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Random Power Flow Calculation of Distribution System based on Distributed Generation

Vanrun Verman*

Bangladesh University of Engineering and Technology, Bangladesh

**corresponding author*

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Abstract: In recent years, distributed generation(DG) has been widely introduced into energy systems. It can not only solve the problem of insufficient security and stability of large-scale energy grid, improve system reliability, but also reduce construction and operation costs and reduce environmental pollution. However, wind power generation, solar power generation and other power generation methods that rely on natural conditions will produce random changes in output, resulting in the system voltage exceeding the limit. On this basis, this paper studies and analyzes the stochastic power flow(PL) calculation of DG and distribution system(DS). A stochastic PL algorithm is proposed. The experimental results show that the stochastic PL calculation of DG and DS is very important to improve the quality of power supply.

1. Introduction

The calculation of PL distribution in power system is an important step to determine the location planning of power grid, which is directly related to the safe operation of power grid. Whether the calculation of PL distribution is accurate or not has a great impact on the safe and economic operation of power system. The traditional PL calculation method assumes that the topology structure and parameters of the power grid are determined, and based on this, the PL calculation of the power grid is carried out. However, in the actual operation of the power grid, the topology and parameters of the system are changing all the time because of the switching of components, the change of load power and the switching of lines. In addition, with the acceleration of national investment in smart grid construction, more and more distributed power sources are incorporated into the grid. Because of the randomness of the output of the DG, the PL of the power grid is more difficult to predict. Since the original assumption that the topology and parameters are constant cannot be established, new methods must be studied to calculate the PL of the system.

Many scholars at home and abroad have studied and analyzed the stochastic PL calculation of DG DS. Alemazkoor n's research shows that the distribution network is generally closed-loop design and open-loop operation. In the case of power grid equipment maintenance, accident exception handling and maximum demand regulation, it is necessary to transfer the load in the closed loop. However, the forward push back method cannot handle the distribution network with the loop. When the PL calculation is carried out for the distribution network with ring, the ring network is opened at the middle of the tie line to form two new virtual nodes. The injection current of the virtual node is obtained through the equivalent impedance of Thevenin and the voltage difference of the virtual node, so that the processed network is completely equivalent to the original ring network, and the conclusion is drawn that it is not necessary to judge the accuracy of the voltage difference of the virtual node, which can reduce the time of PL calculation [1]. Sharma s k et al. Applied the ring network processing method and PV node processing method to the actual elbow line 115 for verification, that is, assuming that the output of the distributed power supply is constant and the load in the distribution network is constant, while the load in the actual distribution network is constantly changing, and the output of the photovoltaic power generation system(PGS) will change with the solar intensity [2].

This paper briefly analyzes the concept of DG model, focuses on photovoltaic power generation, and discusses the actual output characteristics of photovoltaic PGS; The mainstream stochastic PL algorithms including analytical method, simulation method and approximate method are analyzed. This method applies the stochastic PL algorithm based on the semi invariant method on the basis of establishing the stochastic model of distributed power generation, and uses the combination of photovoltaic PGS and energy storage device to improve the stability and power quality of the power system; Finally, the stochastic PL algorithm is used to calculate the PL of the radial distribution network after the DG is connected. The results show that the half invariants of the node voltage are significantly improved after the DG is added [3-4].

2. DG Model

Distributed power generation refers to the installation of some environmentally friendly, low-power, several kilowatts to 50MW power generation facilities near the customers on the basis of the current distribution network technology without affecting the economy of the distribution network. Due to its advantages of environmental friendliness and sustainable and stable power supply, its grid connection technology has been rapidly developed. Before the PL calculation of the distribution network after the DG is connected, it is necessary to convert the DG into the PL calculation model while considering the output characteristics of the DG [5-6].

2.1. Photovoltaic Power Generation

The solar energy that the earth can obtain in a year is tens of thousands of times the energy required by mankind. However, due to the extremely low efficiency of the current photovoltaic panels in converting solar energy into electric energy, the photovoltaic power generation covers a large area and causes a large amount of land waste [7-8]. The photovoltaic greenhouse scheme proposed in recent years places the photovoltaic panel on the greenhouse and applies it to practice, effectively saving land resources.

Photovoltaic PGS model:The maximum voltage output by a single photovoltaic panel is about 600mV. When the photovoltaic power generation is connected to the grid, multiple photovoltaic panels must be connected in series and parallel to form a photovoltaic array to play the role of voltage stabilization and boosting. The structure of the grid connected photovoltaic PGS is shown in Fig. 1.

