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New energy grid connection power control method based on predictive tuning performance and embedded system

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Nowadays, due to the cleanliness and high efficiency of grid-connected new energy, it has become more and more popular in the market. However, there are still some problems in grid-connected power control and cannot be well supervised. Therefore, this paper studies a new energy grid-connected power control method based on predictive regulation performance and embedded systems, aiming to control new energy grid-connected power through predictive regulation performance and embedded systems. In this paper, the predictive regulation performance and energy conversion rate of the embedded system new energy grid connection are tested. In the experiment, the energy conversion rate was between 60% and 70%, while the traditional new energy grid connection rate was between 40% and 60%. The maximum power generation efficiency of new energy grid-connected with predictive regulation performance and embedded systems was 83%, while the maximum power generation efficiency of traditional new energy grid-connected was 68%. It can be seen from these experimental results that predictive regulation performance and embedded systems have good effects on new energy grid-connected power control.

KEYWORDS

new energy, grid connection, embedded system, predictive regulation, power control

1 Introduction

With the continuous updating and iteration of the power system, NE grid connection has become a popular power generation method. In traditional power generation methods, coal is often used as fuel, which poses harm to the environment. Therefore, the clean power generation method of NE grid connection is becoming increasingly popular. The power control method for NE is the focus of research by researchers, and better control of NE grid connection power can improve the efficiency of NE grid connection.

NE grid connection is now a hot research direction. Scholar Taul Mads Graungaard believed that grid connected converters exposed to weak current grid conditions and severe fault events faced the risk of losing synchronization with external power grids and adjacent converters. This dilemma had led to an increasing interest in analyzing synchronization mechanisms and developing modeling tools to predict the transient stability of grid connected converters (Taul et al., 2019a). Liu Ju conducted modal analysis on grid connected wind turbines under different operating conditions and grid strengths. The modal analysis results showed that weak current networks were prone to instability under

heavy load conditions due to phase locked loop oscillations (Liu et al., 2019). Zhang Xueguang believed that phase locked loop (PLL) was a common method for three-phase grid connected inverters to obtain grid synchronization information, and the dynamic characteristics of PLL were key factors for stable operation of inverters (Zhang et al., 2018). Liang Xiaodong believed that as more distributed generation units based on renewable energy were connected to the public grid, the deterioration of power quality at public coupling points had become a major issue (Liang and Chowdhury, 2018). The research on NE grid connection is of great significance for improving the quality of NE grid connection. If NE grid connection is combined with predictive regulation performance and embedded systems, then NE grid connection plays a greater role. Embedded systems can provide better power control for NE grid connection, which improves the efficiency of NE grid connection. Increased efficiency also means reduced costs.

Predictive regulation performance and embedded systems can both be helpful for the NE grid connection function. Chen Min believed that grid connected inverters without isolation transformers usually injected a certain amount of DC (direct current) components into the AC (alternating current) power grid due to current sensor errors, tolerance of power switching devices, and asymmetry of drive pulses (Chen et al., 2018). Soliman Mahmoud A proposed a new adaptive fuzzy logic control strategy for improving the performance of grid connected wind power generation systems. The permanent magnet synchronous generator driven by a variable speed wind turbine was connected to the power grid through a full capacity power converter (Soliman et al., 2018). In the grid-connected power system dominated by voltage source converters, Hu Qi also encountered the common signal synchronization instability problem in traditional power systems, which has received more reports and research (Hu et al., 2019). Zhang Qianjin proposed to incorporate nonlinear factors such as dead time and phase locked loops into the impedance model of large-scale grid-connected photovoltaic systems, and consider the changes in photovoltaic capacity to study their impact on system power quality and stability (Zhang et al., 2018). Alceu Bernardes Castanheira de Farias proposed a manual implementation of linear model predictive control (register-transfer level implementation) and a floating-point digital representation applied to the use of quadrotor systems (Bernardes et al., 2022). Dominique Bonkoungouric researched and designed a DC/AC energy converter using the harmonic selective elimination (HSE) method. To do this, he combined two power stages connected in the derivation. Each power stage consists of transistors and transformers. The quasi-sinusoidal output voltage of the inverter can be generated by switching the connection of two rectangular waves transmitted by each stage. The results show that the energy conversion device has good robustness and technical performance. It can be seen from this analysis that the control of the inverter output voltage and the resulting simulated phase angle is very important in order to transfer the current from the continuous battery to the AC battery (Bonkoungouric et al., 2022). With predictive regulation performance and the support of embedded systems, NE grid connection can provide better control over power.

The era of using traditional fuels is slowly passing, and now the use of NE is slowly emerging. NE grid connection is now a popular way of generating electricity, with great research value. This article focused on predictive regulation performance and embedded system power control methods for NE grid connection, which improved power control for NE grid connection through predictive regulation performance and embedded system methods. This article has experimentally tested the predictive regulation performance and the energy conversion rate, power generation efficiency, and power generation cost of the embedded system's NE grid connection. From the data point of view, it is better than the traditional NE grid connection, which also shows that the predictive regulation performance and the embedded system have a high degree of compatibility with the NE grid connection.

2 NE grid connection power control method

2.1 Types and characteristics of NE grid connected power generation

NE mainly refers to various energy sources generated by the sun or the earth, including solar energy, wind energy, etc. NE is characterized by less pollution and large reserves. Therefore, making good use of NE can solve people's energy problems.

