INTELLIGENT CONTROL OF GRAVITY ENERGY STORAGE SYSTEMS TO ENHANCE THEIR UTILIZATION

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INTELLIGENT CONTROL OF GRAVITY ENERGY STORAGE SYSTEMS TO ENHANCE THEIR UTILIZATION

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A project report submitted in partial fulfilment of the

requirements for the award of Master of Luo，Xianzhe

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December 2023

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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ABSTRACT

As the demand for energy grows, the significance of energy storage technology increases. However, current technology lacks flexibility and is only available as a separate operation in the power grid. In the future, energy storage technology will move towards a hierarchical approach. Energy storage will no longer be considered as a separate entity, rather it will be distributed according to the size of power generation and transmitted through the grid to store any excess power.

This project focuses on the analysis of a new gravity energy storage technology, focusing on its charging, discharging and grid connection, in order to provide guidance for its future operation in the combined power grid. In order to achieve the goal, the project takes wind and solar power generation samples as the main body, takes the grid-connected stability as the goal, models and simulates the gravity energy storage grid-connected system through the PID intelligent control system, and obtains the grid-connected grid voltage through Smulation. In this simulation, a bidirectional converter is used in the circuit design, and in this system, it is possible to store energy and release power at the sametimeFinally, through the simulation design, a stable grid-connected voltage of the grid is obtained

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CHAPTER 1

INTRODUCTION

1.1General Introduction:

In recent years, there has been rapid development in renewable energy as a solution to the issues of dwindling traditional fossil fuels and environmental degradation. However, renewable energy is characterized by its unpredictability, volatility, and intermittent nature. As the proportion of renewable energy in power grids continues to rise, it poses increasingly serious challenges to the secure and stable operation of these grids. Addressing these challenges necessitates the development of various energy storage technologies, which serve as crucial measures to ensure the stability of grids heavily reliant on renewable energy sources and are indispensable for balancing electricity supply. C.D. Botha(2021)mention that energy storage methods predominantly fall into three main categories. While electrochemical energy storage is known for its cost-effectiveness, apprehensions endure over its safety and environmental implications when employed in large-scale applications.Conversely, physical energy storage finds suitability in grid peaking and enables the effective transfer of electric energy between day and night cycles. As we all know that physical energy storage includes four kinds. GES is one of them, and it has received more and more attention in recent years due to its intrinsic safety, flexible location, zero self-discharge rate, large storage capacity, high discharge depth, etc. In this paper, we have studied some gravity potential energy storage applications and their control systems in addition to pumped storage.

Gravity energy storage, a form of mechanical energy storage, utilizes either water or solid materials as its primary energy storage medium. The system operates by leveraging the elevation difference of the storage medium to facilitate the charging and discharging processes.

The water-based gravity energy storage system, owing to water's high mobility, employs well-sealed pipelines, shafts, and similar structures. This design offers flexibility in location and storage capacity, dictated by the terrain and proximity to water sources. This makes it easier to construct large-scale energy storage systems near natural water sources.

On the other hand, solid weight GES relies on structures like mountains, underground shafts, and artificial constructions. Typically, heavy materials with greater density, such as metals, cement, sand, and gravel, are chosen to achieve higher energy density objectives.

The energy storage system using water as a medium primarily involves the conversion of potential energy to electric energy through the utilization of electric generators and water pump turbines. Control over the charging and discharging processes is achieved by managing parameters like water valves and electric generator currents.

As for solid weight energy storage systems, the lifting and dropping control of heavy loads is accomplished through structures like cranes, cable cars, rail trains, winches, and hoists. Their power conversion system, consisting of electric generators and mechanical transmission systems, controls the charging and discharging processes by regulating parameters including electric generator currents.

1.2Importance of the Study

Currently, there are many studies on energy storage technologies, and each storage technology has been studied in various optimisation schemes, but the future development of electricity, fluctuating electricity consumption makes the energy storage system to intelligent, joint development. With regard to each energy storage technology, each study wants to maximise the capacity of a single nature of energy storage, but based on the current level of technological knowledge, the largest energy storage system is pumped storage stations, other types of energy storage systems, such as physical energy storage: compressed air, flywheel energy storage, etc.. Chemical energy storage: batteries, capacitor storage, etc., these technologies can do a short period of time to store energy, but the energy storage capacity compared to pumped storage station is much smaller. Therefore, these storage technologies should be close to the power generation side, especially the new energy generation side with fluctuation, so as to make the new energy grid to obtain the maximum efficiency. This paper uses a new physical energy storage technology - gravity energy storage. This paper explores whether energy storage technology at the new energy terminal can achieve positive benefits for its grid connection.

1.3Problem Statement

At present, with the rapid development of society, there is rapid urbanization in developing regions, and a large increase in urban electricity consumption. At present, most of the world's power supply still depends on thermal power plants, and thermal power generation still accounts for more than 70%. It is difficult for coal-fired power plants to greatly adjust the electricity generation. In order to meet the peak period of electricity consumption for urban residents during the day, part of the electricity generated at night will be wasted. In order to cope with this, most parts of the world have introduced ladder electricity prices to solve this problem and encouraged people to use more electricity at night by lowering the night price. But because of human living habits, this move has had little impact. So energy storage systems are now favored by all countries. Energy storage systems can balance excess electricity generated at night and replenish the grid during peak consumption periods. However, the current energy storage system still faces many problems, such as the commonly used physical energy storage technology: pumped storage, which has certain requirements for terrain and is difficult to build in a plain area. Or, chemical energy storage technology: battery energy storage – in battery energy storage, the biggest problem is the decay of battery capacity after multiple charges and discharge, as well as the environmental pollution and economic loss caused by the replacement of batteries, and chemical energy has the characteristics of flammable and explosive, as the urban population high-density area energy storage system is very dangerous.So we need a new safe and smart storage system.

1.4Aim and objectives

This project aims to investigate the performance of an intelligent controller in a gravity energy storage system in terms of meeting peak consumption demands, balancing supply and demand, and replenishing the grid. The main objectives of this study are as follows:

1. Design and develop the simulation model of a hybrid power system integrated with GES.
2. Design an intelligent controller for the GES system.
3. Evaluate the effectiveness of the controller in improving the utilization of the system.

CHAPTER2

2.1.Literature review

GES is a kind of mechanical energy storage, Water and solid materialits are the main medium, based on the height difference of the storage medium for lifting and lowering to achieve the charging and discharging process of the GES. Because of the strong mobility of water, the water medium type GES system can be used with the help of well-sealed pipelines, shafts and other structures, the flexibility of its location and storage capacity by the terrain and water source restrictions, in the natural water source near the easier to build large-scale energy storage system. Solid weight-type gravity energy storage mainly with the help of mountains, underground shafts, artificial structures and other structures, the weight of the general choice of higher gravity materials, such as metal, cement, gravel, etc. to achieve higher energy storage.

2.2.GES SYSTEM

Gravity energy storage system has different technical routes in recent years, the following are the main methods of gravity energy storage.

2.2.1 Piston Gravity energy storage device

A schematic representation of this technique is shown in Fig1.1.Gravity energy storage consists of a sealed container filled with liquid (water/oil) and a heavy piston, which is connected to a return pipe that allows the flow of liquid streams. The whole system consists of a pump, a turbine, a motor and a generator. In discharge mode, gravity storage generates energy through the downward motion of the piston, which applies high pressure to the water flowing in a clockwise direction through the return pipe. The movement of the water drives a turbine within the power generation, and the kinetic energy of the flow is converted into mechanical energy by the turbine, which rotates the generator and generates energy. In storage mode, the motor driving the pump converts the electrical energy into mechanical energy, and the pump converts the mechanical energy into kinetic energy by applying pressure under the piston to move the piston upwards.

In this system there are several indicators that have the greatest impact on the efficiency of the system, including: water flow pressure, piston size, piston height, return line size, etc.among others the piston diameter and height are the two most significant parameters for the gravity system performance compared to the other parameters, as they contributed by 35.11% and 30.28%, respectively (Elsayed, M.E.A. et al. 2022).

Figure. 1.1 Piston Gravity energy storage Berrada, A., Loudiyi, K. and Zorkani, I. (2017)

2.2.2 Tower Solid Gravity Energy Storage

Moore, S.K. (2021) proposed an energy storage system based on the construction of a weight block, which consists of a crane and a weight block, and its main principle of operation is to use the crane to lift the weight block when there is a surplus of power, and to use the energy change generated by the fall of the weight block when the power grid needs more power: gravity-velocity. The gravitational potential energy of the heavy block into the speed of the crane cable, while the cable through the gear system to drive the power generation equipment to generate electricity. However, the difficulty of this technology is that the crane must accurately drop the weight everytime, the whole system requires a high degree of precision. But the technology for the geographic environment is not high, the danger compared to chemical energy storage, other physical energy storage, etc., more secure, can be built near the crowded places.

