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Evaluation and Analysis of Three Phase Smart Power Distribution Networks in the Presence of Distributed Generation

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ABSTRACT

As the installations of distributed generators (DGs) within distribution systems increasing, power flow analysis of unbalanced distribution networks needs special algorithms to handle multiple sources. In this paper, the development of an unbalanced three phase power flow algorithm which can handle multiple sources is described. According to the control and characteristics of output power, DGs can be specified as constant power factor model and constant voltage model. In this paper, these two models are all derived and integrated into the proposed load flow method. This load flow is capable of switching the DG mode of operation from constant voltage to constant power factor in the presence of multiple DGs. This algorithm has been tested with IEEE 8 bus and IEEE 25 bus unbalanced radial distribution networks and the results are presented in this paper.

1. INTRODUCTION

Electrical energy is generated at the power stations (hydro-electric, thermal or nuclear) which are usually situated far away from the load centers. Hence an extensive network of conductors between the power stations and the consumers is required. This network of conductors between the power stations and the consumers is called transmission and the distribution system. The generation, transmission and the distribution system of electrical power is called Electrical system. The transmission system is to deliver bulk power from power stations to load centres and large industries beyond the economical service range of regular primary distribution lines whereas distribution system is to deliver power from power stations to various consumers. Although electrical power can be transmitted and distributed by either ac or dc but in practice 3-phaxe 3 wire A.C system is universally adopted for transmission of large blocks of power and 3-phase, 4-wire system is universally adopted for distribution network.

In this paper we developed an unbalanced distribution power flow algorithm using Dynamic Data Structure (DDS) and PV node sensitivity matrix. This algorithm can handle multiple DGs for their both modes of operation (PV and PQ). This algorithm is tested for the impact of DGs on the two unbalanced radial test systems by considering all the loads as constant power loads and the results are presented. However, this algorithm can also handle composite load modeling.

Load flow technique is very important tool for analysis of power systems and used in operational as well as planning stages. Certain applications, particularly in distribution automation and optimization require repeated load flow solutions. As the power distribution networks become more and more complex, there is a higher demand for efficient and reliable system operation. Consequently, the most important system analysis tool, load flow studies, must have the capability to handle various system configurations with adequate accuracy and speed. Power distribution systems have different characteristics from transmission systems [1], [2].They are characterized as Radial/weakly meshed structures, Unbalanced networks/loads: single, double and three phase loads, High resistance/reactance(R/X) ratio of the lines, Extremely large number of branches/nodes, Shunt capacitor banks and distribution transformers, Low voltage levels compared with those of transmission systems and distributed generators [3].[4]. Because of the inherent unbalanced nature of the power distribution system, each bus may be having loads that can be three phase grounded wye or ungrounded delta connected, two-phase grounded or single-phase grounded [5]. The unbalanced nature of power distribution systems requires special three phase component and system models [6]. Due to high R/X ratio, the conventional

Newton Raphson method and Fast De-coupled Load Flow method fail to converge to a solution. Many other researchers [7-10] have suggested modified versions of conventional load flow methods for radial distribution networks with high *R/X* ratio. Basu and Goswami [11] have also proposed a method for solving unbalanced radial distribution networks based on the Newton-Raphson method. Thukaram et al.[12] and Miu et al.[13] have also proposed methods for solving three-phase radial distribution networks. Cheng and Shirmohammadi [6] proposed a load flow solution for real-time distribution system and it gives some initial discussions on a PV node concept in unbalanced power flow.

2. POWER FLOW ALGORITHM WITH DISTRIBUTED GENERATION

According to the characteristics and control on the output power, the DGs can be modeled as constant power factor model small DGs and constant voltage or variable reactive power model for large DGs. The constant power factor model can be taken as PQ node model in the power flow algorithm, and constant voltage model or variable reactive power model is taken as PV node model in the power flow algorithm.

