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Application of ETAP in distributed power supply and micro-grid interconnection

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Abstract—**With the development of the global economy, the demand for energy is getting higher and higher and the advantages of the distributed power generation technology and micro-grid are more and more prominent. The author refers to the model of wind, light and micro-grid in a certain island in China, and uses ETAP to design the micro-grid model. Combined with the models in ETAP (wind turbine model, photovoltaic and photovoltaic inverter model, energy storage model, gas generator generation model, user-side load, industrial system load, cable transmission line model, transformer model, etc.), simulation analyses of micro-grid system under different operating conditions are carried out, including transient analysis of the micro-grid in grid-connected operation and transient analysis of the micro-grid system under external power network fault and recovery operation in grid-connected state. The simulation results have practical significance for real engineering.**

Keywords—distributed power supply; micro-grid; micro-grid interconnection; low voltage ride-through simulation; wind power generation; photovoltaic; ETAP

I. INTRODUCTION

In recent years, smart grid has become a research hotspot and focus in the field of energy. micro-grid is an important part of smart grid. micro-grid is a new type of network structure, which is composed of a set of micro power supply, load, energy storage system and control device. The micro-grid can be operated in parallel with the external power grid or on an isolated network. For distributed energy sources such as photovoltaic, gas, wind power, biomass energy, and geothermal energy, their advantage is that they can be used for power system peak regulation and they help improve the reliability of power supply, so they're a very economical choice in remote areas. Distributed power supply has been widely used as a new type of power distribution structure and micro-grid has gained wide attention due to its advantages of small pollution, high energy efficiency, low consumption of power transmission and distribution resources and low operating costs. An accurate reference on the design of micro-grid system and parameters test are provided by using ETAP to analyze the different operating states of the micro-grid system so as to make the micro-grid system stable, economical, safe and flexible. Based on the power grid wind storage micro-grid project in a certain region of China, the author studies the operating state and model characteristics of the system. At the same time, through the analysis process of electromechanical transients, the process of micro-grid interconnection, external power network fault and malfunction clearing are simulated, and the accurate analysis of distributed energy and the further analysis and demonstration of micro-grid interconnection technology are achieved.

II. INTRODUCTION OF ETAP APPLICATION SOFTWARE FOR POWER SYSTEM ANALYSIS AND CALCULATION

ETAP (Electrical Transient Analysis Program) is an international commercial software for analysis and calculation of power and electrical systems, which was officially developed by ETAP in 1983. It is a comprehensive and integrated power and electrical analysis and calculation software, including more than 50 functional modules such as power flow calculation, short circuit calculation, motor starting, and transient stability, thus providing a comprehensive and powerful solution from planning to design, from analysis, calculation, simulation to real-time operational control for power generation systems, transmission systems, power distribution systems, micro-grid systems and industrial power electrical systems. The author applies power flow analysis, renewable energy, transient stability and other modules of ETAP simulation software and the functional expressions in each module are very intuitive and easy to understand. The simulation modules of various electrical components and power equipment required for building wind farms and photovoltaic models are very vivid, and the model is built by dragging directly with the mouse, making the operation very convenient.The data representation of the ETAP simulation software is also very straightforward. Once the distribution network model is built, the data of each part is directly expressed in the model and the simulation results of each part can also be given in the form of a report when the simulation analysis is carried out.

In summary, the ETAP software is used to combine the simulation model with the theoretical analysis to make the results more scientific.

III. MAIN POWER EQUIPMENT SIMULATION MODELS AND PARAMETERS

A. Equivalent power grid model

The equivalent poewr grid model established by ETAP is a constant voltage source with impedance. The load flow analysis only requires the equivalent power grid bus voltage and phase angle while for transient stability analysis, an equivalent motor is required to simulate the equivalent power grid (external network equivalent system). Usually, the equivalent power grid is treated as a point in a large power grid, and its voltage and frequency are essentially constant, so the equivalent power grid is supposed to have a constant internal potential and an infinite inertia. In this way, according to Thevenin's theorem, the equivalent grid of ETAP is equivalently replaced,[2] as shown in Figure 1 equivalent circuit diagram:

