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Solar Photovoltaic and Wind Turbine System Design and Optimization Analysis for Commercial Building

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Abstract:*In recent years, global warming and limited reserves of conventional energy, such as coal and oil, have become critical problems for all countries. Therefore, governments have invested a lot of resources in the development and promotion of renewable energy sources, which can achieve the goal of energy saving and emission reduction. The development of renewable energy in Hong Kong has encountered more obstacles than other countries, such as small space, high-rise buildings, and unpredictable weather. Fortunately, solar and wind technologies have developed rapidly and maturely, and there is less system space than other renewable energy sources, so they are more suitable for use in Hong Kong. In this paper, the feasibility of solar and wind energy application in commercial buildings will be explored in detail. The working principles and design methods of the two systems are described respectively. The main components of the system, such as PV panels, wind turbines, inverters and control circuits, are analyzed and described in detail. Using PVSYST and other software to analyze the solar radiation and wind intensity in the area in a year, find out the appropriate installation angle and location for the system. Finally, the power output of solar and wind power systems are calculated and the control circuit is simulated and modeled by using MATLAB software.*

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I. Introduction

There are two main types of renewable power systems: Grid-connected system and Off grid System. In this paper, solar energy and wind energy will be represented in Grid-connected and off-grid form respectively [1].

1.1.Grid Connected System

Solar or wind power systems are interconnected with the public grid, which is called grid-connected systems. It brings solar and wind energy into the stage of large-scale commercial power generation and promotes the mainstream trend of the integration of building and renewable energy in the world today. Most grid-connected systems are generally not equipped with storage batteries because the utility grid is a large storage battery. Electricity generated by photovoltaic and wind power systems will be preferentially supplied to the load. When there is excess electricity, excess electricity can be transferred to the grid. The excess electricity will be converted into AC power that corresponds with the public grid through power electronic devices. The system may also have insufficient power generation due to cloudless, windless or self-failures. At this time, it will automatically switch to the public grid, which will supply power to the load instead of the renewable energy system.

1.2.Off Grid System

Due to high mountains, sea islands and other remote areas, public grids may not be able to reach. In addition to environmental and technical considerations such as steep slopes and mounting submarine cables, the establishment of transmission systems should also be consideration of price, which may not be affordable for users. Independent photovoltaic or wind systems can overcome the above problems. The independent system of wind and solar is also called the off-grid system. Its main components are charge controllers and batteries. If the load is Alternating Current (AC), the system also needs to configure the AC inverter.

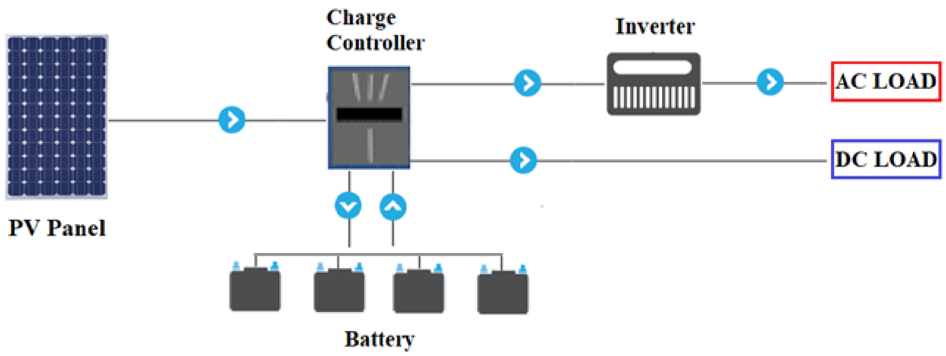


Figure 1.2 - Off-Grid System

The DC and AC PV system with battery is shown in Figure 1.2. When there is sunshine, solar panels convert light energy into electricity for load use and store energy to batteries at the same time. In the night and rainy days, the battery supplies power to the load.

1.3.Aims and Objectives

To explore the feasibility of developing solar energy and wind power as auxiliary fossil fuel power generation in Hong Kong. The industry and commerce have immense demand for power in the daytime that is a peak of electricity. If we utilize the characteristics of renewable energy wisely, we can not only achieve the goal of carbon reduction and environmental protection but also reduce the pressure of users on the utility grid [2].

1. In view of the geographical location and overall environmental conditions of commercial buildings, appropriate renewable energy systems are selected.
2. Through optimum design and analysis ensures the system fully meets the technical requirements, achieves the maximum power generation and reduces the construction cost.

PV system

1. Select the most suitable string from the power generation and power of the panel
2. The direction of the panel
3. Inverter selection

Wind system

1. The primary objective of wind turbine design is to maximize the aerodynamic efficiency or power extracted from the wind

II. Photovoltaic And Wind Turbine System Principle And Structure

2.1 The Principle of Solar Light Converting Electricity

Solar radiation from the sun to the earth contains light energy, which is absorbed by solar photovoltaic panels and converted into current, which is also known as direct conversion. Solar panels generate DC electricity when exposed to sunlight via the photovoltaic effect, first observed by a French physicist in 1839. A simple explanation is that the photons from sunlight are absorbed by a semiconductor material such as silicon. Negatively charged electrons are dispersed from the atom, then flow from the negative side to the positive side, and recombine with the holes there. At this time, if the load is connected to both sides of the built-in electric field,acurrentisgeneratedtosupplypowertotheloadasshowninFigure2.1.

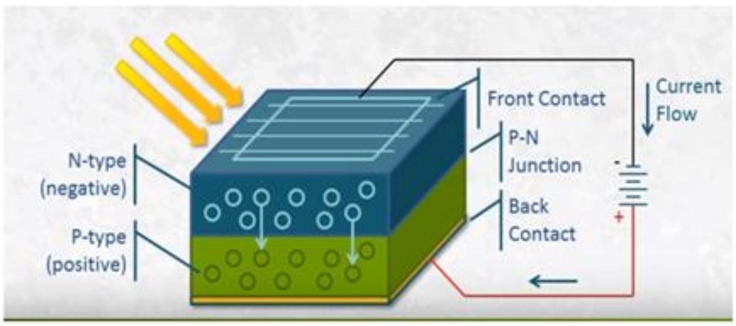
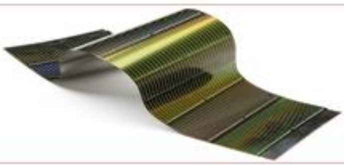


Figure 2.1 - Basic structure of photovoltaic cells from light to electricity conversion

2.2 Types of photovoltaic panels

Silicon and compounds are the main materials of solar panels. Monocrystalline silicon and polycrystalline silicon are the most common types of solar panels on the market. Compound semiconductors have high conversion efficiency but are expensive. It is mostly used in space science and technology and is generally not used for civilian purposes. The following table shows the efficiency of various solar panels.

