Research on Multi-CPU Cluster Modeling and Real-Time Simulation Analysis of High Proportion Active Distribution Network

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***Abstract*—High proportion of renewable energy was increased in the distribution network, which will face complex grid complex test and show the scale the diversity and complexity of the operating state. So that the evolution of Wind-photovoltaic-energy storage(Wind-PV-ES) hybrid network transient process is not clear. In the other hand, Transient simulation tool plays a significant role in obtaining a full and detailed response under various operation conditions. However, the simulation capability and speed become limited with increased system size. In order to study the background of high proportion of Wind-PV-ES in the distribution network, this paper model Wind-PV-ES and its control system in the multi-CPU cluster fine-grained real-time simulation platform. The control system was further decoupled according to its topology. The multi-CPU can be easily realized, and the computation loads are balanced by DG modeling. The model is used to calculate the load balancing as the optimal condition to be decoupled by the distribution parameters. Parallel computing to ensure the accuracy of the transient simulation results and convergence effect and improve the simulation speed. Then this paper used two typical examples to realize the verification of Multi-CPU simulation results. The simulation results show that the simulation accuracy decreases with the increase of model computation, but the simulation speed is greatly improved. The result reflects the characteristics and transient characteristics of grid -connected transient operation. The effectiveness of the proposed method is validated in integrated simulation of distributed generation system.**

Keywords-wind-photovoltaic-batter storage modeling; multi-CPU cluster calculate; real-time simulation; distributed parameter decoupled model; transient grid process

I. INTRODUCTION

The environmental problems and energy shortages become increasingly prominent, to clean and sustainable new energy which will be vigorously developed. In order to coordinate the contradiction between the large power distribution network and the renewable distributed power supply, we can fully explore the value and benefit of the renewable energy source to the power distribution network. The distribution network now containing a large amount of high frequency power switches puts forward high requirements for the real-time simulation of hardware-in-the-loop of power system. The real-time simulation system simulates the distribution network, closer to the actual situation. Since few decades, fully digital real-time simulators have become essential for such studies [1], [2]. A first study has leaded to validate a Multi-Agent System implemented in real-time in that way [3], [4]. At the same time, through the power amplifier to the real photovoltaic, fan equipment into the distribution network, simulate the real network phenomenon. For the effective realization of distribution network energy management and optimization of operation, it is necessary to study real-time simulation for the testing and verification of distribution network control equipment and protection devices.

High proportion of renewable energy distribution network large-scale in the ordinary PC machine simulation is slow, simulation system easy to collapse simulation problem, the controller tuning cumbersome and other issues. The reason is due to the high proportion of the network structure. The network is closely linked、large scale、more nodes and multi-mode operation. On the other hand, a renewable energy power generation system is a complex nonlinear system with a large variables number of different time constants. Modern power electronic components develop toward the direction of high frequency, the switching frequency up to 700 kHz [5]. At least, a renewable energy power generation system is a dynamic system that includes transient and steady-state time scales, which presents a great challenge for its analysis and simulation. But also in the source-network-load different parts of the popularity of power electronic components continue to improve. The characteristic is different, leading to the transient characteristics of the power system which is difficult to use the existing classical theory to explain and analyze the power system stability mechanism.

In order to truly reflect the distribution network electromagnetic transient process, the simulation step should be short to microsecond, or even sub-microsecond [6], [7]. The basic idea is to decompose a complex large-scale computing task into a number of relatively independent small and medium-sized sub-computing tasks, and then assigned to the various computing nodes for parallel operation. Many researchers in the field of power systems have tried to theoretically explore how to parallelize transient stability simulations and analyze the theoretical feasibility [8]-[10] [11]-[13]. In this paper, multi-CPU and a variety of energy simulation combined with the practical application of fine-grained simulation platform modeling and simulation. Multi-

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CPU makes full use of its computing performance and running speed to real-time simulation of partitioned distribution network.

