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Modelling of agricultural energy internet considering the integration of planting industry and new energy

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1 Introduction

The technology of energy agriculture is the key to rural development. Given the disadvantages of petroleum agriculture, rural electrification and the installation of new energy in rural areas have become the focus of attention in the field of new power systems. From the perspective of long-term development, the new energy industry will become an important supplement to the rural economy and an important channel for farmers to increase their income. A rural microgrid with new energy as the main body has become the development trend of rural energy systems, accompanied by the substitution of electric energy on the load side for petroleum and chemical agriculture.

Worldwide, photovoltaic power generation is developing rapidly. However, to further realize the transformation from supplementary power supply to main power supply, it is necessary to solve its volatility (Fu et al., 2020a). Due to the continuous increase in computing power, tools and data generation, the use of statistical machine learning technology is increasing in the operation and planning of photovoltaic systems (Fu, 2022). Power transmission cannot be realized in remote rural areas, so an independent photovoltaic power generation system has almost become a necessity, and it can also supply power for heterogeneous mobile networks in rural areas (Vinicius dos Passos Oliveira et al., 2020). Wind-solar complementary power generation system can provide a stable power supply by using the principle of wind-solar-power conversion in remote rural areas (Gabriel Filho et al., 2016). The technology of combined generation of wind power and small hydropower can effectively solve the problem of effectively reducing abandoned wind power (Pathak et al., 2019). Zheng and Huang presented an optimization strategy for rural water well pump power that realized water saving and energy saving (Zheng and Huang, 2016). Long et al. investigated rural electrification projects and showed the cutting-edge energy technologies in rural domestic energy consumption, planting energy consumption and fishery energy consumption (Long et al., 2022). The rural energy system is sensitive to weather conditions (Fu et al., 2020b). Solar radiation is the energy source of roof photovoltaics, and rural power load will also be affected by weather factors such as solar radiation and temperature. Agricultural energy internet (AEI) is a microgrid, which is considered a form of integrated development of modern agriculture and microgrid (Fu and Yang, 2022). With the increase in agricultural energy consumption intensity and rural renewable energy installation, rural microgrid has the conditions to develop virtual power plant technology (Ju et al., 2022). 5G has a great impact on the management of agriculture and energy systems (Tang et al., 2020). studied the impact of 5G on smart agriculture, and (Fu et al., 2021) investigated the impact of 5G on agricultural energy systems. The 5G era has opened a new space for the development of the Internet of things (IoT) (Zhang, 2022), which has a broad application scenario in the AEI. The development of wireless communication, IoT, smart grid, smart agriculture and other technologies has laid a technical foundation for the development of AEI, which is the future of rural microgrids.

The urgency of AEI research includes the following aspects. 1) Rural electrification should replace traditional oil agriculture and is a key factor in implementing the national food security strategy. 2) Power poverty alleviation supports China to implement the rural revitalization strategy. 3) China's agricultural power consumption is close to the traffic power consumption, but the power grid construction in rural areas is backward. 4) Water and soil loss in the Yangtze River and land desertification in Northwest China have seriously destroyed the agricultural environment. The technological development of agrivoltaic systems can not only solve the source of rural agricultural energy but also improve the local environment.

The agricultural electrification model established in the field of agricultural engineering regards the power system as a completely reliable power supply, which is not in line with the reality of power engineering. In terms of the rural power grid model established in the field of power systems, power generation and network models are very mature, but there has no accurate model of agricultural load. It can be concluded that the model research of the interaction between agriculture and energy systems is a blank field of the study of rural energy systems. The innovation of this paper is to give the framework and idea of unified modelling of AEI, considering the uniqueness of agricultural load, which can meet the dual requirements of the theoretical analysis of agriculture and energy system.

Modelling theory

Model architecture of an AEI for the planting industry

In the agricultural AEI, the deep coupling between agriculture and energy is realized between the facility agriculture and the energy system through the facility agricultural environment regulation load. We can regulate and control the light, thermal, water and gas environments of facility agriculture by controlling the lighting lamps, heat boilers, water pumps and fans. Renewable energy such as greenhouse photovoltaic generation and biogas generation is the primary power source of AEI. Micrometeorology has a dual impact on the power flows in an AEI. On the power side, micrometeorology such as solar radiation and ambient temperature are key conditions for photovoltaic and biogas generations. On the demand side, extreme weather will cause a sharp increase in the light and heat demand of crops, resulting in a surge in power and thermal loads. As shown in Figure 1, the AEI model is divided into four modules: the micrometeorology model, plants' growth model, energy load model and renewable energy model. Micrometeorology is the input of plants' growth model and renewable energy model, and plants' growth mode is the input of the energy load model.