The methodology for modeling PV node in the power flow algorithm is explained in as follows. After the power flow explained in section II is converged, suppose the voltage magnitudes at PV nodes is not equal to the scheduled values, In order to obtain the scheduled voltage magnitude at the PV node, we need to determine the correct amount of reactive power generated by the unit. The reactive power generation can be found from reactive current injection. Therefore, the problem of compensating PV node voltage magnitude becomes: Find the reactive current injection for each PV node so that the voltage magnitude, V, of this node is equal to the scheduled value. Since the relation between reactive current injection and magnitude V is nonlinear, reactive current can only be determined iteratively. The methodology followed for modeling PQ node is model it as negative load and inject the specified active and reactive powers in to the node. Since the terminal voltages may be unbalanced, the injected currents may also be unbalanced. If there is a large imbalance in the injected currents the machine may be shut down by its protection system.

2.1 Algorithm for power flow with DGs

The detailed iterative procedure for power algorithm with the DGs is explained as follows,

1. Run the unbalanced radial distribution power flow

as explained in section II.

2. After the load flow is converged, for the outside k^{th} iteration, check the type of DGs available.
3. If the DGs available are output power at constant power factor then model that nodes as PQ node and inject complex powers specified by the generator in to each phase Sgi^{a}, Sgi^{b} & Sgi^{c} at that node by taking them as negative load.

   where,

$$\begin{bmatrix} S_{gi}^{a} \\ S_{gi}^{b} \\ S_{gi}^{c} \end{bmatrix} = \begin{bmatrix} P_{gi}^{a} \\ P_{gi}^{b} \\ P_{gi}^{c} \end{bmatrix} + j^{*} \begin{bmatrix} Q_{gi}^{a} \\ Q_{gi}^{b} \\ Q_{gi}^{c} \end{bmatrix} \quad (1)$$

The power injections in to each phase are found by dividing the total specified power by three.

4. If the DGs available are output power at constant voltage or variable reactive power the model that node as PV node. And calculate the voltage mismatches at all the PV nodes as,

$$\Delta Vi^{k} = |Vi^{sp}| - |Vi^{cal\,(k)}| \quad \text{for all the PV nodes i} \quad (2)$$

5. If any of the ΔVi^{k} is not less than the specified tolerance, then reactive current injection at the PV node in order to maintain the specified voltage needs to be calculated for the k^{th} iteration. Reactive current injection is calculated using equation (3).

$$[\Delta Iq]^{k} = [Zpv]^{-1} [\Delta V]^{k} \quad (3)$$

Where, the size of $[\Delta V]^{k}$ & $[\Delta Iq]^{k}$ is 3*n x1. (n indicates the number of PV busses). And [Zpv] is the PV node sensitivity matrix. The procedure to form [Zpv] is explained in next step.

6. The [Zpv] can be formed by observing the following numerical properties of its entries. The diagonal entry, Zii in [Zpv] is equal to the modulus of the sum positive sequence impedance of all line sections between PV nodes „i" and the root node (substation bus). Since all the lines are three phase line sections, the size of Zii is 3x3. If two PV nodes, i and j, have completely different path to the root node, then the off-diagonal entry Zij (size 3x3), is zero. If i and j share a piece of common path to the root node, then Zij is equal to the modulus of the sum positive sequence impedance of all line sections on this common path. Based on these, [Zpv] can be formed by identifying the path between PV nodes and the root node. The dimension of [Zpv] is equal to three times the number of PV nodes since it consists of 3x3 block sub matrices.
7. If the reactive power generations (Q without limits) were unlimited at the PV node, we would inject the reactive currents at 90 degrees leading the corresponding node voltages Vi^{a}, Vi^{b} & Vi^{c} at each PV node. The reactive current to be injected at the i^{th} PV node is given in equation (3).

$$\begin{bmatrix} I_{qi}^{a} \\ I_{qi}^{b} \\ I_{qi}^{c} \end{bmatrix}^{K} = \begin{bmatrix} |\Delta I_{qi}^{a}|^{k} (\cos(90^{o}+\delta_{vi}^{a}) + j^{*}\sin(90^{o}+\delta_{vi}^{a})) \\ |\Delta I_{qi}^{b}|^{k} (\cos(90^{o}+\delta_{vi}^{b}) + j^{*}\sin(90^{o}+\delta_{vi}^{b})) \\ |\Delta I_{qi}^{c}|^{k} (\cos(90^{o}+\delta_{vi}^{c}) + j^{*}\sin(90^{o}+\delta_{vi}^{c})) \end{bmatrix} \quad (3)$$

Where $\delta\, vi^{a}$, $\delta\, v^{b}$ & $\delta\, vi^{c}$ are the voltage angles of the three phases at the i^{th} PV node.

