CHAPTER 1

Introduction

1.1 Background

The needs for cleaner environment and the continuous increase in energy consumption have made decentralized renewable energy production more and more important. The photovoltaic, hydro, and wind energy production technologies are considered to replace the unclean with the clean technologies based on fossil fuels and nuclear fission. Among the clean technologies, using photovoltaic energy could be a solution for balancing continuously-increasing energy needs. According to the report of International Energy Agency Photovoltaic Power systems (IEA PVPS) on the installed PV power, during 2000-2015, more than 50 GW PV power increasingly installed by the 24 IEA PVPS countries and other countries around the world, which is higher than the additional PV power installed in 2013 and 2014. The trend of 2015 is the significant extension of the global PV market around 26,5%, as shown in Figure 1 [1]. Most of the installed PV power is the grid-connected PV systems (GCPVS) type (>97%).

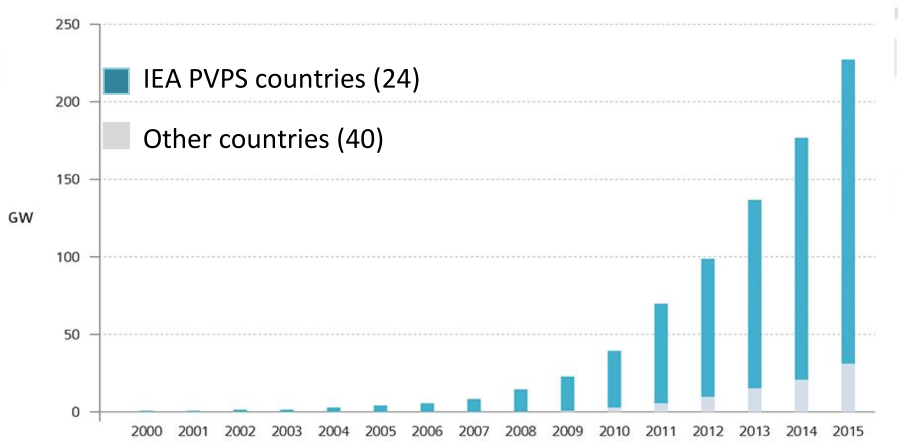

Figure 1.1 Evaluation of photovoltaic systems installation (GW) reported by IEA-PVPS

Thus, making the GCPVS is a crucial part of the future electric energy system and smart grids. The grid-connected PV system consists of 3 main parts: 1) PV array, 2) inverter, and 3) utility grid. Generally, the overall GCPVS efficiency is still low because the commercial PV panel’s efficiency is around 14-22% and the requirements of the utility grid in each country are mostly based on the power quality international standard involving with interconnections of GCPVS such as IEC, IEEE or EN. Therefore, it is very important that the inverter must be able to produce the ac power with high quality covering those requirements of the utility grid by using the efficient grid-connected inverter.

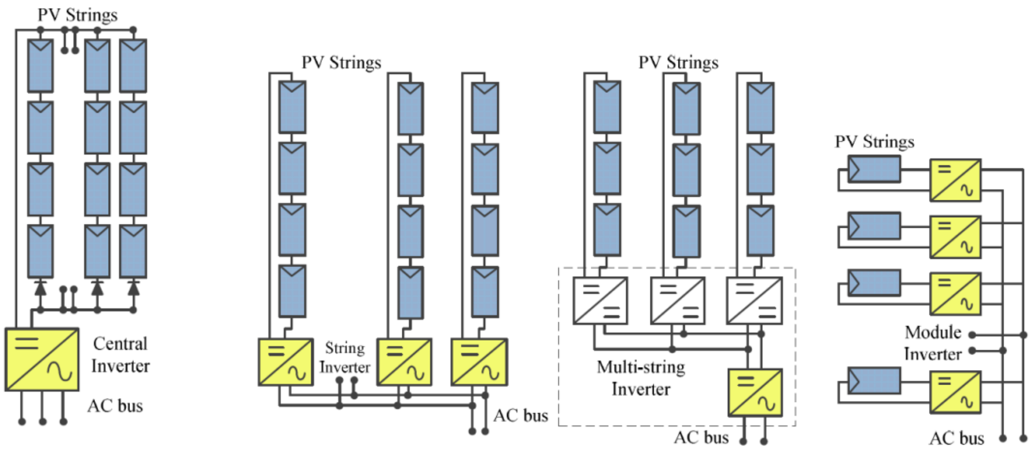

Figure 1.2 Overview of grid-connected PV inverters, (a) Centralized technology, (b) String technology, (c) Multi-string technology, and (d) AC-module and ac cell technologies.