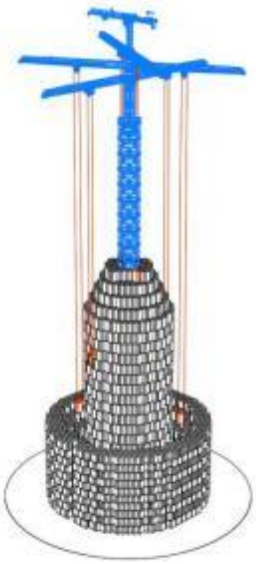

Figure. 1.2.Tower Solid Gravity Energy StorageFyke,A. (2019)

2.2.3 Shaft Solid Gravity Energy Storage

S-SGES is a kind of energy storage system based on deep wells, the system uses the height difference of the deep wells to control the energy of the system through the cable car rise or down weight block, the system configuration is simple, the principle is similar to tower Gravity Energy Storage, but compared with T-GES, S-SGES needs a larger and heavier weight block, and each deep well is equipped with only one weight block, so considering the energy conversion, under the condition of fixed height and constant gravitational acceleration, raising the mass of weight block M can effectively enhance the energy of the whole system. Each deep shaft is equipped with only one weight, so considering the energy conversion, raising the mass of the weight M can effectively increase the energy of the whole system with a fixed height and constant gravitational acceleration. In addition, deep shafts are usually based on mines or abandoned natural shafts, and their depth is significantly higher than that of T-GES, so the energy per unit of the system is higher than that of T-GES.In addition, S-SGES could be an essential way to reuse abandoned mines(Gravitricity ,2021)

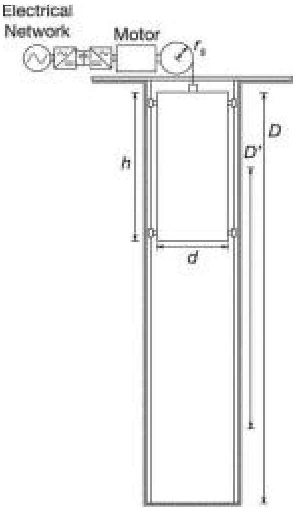

Figure.1.3 Shaft Solid Gravity Energy Storage   Morstyn, T., Chilcott, M. and McCulloch,M.D.

(2019)

2.2.4Mountain Cable-Car Solid Gravity Energy Storage

Mountain Gravity Energy Storage (MGES) is a newtype of energy storage that utilises the natural topography of mountainous areas. The system works by lifting materials such as sand or gravel from a lower storage point at the base of a mountain to a higher point at the top. In its charging mode, these materials are lifted and store energy in the form of potential energy. During discharge, they are released, allowing gravity to convert the stored potential energy back into electrical energy.

One of the main advantages of the MGES is that it is suitable for long-term energy storage, ranging from a few months to a few years, making it very effective for seasonal and long-term energy storage requirements. The system is modular and flexible, allowing capacity and speed to be adjusted to suit different grid sizes. In addition, MGES tends to have a lower environmental impact than large hydroelectric plants, especially in geographically suitable areas. Under certain conditions, such as isolated islands or remote areas, MGES offer a more cost-effective solution compared to other energy storage technologies.

However, MGES relies heavily on specific terrain, such as steep hillsides, which limits its widespread adoption. Initial investment in construction can be high, especially in areas where extensive civil engineering and crane facilities are required. Energy loss during material movement, especially during loading and unloading, is also a problem.

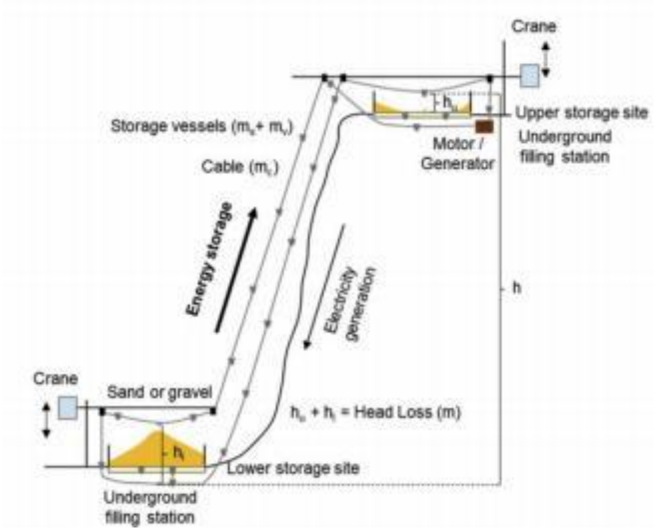

Figure.1.4 MGES Hunt, J.D. et

Compare kinds of GES

Year	Title	Author name	research method	advantage	control system	System type
2017	System design and economic performance of gravity energy storage	Berrada, A., Loudiyi, K. and Zorkani, I.	**LCOE** comparative,This research method can determine the gravity energy storage system to obtain the maximum return on investment in the entire power system.	➢ Low cost ➢ Long Life cycle ➢ The capacity is more suitable for the entire power system		Piston Gravity energy storage system
2021	The Ups and Downs of Gravity Energy Storage: Startups are	Moore, S.K. (2021)	By changing the energy form, we get a new model of gravity energy storage.	➢ Easy to install ➢ Safety, low investment		Tower Solid Gravity Energy Storage

	pioneering a radical new alternative to batteries for grid storage			➢ Simple in structure and easy to maintain		
2019	Gravity energy storage with suspended weights for abandoned mine shafts	Morstyn, T., Chilcott, M. and McCulloch, M.D.	It uses real-world data (GIS data) to estimate potential storage capacity in actual mine shafts.	➢ Minimal Surface Land Use ➢ Utilization of Existing Excavations ➢ Potential for Hybrid Systems	Advanced Control Techniques	Shaft Solid Gravity Energy Storage
2020	Mountain Gravity Energy Storage: A new solution for closing the gap between existing short- and long-term storage technologies	Hunt, J.D.	A model was created to assess the global potential of MGES to potentially reduce the capital cost of the MGES system by accounting for variations in the height of grid cells around the points analysed, particularly for very steep locations.	➢ Long-Term Energy Storage ➢ Modularity and Flexibility ➢ Utilization of Natural Terrain		Mountain Gravity Energy Storage

Table 2.1compare difference of some GES researchers

2.3 . Control system

2.3.1PID Control Systems

PID control systems (Proportional-Integral-Derivative control systems) are widely used in industrial and engineering fields, especially in situations where precise control of output is needed. A PID controller operates through three main components—Proportional (P), Integral (I), and Derivative (D) elements—to achieve the desired control effect.

- Proportional (P) component adjusts the output based on the current error (the difference between the desired value and the actual value).

- Integral (I) component accumulates past errors to address long-term steady-state errors.

- Derivative (D) component predicts future errors, helping to reduce overshoot and oscillations.

Advantages

1. Simple and Easy to Understand**: The principle of PID controllers is straightforward and intuitive, making them easy to implement and adjust.
2. Widely Applicable: It can be used in a variety of control systems, from simple household appliances to complex industrial processes.
3. Highly Tunable: The controller can be adapted to different system needs and dynamics by adjusting the PID parameters.
4. Cost-Effective: Due to its simplicity, PID controllers are generally more economical than more complex control systems.

Disadvantages

1. Complexity in Tuning Parameters: Although the PID controller itself is simple, finding the optimal combination of PID parameters can be challenging, especially for complex or nonlinear systems.
2. Performance Limited by System Dynamics: PID controllers may have limited performance in handling highly dynamic or nonlinear systems.
3. Not Suitable for Large Delays: If the system has significant time delays, the effectiveness of the PID controller maybe poor.
4. Lacks Adaptive Capability: Traditional PID controllers cannot automatically adjust their parameters to cope with changes in the environment or the system itself.

Dai,Y. et al. (2018) explored a method of combining PID controllers with RBF

(Radial Basis Function) neural networks to enhance the performance of PID control in photovoltaic energy storage systems. This combined approach utilizes the adaptive capability of neural networks to optimize the performance of PID controllers, especially in dealing with changing environmental conditions (like sunlight and temperature) in photovoltaic systems. Through this approach, some of the limitations of traditional PID controllers, such as the complexity of parameter tuning and adaptability to dynamic environments, can be overcome.

2.3.2Fuzzy Logic Control Systems

Fuzzy Logic Control Systems are a form of intelligent control that differs from traditional control methods like PID (Proportional-Integral-Derivative) controllers. Instead of dealing with precise inputs and outputs, fuzzy logic systems operate on "fuzzy" rules and sets,which are much closer to human reasoning. These systems use linguistic variables, rather than precise numerical inputs, to handle uncertainty and imprecision effectively.

Advantages

1. Handling Uncertainty and Imprecision: Fuzzy logic is well-suited for situations where data is imprecise or uncertain, which is common in real-world scenarios.

2. Flexibility: It can model nonlinear functions of arbitrary complexity, providing a flexible approach to control complex systems where traditional approaches might struggle.

3. Intuitive Rule-Based Approach: Fuzzy logic controllers use a set of intuitive, human-like rules, making them easier to understand and implement in certain contexts.

3. Robustness: They are generally robust to variations and disturbances in the system, maintaining performance even when the input data is noisy or uncertain.

Disadvantages

1. Complexity in Design: Designing a fuzzy logic controller can be complex, especially in determining the membership functions and the rules.
2. Computational Intensity: Depending on the complexity of the system, fuzzy logic controllers can be computationally intensive, requiring more processing power.
3. Lack of Standardization: There are no standardized methods to design fuzzy controllers, which can lead to inconsistency and difficulty in comparison with other control strategies.
4. Optimization and Tuning Challenges: While the rule-based nature is intuitive, it can be challenging to optimize and tune these systems for the best performance, especially in systems with a large number of variables and rules.

(2016) Teo, T.T. used MATLAB/Simulink to create a microgrid test bench for implementing and testing the FIS.The paper presents simulation studies which show that the FIS effectively reduces power grid fluctuations and prolongs the ESS's life-cycle compared to traditional rule-based control strategies.

2.4.3 Model Predictive Control

Model Predictive Control (MPC) is an advanced control strategy used in a variety of industrial and engineering applications. It is particularly effective in managing complex systems where future prediction and handling constraints are crucial. Here's an overview of MPC control systems:

How MPC Works:

1. **Model-Based Prediction:** At its core, MPC uses a mathematical model of the system to predict the future behavior of the system over a finite time horizon. This model can incorporate various system dynamics, constraints, and input-output relationships.
2. **Optimization:** Based on these predictions, MPC solves an optimization problem

at each control step. The goal is to find the control inputs that will optimize a certain performance criterion (like minimizing energy costs or maximizing output) while respecting system constraints (such as physical or operational limits).

