Reliability Evaluation of Microgrid with PV-WG Hybrid System

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Abstract—**This paper presents a research method of reliability of Microgrid. Firstly, according to different features between the traditional power sources and distributed power supply, the models of power generation reliability evaluation including wind power and solar power are established. Secondly, on the basis of the different operation modes and the importance of the loads, the reliability evaluation index of the sensitive load and non-sensitive load in Microgrid are identified in the condition of their component failure, the external power failure, the micro-source fault as well as in case of lack of micro-source and so on when the Microgrid connected to the great power network or running isolated. Finally, a case of a typical Microgrid system is exhibited. The effectiveness and feasibility of the transactions and optimization model are also overall demonstrated by this simulation.**

Keywords- Microgrid; Reliability; PV-WG

I. INTRODUCTION

With the development of new power generation technologies take advantage of efficient fossil fuel and renewable energy including wind power, solar and so on, distributed generation system(DGS) is becoming an effective way to meet the load growth needs, reduce environmental pollution, improve energy utilization efficiency and reliability. The superiorities comprising less investment, flexibility, compatible with the environment, etc., make DGS widely used in the distribution network. Paper [1] researched on the effect of simple distributed power on the reliability of low voltage distribution network, the results show that the access of DGS can improve users and even overall system reliability.

However, large-scale penetration of DGS has also had some negative effects, such as high cost and more complex control of stand-alone distributed generation access. In addition, from the perspective of power system, DGS is not controllable power generation unit, so the system always tries isolated or cut way to control the micro-power generation system to eliminate its voltage and frequency shocks to bulk system. At the time of system failure, DGS must be running out within2s which limits the operation mode of distributed power generation, weakening its strengths and potential [2]. For the integration of distributed generation advantages, decreasing its negative impact on the grid, full exerting the benefits and value of DGS, the relevant experts put forward the concept of Microgrid.

II. MODEL OF MICROGRID AND ITS RELIABILITY INDEX

A. *Microgrid Conception*

The Microgrid structure assumes an aggregation of loads and micro-sources operating as a single system providing both power and heat. The majority of the micro-sources must be power electronic based to provide the required flexibility to insure controlled operation as a single aggregated system. This control flexibility allows the Microgrid to present itself to the bulk power system as a single controlled unit, have plug-and-play simplicity for each micro-source, and meet the customers' local needs. These needs include increased local reliability and security. [3]

B. *Microgrid Structuer and Operation Mode*

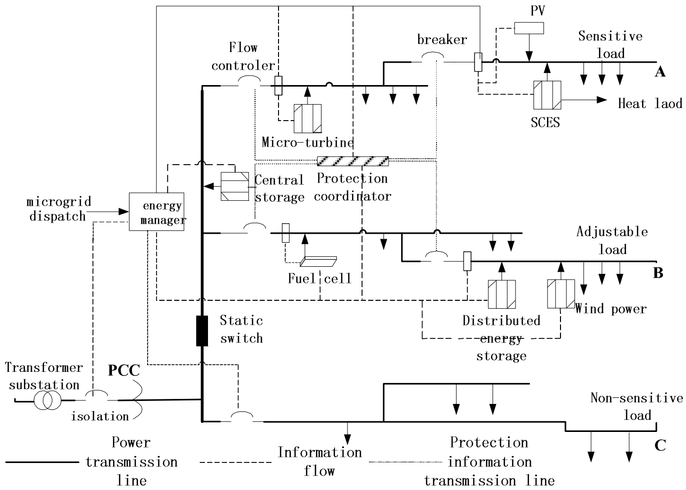

Figure 1. basic Microgrid architecture

Figure 1 illustrates the basic Microgrid architecture. The electrical system is assumed to be radial with three feeders – A, B, and C – and a collection of loads. The microsources are either microturbines or fuel cells interfaced to the system through power electronics. The Point of Common Coupling (PCC) is on the primary side of the transformer and defines the separation between the grid and the Microgrid.