8. Now, to find the reactive power injection needed to eliminate the voltage mismatch at k^{th} iteration is obtained by applying the KCL at node „i" at k^{th} iteration for the Fig.3.

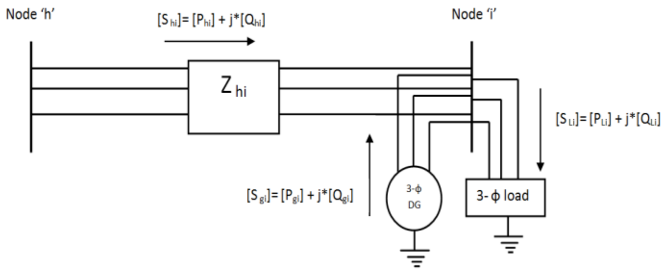

Fig.11 A sample two nodes in the system with DG placed at node „i".

$$\begin{bmatrix} \Delta Q_{gi}^{a} \\ \Delta Q_{gi}^{b} \\ \Delta Q_{gi}^{c} \end{bmatrix}^{K} = \begin{bmatrix} Q_{Li}^{a} \\ Q_{Li}^{b} \\ Q_{Li}^{c} \end{bmatrix} - \begin{bmatrix} Q_{hi}^{a} \\ Q_{hi}^{b} \\ Q_{hi}^{c} \end{bmatrix}^{K} \quad (4)$$

Where, $[Q\,hi]^{k}$ is the reactive power flowing in the line „hi" for the k^{th} iteration. It can find from equation (5)

$$[Q_{hi}]^k = \begin{bmatrix} V_i^{\,a} * ((I_{hi}^{\,a})^k)^* \\ V_i^{\,b} * ((I_{hi}^{\,b})^k)^* \\ V_i^{\,c} * ((I_{hi}^{\,c})^k)^* \end{bmatrix} \quad (5)$$

The branch currents in equation (6) at the k^{th} iteration are calculated as,

$$\begin{bmatrix} I_{hi}^{\,a} \\ I_{hi}^{\,b} \\ I_{hi}^{\,c} \end{bmatrix}^K = \begin{bmatrix} I_{Li}^{\,a} \\ I_{Li}^{\,a} \\ I_{Li}^{\,a} \end{bmatrix} - \begin{bmatrix} I_{qi}^{\,a} \\ I_{qi}^{\,a} \\ I_{qi}^{\,a} \end{bmatrix}^K \quad (6)$$

The reactive power generation needed at i^{th} PV node for k^{th} iteration is,

$$\begin{bmatrix} Q_{gi}^{\,a} \\ Q_{gi}^{\,b} \\ Q_{gi}^{\,c} \end{bmatrix}^K = \begin{bmatrix} Q_{gi}^{\,a} \\ Q_{gi}^{\,b} \\ Q_{gi}^{\,c} \end{bmatrix}^{K-1} + \begin{bmatrix} \Delta Q_{gi}^{\,a} \\ \Delta Q_{gi}^{\,b} \\ \Delta Q_{gi}^{\,c} \end{bmatrix}^K \quad (7)$$

9. Then inject complex power generations at the PV nodes for the k^{th} iteration as,

$$\begin{bmatrix} S_{gi}^{\,a} \\ S_{gi}^{\,b} \\ S_{gi}^{\,c} \end{bmatrix}^K = \begin{bmatrix} P_{gi}^{\,a} \\ P_{gi}^{\,b} \\ P_{gi}^{\,c} \end{bmatrix} + j* \begin{bmatrix} Q_{gi}^{\,a} \\ Q_{gi}^{\,b} \\ Q_{gi}^{\,c} \end{bmatrix}^K \quad (8)$$

Where, P_{gi} is the specified real power generation at the i^{th} PV node.

10. If the reactive power generations (Q with limits) were limited at the PV node, then reactive power limits must be checked first. The total 3-ϕ reactive power needed at i^{th} PV node is the sum of reactive power generations of three phases.

$$(Q_{gi}^{\gamma})^k = (Q_{gi}^{a})^k + (Q_{gi}^{b})^k + (Q_{gi}^{c})^k \quad (9)$$

11. The $(Q_{gi}^{\gamma})^k$ is the compared with the reactive power generation limits, if the Q_{gi}^{γ} is within the limits, i.e.,

$$Q_{gi,\,max} \le (Q_{gi}^{\gamma})^k \le Q_{gi,\,max}$$

Then inject the complex power as given equation (10).