Figure 2 shows the overview of inverter technologies for grid-connected PV systems consisting of 4 types as follow: 1) centralized, 2) string, 3) multi-string and 4) AC-module technology. The centralized technology need to have via connections of PV modules (a PV string) in series to avoid boots converters or voltage amplification from using transformers, then connected in parallel, through string diodes, in order to achieve the desired power levels. Using centralized technology causes power losses due to a centralized maximum power point tracking (MPPT), mismatch losses between the PV modules, losses in the string diodes, and a nonflexible design. The string technology may use the high input voltage to avoid voltage amplification (transformerless) or using fewer PV modules in series, if a dc/dc converter or line-frequency transformer is used for voltage amplification. There are no losses associated with string diodes and individual MPPTs can be applied to each string. This increases the overall efficiency compared to the centralized. The multi-string technology is developed from the string technology by using many strings interfaced with each own dc/dc converter, this is very flexible when compared with the centralized and the MPPT of every string can be controlled individually as the string technology but its each PV string voltage can be lower. Finally, the ac module system is the case where one large PV cell is connected to a dc/ac inverter. The main challenge for the designers is to develop an inverter that can amplify the very low dc voltage with small area of a PV module, up to an appropriate level for the grid, and at the same time reach a high efficiency.

Two major tasks of inverters for grid-connected PV systems are presented as follow: 1) the inverters have to ensure that they can inject the sinusoidal current into the utility grid according to the specific standards involving the power quality defined by the utility in each country, such as the international standard IEC61727, EN61000-3-2, IEEE1547 and the U.S. National Electrical Code (NEC) 690. 2) The inverters must guarantee that the power can be transferred from PV module(s) to the grid at the maximum power point (MPP). Additional, they have to support the requirements of operators to produce the inverters which are high efficiency, low cost, long lifetime and wide range of input voltage [2]. From the report of more than 400 commercially available PV inverters, the transformerless inverters can reach maximum efficiencies, the majority of higher efficiency, smaller weight and size than their counterparts with galvanic separation [3]. In this concern, the string and multi-string technologies have been proposed to improve the features of the centralized technology [2]–[7].

The power converter topologies utilized in the aforementioned technologies, multilevel inverter topologies are being investigated for grid-connected PV systems [8]–[19].There are three common topologies of multilevel inverters: neutral-point-clamped, flying-capacitor, and cascaded H-bridge. Only the cascaded H-bridge multilevel voltage source inverter (CHB-MLI) topology, as shown in Figure 3, requires separated dc sources which allow different or equal input voltage values for each H-bridge cell. This topology can support the mentioned two major tasks of the inverter with a power processing stage. From these features, it can be noted that the advantage of string and multi-string technologies are properly applied to the CHB-MLI topology and attractive for grid-connected PV systems (GCPVS) as following present [4], [8], [10], [14]-[15],[19]:

1) It can generate the multilevel output voltage following the sinusoidal pattern waveform causing lower total harmonic distortion (THD) of the output current injected to grid compared to the output current generated by two or three-level-based inverters.

2) Reducing voltage stressing in power switches causes lower switching losses, electromagnetic interference (EMI), more compact filter size and lower cost.

3) Flexible for increasing or decreasing the number of voltage levels.

4) Each H-bridge inverter can be independently controlled; the maximum power extraction from PV modules can be achieved with the help of maximum power point tracking (MPPT) algorithms improving both reliability and energy production of PV system when the PV modules operate under mismatching conditions such as in the case of partial shading irradiance.