NE power generation has certain requirements for time and season, sometimes requiring light and sometimes wind. This requires sufficient sunlight and light to transmit a large amount of electricity to the public grid. However, if there is insufficient wind or light, the generator is stopped.

2.2 Impact of grid connection use of NE

The traditional energy structure has been unable to meet the needs of sustainable development, and today, people use a lot of electricity. In this case, fossil fuels would run out if only fossil fuels were burned to generate electricity. Therefore, the development of NE sources is of great significance, which can enable the sustainable development of resources.

NE grid connection uses advanced technology. NE grid connection proposes a fast and accurate voltage feedback detection method, in which an output voltage is injected into the inverter current to adjust the power output. NE grid connection can convert solar and wind energy into electric energy, and can diversify the energy structure, so it can replace traditional power systems. However, as the NE grid connection technology is not yet mature, it is necessary to take reasonable measures to strengthen the application of NE power generation grid connection to provide assurance for the stable operation of the distribution network, which is widely used in grid connected converter systems.

The effects that NE grid connection can produce are as follows. NE grid connection is conducive to the sustainable development of electricity. Traditional power generation is mainly based on coal, which leads to the loss of many non renewable resources, while NE is an energy that cannot be exhausted.

Disadvantages of traditional power generation.

1) Smoke pollution

Acid rain has increased in many parts of China due to the growing volume of gases such as SO_2 from direct coal combustion. The country produces 1.4 million tons of dust pollution every year, causing fly ash pollution to the environment near the power station, causing adverse effects on people's lives and plant growth. The country produces 15 million tons of soot every year.

2) Resource consumption

Power generation steam turbines usually use water as a cooling medium, and a 1,000 MW thermal power plant consumes about 100,000 tons of water per day. The country consumes 50 million tons of standard coal every year.

Therefore, with the continuous development of NE, it is possible to solve the problem of power resources. NE grid connection is conducive to optimizing the power supply layout. For example, when the location of solar power generation is insufficient, free space on the roof can be used. NE grid connection is conducive to improving the efficiency of electric power enterprises. It is a relatively decentralized power generation method that can ensure that electricity is available to residents in various regions. Therefore, NE access and grid connection can improve people's quality of life.

NE grid connection also has an impact on power quality, such as voltage. During grid operation, specialized equipment is often used to adjust the voltage. Voltage regulation equipment can be used to adjust the voltage value can effectively improve the power quality. The voltage regulator is the equipment that makes the output voltage stable. It is composed of voltage regulator, constant voltage, control circuit, and servo motor. When the input voltage or load changes, the control circuit samples, compares, amplifies, and then drives the servo motor to rotate. The position of the regulator carbon brush is changed, and the output voltage is kept stable by automatically adjusting the coil turn ratio.

As the proportion of NE increases, parameters such as the impedance of the power grid are changed, and using traditional power grid modes cannot ensure the quality of the power grid. Therefore, there is a connection point between the power grid and NE. At the connection point, the penetration ability of the power grid is affected by voltage. When adjusting the voltage, it is necessary to adjust it according to the actual situation of the power grid. Because the power supply line is long, there is a voltage drop on the line. Therefore, the near end voltage is high, and the far end voltage is low, which makes the transformer primary input voltage inconsistent. In order to ensure that the output voltage of the secondary side of the power transformer is certain, it is necessary to adjust the tap changer gear according to the level of the input voltage of the primary side to change the number of turns of the primary coil and change the transformer ratio to ensure that the secondary output remains constant.

During the use of NE grid connection, harmonics also occur, which have a significant impact on the power system. For example, many photovoltaic inverters are used in photovoltaic power generation systems, which are composed of electronic components. The harmonics generated by wind farms are from inverters in the power conversion system, which also inject harmonics into the grid during grid connection. Grid connected voltage source converters are currently an inevitable means of expanding and supporting power systems. However, their harmonic injection and high-frequency switching may lead to reduced power quality and equipment reliability. Therefore, the harmonic injected into the converter must comply with the corresponding standards (Xing et al., 2021).

The method for improving the power quality of NE grid connection includes installing power quality adjustment equipment, specifically by using dynamic reactive power compensators on both sides of the power supply to quickly adjust the power. Reactive power compensation is mainly set at the low voltage side of the NE output terminal, and the voltage at the access terminal is adjusted by adjusting the compensated reactive power. To solve the harmonic problem, a multi pulse converter can also be used to absorb harmonics, which can ensure the normal operation of the power grid.

Another improvement method is to unify the grid connection standards for NE. Currently, the standards for NE grid connection are not uniform, and the relevant regulations are not too perfect. Therefore, technical personnel cannot well control the stability of the power grid and cannot handle various issues during operation. In the actual operation of NE grid connection, it is necessary to accelerate the speed of technological research and development, solve various problems for NE grid connection, and require all departments to strictly comply with grid connection specifications, in order to enhance the safety of NE grid connection. An unstable condition of grid connected voltage source converters is caused by the limit current of the external control circuit (Basit et al., 2020).

To adapt to the development of NE grids, it is necessary to start with the structure of the grid. By changing the structure of the power grid and selecting the appropriate reactance and resistance of the line, voltage fluctuations can be reduced. NE technology requires continuous innovation, which can minimize the number of starts and stops of the power grid, ensure the safety of the power grid, and solve problems such as transient power outages, voltage dips, and voltage rises.