12. Otherwise, if (Q_{gi}^{γ}) violates any reactive power generation limits, it will be set to that limit, divided by three for three phases. i.e.,

If $Q_{gi}^{\gamma} \le Q_{gi,\,min}$ then set $Q_{gi}^{\gamma} = Q_{gi,\,min}$ and $(Q_{gi}^{a})^k = (Q_{gi}^{b})^k = (Q_{gi}^{c})^k = Q_{gi,\,min} / 3$

If $Q_{gi}^{\gamma} \ge Q_{gi,\,max}$ then set $Q_{gi}^{\gamma} = Q_{gi,\,max}$ and $(Q_{gi}^{a})^k = (Q_{gi}^{b})^k = (Q_{gi}^{c})^k = Q_{gi,\,max} / 3$

These reactive power generations are combined with the active power generations at that node and inject into the node.

13. Now set k=k+1 and run the load flow with the complex power injections at the PV nodes and PQ nodes.
14. Stop the iterations when the voltage mismatches at all the PV nodes is less than the threshold values or the changes in the bus voltage magnitudes in two successive iterations at all nodes are less than the threshold values.

3. CASE STUDIES

The impact of the DGs on the distribution network is examined on two unbalanced distribution networks with the algorithm presented in this paper.

3.1 IEEE 8-bus system

A sample system 14.4 kV of 8 buses shown in Fig.1 has been taken from the Taiwan Power Corporation [16. It is assumed that the transformer at the substation is balanced, voltage regulators and capacitors at various buses is neglected. The base values of the system are chosen 14.4 kV and 300 kVA. The convergence tolerance specified for the load flow analysis is 0.00001 p.u. and the convergence tolerance for voltage mismatches at PV nodes is taken as 0.0001 p.u. The load flow solution without DGs and impacts of DGs on the system with the following cases is presented in the Table II.

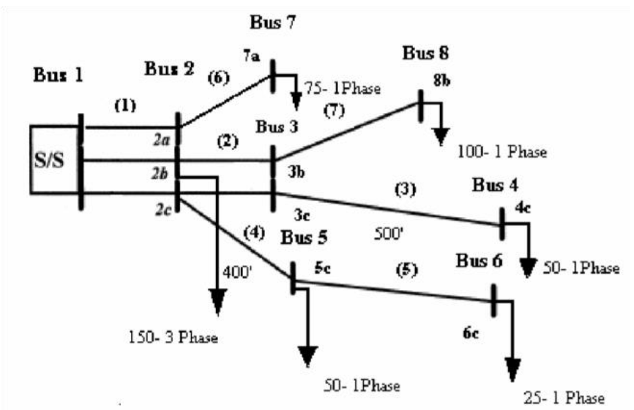

Fig.1 IEEE-8 bus radial distribution system

Load Flow Solution for IEEE-8 Bus System

Without DGs: The first two columns in the Table-1 is the power flow solution of the system without injecting DGs into it.

Case-I: From the Table-1 the case- I is the power flow solution of the system when a 1-ϕ DG is connected at node 6 between the phase C and neutral with injecting 30 KVA at power factor 0.8. This node is modeled as PQ node for the power flow analysis. It is found that voltage profile is improved at all busses when compared with without DGs.

Case-II: A 1-ϕ DG is placed at node 6 between phase C and neutral with injecting 30 KW and it has no limits on reactive power generation. At the end of the convergence to get the voltage profile as in Table-1 the generator is required to generate reactive power 73.726 KVar. It is found that phase voltage at bus 6 is 1 p.u.

Case - III: The 1-ϕ DG is placed at node 6 between phase C and neutral with injecting 30 KW and the generator has the limits on the reactive power -24 KVar ≤ Q ≤ 24 KVar. Since it has limits on reactive power generation the voltage profile is less than case-II.

