A practical three-phase Power Flow Algorithm for Ungrounded Distribution Networks with Wind Generators

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Abstract

This paper proposes a balanced line parameters and ungrounded distribution networks three-phase power flow with Wind generators (WGs). By using the characteristic of none zero sequence current in the ungrounded distribution networks, this paper establishes three–phase impedance matrix of line, load power, capacitor and WGs models based on the given measured data. The Newton method is used to get the three-phase power of load. Then the three-phase power calculation model of distributed generation node is given. Finally the forward/backward power flow of phase-coordinate method is presented. Different distribution systems are adopted to test the accuracy and practicality of the proposed algorithm.

Keywords

distribution network, three-phase power flow, forward/backward power flow algorithm.

1. Introduction

The calculation of distribution power flow equation is the basic of distribution modeling and simulation. The distribution networks have two operations style. One is general neutral grounding state of transformer; the other is neutral ungrounded state of transformer [1, 2]. The three line parameters are symmetrical in reference [1, 2]. The give measures are total power of three phases and two phase current in reference [1, 2]. Now the references [3-16] about three phase power flow calculation are almost for neutral grounding networks in distribution systems. The algorithm cannot be used for ungrounded networks.

The three-phase load is resolved into positive/negative sequence power and coupling power in reference [17]. Thus decoupling three phase power flow into sequence component power flow. The three phase power flow can be obtained by just finding the positive and negative sequence power flow. But each phase power that cannot be got in reference [1, 2] must be given. Reference [18] establishes the model for PQ, PV and slaving node according to the fact that zero sequence current is 0 in a neutral ungrounded system. Then a three phase power flow model with injection current form was developed for a neutral ungrounded system. Newton-Raphson method was used to solve the presented model. But the real measures in reference [1, 2] are not dealt. The Newton-Raphson method is not efficiency for three phase power flow calculation in a large distribution network.

This paper proposes a practical algorithm for the ungrounded networks. The component model is given in section II. The algorithm is given in section III. The tests and results are given in section IV. The conclusions are given in section V.

2. Detail component model

2.1 Model of feeder.

Z_l is the impedance matrix of fig.1. Z_l is $n \times n$ complex matrix. n is the phase number. Z_l is expressed as following:

$$Z_l = \begin{bmatrix} Z_{aa,l} & Z_{ab,l} & Z_{ac,l} \\ Z_{ba,l} & Z_{bb,l} & Z_{bc,l} \\ Z_{ca,l} & Z_{cb,l} & Z_{cc,l} \end{bmatrix} \quad (1)$$

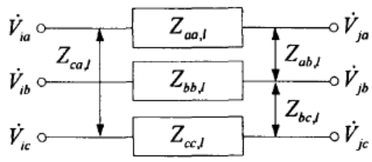

Fig.1 Feeder model

There is no zero sequence current in ungrounded distribution networks. There is no zero impedance also. If the three-phase circuit parameters are Symmetrical, the line phase parameters in (1) is calculated by positive sequence impedance and Negative sequence impedance of line.

$$Z_l = T\begin{bmatrix} Z_1 & 0 & 0 \\ 0 & Z_2 & 0 \\ 0 & 0 & 0 \end{bmatrix} T^{-1} = \begin{bmatrix} 2Z_1 & -Z_1 & -Z_1 \\ -Z_1 & 2Z_1 & -Z_1 \\ -Z_1 & -Z_1 & 2Z_1 \end{bmatrix} \quad (2)$$

Where

$$T = \begin{bmatrix} 1 & 1 & 1 \\ a^2 & a & 1 \\ a & a^2 & 1 \end{bmatrix}, \ a = e^{j120^0}; Z_1 = Z_2$$

2.2 Load Model.

Load model is shown in Fig.2. The given variables are P_Σ, Q_Σ, and current magnitude of any tow-phase. For example I_a and I_c are given.

