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The impact of large-scale distributed generation on power grid and microgrids

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ABSTRACT

With the widespread application of distributed generation (DG), their utilization rate is increasingly higher and higher in the power system. This paper analyzes the static and transient impact of large-scale DGs integrated with the distribution network load models on the power grid. Studies of static voltage stability based on continuous power flow method have shown that a reasonable choice of DG's power grid position will help to improve the stability of the system. The transient simulation results show that these induction motors in the distribution network would make effect on the start-up and fault conditions, which may cause the instability of DGs and grid. The simulation results show that modeling of distributed generations and loads can help in-depth study of the microgrid stability and protection design.

1. Introduction

A large number of DGs connected with the power grid will make a certain effect on all aspects of power system operation. Voltage stability is also an important aspect which has become one of the important research topics in the smart grid development [1–4].

Researchers have used different methods to construct a variety of stability index to study the voltage stability problem [5–9]. Voltage stability analysis includes two parts: the static stability and dynamic stability. The indicators measuring static voltage security and stability are as follows: various types of sensitivity index, the Jacobi matrix singular index, the minimum modulus eigenvalue index, distance index between the multiple solutions of flow in the load space, threshold voltage index and margin index ΔP, ΔQ and ΔV [10]. Among them, the margin index with good linearity is widely used in power system stability analysis.

Dynamic stability analysis of distribution network with DGs should consider a large number of induction motor loads in the distribution network. The load model is critical to the study of dynamic stability on the power grid as well. In particular, the transient stability problem of the rotation type DGs must be taken into account after power grid commits fault. If the power system becomes unstable after a fault, not to remove the DGs will take a negative impact on it. For example, the induction generator would absorb a large amount of reactive power from the system so as to causing the system voltage to drop. Generally it requires removing the DGs if the power grid faults occur.

From a control theory point of view, the power system is a very high-order multivariable process, operating in a constantly changing environment. Because of the high dimensionality and complexity of the system, it is essential to simplify assumptions and to analyze specific problems using the equivalent system model with right detailed-degree. This requires a good grasp of the characteristics of the overall system as well as its individual elements [11].

Reference [12] uses Newton Raphson power flow method to estimate the power system stability limit, it can give reasonable results, but may also cause convergence problems, and this method is very time-consuming. So its application is limited. Some scholars use parameter sensitivity to estimate the voltage stability [13]. Reference [14] calculates the voltage collapse critical point by an improved zero-eigenvalue method. Based on artificial neural networks method, reference [15] assesses the voltage security after the complex power system fault. Based on the above literatures this paper has improved the continuation flow method.

In order to study the static stability influence of DG on the power grid, firstly, it analyzes the power flow models of DFIG, PV, and battery storage, and then taking IEEE 30-bus system as an example. This paper uses an improved continuous flow method to obtain voltage stability limit point of the power gird with or without DG respectively, and analyzes the influence of the DG on load margin. Then, it discusses the dynamic effects on the microgrid in the case of motor start-up and power grid fault.

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2. Static voltage stability analysis of DG on the power grid

2.1. DG flow models

2.1.1. The power flow calculation model of the double-fed induction generator (DFIG)

The stator of DFIG is connected to the power grid, and its rotor provides the excitation current through bi-directional converter connected to the power grid. It realizes AC excitation of rotor side by controlling the converter to determine the frequency, amplitude and phase angle of rotor excitation current.

In this control mode, the running of wind turbines has four work zones: start-up zone, wind tracking zone, constant speed zone, and the constant power zone.

When stator voltage of DFIG is equal to the power grid voltage, the operation state of DFIG off the power grid with no-load and that of DFIG on the power grid with zero output power is the same, so its power grid control is a special case of the power decoupling control ($P = 0$, $Q = 0$). It can be processed as PQ node in the power flow calculation.