Table 1 converged voltage solution of IEEE-8 bus system

Node no.	Without DGs		Case -I		Case -II		Case -III	
	|V| in P.U	∠V in (rad)	|V| in P.U	∠V in (rad)	∠V in P.U	∠V in (rad)	|V} in P.U	∠V in (rad)
2a	0.9975	-0.0009	0.9972	-0.0008	0.9970	-0.0002	0.9974	-0.0006
2b	0.9969	-2.095	0.9969	-2.0959	0.9965	-2.0965	0.9967	-2.095
2c	0.9961	2.0918	0.9971	2.0924	0.9990	2.0918	0.9969	2.0915
3b	0.9944	-2.095	0.9944	-2.096	0.9940	-2.0965	0.9942	-2.095
3c	0.9955	2.0913	0.9964	2.0919	0.9984	2.0913	0.9963	2.091
4c	0.9932	2.0913	0.9941	2.0918	0.9960	2.0913	0.994	2.091
5c	0.9934	2.0918	0.9954	2.0924	0.9988	2.0903	0.9947	2.0908
6c	0.9924	2.0918	0.9956	2.0924	1.000	2.0888	0.9943	2.0901
7a	0.9940	-0.0009	0.9937	-0.0008	0.9935	-0.0002	0.9940	-0.0007
8b	0.9897	-2.095	0.9898	-2.096	0.9893	-2.0966	0.9895	-2.0958

3.2 IEEE 25 Bus System

A 4.16 kV IEEE 25 has taken from [18] as shown in Fig.2. It is assumed that the transformer at the substation is balanced, voltage regulators and capacitors at various buses is neglected. For the load flow, base voltage and base MVA are chosen as 4.16 kV and 1000 KVA respectively. The Impedance data for IEEE-25 bus system is given in Table 2. The line data for IEEE-25 bus system is presented in Table 3. The power flow solution of IEEE-25 bus system without DGs is given in Table 4.

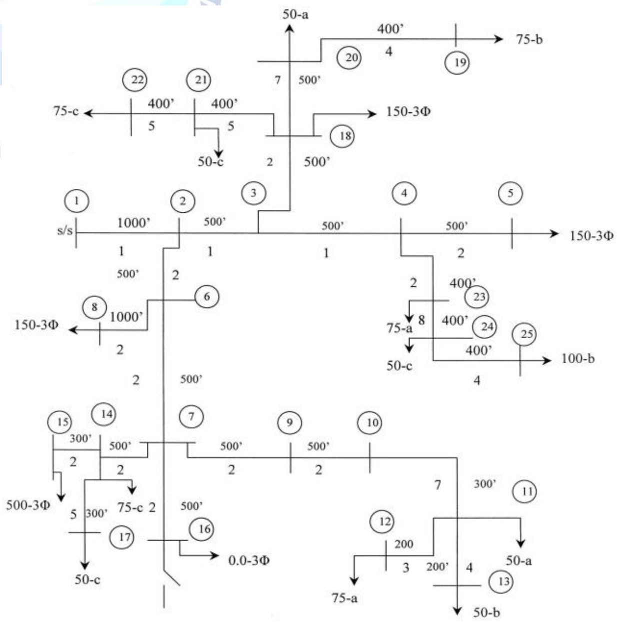

Fig.2 IEEE-25 bus distribution system

Table 2 Impedance data for IEEE-25 bus system

Conductor code	Self impedance per mile (Ω)	Mutual impedance per mile Ω)
1 (3-ϕ)	Ze^{aa}=0.36867+j0.68522 Ze^{bb}=0.37568+j0.67146 Ze^{cc}=0.37226+j0.67817	Ze^{ab}=0.016979+j0.15145 Ze^{bc}=0.018826+j020723 Ze^{ca}=0.01545+j0.10979
2(3-ϕ)	Ze^{aa}=0.97748+j0.87166 Ze^{bb}=0.98439+j0.86543 Ze^{cc}=0.98102+j0.86477	Ze^{ab}=0.01674+j0.16968 Ze^{bc}=0.01856+j0.22754 Ze^{ca}=0.01523+j0.12638
3(1- ϕ)	Ze^{aa}=1.9280+j1.41939	-
4(1- ϕ)	Ze^{bb}=1.9280+j1.41939	-
5(1- ϕ)	Ze^{cc}= 1.9280+j1.41939	-
6(2- ϕ)	Ze^{aa}=0.97748+j1.87166 Ze^{bb}=0.98102+j0.86847	Ze^{ab}=0.01523+j12638
7(2- ϕ)	Ze^{bb}=0.97748+j1.87166 Ze^{cc}=0.98102+j0.86847	Ze^{bc}=0.01523+j12638
8(2- ϕ)	Ze^{aa}=0.97748+j1.87166 Ze^{cc}=0.98102+j0.86847	Ze^{ca}=0.01523+j12638

