7	2000	3	-1500	2000	MG2
16	2000	3	-1500	2000	MG3
23	2000	2	-1000	2000	MG4

The power flow analysis done for three case studies is given in Table VI. Case study I in Table VI shows the state vector of power flow analysis of the combined network connected to the main grid without considering DERs and SGs. Case study II in Table VI shows the state vector power flow analysis results of the networked micro grid connected to main grid by considering SGs at first bus of each micro grid and without considering DERs. Case study III in Table VI shows the state vector of power flow analysis of Networked micro grid considering DERs and SGs integrated into the network. The voltage profile plots of all three case studies of combined networked are pictorially shown in Figure 2.

When the network is disconnected from the main grid and when PCC1 and PCC2 switches are off, Microgrid 1 will operate using SGs and DERs. The power flow results of MG

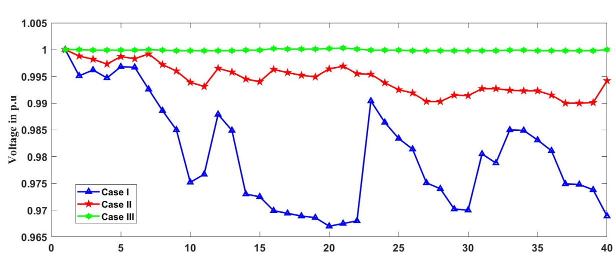

Fig. 2. Voltage profile plots of Networked Microgrid for different case studies

Algorithm 1 *: Power Flow Algorithm based on Current Injection Method*

Step1: Read line data, load data, Distributed Energy Resources data, SGs data of Networked Microgrids i.e.. number of buses, number of lines, slack bus, maximum number of iteration, epsilon for tolerance (0.0001), sending end bus, receiving end bus, active power load, reactive power load at each bus and active and reactive power generation of DERs, initial guess voltages.
Step2: Print and cross check data given to computer.
Step3: Compute Admittance matrix (Y_{BUS}) using sparsity technique.
Step4: Compute active and reactive power injections for all buses.
Step5: Set iteration count = 0
Step6: Set $\Delta I_{real}^{max} = 0$ $\Delta I_{imag}^{max} = 0$
Step7: Compute specified current (I_{sp}) for all buses using equation 3.
Step8: Compute current (I_{cal}) for all buses using equation 2 and compute ΔI using equation 4.
Step9: Compute ΔI_{real}^{max} and ΔI_{imag}^{max} values and check for convergence ($\Delta I_{real}^{max} \leq \epsilon \& \Delta I_{imag}^{max} \leq \epsilon$) :If converged Go To Step 14 or else Go To Step 10.
Step10: Form Jacobian Matrix (A).
Step11: Solve equation 7 using Gauss elimination technique.

$$\begin{bmatrix} \Delta I_{imag}^{max} \\ \Delta I_{real}^{max} \end{bmatrix} = \begin{bmatrix} A \end{bmatrix} \begin{bmatrix} \Delta e \\ \Delta f \end{bmatrix} \quad (7)$$

Step12: Update the Voltage Magnitudes and Phase angles
Step13: Update iteration count until solution converges.
Step14: Print the bus voltages, phase angles, losses, iterations and computation time.

1 are given in Table VII. The voltage profile plot of MG 1 is as shown in Figure 3. When PCC1, PCC3 and PCC4 switches are opened, we can operate Microgrid 2 using SGs and DERs integrated in that network. The power flow results of MG2 are given in Table VIII. The voltage profile plot of MG 2 is shown in Figure 4. If PCC3, PCC4 and PCC5 switches are opened, then one can operate Microgrid 3 using SGs and DERs connected to MG3 network. The power flow results of MG 3 are given in Table IX. The voltage profile plot of MG 3 is pictorially represented in Figure 5. When the tie lines PCC 2, PCC 3 and PCC5 are opened, one can operate Microgrid 4 using SGs and DERs integrated in MG 4 network. Table X gives the power flow results of MG 4. The voltage profile plot of MG 4 is shown in Figure 6. The total active power loss, reactive power loss, iteration number, and computational time in NMGs are given in Table XI.