3. **Feedback Mechanism:** MPC operates in a receding horizon manner. This means that at each control step, the optimization is performed over a moving time window, and only the first control action is implemented. The rest of the control sequence is recalculated at the next step, incorporating new measurements and predictions.

Advantages:

1. **Predictive and Proactive Control:** MPC anticipates future events and takes control actions accordingly, making it highly effective in systems where future states significantly influence current decisions.
2. **Handling Constraints:** It can efficiently manage complex constraints, which is essential in many real-world systems where safety, capacity, and operational limits are critical.
3. **Flexibility:** MPC can be adapted to a wide range of systems and objectives, making it versatile across various applications.
4. **Robustness:** It offers robust performance in the face of uncertainties and disturbances, as it continuously updates its predictions and control actions based on new data.

Disadvantages:

1. **Computational Intensity:** The need to solve an optimization problem at each control step makes MPC computationally demanding, especially for large-scale or highly dynamic systems.

2. **Model Dependency:** The effectiveness of MPC heavily relies on the accuracy and fidelity of the system model, which can be a limitation in systems with complex or poorly understood dynamics.

4. **Implementation Complexity:** Designing and implementing an MPC system requires significant expertise in control theory, system modeling, and optimization, which can be a barrier in some applications.

Lyu, C., Jia, Y. and Xu, Z. (2021) develop and successful supplicate a tube-based MPC approach for real-time energy management in microgrids. This approach effectively balances energy storage with renewable energy sources, handling uncertainties and system constraints while minimizing degradation costs of the battery ESS. The approach demonstrates improved robustness and efficiency in managing energy storage systems, which is crucial for the effective integration of renewable energy into microgrids.

CHAPTER3

METHODOLOGY AND WORK PLAN

3.1The overall Structure

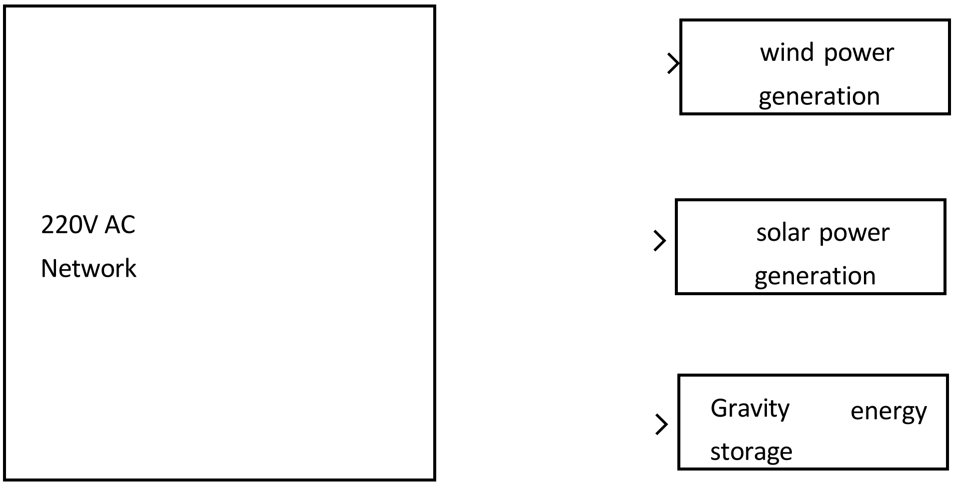

Figure.3.1.1 composition of totality

The above picture shows the new energy grid structure with gravity energy storage system, the new energy generation can not only transmit power to the grid, but also supply power through the grid when it needs to be shut down for maintenance and other operations.

3.2 Principle of each module circuit

3.2.1 Pv module

Photovoltaic power generation is essentially the direct conversion of light energy into direct current (DC), which is then inverted into usable alternating current (AC) by a power electronic inverter. The photovoltaic power generation system model is mainly divided into two parts: the photovoltaic cell and the inverter. The structure of the photovoltaic power generation system is shown in Fig. 3.2.1.

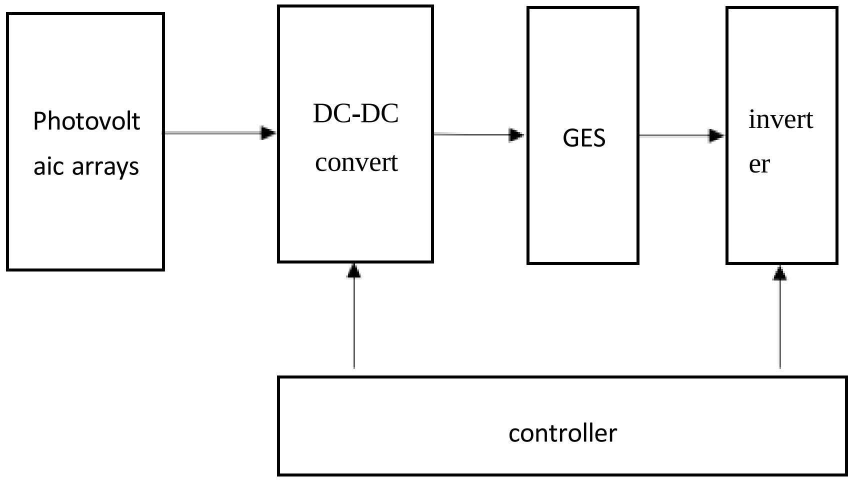

Figure.3.2.1 Photovoltaic power generation system

Among them, the photovoltaic cell is the core of the system. It produces a photovoltaic effect when it receives sunlight, converts light energy into energy for the load to work, and sends the remaining power to the energy storage device for storage. Anti-reverse charge diodes, also known as blocking diodes in engineering, are used to prevent the energy storage device from discharging backwards through the photovoltaic array when the photovoltaic array stops outputting power or malfunctions in the presence of very weak light intensity. Anti-reverse charging diode connected in series in the circuit of the photovoltaic array, the use of its unidirectional conductive role, the photovoltaic cell to play a protective role. Therefore, it is required that it must be able to withstand large currents, in addition, it is required that its forward voltage drop and reverse saturation current should be small enough. In the project choose to meet the above performance requirements of the rectifier diode as an anti-reverse charging diode.DC/DC converter's role is to raise the output DC voltage of the PV cell to a suitable level, so that the DC power generated by the PV power generation to meet the user's requirements on the voltage level. The PV power generation takes MPPT control and PI intelligent control.

The Maximum Power Point Tracking (MPPT) control strategy continually monitors the generated power output of the PV system. Employing a control algorithm, it estimates the system's maximum power output based on prevailing conditions and adjusts the load impedance accordingly to achieve this maximum power output. This method ensures optimal system performance even as the array's output power might diminish due to elevated junction temperatures, maintaining the system in its most efficient operational state under prevailing conditions.In this way, when the PV power generation system reduces the output power of the array due to the increase injunction temperature, it can still ensure that the whole system operates in the best matching state under the current working conditions. This technique in this study ensures that the energy output from the PV modules is stable before the photovoltaic is connected to the grid.

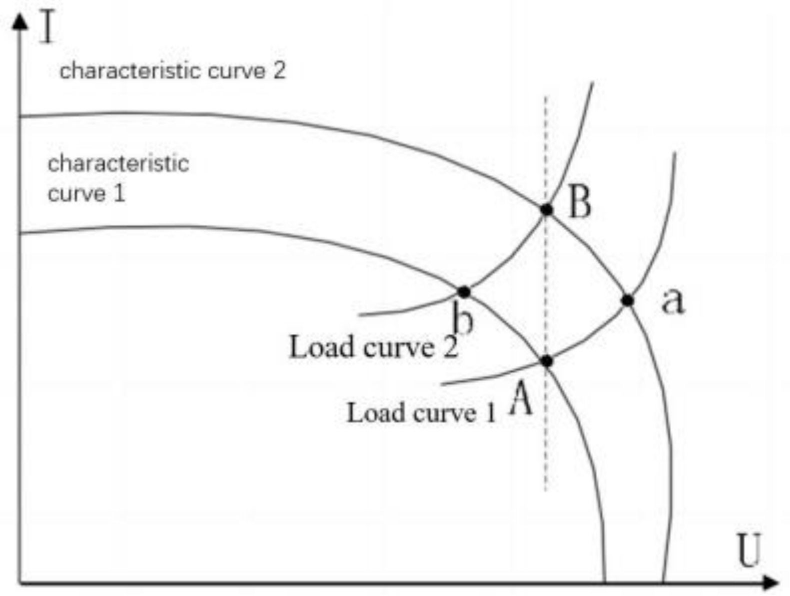

Figure.3.2.2 Schematic diagram of MPPT

The illustration above showcases two sets of output characteristic curves (I-U) for photovoltaic (PV) arrays at different irradiation levels. Points A and B represent the maximum power output for curve 1 and curve 2, respectively. If the PV system is initially functioning at point A and encounters an increase in irradiation intensity, the output characteristic shifts from curve 1 to curve 2. In this scenario, without altering load 1, the PV system would operate at point a, deviating from the new maximum powerpoint, B.

To maintain alignment with the maximum powerpoint under the altered conditions (B), adjustments in the load characteristic curve, from load 1 to load 2, are necessary. This ensures that the system remains at the new maximum powerpoint B. Conversely, if the change in irradiation intensity prompts the characteristic curve to transition from curve 2 back to curve 1, the operating point shifts from B to b.

In practical terms, to retain operation at the original maximum powerpoint A despite alterations in irradiation intensity, readjustments in the load characteristic curve from load 2 to load 1 become imperative. This adjustment enables the photovoltaic system to maintain operation at its optimal maximum powerpoint,A, even amidst changes in irradiation intensity.