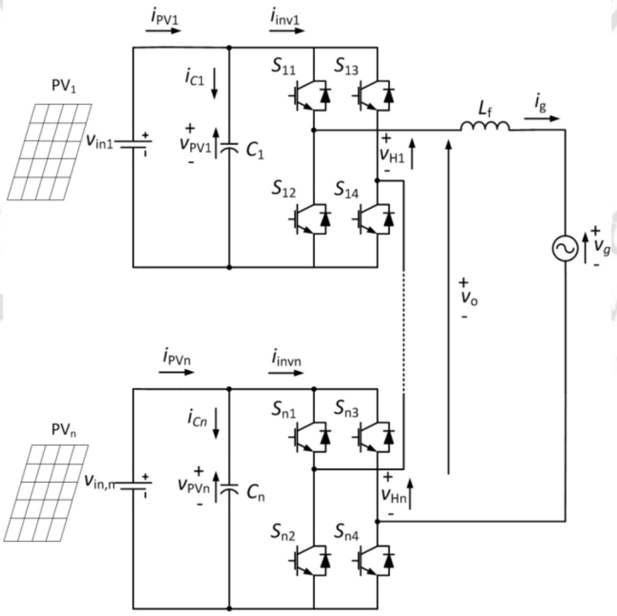

Figure 1.3 Circuit configuration of single-phase single-stage CHB-MLI for grid-connected PV system.

Although the mentioned feature of CHB-MLI is corresponding the aforementioned requirements of grid-connected inverter, and very suitable to be used to implement high-efficiency transformerless inverters [16], [19]. From [14]-[24], there are some disadvantages of CHI-MLI for grid-connected PV systems. They can be summarized in the following topics.

1) Isolated ground measuring

The strings of PV panels are not grounded, it causes the measuring of each cell of H-bridge need to be isolated grounding in order to avoid currents due to stray capacitances between the panel and the earth

2) The proper control method of CHB-MLI

In order to achieve the power transferring at MPP with high power quality following the required standards of the inverters for GCPVS, the proper operating of the cascaded n cells of H-bridge inverter with the independent control of the dc-link voltages and the control of the grid current are necessary. This task must be accomplished by using the n available actuation signal corresponding to the modulation unit of each H-bridge cell.

3) MPPT method

The high efficient inverter for grid-connected PV systems need to have appropriate MPPT to continuously control the maximum power transferring from the PV strings to the grid. The characteristic of PV power is nonlinear and time varying caused by changing of the atmospheric conditions. In particular, the CHB-MLI topology is designed for operating under mismatching conditions of PV strings such as in case of difference partial shadowing between PV strings, it causes the MPP of each string unequal. In order to extract the maximum power continuously, the use of fast response and correct MPPT method lead to achieve higher efficiency.

4) To improve the grid current quality

In most control configuration, the 3rd harmonic component appears in the grid current. In order to mitigate this harmonic component in the injected grid current, a band reject filter centered in double of fundamental frequency of grid voltage has been placed between the voltage measurements of each H-bridge and the inputs of voltage controllers. The quality of the grid currents is improved.

From [16]-[24], many methods have been used to solve the above mentioned problems of CHB-MLI for GCPVS. They can be summarized as follow:

1) Use the voltage control with PI controller for reaching the MPP in each cell of CHB-MLI.
2) Use the current control with PI controller and sinusoidal pattern from grid voltage to inject the sinusoidal grid current to the grid with unity power factor.
3) Use the multicarrier techniques with sinusoidal pulse width modulation (SPWM) to reduce the distortion in output current of inverter injected to grid.
4) Use the perturb and observe (P&O) MPPT method to generate the MPP reference voltage delivering to voltage controller of each cell of CHB-MLI.
5) Use the passivity-based controllers to reduce the THD of output current of CHB-MLI in case of stand-alone system.
6) Use the energy-balance control method to control the active power transferring with power function.

