

DEVELOPMENT OF 3-PHASE INVERTER WITH PID VOLTAGE CONTROL

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ABSTRACT

The inverter converts electrical signal from DC to AC by using power electronic circuits. Inverter output is square waves and a filter is needed to change the output to a sinusoidal wave. A control method is implemented in this project to create stable sinusoidal voltage amplitude. The benefit of using control method is the inverter can be adjusted to adapt to a variety of loads and able to mitigate any small disturbance in the system. PID controller is chosen for this project because the PID controller can solve a very complex control for nonlinear element. The PID controller is developed in Matlab Simulink simulation and coded into TMS320F28335 board. In TMS320F28335 board, the desired voltages are compared with the output voltages to get the error signal that will go into the PID controller. SPWM signal is created by using the correction signal from PID controller and fed to the three-phase inverter with filter to give a sinusoidal output. Based on the result obtained, the three-phase inverter has successfully created a stable sinusoidal voltage output for any given voltage references by utilizing the ADC module and the PID controller.

ABSTRAK

Penyongsang menukarkan isyarat elektrik dari DC ke AC dengan menggunakan litar elektronik kuasa. Keluaran pengongsang adalah gelombang berbentuk segiempat dan penapis diperlukan untuk menukar keluaran kepada gelombang berbentuk sinusoidal. Satu kaedah kawalan perlu digunakan di dalam projek ini untuk mencipta voltan sinusoidal. Manfaat menggunakan kaedah kawalan adalah penyongsang boleh diselaraskan untuk menyesuaikan diri dengan pelbagai beban dan dapat mengurangkan apa-apa gangguan kecil dalam sistem. PID telah dipilih untuk projek ini kerana PID boleh menyelesaikan masalah yang kompleks. PID telah dibangunkan menggunakan Matlab Simulink dan dimuat turun ke dalam papan TMS320F28335. Voltan yang dikehendaki dibezakan dengan voltan keluaran untuk mendapatkan isyarat yang salah untuk dimasukkan ke dalam PID. Isyarat SPWM dicipta dengan menggunakan isyarat pembetulan dari PID dan disambung kepada penyongsang tiga fasa dengan penapis untuk memberi keluaran berbentuk sinusoidal. Berdasarkan keputusan yang diperolehi, penyongsang tiga fasa telah berjaya mewujudkan output voltan sinusoidal yang stabil bagi setiap voltan yang dikehendaki dengan menggunakan modul ADC dan kaedah kawalan PID.

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LIST OF SYMBOLS AND ABBREVIATION

ADC	-	Analog to Digital Converter
DAC	-	Digital to Analog Converter
DG	-	Distributed Generation
DSP	-	Digital Signal Processing
IC	-	Integrated Circuit
PID	-	Proportional Integral Derivative
PWM	-	Pulse Width Modulation
SPWM	-	Sinusoidal Pulse Width Modulation
V	-	Voltage
V_{dc}	-	Direct Current Voltage
V_{ref}	-	Voltage Reference
V_{p-p}	-	Voltage Peak to Peak
VSI	-	Voltage Source Inverter

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Malaysia is actively involved with promoting renewable energy to feed the needs of the country. Renewable energy is opportunities and challenges in unlocking the potential of biomass, solar, wind and small hydro through a clear regulatory and incentive driven framework. The government of Malaysia has launched a feed in tariff scheme for renewable energy in December 2011 to encourage the development of renewable energy [1]. The continuously increasing energy consumption may cause overloads and creating problems such as outages, grid instability or deterioration of power quality. To balance the energy demand and generation, renewable energy resources such as Photovoltaic (PV), Wind, and Biomass is a good solution to these problems. Since the generated renewable energy is in DC, an inverter is needed to convert the DC supply to AC supply before connecting it to the equipment. There are three basic types of DC to AC converters, depending on their output waveform which are square wave, modified sine wave and pure sine wave. Considering power wattage, efficiency and harmonic content, pure sine wave inverters has proved to have the best quality among the three types because a pure sine wave inverter produces power that is exactly like the power which is produced by the utility company.