V. CONCLUSIONS

In this paper, the current injection based power flow method was extended to Networked Microgrids. The power flow solutions were determined for combined network of all microgrids and four independent MGs of different sizes and

TABLE VI
VOLTAGE AND PHASE ANGLES OF COMBINED NETWORKED MICRIGRIDS

Bus No	Case I (Base Case)		Case II (SGs only)		Case III (DERs & SGs)	
	Voltage (p.u)	Angle (degree)	Voltage (p.u)	Angle (degree)	Voltage (p.u)	Angle (degree)
1	1	0	1	0	1	0
2	0.9951	0.0045	0.9988	0.0019	1	0
3	0.9962	0.0033	0.9982	0.0019	0.9999	0.0022
4	0.9947	0.0048	0.9973	0.0029	0.9999	0.0022
5	0.9968	0.0029	0.9987	0.0015	0.9999	0.0022
6	0.9967	0.0029	0.9983	0.0018	0.9999	0.0022
7	0.9926	0.0071	0.9992	0.0022	1	0
8	0.9886	0.0106	0.9972	0.0043	0.9999	0.0022
9	0.985	0.0139	0.996	0.006	0.9998	0.0019
10	0.9752	0.0188	0.9939	0.0087	0.9998	0.0019
11	0.9767	0.018	0.9931	0.0092	0.9998	0.0019
12	0.9879	0.011	0.9965	0.0048	0.9998	0.0019
13	0.9849	0.0141	0.9958	0.0062	0.9998	0.0019
14	0.973	0.021	0.9945	0.009	0.9999	0.002
15	0.9725	0.0213	0.994	0.0093	0.9999	0.0022
16	0.9699	0.0237	0.9963	0.0086	1.0002	0.0002
17	0.9694	0.024	0.9957	0.0089	1.0001	0.0003
18	0.9689	0.0242	0.9952	0.0092	1.0001	0.0003
19	0.9686	0.0244	0.9949	0.0095	1.0001	0.0003
20	0.967	0.0253	0.9964	0.0091	1.0002	0.0002
21	0.9675	0.025	0.9969	0.0087	1.0003	0.0004
22	0.968	0.0248	0.9955	0.0093	1.0001	0.0003
23	0.9904	0.0093	0.9954	0.0054	0.9999	0.0022
24	0.9864	0.0128	0.9938	0.0073	0.9999	0.0022
25	0.9834	0.0155	0.9925	0.0088	0.9999	0.0022
26	0.9814	0.0175	0.9919	0.0096	0.9998	0.0019
27	0.9751	0.0206	0.9903	0.0108	0.9998	0.0019
28	0.974	0.0216	0.9903	0.0109	0.9998	0.0019
29	0.9702	0.0235	0.9915	0.0109	0.9998	0.0019
30	0.97	0.0237	0.9914	0.011	0.9998	0.0019
31	0.9805	0.0151	0.9927	0.0087	0.9998	0.0019
32	0.9788	0.0164	0.9927	0.0091	0.9998	0.0019
33	0.985	0.0134	0.9924	0.008	0.9999	0.0022
34	0.9849	0.0135	0.9923	0.0081	0.9999	0.0022
35	0.9831	0.0157	0.9923	0.0089	0.9998	0.0019
36	0.9811	0.0177	0.9915	0.0097	0.9998	0.0019
37	0.9749	0.0208	0.99	0.011	0.9998	0.0019
38	0.9748	0.0209	0.99	0.0111	0.9998	0.0019
39	0.9738	0.0217	0.9901	0.011	0.9998	0.0019
40	0.9689	0.0242	0.9942	0.01	1	0

TABLE VII
POWER FLOW RESULTS OF MICRO GRID 1 (MG1)
(MAIN GRID OFF; PCC1 & PCC2 ARE OFF)

Bus No	Voltage (p.u)	Angle (degree)	Pgen (kW)	Pload (kW)	Qgen (kVAR)	Qload (kVAR)
1	1.0000	0.0000	3819.16	0	2466.90	0
2	0.9993	0.0002	2000	2125	0	336
3	0.9992	0.0002	2000	3329	0	1023
4	0.9993	0.0001	2000	2050	0	555
5	0.9992	0.0003	0	1257	0	310
6	0.9993	0.0002	0	1056	0	240

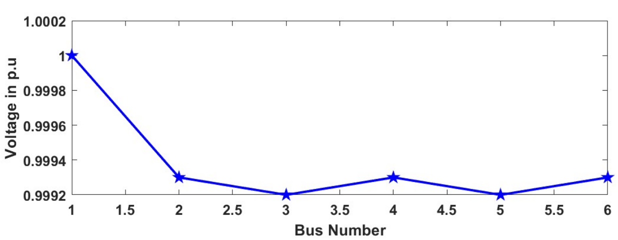

Fig. 3. Voltage profile plot of Microgrid 1

TABLE VIII
POWER FLOW RESULTS OF MICRO GRID 2 (MG2)
(MAIN GRID OFF; PCC1, PCC3, & PCC4 ARE OFF)

Bus No	Voltage (p.u)	Angle (degrees)	Pgen (Kw)	Qgen (kVAR)	Pload (kW)	Qload (kVAR)
7	1.0000	0.0000	404.54	1530.73	600	100
8	0.9994	-0.0005	1600	0	1250	487
9	0.9988	-0.0007	1600	0	1203	410
10	0.9975	-0.0009	2400	0	1366	443
11	0.9971	-0.0004	0	0	764	36
12	0.9998	-0.0008	800	0	503	21
13	0.9986	-0.0005	0	0	345	11
14	0.9973	-0.0006	0	0	629	8
15	0.9972	-0.0005	500	0	642	12