Table 2.2- Efficiency of Various Solar Panels

Material type		Conversion efficiency
Monocrystalline Silicon		13-16%
Polycrystalline Silicon		12-15%
Amorphous Silicon (SiH_4)		6-10 %
Thin Film		15%

Individual solar cells produce approximately 0.5V, which is not sufficient for the load to operate. Thus, the cell must be connected in series and parallel in order to generate sufficient power for high-power applications. Multiple solar cells are connected together to form a module, or more modules are used to form thearray,asshowninFigure2.2.1

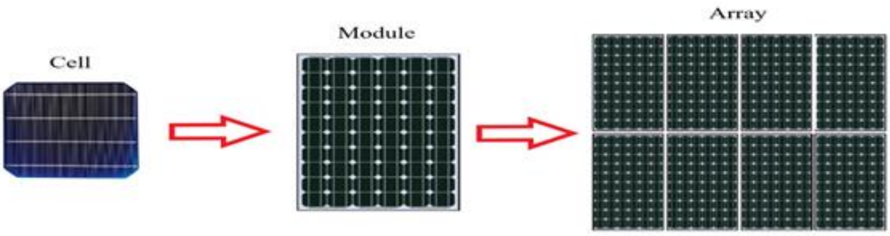


Figure 2.2.1 - Photovoltaic cells, Modules, and Arrays

2.3 Conversion process of wind energy into electrical energy

Wind is the flow of air. Windmills convert the kinetic energy of wind into mechanical rotational energy, which can turn generators to generate electricity. This conversion process is called indirect conversion, which is different from solar power generation. Wind turbines can also be divided into horizontal axis wind turbines (HAWT) and vertical axis wind turbines (VAWT) [3.4].

Figure 2.3.1 - Horizontal axis wind turbines (HAWT) in HK Lamma Island

Figure 2.3.2. - Vertical axis wind turbines (VAWT) on the commercial building

The direction of the shaft and the rotating axis determines the type of wind turbine. Turbines with the main rotor shaft installed parallel to the ground level are called horizontal axis wind turbines or (HAWT). The main rotor shaft is oriented vertically instead of horizontally that is known as the vertical axis wind turbine or (VAWT).

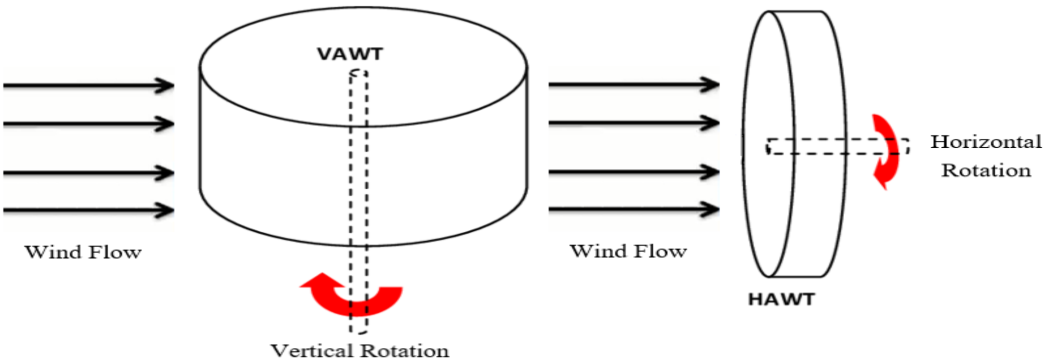


Figure 2.3.3. - Configurations for shaft and rotor orientation

Table 2.3.1 - VAWT Comparison With HAWT

	HAWT (Horizontal Axis)	VAWT (Vertical Axis)
Terrain	limited by terrain	Unlimited by terrain
Noise Level	High	Low
Maintenance Costs	High	Low
Installation Cost	High	Low
Output Efficiency	High efficiency at high wind speeds	Lower efficiency

Today's wind turbines convert large amounts of wind energy into electricity. This is due to the blades which are developed using state-of-the-art aerodynamic analysis and other performance-enhancing equipment. When the wind can turn the wing, we will receive electricity from the generator connected to it.

2.4 Main components of the wind turbine

The main components of horizontal axis wind turbines are wind wheels, towers, wind control devices, and gearboxes. The structure is shown in fig 2.4.

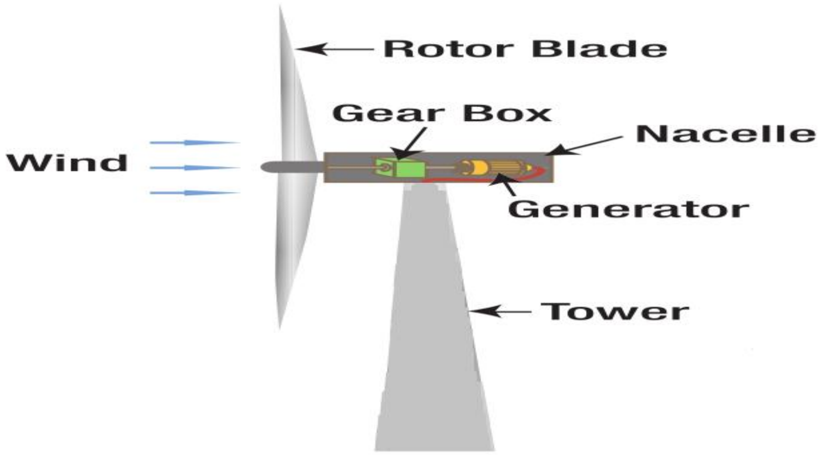


Figure 2.4 - Basic Structure of Wind Turbine

1.) Rotor Blade: In this paper, a small wind turbine composed of three-blade rotors will be selected. It is to be designed to rotate in a clockwise direction to utilize the energy from the wind. The blades are normally fixed to the hub at an appropriate angle of attack for the lift force to act upon and make them rotate.
2.) Gear Box: The wind speed often changes, and the rotor runs at a lower rotational speed cannot rotate the generator directly. In this time wind turbine use a gearbox to convert relatively slow rotation of the rotor to match the high RPM of the electric generator. The gearbox contains braking devices to prevent excessive rotor speed.
3.) Tower: Wind turbines need to be far from the ground to generate higher wind speeds. Towers need to withstand two main loads 1) the weight of wind turbines 2) wind resistance.

2.5 Integration of technology and components

Storage Battery

Batteries can store electricity generated by solar and wind power systems. It can provide power to loads when insufficient sunshine and wind, at night and in emergencies. Renewable energy systems often use lead-acid batteries, which can divide into two types of power battery (shallow cycle battery) and deep cycle battery. Power batteries can generate a very large amount of current for a short period of time. They are often used to start car motors or engine, so they are called car batteries. When the engine has started, the alternator will replace the battery and supply all the power for the car. Deep-cycle batteries can provide a steady current to the load for a long time. The discharge depth of shallow-cycle batteries is less than 25%, while deep-cycle batteries can release 80% of the electricity. Deep cycle batteries have a longer life than power batteries and more times of discharge and charging. Therefore, deep cycle batteries are more suitable for renewable energy systems.

Charge Controllers

The characteristic of the solar photovoltaic controller is to control the working state of the entire system. The main function of the controller is to prevent the battery over-charging and over-discharging. Cyclic charging and discharging times and discharging depth are important factors to determine the battery life, so a good controller can provide a good working environment, which greatly prolongs the battery life.

The function of the Inverter

Whether wind or solar or other renewable energy systems must use it, it is an inverter.The inverter changes a dc voltage into an ac voltage and either increase or decrease it into the appropriate level, for instance, converting 12V, 24V or 48V DC to 110V or 220V AC power.

With the development of power electronics technology, high-frequency switching technology, and soft switching technology are used in the new photovoltaic inverters to realize high power density multi-stage topology, such as the two-stage (DC-DC-AC) or three-stage (DC-AC-DC-AC) circuit.

