Chapter 6

Power Electronics Platforms for Grid-Tied Smart Buildings

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/62920

Abstract

Renewable energy sources (such as sun, wind, water, or fuel cells) are attracting great interest for either grid-tied or off-grid arrangements in smart green buildings. It must be either used when generated, stored for future use on-site, delivered to the power grid, or shared among combination of these. Grid-tied buildings are connected to the utility grid service lines. Off-grid buildings have no connection to utility service lines. Both types employ inverters to convert power from direct current (DC) to alternating current (AC), and most off-grid systems have batteries to store energy for use when needed. Accordingly, power electronics systems are playing an important role as the enabling technology for smart grid. In addition, smart meter represents the interface part between the green building and the utility grid. In order to realize the interaction between both systems, a bidirectional power conditioning module is needed. This chapter introduces the different power electronics platforms suitable for grid-tied smart green buildings (such as residential homes, commercial, and industrial) as well as its integrative functionality with advanced metering infrastructure (AMI). In order to show the superiority of these platforms in conjunction with smart meters, a hardware case study with one of the most popular power electronics topologies is presented.

Keywords: power electronics, smart meters, green buildings, grid-tied systems, net meters

1. Introduction

In the future smart green buildings, there will be increasing connection to the distribution network of renewable energy sources, electric vehicles, and heat pumps. Most of alternative energy sources generate direct current (DC) power (for example, photovoltaic and fuel cell systems). As a result, a power electronics inverter is required to connect them into the utility grid. On the other hand, the alternating current (AC)-based alternative energy sources (for example, wind, wave, and hydro systems) can be either directly connected to the AC grid or indirectly through AC-DC and DC-AC conversion interface stages. Power electronics converters are then represents rapid independent control means of real-reactive power to satisfy grid-connected alternative energy conversion system needs [1]. In this chapter, we will explore the different power conversion topologies and energy link integration methodologies based on the renewable energy system structure (single or hybrid).

Grid-tied buildings are classified as either feed-in-tariff (FIT) or net metered (NM). In FIT systems, utilities purchase renewable energy at variable rates, which are usually higher than the sales price. This is tracked by using two meters: one to measure electricity going to the grid, and another for electricity coming from the grid. NM systems buy and sell electricity at the same rate, using a single meter, which runs either forward or reverse, depending on the direction of power flow. Most NM systems do not provide homeowners with credit for any electricity they generate beyond what they use. FIT systems, however, provide 100% credit for power put into the grid, allowing homeowners to receive a check from their utility when their production exceeds their use. In USA, regulations for grid-tied systems are established by the local municipality or state. Not all utilities allow FIT or net metering [2].

In fact, both FIT and NM systems can operate with either analog or digital (smart) meter. It became feasible to most people that smart meters are considered an integral part of any intelligent-based green building. In the past, analog regular meters can only provide distributors with power flow data at the substation level. With smart meters, it can deliver detailed in-depth real-time information about load energy consumption which extends visibility down to the consumer level. In addition, smart meter can help to manage and control customer loads remotely by involving more IQ functionalities into metering system design [3].

2. Home smart grid

In general, smart grid is considered an integrated and interactive power network. It brings generating units closer to consumers. On the other hand, consumers may also act as generators. A smart home involves three new components: smart control and measuring devices, digital communications systems, and computer software programs [4, 5]. **Figure 1** shows the smart grid simple structure that allows power to be fed into it from different energy sources and provides real-time management to maximize efficiency. The home smart grid makes individual homes energy efficient by reducing total energy consumption and lowering peak demand. Homeowners can install renewable energy generating components to supplement power they draw and feed power back when production exceeds home requirements. Home energy efficiency requires three devices: smart meter that measures power in real time, home receiver that allows homeowner to monitor power use over time, and power usage monitor (watt meter) that accurately measures power consumption by individual devices.

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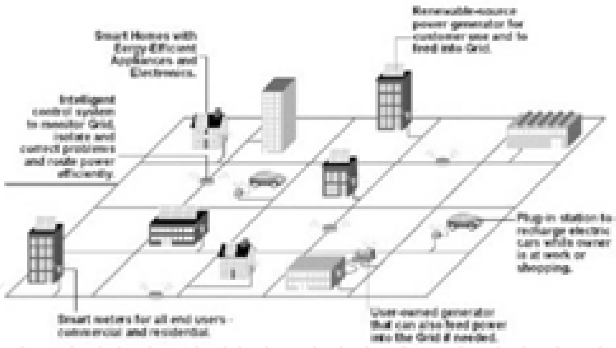

Figure 1. Home smart grid infrastructure.

2.1. Home meters

There are two common types of metering home systems: analog and digital meters, as shown in **Figure 2**. The analog (electric, gas, and water) meter measures flow over a given period of time but cannot transmit measurement data. Utility companies are unable to charge according to production costs. Users have no incentive to minimize use during peak demand. Digital metering system represents an advanced smart meter that can be used to monitor the energy consumption remotely and transfer this information to the control center through secured communication network [5]. In order to facilitate monitoring functionality, we can add a digital display to show the energy consumption and its corresponding cost to the customers. The in-home display (IHD) is mainly used for this purpose. Another type of smart meters is the power strip one. It contains one or more channels with voltage/current transducers to monitor the amount of the power usage and relay contact to control major equipment in the building [6–8]. The smart meter has the following features:

- Read electric use at least once per hour

- Transmit data to electric company

- Monitor for disturbances or interruptions

- RF- or IP-based wireless network

- Net meters allow homeowners to produce electricity and sell excess to utility company

Figure 2. A typical residential analog and digital (smart) electric meter with a digital display showing cumulative kilowatt hours used.

2.2. Smart meter and smart building

Giving everyone a smart meter will not deliver a smart building. Although smart meters are an essential component of a truly smart home, there is more to smart buildings than just smart meters (hardware, software, communication links, and controllers). It is called advanced metering infrastructure (AMI) that measures, analyzes, and regulates energy usage. The IHD plays an important role in real-time information monitoring. It may communicate directly with appliances. It also provides simple tools for cutting energy consumption by 5–10% [9, 10]. **Figure 3** shows different popular IHD units that allow electrical consumers to read data from their home's smart meter and other measuring devices.

Figure 3. The PowerPortal Home display unit and real-time power, cumulative use, and other data.

3. Renewable energy sources

Renewable energy sources are being developed in many countries to reduce CO_2 emissions and provide sustainable electrical power. The balance of particular technologies and their scale changes from country to country. However, hydro, wind, biomass, tidal stream, and photovoltaic (PV) are common choices. Substantial equipment cost investment is generally recovered and cost savings are realized over time [11, 12]. **Figure 4** shows photographs for different renewable energy sources.

Figure 4. Renewable energy sources.

3.1. Power converters platforms

Power electronics represents the enabling technology for green alternative energy sources in smart buildings. It involves sophisticated conversion topologies as an interface integral part between smart power distribution network and local microgrid sources [5]. The installation of the new advanced alternative energy technologies (e.g., PV and wind) is playing a vital role in residential and commercial smart buildings. Typically, installed capacity ranges from few kilowatts for distribution-customer level to several megawatts for high-voltage transmission grid. The following characteristics are important for power electronics systems for smart grids: high efficiency, optimal energy transfer, bidirectional power flow, high reliability, synchronization capabilities, EMI filtering, smart metering, real-time information, communications, and fault tolerance/self-healing. **Figure 5** shows different power electronics layers to integrate a cluster of prosumers (an entity in the future grid capable of both producing and consuming electric power) into the smart building.