The Incremental Conductance (INC) method is a widely adopted Maximum Power Point Tracking (MPPT) control algorithm. It establishes the correlation between the conductance and its change rate when the Photovoltaic (PV) system operates at the maximum powerpoint, based on the changes in output power and output voltage.

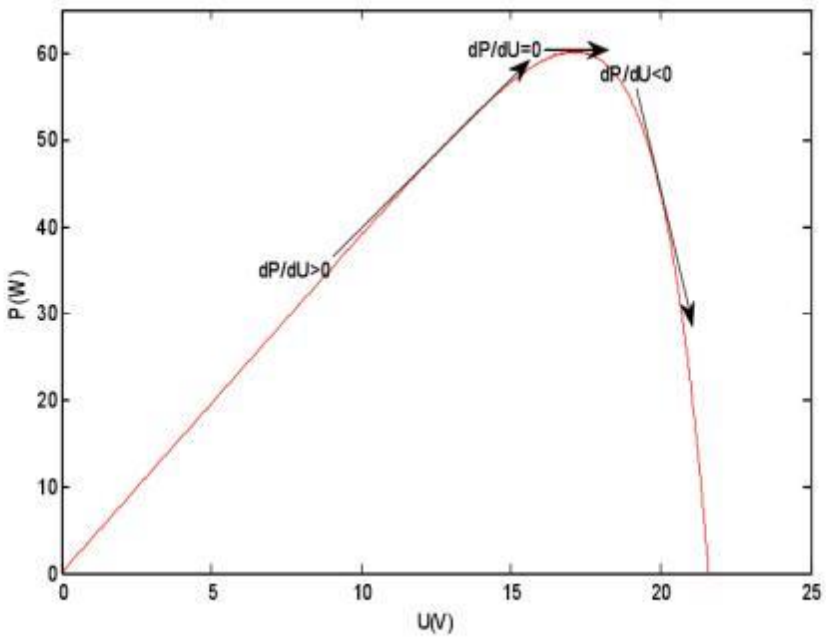

Figure.3.2.3Schematic diagram of P-U characteristics ofphotovoltaic array and variation of dP/dU

From Fig. 3.2.3, it's evident that the P-U characteristic curve of the photovoltaic array depicts a single-peaked curve, indicating the presence of only one maximum value where dP/dU equals zero. When the system operates at the maximum power point, dP/dU is either greater than zero to the left or less than zero to the right.

In the case of the photovoltaic system operating at the maximum powerpoint, the system's output power can be described as:

$$P = UI \tag{3.1}$$

Deriving the PV array inlet output voltage U obtained on both sides of the above equation, we have:

$$\frac{dP}{dU} = I + U\frac{dI}{dU} \tag{3.2}$$

When the derivative of the power output with respect to the voltage (dP/dU) equals zero, it signifies that the output power of the photovoltaic array reaches its maximum value. This condition indicates that the system operates at the point of maximum.

$$\frac{dI}{dU} = -\frac{I}{U} \tag{3.3}$$

In practical applications, the sign of (dI/dU+I/U) serves as a determinant for assessing the photovoltaic system's status at the maximum powerpoint. A zero value signifies that the system precisely operates at the maximum power point. A positive symbol implies that the system is at the left of the maximum power point, whereas a negative symbol suggests the system operates to the right of the maximum power point. For a detailed algorithm flowchart illustrating this process, please refer to Figure 3.2.4.

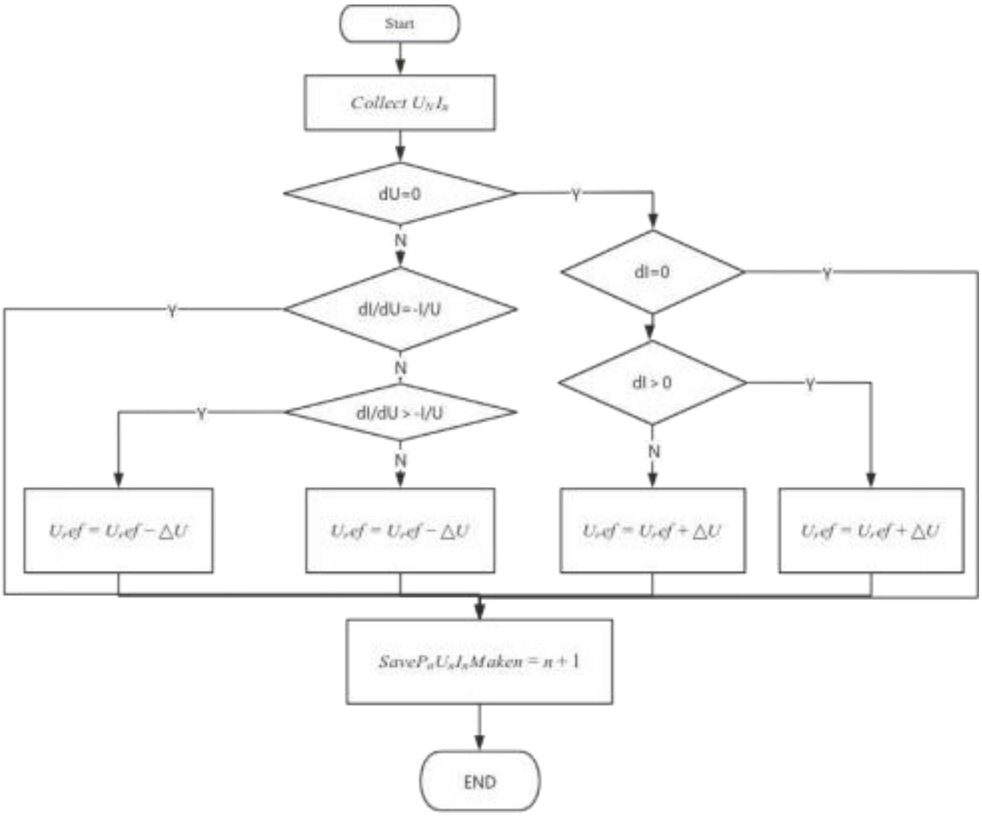

Figure.3.2.4Flow chart of the conductance increment method

3.2.2 Wind module

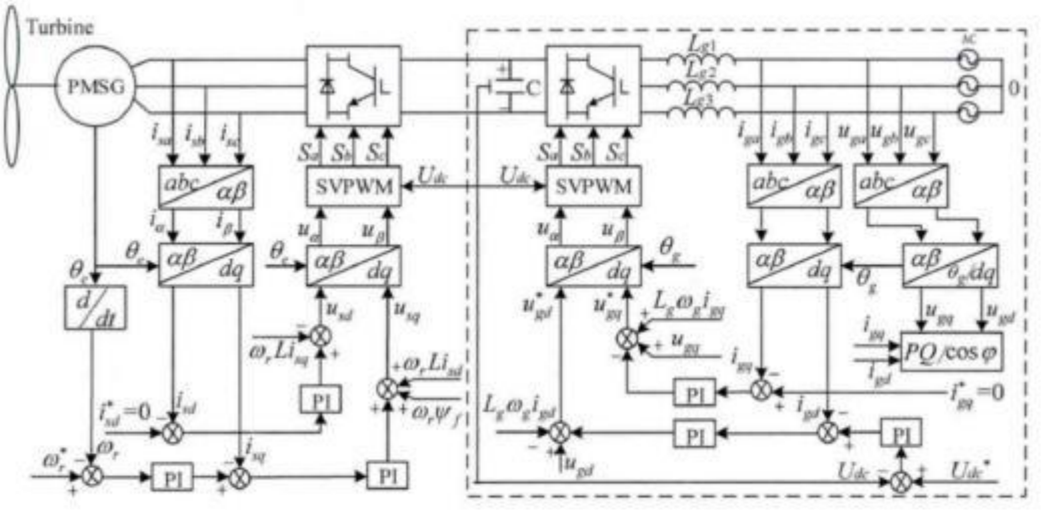

Figure.3.3.1 Wind module construction

As shown in the figure above, the wind power generation adopts the structure of permanent magnet synchronous wind power generation system, and the control structure adopted is generally a double closed-loop PI intelligent control with outer-loop voltage control and inner-loop current control. The mathematical model of the permanent magnet synchronous motor is shown below:

The current equation of state of the permanent magnet synchronous generator in the $a-\beta$ coordinate system is:

$$\begin{cases} \dot{i}_a = -\frac{R_s}{L_s} i_a + \frac{u_a}{L_s} - \frac{e_a}{L_s} \\ \dot{i}_\beta = -\frac{R_s}{L_s} i_\beta + \frac{u_\beta}{L_s} - \frac{e_\beta}{L_s} \end{cases} \tag{3.4}$$

In the above equation: superscript "." It represents the state variable of the corresponding variable; R_s and L_s Is the motor stator resistance and the inductor; i_a, i_β are the stator current components of the motor in the $a-\beta$; u_a, u_β are the stator voltage components of the motor under the $a-\beta$; e_a, e_β are the components of the motor's reverse electromotive force in the $a-\beta$, which are calculated using the following equation:

$$\begin{cases} e_a = -p n_r \Psi_f \sin(\theta) \\ e_\beta = -p n_r \Psi_f \cos(\theta) \end{cases} \tag{3.5}$$

In the above equation, p denotes the number of motor pole pairs; n_r denotes the rotor mechanical angular velocity; Ψ_f denotes the motor magnetic chain; and θ denotes the motor rotor position angle.

3.2.3Gravity energy storage module

Gravity energy storage can be roughly divided into 2 kinds, one is the use of vertical energy storage in the form of pylons or deep wells, and the other is the use of mountains to build tracks in the form of slope energy storage. Regardless of which one, the principle is to use the height of the drop to store energy, in the low demand for power loads, electric motors from the grid to absorb power, and pull the movement of the weight until it reaches a certain height, the process of energy conversion process for the conversion of electrical energy into gravitational potential energy, and ultimately the energy in the form of gravitational potential energy storage; in the high demand for power loads, the release of the weight, the weight driven generator to generate electricity, and will be The power generated is fed back to the grid, and the energy conversion process in this process is the conversion of gravitational potential energy into electrical energy. The energy conversion in this process is shown in the figure below.