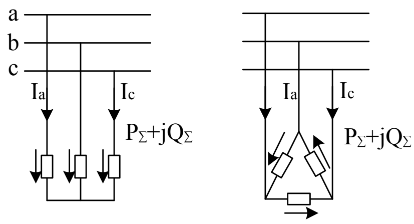

Fig. 2 Load model in ungrounded network

Three phase power and two phase current satisfy the following equation:

$$\begin{cases} P_\Sigma = P_a + P_b + P_c \\ Q_\Sigma = Q_a + Q_b + Q_c \\ \left|\dfrac{P_a + jQ_a}{e_a + jf_a}\right| = I_a \\ \left|\dfrac{P_c + jQ_c}{e_c + jf_c}\right| = I_c \end{cases} \quad (3)$$

Where P_a, P_b, P_c and Q_a, Q_b, Q_c are real and reactive power in three phase respectively. I_a and I_c are the magnitude of current in A and C phase. e_a, f_a and e_c, f_c are the voltage of the real part and imaginary part at A and C phase.

According to the situation that there are no zero sequence current in ungrounded network, the sum of three phase current must be zero.

$$\frac{P_a + jQ_a}{e_a + jf_a} + \frac{P_b + jQ_b}{e_b + jf_b} + \frac{P_c + jQ_c}{e_c + jf_c} = 0 \tag{4}$$

Where

e_b and f_b are the real part and imaginary part of phase voltage at node B.

The following equation is obtained by the combination of (3) and (4).

$$\begin{cases} P_\Sigma = P_a + P_b + P_c \\ Q_\Sigma = Q_a + Q_b + Q_c \\ \dfrac{P_a e_a + Q_a f_a}{e_a^2 + f_a^2} + \dfrac{P_b e_b + Q_b f_b}{e_b^2 + f_b^2} + \dfrac{P_c e_c + Q_c f_c}{e_c^2 + f_c^2} = 0 \\ \dfrac{Q_a e_a - P_a f_a}{e_a^2 + f_a^2} + \dfrac{Q_b e_b - P_b f_b}{e_b^2 + f_b^2} + \dfrac{Q_c e_c - P_c f_c}{e_c^2 + f_c^2} = 0 \\ \dfrac{P_a^2 + Q_a^2}{e_a^2 + f_a^2} = I_a^2 \\ \dfrac{P_c^2 + Q_c^2}{e_c^2 + f_c^2} = I_c^2 \end{cases} \tag{5}$$

Equation (5) must be satisfied in the ungrounded network. If the node voltage is given, Equation (5) is a nonlinear equation set. The variables P_a, P_b, P_c and Q_a, Q_b, Q_c can be calculated by Newton iteration. The initial values for P_a, P_b, P_c and Q_a, Q_b, Q_c are equal to $P_\Sigma / 3$ and $Q_\Sigma / 3$ respectively.

2.3 Shunt capacitor Model.

The shunt capacitor model is like load model. The difference is there is no real power equation in equation (5).

Wind generators model as PQ node.

If WGs are regarded as PQ nodes, the real and reactive powers are obtained according to wind speed forecasting. The detailed processes are as follows.

1） The total real power $P_{T,\Sigma}$ of WGs are calculated according to wind power curve. The slip ratio s is calculate according to speed control law；

2） The total power of the stator $P_{s,\Sigma}$ is calculated by the equation $P_{s,\Sigma} = P_{T,\Sigma} /(1-s)$;

3） Each phase power factor is equal to total power factor. The equation is as following. $\cos\varphi = \cos\varphi_a = \cos\varphi_b = \cos\varphi_c$ .The equation for calculation each phase power is as following.