The AEI can promote the integration and development of new energy and facility agriculture. However, the environment in facility agriculture is sensitive and fragile, and the new energy grid-connected power increases the risk of microgrid safe operation. Therefore, the AEI model needs to take into account the dual requirements of agriculture and energy for modelling. The AEI model can be written as the following formulas.

$$f_a(x_a, x_{a,c}) = 0 \quad (1)$$
$$f_c(x_{a,c}, x_{e,c}) = 0 \quad (2)$$
$$f_e(x_{e,c}, x_e) = 0 \quad (3)$$

where (1) stands for a plant's growth model, (2)stands for energy load model, and (3) stands for microgrid model consisting of load, source and other energy models; x_a stands for physiological state of plants, $x_{a,c}$ stands for to the facility environment required by plant production, such as facility light environment, facility water environment, facility thermal environment, etc; $x_{e,c}$ stands for the energy consumed by the maintenance of the facility environments, such as the electric power of artificial light, the electric power of water pump, and the heating demand, etc; x_e stands for the state variables in the AEI, such as the active power and reactive power of the electricity networks, and the flow rate of the thermal networks.

Modeling ideas in plant energy consumption

Agricultural load is a unique weather-sensitive load, which is closely related to solar radiation, ambient temperature, rainfall and other micro meteorological conditions. Based on the principle of material and energy conversion, we should first analyze the interaction mechanism of weather conditions,