A number of different controllers are used in industry and in many other fields. Generally, these controllers can be divided into two main groups that are conventional controllers and unconventional controllers. The example of conventional controllers is P, PI, PD, PID and Otto-Smith [2]. A mathematical model

for the process of conventional controller is needed in order to design these controllers. While unconventional controllers utilize a new approaches to the controller design in which knowledge of a mathematical model of a process generally is not required. The examples of unconventional controller are fuzzy controller and neuro-fuzzy controllers [2]. Majority of industrial processes are nonlinear and thus complicate to describe mathematically. However, it is known that many processes can be controlled using PID controllers providing that controller parameters have been tuned well. This type of control has a lot of sense since it is simple and based on 3 basic behavior types that is proportional (P), integration (I) and derivation (D). Instead of using a small number of complex controllers, a larger number of simple PID controllers are used to control simpler processes in an industrial assembly in order to automate the certain more complex process. In spite their simplicity, they can be used to solve even a very complex control problems. While proportional and integrative modes are also used as single control modes, a derivative mode is rarely used on its own in control systems. Combinations such as PI and PD control are very often in practical systems. PID controller can be integrated with inverter as one of its controlling techniques to ensure a stable voltage[3].

1.2 PROBLEM STATEMENT

Electrical power system consists of several stages, which are power generation, power transmission and power distribution. Usually power generated from the power plant is in DC but it will be converted to AC in order to be transmitted. For power transmission, the AC voltage is connected through the National Grid for Malaysia and then it is distributed to different kind of user such as industrial and domestic user. System frequency is a continuously changing variable that is determined and controlled by the real time balance between system demand and total generation. Nowadays renewable energy is becoming popular in this country because the government is encouraging the usage of the renewable energy to promote green technology. The most common renewable energy that can be generated in Malaysia is solar energy.

The problem with solar energy is the voltage generated in DC, while majority of electrical appliance in Malaysia is using AC system. A solution to this problem is using a three-phase inverter. A three-phase inverter can only change the output waveform from V_{DC} to V_{AC} but the V_{AC} amplitude is directly proportional to the input of the V_{DC} . Thus, a control method is needed to enable the V_{AC} to be adjusted without changing the V_{DC} input of the inverter. The benefit of using a control method is the three-phase inverter can adapt to a variety of loads and able to mitigate any small disturbance in the system.

1.3 AIM AND OBJECTIVES

Creating a stable voltage output for 3 phase inverter is the aim of this project. To achieve this aim, the objectives are shown as below:

- a. To design a 3 phase inverter.
- b. To use TI C2000 TMS320F28335 board as a signal processing device.
- c. To implement PID control system in voltage control of the inverter.

1.4 SCOPE

This project is primarily concerned with the control method of the 3 phase inverter. To achieve the objective, these are the scope that needed to be done:

- a. To simulate the inverter in closed loop and open loop system by using Matlab Simulink.
- b. Voltage sensor techniques are needed in determining the appropriate SPWM signal to be feed to the inverter.
- c. Development of the Matlab Simulink model for hardware implementation

CHAPTER 2

LITERATURE REVIEW

2.1 Inverter

Inverter is one of static power converters. It produces an ac output waveform from a dc power supply. These are the types of waveforms required in adjustable speed drives (ASD), uninterruptible power supplies (UPS), static var compensators, active filters, and voltage compensators, which are only a few applications. For sinusoidal AC outputs, the magnitude, frequency, and phase should be controllable. According to the type of ac output waveform, these topologies can be considered as voltage source inverters (VSI), where the independently controlled ac output is a voltage waveform. Static power converters, specifically inverters, are constructed from power switches and the ac output waveforms are therefore made up of discrete values. This leads to the generation of waveforms that feature fast transitions rather than smooth ones [4],[5].

