Transformerless dc Converter for Distributed Solar Power Generation System

Heri Suryoatmojo, Akbar Faiz, Mochamad Ashari, Ronny Mardiyanto
Electrical Engineering Department, Institut Teknologi Sepuluh Nopember (ITS)
Jl Arief Rahman Hakim, Surabaya 60111
E-mail: suryomgt@gmail.com

Abstract-There are two types of distributed solar power generation system, stand-alone system and grid connected system. Grid connected system are usually equipped with additional transformer to transfer the energy from solar power to the grid. However, providing additional transformer will add extra cost to the system. Therefore, this research develops transformerless boost inverter system. The proposed system consists of a boost converter and transformerless inverter. Boost converter is used to increase the dc voltage yield by photovoltaic (PV) to be slightly higher than the grid voltage. In order to maximize the power from PV, the proposed system is also designed with Maximum Power Point Tracking (MPPT) by changing the value of modulation index in the transformerless inverters. The simulation results show that the system can work effectively in a various conditions such as fluctuating light intensity and grid voltage.

Keyword-Inverter; Transformerless; Boost Converter; MPPT; Photovoltaic.

I. INTRODUCTION

The supply of fossil fuels is increasingly depleted. In recent years, it has become one of the popular topics in any discussion. The utilization of renewable energy can be an attractive alternative as a replacement for fossil fuels[1]. Not only utilize renewable energy, but people should also compete to find another types of alternative energy. If this is done, it will reduce human dependence on fossil fuel use. A lots of renewable energy that can be used as a substitute for fossil fuels.

Photovoltaic is used to convert solar power into electric power. Electricity generated by the solar cells have properties that do not generate noise during operation and does not generate toxic particles in the generation of electricity. So, we can conclude that this plant is an environmentally friendly power plant. In grid-connected photovoltaic an inverter system is required, due to the output of the photovoltaic is DC voltage. Transformerless dc-dc converter is required to deliver the power from solar cells to the grid. Meanwhile, in order to adapt the fluctuation from solar irradiance, maximum power point tracking is also developed in this research. Perturb and observe method is required in this model.

II. SOLAR POWER SYSTEM NETWORK

A. Photovoltaic

Photovoltaic or PV is a renewable energy converter that use sunlight as an energy source into electrical energy [2]. PV consists of a series of two or more layers of semiconductors. The principle is related with the photoelectric principle. Sunlight contain energy form photons. When these photons on the surface of the PV, the excess electrons from the n-type semiconductor will move toward the hole on the p-type semiconductor. Because of the flow of electrons and holes is then formed an electric field.

PV module is a collection of several PV cells. This research uses Solarex module MSX-60 [3]. Module consists 36 cells that can generate a maximum power of 60W with light intensity conditions ($I_{radiance}$) of 1000W/m^2 and 25°C in temperature. Characteristics of power which can be generated versus the magnitude of light intensity on the PV surface can be seen in Figure 1 and the ambient temperature can be seen in Figure 2.

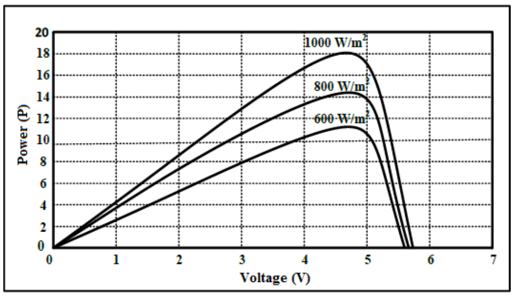

Figure 1. P - V Curve with $I_{radiance}$ change

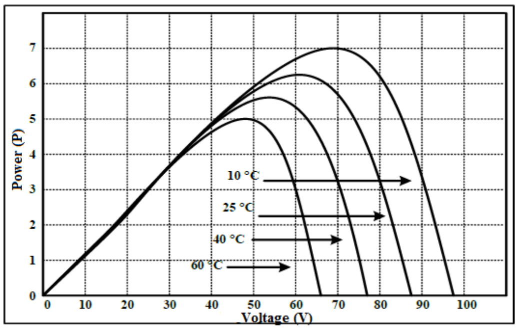

Figure 2. P – V Curve with Temperature Change

The array is a connection of PV modules that connected to one another both serial and parallel. Serial installation will cause voltage to increase according to the number of serially-connected modules, while parallel installation causes the increase of the resulted current.