2.3 NE grid connection standard system

The NE industry involves multiple aspects such as planning and equipment manufacturing. Establishing a technical standard system for each link can promote the overall coordination of power supply and power grid, ensuring the sustainable development of NE.

The need for sustainable development requires meeting three principles:

The first is the principle of fairness. The so-called fairness refers to the equality of opportunity choice:

Second is the principle of sustainability. Sustainability here refers to the ability of an ecosystem to maintain its productivity in the face of certain disturbances.

The last is the harmony principle of sustainable development. If each person considers and arranges his or her actions in a way that takes into account their impact on others (including future generations) and on the ecological environment, and acts in good faith according to the principle of "harmony," then a mutualistic and symbiotic relationship between humans and nature can be maintained, and only in this way can sustainable development be achieved.

NE grid connection is now a hot topic in international energy and power technology. In order to make grid connection of NE more

standardized, researchers have developed a series of standard systems for grid connection of NE. In the wind power standard system, there are standard systems for wind farm planning and design, wind farm construction and installation, wind farm operation and maintenance management, wind farm grid connection management technology, wind power electrical equipment, wind farm meteorological observation, etc.

In the field of photovoltaic power generation, in order to promote the development and standardization of the photovoltaic power generation industry, the Energy Administration has established photovoltaic power generation and promoted industrialization standards. In order to accelerate the establishment of a standard system for photovoltaic grid connection, a standard system for photovoltaic power generation has been studied and established. The grid-connected photovoltaic power generation standard system includes national standards such as electrical design, commissioning, project budget estimate, management, planning, foundation, and technical conditions. Industry standards include power station testing, key parts testing, and technical conditions. However, with the gradual improvement of the penetration rate of NE power generation, NE grid connection faces many new challenges. Therefore, it is necessary to revise the original standards and specifically propose technical requirements for high voltage ride through of NE power generation.

Immature new energy grid-connected technology may have the following effects: first, it would lead to the sensitivity of the line protection reduction and rejection; second, it would lead to the misoperation of the line protection; third, it would cause the instantaneous speed of adjacent lines to break protection and lose selectivity; fourth, it would lead to unsuccessful reclosing.

2.4 NE grid connection power control

The NE grid connected power control method includes multiple source information integrated processing, external information integrated processing subsystem, and various automation systems. Through design data access, information processing, and other modules, it can not only use standardized interfaces to obtain platform models and data, but also adapt to external system specifications. Through unified processing of data from different manufacturers, it can be transformed into a model that uniformly describes system models and data structures, which can provide information publishing related services.

NE grid connected power control is usually controlled based on a specified correlation relationship, and the sensitivity is generally calculated and configured in a typical offline manner. When complex cross-sectional structures occur, offline sensors become very cumbersome and difficult to adapt to changes in the power grid. Therefore, a new sensitivity calculation method is needed to control the power of NE sources.

There is also the use of wind and fire coordination control under section constraints. Section operation status can be divided into safety zone, early warning zone, etc. For the strategy of wind and fire coordination, when the sectional power flow is greater than the early warning limit and less than the emergency limit, it is the early warning zone, and then the NE power control system is activated for control. Due to the fact that the cross-section does not actually exceed the limit, and there may be room for the thermal power unit to be lowered, the NE power plant instructions given by the system have fluctuated to a certain extent, and the actual power limit does not occur. However, it is also not allowed to exceed the instructions, and the thermal power unit must be gradually lowered.

Establishing a resource priority and fair inter station allocation of NE is also one of the power control methods for NE grid connection. If market factors are not considered, stations need to have consistent generation orders and installed capacity for controlled periods of time. Due to the different power generation capabilities of different NE sources, it is not possible to simply issue power generation instructions based on the installed capacity. Otherwise, some stations with poor power generation functions waste space, while those with strong power generation functions are limited.

It is also necessary to dynamically update the control sequence based on real-time power generation capacity. Because a station with a high equivalent load rate occupied a station with a low load rate, it is necessary to select a sub station when a station with a high load rate is not required. The method is to rank the load rate from high to low. Then, the load of the station ranking first is reduced, making its load consistent with the load ranking second.

2.5 Breakthrough direction of NE grid connection technology

The high penetration rate of NE grid connection leads to large fluctuations in tie line power flow, which has a significant impact on the operation of the power system. This may lead to some technical issues, such as excessive voltage fluctuations leading to power losses (Taul et al., 2019b). The technologies that need to be breakthrough in NE grid connection technology include electric power meteorological technology. Meteorological conditions are the most critical factor in a high proportion of NE power systems, with a wide range of impacts. It is widely believed that meteorological factors are one of the factors that affect the operation of power grids in the future. In order to prevent electric power meteorological disasters from being affected, it is necessary to develop the technology of electric power meteorological disaster prediction and alarm.

NE grid connection technology also requires breakthroughs in NE high-precision power prediction technology. Due to the imperfect use of NE, it is still difficult to predict high-precision power. The power prediction of NE generation is bidirectional, and it is necessary to study NE generation power prediction technologies with smaller time intervals and better spatial resolution.

NE grid connection technology also requires breakthroughs in NE active support technology. After a high proportion of energy is connected to the grid in the future, it affects the shape and operation mechanism of the power system, which requires the ability of NE to have active support.

The NE grid connection technology also needs to break through the fault mode controller technology, which limits the converter current within the allowable range while maintaining the voltage mode characteristics of the grid connection structure (Guo et al., 2020).