2.1.1 Three Phase Voltage Source Inverter

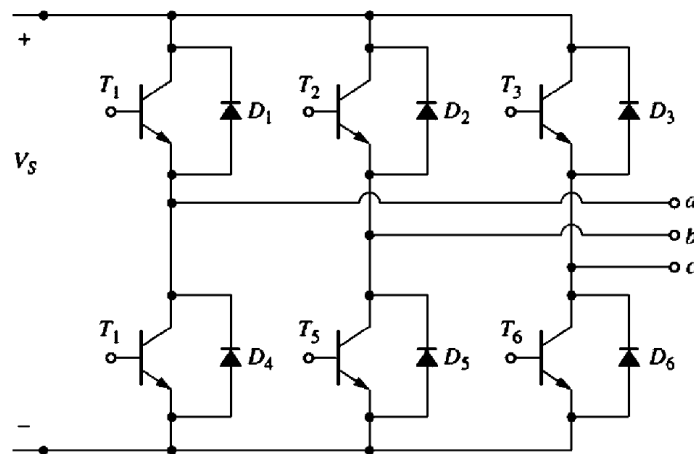


Figure 2.1: 3 Phase Voltage Source Inverter [6]

Bridge configuration is most commonly used for generating output because the transformer required in this case is not as complicated as in the case of other inverter circuits. For high power applications a fast switching thyristors are used. While for low and medium power applications IGBT is used.

Figure 2.1 shows the circuit topology for a three-phase inverter. In this circuit, the transistors are made to conduct in the order $T_1, T_6, T_2, T_4, T_1, T_5$. The recommended operation for this inverter is 120° inverter. Each leg is delayed by 120° . This mode of operation has the advantage of no possibility of a short circuit across the dc input because the period of 60° elapses between the end of conduction of one thyristor and the beginning of conduction of the other thyristor of the same branch. In this particular mode of operation, three thyristors will be conducting at any time. Triggering frequency of the thyristors will decide the output voltage wave frequency. The output voltage amplitude can be change by changing the dc input voltage [6].

2.1.2 PWM

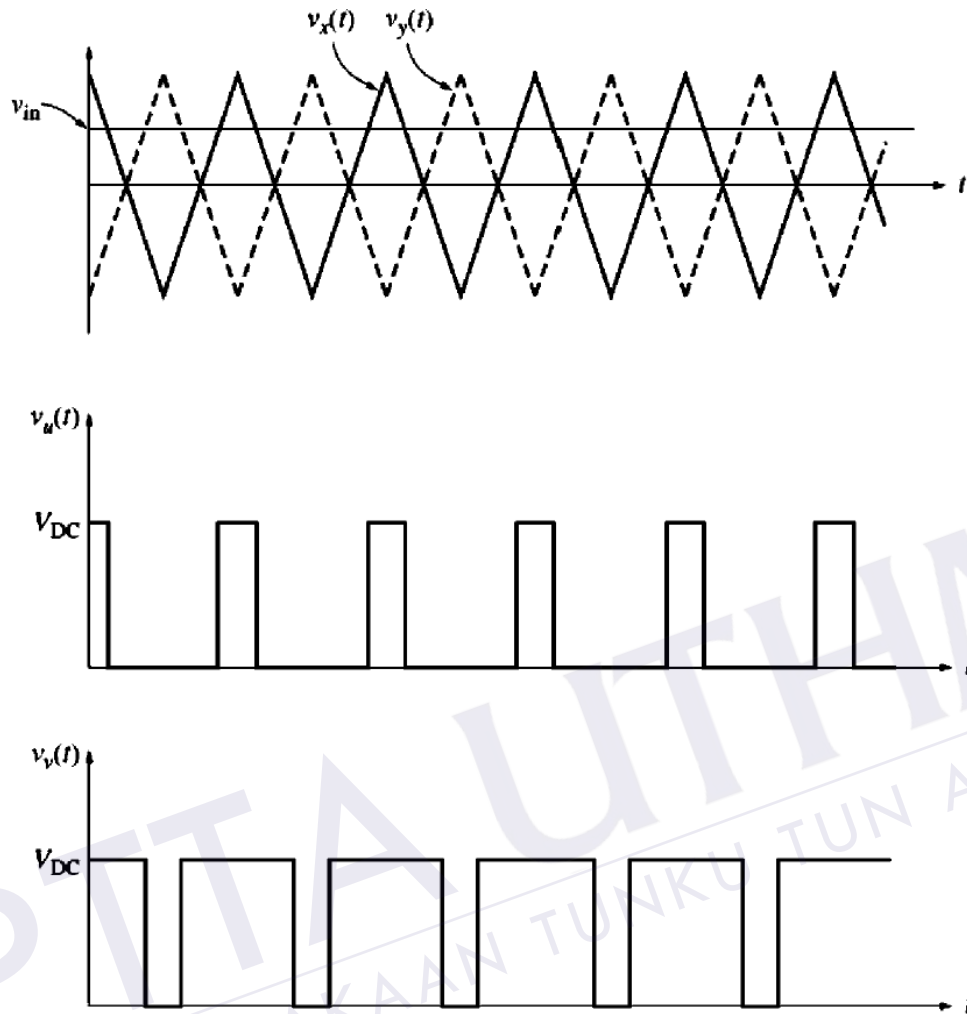


Figure 2.2: PWM waveform [6]