$$\begin{aligned} & P_{s,\Sigma} = P_{s,a} + P_{s,b} + P_{s,c} \\ & Q_{T,a} = Q_{s,a} = P_{s,a} \tan\varphi \\ & Q_{T,b} = Q_{s,a} = P_{s,b} \tan\varphi \\ & Q_{T,c} = Q_{s,a} = P_{s,c} \tan\varphi \\ & \frac{(1-s)P_{s,a} e_a + Q_{T,a} f_a}{e_a^2 + f_a^2} + \frac{(1-s)P_{s,b} e_b + Q_{T,b} f_b}{e_b^2 + f_b^2} \\ & + \frac{(1-s)P_{s,c} e + Q_{T,c} f_c}{e_{Tc}^2 + f_c^2} = 0 \\ & \frac{Q_{T,a} e_a - (1-s)P_{s,a} f_a}{e_a^2 + f_a^2} + \frac{Q_{T,b} e_b - (1-s)P_{s,b} f_b}{e_b^2 + f_b^2} \\ & + \frac{Q_{T,c} e_c - (1-s)P_{s,c} f_c}{e_c^2 + f_c^2} = 0 \end{aligned} \tag{6}$$

Where

$P_{s,a}, P_{s,b}, P_{s,c}$ and $P_{s,a}, P_{s,b}, P_{s,c}$ are real and reactive power for each phase of stator ,respectively. $Q_{T,a}, Q_{T,b}$ *and* $Q_{T,c}$ are reactive power for each phase in WGs.

4）Each phase real power is calculated by the equation $P_{T,abc} = P_{s,abc}(1-s)$.

2.4 Wind generators model as PV node.

If WGs are regarded as PV nodes, the real and reactive powers are obtained according to wind speed forecasting. The detailed processes are as follows.

1）The total real power $P_{T,\Sigma}$ of WGs are calculated according to wind power curve. The slip ratio s is calculate according to speed control law;

2）The reactive power for each phase is calculated according the algorithm in reference [5].

3）The real and reactive power for each phase of WGs are calculated by equation (5).

2.5 The flowchart of algorithm.

Based on the forward/backward distribution power flow algorithm, the flowchart of the proposed algorithm is as following.

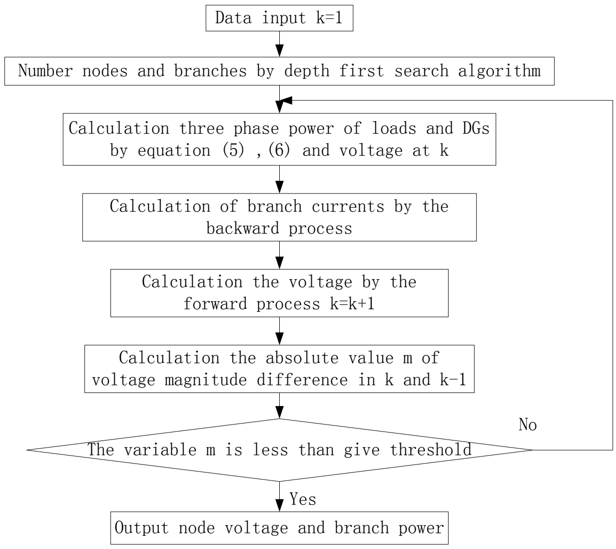

Fig. 3 Flowchart of algorithm

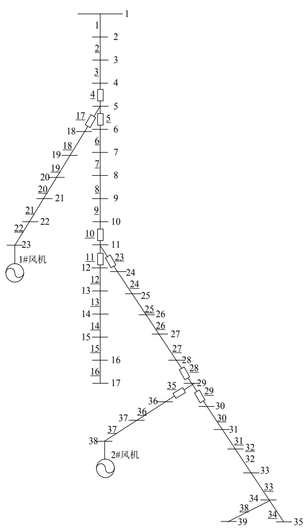

Fig. 4 A real distribution network

3. Test and analysis

A practical distribution network is shown in Fig.4.The detail parameters can be find in reference [19].

3.1 Calculation without WGs

Assume that there are no WGs in Fig.4. The partly power flow results are given in Tab.1.To verify the accuracy of the proposed algorithm, Tab.1-4give the results of comparison between the calculated values and measurement value. The comparison result shows the accuracy of the proposed algorithm.