2.6 NE grid connected power control method for predictive tuning performance embedded systems

2.6.1 New energy power grid operation control strategy

First of all, in the process of grid access to new energy, it is necessary to optimize the settings of grid power supply, grid compliance and transmission congestion, so as to reduce the impact of new energy access on the stability of grid operation. In addition, for the harmonic problems generated by new energy access, relevant processing equipment can also be set up in the process of new energy access to implement reactive power compensation for power grid operation. For example, the use of new SVG equipment, in the process of new energy access to the power grid operation, the setting of SVG equipment can promote the stability of the power grid operating voltage; when the voltage tends to be stable during the power grid operation, the harmonic of the power grid operation would also be reduced.

Then, the new energy access of the current power grid operation is mainly the access method of solar energy and wind energy. Therefore, in the process of two kinds of energy access, it is necessary to pay attention to the reasonable access of new energy, before the photovoltaic power supply access or wind turbine grid access, strict calculations should be carried out to ensure that the included power supply energy can promote the stable operation of the grid. In the calculation process, the random power flow calculation method can be used to carry out the access calculation, and the factors of the random output model should also be taken into account in the calculation. The power probability part of new energy access to the grid should be calculated jointly according to the random power flow calculation and the random output model, so as to ensure the deployment function of the grid operation in the process of new energy access.

Finally, the normal operation of the power grid has a very large connection with the power production within the scope, and the power energy plays a very important role in both residential life and industrial production. Therefore, this feature also requires the power grid operation to have continuity and stability. After the new energy access, the continuity and stability of the power grid operation cannot be changed, and the efficiency cannot be reduced, which requires that the new energy access must make the power grid maintain energy saving, environmental protection and efficiency.

Model predictive control is widely used in the control of grid connected inverters due to its advantages. However, traditional model predictive control methods typically require two AC voltage and current sensors to sample the grid voltage and current (Kammer et al., 2018). Due to the instability of NE power generation, large-scale grid connection poses hidden dangers to the power system. To reduce this situation, it is necessary to predict and adjust the output power of power generation before planning the power system, which can reduce the security risks of NE grid connection and reduce the use of traditional fuels.

The prediction methods include direct prediction and indirect prediction. Direct prediction is to directly predict the output power of a power station, and then predict the power of photovoltaic power generation based on weather information (Zhao and Kok Foong, 2022). Direct power prediction avoids complex calculations. In the simplified modeling, the prediction accuracy is very high. However, due to too many factors affecting the output power, the prediction error is relatively large (Meng et al., 2022).

The indirect prediction rule is to predict the illumination amplitude using weather forecasts, and then establish a photovoltaic power generation system formula to solve. First, it is necessary to obtain the value of horizontal solar radiation (Verman, 2020). Then, according to the angle information of the photovoltaic receiving surface, the horizontal radiation amount is converted into the radiation amount of the inclined surface, and the output power of the photovoltaic power generation is calculated (Yin et al., 2017).

Embedded systems are devices composed of hardware and software that can operate independently (Jumshaid, 2022; Kim, 2022). The hardware content includes memory and processors. Embedded systems can choose the necessary software and hardware according to people's needs (Mansour, 2021). It is based on modern technology, and then coupled with user needs to change. It is flexible and changeable, so adding embedded systems to the NE grid can have a good effect. Embedded systems can regulate NE grid connection through hardware and software devices (Wang et al., 2021).

The embedded NE grid connection system includes a main control module, a dead time delay module, a drive module, and a signal acquisition module. The main control module of the system needs to complete the output of sine waves, as well as the acquisition of power grid signals, and data display level communication functions (Çelik et al., 2023). The embedded NE grid connection system has a drive circuit design. In the drive circuit design, there are high-end suspension circuits inside, which can reduce the number of power supplies (Sadia, 2022). In practical use, it can be directly used in low-power converters without expansion. In the design of power network signal acquisition circuit, voltage transformers are used for power network voltage signal acquisition. In order to ensure the consistency of telecommunication signals, it is necessary to add a detection circuit in the module. In the design of the inverter circuit, it is necessary to use a three-phase full bridge circuit to establish the circuit (Li et al., 2022).

2.6.2 Impact of cleaner grid connection of new energy sources

After the access of new energy, the full load management of power grid operation can be implemented; the full load management of power grid can be implemented; the stability of power grid operation can be improved; the network loss of power grid operation can be reduced. In addition, it ensures that the access of new energy is more efficient, does not cause energy consumption, but also avoids power consumption, and realizes the university and stability of new energy access to the power grid.

In the design of system software, it is necessary to use programming language for programming, and the system program includes the acquisition of power grid signals, data processing, and output of corresponding sine wave data (Narayanan et al., 2021). After the system is started, it is initialized and then checked to see if the power grid is normal. If problems such as power failure, overload, etc., occur, the output is blocked. If the power grid is normal, the zero crossing of the power grid is triggered and converted to the corresponding sinusoidal value. By sending the sinusoidal value data to the modulation module, after modulation, the DC power generated by the power station can be converted into AC power with equal amplitude and phase of the power grid (Jabbarnejad et al., 2019; Long et al., 2021). The system structure design is shown in Figure 1.