Pulse Width Modulation is a signal which is generated by comparing the amplitudes of the triangular wave (carrier) and sine wave (modulating). These are done by using simple analogue comparator. Another method to create a PWM is using digital sampling. Digital sampling is widely used in industry. The duty ratio D is the fraction of time during which the switch is on. For control purposes the pulse width can be adjusted to achieve a desired result by adjusting the V_{in} for the comparator. Figure 2.2 shows the waveform of PWM [7].

2.1.3 SPWM

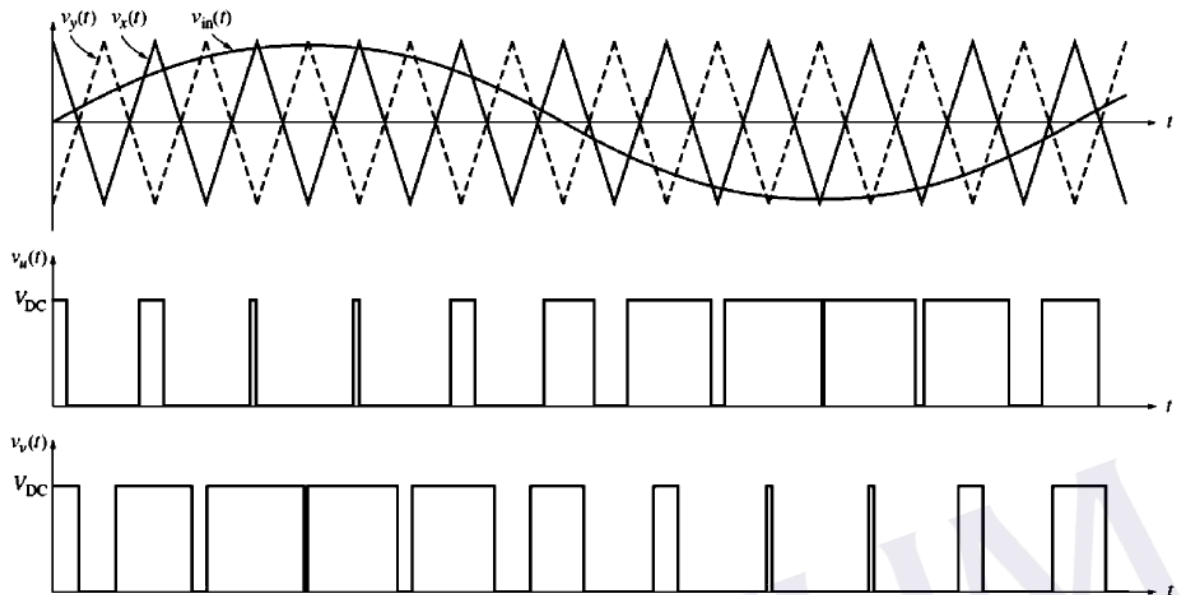


Figure 2.3: SPWM waveform [6]

The sinusoidal PWM (SPWM) method also known as the triangulation, subharmonic, or suboscillation method, is very popular in industrial applications. For creating a SPWM signal, a high-frequency triangular carrier wave is compared with a sinusoidal reference of the desired frequency. The intersection of wave determines the switching instants and commutation of the modulated. When sinusoidal wave has magnitude higher than the triangular wave the comparator output is high, otherwise it is low [6].

2.2 Distribution Generation

Distributed generation is electric power generators that produce electricity at a site close to customers or that are tied to an electric distribution system and generally refers to small-scale generation from 1 kW to 50 MW.