These designs do not propose in following topics; usage of pulse width modulation (PWM) technique leads to the lowest THD of grid current of a single-phase CHB-MLI for GCPVS, the used of MPPT technique can rapidly correct the MPP for GCPVS, the control methods can control the injecting of the active and reactive power to the grid, and the system stability for the whole irradiance and temperature operating ranges since the nonlinear parametric dependence of the system following the nonlinear current to voltage characteristics (i-v curve) of the PV arrays. From the mentioned problems, this research presents the concept of solving the problems as follows

1) Minimize THD of the CHB-MLI output voltage with carrier-based PWM.

2) Correct the MPPT condition of PV systems with the new modified MPPT method corresponding to the mismatch circumstance of PV modules in case of rapidly shading irradiance.

3) Control the injecting of active and reactive power from PV modules to the grid of the CHB-MLI for GCPVS under the required international standard of the grid.

1.2 Problem solving method

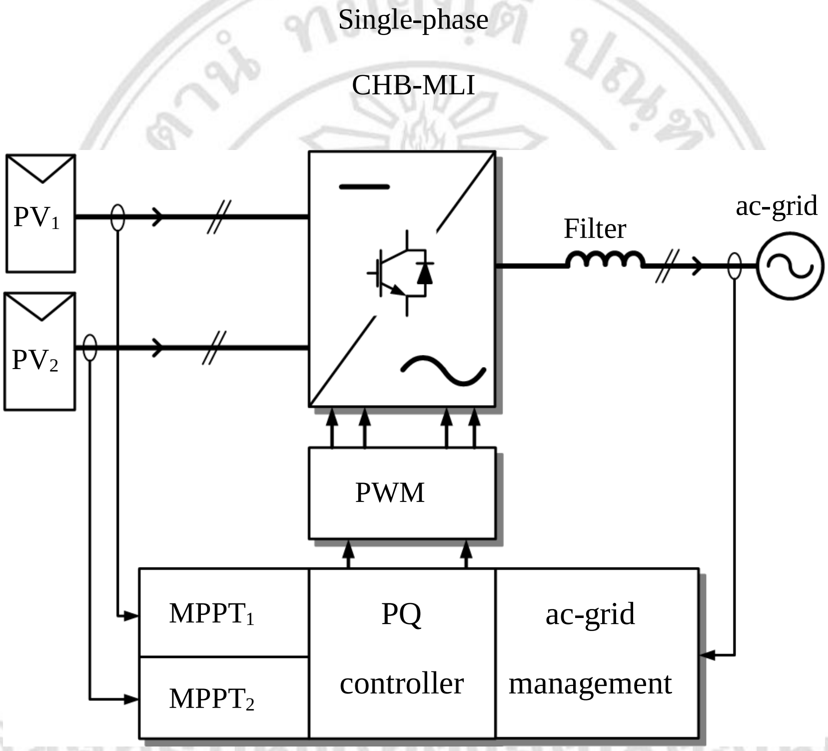

Figure 1.4 Conceptual scheme of the proposed grid-connected PV system

The proposed conceptual scheme is illustrated in Figure 4. It consists of n separated PV string power sources for n cells of CHB-MLI, a single-phase ac grid, the new modified MPPT control used for maximum power transferring from the PV array to the grid and supporting rapidly changing of the atmospheric conditions, the controller used for injecting the active power and reactive power to the grid in the condition of grid requirement and power limiting of PV system, and the last one, multilevel carrier-based PWM unit for driving the power switches in CHB-MLI.

The carrier-based modulation (CBPWM) schemes for CHB-MLI can be generally classified into two categories: level-shifted and phase-shifted modulations. The level-shifted carrier-based PWM consist of 3 methods: (a) In-Phase Disposition (IPD), where all carriers are in phase; (b) Alternative Phase Opposite Disposition (APOD), where all carriers are alternatively in opposite disposition; and (c) Phase Opposite Disposition (POD). The phase-shifted carrier-based PWM (PS-CBPWM) features with all the triangular carriers have the same frequency and the same amplitude, but there is a phase shifted between any two adjacent carrier waves. Controlling the single-phase CHB-MLI by PS-CBPWM can generate highest switching frequency of inverter output voltage compared with another schemes of carrier-based PWM. It causes smallest inductor filter in the ac-side of GCPVS. From this reason, the PS-CBPWM is selected to control the CHB-MLI power switches in this research.