B. Boost Converter

Boost converter is one of DC–DC converter that used to increase DC voltage. The output voltage of boost converter is always greater than the input voltage. The topology of boost converter generally consists of inductor, diode, and switch. Inductor and diode on boost converter are serially connected towards the voltage source, while the switch is parallelly connected. The inductor is used as a current and voltage source to limit the ripple of output current. The Capacitor on boost converter is used to limit the ripple of the output voltage. The circuit of boost converter is shown in Figure 3.

The value of the output voltage of boost converter is determined by setting duty cycle value, as shown in equation 1. Duty cycle is a ratio between the time when the switch is on towards switching period.

$$V_{out} = \frac{V_{in}}{1-D} \qquad (1)$$

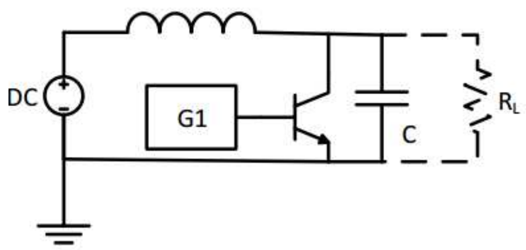

Figure 3. Boost Converter Circuit

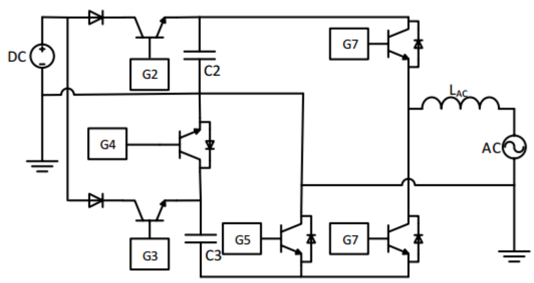

Figure 4. Transformerless Inverter Circuit

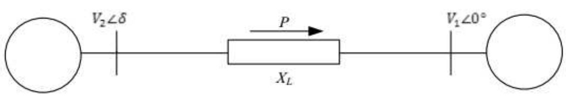

Figure 5. Power Flow Two Sources

C. Transformerless Inverter With Grid Connected

Inverter is an electronics circuit which converts DC input voltage to AC output voltage with the controllable amplitude and frequency. The output voltage can be obtained by control the switching of the inverter. The output voltage is ideally sinusoidal form and contains harmonics. Transformerless inverter is a type of bridge inverter which can result in sinusoidal voltage. This inverter is designed to directly connected to grid without transformer as a linker. The result of the transformerless inverter is better than inverter which still uses a transformer to connect to the grid. Transformerless inverter circuit can be seen in Figure 4. Power flow process in the system connected to grid needs an inductor in the transmission process. As shown in Figure 5 [4]. A voltage source V_1 with an angle phase δ_1 is connected to another source, V_2 with an angle phase δ_2. If both of sources are connected through a transmission line which exists an inductance X_L, the current (I) will flow between both. Because of the current flow in the line, active power (P) and reactive power (Q) also flows between both sources. Equation (2) is used to obtain the power supplied.

$$P = \frac{V_1 . V_2 . \sin\delta}{X_L} \qquad (2)$$

D. Maximum Power Point Tracker

Perturb method and Observe (P & O) is one of methods MPPT [5]. P & O method is easy to use and costs less than the existing methods. This method has a simple feedback and multiple parameter measurements. This method operates in stages (such as addition or subtraction). When there is a change on duty cycle, it compares the output power of the PV with the increase in the previous cycle. If the disruption tends to show an increase (or decrease) of power array, the next disruption will be formed in the same direction (or the opposite). In this condition, the peak power tracker will seek continuous peak power conditions.

III. TRANSFORMERLESS BOOST INVERTER SYSTEM

A. System Configuration

The main components used in the system are shown in Figure 6 and consist of . solar modules (PV), boost converters, transformerless inverter, inductors, and controller.

In general, a PV absorbs sunlight and generates voltage. The output of a PV is direct current. The output voltage of the PV is then stepped-up by the boost converter. A PI controller controls the converter output at a specified reference voltage. This allows the PV to work at a lower voltage level than the fixed network without causing over-modulation on the inverter.