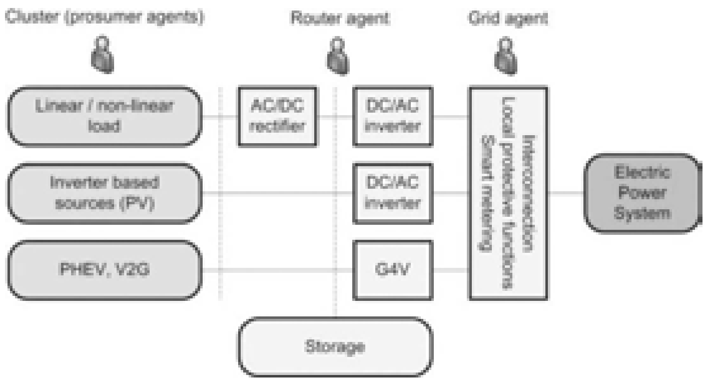

Figure 5. Power electronics control and communication structure in smart buildings.

Power electronics converters can operate renewable sources on either off-grid standalone basis or grid-connected basis. Grid-tied platforms can be classified into two main categories: single input single output (SISO) platform and multi-input single output (MISO) platform. As an example, a building that involves only one DC renewable energy source such as PV modules mounted on the roof, then, the platform structure needed to connect the grid-tied FIT building is SISO as shown in **Figure 6**. The output of a PV system is DC and therefore a DC-AC converter is essential for grid connection.

Figure 6. DC source-based SISO platform for grid-tied FIT system.

Another SISO platform can be used if the source was AC-based variable speed turbines such as wind, small hydro, and tidal power generation as shown in **Figure 7**. Typically, this platform uses two stages of power conversion. The first stage is AC-DC to convert from the variable frequency AC generator power output to controlled/uncontrolled DC. The second stage is then DC-AC to convert from DC into synchronized 50/60 Hz AC utility grid. To capture the maximum power, the turbine rotational speed is set to the optimum range.

Figure 7. AC source-based SISO platform for grid-tied FIT system.

There are several other renewable technologies that use steam or gas turbines with synchronous generator such as biomass energy. This technology can be directly connected to utility grid and is not discussed in this chapter. In general, power converter interface units can be used to control the amount of the reactive power injected from renewable energy systems into main AC grid. Then, network voltage is controlled while managing active power to satisfy the requirements of the utility grid. On the other hand, **Figure 8** shows hybrid connectivity to provide larger energy production to the building as well as the utility grid which is called as MISO platform. Additionally, MISO platform is sometimes called as multi-port power converter (MPPC) since it combines more than one input port based on the number of the micro energy sources and storage installed in the building.

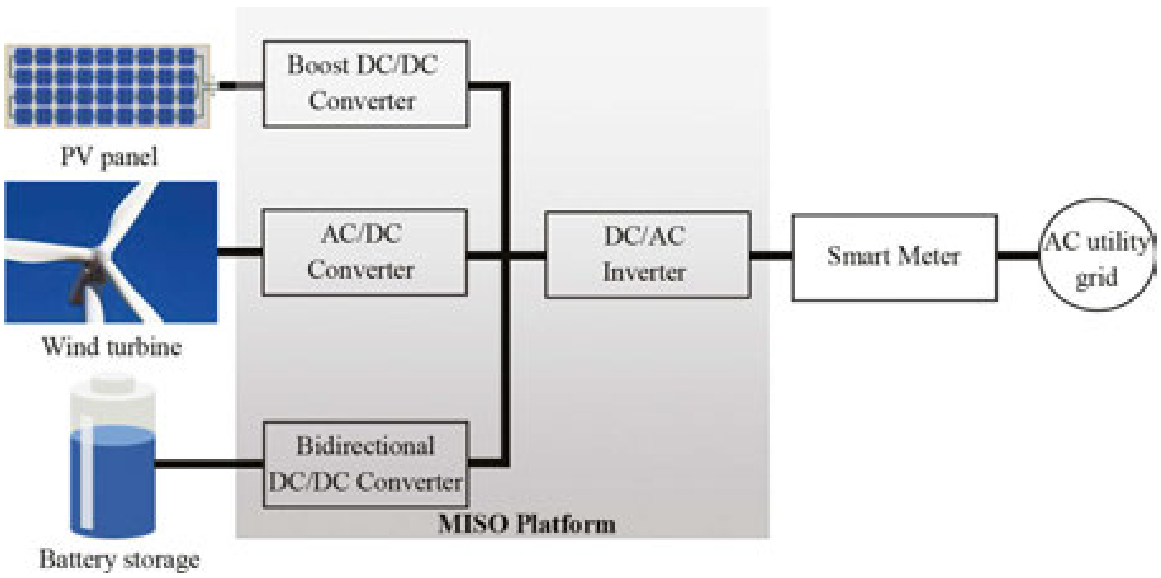

Figure 8. Hybrid source-based MISO platform for grid-tied FIT system.

3.2. PV system in home

Energy from sun is transformed into an energy source that can do useful work or provide useful heat. We pay cost of converting stored sun energy into useable energy form. Most energy sources originated from sun except geothermal energy. The sun's free energy can be utilized in three forms:

- Passive use; for example, allowing natural sunlight in for heat.
- Direct heat transfer; for example, water heater collects solar heat and transfers it to water
- PV effect; causes some substances to generate an electric current when exposed to sunlight

Many countries such as USA, Spain, and Germany, have extended their PV system installation to larger capacities. FITs are finding great interest with PV as it provides guaranteed payment per energy unit (p/kWh) generated from local renewable power sources. Professional help is essential to install a grid-connected solar power system in home. It requires "balance-of-system" equipment such as power conditioning, safety, meters, and instrumentation. On the other hand, installing a standalone PV power system is usually chosen for homes in remote areas. Successful systems employ a combination of power-generating technologies and techniques to reduce electric energy requirements. Standalone system is still not as complex as creating grid-connected system. **Figure 9** shows both grid-connected and standalone PV systems in home. The grid-connected generating system feeds power into the grid through one meter while the home's electric current is brought into the home from the grid through another meter. The standalone solar generating system with PV panels connected through a controller to a battery stack and an inverter.

3.2.1. Maximum power point tracking (MPPT) control

Figure 10 represents the maximum output power locus for an individual PV cell. It is interesting to observe that neither the maximum voltage nor the maximum current are the same for different levels of illumination at the maximum power point. As the output power (Po) is given as:

$$P_o = V_o I_o \tag{1}$$

Then the peak power may be given from the following condition:

$$\frac{dP_o}{dV_o} = V_o + I_o \frac{dV_o}{dI_o} = 0 \tag{2}$$

that is:

$$\frac{dV_o}{dI_o} = -\frac{V_o}{I_o} \quad (3)$$

The meaning of this expression is that the dynamical internal resistance of the source should match the external load resistance, leading to special power peak tracking control approaches.