The CHB-MLI topology is designed for supporting the independent MPPT for each set of H-bridge. Using the suitable MPPT algorithm is a choice to increase the efficiency of MPPT. Numerous MPPT techniques have been proposed for maximum power tracking such as hill-climbing, fractional open-circuit voltage control, P&O, incremental conductance (Inc Cond), fractional short-circuit current control, fuzzy logic control, neural network, ripple-correlation control and several others [25]–[28].The ripple-correlation control MPPT (RCC-MPPT) is the one which is convenient for GCPVS with the following features: very fast convergence to reach MPP, parameter-insensitive MPPT of PV systems, several straight forward circuit implementations and well developed theoretical basis. It would be suitable for a modular application, which uses small converters and the applications requiring a high rate of convergence [29]-[30]. From above reason, the RCC-MPPT technique is selected to use in this research. However, the conventional RCC-MPPT has some disadvantage about to define the suitable time constants of the filters to generate the desired output signal for correcting MPPT control which causes slow response especially in case of rapidly shading irradiance. In this research, the RCC-MPPT technique will be improved with a simple modified ripple-correlation control MPPT method that produces a fast respond MPPT and guarantees the correction of MPPT operating for single-phase CHB-MLI for GCPVS.

Moreover, the control technique for injecting power from PV modules to the grid will be developed by using the current control technique applying for the proposed single-phase CHB-MLI scheme. This technique is emphasized that the injecting active and reactive power under the international standard requirement of the grid focusing on THD.

1.3 Thesis objectives

From the mentioned problems, this research presents the concept of solving the problems, the main objectives of this thesis are as follows:

1) To study and present the control of a single-phase CHB-MLI with independent MPPT for grid-connected photovoltaic systems based on the new modified MPPT technique.

2) To develop single-phase single-stage CHB-MLI with independent MPPT for grid-connected photovoltaic systems and the controller using the active and reactive power control technique

1.4 Outline of the thesis

This thesis is organized into six chapters as follows:

Chapter 1 presents concise information of the background and problem of this research. The state-of-the-art and related researches for the single-phase CHB-MLI grid-connected PV systems and the control schemes are reviewed in this chapter. And the objectives of the thesis are also clearly represented.

Chapter 2 reviews the maximum power point tracking (MPPT) techniques for photovoltaic systems. The disadvantages of PV systems are the low efficiency of the energy conversion, the maximum power point (MPP) depended on the weather and irradiation conditions and the nonlinear characteristics of PV current-voltage (I-V) and power-voltage (P-V). The PV system need to operate at the MPP continuously, to get this, the suitable MPP tracking technique is necessary to take the PV system achieving the MPP operation. The most popular of the conventional MPPT techniques will be discussed with a brief review and then investigates the advantages and drawback which critically affect to the system performance.

Chapter 3 presents the modified MPPT based-on ripple correlation control and the simple sinusoidal pattern current control for single-phase single-stage VSI grid-connected PV systems. Furthermore, the principle of the RCC-MPPT algorithm, the conventional RCC-MPPT (CRCC-MPPT) technique and the proposed modified RCC-MPPT (MRCC-MPPT) technique applied in the grid connected PV system are discussed. The performance analysis of the proposed MRCC-MPPT and the CRCC-MPPT algorithms is verified and compared through simulation results.

Chapter 4 presents the proposed modified RCC-MPPT algorithm for a single-stage single-phase three voltage-levels VSI on a grid-connected PV system. The performance of the proposed algorithm is verified and discussed through simulation and experimental results.

Chapter 5 presents the investigation and the development the control of a single-phase single-stage CHB-MLI with independent MPPT for grid-connected PV systems based on the modified RCC-MPPT technique. The performance of the proposed algorithm is verified and discussed through simulation and experimental results based on the real PV power source.

Finally, chapter 6 gives the conclusions and suggestions for future research.