III .Methodology

3.1 Introduction

The commercial building power generation is divided into two parts: 100 kW roof solar photovoltaic array and 2kw small wind turbine system [5,6]. Since the solar system is connected to the grid, there is no need to equip the storage battery. On the contrary, the wind system turbine is an off-grid system that is not connected to the grid. Therefore, it is necessary to assemble storage batteries to ensure steady power supply. In this chapter, the design methods, performance characteristics, and applications of each system will be introduced.

3.2 100kw Grid-Connected PV array in building roof [7,8]

The solar arrays on the top floor of the building mainly provide a total of 100kW for lighting, computer circuits, air conditioning systems and other loads. The load operates in the daytime for approximate 8 hours, the average electricity consumption is 90kwh, and the utility power supply is three-phase AC 380V/220V 50Hz. System content is shown in Figure 3.2.

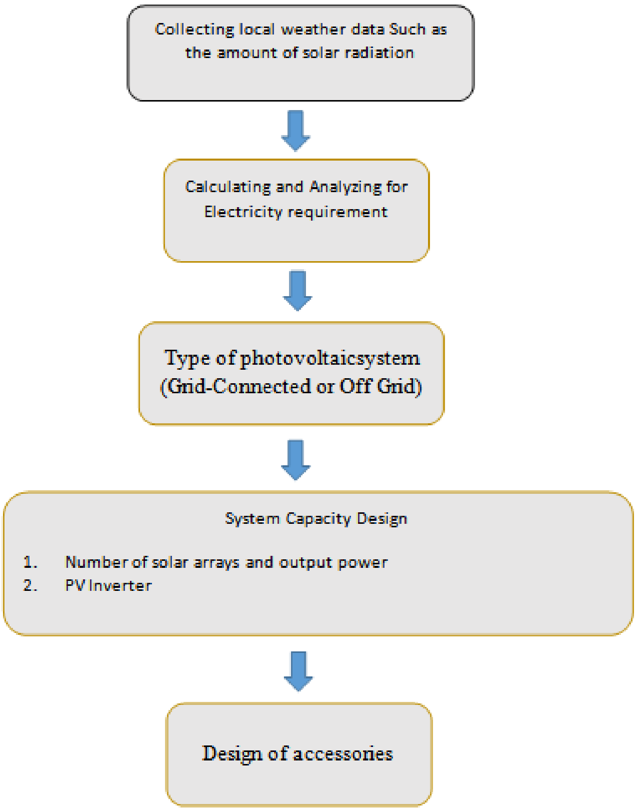


Figure 3.2 - Design steps and contents of the 100kW solar system

Table 3.2 - Load usage power situation for 1-10F office

Load description	Load power (VA)	Quantity	Totals Load (VA)
Lighting circuit	1200	4	4800
Computer circuit	300	4	1200
Refrigerator	125	2	250
Coffee maker	1000	1	1000
Microwave oven	900	1	900
Printer	50	2	100
Projector	80	1	80
Television	100	1	100
Air-conditioners	1500	1	1500
Furnace blower	500	2	1000
Totals	5755		10930

3.21 Selection of photovoltaic panels

The original design is to select the SANYO HIT panels to meet the demand, but the cost is too high. After optimization design and cost comparison analysis, TSM-180 Monocrystalline silicon module is adopted instead. It has a conversion efficiency of 14.1% and stable performance, which fully meets the requirements. It is worth mentioning that its cost is nearly 30% cheaper than HIT and the output efficiency of both is quite close. The parameters of two solar modules are shown in Table 3.21.

Table 3.21 - Specifications of TSM-180 and HIT-210N

Model	HIT-210N	TSM-180
		
Size (length X width X height)	1581 X 789 X46	1581 X 809 X 40
Peak Power（Pm）	210W	180W
Open Circuit Voltage (Voc)	50.9V	44.2V
Short Circuit Current（Isc）	5.57A	5.35A
Maximum Power Voltage（Vmp）	41.3V	36.8V
Maximum Power Current （Imp）	5.09A	4.90A
Maximum System Voltage	600V	1000V
Temp. Coefficient of Power	-0.34%	-0.45%
Temp. Coefficient of Voltage	-0.142	-0.35
Peak Efficiency	16.70%	14.10%

The PV module has a power of 180W, a peak output voltage of 36.8V and an open circuit voltage of 44.2V. A total of 648 solar cells are configured. 18 PV modules are connected in series to a photovoltaic array, which consists of 36 photovoltaic arrays in parallel as shown in Figure 3.21. PV array can produce a total of 116,640W of electricity.

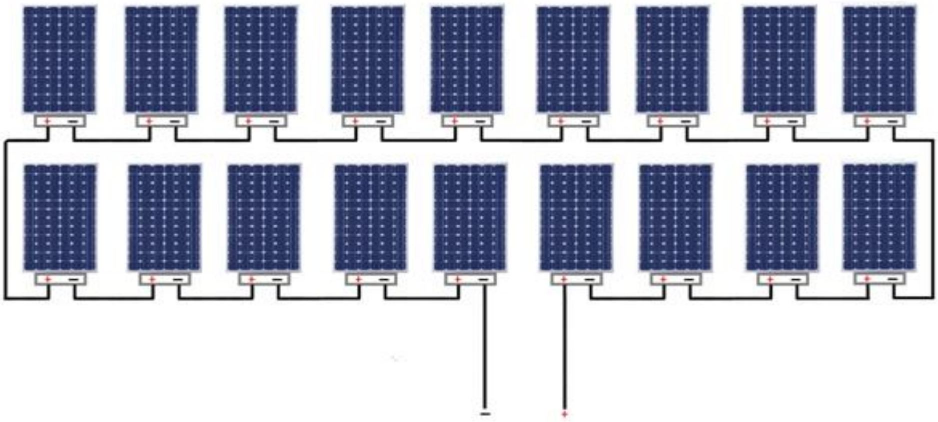


Figure 3.21 - 18 PV modules (TSM-180) in series

3.22 Installation Position and Direction of Solar Array

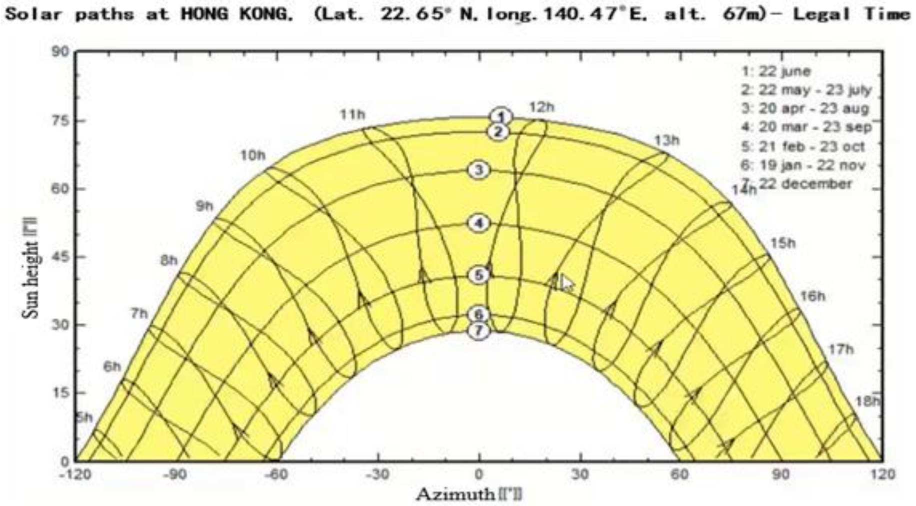


Figure 3.22A - Measurement of solar radiation in Hong Kong using PVSYST

In this paper, PVSYST software is used to measure the annual sunshine time and solar radiation of commercial buildings as shown in Figure 3.22A. The results show that the longest sunshine time and solar radiation are in June (Line 1), and the shortest is in December (Line 7). There are obvious differences in the amount of radiation in winter and summer, so the bracket adopts the adjustable tilt angle mode. As long as the tilt angle is adjusted twice a year, the system can make 3% more electricity. The two optimal angles for the adjustable bracket system design are 10°and 25°respectively.
(22 May - 26 November): Solar panel tilt angle is 10
(27 November - 21 May): Solar panel tilt angle is 25

In order to obtain a larger amount of electricity, all the PV panel will always be 22.5° south facing direction. Ensure that solar panels are firmly fixed to the ground through cement grouting so that they can be protected in all weather conditions.