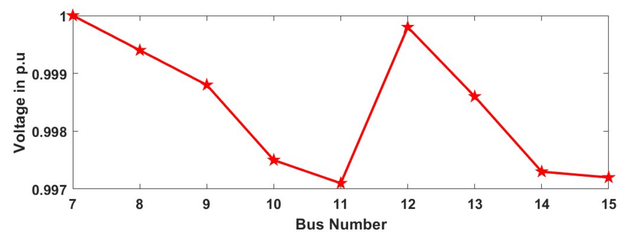

Fig. 4. Voltage profile plot of Microgrid 2

TABLE IX
POWER FLOW RESULTS OF MICRO GRID 3 (MG3)
(MAIN GRID OFF; PCC3, PCC4 & PCC5 ARE OFF)

Bus No	Voltage (p.u)	Angle (degrees)	Pgen (Kw)	Pload (kW)	Qgen (kVAR)	Qload (kVAR)
16	1.0000	0.0000	95.707	1113.58	426	80
17	0.9998	0.0000	0	0	318	78
18	0.9996	-0.0000	0	0	356	81
19	0.9996	-0.0001	0	0	459	88
20	1.0001	-0.0003	1600	0	820	91
21	0.9998	-0.0003	2400	0	2500	635
22	0.9999	-0.0004	1600	0	816	60

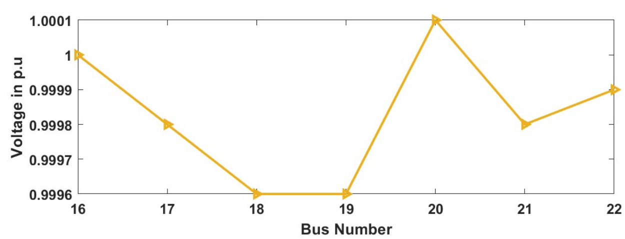

Fig. 5. Voltage profile plot of Microgrid 3

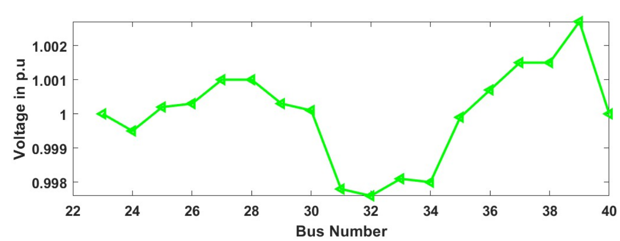

Fig. 6. Voltage profile plot of Microgrid 4

TABLE X
POWER FLOW RESULTS OF MICRO GRID 4 (MG4)
(MAIN GRID OFF; PCC2, PCC4 & PCC5 ARE OFF)

Bus No	Voltage (p.u)	Angle (degrees)	Pgen (Kw)	Pload (kW)	Qgen (kVAR)	Qload (kVAR)
23	1.0000	0.0000	700.41	1280.50	580	150
24	0.9995	-0.0002	0	0	650	85
25	1.0002	-0.0020	2000	0	673	96
26	1.0003	-0.0029	400	0	439	135
27	1.001	-0.0048	800	0	600	128
28	1.001	-0.0051	800	0	560	112
29	1.0003	-0.0047	800	0	851	145
30	1.0001	-0.0045	0	0	420	25
31	0.9978	0.0006	0	0	500	45
32	0.9976	0.0009	0	0	637	33
33	0.9981	0.0003	0	0	788	95
34	0.9980	0.0004	0	0	125	50
35	0.9999	-0.0019	0	0	169	20
36	1.0007	-0.0033	500	0	200	43
37	1.0015	-0.0049	800	0	250	32
38	1.0015	-0.0049	0	0	213	12
39	1.0027	-0.0060	1200	0	133	25
40	1.0000	-0.0046	0	0	200	38

TABLE XI
ACTIVE POWER, REACTIVE POWER LOSSES, ITERATIONS, AND COMPUTATION TIME RESULTS FOR NETWORKED MICRO GRID

Parameters	Ploss (kW)	Qloss (kVAR)	iterations	Time (seconds)
MG1	2.16	2.90	2	0.1686
MG2	2.55	2.73	3	0.3668
MG3	0.71	0.58	2	0.2451
MG4	12.42	11.50	3	0.2190

topological configurations. The power flow results of NMGs such as bus voltages, phase angles, reactive and active power losses, iterations, and computational time were investigated. The study concludes that instead of operating a large distribution network, small networking of microgrid yields better results in terms of performance and operation. The networked microgrid concept is a very significant concept for researchers and suitable for several studies like optimal power flows, energy management, control stability, reliability, resiliency etc.., when one consider the intermittent nature of renewable energy generation and load uncertainties.

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