The Microgrid can operate connected to the grid as well as smooth transition to and from the island mode is another important function. In Figure 1 there are two feeders with microsources and one without any generation to illustrate a wide range of options. During disturbances on the bulk power system Feeders A & B can island using the separation device (Static switch) to minimize disturbance to the sensitive loads. Of course islanding does not make sense if there is not enough local generation to meet the demands of the sensitive loads. The traditional loads on Feeder C are left to ride through the disturbance.

C. Microgrid reliability index with minimal path

Based on the above analysis of the Microgrid operation mode, A for the sensitive load, its failure in three cases:

1) component failure on itsminimal patch;
2) failed to isolated operation when external power failure;
3) the success isolated operation when the external power failure, , but the distributed power failure (as a second-order faults considered[4,5]).

Therefore, the failure rate can be expressed as:

$$\lambda_A = \sum_{i\in A}\lambda_i + P\lambda_{up} + (1-P)\sum_{i\in A}\lambda_{DG(i)}\lambda_{up}(T_i + r_{up}) \quad (1)$$

average fault outage time as:

$$r_A = \frac{\sum_{i\in A}\lambda_i r_i}{\sum_{i\in A}\lambda_i} + \mathrm{P}\frac{\lambda_{up}r_{up}}{\lambda_{up}} + (1-P)\sum_{i\in A}\frac{T_i r_{up}}{T_i + r_{up}} \quad (2)$$

average annual outage time as

$$U_A = \lambda_A r_A \quad (3)$$

Where:

λ_i and r_i respectively are the failure rate and repair time of component on the minimum path of load A;

λ_{up} and r_{up} respectively are the failure rate and repair time of the network upstairs;

P is the probability of unsuccessful isolated operation;

$\lambda_{DG(i)}$ and T_i respectively are the failure rate and fault repair time of DG i.

C is for non-sensitive load, based on λ_A, its failure rate has to plus the probability that cut off this load due to lack of distributed power. $P_{L(i)}$ is the probability of the distributed power less than the whole load in the Microgrid.

$$\lambda_C = \sum_{i\in C}\lambda_i + P\lambda_{up} + (1-P)\sum_{i\in A\cup B}(1+P_{L(i)})\lambda_{DG(i)}\lambda_{up}(T_i + r_{up}) \quad (4)$$

III. RELIABILITY INDEX OF WIND POWER

A. Model of wind turbine power output

The curve that describes the relationship between wind turbine power output and wind speed is called wind turbine power curve. Figure 2 shows a typical wind turbine power curve, and its sub-function expression is:

$$p(v) = \begin{cases} 0, & (v \le v_{ci}) \cup (v \ge v_{co}) \\ \dfrac{P_R}{v_R^3 - v_{ci}^3}(v^3 - v_{ci}^3), & v_{ci} < v < v_R \\ P_R, & v \ge v^R \end{cases} \quad (5)$$

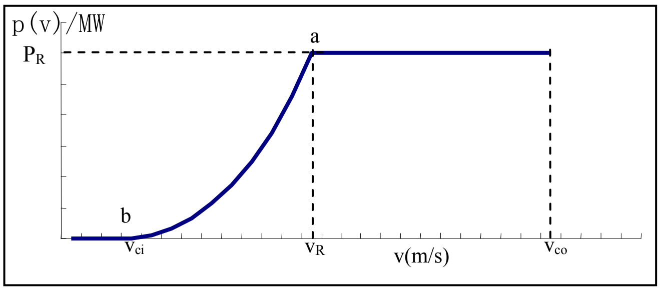

Figure 2. Curve of WTG electrical output

If the curve "a-b" in Figure 1 replaced by a straight line, the sub-function becomes:

$$p(v) = \begin{cases} 0, & (v \le v_{ci}) \cup (v \ge v_{co}) \\ P_R\dfrac{v - v_{ci}}{v_R - v_{ci}}, & v_{ci} < v < v_R \\ P_R, & v \ge v^R \end{cases} \quad (6)$$

Where: v is the wind speed at the height of the wind turbine hub; v_{ci} is cut in wind speed; v_{co} is cut out wind speed; v_R is rated wind speed; P_R is the rated output power.