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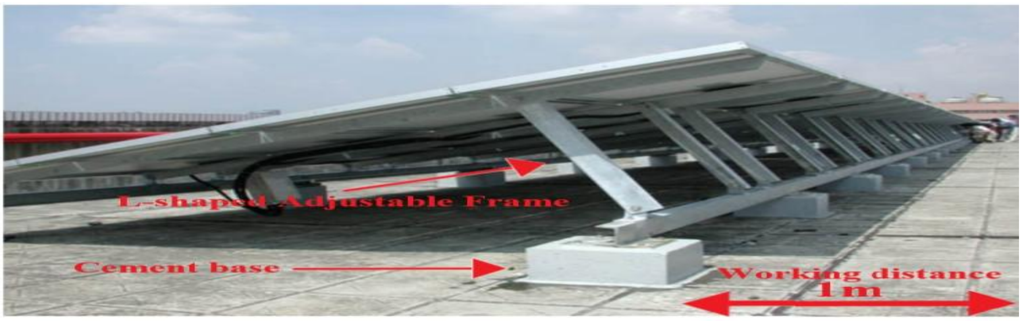


Figure 3.22B - Installation position and situation of solar array

This project uses monocrystalline silicon solar cell components, which will have a great impact on power generation if there is shadow blocking. Since solar radiation is the largest during the period from 9 a.m. to 14 p.m., the spacing design should ensure that the arrays are not shaded by each other during this period. Combined with geographical location and shadowing software analysis and calculation, the installation distance between the front and rear of the solar panel is set to 1m.

3.23 Bypass Diode in PV panels

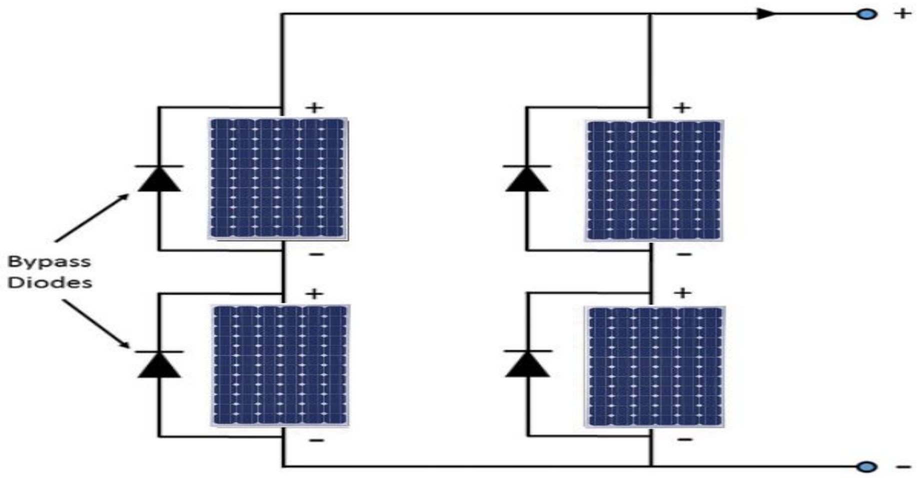


Figure 3.23A - Bypass diode connection diagram

The bypass diodes are connected in parallel with each PV module as shown in Figure 3.23A, which is vital components to provide the first protection for the entire 100 kW solar energy system. Bypass diodes are used to reduce the power loss of solar panels caused by shadows. According to the characteristics of current flowing from high voltage to low voltage, when solar panels have partially shaded cells, current is forced to pass through low voltage shaded cells. This causes solar panels to heat up and suffer severe power losses. In this case, shadowed solar panels will only become electricity consumers rather than producers.

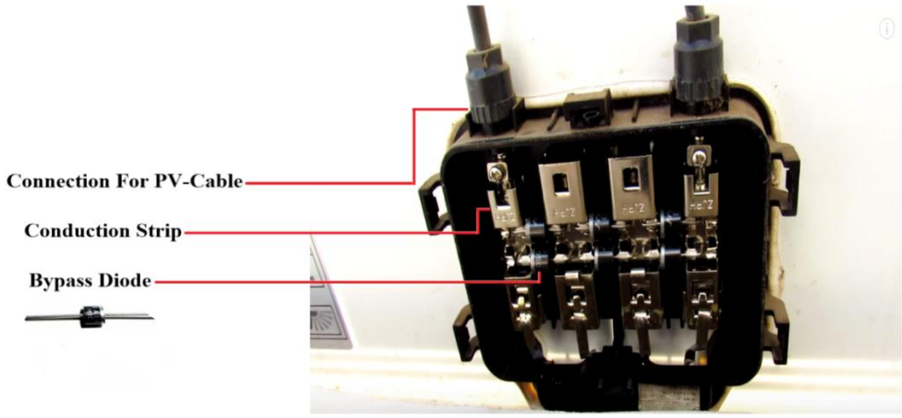


Figure 3.23B - Junction Box of Solar Panel with Bypass Diode

As shown in Figure 3.23B, the bypass diode is mounted in the junction box to provide a low resistance path for the current to bypass a series of shaded solar cells. Diodes are connected in parallel with the panel. Since the current takes the path with the smallest impedance, it is easier for the current to pass through the diode than through the shadow cell.

3.24 Design and layout of DC Combiner Box

In order to reduce the number of the line between the PV array and the inverter, and to make the maintenance more convenient in the future, the combiner box is installed at the DC terminal. The reduction of the DC cable will reduce the loss of the line and ensure the maximum efficiency of the whole system. At the same time, it also reduces the cost, because the prices of dedicated DC photovoltaic cables are much higher than AC cables. The input of the combiner box is 6 DC lines and the output is 1 DC line. That is the 6-channel photovoltaic arrays are merged into one DC output, and each 50kW inverter needs to be equipped with 3 sets of combiner boxes. Electrical schematic of the DC combiner box is showed below.

