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Forestry energy internet with high permeability of photovoltaic

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Introduction

The rapid development of the photovoltaic (PV) generation industry in recent years is due to the strong support from the policies of the governments of various countries, and the sharp drop in the economic costs of the PV generation industry chain brought about by its scientific and technological progress (Hansen et al., 2019). This has prompted many countries to choose PV generation to replace traditional, high-cost, thermal power generation, *etc.* To supply power to remote areas, it is necessary to establish a long-distance transmission line, which increases the energy loss of the line and is not conducive to the economic operation of modern power grids (Gabriel Filho et al., 2016). Solar radiation is the direct factor of PV power generation, and strong sunlight can guarantee power generation (Fu et al., 2020). Remote areas in China have good solar radiation conditions, such as Inner Mongolia, Tibet, Xinjiang, *etc.* If we make rational use of their solar energy resources and establish a microgrid with PV generation, we can greatly reduce the energy loss of the transmission line and meet the requirements of environmental power supply. However, photovoltaic power generation also has disadvantages, and the most important thing is that power generation cannot be reliably powered due to weather uncertainty (Fu, 2022). The most classical method to deal with PV uncertainty is to use the digital features in probability theory for uncertainty modelling, including mean value, variance, central distance and origin distance (Fu and Zhang, 2018). Energy storage is considered an effective technology to store the surplus power generated by PV systems (Debnath and Chatterjee, 2015), and the integration of PV projects should be equipped with a certain capacity of energy storage, which has become China's PV policy. Alam et al. (2014) presented an effective method for the control of the combination of PV and storage systems based on the ramp rate to reduce the uncertainty of PV power. von Appen et al. (2014) presented a novel voltage control for the control of the combination of PV and storage systems, and the local control benefits both the energy storage system and the power grid. When planning and designing the power grid, the impact of uncertainty of PV power generation on the economy and security can be considered, and statistical machine learning can be used to model uncertainty (Fu et al., 2022). In actual projects, the capacity of energy storage is configured according to the requirements of government documents. In China, the capacity of energy storage facilities is required to be no less than one-tenth of the PV installed capacity, and some provincial capitals require this ratio to reach one-fifth. Energy internet is dominated by renewable energy, providing theoretical and engineering support for the development of PV power generation (Ma et al., 2017). The level of electrification

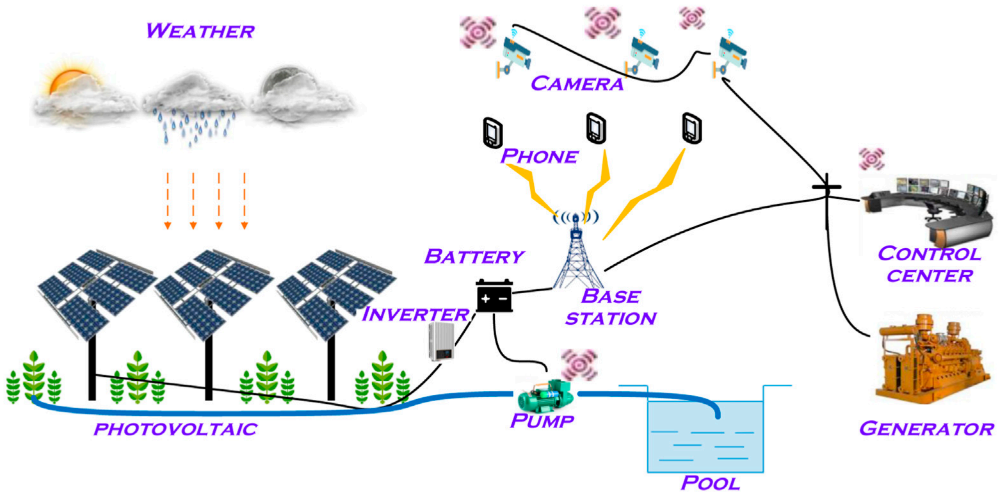

FIGURE 1
The architecture of a forestry energy internet.

of modern agricultural parks and agricultural processing enterprises is constantly improving, which puts forward higher requirements for the energy supply system. In this context, the agricultural energy internet has developed due to its clean, low-carbon energy sources (Fu and Niu, 2022). The land area occupied by PV power generation construction projects is often tens to hundreds of hectares. We should not only protect green water and green mountains but also develop economic construction. In the face of the practical requirements, the forestry-PV complementary becomes a feasible solution (Yu, 2018). The large-scale use of forest land in PV construction will cause a large-scale reduction in the national forest land area, which will pose a huge challenge to the national ecological security and the amount of forest land. The State Forestry Administration of China has specified the types of forest land that can be used for PV land occupation. The land use mode of "forestry-PV complementary" shall be adopted for the land, that is, determined to be suitable for forest land. It should be noted that, first, only the forestry-PV complementary mode can only be used, and second, the nature of forest land cannot be changed. The forestry energy internet (FEI) has become the key technology and development trend of "supporting the combination of PV power station construction, sand prevention and control, afforestation, *etc.*"

Forestry energy internet

Architecture of forestry energy internet

The architecture of the FEI is shown in Figure 1, which is mainly used to protect the security of forestry, and has the functions of monitoring, alarm, intelligent irrigation, *etc.* At the physical level, the water network and the power network are coupled. In terms of information physics, the Internet of Things provides control information for water networks and heat networks. The forestry information system can realize real-time continuous automatic monitoring and data transmission of ecological environments in complex environments by using sensors, computers, wireless communication and modern control technology.