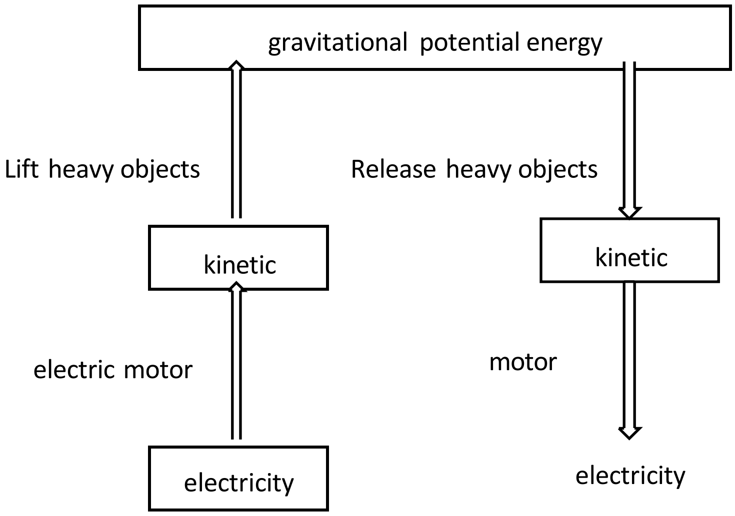

Figure.3.2.6 Gravity energy storage module

3.3 Energy storage process

How much energy is the weight and the height of the improvement, and how much power density can be stored and released is the quality of the weight and the speed of the improvement. In the storage process, the motor needs to consume electric energy, and the heavy object is promoted by the transmission mechanism. In this process, the gravitational potential energy is increased, and finally stored at a high level. And the motor maintains a uniform speed in the process of lifting the heavy object. For the vertical gravity energy storage system, the force balance of heavyweight can be expressed in the following formula：

$$F_{drag,V} = mg + F_{\mu 1} \tag{3.6}$$

In the above equation,$F_{drag,V}$ represents the motor lifting traction; $F_{\mu 1}$ represents the pulley system friction; m represents the mass of the weight; and g represents the acceleration of gravity.

For the ramp gravity energy storage system, the weight force balance is expressed by the following equation:

$$F_{drag,S} = mg \sin\theta + F_{\mu 1} + F_{\mu 2} \tag{3.7}$$

In the above equation, $F_{\mu 2}$represents the track system friction andθrepresents the slope angle.

In both cases, the motor lift traction power is expressed as：

$$P_{drag,V} = F_{drag,V} \cdot v_{drag} = \left(mg + F_{\mu 1}\right) \cdot v_{drag} \tag{3.8}$$

$$P_{drag,S} = F_{drag,S} \cdot v_{drag} = \left(mg \cdot \sin\theta + F_{\mu 1} + F_{\mu 2}\right) v_{drag} \tag{3.9}$$

In the above equation,$P_{drag,V}$ and $P_{drag,S}$ are the vertical and slope storage motor lifting traction power, respectively; v_{drag} is the uniform rate of ascent of the weight

3.4Energy release process

The energy release process is relatively complex, the weight falling first experienced a small period of acceleration, the process of generator output is unstable, if this time grid connection, easy to cause grid fluctuations, so the process is usually not grid connection. When the weight accelerated to reach the rated descent speed, the speed began to maintain a stable, this time need to add a certain additional motor traction to make the generator force balance, to ensure the stability of the speed and power output. In this case, for vertical and sloping gravity energy storage systems, the balance of force on the weight is expressed by the following equation:

$$F_{gen,V} = mg - F_{\mu 1} - F_{drag2} \tag{3.10}$$

$$F_{gen,S} = mg\sin\theta - F_{\mu1} - F_{\mu2} - F_{drag2} \tag{3.11}$$

In the above equation,$F_{gen,V}$ 、 $F_{gen,S}$ are the vertical and ramp storage generator tractive forces, respectively; F_{drag2} represents the motor maintenance tractive forceThe traction power of the generator in these two conditions is expressed as:

$$P_{gen,V} = F_{gen,V} \cdot v_{rels} = \left(mg - F_{\mu1} - F_{drag2}\right) \cdot v_{rels} \tag{3.12}$$

$$P_{gen,S} = F_{gen,S} \cdot v_{rels} = \left(mg\sin\theta - F_{\mu1} - F_{drag2}\right) v_{rels} \tag{3.13}$$

In the above equation, $P_{gen,V}$ 、 $P_{gen,S}$ are the traction power of the vertical and ramp storage generators, respectively; v_{rels} is the uniform descent speed of the weight. The power consumed by the traction force exerted by the motor to maintain the speed of the weight during its descent is provided by the grid.

3.5 PID Intelligent control strategy

The PID controller is a common controller that can control the output of the system by processing the feedback signals of the system. The core of the PID controller is a weighted sum of three parts: proportion, integral and differentiation.

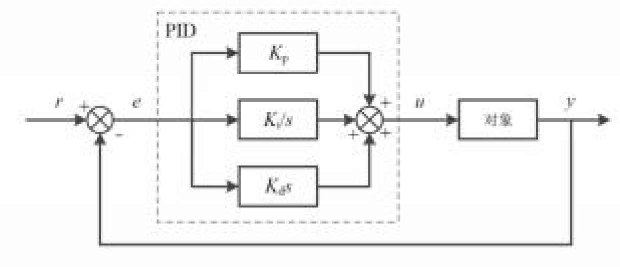

Figure.3.2.7 PID control structure

According to the representation of the PID algorithm in a computer system, its discrete mathematical expression is:

$$u(k) = k_p \cdot e(k) + k_i \cdot \sum_0^k e(j) + k_d \cdot [e(k) - e(k-1)] \tag{3.14}$$

Where, e(t) represents the error of the system, i.e. the difference between the desired output value and the actual output value; Kp, Ki, Kd are the coefficients of the proportional, integral and differential parts respectively, which are used to regulate the performance of the controller in terms of response speed and stability.

The proportional part achieves the fast response of the system, the integral part eliminates the steady state error of the system, and the differential part improves the stability and response speed of the system.The PID parameter tuning strategy is:

(1) Determining proportional gain

Set the two parameters other than the proportional gain to 0, set the proportional gain to 60%~70% of the maximum value allowed for the system, gradually increase the proportional gain to the system oscillation, and viceversa, gradually reduce it to the disappearance of the system oscillation, record the value of the proportional gain at the time of the disappearance of the oscillation, and set the proportional gain P of the PID to 60%~70% of this value.

(2) Determine the integration time constant I

Set the integration time constant D to 0 and the P value to the value already determined above, test in the same way to the value at which the system oscillation disappears, record the I value and set the PID integration time constant I to 150%~180% of the current value.

(3) Determine the integration time constant D

After the value of PI is determined, test the D value until the system oscillation disappears in the same way, and set the D value inside the PID controller to 150%~180% of the test value.

Finally, the system is modified by simulating the system to achieve the best results.

3.6Modal analysis of GES operation

In the gravity energy storage control system, the controller collects the output voltage and current of the gravity energy storage as the detection value, compares it with the reference value, and then the difference is used as the input to the controller, and the source of the reference value is the DC voltage and current values of the output of the front-stage buck. The energy storage container in the gravity energy storage part is a battery pack, and in this study, three basic batteries are connected in series to simulate it, and the voltage and current values collected by the energy storage controller are the average values of the three series-connected batteries. The Buck structure of the front stage is shown below:

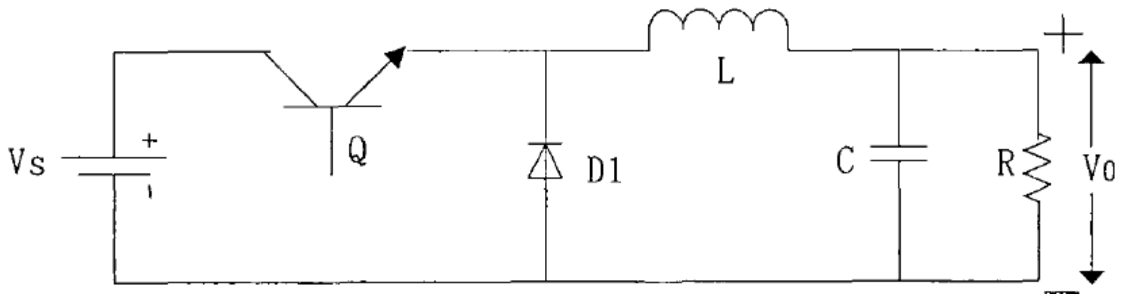

Figure 3.2.8 Circuit diagram of Buck converter

The figure consists of supply voltage Vs, transistor Q operating at duty cycle D, diode D1, inductor coil L, capacitor C and load R. By controlling the ratio of Q conduction and turn-off time, it realises the step-down of DC input voltage Vs to output voltage V0. The operation of a buck converter: When switch tube Q is switched on, as shown in the figure. The current through the inductor L increases gradually until it saturates,and the value of the same with the input current i_S; load R through the current value of the size of i_o, R output voltage value of the two sides of the value of V_0. When $i_L > i_0$, the capacitor C charging, the voltage of the diode D_0 for the upper positive and lower negative, was inverted cut-off. The switch Q on time is D_{TS}, for the switching cycle. In the figure, switching tube Q cut-off when. In order to keep the value of the inductor current constant, the polarity of the voltage across the coil L is altered by the action of the magnetic field in L. The inductor current i_L is set at a value of i_o.When $i_L < i_0$ capacitor C discharges to the load to keep the output voltage and current constant. At this time, the voltage of diode D_1becomes negative up and positive down, and the inductor current i_l provides a path during positive conduction operation, and is known as a continuity diode.