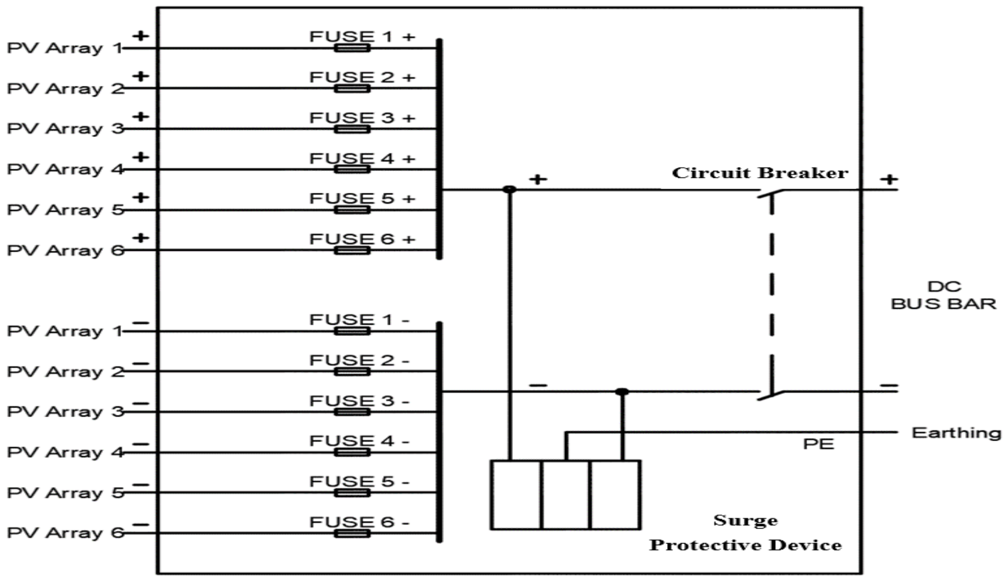
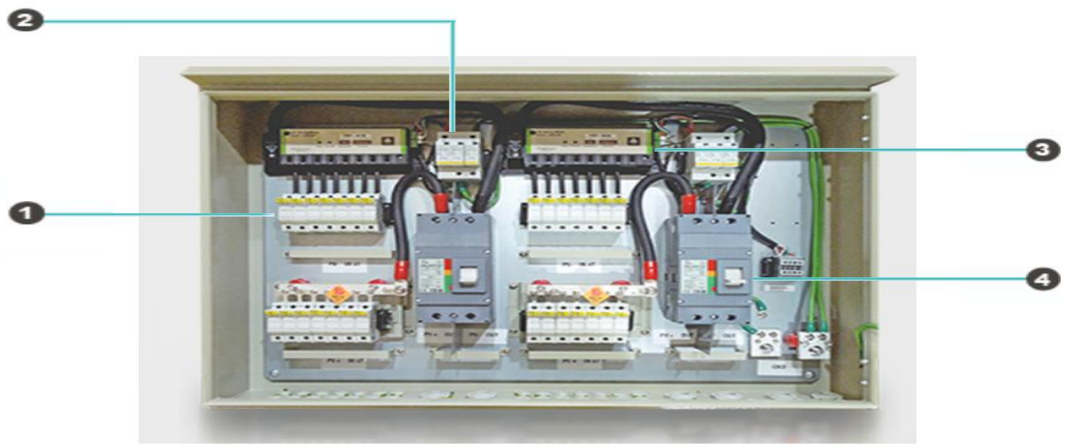


Figure 3.24A - Electrical schematic of the DC Combiner Box

Figure 3.24B shows the internal basic circuit of the DC combiner box, which consists of fuses, DC circuit breakers, PV string monitors and other components. Ensuring the safety and reliability of the photovoltaic power generation system, to prevent damage to the system components caused by external factors such as lightning strikes and surges, it is equipped with a Surge Protective Device (SPD).

Figure 3.24B - Internal Structure of DC Combine Box

1. PV Special fuse



2. Surge Protective Device (SPD)
3. PV string monitors
4. DC Circuit Breakers

3.25 PV Inverter Selection

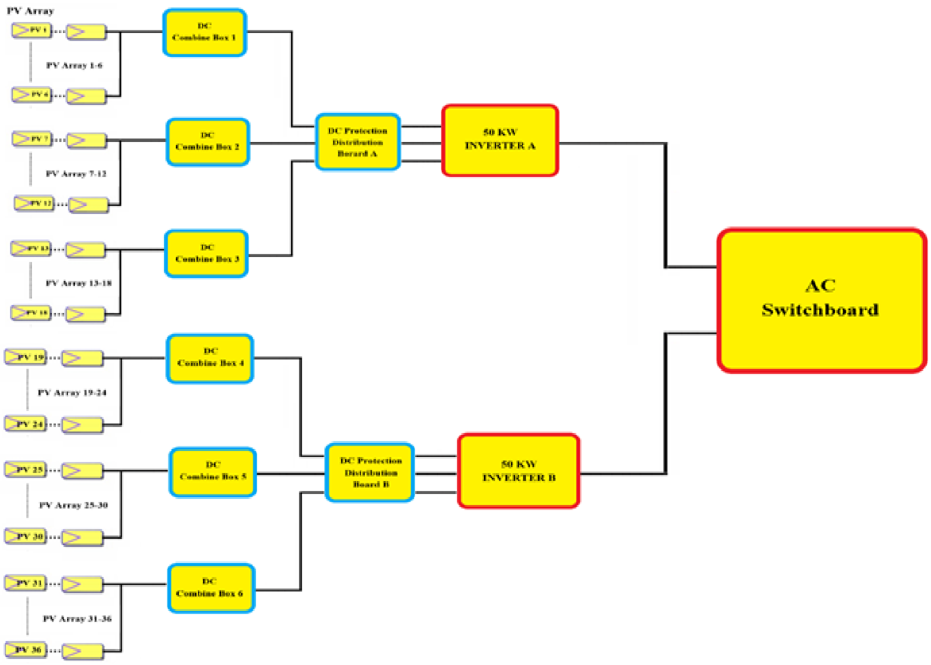


Figure 3.25A - Solar system Circuit Diagram

This design does not use a 100KW three-phase inverter but chooses two 50KW three-phase grid-connected inverters. The main reasons are as follows.

The selection of photovoltaic inverters is based on the DC output voltage of PV array and type of the load. The inverter power should be greater than the total load power.

The PV array passes through the 6 DC combiner boxes, 2 lightning protection distribution boxes and then enters the 2 inverters as shown in Figure 3.25A. We chose SUNGROW's SG50KTL-M-20 inverter, which is a string inverter with up to 3 MPPTs as shown in Figure 3.25B. In the selection of inverters, central inverters have been considered at the begin, but its maximum power tracking (MPPT) system cannot monitor the operation of each PV cell string. Therefore, it is not possible to bring each PV array to the state of MMPT. Since the PV module may be covered by buildings in the north and east at 9 am, the SG50KTL-M-20 inverters have their own MPPT functions, which are not affected by the performance difference and partial shading of the photovoltaic modules between the strings.

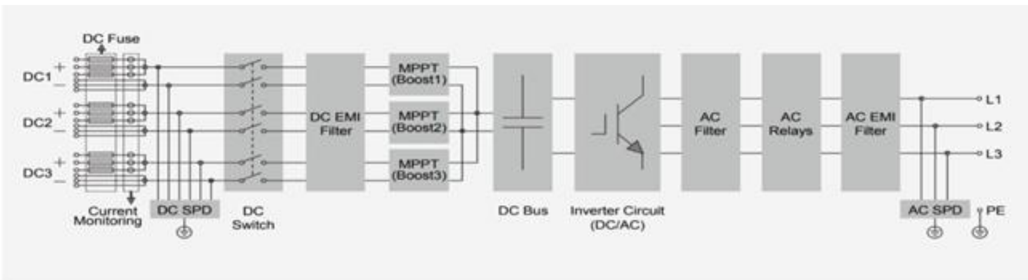


Figure 3.25B - Basic Structure of SG50KTL-M-20 Inverter

PID

The circuit principle of three-phase grid-connected inverters is shown in Fig. 3.25B, which is divided into two parts: the main circuit and a microprocessor circuit. The main circuit mainly carries out DC-DC-AC conversion and inversion process, and the microprocessor circuit mainly processes the control process of grid connection. The purpose of system grid-connected control is to maintain the AC voltage value, waveform, phase, etc. at the output of the inverter within the specified range. Therefore, the microprocessor control circuit needs to complete the grid, phase real-time detection, current phase feedback control, photovoltaic Maximum power point tracking (MPPT) and real-time Sinusoidal Pulse Width Modulation (SPWM) signal.