2.2.1 Introduction

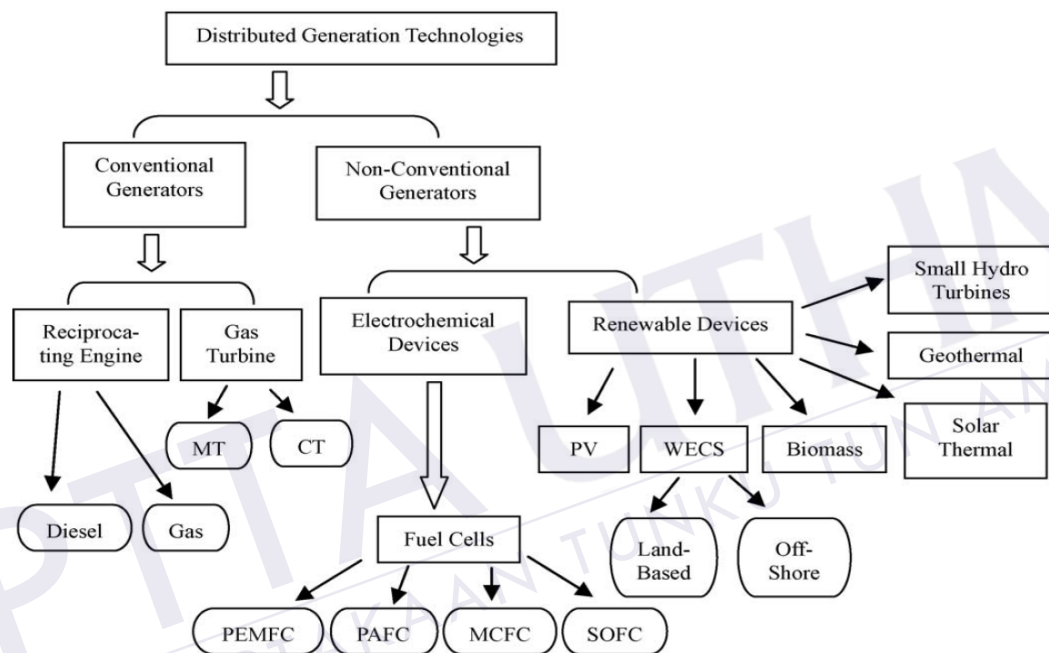


Figure 2.4: Distributed Generation Technologies [8]

Figure 2.4 shows the distributed energy generation that are divided into two, which are conventional generators and non-conventional generators. It is shown that DG can be powered by reciprocating engine, gas turbine, electrochemical devices and renewable energy devices. DG takes place on two levels that is the local level and the end point level. Local level power generation plants often include renewable energy technologies that are site specific, such as wind turbines, geothermal energy production, solar systems, and some hydro-thermal plants. At the end-point level, the individual energy consumer can apply many of these same technologies with similar effects. One DG technology frequently employed by end point users is the modular internal combustion engine [8].

2.2.2 Fuel cells (FCs)

Fuel cells have the same process with normal batteries as they both convert chemical energy directly into electrical energy and heat. Fuel cells have two electrode separated by an electrolyte. Fuel cells are generally characterized by the material of electrolyte used. Presently five major types of fuel cells in different stages of commercial availability exist. They include proton exchange membrane fuel cell (PEMFC), alkaline fuel cell (AFC), phosphoric acid fuel cell (PAFC), solid oxide fuel cell (SOFC), and molten carbonate fuel cell (MCFC). AFC is not suitable for DG application since they are nearly zero tolerance to CO₂ and CO constituents in the fuel. To obtain AC current from fuel cell technology, power conditioning equipment is required to handle the inversion of DC current generated by fuel cell to AC current that is required to be integrated into the distribution network. Physically a fuel cell plant consists of three major parts as shown in Figure 2.5. A fuel processor that removes fuel impurities and may increase concentration of hydrogen in the fuel, a power section (fuel cell itself) which consists of a set of stacks containing catalytic electrodes, generating the electricity and lastly a power conditioner that converts the direct current produced in the power section into alternating current to be connected to the grid. Resulting advantages of this technology are high efficiency, almost at partial load, low emissions, and noiselessness as a result of non-existence of moving parts, and free adjustable ratio from 50 kW to 3MW of electric and heat generation. The energy savings result from the high conversion efficiency, is typically 40% or higher, depending on the type of fuel cell. When utilized in a cogeneration application by recovering the available thermal energy output, fuel cell's overall energy utilization efficiencies can be in the order of 85% or more [8].