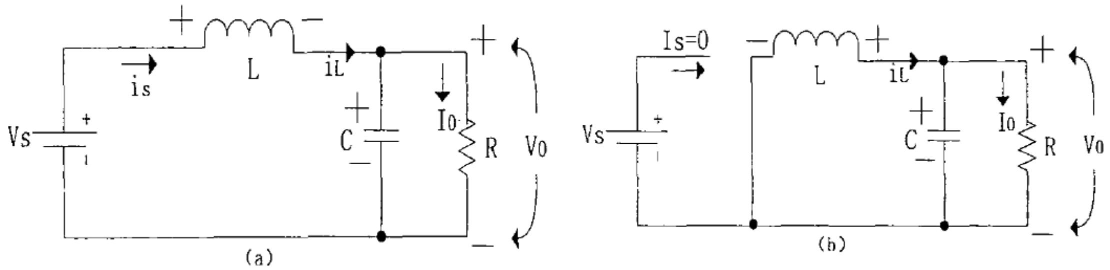

Figure 3.2.9 Buck converter circuit operating process

After the voltage reduction, the battery pack is charged and discharged through the Buck-Boost half-bridge structure, and the determining factor for charging and discharging is the PWM control signal, which is also the signal from the energy storage control system. From the energy conversion point of view, gravity energy storage is divided into two parts, energy storage and energy release, these two modes of operation are controlled through the energy storage and energy linkage device buck-boost to achieve, energy storage corresponds to the charging mode of the buck-boost device, energy release corresponds to the discharging mode of the buck-boost device. The following section explains the energy storage and potential energy process of gravity energy storage in terms of the control switching of the buck-boost mode.

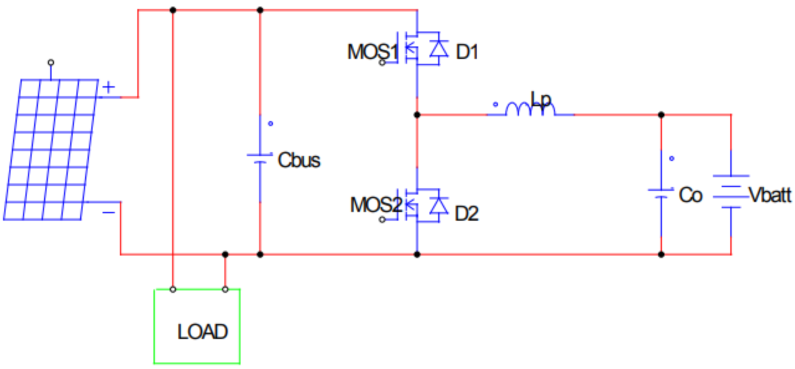

Figure 3.2.10 Buck-Boost Half-Bridge Converter

The above figure shows the schematic diagram of the half-bridge converter circuit, the structure type is buck-boost, the working principle of this structure is that if the power supply provides enough energy, the circuit works in charging mode, charging the electrical energy to the battery pack. If the energy provided by the power supply is insufficient, the circuit operates in discharge mode, and switching between the two modes can be achieved through the control of MOS or IGBT tubes. In the figure $L_P$is the filter inductor and C_o is the output capacitance which is chosen to be removed because of the intelligent control system system used in this paper.C_{bus} is the DC bus capacitance. The MOS switches D1 and D2 in the figure are processed with IGBT instead to obtain more excellent driving performance. In charging mode, the half-bridge Buck-Boost converter is used as a Buck converter and the current flow of the converter is from the DC bus to the gravity storage. In discharge mode, the half-bridge DC converter is used as a Boost converter and the converter current flows from the gravity energy storage to the DC bus.

CHAPTER4

RESULTS AND DISCUSSION

4.1 introduction

Based on the parameters and Mathematical equations discussed on Chapter 3 a PID based intelligent controller has been designed and developed using MATLAB together with GES model.

4.2Simulation modeling

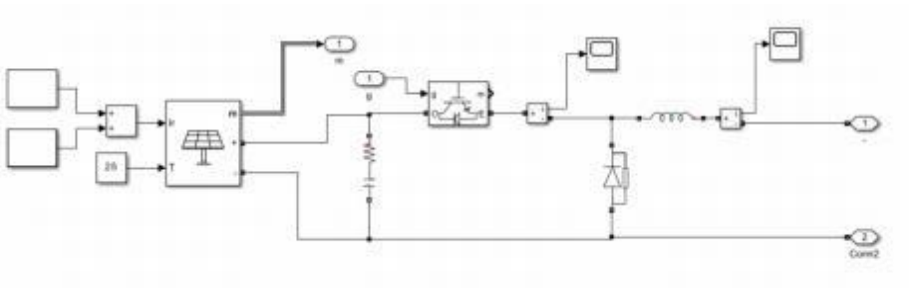

Fig.4.1.1 Photovoltaic Power Modules

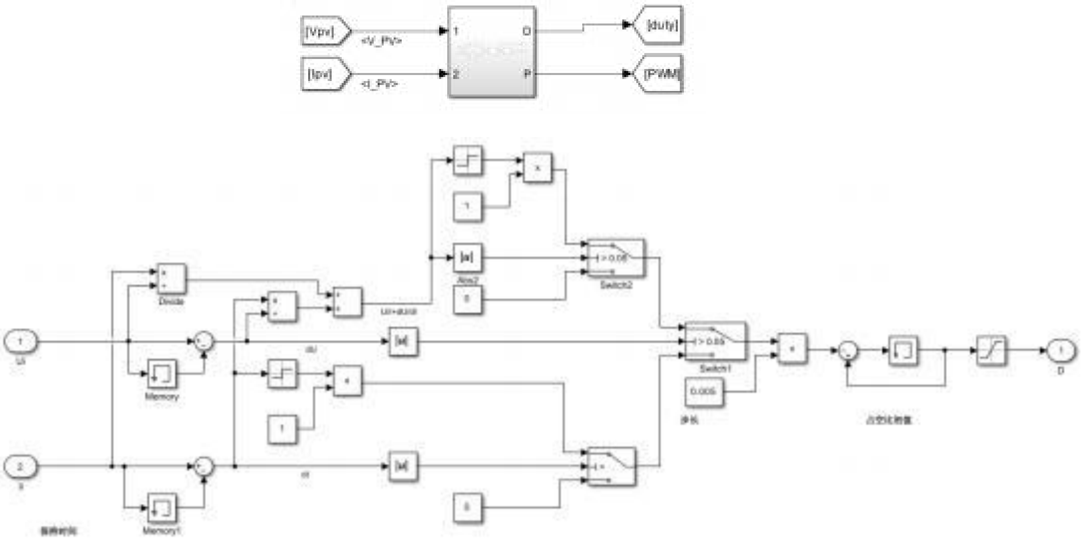

Figure.4.1.2 conductivity increment method

The above figure shows the PV power module which contains PV module and converter. The MPPT maximum powerpoint tracking strategy is adopted.

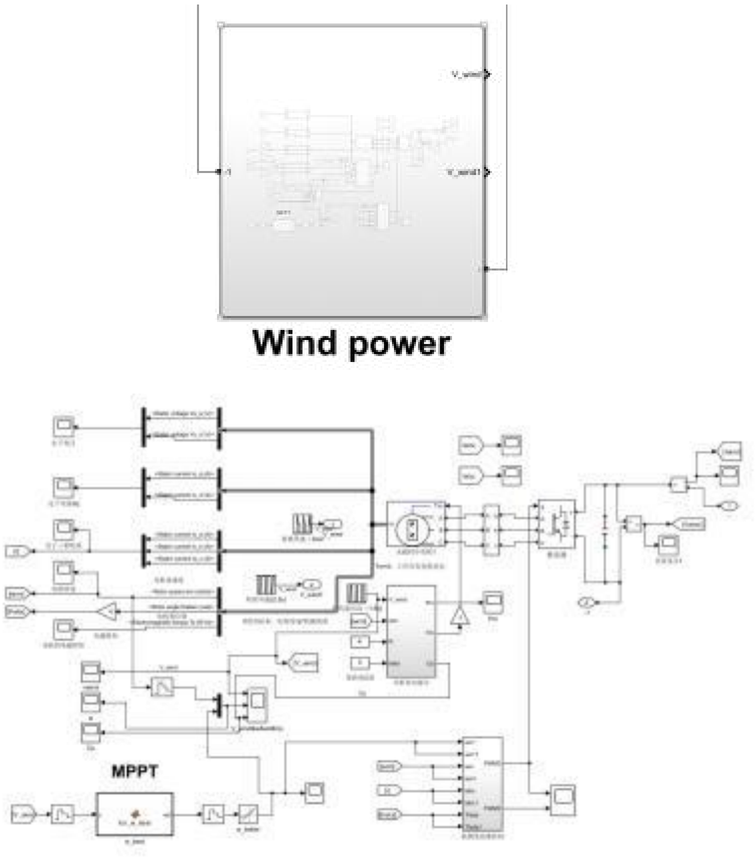

Figure.4.1.3 Wind power module

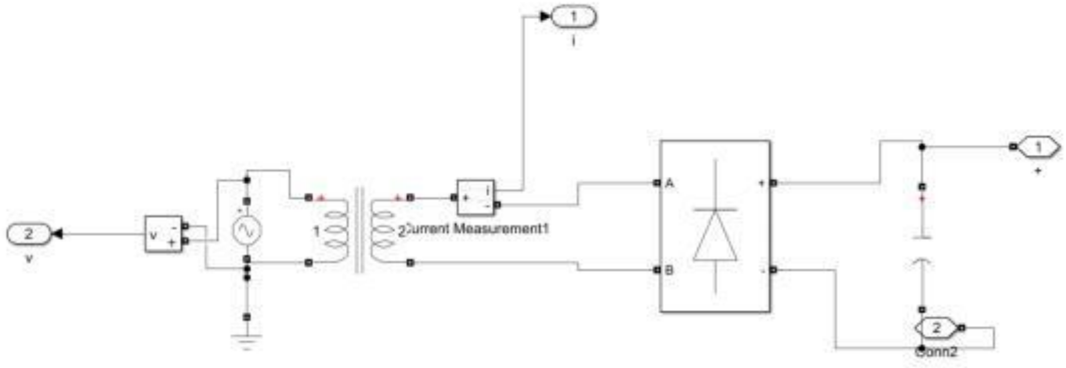

Figure.4.1.4 Inverse grid connection module

The inverter and grid-connection module consists of an uncontrolled inverter and a transformer to link the energy generated from power generation to the larger grid.