1.) The monitoring process of the inverter control part is as follows:
Firstly, the voltage and phase of the utility grid are transmitted to the microprocessor's A/D converter via the Hall-effect sensor. Then the phase of the feedback current of the microprocessor is compared with the voltage phase of the utility grid. Finally, the error signal is transmitted to the PWM by the operation and adjustment of the PID arithmetic, which completes the power factor 1 power feedback process.

The other main task of the microprocessor is to achieve the MPPT of the PV array.

2.) The MPPT process of the inverter control part is as follows:

Voltage and current sensors detect the output voltage and current of the photovoltaic array and multiply them to obtain the output power of the PV array and then to adjust the duty cycle of the PWM output. The adjustment of this duty cycle is actually to adjust the magnitude of the feedback voltage to achieve Maximum power point tracking.

String Maximum power point tracking (MPPT)

SG50KTL-M-20 Inverter with three-way MPPT function allows only three-way photovoltaic module input. After calculation, each MPPT can input 6 sets of PV arrays, and 3 MPPT can input 18 sets of PV arrays. Since the system uses two 50 kW inverters instead of one 100 kW inverters, the number of MPPTs increases. Therefore, MMPT can monitor more groups of photovoltaic arrays.

Anti-islanding effect function

SG50KTL-M-20 Inverter uses passive detection method (voltage phase jump method). The inverters periodically detect the AC voltage period of the inverters. If the voltage cycle deviates and exceeds the set value, the system will be judged as a separate operation state. At this time, the inverter stops running or disconnects from the grid.;

(1) It can avoid huge power loss when some photovoltaic modules are shaded, and improve the overall efficiency of power generation system.
(2) The system is divided into two 50KW grid-connected units with a total power of 100KW. SG50KTL-M-20 is a string inverter with up to 3 series MPPTs.

3.26 Monitoring and Communication System

The building uses SUNWARE monitoring software to monitor the solar energy system 24 hours in real time. The operation parameters of the two inverters are transmitted to the data collector through RS485 communication. The data collector receives the signals of the inverters and sensors including temperature, humidity and solar radiation, and then transmits the data to the monitoring computer for analysis and processing. SUNWARE monitoring software will display the output power of the photovoltaic system, the day (cumulative) power generation and generation time, the voltage and current of the photovoltaic array, the intensity of sunshine and environmental temperature and other operating parameters. At the same time, it has a built-in database, users can query the system's historical records.

- List of Solar Energy System Structures

Z	Specifications		Quantity
PV Panel	TSM-180		648 pieces
PV panel bracket			
DC Combine Box			6 Sets
DC Protection Distribution Board			2 Sets
Grid-connected inverter	SG50KTL-M-20		2 Sets
AC Switchboard			1 Set
Data Collector			1 Set
Environmental Sensor			3 Sensors (Temperature, Humidity and Solar Radiation)
Monitoring platform			1 Set
Wires and accessories			

3.3 2 kW Wind Turbine System for Staff Lounge
3.31 Regional Wind Speed Prediction

In this paper, the average annual wind speed of the Hong Kong Observatory is used as a reference to evaluate the wind speed in selected areas as shown in Figure 3.31. Table 3.31 is based on the discrete data of Figure 3.31, which makes it easier to understand the 24-hour wind conditions in the area. As can be seen from the figure below, the wind speed in this area is over 8 m/s for most of the time, only from 9:00 to 10:00 am is breeze or windless. The cut-in wind speed of small wind turbines is usually about 3 m/s, while the rated wind speed is 12 m/s or higher. Therefore, small wind turbines are best installed at an average wind speed of more than 5 m/s. According to Table 6, the average wind speed in Tsuen Wan is greater than 5m/s, so the building is suitable for installing small wind turbines.

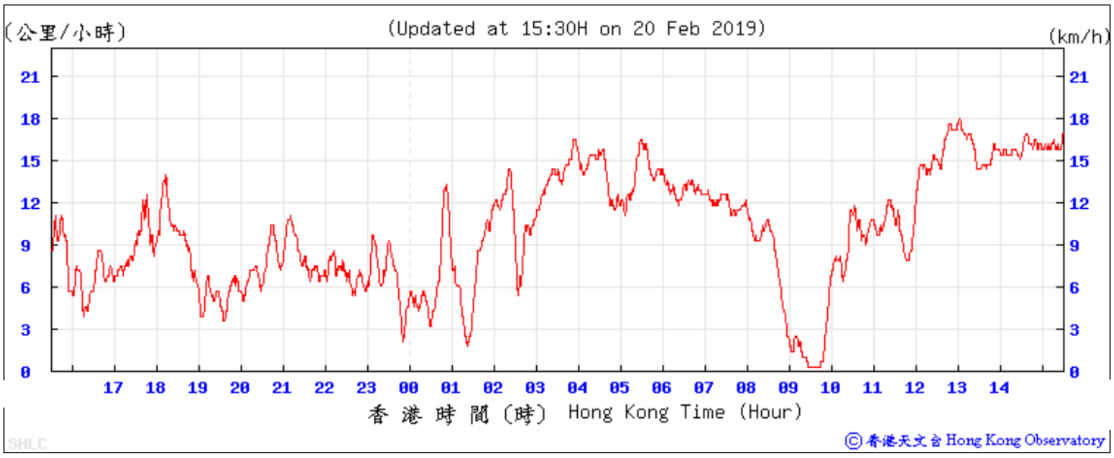


Figure 3.31 - 24-hour Average Annual Wind Speed and Duration

Table 3.31 - Wind Speed Duration Time Table

Wind Speed Duration Time Table				
Wind speed (m/s)	0-3	3-8	8-12	>12
Duration Time (hrs)	1	4	7	12

3.32 Load power consumption

In addition, whether the power generated by the wind turbine can meet the load should also be considered. Assume that the load of the lounge has five energy-saving lights, TV, refrigerator, fan and computer as shown in Table 3.32.

Table 3.32 - Electricity Consumption in The Lounge

It can be seen from the Table 3.32 that the average daily electricity consumption in the lounge is about 3 kwh.