The forestry microgrid takes PV power generation as the main body and uses batteries to store the remaining electric energy during the day to provide a reliable power supply for forestry. Forest fire is sudden and random, which can cause huge losses in a short time. The hydraulic system automatically sprays according to the temperature or dust concentration. The forestry microgrid takes PV power generation as the main body and uses batteries to store the remaining electric energy during the day to provide a reliable power supply. The reliable supply of electrical energy is the basis of wireless communication networks and hydraulic networks. In addition, forestry ecological energy can be used as fuel. The carbon dioxide emitted by combustion is equivalent to the total carbon dioxide absorbed during its growth. The sulfur content of trees is low, and the sulfur oxides generated by combustion are low. Forestry ecological energy is convenient for storage and transportation and can be converted into electricity, heat, steam, cold and other energy sources. PV power generation and forestry power generation can complement each other and develop in a coordinated way, which can not only enhance the reliability of PV power supply but also restrain the disturbance of PV power generation to the power grid. To develop the forestry ecological energy system, it is necessary to innovate the biomass combustion mechanism, support the application of forestry ecological energy with efficient, low emission and low energy consumption combustion technologies, and achieve sustainable development of forestry ecological energy. There are rich types of forestry biomass energy, including fuel ethanol, cellulosic ethanol, synthetic liquid fuels, solid, gas, electric fuels, biodiesel, basic materials of biochemistry, *etc.*

Due to the impact of PV generation on the environment, it is necessary to delimit the prohibited construction area of FEI. First, various nature reserves, forest parks, habitats of endangered species, and natural forest protection project areas are prohibited construction areas. Second, forest land, sparse forest land, forest land not yet planted, cutting slash, burning slash, and areas with annual rainfall less than 400 mm are also prohibited construction areas.

Function description

FEI integrates the water network, power network and communication network, which can realize the integrated management of forestry. The water supply system includes fire pools and a fire pipe network, and the water network covers the whole forest. The forestry microgrid takes distributed PV power generation and other renewable energy as the main body to realize that there is electric energy on the mountain. In terms of communication systems, it is necessary to build a large broadband, full-coverage forestry wireless communication network. Forest fire prevention video monitoring adopts visible light heating imaging dual spectrum heavy load PTZ camera. The image is transmitted back to the main station through a wireless network, and then the water pump is controlled through the forestry automation system to realize remote control of the automatic water supply in the forest area. FEI realize the transformation of forest fire prevention from "physical prevention" to "intelligent prevention".

Discussion

Benefits of photovoltaic to forestry

Desertification has become an important factor restricting economic and social development in arid areas for a long time. To avoid the event of "sand entering and people retreating", the traditional method of sand control is planting trees and grass, but this method has large investments, low income and long-time consumption. FEI development is one of the effective means of sand control and has been widely applied in the southern edge of the Tengger Desert in China. PV arrays are generally arranged in the east-west direction, while the sand area is windy from the northwest. Rows of PV arrays can significantly reduce wind speed, effectively fix the sand, reduce local sand lifting, and play a good role in wind prevention and sand fixation. The shielding of PV cell modules can effectively reduce the direct sunlight on the ground, play a good shading effect, and reduce the ground temperature, thus reducing the evaporation of groundwater and providing water for plant growth. PV panels have the function of collecting rain. Rainwater dripped from PV panels will gather onto planting soil, providing enough water for trees. Ecological restoration under the PV panel is carried out by setting sand barriers and planting shade-tolerant desert shrubs and grasses, mainly by planting astragalus surgeons, alfalfa, artemisia selengensis, *etc.* To reduce the impact of wind and wind erosion on the PV power station, protective green belts are built at the periphery and on both sides of the trunk road to form a forestry-photovoltaic complementary model to harness desert. The area several hundred meters away from the PV station is mainly planted with trees and shrubs, and the area 1 km away from the PV station is planted with shrubs. The forestry-PV complementation mode can not only ensure the safe operation of PV power generation but also increase the ecological forest.

Difference between agricultural-photovoltaic complementation and forestry-photovoltaic complementation

The agricultural-PV complementation and forestry-PV complementation are the new models of PV power station construction. The nature of the land has not been damaged, which does not hinder agricultural or forestry production activities. The forestry-PV complementation is different from the agricultural-PV complementation. Concerning agricultural-PV complementation, it is a technology that combines PV power generation with agricultural planting. It is pollution-free, zero-emission, and does not occupy additional land. PV power generation is outside the shed, and vegetables are planted in the shed. Concerning forestry-PV complementation, it is a unique afforestation mode, which makes full use of the sufficient space of the height difference of more than 2 m between the PV panel frame and the ground. It vigorously develops economic shrub planting and organically combines PV power generation with forestry development, which can not only realize three-dimensional value-added use of land but also improve green development. According to the regulations, the combination of forest-suitable land and the PV industry should first focus on forest improvement, and then find a suitable mode to promote the construction of PV power stations. As long as the coverage rate is less than 30%, both tall trees and low shrubs can be used as land for the PV power station. However, without changing the nature of land use, how to plant low shrubs under PV panels is a problem to solve. The forestry-PV complementation is mainly concentrated in the middle east of China, which has a strong power consumption capacity and is less likely to abandon PV power.

Conclusion

The proposed forestry energy internet (FEI) based on the forestry-PV complementation not only ensures the construction of PV power generation projects, but also improves forestry planting, increases the income of forest farmers, and solves the contradiction between the development of PV power generation projects and green homeland. FEI is a distinctive theory of energy internet in the forestry field. Forestry informatization is the key to the modernization of forestry governance, and the construction of a forestry comprehensive dynamic monitoring system is the top priority. Forestry informatization is the key to the modernization of forestry governance, and the construction of a forestry comprehensive dynamic monitoring system is the top priority. Forestry electrification is to enable forestry modernization, realize power uphill and provide power for the forestry information system. FEI integrates information systems and energy systems, and it can realize PV power generation, forest seedling irrigation, forest fire prevention, *etc.*

Author contributions

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

Conflict of interest

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