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Wavelet technique based islanding detection and improved repetitive current control for reliable operation of grid-connected PV systems

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ABSTRACT

Recent years have witnessed a thrust towards the use of solar energy as the major renewable energy source for distributed power generation. The proposed system requires reliable detection technique and suitable current control strategy for proper operation. This paper focuses on plug-in repetitive current (RC) control strategy for grid connected inverter system and wavelet technique for electrical grid status identification. The performance of proposed current control technique employed for grid connected inverter system under distorted and unbalanced grid voltage is compared with the existing conventional methods like PI and PR controller. This controller uses the feedback control system for attenuating periodic disturbances, improving high quality sinusoidal output current and high power factor. The proposed scheme employs fourth order infinite impulse response (IIR) filter for maintaining its resonance frequency, output frequency matching with grid fundamental frequency and reduction of harmonics. The DC-DC boost converter implements incremental conductance based (INC) maximum power point tracker (MPPT) algorithm. The effects of LCL filter for improving disturbance rejection capability and dynamic performance of the proposed system is also demonstrated. Grid connected PV inverter employs wavelet technique for an islanding detection functionality in order to determine the status of the electrical grid. In order to show the effectiveness of the proposed algorithm, modeling and simulation for grid connected PV system is performed using MATLAB/SIMULINK and its PowerSim toolbox.

Introduction

With the global warming and the increasing power crisis today, renewable energy sources and among them solar energy and wind energy have become very popular and demanding due to advancement in modern power electronics techniques. Photovoltaic (PV) sources are extensively used in many applications as they have the advantages of being maintenance and environmental friendly. Grid connected photovoltaic (PV) system can reduce investment outlay because it does not need battery for storing energy. The efficiency, output energy quality and reliability will directly affect the performance and investment efficiency of the entire photovoltaic power generation system [1]. DC/AC grid-connected inverter transforms DC to AC sine wave and delivers to the grid after suppressing harmonics with the help of AC filter. The inverter output voltage and the grid voltage are to be maintained of the same frequency and amplitude. Grid connected inverter, which is the heart of a PV system, is used to convert dc power obtained from PV modules into ac power to be fed into the grid. The efficiency of the grid connected PV system is affected by the inverter operation, structure of the PV panel and maximum power point algorithms. Improvement of the inverter and PV panels are dependent on the control technique available, topology, material and components used. The PV panels are classified as a single panel, strings of panels or a multitude of parallel strings and the inverter topologies are of central, string or modulo integrated [2,3].

A dye-sensitized solar cell (DSSC) is a low cost and high efficiency to the group of thin film solar cell which can be used as an alternative to conventional silicon P-N junction photovoltaic devices. It is a photoelectrochemical flexible DSSC system based semiconductor formed between a photo-sensitized anode and an electrolyte. The conversion efficiency of sunlight to electricity was improved to 3.4% under 1 sun irradiation using TiO_2 and polymer based membranes [4,5]. A quasi-solid-state dye-sensitized solar cell (QS-DSSC) was fabricated using dual function polymer hybrid material that improves photovoltaic conversion efficiency of 6.35% under full sunlight illumination. This efficiency is reduced to 6.03% after 100 days indicating QS-DSSC has long term stability [6]. The inverted organic solar cell (OSC) was fabricated with a Sn-doped TiO_2 film that exhibited a significant improvement in power

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conversion efficiency of 7.59% as compared to conventional TiO_2 film [7].

More active materials are needed not only for the high energy conversion efficiency but also for wide range absorption of the solar spectrum. A copper indium gallium selenide solar cell (CIGS cell) is a thin film solar cell used to convert light into electric power. It is low cost and high absorption efficiency above 20%. This high performance level requires a small amount of alkaline metals incorporated like NaF or KF into the CIGS layer which is a post deposition treatment (PDT) [8,9]. The novel device structures and fabrication processes which may trigger advanced efforts in the production of non-toxic, fast throughput and large area organic solar cells [10].