B. Simulated wind speed model

There are many ways to simulate wind speed, mainly are time series analysis [6-7], two-parameter Weibull distribution [8] and Rayleigh distribution [9]. Statistical results of a large number of measured data show that in most of the regions, wind speed can be simulated using two parameter Weibull distribution. The distribution function is:

$$F_w(v) = P(V \le v) = 1 - \exp[-(v/c)^k] \quad (7)$$

Where: k is the shape parameter of Weibull distribution, reflecting the skew ness of the Weibull distribution, the value of 1.8 to 2.3, in general, take k = 2; c for the scale parameter, reflecting the average wind speed.

Random variables subject to the given distribution can be generated using random numbers. Commonly used method is inverse functional transformation. Inverse functional transformation method based on the following proposition: If the random variables obey the U [0, 1] uniform distribution, then the random variable $X = F^{-1}(U)$ has a continuous cumulative probability distribution function F(X). Based on the inverse functional transformation method, so that:

$$x = F(v) = 1 - \exp[-(v/c)^k] \quad (8)$$

So:

$$v = c[-\ln(1-x)]^{1/k} \quad (9)$$

1-x and x and are uniformly distributed random variables, so that 1-x can be replaced by x. The above equation becomes:

$$v = c[-\ln X_i]^{1/k} \quad (10)$$

Where Xi is uniformly distributed random variables.

The sample values of the hourly wind speed can be calculated by the equation above.

C. *Reliability index of wind power*

Using Weibull distribution to model wind speed applications, where c gets 8.03, k takes 2.02, characteristic equation of wind turbine power using equation (10), rated power of each turbine 1.2MW, impeller high 60m, cut in wind speed, cut out wind speed, rated wind speed take 3m/s, 25m/s and 12 m/s, respectively, wind speed is simulated and wind turbine power output calculated in 8760h. The results are shown in Figure 3 and 4.

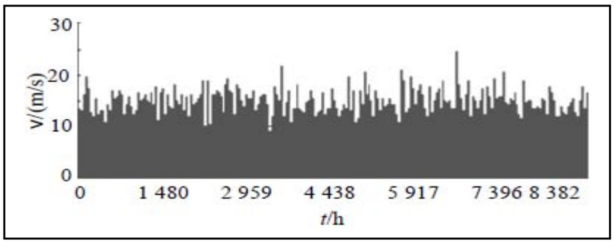

Figure 3. Weibull distribution simulation curve in 8 760 hours

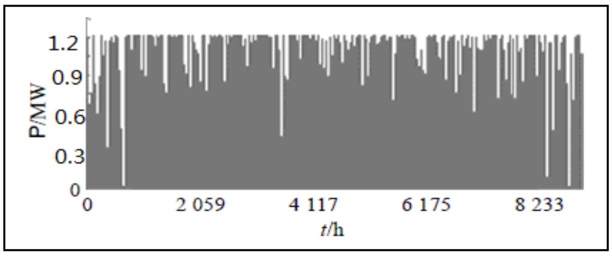

Figure 4. Wind farm electrical output curve in 8 760 hours

According to the statistics of wind turbine power output simulation, the probability distribution of wind turbine power output is shown in the table below:

TABLE I. WIND ENERGY AVAILABILITY AND THE PROBABILITY

% of Capacity	Probability
0	0.0933332
10	0.0162963
20	0.0192593
30	0.0222222
40	0.0251852
55	0.0059259
70	0.0118519
85	0.002963
100	0.802963

IV. RELIABILITY INDEX OF PV

A. *Model of PV power output*

PV is the technology that change light energy directly into electrical energy based on the photovoltaic effect of semiconductor interface. Due to the great influence of external factors (temperature, sunlight intensity, etc.), the output of the battery is obviously nonlinear.