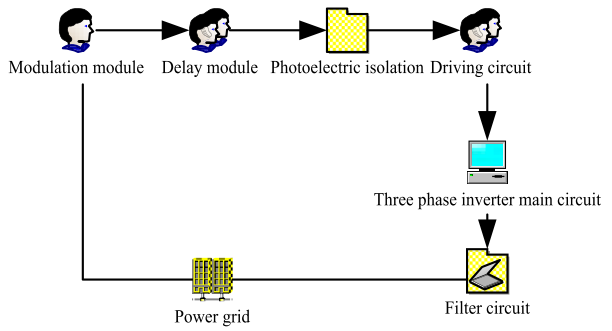

FIGURE 1
System structure design process.

2.7 Application of clustering algorithm in embedded NE grid connection

Clustering algorithms are often used in embedded NE grid connection, which can improve the power control ability of NE grid connection. Clustering algorithm is a method of grouping data into different classes based on their inherent scheme. The clustering algorithm sets the initial dataset to x. Then, the dataset is divided into a category according to the requirements, and there is a category in the requirements. Each group of data v has a membership degree m corresponding to the cluster center b. The clustering function and constraint function formulas are shown in Formulas 1, 2:

$$Q = \sum_{b=1}^{a}\sum_{v=1}^{a} m^{k}\|x_b - a_b\| \quad (1)$$

$$\sum_{b=1}^{a} m = 1, v = 1, 2, \ldots n \quad (2)$$

From the functional relationship in Formulas 1, 2, it can be seen that there is a corresponding membership relationship between any data, and there is a direct relationship with the cluster center. The k in Formula 1 is a membership metric factor. From the constraint function Formula 2, it can be seen that the sum of the membership degrees of all categories divided by the dataset is equal to 1. The Formulas 1, 2 can be used to calculate m, and the calculation method is shown in Formula 3:

$$m = \frac{1}{\sum_{b=1}^{a} \frac{\|x_b - a_b\|}{\|x_z - a_z\|}} \quad (3)$$

Because there is a_b in Formula 3, the formula obtained by taking its second derivative is shown in Formula 4:

$$a_b = \frac{\sum_{b=1}^{a}(x_b m^k)}{\sum_{b=1}^{a} m^k} \quad (4)$$

3 Embedded NE grid connected power control experiment with predictive regulation performance

Embedded NE grid connection with predictive regulation performance can make power generation more efficient. In this paper, experiments were conducted to test the effectiveness of embedded systems that predict and adjust performance for NE grid connected power control. In this paper, 100 groups of embedded network elements were selected to be connected to the grid and 100 groups of traditional network elements with predictive adjustment performance were connected to the grid for energy conversion rate testing, proving that embedded network elements with predictive adjustment performance can be connected to the grid to reduce unnecessary losses. In this paper, the energy conversion rate of embedded networks with predictive and adjustable performance is obtained by calculating proportional integrals, active and reactive currents, etc. Due to the limited space of this paper, the specific calculation method is not described here.

3.1 Operating conditions

Since the high frequency current ripple may cross the zero point during an on-off cycle, it is necessary to revert to the modulation state of the insertion dead zone. The direction and magnitude of the current are calculated by the parallel current modulation function. The methods is as follows:

When the modules are used in parallel, the voltage error amplifiers of each slave module are connected into the form of followers. The voltage error Ue of the main module is input to each follower, and the output of the follower is Ue, which becomes the current reference of each slave module. Therefore, the current of each slave module is modulated according to the Ue value, which is basically consistent with the current of the main module, so as to achieve the current sharing between modules.

However, the premise of this tuning formula is that the power factor of the electrical network is a unit power factor. In reactive power output, the above strategy may lead to abnormal changes in the current and voltage between reactive power zones. The energy conversion rates of embedded NE grid connection and traditional NE grid connection for predicting and regulating performance are shown in Figure 2.

Figure 2A represents the energy conversion rate of an embedded NE grid connection that predicts regulatory performance. From the experimental results, it can be seen that the energy conversion rate of the embedded NE grid connection with predicted adjustment performance was between 60% and 70%. Figure 2B represents the energy conversion rate of traditional NE grid connection. The energy conversion rate was between 40% and 60%. From this experiment, it can be seen that the energy conversion rate of embedded NE grid connection that predicted and regulated performance was much higher than that of traditional NE grid connection. The reason for this may be that the embedded NE grid connection that predicts and regulates performance has tighter power control, which reduces energy waste in unnecessary places. Therefore, the energy conversion rate is higher than that of traditional NE grid connection.

The meteorological instrument can record the total amount of radiation per hour and transmit the data to the monitoring center. This paper calculates the average monthly overall power generation efficiency according to PRE recorded daily overall power generation efficiency, which is more scientific in the final

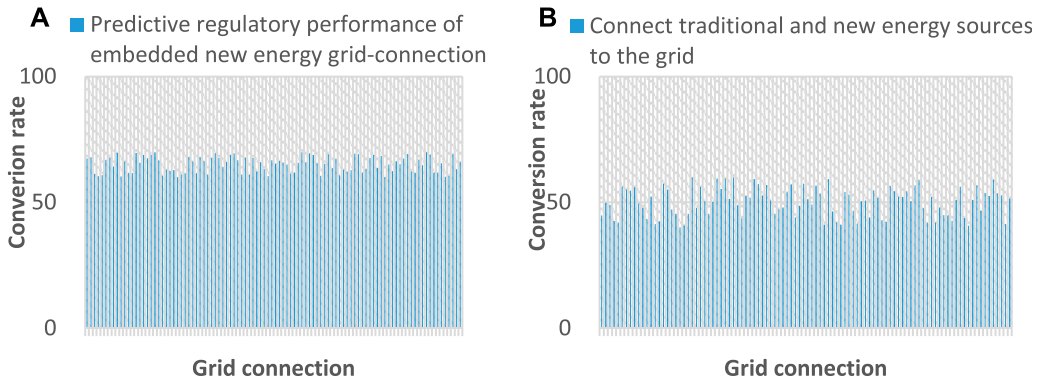

FIGURE 2
Comparison of energy conversion rate of two NE sources connected to the grid. **(A)** Predict the energy conversion rate of embedded grid pole grid connections with adjustable performance. **(B)** The energy conversion rate of traditional network element grid-connected connections.