The output of the converter will be stored in two capacitors in turns based on the frequency of the network. Two capacitors output the voltage to the network through an inverter to get the amount of single phase AC voltage. Inverter will adjust the output voltage through an inverter modulation index obtained from the MPPT Perturb and Observe process (P & O). The inverter output voltage phase leads the network phase by 1° so that the power flows to the network.

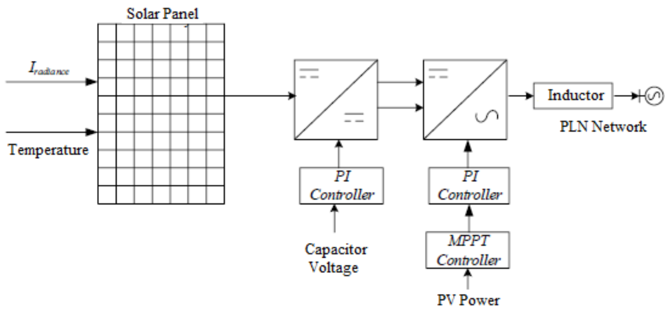

Figure 6. Block Diagram System

B. Design of Photovoltaic

PV modules used are Solarex module MSX - 60. The module is composed of an array consisting of 12 modules in series connection then the array is paralleled by 3 arrays PV parameters are shown in Table 1.

TABLE 1. PHOTOVOLTAIC MODUL PARAMETERS

Parameters	Rate
Number of Module	12 Module
Number of Cells (N_S)	432 Cells
Maximum Power(P_{max})	2160 W
Voltage at The Maximum Power(V_{mp})	205,2 V
Current at The Maximum Power (I_{mp})	10,5 A
No Load Voltage(Voc)	253,2 V
Short Circuit Current(I_{sc})	11,4 A

C. Design of Boost Inverter Transformerless

1. System Parameters

All parameters used in this model are shown in Table 2.

TABLE 2. SYSTEM PARAMETERS

Figure 8. System Switching Technique

PARAMETERS	Rate
Maximum Power PV (P_{PV})	2160W
Voltage PV (V_{in})	0 – 253,2 V
DC Capacitor PV (C_1)	470µF
Inductor *boos Converter t*(L_b)	2,8mH
Capacitor DC*bus*(C_2&C_3)	1680 µF
Frequency*Carrier*(f_s)	18000 Hz
Inductor Conected (L_{ac})	2,5mH
Network Voltage(V_{grid})	220 V
Network Frequency(f_g)	50 Hz

2. Swithing Techniques

The system consists of a boost converter and inverter transformerless. There are seven switches on the system: G_1, G_2, G_3, G_4, G_5, G_6 and G_7. The operation of the switch has a different firing time and technique. Switching time can be seen in Figure 7. The switching technique can be seen in Figure 8.

G_1 is operated by switching technique Pulse Width Modulation (PWM) analog. Analog PWM signal is generated from references DC voltage and carrier signals in the form of a saw tooth voltage with a frequency of 18 kHz. It is to charge and discharge the PV voltage source in the inductor (L_{DC}). Then, this energy from inductor discharges to the bus capacitor
(C_2 and C_3).

G_2, G_3, G_5 and G_7 operated with the switching zero crossing detector (ZCD). ZCD PWM technique is a technique that ground the carrier signal while the signal voltage reference using the network. Switching G_3 and G_5 is done according to the positive cycle of the grid voltage while the G_2 and G_7 contrary to the negative cycle of the network voltage.