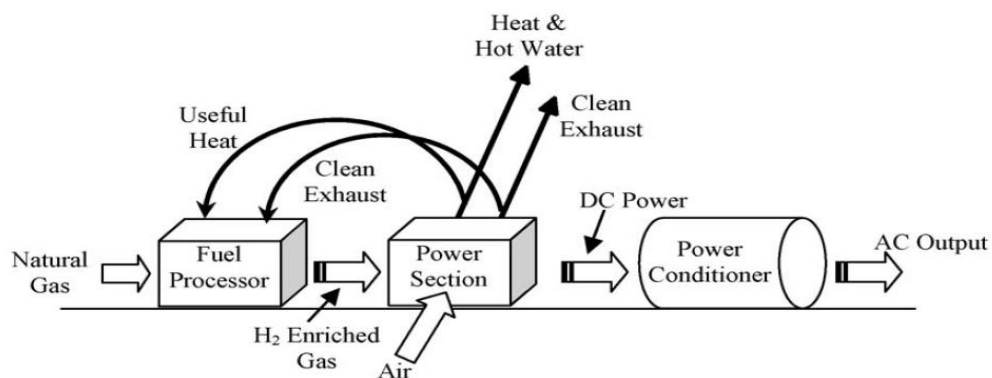


Figure 2.5: Fuel Cell System [8]

2.2.3 Micro-turbines (MT)

Micro-turbines are becoming widespread for distributed power and combined heat and power applications as they can start quickly. They are one of the most promising technologies for powering hybrid electric vehicles. Generally micro-turbine systems have range of power from 30 to 400 kW, while conventional gas turbines range from 500 kW to more than 300MW. Part of their success is due to advances in power electronics, which enables unattended operation and interfacing with the commercial power grid. Typical micro-turbine efficiencies are between 33% and 37%, especially with 85% effective recuperator. It could achieve efficiencies above 80% in a combined heat and power (CHP) application. Micro-turbines operate in a similar manner as conventional gas turbines, based on the thermodynamic cycle known as the Brayton cycle. Air is drawn into the compressor via the air inlet pipe as illustrated in Figure 2.6. In the compressor, it is pressurized and forced into the cold side of the recuperator, where it is preheated before it enters the combustion chamber. The heated air and fuel are thoroughly mixed together and burnt. It is the mixture, which expands through the turbine that is used to drive the turbine at a speed of 96,000 rpm, since this has been coupled to the shaft of the generator. The generator thus produces high frequency AC power that is converted to power frequency by the use of power electronic devices. Micro-turbine systems have many advantages over reciprocating engine generators, such as higher power density, with respect to footprint and weight, extremely low missions and few or just one moving part. Those designed with foil bearings and air-cooling operates without oil, coolants or other hazardous materials. Micro-turbines also have the advantage of having the majority of their waste heat contained in their relatively high-temperature exhaust, whereas the waste heat of reciprocating engines is split between its exhaust and cooling system. However, reciprocating engine generators are quicker to respond to changes in output power requirement and slightly more efficient. Micro-turbines also lose more efficiency at low power levels than reciprocating engines [8].