0	Energy-Saving Lights	TV	Computer	Refrigerator	Fan
Rated Power (W)	15	200	150	120	50
Average Daily Power Consumption Time (h)	5	5	2	10	8 (From June to September)
Quantity	5	1	1	1	1
Daily electricity consumption (kWh)	0.375	1	0.3	1.2	0.05
Total daily electricity consumption (kWh)	2.925 kWh				

3.33 Generator selection

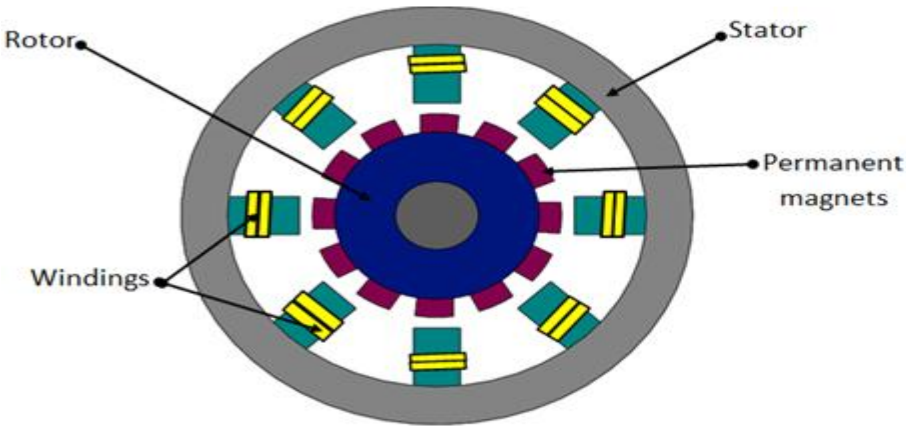


Figure 3.33 - Structure of Permanent Magnet Synchronous Generator (PMSG)

Generators convert the mechanical energy of wind turbines into electrical energy, whose performance directly affects the whole wind power generation system. In small wind power generation systems, Permanent Magnet Synchronous Generator (PMSG) are mostly used as shown in Figure 3.33. PMSG uses permanent magnet excitation without additional excitation device, which reduces excitation loss, so it generally has higher output efficiency. It is a brushless motor without a slip ring and brush device that would be more reliable in operation because of the simple construction. PMSG rotor is permanent magnets, which do not have copper losses of asynchronous generators.

If an asynchronous generator is chosen as the generator of the system, it must rely on the grid or battery to provide excitation. On the one hand, it consumes the battery's power, on the other hand, it is not conducive to maximizing the utilization of wind energy.

According to the capacity and selection principle of wind turbine, the small wind turbine model FD3-2/8 is chosen. The main technical parameters are shown in Table 3.33.

Table 3.33 - FD3-2/8 wind turbine parameters

Starting wind speed	4m/s	The output voltage	AC 56V
Rated wind speed	8m/s	Generator	PMSG
Working speed	5~20m/s	Wind wheel diameter	4m
Highest safe wind speed	20m/s	Weight	350kg
Rated power	1000W	Tower height	4m
Maximum power	1500W	Service life	20yrs
Generator efficiency	≧71%		

3.34 AC-DC-DC-AC Circuit design part

As the wind power is unpredictable, the wind turbines generated AC power is unstable, and the frequency and amplitude of alternating current are constantly changing. The system needs the stable alternating current of normal frequency (220V/50HZ), so the multiple conversions (AC-DC-DC-AC) must be performed. Firstly, 3 phase AC power is converted into DC power through a rectifier, then Bust converter steps down the DC voltage, and finally, that is converted into standard AC power through inverters. The following conversion process will be described in three parts: 1) Three phase bridge rectifier, 2) DC/DC Buck converter 3) SPWM inverter.

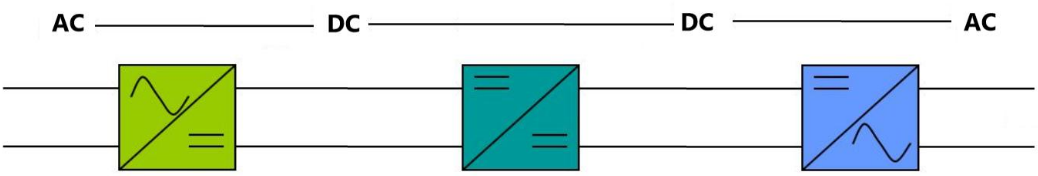


Figure 3.34A - AC-DC-DC-AC conversion diagram

Three Phase Bridge Rectifier:

The main function of the rectifier is to convert the three-phase alternating current (AC) of the wind turbine into direct current (DC) and the three-phase bridge rectifier will be used in the rectifier part of the system. When the wind speed is too small or windless, the output power of the generator will also be reduced, and the battery may transmit the reverse current to the generator side. Since the three-phase bridge rectifier is composed of a diode, its conduction direction can only be one direction (output of the generator to the battery) that can protect the circuit of the wind turbine.

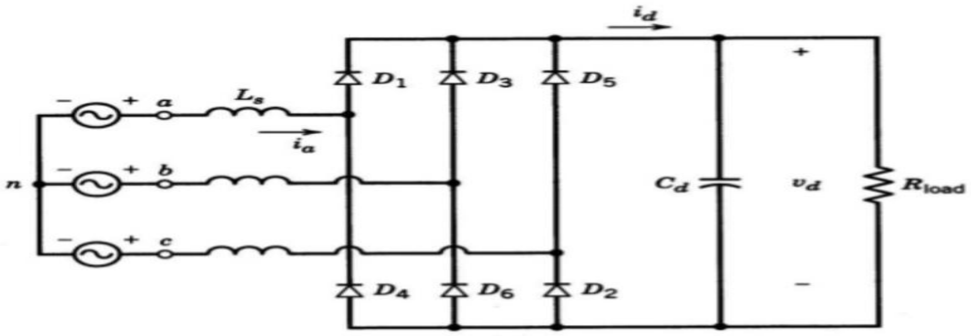


Figure 3.34B - Three-phase bridge rectifier

DC/DC Buck Converter:

A non-isolated DC/DC converter is used in the system because of its simple circuit structure and high output DC efficiency. The basic principle diagram is shown in Fig. 3.34C. As a part of the main circuit, a buck converter is mainly used to charge batteries and supply power to the inverters. At the same time, it can also maximize power. The main components of buck converter are power switching device T, freewheeling diode D, output filter capacitor C, inductance L, input filter capacitor C1.

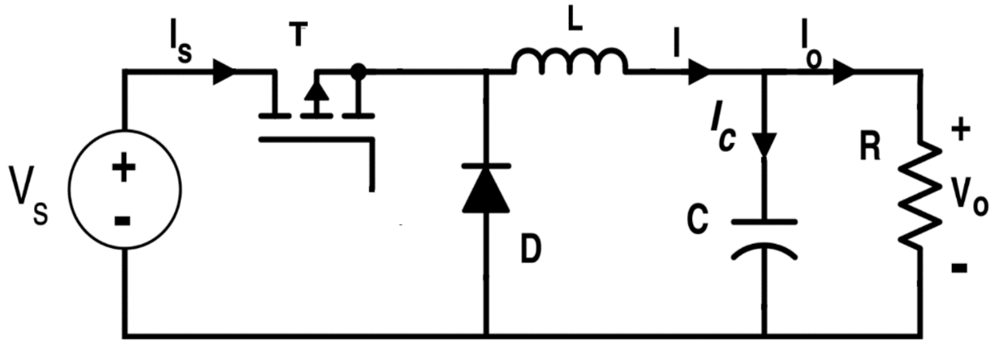


Figure 3.34C - Buck converter

In the Figure 3.34C, the full-type transistor T and the freewheeling diode D construct a basic switching DC/DC converter. By periodically controlling the switch T to be turned on and off, the input voltage Vs can be converted to a voltage V0 and output to the load. LC filter circuit is adopted in the output terminal (Shunt Capacitor and Series Inductor). The function of the LC filter circuit is to minimize the AC component of the pulsating DC voltage and retain its DC component so that the ripple coefficient of the output voltage is reduced and the waveform becomes smoother. Following will be based on the design requirements to determine the parameters and selection of components.