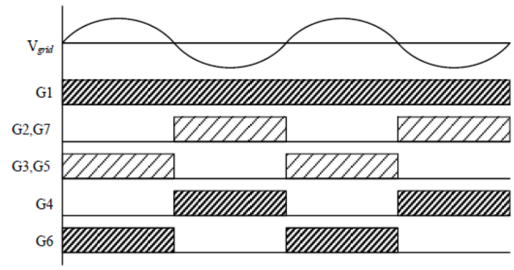

Figure 7. Switching state

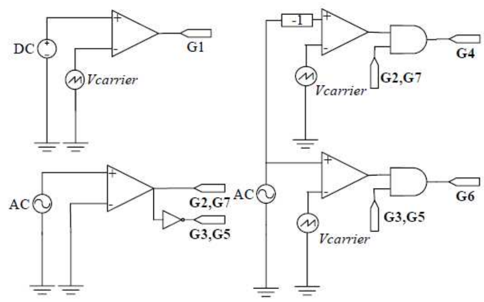

Figure 8. Switching technique

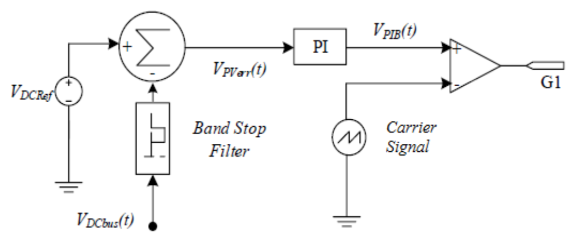

Figure 9. Boost Converter Controller

G_4 and G_6 operated with sinusoidal PWM switching technique (SPWM). This technique uses a sinusoidal reference signal with a frequency of 50 Hz, while the carrier signal from the saw tooth voltage 18 kHz. Losses due to the switching process is reduced because only two switches are operated.

3. *Controller System*

There are two PI controllers used in this system to control boost converter and the transformerless inverter. Boost converter controller schematics can be seen in Figure 9. The boost converter controller adjusts the value of voltage at the DC bus capacitors (C_2 and C_3). This error signal obtained from the subtraction between the reference signal and the measured signal at the capacitor C_2. Previously measured signal passes the band stop filter to smoothen the results. While the reference signal in the form of a DC voltage source. The results of the error signal become analog PWM reference signal to trigger the switch G1.

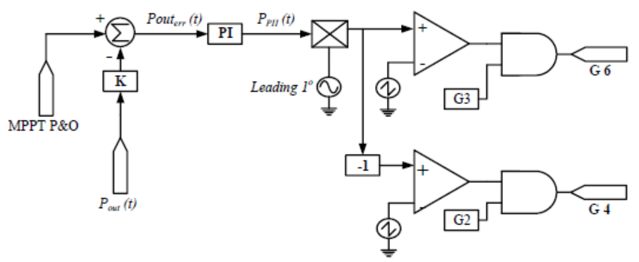

Figure 10. Transformerless inverter controller

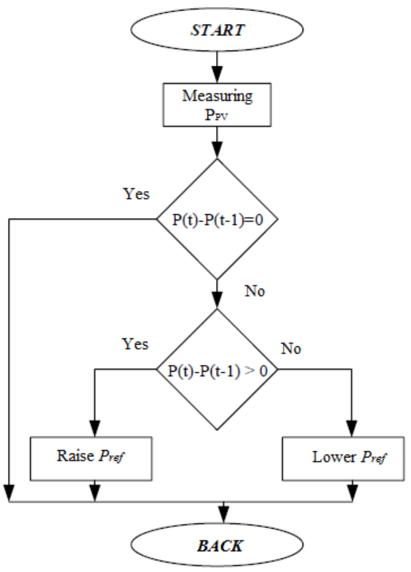

Figure 11. MMPT Perturb and Observe Flowchart

Transformerless inverter controller adjust the value of modulation in the inverter to vary the value of output voltage inverter. This controller error signal obtained from the subtraction between the reference signal and the signal measured at the output power of the system. Previously measured signal is lowered to make it easier to see the changes. While the reference signal obtained from the MPPT process. The results of the error signal would then become the SPWM reference signal for switching on the switch G_4 and G_6.

4. *Maximum Power Point Tracker*

MPPT method which used is Perturb and Observe. MPPT design that used has an input in form a power of PV (P_{pv}). Then P_{pv} will be differentiated through the process dP_{pv} / dt. If the result is not zero, then it means that PV power is not maximum. That differential result will raise or lower the reference voltage PV which is then processed by a control circuit for resulting a reference signal P_{PVref} replacing P_{PVref} in the inverter controller. When the results dP_{PV} / dt is positive then P_{PVref} raised and otherwise when the results dP_{PV} / dt is negative then P_{PVref} lowered. This will generate value P_{PVref} which makes the modulation index may issue a maximum power.