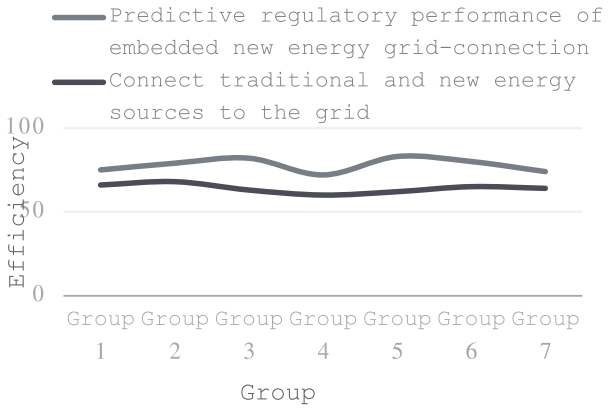

FIGURE 3
Comparison of power generation efficiency of two NE sources connected to the grid.

data obtained from the experiment. The theoretical power generation can be calculated by collecting the optimum amount of angular radiation from the meteorological instrument. The actual power generation of each PV array can be obtained through the communication between the DC measuring instrument configured in the DC distribution cabinet of the inverter in each district and the monitoring system.

The new energy power generation efficiency is calculated as follows: PRE = PDR/PT.

PDR is is the actual power generation during the test interval (t); PT is the theoretical power generation within the test interval (t); PRE is the new energy power generation efficiency.

In this experiment, seven groups of embedded NE grid connected and seven groups of traditional NE grid connected with predictive regulation performance were tested again to test their power generation efficiency. If the power of embedded NE grid connected with predictive regulation performance can be well controlled, the efficiency of power generation can also be improved, and the power supply of residents can also be better guaranteed. The power generation efficiency of embedded NE grid connection and traditional NE grid connection for predicting and regulating performance is shown in Figure 3.

From the experimental results in Figure 3, it can be seen that the highest efficiency of embedded NE grid connected power generation with predicted regulation performance was Group 5, with a power generation efficiency of 83%, while the lowest efficiency was Group 4, with a power generation efficiency of 72%. The traditional NE grid connection had the highest power generation efficiency in Group 2, with a power generation efficiency of 68%, while the lowest power generation efficiency was in Group 4, with a power generation efficiency of 60%. From this experimental data, it can be seen that the efficiency of embedded NE grid connected power generation with predictive regulation performance was significantly higher than that of traditional NE grid connected power generation. The reason for the results can be that embedded NE grid connected power generation with predictive regulation performance can perform digital management during power generation, better controlling the power generation process, which is significant for residents to better use electricity and reduce energy consumption.

By using embedded NE grid connection for predictive tuning performance, energy consumption can be reduced. This article explored the cost savings of embedded NE grid connection by predicting and adjusting performance. Since embedded NE grid connection with predictive regulation performance can improve the efficiency of power generation, the cost should be reduced. This article investigated the power generation costs of five groups of embedded NE grid connections that predict and adjust performance, as well as five groups of traditional NE grid connections. The power generation costs are shown in Figure 4.

From the experimental results in Figure 4, it can be seen that the highest cost of power generation for embedded NE grid connection systems that predicted and adjusted performance was Group 1, which accounted for 45% of the cost, while the lowest cost was Group 2, which accounted for 35%. The highest cost of traditional NE grid connection power generation was Group 4, accounting for 69% of the cost, while the lowest cost was Group 1, accounting for 60%. From the experimental results, it can be seen that the embedded NE grid connection with predictive regulation performance had the effect of reducing power generation costs.

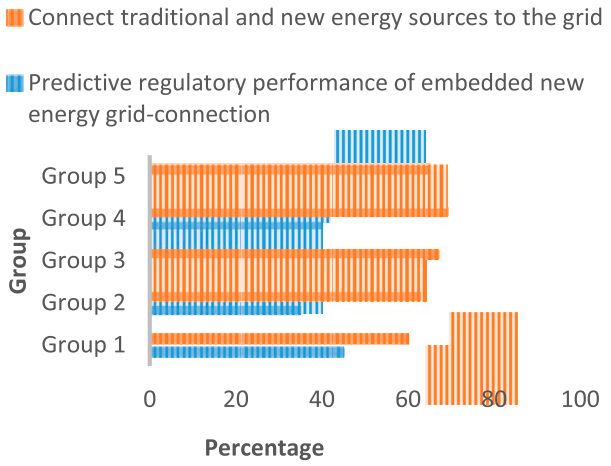

FIGURE 4
Comparison of grid connection power generation costs of two NE sources.