Table 3 Line data for IEEE-25 bus system

Sending End node	Sending End node phase	Receiving End node	Receiving End node phase	Br.no	Conf.id	Branch Length(fts)
1	3	2	3	1	1	1000
2	3	3	3	2	1	500
3	3	4	3	3	1	500
4	3	5	3	4	2	500
2	3	6	3	5	2	500
6	3	7	3	6	2	500
6	3	8	3	7	2	1000
7	3	9	3	8	2	500
9	3	10	3	9	2	500
10	3	11	2	10	6	300
11	2	12	1	11	3	200
11	2	13	1	12	4	200
7	3	14	3	13	2	500
14	3	15	3	14	2	300
14	3	16	1	15	5	300
7	3	17	3	16	2	500
3	3	18	3	17	2	500
18	3	19	3	18	2	500
19	2	20	1	19	4	400
18	3	21	1	20	5	400
21	1	22	1	21	5	400
4	3	23	3	22	2	400
23	3	24	2	23	7	400
24	2	25	1	24	4	400

TABLE 4 Power flow solution of IEEE-25 bus system without DGs

Node	Converged voltages					
	Va(p u)	Angle(rad)	Vb(p u)	Angle(rad)	Vc(p u)	Angle(rad)
1	1	0	1	-2.0944	1	2.0944
2	0.98599	-0.00478	0.98789	-2.0973	0.98878	2.0893
3	0.98362	-0.00548	0.98491	-2.0979	0.98637	2.088
4	0.98221	-0.00585	0.98335	-2.0985	0.98564	2.0876
5	0.98118	-0.005833	0.98233	-2.0984	0.98471	2.0875
6	0.97717	-0.00487	0.98167	-2.0968	0.98219	2.0893
7	0.97509	-0.004834	0.97965	-2.0967	0.98033	2.0892
8	0.96938	-0.00498	0.97647	-2.0964	0.97654	2.0893
9	0.96484	-0.005084	0.97483	-2.0967	0.9768	2.0897
10	0.96196	-0.005042	0.97298	-2.097	0.9771	2.0899
11	0.95949	-0.006193	0.97248	-2.0971	--	--
12	0.95826	-0.006182	--	--	--	--
13	--	--	0.97167	-2.0971	--	--
14	0.96614	-0.004986	0.97291	-2.0957	0.97063	2.089
15	0.96404	-0.004950	0.97086	-2.0956	0.96874	2.089
16	--	--	--	--	0.96941	2.0891
17	0.96938	-0.00498	0.97647	-2.0964	0.97654	2.0893
18	0.98169	-0.005413	0.98224	-2.0976	0.98295	2.0878
19	0.98054	-0.005299	0.98074	-2.0977	0.9832	2.0878
20	--	--	0.97833	-2.0977	--	--
21	--	--	--	--	0.97893	2.0878
22	--	--	--	--	0.97651	2.0878
23	0.98092	-0.005762	0.98171	-2.0985	0.98504	2.0875
24	--	--	0.97912	-2.0997	0.98433	2.0874
25	--	--	0.9759	-2.0996	--	--

Case-I: two DGs are injected in the system. The first 3-ϕ DG is connected at bus number 15 is output 3000 KW and it has no limits on the reactive power generation hence it is modeled as PV node. The second 3-ϕ DG placed at bus 18 is output 300 KVA at 0.8 p.f, which is modeled as PQ node. At the end of the power flow algorithm to get the voltage profile as in Table-IV the generator is required to generate total reactive power 4252.1KVar. The Table-5 presents the power flow solution and the phase voltages at bus 15 are found to be 1 p.u.