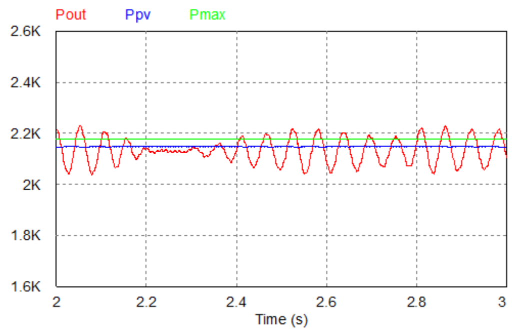

Figure 12 .Power System Normal Condition

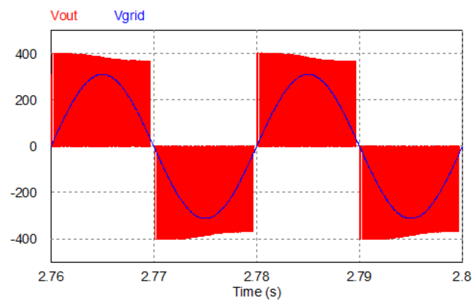

Figure 13. Voltage System Normal Condition

IV. System Simulation Results

In this simulation boost transformerless inverter system will be simulated with inputs from PV sources is already assembled and has parameters as shown in Table 2. The intensity of the light incident on the surface of the PV is set to the maximum condition is 1000W / m^2. Voltage network to be associated with PV regulated under normal conditions, namely 220V 50Hz. In Figure 12 the output power of the system has an accuracy rate of PV maximum power of 98.39%. This indicates that the P & O MPPT controller is quite successful in their use tracking for maximum power value. P & O method of tracking maximum power value based on changes in the PV power output at a continuous time. This resulted in a continuous change in the results of Power. In Figure 13 the output voltage leads the grid voltage by 1°. This is useful for the system to power the grid in accordance with Equation (2). the switching process is adjusted so that the grid and phase voltage to intersect. In Figure 14, the output current is approaching sinusoidal-shaped system 50Hz frequency as the frequency of the grid.

A. Changes in light intensity

In this simulation transformerless inverter system boost will be simulated with a variation irradiance starting from 1000W / m^2 to 600W / m^2 and made fixed line voltage is 220V. $I_{radiance}$ changes will affect PV maximum power that can be streamed. It also resulted in changes in the maximum power output of the system. Therefore, it is necessary MPPT capable of searching the maximum power of the system that can be supplied to grid. The changes in irradiance also affect the value of the voltage and current PV.

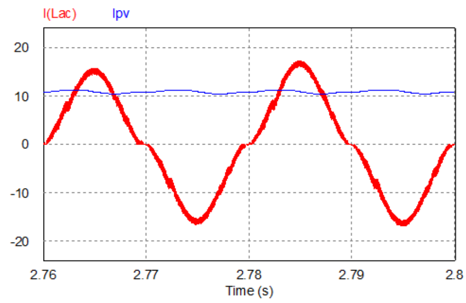

Figure 14. Current System Normal Condition

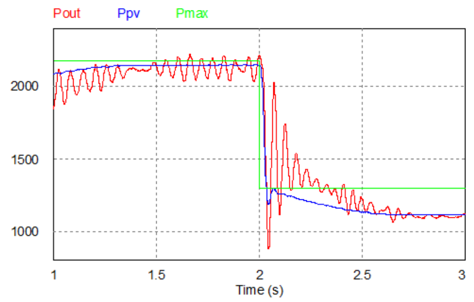

Figure 15. Power System Light Intensity Decreases

In Figure 15 changes in power when the light intensity decreases significantly with the accuracy of the power of 86.23%. We also see that differences in power output PV and the output power of the system or the system efficiency is not big. This is due to MPPT method used by the PV output power changes as shown in Figure 11.

In Figure 16, the output voltage is decreased in accordance with the system of power that decreased as well. This was proof Equation (2). In Figure 17 the system output current distortion is even greater. It is inversely proportional to the reduction in power that can be supplied. PV output current is getting smaller because of the intensity of light incident on the surface of the PV decreased.