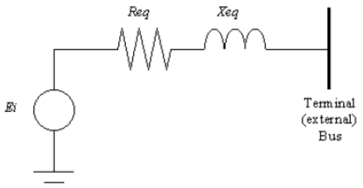

Figure 1.equivalent circuit model diagram of equivalent power grid

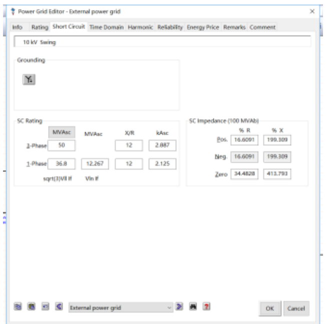

Figure 2.parameters of equivalent power grid short-circuit page

The equivalent power grid parameters in this model are as follows. The three-phase short circuit capacity is 50MVAsc,and for X/R is to calculate the internal resistance of the equivalent grid, specifying three-phase and single-phase (line-to-ground) fault short circuit MVA, the parameters are shown in Figure2. When MVAsc or X/R is entered or modified, ETAP will recalculate the corresponding short circuit impedance value. The three-phase and single-phase (line-to-ground) fault current short-circuit MVA are calculated as follows:

$$MVA_{3p} = \sqrt{3} \times KV \times I_{3P} \tag{1}$$

$$\text{sqrt（3）} V11If\text{：} MVA_{1P} = \sqrt{3} \times KV \times I_{1P} \tag{2}$$

$$V1\text{n If：} \mathrm{MVA}_{1P} = (KV \div \sqrt{3}) \times I_{1P} \tag{3}$$

B. Model of generator

ETAP offers five different synchronous generator models for transient stability analysis. These complex models range from simple equivalent models to excitation voltage models including salient machines, damper windings, and variations. These models are equivalent model, hidden polar machine transient model, convex machine transient model, hidden pole machine transient model, convex machine sub-transient model and frequency-based model. This analysis employs a microturbine with a rated power of 100 kW and a hidden current generator with a rated voltage of 0.4 Kv, a power factor of 85%, and a 95% efficiency.

C. Model of synchronous motor

The synchronous motor can operate at an advanced power factor by adjusting the excitation current, which helps to improve the power factor of the grid. Therefore, large-scale equipment, such as blowers, pumps, compressors, and the like, are commonly driven by synchronous motors. The circuit model and load model of the synchronous motor at start-up are the same as those of the induction motor. The secondary transient impedance model and the excitation system control model are similar to the synchronous generator. This analysis uses two synchronous motors with a rated power of 300 KW and a power factor of 90%.

D. Energy storage model

Energy storage is an essential element in micro-grid, which plays an important role in the operation and management of micro-grid and it has obvious effects.

a) Realize power control between micro-grid and grid tie line

b) As the main power source, maintain the stability of voltage and frequency when the power grid is off-grid

c) Provide fast power support for micro-grid and realize flexible switching of grid-connected and off-grid operation modes

d) Participate in the optimal management of micro-grid energy to realize the economical and efficient operation of micro-grid[6]

A common battery model is used in ETAP, and its transfer function parameters can be edited in the ETAP software's user-defined model. The energy storage model is connected to the power grid through the inverter. When large disturbances occur, the system can quickly provide power support, realize flexible switching under different operating conditions, and improve system stability.The energy storage inverter adopts the control mode of the balance node, and sets its control voltage range from 95% to 105%. According to the parameters of the grid-connected busbar, it can flexibly control the output force to achieve the purpose of maintaining system stability, energy storage and reverse the specific parameters of the transformer are as follows.