Table 5 Case -1

Node no.	|Va| in P.U	∠Va in rad.	|Vb| in P.U	∠Vb in rad.	|Vc| in P.U	∠Vc in rad.
1	1	0	1	-2.094	1	2.094
2	0.9978	-0.009	0.9974	-2.102	0.9989	2.086
3	0.9966	-0.010	0.9955	-2.102	0.9974	2.085
4	0.9952	-0.010	0.994	-2.103	0.9966	2.085

5	0.9942	-0.010	0.993	-2.103	0.9957	2.085
6	0.9957	-0.017	0.9966	-2.108	0.9981	2.079
7	0.9936	-0.017	0.9946	-2.108	0.9963	2.079
8	0.9946	-0.0255	0.9968	-2.115	0.9983	2.073
9	0.9902	-0.025	0.9952	-2.115	0.9985	2.073
10	0.9874	-0.025	0.9934	-2.116	0.9988	2.073
11	--	--	0.9929	-2.116	0.9988	2.073
12	0.9838	-0.026	--	--	--	--
13	--	--	0.9921	-2.116	--	--
14	0.9980	-0.033	0.9987	-2.122	0.9983	2.066
15	0.9999	-0.038	0.9999	-2.126	0.9999	2.062
16	--	--	--	--	0.9971	2.066
17	0.9946	-0.025	0.9968	-2.115	0.9983	2.073
18	0.9967	-0.010	0.9949	-2.102	0.9958	2.085
19	0.9956	-0.009	0.9934	-2.102	0.9961	2.085
20	--	--	0.9910	-2.102	--	--
21	--	--	--	--	0.9919	2.085
22	--	--	--	--	0.9895	2.085
23	0.9939	-0.010	0.9923	-2.103	0.9960	2.085
24	0.9939	-0.010	--	--	0.9953	2.085
25	--	--	0.9866	-2.104	--	--

Case-II: The 3-ϕ DG placed at bus 15 with injecting total power 1800 KW and the generator has the limits on the reactive power -1350 KVar ≤ Q ≤ 1350 KVar. The Table-6 Presents the power flow solution.

Table 6 Case- II

Node No.	$\|V_a\|$ in P.U	$\angle V_a$ in rad.	$\|V_b\|$ in P.U	$\angle V_b$ in rad.	$\|V_c\|$ in P.U	$\angle V_c$ in rad.
1	1	0	1	-2.094	1	2.094
2	0.9915	-0.002	0.9931	-2.096	0.9933	2.091
3	0.9891	-0.003	0.9901	-2.096	0.9909	2.090
4	0.9877	-0.004	0.9886	-2.097	0.9902	2.089
5	0.9867	-0.003	0.9876	-2.097	0.9892	2.089
6	0.9880	-0.003	0.9920	-2.095	0.9915	2.091
7	0.9859	-0.003	0.9900	-2.095	0.9896	2.091
8	0.9855	-0.003	0.9919	-2.095	0.9905	2.091
9	0.9810	-0.003	0.9903	-2.096	0.9908	2.092
10	0.9782	-0.003	0.9885	-2.096	0.9911	2.092
11	--	--	0.9880	-2.096	0.9911	2.092
12	0.9745	-0.004	--	--	--	--

13	--	--	0.9872	-2.096	--	--
14	0.9874	-0.003	0.9934	-2.095	0.9894	2.091
15	0.9884	-0.003	0.9944	-2.095	0.9903	2.091
16	--	--	--	--	0.9882	2.091
17	0.9855	-0.003	0.9919	-2.095	0.9905	2.091
18	0.9872	-0.003	0.9875	-2.096	0.9875	2.09
19	0.9861	-0.003	0.9860	-2.096	0.9877	2.09
20	--	--	0.9836	-2.096	--	--
21	--	--	--	--	0.9835	2.09
22	--	--	--	--	0.9811	2.09
23	0.9865	-0.003	0.9869	-2.097	0.9896	2.089
24	0.9865	-0.003	--	--	0.9889	2.089
25	--	--	0.9812	-2.098	--	--

CONCLUSION

In this paper a 3-ϕ unbalanced radial distribution power flow algorithm which can handle multiple DGs is presented. The impact of DGs on the system voltage profile has seen. It is basically a Forward Backward Sweep based method which requires dynamic data structure (DDS) to store the details of a branches of RDS and PV node sensitivity matrix to find the reactive current injections at the PV nodes. The proposed method has good convergence property for any practical distribution networks with practical *R/X* ratio.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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