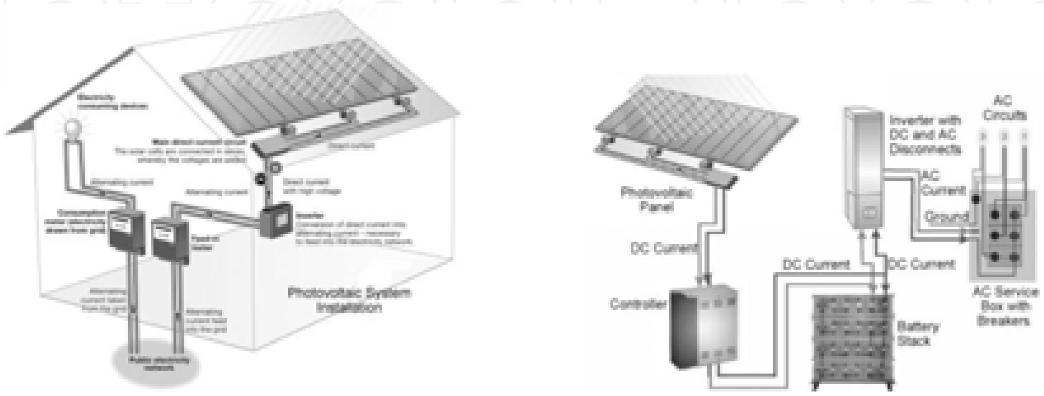

Figure 9. A schematic diagram shows installation of a grid-connected and standalone PV power system in home.

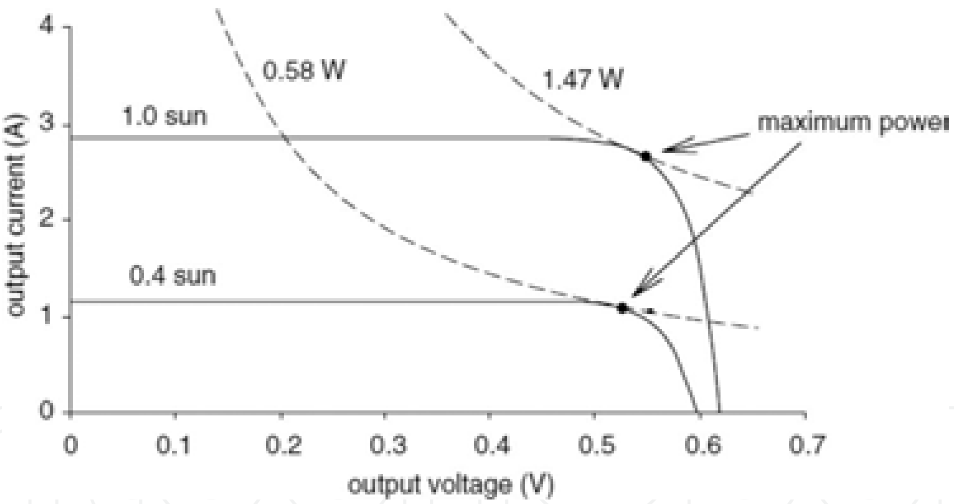

Figure 10. Conditions of maximum power for various illumination (insolation) levels.

3.2.2. PV-based SISO platform

Figure 11 shows the schematic of SISO-based grid-connected PV system. The main elements of this system are:

1. Boost DC-DC converter to increase the output voltage and extract the max. power

2. Single-phase DC-AC voltage source inverter (VSI)

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3. Grid interface output filter with/without isolation transformer

4. Voltage/power controller

There are several other DC-DC conversion topologies that can be used in the first stage such as flyback, half bridge, full bridge, and push-pull [13]. Generally, the DC-DC converter output is maintained to be constant as an input of the inversion stage. On the other hand, the MPPT technique is continuously used to find the proper PV voltage that allows most power to be extracted while PV system parameters (for example, insolation and cell temperatures) changes. The DC voltage obtained from the DC-DC converter is inverted to 50/60 Hz AC. A VSI is widely used. Typically, VSI uses a pulse width modulation (PWM) switching pattern to reduce the output harmonic contents. Then, a final stage of grid-tie-filter is connected between VSI output and AC grid in order to minimize the current harmonics injected into main power network. An isolation transformer is sometimes placed at the VSI output to prevent DC injection into the grid.

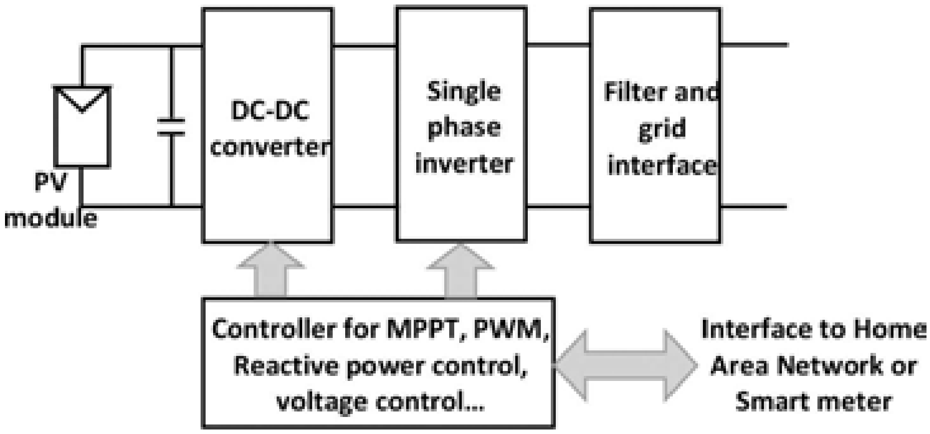

Figure 11. Domestic grid-connected SISO PV system block diagram.

3.3. Wind energy system in home

Wind is a manifestation of solar radiation. Air currents are winds that power weather systems continuously across the surface of the planet. The annual average wind speed is larger than or equal to 12 mph considering terrain and wind gusts. Favorable locations have wind resource potential of 510 kWh or more. We should also consider other factors such as investment, zoning codes, location, and so on. For home-scale wind turbines, residential typical range is 500 W–100 kW. It is determined based on amount of electricity to generate, budget, and wind resource. The 5–15-kW turbine should provide 75–100% of the typical home's power requirements. **Figure 12** shows how a wind turbine works for small-scale 2-kW home model and the main components for grid-connected wind turbine generating system [14].

According to Betz theory, the turbine mechanical power (P_t) is given by:

$$P_t = 0.5 C_p \rho A V^3 \quad kg \cdot m / s \tag{4}$$

where ρ is the air density, C_p is the power coefficient, V is the wind speed, and A is the area of the rotor blades. Considering the wind speed, wind generation system (WGS) can be classified into no, partial, and full load conditions. The wind turbine operates in the no load condition if the measured wind speed is not within the cut-in/cut-out wind speed range. On the other hand, WGS output power is regulated at full load power region by changing the pitch angle. In addition, the maximum extracted power can be achieved by controlling the tip speed ratio. As the rotor speed must change according to the wind intensity, the speed control of the turbine has to command low speed at low winds and high speed at high winds, so as to follow the maximum power operating point as indicated in **Figure 13**. It is observed that the maximum power output occurs at different generator speeds for different wind velocities [15].