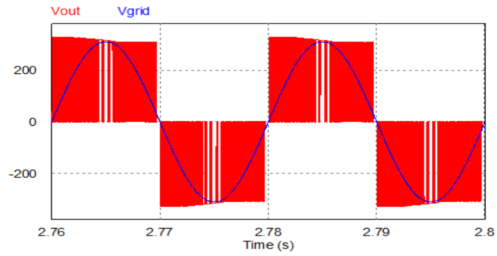

Figure 16. Power System Decreased Intensity

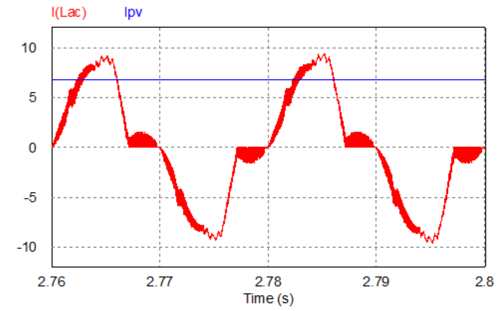

Figure 16. Current System Decreased Intensity

B. Changes Voltage Network

From simulation, it can be observed that voltage variation transformerless inverter systems with major changes with an increase of about 5% that of 230 V and a decrease of approximately 10 % is 200V, but still irradiance 1000W/m^2. Changes in the value of the grid voltage will affect the value of the index modulation inverter which serves to determine the output voltage of the inverter. PV maximum power out remains unaffected but it will affect the flow of electricity to the network. In Figure 18, when the grid voltage is increased by 5% results decrease in power. This is because power flowing exceeds PV capability (2) Eq. So, the power that flows decline. The accuracy of this method reached 97.36%. In Figure 19, when the grid voltage is decreased by 10% the power that flows decline as well. This is in accordance with Equation (2). accuracy power supplied by 88.01%.

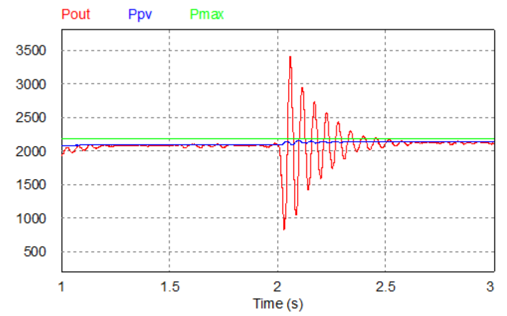

Figure 19. Power System Network when Voltage Increased

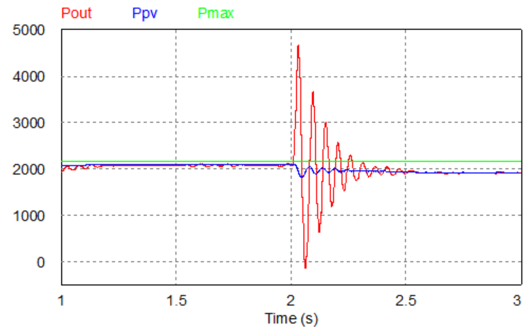

Figure 19. Power System Network when Voltage Decreased

V. CONCLUSION

Based on simulation results, we can conclude the following.

1) The transformerless inverters can be connected directly to the grid and can deliver maximum power.
2) MPPT controller capable of tracking for maximum power output with a various of conditions such as changes in light intensity and large changes in the voltage network
3) Accuracy of power that can be flow to a sufficiently large grid with an average of 90.98% in terms of changes in light intensity and an average of 94.59% when the network voltage changes.

REFERENCE

[1] Jia-Min Shen, Hurng-Liahng Jou, and Jinn-Chang Wu, "Novel transformerless grid-connected power converter with negative grounding for photovoltaic generation system", IEEE Trans. Power Electron., vol. 27, no. 4, Apr. 2012.

[2] Rashid, Muhammad H."Power Electronics: Circuits, Devices, and Applications", Pearson Prentice Hall. 2009.

[3] Solarex."MSX-60 and MSX-64 Photovoltaic Modules", USA, 1998.

[4] Safi'i, A.Y., "Design and simulation full bridge converter DC link voltage to regulate the dispersed generation systems using fuel cells", Teknik Elektro ITS, Surabaya, Juli, 2011.

[5] Widodo, Rusminto T., Rugianto, Asmuniv, Sejati, Purnomo, "Maximum Power Point Tracker Solar Cells Using Algorithms Observe and Perturb ", Politeknik Elektronika Negeri Surabaya-ITS, Surabaya, Indonesia.

[6] Schimpf, F., Norum, L.E., "Grid connected converters for photovoltaic, state of the art, ideas for improvement of transformerless inverters", Norwegian University of Science and Technology.

[7] Riawan D.C., *"Grid-Connected Buck-Boost Inverter for Variable Speed WECS Applications"*, Chapter 5, Curtin University of Technology, Perth, Western Australia, 2010.