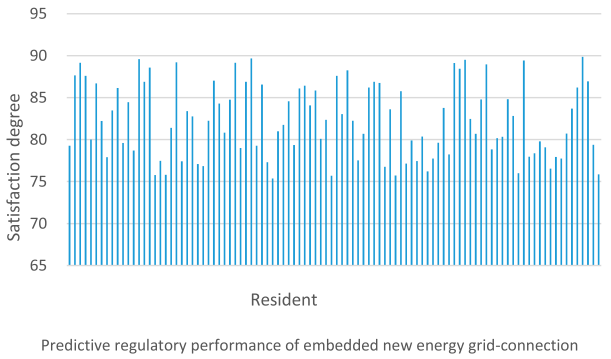

FIGURE 5
One hundred residents' satisfaction with the grid connection of embedded NE for predicting regulatory performance.

The reason may be that the embedded NE grid connection with predictive regulation performance for NE reduces power consumption after power control, thereby saving costs.

In this experiment, 100 residents were selected to investigate their satisfaction (satisfaction) with the embedded NE grid connection for predicting regulatory performance. Satisfaction is shown in Figure 5.

From the experimental results in Figure 5, it can be seen that 100 residents' satisfaction with the predicted regulatory performance of embedded NE grid connection ranged from 75 to 90 points, indicating that residents were relatively satisfied with the predicted regulatory performance of embedded NE grid connection. The reason for this is that embedded NE grid connection with predictive regulation performance can improve power generation efficiency, which can ensure that residents do not often experience power outages.

4 Conclusion

With the development of the times, people cannot live without electricity, and power resources have become a very important resource nowadays. However, traditional power generation methods often use fossil fuels, which is prone to cause pollution. Therefore, the NE grid connection power generation method has been introduced, which is highly efficient and clean, and has now been widely used. This article studied a NE grid connection power control method based on predictive regulation performance and embedded systems, aiming to improve the power control of NE grid connection through the use of predictive regulation performance and embedded systems.

This paper experimentally tested the predictive regulation performance and the energy conversion rate, power generation efficiency, and power generation cost of the embedded system's NE grid connection. Through experimental data, it can be found that the predictive regulation performance and embedded system's NE grid connection data are better than traditional NE grid connection data, indicating that the predictive regulation performance and embedded system's use in NE grid connection have a good effect. Due to the length of this article, the number of experiments done is not enough, and it is necessary to continue exploring the research on NE grid connection in the future. Finally, it is hoped that the field of NE grid connection would develop better and better.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

Author contributions

YL: Writing–original draft. ZL: Writing–original draft. MZ: Writing–review and editing. XW: Writing–review and editing. YC: Resources. JS: Resources.

Conflict of interest

Authors YL, ZL, MZ, XW, YC, and JS were employed by Yunnan Power Grid Co., Ltd.

Publisher's note

References

Basit, M. A., Dilshad, S., Badar, R., and Sami ur Rehman, S. M. (2020). Limitations, challenges, and solution approaches in grid-connected renewable energy systems. *Int. J. Energy Res.* 44 (6), 4132–4162. doi:10.1002/er.5033

Bernardes, A., de Farias, C., Murilo, A., and Lopes, R. V. (2022). Embedded linear model predictive control in field-programmable gate array using register-transfer level implementation and floating-point representation applied to a quadrotor system model. *Proc. Institution Mech. Eng. Part I J. Syst. Control Eng.* 236 (2), 370–381. doi:10.1177/09596518211028093

Bonkoungouric, D., Korsaga, E., Toussaint, G., Sosthène, T., Zacharie, K., and Franois, Z. (2022). Study and design of a DC/AC energy converter for PV system connected to the grid using harmonic selected eliminated (HSE) approach. *Appl. Sci.* 12 (3), 301–316. doi:10.4236/ojapps.2022.123022

Çelik, E., Öztürk, N., and Houssein, E. H. (2023). Improved load frequency control of interconnected power systems using energy storage devices and a new cost function. *Neural Comput. Applic* 35, 681–697. doi:10.1007/s00521-022-07813-1

Chen, M., Xu, D., Zhang, T., Shi, K., He, G., and Rajashekara, K. (2018). A novel DC current injection suppression method for three-phase grid-connected inverter without the isolation transformer. *IEEE Trans. Industrial Electron.* 65 (11), 8656–8666. doi:10.1109/tie.2018.2808916

Guo, L., Li, Y., Jin, N., Dou, Z., and Wu, J. (2020). Sliding mode observer-based AC voltage sensorless model predictive control for grid-connected inverters. *IET Power Electron.* 13, 2077–2085. doi:10.1049/iet-pel.2019.1075

Hu, Q., Fu, L., Ma, F., and Ji, F. (2019). Large signal synchronizing instability of PLL-based VSC connected to weak AC grid. *IEEE Trans. Power Syst.* 34 (4), 3220–3229. doi:10.1109/tpwrs.2019.2892224

Jabbarnejad, A., Vaez-Zadeh, S., and Jahanpour-Dehkordi, M. (2019). Combined control of grid connected converters based on a flexible switching table for fast dynamic and reduced harmonics. *IEEE Trans. energy Convers.* 35 (1), 77–84. doi:10.1109/tec.2019.2944994

Jumshaid, U. K. (2022). Embedded real-time operating system in remote viewing of electrical automation equipment. *Distrib. Process. Syst.* 3 (2), 42–59. doi:10.38007/DPS.2022.030204

Kammer, C., D'Arco, S., Endegnanew, A. G., and Karimi, A. (2018). Convex optimization-based control design for parallel grid-connected inverters. *IEEE Trans. Power Electron.* 34, 6048–6061. doi:10.1109/tpel.2018.2881196