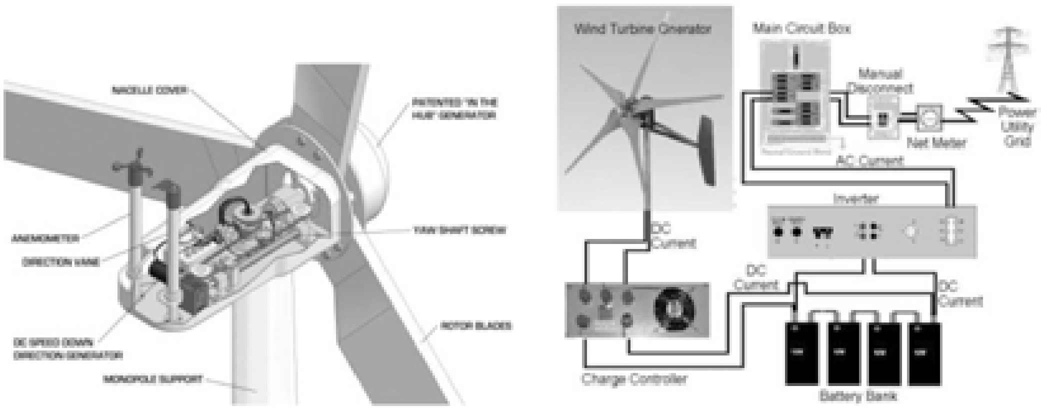

Figure 12. Hummer Wind Power's 2 kilowatt wind turbine and components for a grid-connected wind turbine generating system.

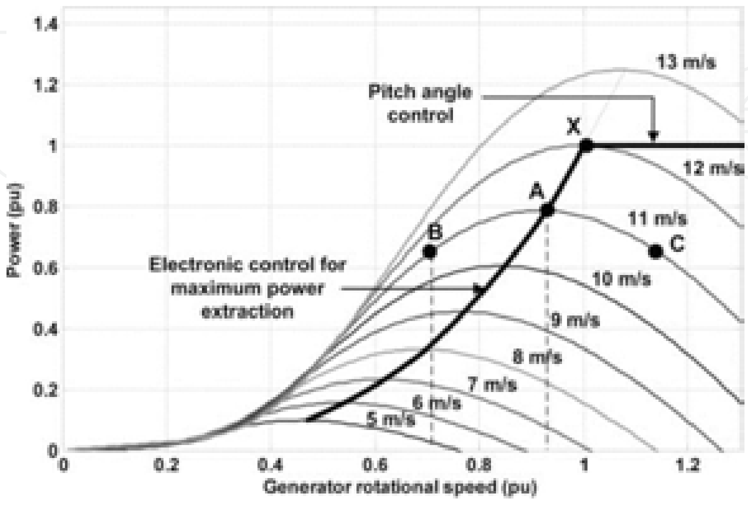

Figure 13. Turbine rotation versus power characteristic related to wind speed.

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3.3.1. Wind turbine generators

For variable-speed wind turbine (VSWT), there are several types of generators that can be used. **Figure 14** shows the doubly fed induction generator (DFIG) which employs a wound rotor induction machine with back-to-back converter-inverter connected to its rotor terminals. The real-reactive power flow of the rotor circuit is controlled via power converters. The rotor side converter is also used to change the rotor speed through the active power absorbed or injected into rotor. Furthermore, the wind generator may be self-excited induction (SEIG) or external excited synchronous (EESG) machine with power converter. The maximum power is captured by controlling the generator speed while stator output frequency varies with wind speed conditions. The first stage of the power converter is used to convert the variable frequency power to DC power. Then, the DC power is inverted to 50/60 Hz AC grid power via the second conversion stage. Additionally, multi-pole permanent magnet synchronous generator (PMSG) represents another wind turbine design with direct-driven gearless advantage. It introduces better mechanical efficiency as well as higher power density.

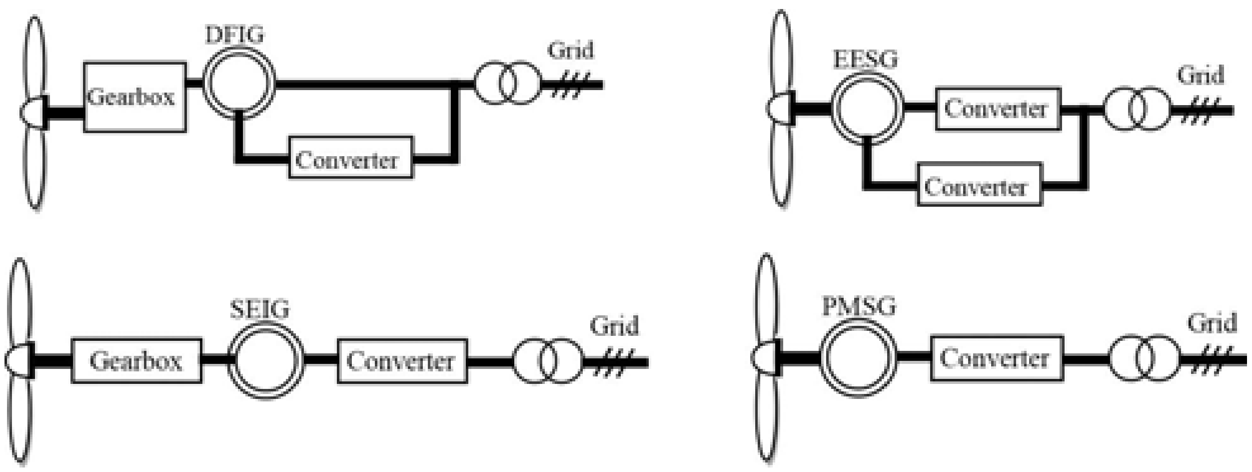

Figure 14. Variable-speed wind turbine generation technologies.

3.3.2. Wind-based SISO platforms with SEIG

Figure 15 shows a simple structure of the SEIG-based SISO platform for wind generation system. The system contains three cascaded stages (AC-DC, DC-DC, and DC-AC). The first stage employs a diode bridge rectifier to convert the variable generator AC output into unregulated DC. Then, the variable DC is converted to constant voltage DC link as an input of the inverter stage. However, diode rectifier stage causes undesirable effects of generator operation through voltage/current low-order harmonic distortion. Another option is to use two stages back-to-back converter/inverter as shown **Figure 16**. The first stage uses a PWM controlled rectifier which achieves high power factor and less harmonic distortion in the generator side. However, this structure needs the use of bootstrap driver circuits as the occurrence of short circuit through each phase is possible. **Figure 17** shows another variation of modified back-to-back power electronic converter structure that only uses four switches in each stage instead of six switches. On the other hand, the use of this topology is limited for loss optimization due to voltage balance problem across DC-link capacitor and less power capability.

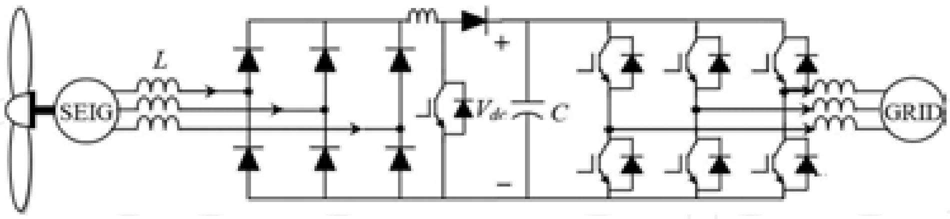

Figure 15. WECS with power factor correction using DC-DC stage.