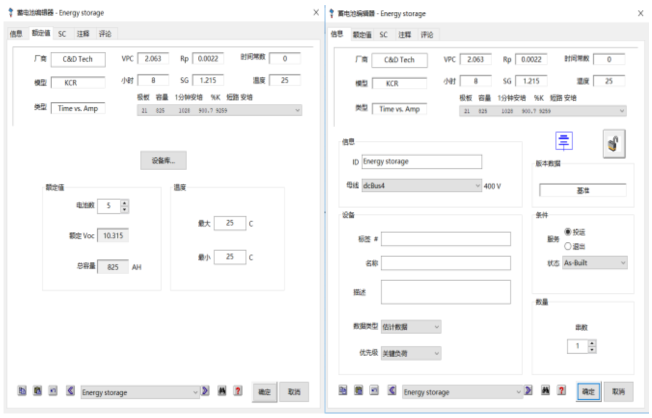

Figure 3.Energy storage model parameters

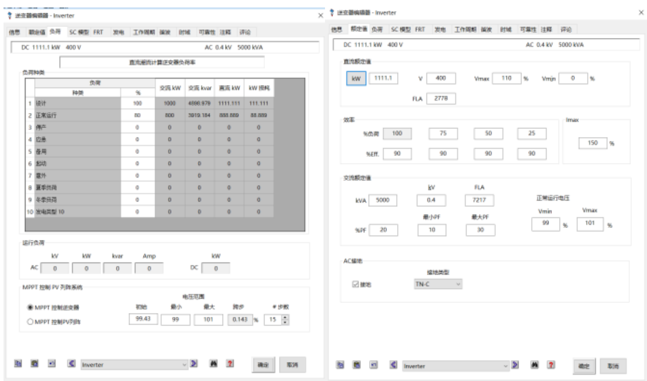

Figure 4.Energy storage inverter parameters

E. *Wind turbine model*

Wind turbine generator (WTG) selects Type 4, Direct drive permanent magnet synchronous generator set（PMSG）, Type 4 is a direct drive variable speed asynchronous generator with full converter interface. The control mode of the wind turbine is voltage control, and the WTG control type is WECC. The rated capacity of the wind turbine can be set according to the requirements. This simulation sets the capacity of the wind turbine to 0.25 MW per unit and performs comparative analysis. The rated voltage of the wind turbine is 0.6Kv; the rated power factor is set to 0.85; the rated efficiency is set to 0.95; the blade radius is 30m; the rated wind speed is 10m/s, and the wind turbine cut in and cut out at wind speeds of 4m/s and 25m/s respectively. Specific parameters are shown in Figure 5 and Figure 6.

Figure 5. wind turbine rating page

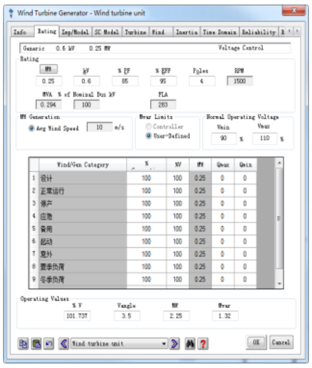

Figure 6.wind turbine page

F. *Photovoltaic (PV) model*

Photovoltaic arrays are an important component in new energy, micro-grid and smart grids. It uses a semiconductor to convert the radiant energy of sunlight into direct current and then convert it into electrical energy through an inverter. The ETAP PV array is used to indicate that a single panel is connected in series and connected in parallel to a grid to be connected to the inverter, which is represented as a photovoltaic power module.

In this micro-grid model, the photovoltaic panel model in the ETAP software equipment library is selected to form a photovoltaic array. The power of a single photovoltaic panel is 3.132 KW, and the maximum peak power voltage of a single panel is 400 V. Eight PV panels are connected in series and 8 PV panels are connected in parallel to form a photovoltaic array. The power of the photovoltaic array is 200.4 KW. The detailed parameters are shown below in Figures 7 and 8 and Figure 7 contains the PV and IV curves of the PV panels.

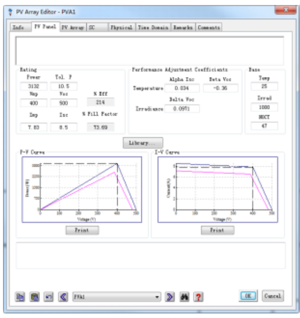

Figure 7. pv panel page parameters

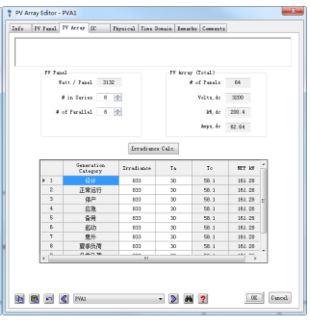

Figure 8. pv array parameter

IV. SYSTEM OVERVIEW

The simulation analysis in this paper takes the single line diagram of the system shown in Figure 8 as an example. There are two ways to operate the system. The first is to open the CB9 circuit breaker. The external power grid, factory load and the micro-grid system operate independently. The second is that the CB9 circuit breaker is closed, the external power grid is connected to the micro-grid system, and the micro-grid system runs in the grid-connected state. The cable parameters are selected from the cable model in the ETAP's own equipment library and users can also add according to their own needs. The direct-drive wind turbine with rated voltage of 0.6Kv. The wind turbine is boosted to 10 Kv by the step-up transformer T1 and then it is transmitted to the step-down transformer through the 5km cable Cable1 to the 0.4Kv user-side busbar. There are 3 photovoltaic PV arrays with a power of 200.4KW, and the PV panel transmits the electric energy through the cable to the 0.4Kv user-side busbar through the PV inverter. The entire micro-grid system can be powered by a step-down transformer T3 with a 10/0.4 step-down transformer connected to the plant system. There is also a factory load rated at 5 MVA, and the factory load uses the equivalent load in the ETAP for equivalent.