Power switching device T (IGBT)

Insulated Gate Bipolar Transistor (IGBT) is selected as the power switch device (T) of the system. IGBT is a composite device, its input part is MOSFET, and the output part is BJT, so it combines the advantages of both: Fast switching speed, high input impedance, low drive current, large voltage and current capacity, high operating frequency (10-40kHz), etc.

SPWM Inverter

The system uses a three-phase bridge circuit that uses IGBT as switching device which can be regarded as three half-bridge inverters. Figure 3.34D is the main circuit diagram of SPWM inverters. VD1-VD6 is the six power switching devices of the inverters, each with a freewheeling diode in reverse parallel, and the inverters are fed by batteries. Its function is to convert the DC of the former stage into AC. At the same time, because we need the 220V/50HZ power supply, we have to go through the boost voltage part and the control part.

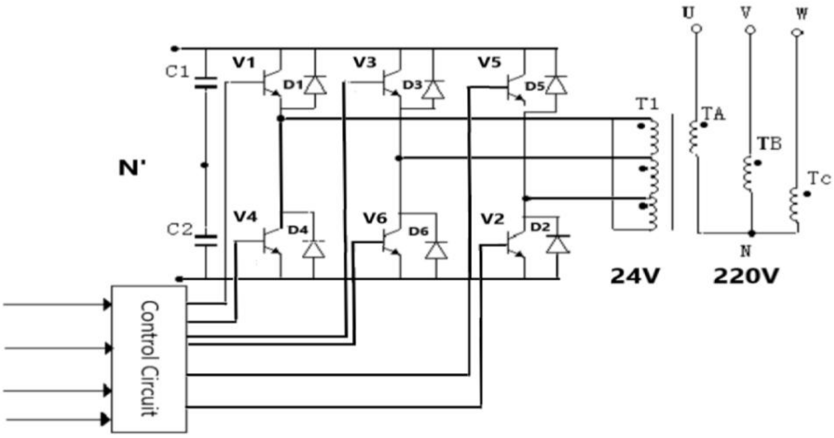


Figure 3.34D - SPWM Inverter main circuit design

(1) Boost voltage part:
The DC Power from the battery will access to SPWM inverter and then boosted voltage by the transformer T1. The wiring connection of the transformer is to use a star/delta (Y/Δ) connection. The conduction mode of the circuit is turned on every 180 degrees, and after the high-frequency power is switched on and off, the output voltage is the substantially sinusoidal wave.

(2) Control part:
Since the IGBT semiconductor is used in the three-phase bridge inverter circuit, it needs a driving circuit to ensure the IGBT to be normally turned on and off. The drive circuit of IGBT must have two functions

1) To achieve electrical isolation between the control circuit and the gate of the driven IGBT.
2) Providing suitable gate drive pulses for electrical isolation using pulse transformers, differential transformers, and optocouplers

Due to limited time, the driving circuit is not described in detail here.

3.35 Voltage regulation

The output voltage of the transformer has been calculated to be 165V-245V, which cannot be directly supplied to the load, so the system also needs to add a three-phase voltage regulator behind the inverter circuit. Its wiring diagram is shown in Figure 3.35.

Figure 3.35 - Voltage regulation

3.36 Design of Storage Battery

Commonly used batteries are nickel-hydrogen batteries, nickel-cadmium batteries and lead-acid batteries. Considering the maturity and cost of technology, lead-acid batteries are selected in the wind system. Battery capacity considerations are as follows

1. The amount of electricity used per day by the load
2. The amount of electricity stored per day by the battery
3. Depth of Discharge (DoD) and Self-Discharge Rate of Batteries

From the data and calculation results, it can be seen that the average daily power consumption of users is 4.5 hours/day, and the total power consumption is about 3 kW. Assuming that each charge can provide 3 days of power consumption, according to the principle that the discharge of the battery is equal to the power consumption of the load, the Storage Battery capacity is:

Q_B : Total capacity of storage battery U_B : Battery terminal voltage
P_L : Total power consumption of load Y_c : Depth of discharge
T : Discharge hours

$$Q_B = \frac{P_L \times T}{U_B \times Y_c} = \frac{1000\text{W} \times 5hrs \times 3days}{24V \times 0.8} = 781Ah$$

The discharge depth of the battery is 80%, the capacity of the battery is 780 Ah after calculation, and 800 Ah is actually selected.
Single batteries have lower nominal voltages, need to be connected in series to supply power to the load. The formula of battery series-parallel connection is as follows:

1. Number of batteries in series $= \frac{\text{Battery terminal voltage}}{\text{Nominal Voltage of The Single Battery}} = \frac{24}{12} = 2$
2. Number of batteries in parallel $= \frac{\text{Total Battery Capacity}}{BatteryCapacity} = \frac{800}{200} = 4$

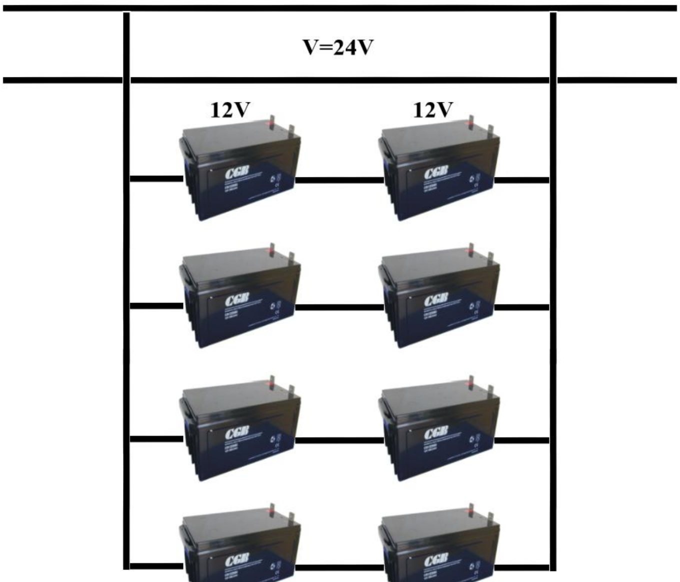


Figure 3.36 - Series-parallel connection of the storage batteries

3.4 Justifications and Limitations

Limitations

The temperature will be higher in summer, which will reduce the conversion efficiency of solar panels. As the temperature of PV panels rises, the working voltage and maximum power will decrease. As the ambient temperature rises by 1°, the output voltage of each cell in the module drops by 5mV. The TSM-180 is composed of 72 cells, so the output voltage of the entire component will drop by 0.36V.

IV. Conclusion

In this paper, the structure and operation of solar energy and small wind power generation systems are studied [9] and explored. Wind and solar energy are volatile and the distance between buildings in Hong Kong is rather narrow (hindering the flow of wind and blocking solar radiation), that directly affects the system's input power. These factors have great difficulties in using renewable energy as the main energy source. Therefore, research on simple, efficient, reliable, low-cost and easy-to-use renewable energy systems is of great significance for its further promotion and application.
The main works of this paper are as follows:

1.) This paper introduces the research background of this topic and summarizes the current status and the technological development of solar energy and wind power in Hong Kong and foreign countries.
2.) The structure of small wind power generation system is proposed. The function and working principle of each part are discussed. The operating characteristics and power regulation principle of a wind turbine (PMSG) are analyzed. The power regulation of the system is realized by BUCK converter.

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