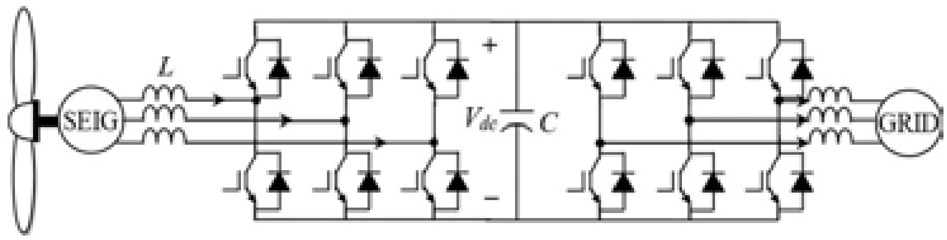

Figure 16. WECS with back-to-back converter.

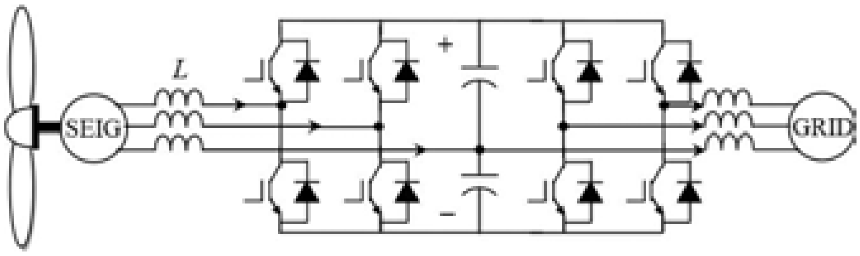

Figure 17. WECS with modified back-to-back converter.

3.3.3. Wind-based SISO platforms with PMSG

Low-speed high-torque PMSGs are used as the preferred solution in variable-speed high-power direct-driven wind generators. However, low-speed operation produces low voltage profile at the generator terminals. As the electrical power available from the wind generation system cannot be delivered directly to the grid, power electronics plays a decisive role in overcoming this limitation. **Figure 18** shows a bridge boost rectifier (BBR) in cascaded with VSI topology. A step-up transformer is used for grid connection; since VSI produces low voltage profile due to low-speed direct-driven generator operation. This topology has same features as the topology that was previously shown in **Figure 15** in addition to the grid-tie-transformer.

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Another option to achieve high power factor in the generator side is to use a voltage source converter (VSC) in cascaded with VSI topology in the WECS as shown in **Figure 19**. The transformer stage still required to boost the inverter output voltage level to the grid voltage level. In **Figure 20**, a semi-controlled rectifier topology was connected to achieve same VSC topology advantages with higher efficiency; since less switching losses can be obtained through reducing the number of switching devices. However, it will produce larger current harmonic distortion because only one half cycle is controlled. The common drawback for all previous configurations is the use of the transformer for grid connection which increases the size of the power converter circuit. Then, this structure becomes feasible for small WECSs.

On the other hand, the same rectifier topologies can be efficiently utilized with current source inverter (CSI) topology feasible for low-speed direct-driven PMSGs. **Figure 21** shows same configuration as the other in **Figure 18** but with CSI working as a boost inverter stage. This configuration has the same drawbacks as illustrated previously. However, omitting the step-up transformer represents an additional advantage which reduces the size and weight of the system.

In **Figure 22**, the VSC topology can be used with CSI topology in order to achieve same advantages as the configuration in **Figure 19**. Dual boost feature is obtained with low harmonic distortion. However, larger losses are expected by increasing the number of switching devices (12-switches) which reduce the overall efficiency. The CSI increases the voltage towards the mains by itself, so the output voltage of the VSC must be lower than the lowest rectified line-to-line voltage.

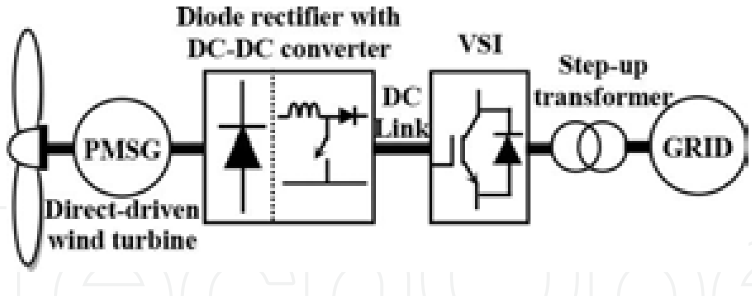

Figure 18. PMSG with BBR and VSI structure.

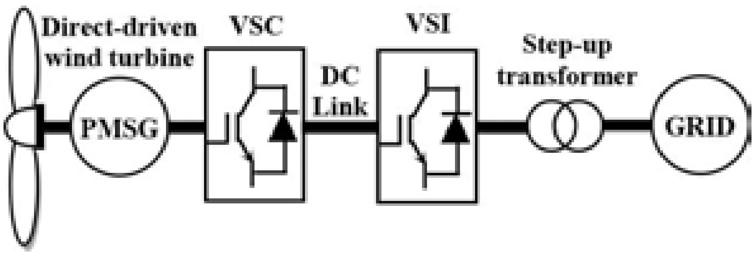

Figure 19. WECS with VSC-VSI converter structure.

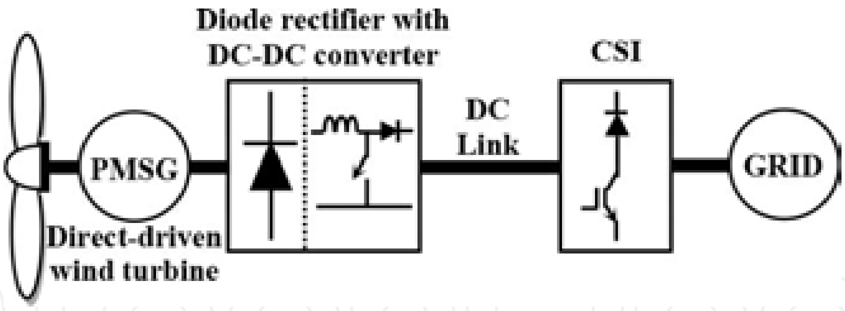

Figure 20. WECS with semi-controlled rectifier and VSI structure.

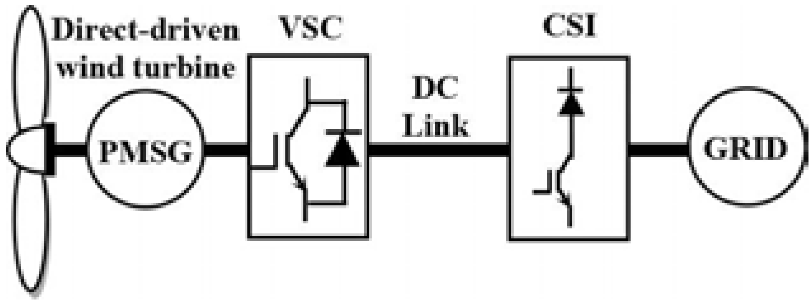

Figure 21. WECS with BBR stage and CSI structure.

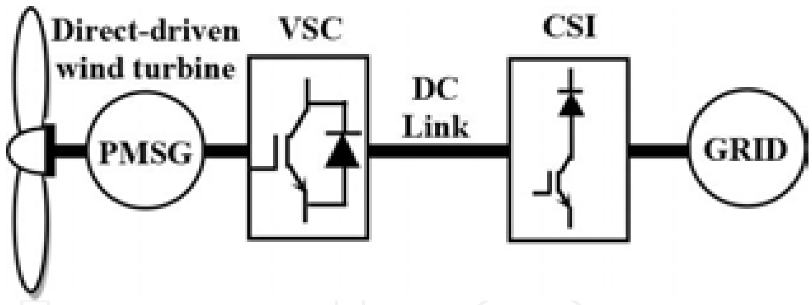

Figure 22. WECS with VSC-CSI structure.