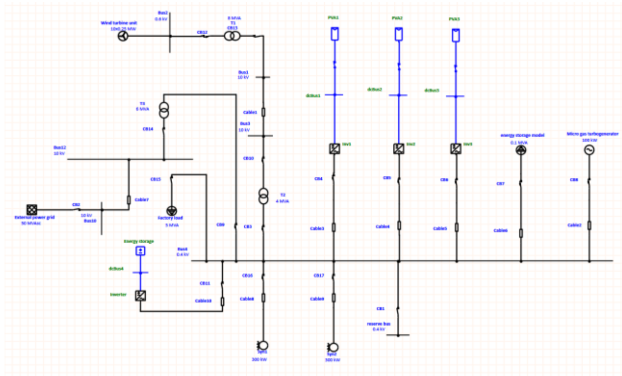

Figure 9.single line diagram of distributed energy micro-grid system established by using ETAP software

A. *Transient Simulation Analysis of External Network Faults during micro-grid Grid-connected Operation*

The total simulation time for setting transient events in ETAP software is 30s. The specific transient analysis event is set to: three-phase fault occurs in the external network at 0.5s, and the energy storage model is put into operation. The fault is cleared at 1.175s. Voltage recovery. Taking the grid bus Bus4 as an example, we can see the changes of the frequency and power distribution of the bus voltage before and after the fault. At the same time, the difference in the variation of the grid-connected busbars under the two conditions of input energy storage and no energy storage is compared..

Due to the largest scale of wind power generation and photovoltaic power generation, and the highest requirements in grid connection technology, the transient analysis module of ETAP is used to analyze the low voltage crossing of the established model. Different countries have different requirements for low voltage crossing, which will not be described here.

Low voltage ride through simulation of wind turbine：Through the ETAP software transient simulation module, compare the voltage curve of the wind turbine grid bus Bus4 when the energy storage model is put into use or not.

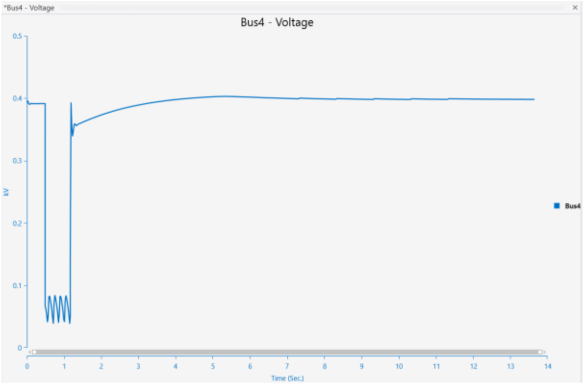

Figure 9.Voltage curve of grid bus 4 when there is no energy storage model

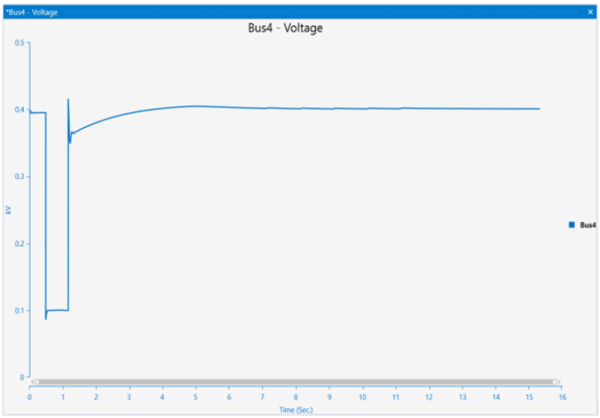

Figure 10.Voltage curve of grid bus 4 when there is energy storage model

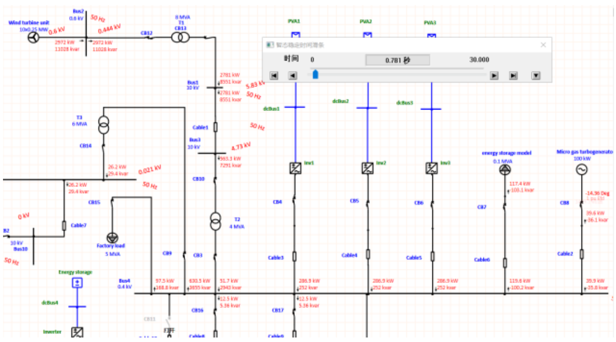

Figure 11.System parameters during transient analysis

Many countries in the world have made clear technical indicators for low voltage ride through technology, and will not go into details here. China's low voltage ride-through technology requires: when the power grid fault or disturbance causes the voltage of the wind farm to drop at the grid point, the wind turbine can run uninterruptedly in the range of voltage drop, and the wind turbine in the wind farm has when the outlet voltage drops to 20% of rated voltage, it can guarantee the ability of continuous operation without 625ms. When the voltage of the wind farm grid is restored to 90% of the rated voltage within 2s, the wind turbine in the wind farm can guarantee no. Off-grid continuous operation. For photovoltaic power stations, when the power grid accident or disturbance causes the voltage drop of the photovoltaic power station to be connected to the grid, within a certain voltage drop range and time interval, the photovoltaic power station can ensure continuous operation without off-grid, and through ETAP simulation analysis, The microgrid model can be verified for technical requirements.