In the recent literature, various MPPT algorithms have been developed. They differ in many aspects such as simplicity, sensors required, efficiency and cost. Commonly used MPPT algorithms are P&O algorithm, incremental conductance (INC), fractional open circuit voltage (FOCV), fractional short circuit current (FCSI), fuzzy logic control (FLC), artificial neural network (ANN), current sweep and some advanced techniques like sliding mode control, one cycle control (OCC), hybrid MPPT, DC link capacitor, etc. [11–22]. The MPP applied is not a real one because the relationship is an approximation. FLC technique deals with imprecise inputs, does not need an accurate mathematical model and handles nonlinearity. This technique offers fast convergence and minimal oscillation around the MPP. However, their effectiveness depends a lot on the skill of the designer. ANN is an intelligent and probabilistic control technique. The demerit of this technique is that the data needed for the training process has to be specifically acquired for every PV array and its location. FOCV method is simple and inexpensive but the disadvantage in measuring open circuit voltage (V_{oc}). Moreover this method requires shut down of the power converter momentarily which results loss of power in each measurement. FSCI requires an additional switch for the power converter to short the PV array periodically and measure I_{sc}. In current sweep method, the *V-I* curve is updated periodically and the MPP voltage can be determined from it at these intervals. This method is complex in nature for which it is not the best option to track the MPP continuously. In DC link dooping control method, modulation is used. It is simple in design but expensive. The OCC method is simple and inexpensive but parameter tuning has to be performed. The P&O and INC algorithms are most efficient methods for reaching MPP. P&O method has low efficiency because of its lack of speed in tracking the MPP, whereas INC has the greater efficiency. The disadvantage of P&O method to track peak power under fast varying atmospheric condition is overcome by INC method. By using INC algorithm, MPP is to be reached and it will stop perturbing the operating point. Moreover, INC can track rapidly increasing and decreasing irradiance conditions with higher accuracy than P&O. One disadvantage of the INC is the increased complexity as compared to P&O. In this paper, an incremental conductance MPPT algorithm has been employed as it can track rapidly increasing and decreasing irradiance conditions with higher accuracy.

Current control methods play an important role in power electronic systems, mainly in current controlled PWM voltage source inverters which are widely used in active filters, AC motor drives, high power factor, continuous AC power supplies and uninterruptable power supply system [23]. Current control techniques help inverter to provide stability, low steady state error, fast transient response, low THD and excellent dynamic performance in the grid connected PV system. In order to incorporate PV into the grid, output current of the inverter must be sinusoidal with frequency of the utility grid. The sinusoidal current is achieved with the help of proposed current control techniques. Recent studies have been devoted towards current control techniques employed for achieving excellent dynamic performance of grid connected PV system [24]. The major control techniques are classified mainly into two types. They are ON/OFF controllers and separated PWM techniques. The ON/OFF controllers can be further classified as hysteresis [25], delta [26] and optimized methods [27]. The separated PWM techniques are divided into linear and non-linear. The main linear techniques are Proportional Integral (PI) [28], Proportional Resonant (PR) [29,30] and predictive controllers [31]. The non-linear techniques such as passivity [32] and fuzzy logic controllers (FLC) have been described in the literature [33]. The dead-beat [34] and feed-forward [35] techniques are derived from predictive controllers. In fact, choice of current controlling methods is mainly dependent on cost, system quality, safety risk, nature of application and system dependent elements. These techniques suffer from stability problems, complexity, bandwidth changes, variation of switching frequency, higher cost and lower THD. A better controller is required with high gain at the harmonic frequencies of interest, therefore plug-in RC has been proposed in this work. It is based on the internal model principle to improve the control performance and improve the stability of the system.

Having the advantages of free and green sustainable electricity, the PV grid connected inverters face a challenging islanding situation that has necessitated the attention of researchers. Islanding is a situation when a DG is disconnected from the main utility but remains energies and continues to supply local loads. This condition can result in many potential hazards since supply is without control and/or supervision of utility. Therefore, this condition needs to be detected and protected [36]. Many studies have been devoted to islanding detection methods and the main techniques can be classified into two types. They are local and remote detection techniques. The local detection method can be further classified as passive, active and hybrid methods. The remote detection techniques are divided into Utility and communication based method [37].

The basic passive protection methods include over current, over/under voltage and over/under frequency, harmonic distortion schemes. In existing literature, many other indicators such as rate of change of frequency, power and phase jump are used to detect islanding. Islanding is detected by observing and analyzing the change in these indicators. The purpose of these schemes is to detect abnormal conditions and to provide signal to switch off the DG. The detectable changes in above parameters occur when there is a large mismatch in the power generated by the DG and power required by the load. When the power mismatch is very low, the above schemes are failed to detect the islanding scenario. This range of power mismatch is known as non detection zone of the schemes. It has been found that effectiveness of passive schemes depends on threshold setting of the parameters and range of their non detection zone (NDZ) [38]. If the threshold range is set small, nuisance tripping could occur. Hence passive methods are not sufficient for anti-islanding protection. To eliminate non detection zone of passive methods, active methods are included in protection. These schemes introduce perturbation to the parameters of the system such as voltage, frequency and impendence. When the DG is grid connected, these disturbance signals do not affect the performance of the system. When the DG is islanded, disturbance signal drift the parameter to detectable limits. But this external disturbance degraded the output power quality. Various active islanding detection techniques that can be used with grid connected PV systems have been reported in Refs. [39–42]. Most commonly referred active islanding techniques are output power variation (OPV), impedance measurement (IM) [39], sliding mode frequency shift (SMS) [40], active frequency drift (AFD) [41], sandia frequency shift (SFS) [42]. Hybrid method is evolved from the combination of both active and passive detection methods. The hybrid methods involve two stages of detecting procedures to overcome the problems of passive method and active method, in order to