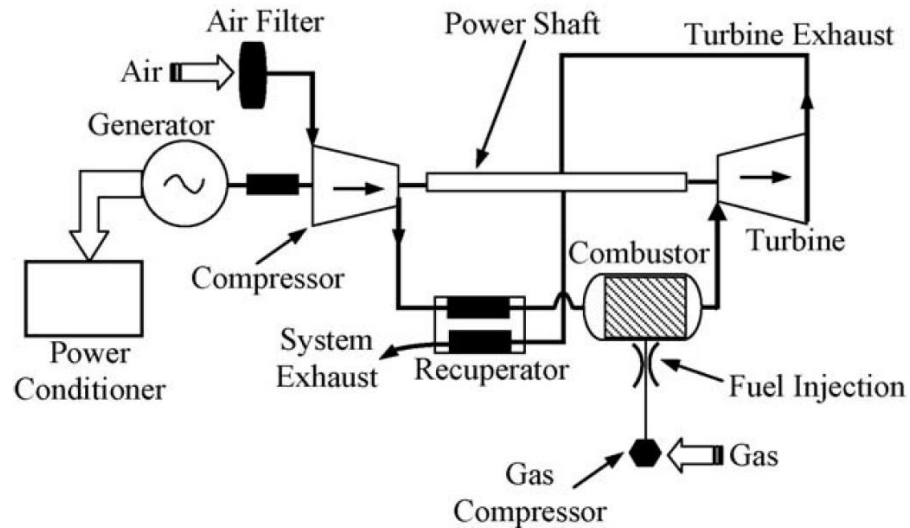


Figure 2.6: Micro Turbine System [8]

2.2.4 Photovoltaic systems (PVs)

Conversion of solar energy directly to electricity is possible by using photovoltaic systems (PVs). These systems are commonly known as solar panels. PV solar panels consist of discrete multiple cells, connected together either in series or parallel, that convert light radiation into electricity. PV technology could be standalone or connected to the grid. The output power of PV panels is directly proportional to the surface area of the cells and footprint sizes. Therefore, footprint needs to be relatively large (0.02 kW/m²). Even though the operating efficiency of this technology may be relatively low (10–24%), nevertheless, it cannot be compared with non-renewable systems. Since the output current of PVs is a function of solar radiation and temperature, a maximum power point tracking (MPPT) stage is required in the converter to always obtain the maximum power output. PV units are integrated into the grid by using inverters [8].

2.2.5 Wind energy conversion system (WECS)

Windmills or wind turbines convert the kinetic energy of the streaming air to electric power. The power from wind turbine is produced in the wind speed of 4–25 m/s range. The size of the wind turbine has increased rapidly during the last two decades with the largest units now being about 4 MW compared to the 1970s in which unit sizes were below 20 kW. Wind turbines above 1.0MW size are equipped with a variable speed system incorporating power electronics to overcome mechanical stresses. Single units of wind turbine can normally be integrated to the distribution grid of 10–20 kV. In the present, the trend for wind turbine is that the wind power is being located off shore in larger parks that are connected to high voltage levels and through the transmission system. The power quality of the wind turbine depends on the system design. Direct connection of synchronous generators may result in increased flicker levels and relatively large active power variation. At present, wind energy has been found to be the most competitive among all renewable energy technologies. Figure 2.7 presents the schematic block diagram of WECS connection to the power grid [8].

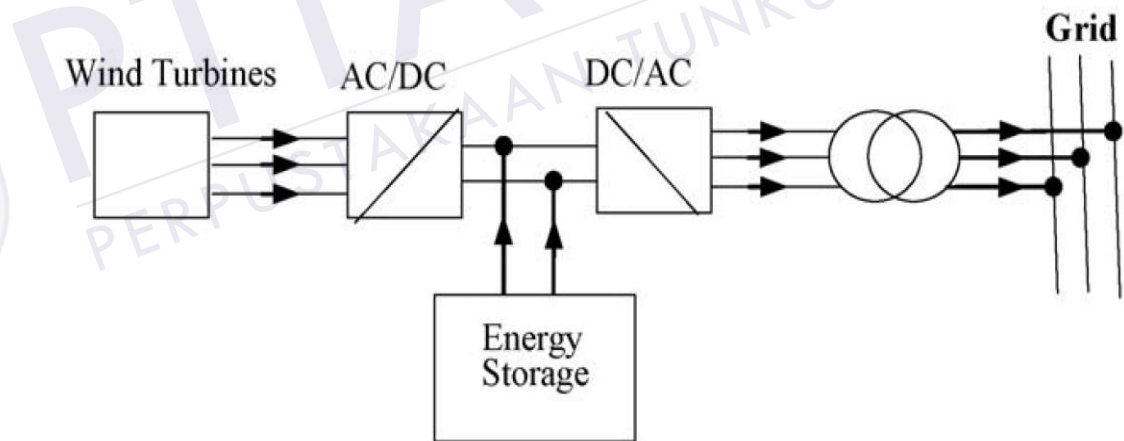


Figure 2.7: Wind Energy Conversion System [8]

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