II. WIND-BAT-PV CONTROL SYSTEM MODEL

A. Description of the Wind-PV-ES Modeling

The aerodynamic model of the wind turbine, the mathematical model of the two-mass axis of the wind turbine and the generator, and the voltage equation and the flux linkage equation of the doubly-fed induction motor [14], [15] are described in detail in the relevant literature. DFIG integrated control system shown in Figure 3, contains two subsystems: the wind turbine control system and DFIG control system. The control of the wind turbine consists of a speed controller and a pitch angle controller. The speed controller provides the converter active power reference value Pref for controlling the power of the dots and the power controller of the doubly-fed rotor-side converter. When the wind speed exceeds the rated wind speed and wind turbine power exceeds its rated power, the pitch angle controller increases the pitch angle to limit the wind turbine active power. While the normal working state under the pitch angle of 0° . For reactive power control of the converter, the Qref of the rotor-side converter is set to a constant value for the degree of reactive power switching at the steady-state operation. The Qref of the grid side converter is set to 0, and the reactive power is not exchanged between the rotor and the grid during normal operation. The details are shown in the Figure 3.

This paper uses a single diode solar PV module model that meets the engineering application accuracy and is easy to simulate. Consider the solar radiation intensity and ambient temperature changes in the PV array U-I equation: [16], [17]

$$I = N_P^{PV} I_{sc} \cdot \left\{ 1 - C_1 \left[\exp\left(\frac{U - dU}{C_2 N_s^{PV} U_{oc}} \right) - 1 \right] \right\} + dI \tag{1}$$

$$\begin{cases} C_1 = \left(1 - \dfrac{I_m}{I_{sc}}\right) \cdot \exp\left(-\dfrac{U_m}{C_2 U_{oc}}\right) \\ T_c = T_a + t_c G \\ C_2 = \dfrac{\dfrac{U_m}{U_{oc}} - 1}{\ln\left(1 - \dfrac{I_m}{I_{sc}}\right)} \\ dI = -\alpha \dfrac{G}{G_{ref}}\left(T_c - T_{ref}\right) + \left(\dfrac{G}{G_{ref}} - 1\right) \cdot N_P^{PV} I_{sc} \\ dU = \beta dT - R_s dI \end{cases} \tag{2}$$

U_{oc} and I_{sc} are open circuit voltage and short circuit current which PV module manufacturers provide; U_m and I_m are the maximum power point voltage and current of the PV module; α and β are the current temperature variation coefficient and voltage temperature change coefficient based on the reference intensity; G is the solar radiation intensity; Ta is the ambient temperature; tc is the temperature coefficient of variation of PV modules; Rs is the series resistance of the component; $N_p^{PV}$and N_s^{PV} are the parallel number and the series number of the components in the PV array.

Photovoltaic power generation integrated control system shown in Figure 4. Photovoltaic power generation system control is divided into two subsystems: photovoltaic control system and grid-connected inverter control system. PV control system MPPT controller provides grid-connected inverter active power reference value Pconv. Inverter reactive power reference value Qconv according to the system power factor requirements set a certain value. Qconv is set to 0 generally. Power reference value is compared with the measured value, through the internal and external ring power control. Then controller gets trigger inverter pulse, combining with phase-locked loop measurement technology to achieve inverter active and reactive decoupling control and synchronous connected-grid. The details are shown in the Figure 4.

The energy storage pack mathematical model [18], [19] is

$$E = N_s^{ES} E_0 - \frac{KSOC}{SOC - N_s^{ES} Q_n \int_0^t i(\tau)\, d\tau} + A \exp\left(-B \int_0^t i(\tau)\, d\tau + C_p\right) \tag{3}$$

$$\begin{cases} SOC = \dfrac{N_s^{ES} N_P^{ES} Q_n - \int_0^t i(\tau)\, d\tau}{N_s^{ES} N_P^{ES} Q_n} \times 100\% \\ C_P = C_t\left(T_b - 25\right) \end{cases} \tag{4}$$

E is the electromotive force in the battery pack;E_0 is the initial internal electromotive force; K is the polarization voltage constant; A and B are the voltage variation coefficient and capacity variation coefficient; Q_n is the battery rated capacity; $i(t)$ is the charge and discharge current; SOC is the percentage of battery remaining capacity(charged state);C_t is the polarization effect coefficient; T_b is the battery temperature; N_s^{ES} and N_p^{ES} are the series and parallel numbers of batteries in the storage battery.

Energy storage system integrated control system shown in Figure 5, the overall control includes two subsystems: energy control system and grid-connected inverter control system. The battery controller detects its output status by monitoring the battery charge and discharge status. Grid-connected inverter control system voltage and frequency set point and measured value by the U / F controller to obtain the power controller active and reactive power reference value, through the power controller and the network side of the active and reactive measurement adjustment Provides