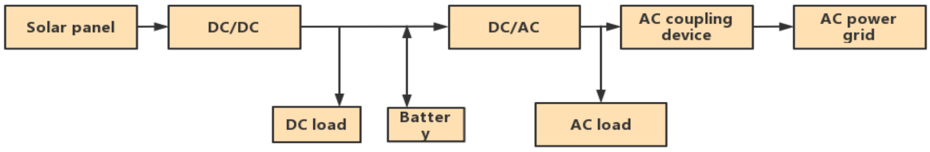

Figure 1.Composition of photovoltaic PGS

2.2. Actual Output Characteristics of Photovoltaic PGS

The solar radiation intensity belongs to natural factors and cannot be controlled by human beings. The change of weather will cause the fluctuation of the output of the photovoltaic system. If the photovoltaic system is directly connected to the grid, the fluctuation of its output will inevitably affect the power quality of the grid [9]. In order to solve the above problems and make full use of natural resources, the energy storage device can be connected to the photovoltaic system: absorb part of the electric energy output by the photovoltaic system at noon on a sunny day; At night or on cloudy days, the energy storage device releases electric energy. The specific charging and discharging time of the energy storage device also needs to be determined according to the historical change law of the grid load. The combination of the photovoltaic PGS and the energy storage device can improve the stability and power quality of the power system [10-11].

3. Random PL Calculation Algorithm for DG

In the actual power system operation, the PL of the system is difficult to determine due to the load change, equipment maintenance, line fault and other factors. So scientists try to express the change of PL with the method of probability theory, and use the corresponding mathematical tools to calculate the system PL. This method is calledRPF calculation. Also called probabilistic PL calculation. It uses random variables to represent the state parameters of each node, and then obtains the PL distribution of the whole system [12-13]. The classical PL algorithm assumes that the network topology is unchanged and the input energy of each node is also unchanged, so as to obtain a fixed value.

However, due to the influence of various random factors in the system, probabilistic PL algorithm can more accurately represent the operation characteristics of the power grid. Probabilistic PL calculation can obtain the probability distribution of all line power and node voltage [14]. So we can have a comprehensive and systematic evaluation of the whole system and give a timely warning of the defects found. The decision-making department can make corresponding planning and adjustment based on these data. With the advancement of electric power reform and the large number of DGS entering the network, the PL in the system will become more and more difficult to determine [15]. This makes probabilistic PL calculation more and more important. The results of probabilistic PL calculation can be expressed by the following data:

Probability distribution, expectation and maximum value of PL of all lines; Probability distribution, expectation and maximum value of on load transformer power.

The expected and maximum value of the node voltage; Expected maximum value and probability distribution of generator output; Probability of system cracking.

Since 1973, B Since borkowska first proposed the concept of probabilistic PL, after decades of development, the algorithm has become increasingly perfect. From the earliest DC model to the later linearized AC model, the active power can only be analyzed and the active and reactive power can be calculated. At present, the mainstream stochastic PL algorithms are analytical method, simulation method and approximation method. This paper will select the most commonly used methods from these three categories for analysis [16-17]. At the same time, this paper expounds their advantages and disadvantages, and proposes a new algorithm - Empire competition algorithm based on heuristic algorithm. Through the simulation experiment of standard ieee33 node, the practicability of the method proposed in this paper is demonstrated by the experimental data and waveforms [18].

3.1. Analytical Method

The analytical method is calculated by convolution. Because the calculation of convolution is too large, the semi invariant method is generally used to calculate convolution, and a special series is used to expand random variables.

(1) Linearization of node power equation

According to the power system analysis, the power equation of the node is:

$$p_i = H_j \sum_{j=1}^{n} H_J (K_{ij} \cos\alpha_{ij} + D_{ij} \sin\alpha_{ij}) \tag{1}$$

$$G_i = H_i \sum_{j=1}^{n} H_j (K_{ij} \sin\alpha - D_{ij} \cos\alpha_{ij}) \tag{2}$$

Where PI and GI respectively represent the active and reactive power injected into node I. Hi and α I represents the amplitude and phase of the voltage at node I. Kij and DIJ are the real and imaginary parts of the elements in the admittance matrix.