Kim, J. (2022). Blockchain supply information sharing management system based on embedded system. *Distrib. Process. Syst.* 3 (2), 60–77. doi:10.38007/DPS.2022.030205

Li, Y., Yang, M., Hua, J., Xu, Z., Wang, J., and Fang, X. (2022). A channel attention-based method for micro-motor armature surface defect detection. *IEEE Sensors J.* 22, 8672–8684. doi:10.1109/JSEN.2022.3159293

Liang, X., and Chowdhury, A. (2018). Harmonics and mitigation techniques through advanced control in grid-connected renewable energy sources: A review. *IEEE Trans. Industry Appl.* 54 (4), 3100–3111. doi:10.1109/tia.2018.2823680

Liu, J., Yao, W., Wen, J., Fang, J., Jiang, L., He, H., et al. (2019). Impact of power grid strength and PLL parameters on stability of grid-connected DFIG wind farm. *IEEE Trans. Sustain. Energy* 11 (1), 545–557. doi:10.1109/tste.2019.2897596

Long, B., Lu, P. J., Chong, K. T., Rodriguez, J., and Guerrero, J. (2021). Robust fuzzy-fractional-order nonsingular terminal sliding-mode control of LCL-type grid-connected converters. *IEEE Trans. Industrial Electron.* 69 (6), 5854–5866. doi:10.1109/tie.2021.3094411

Mansour, K. (2021). Garment plotter based on ARM embedded system. *Distrib. Process. Syst.* 2 (1), 9–23. doi:10.38007/DPS.2021.020102

Meng, F., Yang, S., Wang, J., Xia, L., and Liu, H. (2022). Creating knowledge graph of electric power equipment faults based on BERT–BiLSTM–CRF model. *J. Electr. Eng. Technol.* 17, 2507–2516. doi:10.1007/s42835-022-01032-3

Narayanan, S. J., Baby, C. J., Perumal, B., Bhatt, R. B., Cheng, X., Ghalib, M. R., et al. (2021). Fuzzy decision trees embedded with evolutionary fuzzy clustering for locating users using wireless signal strength in an indoor environment. *Int. J. Intell. Syst.* 36 (8), 4280–4297. doi:10.1002/int.22459

Sadia, U. (2022). Three phase power flow calculation of weak loop distribution network with multiple distributed generators. *Distrib. Process. Syst.* 3 (1), 36–45. doi:10.38007/DPS.2022.030105

Soliman, M. A., Hasanien, H. M., Azazi, H. Z., El-Kholy, E. E., and Mahmoud, S. A. (2018). An adaptive fuzzy logic control strategy for performance enhancement of a grid-connected PMSG-based wind turbine. *IEEE Trans. Industrial Inf.* 15 (6), 3163–3173. doi:10.1109/tii.2018.2875922

Taul, M. G., Wang, X., Davari, P., and Blaabjerg, F. (2019a). An overview of assessment methods for synchronization stability of grid-connected converters under severe symmetrical grid faults. *IEEE Trans. Power Electron.* 34 (10), 9655–9670. doi:10.1109/tpel.2019.2892142

Taul, M. G., Wang, X., Davari, P., and Blaabjerg, F. (2019b). Current limiting control with enhanced dynamics of grid-forming converters during fault conditions. *IEEE J. Emerg. Sel. Top. Power Electron.* 8 (2), 1062–1073. doi:10.1109/jestpe.2019.2931477

Verman, V. (2020). Random power flow calculation of distribution system based on distributed generation. *Distrib. Process. Syst.* 1 (1), 17–24.

Wang, Z., Wang, R., Jiang, Z., Tang, X., Yin, S., and Hu, Y. "Towards a secure integrated heterogeneous platform via cooperative CPU/GPU encryption," in Proceedings of the 2021 IEEE 30th Asian Test Symposium (ATS), Matsuyama, Ehime, Japan, 2021, November, 115–120. doi:10.1109/ATS52891.2021.00032

Xing, G., Min, Y., Chen, L., and Mao, H. (2021). Limit induced bifurcation of grid-connected VSC caused by current limit. *IEEE Trans. Power Syst.* 36 (3), 2717–2720. doi:10.1109/tpwrs.2021.3053142

Yin, L., Li, X., Gao, L., Lu, C., and Zhang, Z. (2017). A novel mathematical model and multi-objective method for the low-carbon flexible job shop scheduling problem. *Sustain. Comput. Inf. Syst.* 13 (3), 15–30. doi:10.1016/j.suscom.2016.11.002

Zhang, Q., Zhou, L., Mao, M., Xie, B., and Zheng, C. (2018b). Power quality and stability analysis of large-scale grid-connected photovoltaic system considering non-linear effects. *IET Power Electron.* 11 (11), 1739–1747. doi:10.1049/iet-pel.2018.0063

Zhang, X., Xia, D., Fu, Z., Wang, G., and Xu, D. (2018a). An improved feedforward control method considering PLL dynamics to improve weak grid stability of grid-connected inverters. *IEEE Trans. Industry Appl.* 54 (5), 5143–5151. doi:10.1109/tia.2018.2811718

Zhao, Y., and Kok Foong, L. (2022). Predicting electrical power output of combined cycle power plants using a novel artificial neural network optimized by electrostatic discharge algorithm. *Measurement* 198, 111405. doi:10.1016/j.measurement.2022.111405