3.4. Hybrid energy system in home

In hybrid energy systems (wind, PV, fuel cell, and battery storage) and its application such as plug-in hybrid vehicles (PHEVs), MISO converters became widely used to enhance the stability and reliability. **Figure 23** shows an application example for the MISO (sometimes called multi-input boost converter MIBC) platform feasibility with PHEVs. In MISO, the AC grid is connected to the DC-Bus via boost rectifier, the PV/fuel cell is connected to the DC-Bus via boost converter and the energy storage system is connected to the DC-Bus through a bidirectional DC/DC converter.

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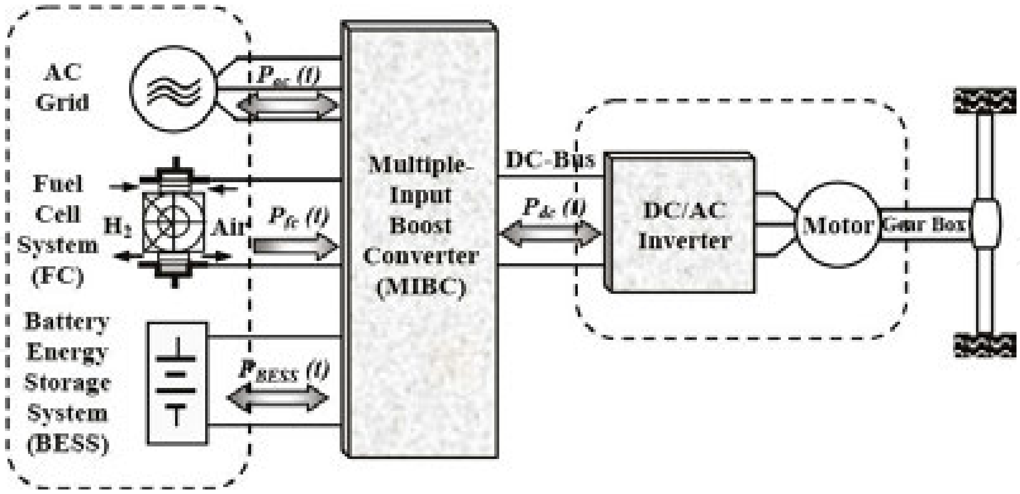

Figure 23. The block diagram of the PHEV drive train with MISO structure.

3.4.1. MISO with vehicle to grid (V2G)

PHEVs have an advantage of AC power grid connectivity compared to self-contained hybrid electric vehicles (HEV). The vehicle-to-grid (V2G) can be utilized when the vehicle battery is in the discharge mode while grid-to-vehicle (G2V) is used when the battery is in the charge mode. The V2G mode is considered as a promising concept for electric power grid stability via large storage vehicular system. However, the availability of electricity supplies to recharge vehicle battery is still a significant challenge to enable this concept. **Figure 24** shows an example of the V2G system components. The system involves six main parts: (1) AC power grid and alternative energy resources; (2) master-based independent control; (3) charging stations; (4) bidirectional power flow and point-to-point Plug-in electric vehicle (PEV) communication; (5) smart metering and control system; and (6) the vehicular technology including its battery charging management.

In general, PEVs with V2G interfaces can charge or inject energy into the grid when parked and connected. The concept requires three elements: a power connection to the grid, a communication connection with the grid operator, and suitable metering. Communications must be bidirectional to report battery status and receive commands. In fact, the current challenge is how to make smart metering system aware of the battery's state of charge (SOC) and its capacity in real time. In [16], smart metering system with both on/off boards was proposed to support V2G concept. As a result, the PHEV can represent a controllable load while integrating it with green energy sources via smart meter information. GPS locators are also useful in the large-scale real-time energy management operation. In addition, field area network is used to realize monitoring and communication functionalities among PHEV charging stations.

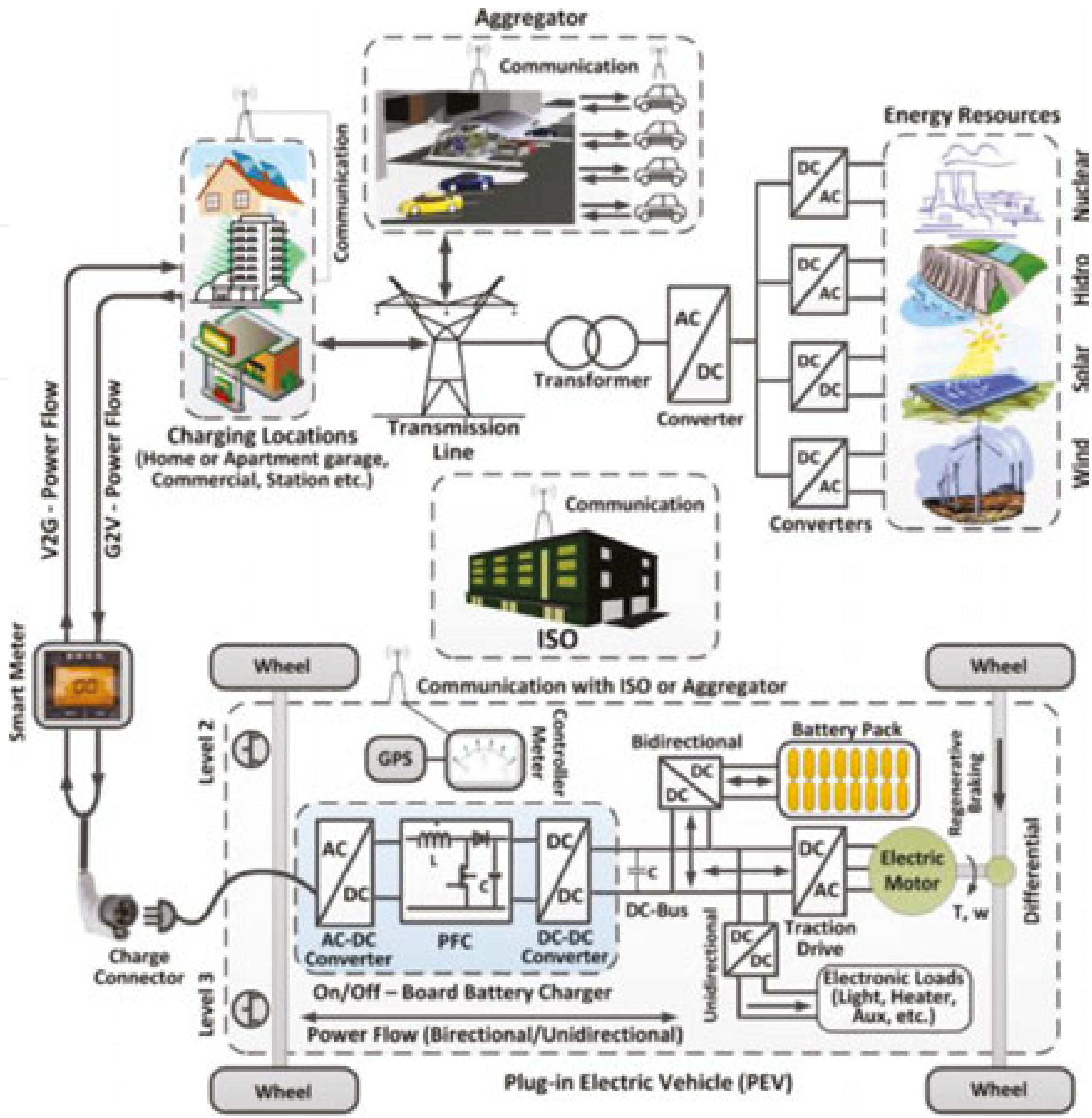

Figure 24. V2G system with smart meter.