B. *micro-grid grid-connected technology*

The supporting technologies of distributed power supply and micro-grid access distribution network are mainly divided into two major parts. One is distributed power grid-connected technology,and the other is micro-grid technology. Distributed power grid-connected is mainly for the specification of distributed power access capacity, access voltage level, power quality, power control, voltage and frequency response characteristics, protection, energy metering, and grid-connected detection. When distributed power generation is connected to the distribution network, in order to ensure the safe and stable operation of the distribution network, the corresponding operational requirements and specifications shall be met, including requirements of harmonics of power quality, voltage deviation, DC component, voltage regulation capability, etc. And requirements of distributed power analysis, protection configuration, and protection equipment for operational control and protection. [5]

Set the transient event at the 2nd second when the micro-grid system and the external network system are closed at the same time. Drag the time slider of the transient module to see the dynamic change of the system current in different time, check the bus voltage curve Bus4 of the grid connection point, and the voltage swells after the grid connection, then the voltage falls back. The voltage tends to be stable at 2.75s, and the voltage is as shown in Fig. 11, while viewing the active, reactive and frequency of the busbar 4. The change is shown in Figure 12.

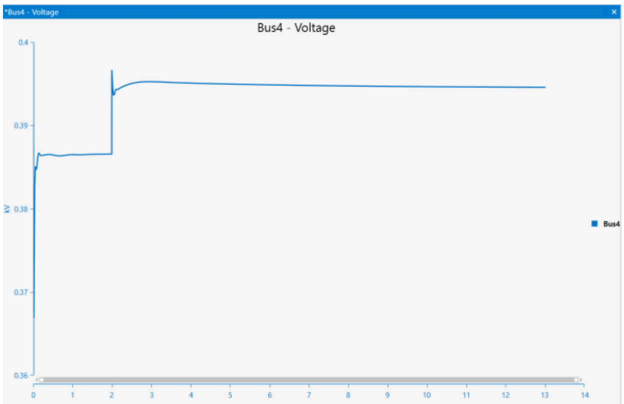

Figure 12.Bus4 voltage curve Bus

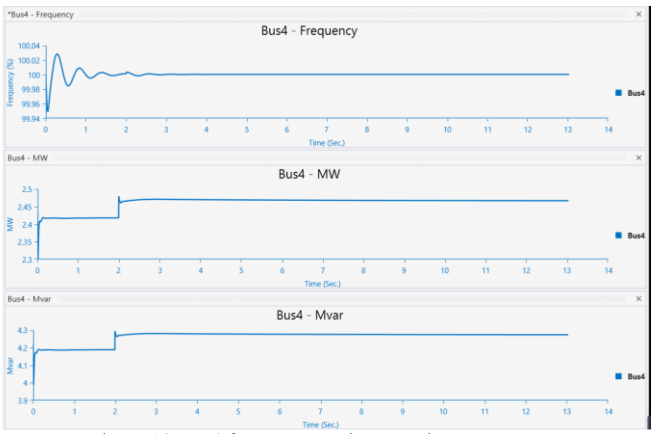

Figure 13.Bus4 frequency, active, reactive power curve

V. CONCLUSION

It is convenient to temporarily simulate several operating conditions of the micro-grid system by using ETAP. From the simulation results, the micro-grid system and the micro-grid grid-connected system can be accurately simulated. Whether it is an existing micro-grid system or the micro-grid system is in the design stage, the different working conditions, the influence of the micro-grid on the system can be checked. And whether the low voltage ride-through capability of the ind turbine and photovoltaic model meets the design requirements can be checked too.The simulation results show that the energy storage system can provide power support for wind power generation, photovoltaic power generation and energy storage microgrid system quickly when large disturbances occur, and realize flexible switching under different operating conditions of microgrid, which helps to improve the low voltage of the system. Crossing ability to improve system stability.

Using ETAP to study system transient stability is not only easy to operate, but also user-friendly, and can greatly improve the efficiency of system engineers for system analysis. It is an important tool for electrical engineers to analyze power systems.

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