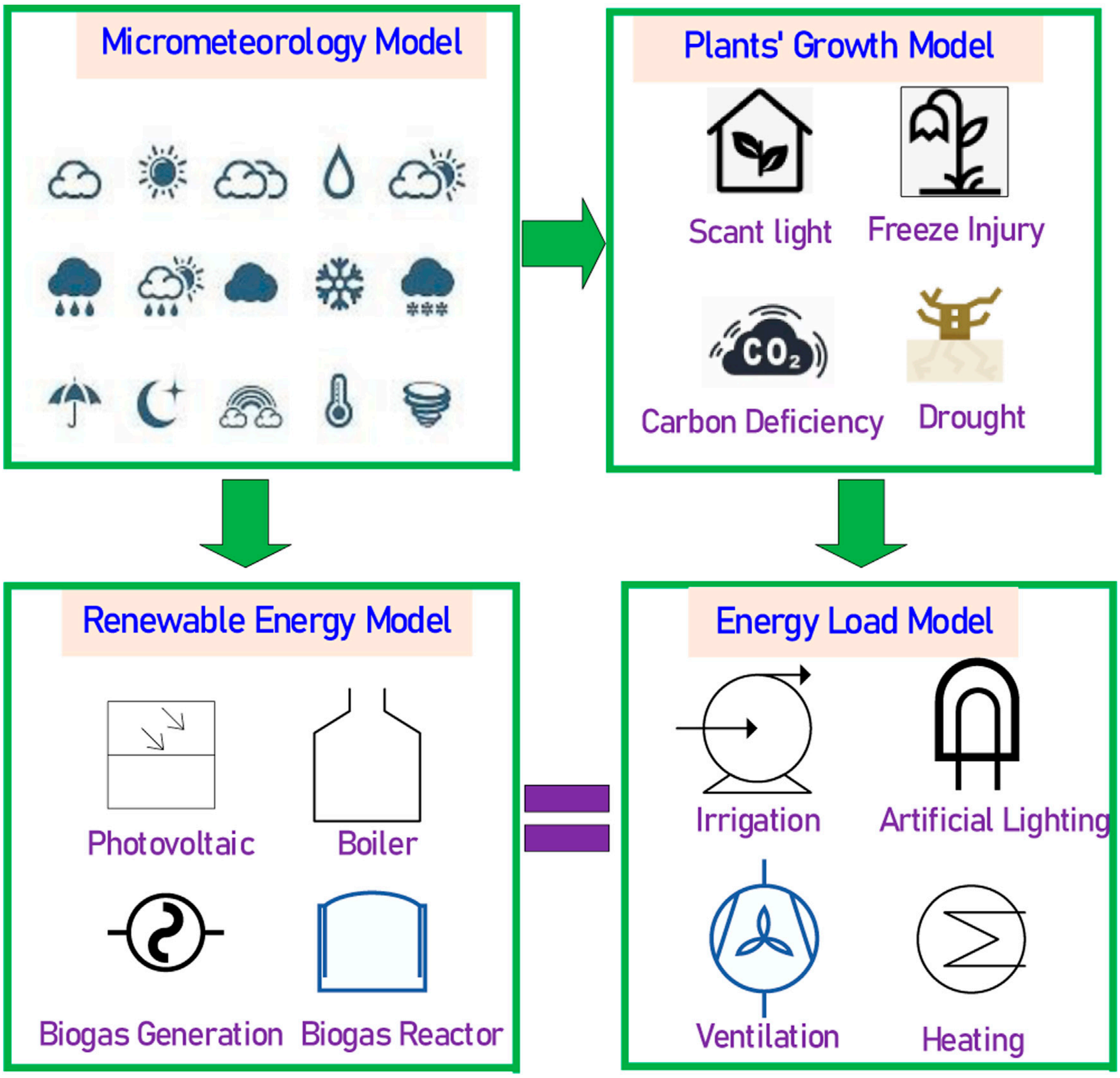

FIGURE 1
The model architecture of an AEI for the planting industry.

facility agricultural environment, crop growth and energy system, and then establish a crop growth model and agricultural load model. The specific modelling ideas are as follows. 1) The interaction mechanism between the facility agricultural environment and crop growth is analyzed, and then a crop growth model based on the principle of material balance in the agricultural ecosystem is established. The crop growth model takes light, temperature, water, and soil as environmental driving variables, and takes important ecological states such as photosynthesis, respiration and transpiration during the crop growth period as state variables. 2) Based on the principles of energy meteorology, agrometeorology and energy conservation, the dual effects of variations in weather conditions on the energy consumption in agricultural parks are analyzed. We establish the model of facility agricultural environment, with weather conditions and energy consumption of facility agricultural equipment as driving variables and facility agricultural environment as state variables. We should establish an artificial light load model, which can describe the relationship between the state of the facility's light environment, solar radiation, and the power consumption of lamps. We should establish a heating load model, which can describe the relationship between the state of the thermal environment of facilities, environmental temperature, and energy consumption of radiators. We should establish a power consumption model, which can describe the relationship between the state of the facility's water environment, rainfall, and irrigation load.

Discussion

Multiple-time-scale design and analysis

There is a great difference between the time scale of the plant's growth model and that of an energy system model. The time scale of the plant's growth model is a daily scale, but the electric energy propagates at the speed of light, which is at a millisecond scale. The pressure in the gas network propagates at the speed of sound, which is at a second scale. In the heating network, the temperature propagates with the flow rate of fluid, which is at a minute scale. How to reduce the impact of time-scale differences on physical models is one of the key scientific problems to be solved in the simulation of an AEI. We need to design different models for different systems and decompose the electricity, heating, gas networks and agricultural system into different speed models to adapt to the multi-time scale characteristics of AEI analysis and controls.

Interdisciplinary unified modeling and solution

The solution of joint solution of agricultural and energy equations for an AEI in a complex weather environment is a combinatorial explosion problem with strong nonlinearity, multi-time scale and multi-system comprehensive analysis. The interaction mechanism between the modern agricultural system and the energy system is complex, and weather changes cause a great disturbance to agricultural load and renewable energy power generation. The state of the energy system under a certain weather scenario can be solved by partial differential-algebraic equations, while the state variables of crops can be simulated via establishing partial differential-algebraic equations. The difference between the AEI model and the traditional power system model is that the partial differential equation part is added for the environment in facility agriculture. Establishing partial differential-algebraic equations with multiple-time scales and solving them uniformly is the key to the modelling and simulations of AEI. However, partial-differential algebraic equations are difficult to solve directly, so an effective numerical method needs to be proposed. Therefore, the establishment of partial differential-algebraic equations suitable for agricultural and energy systems and giving effective solutions are the key to solving an AEI.

Conclusion

With the continuous development of new energy capacity and agricultural electrification levels in rural areas, the energy structure and energy consumption mode of agricultural parks has undergone profound changes. The future trend of facility agriculture in the park is an intelligent greenhouse based on a power supply, rather than a simple greenhouse. It is particularly important to establish a systematic and rigorous AEI knowledge system in the area of rural electrification. There are great differences in composition and physical characteristics between agricultural and energy systems. In the process of modelling the coupling elements of agriculture and energy consumption, the original partial differential and differential equations in the field of agriculture and energy should be modified to meet the practical requirements of AEI analysis. The core contribution of AEI modelling is to give a novel load model to meet the needs of agricultural production, and agricultural load is completely different from the urban and industrial loads. The agricultural load model needs to reflect the demand of plant physiological characteristics for energy consumption.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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