R represents the total injection of the node, including active and reactive power. X is the state variable, including the amplitude and phase of the voltage. When the probabilistic PL algorithm is used for calculation, both R and x represent random variables. It can be expressed by the following formula:

$$R_0 + \Delta R = f(X_0 + \Delta X) = f(X_0) + J_0 + \Delta X + ... \tag{3}$$

3.2. Semi Invariants

A semi invariant is a variable that describes the numerical characteristics of random variables and can be obtained by the moments of each order. The mathematical relationship between them and the moments of each order is expressed by the following formula (the first four orders are taken for calculation):

$$\begin{aligned} \delta_1 &= \mu_1 = m \\ \delta_2 &= \mu_2 - \mu_1^2 \\ \delta_3 &= \mu_3 - 3\mu_1\mu_2 + 2\mu_1^3 \\ \delta_4 &= \mu_4 - 3\mu_2^2 - 4\mu_1\mu_3 + 12\mu_1^2\mu_2 - 6\mu_1^4 \end{aligned} \tag{4}$$

Wherein, δ Represents a semi invariant, and μ represents the moment of a random variable. Through observation, we can find that the first-order semi invariant is the expectation of the random variable. And the second-order semi invariant is the variance of the random variable. The calculation flow of semi invariantRPF algorithm is shown in Fig. 2.

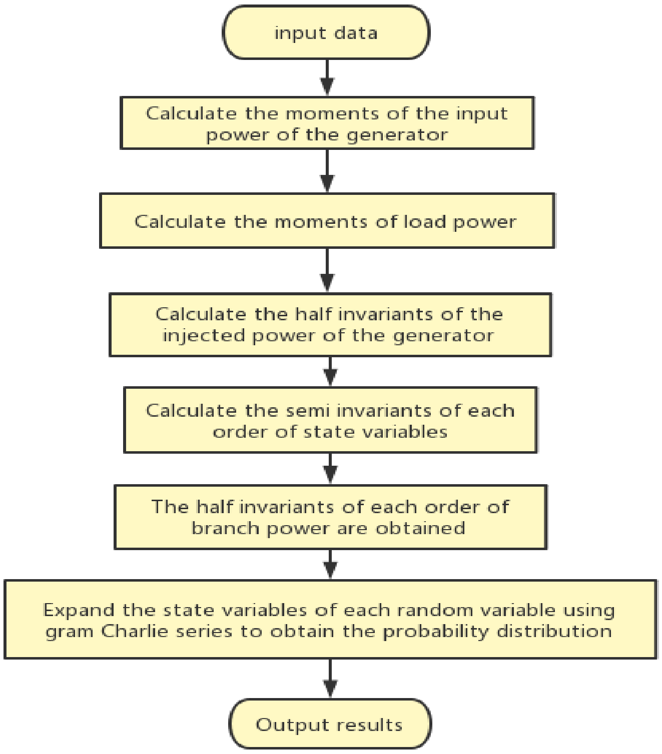

Figure 2.Flow chart of semi invariantRPF calculation

4. Random PL Calculation of DS based on DG

The demand of users for electric energy in the distribution network will change with time. It is not comprehensive to only consider the operation state of the distribution network at a certain time. The load change in the distribution network generally conforms to the work and rest rules of human beings, and the load change curve can be drawn according to historical data; By measuring the data of solar radiation intensity and wind speed in a day, the daily change curve of the output of photovoltaic PGS and wind PGS can be drawn. The RPF algorithm is used to calculate the PL of the radial distribution network after the distributed power generation is connected every 15 minutes (due to the short existence time of the ring network, the static load has been considered). Because the calculated data are too much and the space is limited, this paper only selects the PL calculation results of three typical nodes in the distribution network for analysis, and draws their voltage daily change curves to visually express.

The reference capacity of the system is RB = 1mva. For convenience, the 24.9/4.16kv transformer of the original system is simplified into one line, and the voltage regulator in the original line is eliminated, so that the system is simplified into a voltage level. See Table 1 to table 2 for the original data of the calculation example.