3.4.2. SISO with wireless charging electric vehicle (EV)

Another feasible option for EV is that we can use the simple SISO platform to operate a wireless power transfer charging station as shown in **Figure 25**. There are several stages for wireless charging of EV. Firstly, an AC-DC rectifier with PFC ability is used to convert the AC utility grid power into DC power source. Secondly, the converted DC power is then inverted into a high-frequency AC power as the transmitting primary coil. The insulation failure of the primary coil is possible. As a result, a high-frequency isolation transformer may be connected between the inverter output and the primary side of the transmitting coil to ensure charging system protection. The magnetic field of the primary transmitting coil induces an AC voltage on the secondary receiving EV coil. Finally, the secondary transmitted AC power is then rectified via AC-DC converter to charge the EV battery [17].

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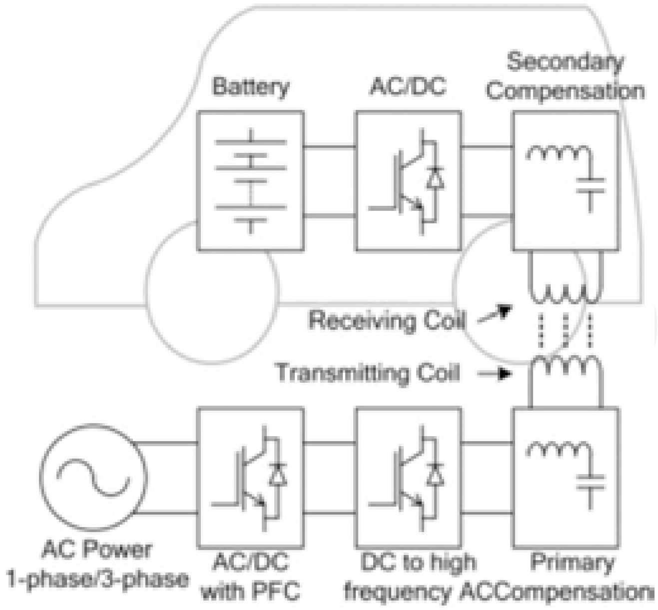

Figure 25. Typical wireless power transfer EV charging system.

4. Case study

VSI is considered one of the most efficient power conversion topologies for AC/DC-source-based MISO platform. A bidirectional power flow control strategy is suggested here to enable the smart operation between local building and electric utility service lines. The primary intent of the inverter development with smart functionalities is to enable an efficient interconnection and economical operation for dispersed PV-based building installations to the utility grid. Some distinctive aspects of this case are smart metering, the provision of pricing information to consumers, the provision of some control options to consumers, and information exchange on a fully networked system enabled by massively deployed sensors [18]. It is in this regard that the inverter with the aforementioned smart functionalities is being proposed in this section.

The PV panels provide the input of the DC-DC converter with 132 V. Then, the step-up converter boosts the PV voltage level to 350 V_{dc} which serves as the input of the smart DC-AC inverter. Moreover, the inverter setup is a part of MISO system structure that involves lead-acid battery energy storage bank with 160 V nominal voltage and 100 Ah rated capacity. The battery storage is connected to the DC link via a bidirectional buck-boost DC-DC power converter.

The case study was performed through Matlab/Simulink software program and real-time experimental hardware implementation in order to verify the validity of this platform with smart meters for grid-tied FIT systems. The test results were acquired through a laboratory-scale MISO frame hardware setup in the sustainable energy systems (SES) laboratory at Manhattan College. The overall system schematic and photograph is shown in **Figure 26**. The system comprises multiple converters used to control power flow under harsh ambient conditions. Different operating modes are possible, for example, the system can be supplied with electric power by way of a 3-phase wind generator, a PV, and batteries. The system is housed in an air-cooled case (with thermal protection) and communicates with the master controller (TMS320F2812 DSP platform) via a D-connector bus. The signal interface features analog and digital I/Os to allow for the connection of a wide variety of sensors, for example, temperature sensors, resolver inputs.

A voltage/current sensor module is connected through the AC-bus common coupling point between the MISO system and utility grid. This module is used to acquire the power measurements as a part of smart meter functionality for real-time energy management operation. The stability of DC-bus voltage is the main parameter to decide on energy flow scenario. Then, we can set upper and lower limits for DC-bus voltage in order to maintain system balance operation while connected to AC grid. For example, if V_{dc} is higher than V_{dc_up}, then it means that there is excess power available from wind and PV generators. Accordingly, the battery will operate in the charging mode to store energy while supplying local load demand and sending power back to grid based on smart building contract agreement. In this case, net meter measurement will show a negative reading which indicates feeding energy into utility grid. On the other hand, if V_{dc} is lower than V_{dc_low}, then it means that either one or both wind and PV generators is supplying less power into MISO system. As a result, the battery will operate in the discharging mode to support local load demand while receiving a portion of the needed power from grid. In this case, net meter measurement will show a positive reading which indicates receiving energy from utility grid. Finally, if V_{dc} is within the upper and lower stability limits, then it means that both wind and PV generators are balanced and sharing power with utility grid to supply building loads. As a result, the battery will operate in the rest mode which improves battery life time. The detailed parameters and specifications of MISO platform are listed in **Tables 1** and **2**.

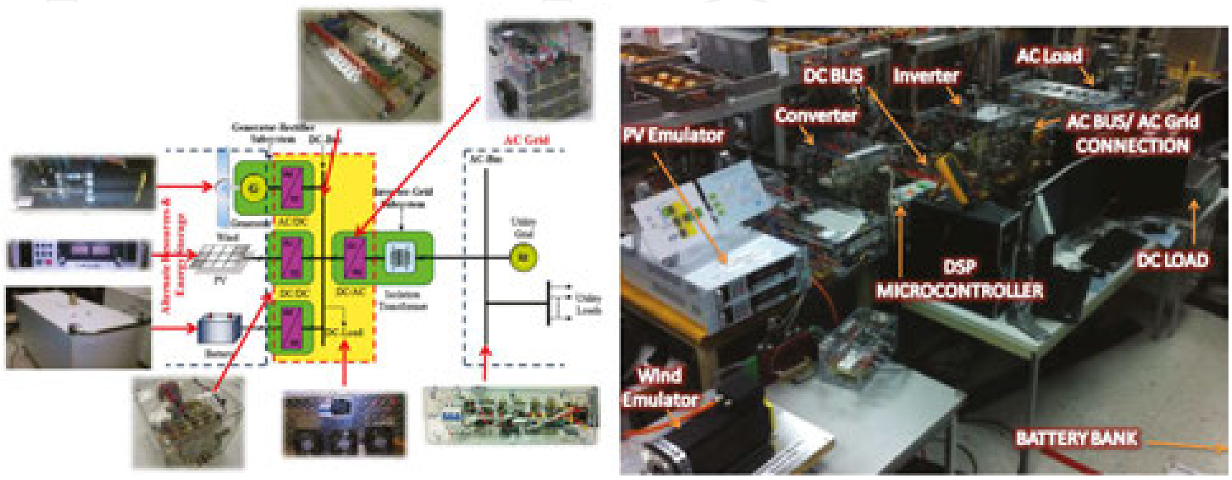

Figure 26. The schematic diagram and photo of the MISO experimental hardware test setup.