It is difficult to measure the battery temperature. For glass - glass encapsulated solar modules; the battery temperature can be calculated according to the following empirical formula, by estimate the environmental temperature：

$$T_c = T_{amd} + 30 \times \frac{G}{1000} \quad (11)$$

Where: T_c battery components temperature; T_{amd} environmental temperature; G received solar radiation.

PV output power can be calculated according to the formula (12) [10-11].

$$P_{PV} = P_{STC} \frac{G_{AC}}{G_{STC}} (1 + k(T_c - T_\tau)) \quad (12)$$

Which, P_{STC} Maximum test power for the STC (standard test conditions: intensity of sunlight 1000W/m2, ambient temperature 25 □); G_{AC} to light intensity; G_{STC} light intensity for the STC 1000W/m2; k power-temperature coefficient of -0.0047 / □; T_c for the solar panels working temperature; T_τ as the reference temperature of 25 □.

B. *Reliability index of PV*

The randomness of sunshine intensity and photovoltaic battery operating temperature will produces certain impact on the reliability of the transmission system interconnection with solar power plant, which makes they are difficult to simulate. In this paper, the reliability indexes of PV are simulated with statistical data, the failure ratio is 5 times/a, and average fault repair time is 50 hours.

V. EXAMPLE

Without considering the energy manager and power flow controller, the typical Microgrid architecture shown in Figure 1 can be simplified as shown in Figure 5. Pursuant to formula (1)~(4), the reliability index of sensitive load A and non-sensitive load C are be calculated. In this simplified model, PV is only available for load A.

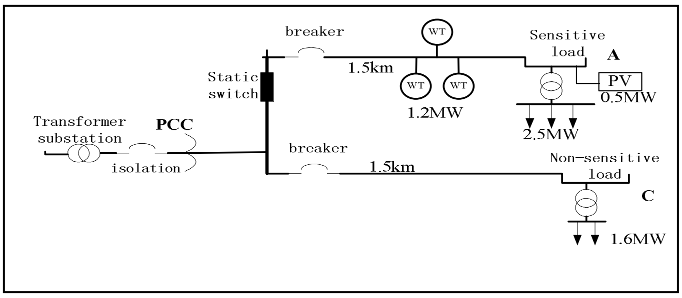

Figure 5. Simplified Microgrid model

The probability of the successful isolated operation is determined by different control method. According to [3], take 0.7 for this value. For non-sensitive load C, the probability of load-cutting when the distributed generations are not enough in isolated operation mode is determined by probability of energy available shown in TABLE I. Equipment parameters are shown in TABLE II.

TABLE II. EQUIPMENTS RELIABILITY INDEX

EQUIPMENT	failure rate	average fault outage time(h/t)
breaker	0.025(t/a)	2
line	0.05(t/km·a)	4
substation	0.015(t/a)	30
Distributed generation	5(t/a)	50
Bulk system	5(t/a)	10

The reliability index of the load in Microgrid are calculated and shown in TABLE III. The results show that Microgrid can reduce the load on power outages, increase the reliability of power supply to the load.

TABLE III. RELIABILITY INDEX OF THE LOAD IN MICROGRID

reliability index	load A	load C	load in normal grid
failure rate(t/a)	1.7862	1.8174	5.1150
average fault outage time(h/t)	15.7899	16.8527	16.9565
average annual outage time(h/a)	28.2039	30.6281	86.7325

VI. CONCLUSION

The Microgrid technology that integrates distributed generation systems, energy storage device and load together is an effective way to solve the problems of large-scale distributed power generation system to network. Based on two operation modes of Microgrid and different types of loads, the reliability model of Microgrid is established and the reliability index of this network including wind power and solar are calculated using a minimal path method. However, with improved control, the change of the Microgrid operation mode has various effects on the network reliability. Meanwhile, how to determine the model of micro-sources and energy storage devices in order to simulate the failure rate is up to us to further study.

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