2.1.2. The power flow calculation model of solar power generation system

Under normal circumstances, the grid-connected PV systems only provide active energy to the power grid, namely convert the DC energy of the solar photovoltaic array to the AC energy with the same frequency and phase to feed to the power grid, ensuring that it has a high power factor. Therefore, in the power flow calculation solar power grid nodes can be processed as PQ nodes, or as PQ nodes with $Q = 0$ under the control of the MPPT [16–21]. During power flow calculation, the active power and current injected into the power grid of photovoltaic cells are constant values and the injected reactive power is as follows:

$$Q = \sqrt{I^2(e^2 + f^2) - P^2} \quad (1)$$

where P is the constant active power of output, I is a constant current injected into the power grid, e and f are the real and imaginary parts of the voltage at the DG nodes respectively. Calculating the real and imaginary parts of voltage in each iteration and the injected reactive power according to Eqn. (1), and then in the next iteration it is converted to PQ node.

2.1.3. The power flow calculation model of battery power system

Control of the battery is basically the same as that of a solar power generation system, the output DC voltage is converted to AC voltage so as to connect to network. The difference is that the battery can be not only used as the power source of the power grid but also used as the load on the power grid. The equivalent circuit of fuel cell connected with power grid shown in Fig. 1.

In Fig. 1, U_{Fc} is the output DC voltage of the fuel cell, R_{FC} is the equivalent resistance of the fuel cell, m is the modulation index of the inverter, ψ is the lead angle of the inverter, U_{ac} is inverter output AC voltage of the inverter, X_T is the equivalent impedance of the transformer, Us is the bus voltage of network, δ and θ are the phase angle of voltage, with the relationship of $\psi = \delta - \theta$.

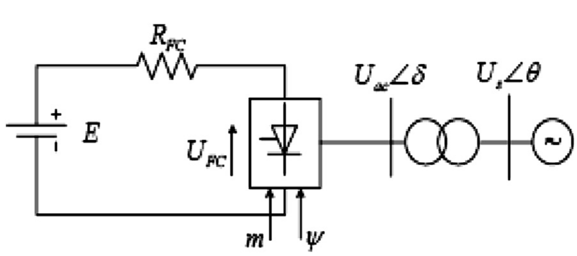

Fig. 1. Equivalent circuit of storage battery connected power grid.

Since $U_{ac} = mU_{Fc}$, combined with the equivalent circuit diagram of the fuel cell on the power grid, we can derive the following relation:

$$P = \frac{U_{ac}U_s}{X_T}\sin(\delta - \theta) = \frac{mU_{FC}U_s}{X_T}\sin(\psi) \quad (2)$$

$$Q = \frac{mU_{FC}U_s}{X_T}\cos(\psi) - \frac{U_s^2}{X_T} \quad (3)$$

The output active power of the fuel cell can be adjusted by controlling the parameter ψ, the output reactive power of batteries can be adjusted by controlling m, which is similar to the active power and reactive power regulation principle of conventional generator. So it is usually regarded as a PV node in the power flow calculation.

Given that Rated active power of the converter output is P_N, the minimum power factor is $\rho_{\min}$, and then the maximum capacity of the converter is:

$$S_{\max} = P_N/\rho^2 \quad (4)$$

Now the maximum reactive power of converter output corresponding to the active power P is:

$$Q_{\max} = \sqrt{S_{\max}^2 - P^2} \quad (5)$$

The fuel cell in the normal operating does not require absorbing reactive power from the power grid. It can be considered that the minimum reactive power is 0. If the reactive power of the battery node is exceeding the boundary, it can be processed as a PQ node, and reactive power injected is the upper or lower limit of the output reactive power.

2.1.4. The flow calculation model of the microturbine power generation system

The general working principle of microturbine is similar to the synchronous generator, with the speed control system and excitation system. Because the microturbine has a high rotational speed and the alternator has a very high frequency, its output is high frequency AC power [22]. It should supply load with the AC power which has stable output voltage and rated frequency by electronic converter.

So microturbine is processed as the PV node, similar to the approach of battery.

2.2. Static voltage stability analysis of power grid with DG

After the DG incorporating into distribution network, the radial structure of distribution network will become the multi-power structure, which may cause the system nodal voltage to change. The voltage of traditional radial distribution network under steady-state operation is gradually reduced along the direction of the power flow of the feeder. After DGs connecting with the grid, due to the reduction of active power on the feeder and reactive power support of DGs, the all load nodal voltage along the feeder are increasing with different degrees. Thereby it enhances the carrying capacity of distribution network. However, if the location of the DG is on the power grid node of the substation, it can only enhance the total capacity of the substation, but cannot improve the load bearing capacity of the distribution line. Therefore, the influence of