Table 1 Voltage comparison results

Measurement type	Voltage magnitude(kV)		
	Node 5	Node 11	Node 29
Calculation value of VAB	10.40	10.34	10.32
Measurement value of VAB	10.39	10.337	10.319
Calculation value of VBC	10.40	10.33	10.32
Measurement value of VBC	10.391	10.314	10.317
Calculation value of VCA	10.40	10.33	10.32
Measurement value of VCA	10.392	10.315	10.316

Table 2 real power comparison results

Measurement type	Real power (Mw)		
	Phase A	Phase B	Phase C
Calculation value of branch 5	1.447	1.351	1.438
Measurement value of branch 5	1.45	1.35	1.44
Calculation value of branch 17	0.62	0.56	0.63
Measurement value of branch 17	0.621	0.557	0.632
Calculation value of branch 29	0.38	0.35	0.38
Measurement value of branch 29	0.381	0.349	0.379

Table 3 reactive power comparison results

Measurement type	Reactive power (Mvar)		
	Phase A	Phase B	Phase C
Calculation value of branch 5	0.32	0.27	0.20
Measurement value of branch 5	0.316	0.265	0.192
Calculation value of branch 17	0.14	0.10	0.07
Measurement value of branch 17	0.144	0.09	0.077
Calculation value of branch 29	0.08	0.07	0.05
Measurement value of branch 29	0.083	0.067	0.056

Table 4 Current comparison results

Measurement type	Current (kA)		
	Phase A	Phase B	Phase C
Calculation value of branch 5	0.142	0.132	0.140
Measurement value of branch 5	0.1422	0.1322	0.1403
Calculation value of branch 17	0.061	0.055	0.060
Measurement value of branch 17	0.0607	0.0545	0.0597
Calculation value of branch 29	0.037	0.034	0.036
Measurement value of branch 29	0.0367	0.0341	0.0358

Table 5 Error of iterations

Iteration number	1	2	3
Minimum error of voltage(p.u.)	0.037727	0.00004115	0.000005967

The proposed algorithm is convergence in three times iteration. The calculation time is 0.15 second. So the proposed algorithm is robust and efficiency.

3.2 Calculation with WGs

A WG with capacity is 800kW is connected at node 23 in parallel in Fig.4. It is regarded as a PQ node. The power factor is 0.95. Prediction of wind speed is 6m/s. The real power output is 0.732MW. The slip ration is 0.132. A WG with capacity is 1500kW is connected at node 38 in parallel in Fig.4. It is regarded as a PV node. The objective voltage is 10.4kV at node 38. Prediction of wind speed is 8.3m/s. The real power output is 0.732MW. The slip ration is 0.072. The reactive power range is in [-0.83, 0.68] Mvar. The detail parameter can be found in reference [20].

Tab.6 gives the three phase power of the two WGs.

Table 6 Three phase power of the two WGs.

WG number	Real power			Reactive power		
	A	B	C	A	B	C
1#	0.251	0.238	0.243	0.0825	0.0782	0.0798
2#	0.256	0.281	0.297	-0.23	0.33	0.35

Fig.5 gives the comparison of voltage between with WGs and without WGs.

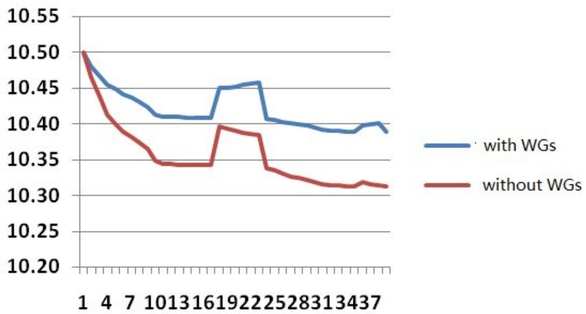

Fig.5 Voltage curve comparison

It is can be shown that the voltages are improved by adding the WGs.

4. Conclusion

The aim of this research work has been to propose a method to solve the three phase power flow calculation in ungrounded distribution networks. The test systems show the good results. The algorithm results are precise. The forward/backward power flow algorithm ensures the robust and efficiency of the proposed algorithm. Considering the results obtained, the algorithm can be used in commercial programs.

Acknowledgements

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