4.1 Pure *P*-*Q* injection capability

An inverter grid-tie system has been designed to verify the effectiveness of the MISO injection capability for AC power into the grid. The inverter has been tested under various power factor and command step conditions with 12 mH grid filter. The switching frequency of the devices is set to be 5 kHz. The grid voltage is 120 V, 60 Hz. The system controller and PWM generation are conducted by DS1103 PPC Controller Board. **Figure 27** shows the grid-tie inverter control under pure active power, pure leading, and lagging reactive power conditions. The output is 5 kW active power (0°), 2.5 kVar lag reactive power (−90°), or 5 kVar lead reactive power (90°).

4.2 Hybrid *P*-*Q* injection capability

Figure 28 shows the grid-tie inverter control with equal active power and reactive power command. The active power is 3 kW with either lagging (1.5 kVar) or leading reactive power (3 kVar). We can notice that the grid voltage-current angles are always larger than 0° and smaller than 90° (lag or lead). The testing results and measurements are confirming the validity and superiority of the developed MISO platform with smart inverters interconnecting green buildings to utility grid network.

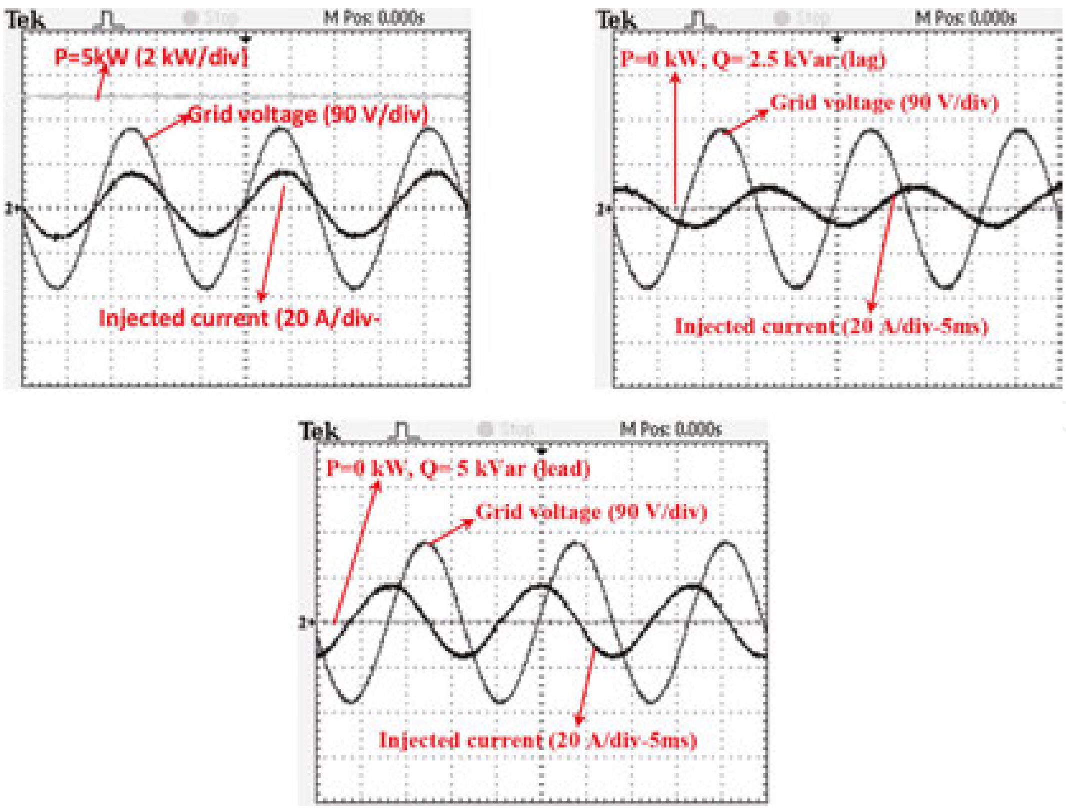

Figure 27. Pure active-reactive power injection test results for 5 kW active, 2.5 kVar lag reactive, and 5 kVar lead reactive powers.

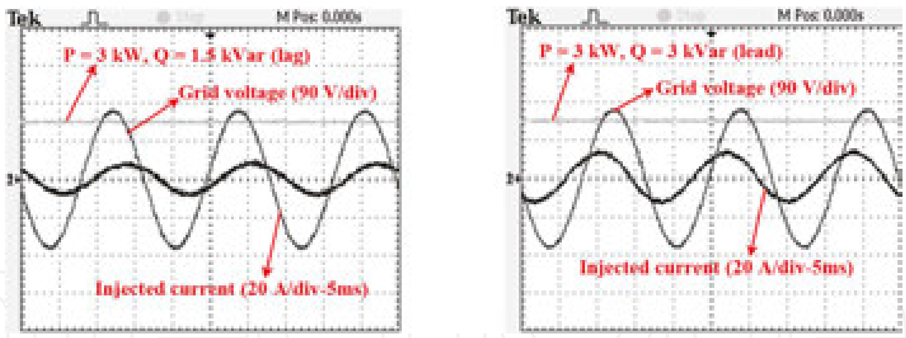

Figure 28. The test results for the hybrid active-reactive power injection for 3 kW active with 1.5 kVar lag reactive powers and 3 kW active with 3 kVar lead reactive powers.

5. Conclusion

In this chapter, a detailed study of the different power electronics platforms for grid-tied smart buildings was presented. Both analog and digital (smart) metering systems were discussed including FIT and NM infrastructures. The main power electronics converter platforms were categorized into two types as SISO and MISO structures. Each platform was introduced in regards to several types of alternative energy resources (wind, PV, etc) involving battery storage and its use in our home applications. PHEV technology with (V2G-G2V) concepts and its wireless power transfer operation were discussed. A hardware experimental case study with MISO platform involving smart bidirectional grid-tied inverter was performed to verify the validity of the developed power electronic structure for smart systems. The new power electronics platforms were studied to prove its superiority for grid-tied smart metering systems.

Symbol	Quantity	Value
f_s	Grid frequency	60 Hz
V_s	Grid voltage	120/208 Vrms
V_{dc}	DC-link voltage	350 V
C_{dc}	DC-link capacitance	1200 μf
L_f	Filter inductance	12 mH
f_{sw}	Switching frequency	5 kHz
kp^i	Proportional current controller	10
ki^i	Integral current controller	100
kp^c	Proportional voltage controller	0.07
ki^c	Integral voltage controller	0.7

Table 1. PV and battery storage specifications and control parameters.

IntechOpen

PV		Battery bank	
Parameter	Specification	Parameter	Specification
Output power	0–6 kW	Rated voltage	160 V
OC and SC points	(10 A, 140 V)	Connection	10-series
Max, operating point	(9 A, 132 V)	Rated capacity	100 AH
Switching frequency	50 kHz	Battery type	Lead-acid
Input inductor	0.33 mH	Total power	12 kW

Table 2. Smart bidirectional inverter specifications and control parameters.

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