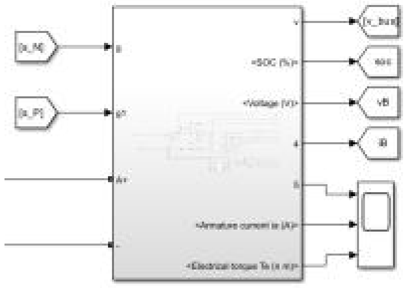

Figure.4.1.5 Gravity Energy Storage Module

In the figure, s_N and s_P are the output signals regulated by the PID controller that will act on the IGBT power tubes. v_bus is the DC voltage output from the buck module. iB and vB are the current and voltage values of the energy storage outputs

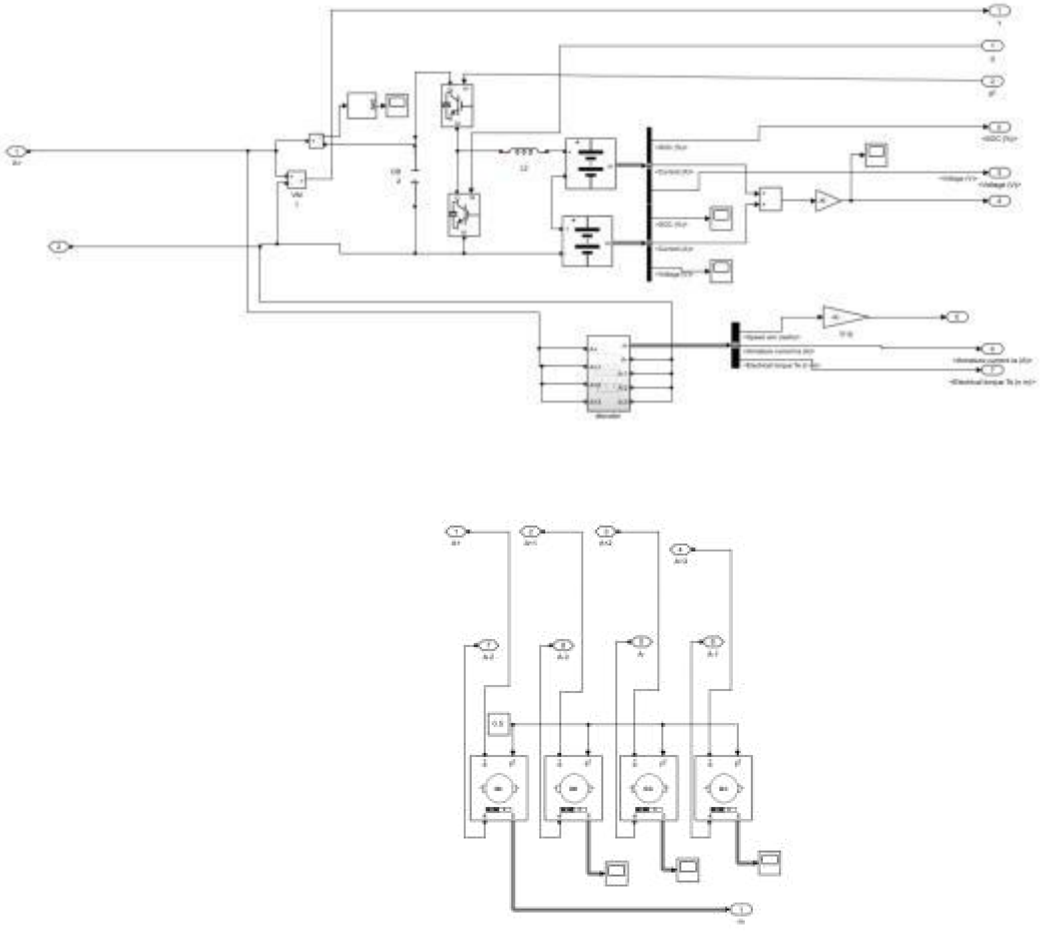

Figure.4.1.6 Gravity energy storage internal circuit

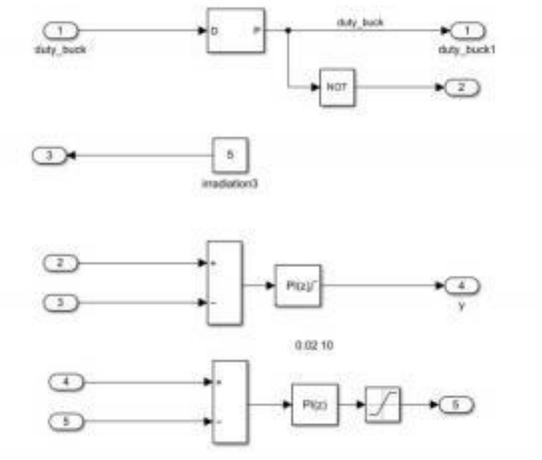

Figure.4.1.7 Gravity energy storage management strategy

In this study, when doing the modelling of gravity energy storage, the energy storage process is replaced by an electric motor and the potential energy process is replaced by an energy storage assembly to perform equivalent simulation of gravity energy storage. The intelligent control is taken as PID control strategy.