Table 1. Random data table of node load

Node	Active load (p.u.)		Reactive load (p.u.)	
	expected value	Mean square deviation (%)	expected value	Mean square deviation (%)
1	1.910000E-02	5.220000E-02	9.870000E-03	5.220000E-02
3	5.290000E-03	1.650000E-01	2.740000E-03	1.650000E-01
8	1.300000E-04	8.700000E-02	7.000000E-05	8.700000E-02
9	1.130000E-02	7.500000E-02	5.840000E-03	7.500000E-02
10	1.490000E-02	1.050000E-01	7.710000E-03	1.050000E-01

Table 2. Ieee-34 node line original data sheet

Start node	End node	Resistance (p.u.)	Reactance (p.u.)	Susceptance (p.u.)
0	1	2.030825E-03	8.953083E-04	9.0000E-07
1	2	1.361754E-03	6.003423E-04	1.0000E-06
2	3	2.536956E-02	1.118441E-02	1.1000E-05
3	4	4.596905E-03	2.026589E-03	2.0000E-06
3	5	2.951780E-02	1.301320E-02	1.3000E-05
5	6	2.340171E-02	1.031687E-02	1.0000E-05
6	7	7.871413E-04	3.470187E-04	0.0000E-00
7	8	2.440138E-04	1.075758E-04	0.0000E-00
8	9	1.346012E-03	5.934020E-04	5.0000E-07
8	10	8.036713E-03	3.543061E-03	3.0000E-06
9	11	3.790085E-02	1.670895E-02	1.6000E-05
10	12	6.611987E-04	2.914957E-04	2.0000E-07

The simulation results of this paper will be reflected in the form of phase angle, amplitude, power loss and flow direction of node voltage. It is not only accurately expressed in the form of tables, but also intuitively expressed in graphics. For the expected voltage value and mean square error data of each node of the system in the first day in case1, see Figure 3.

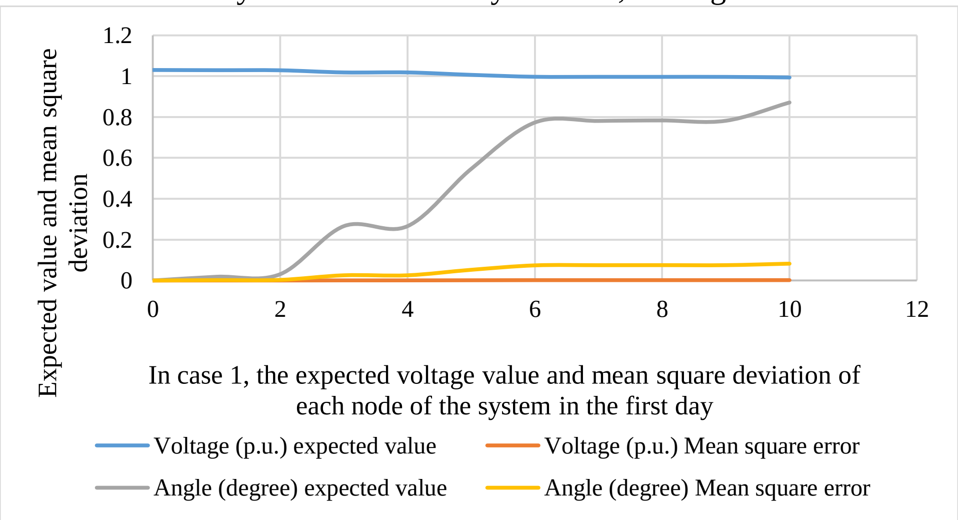

Figure 3. Expected voltage and mean square deviation of each node of the system in the first day

In the study of the impact of the random output of DG on the system in a day, it can be seen that the first-order half invariants of the node are the expected voltage value of the node. After the DG is added, the half invariants of each order of the node voltage are significantly increased. The change of the curve can also be seen that for the wind solar hybrid PGS, the voltage out of limit probability is also significantly reduced.

5. Conclusion

In this paper, theRPF calculation of distributed power DS is studied and analyzed, and the dynamic models of photovoltaic PGS and wind PGS are established. These distributed power sources are connected to the ieee36 system whose load changes at any time. Through PL calculation, it is concluded that distributed power sources are connected to the distribution network dispersedly to improve the power quality in the distribution network. Good results have been achieved. However, there are also some shortcomings. In the simulation experiment of the system, the load and various power mathematical models will be used. The characteristics of the components described by these mathematical models are somewhat different from the actual situation; In the simulation test, it is assumed that the system is in normal operation state, without considering the conditions such as open circuit or power withdrawal; Whether the proposed calculation process is simplified or improved remains to be further studied by peers. In the future, it is also necessary to conduct in-depth research on the PL changes of the system under fault conditions.

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Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

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