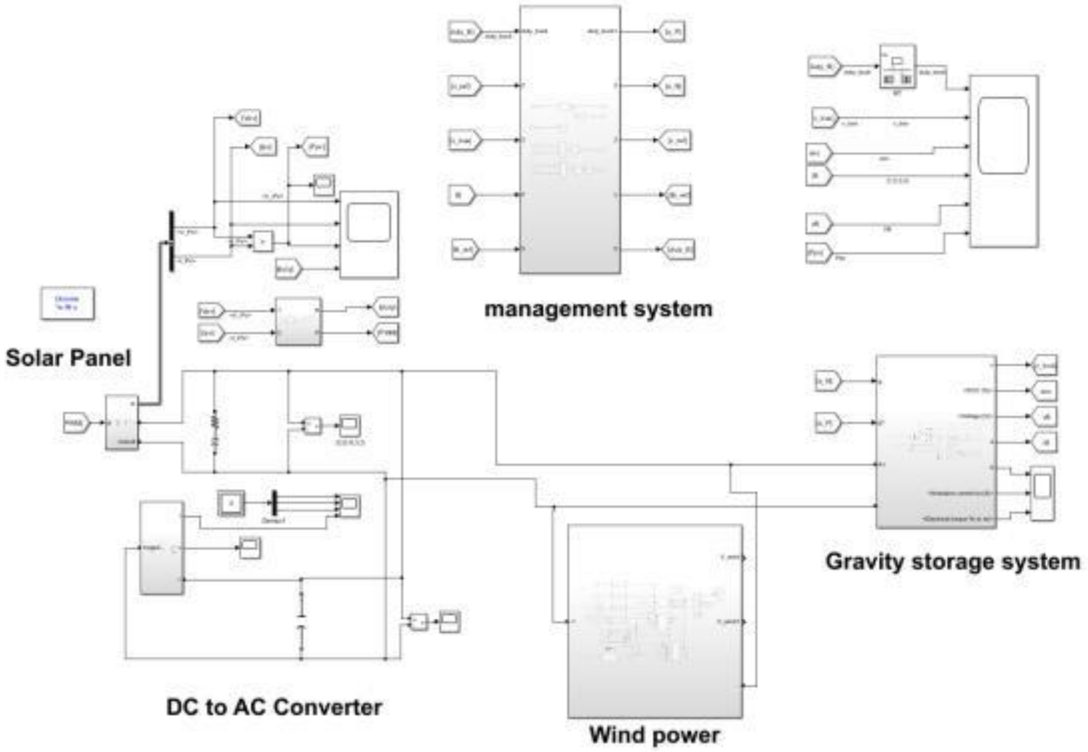

Figure4.1.8 Intelligent Control System for Wind and solar Energy Storage

4.2 simulation result

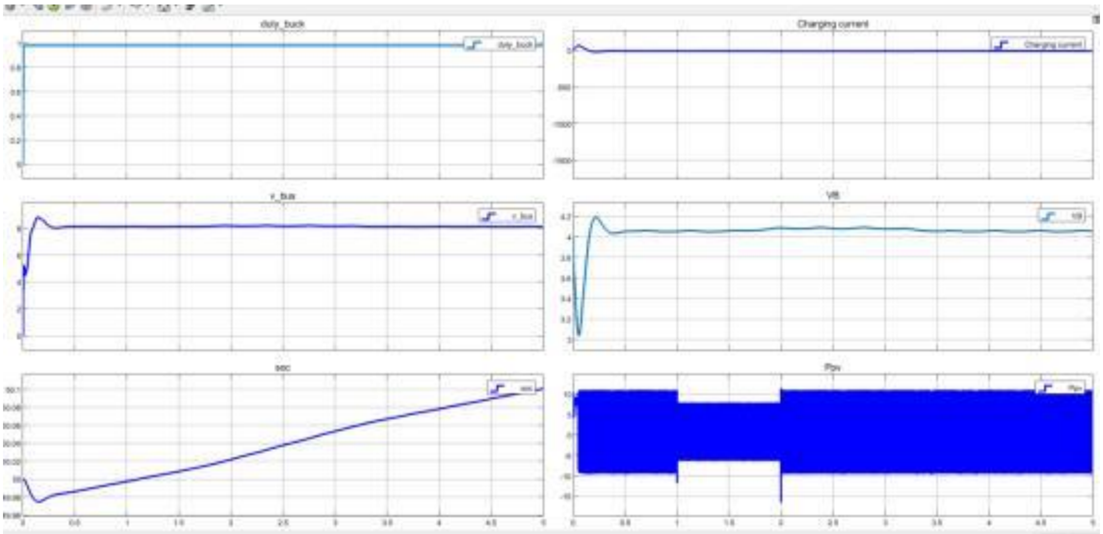

Figure.4.2.9 Simulation Results Figure 1

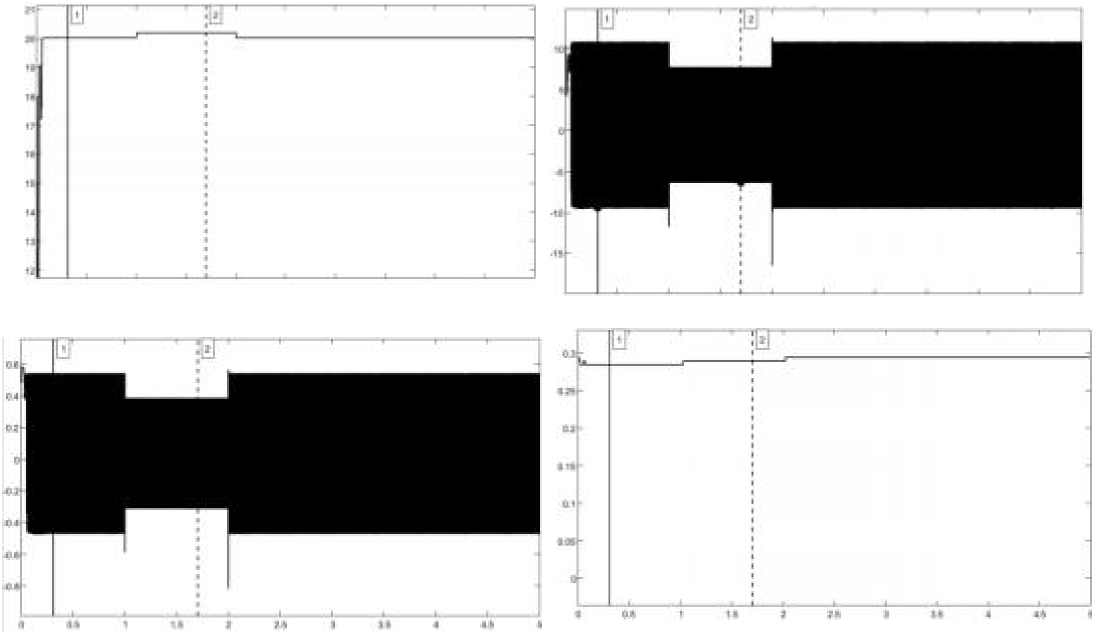

Figure.4.2.10 Simulation results 2(solar output voltage、power、current、PWMduty)

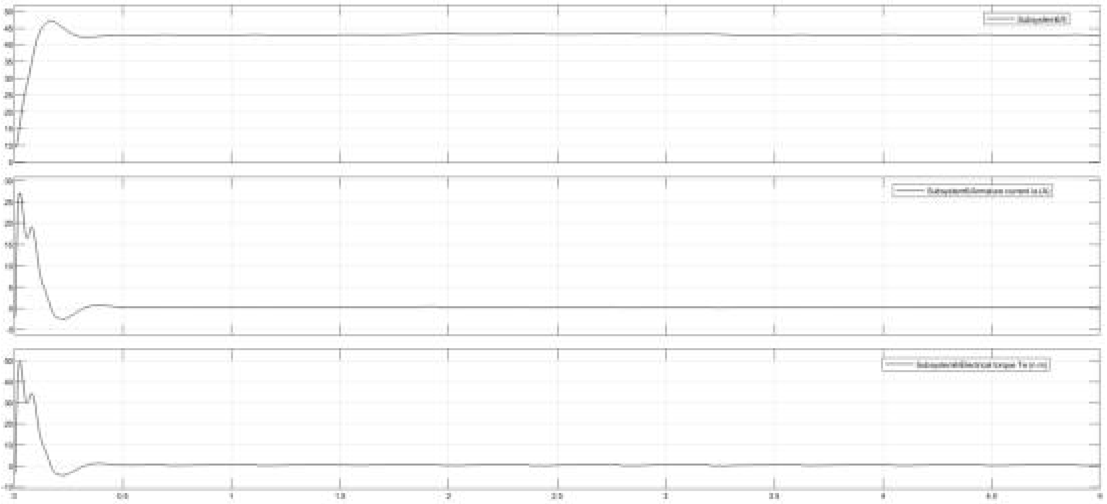

Figure.4.2.11 Simulation Results 3

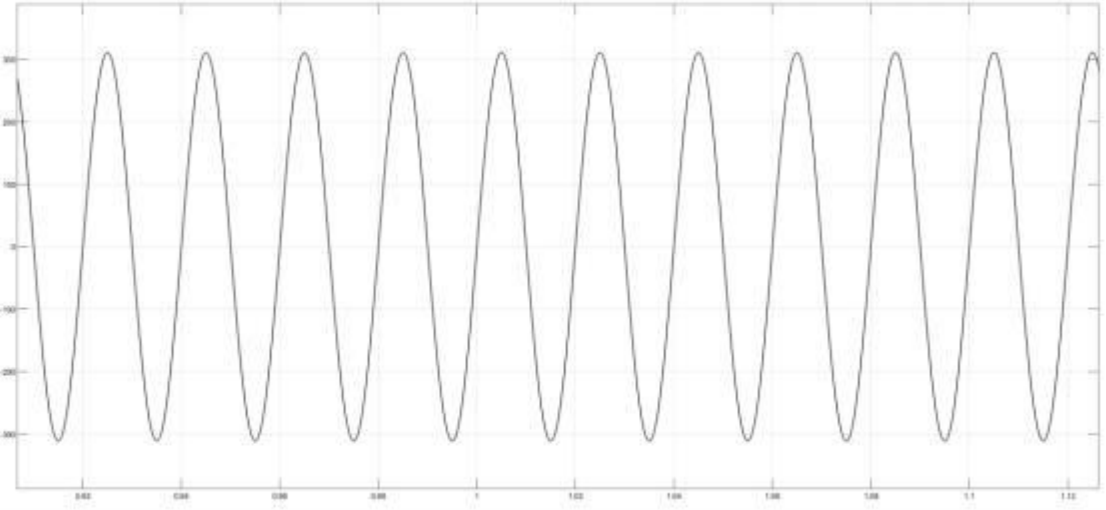

Figure.4.2.12 Simulation results 4

From Fig.4.2.11 subsystem6/5 it’s show the speed of the elevator, At the outset, voltage gradually increases due to the commencement of solar and wind power. Any excess power can then be channelled to elevate the piston in the gravity energy storage via the elevator. Once operational, voltage stabilises and the energy storage system's piston moves uniformly to store the power. Additionally, it is evident from Figure 4.2.9 that the Storage capacity of the system progressively increases, demonstrating the ability of the GES to store excess power when new energy sources are in use. The system is capable of storing surplus energy in the GES when newly produced. Nevertheless, the voltage that measures the strength of the energy storage system, Vb, also increases. Gravity energy storage differs from other forms of energy storage in that it requires a specific duration to accumulate energy. It is essential to note that Vb refers to the force arising from the directed acceleration of gravity acting on the energy storage system's mass.

From Figure 4.1, the management system receives force and connects the same ports. The energy storage system's voltage and current are measured at Vb Ib and sent to the PWM generator, which emits a signal to the open light device s_N. This device is utilized to regulate the energy storage system's charging and discharging. The PID control system introduced in Chapter 3 controls the entire control system's logic.

At the beginning of the simulation, I in the PID control system is set to 0, the P value set in 60% -70% of the allowable range of the system, after running simulation will appear system shock, then adjust the P value until the system shock stability, get set p value of 0.05. Next keep P value unchanged, in the case of time integral to 0,the I value set in the system allowed range, this range is usually between 60% and 70%, through running simulation, gradually lock I value, until the system shock stability. Finally, the I value is set to 1.5 of the obtained value (the I value is 10), and the D value is obtained with the same operation.

As shown in the above results, after grid-connected control, each wind-solar-storage module can reach a stable state, and the output waveform of the large power grid after grid connection.

Chapter5 Conclusions and Recommendations

5.1Problems Encountered

The development of the GES system, being a nascent technology, faces significant research gaps. Gravity energy storage systems have limited literature available, predominantly focusing on the economic perspectives rather than the technical intricacies. So the internal modeling of gravity energy storage is rough, This dearth of information, coupled with the complexity inherent in GES systems, poses challenges in system design.

Moreover, the utilization of MATLAB/SIMULINK software has introduced troubleshooting complexities, significantly slowing down simulations and causing frequent crashes. These software-related issues have impeded the acquisition of substantial results, addingto the difficulties in the research process.

Recommended Solution

In the future, for the grid-connected operation of gravity energy storage, it is necessary not only to pay attention to the optimization and analysis of the control system, but also to optimize the gravity energy storage in terms of structure and raw materials

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