UNIVERSITY OF CENTRAL FLORIDA

PV Energy Conversion and System Integration

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Description: The objective of this project is to develop a system-driven Plug'N'Gen solar power system demonstrating architecture of decentralized, low-cost, mass-produced, PV panel-mounted micro-inverters. This system will be able to compete with today's centralized multi-kW PV inverters that require cost prohibitive professional installation. The project tasks are: 1) novel inverter topology and control concepts; 2) advanced digital control algorithms; 3) SmartTie interface with the utility grid; and 4) low cost and ultra-compact PV inverter in package.

Budget: $1,267,000

Universities: UCF

Progress Summary

In this project, a novel adaptive digital signal processing and control algorithm is developed that optimizes the overall PV system output power by adjusting the position angles of the solar panel on both the elevation and azimuth axes. Simulation results show that the proposed technique demonstrates fast convergence and excellent tracking accuracy at all times of the day. During the study, two new ideas came up and are being investigated. The first idea that uses the pulse skipping control strategy to improve the efficiency of the inverter at low input power levels comes from the fact that the efficiency of a grid-tied inverter drops dramatically when the input power is relatively low. The second idea is that most of grid-tied inverters are operating in continuous current mode(CCM), in which it is hard to achieve the soft switching without additional circuitry, while in discontinuous current mode(DCM), it is relatively easy to achieve the soft switching. These investigations are described below.

2010 Annual Report

Advanced Digital Control algorithms

a. Adaptive PV Sun Tracking System

In this project, a novel adaptive digital signal processing and control algorithm is developed that optimizes the overall PV system output power by adjusting the position angles of the solar panel on both the elevation and azimuth axes. Since the proposed approach is adaptive in nature, the optimal position angles for the solar panel are iteratively computed using the adaptive gradient ascent method, until the incident solar radiation, and hence the output power is maximized. Furthermore, a Taylor's series approximation is employed for generating a unique optimal position angle increment/decrement at each iteration. Simulation results show that the proposed technique demonstrates fast convergence and excellent tracking accuracy at all times of the day. The progress made in the construction of a prototype sun tracking system employing the developed algorithm is also described.

Simulation Results The proposed signal processing algorithm was tested on a 16 bit Microchip dsPIC33fJ32MC204 Digital Signal microcontroller by varying the solar elevation angle from 0 to 180 degrees (sunrise to sunset), and calculating the tracking error and speed of convergence in each case, after the proposed adaptive algorithm converges. The algorithm is initiated by modeling the panel as facing east during sunrise. With increase in the elevation angle of the sun from 0 to 180 degrees as the day progresses, the adaptive control algorithm monitors the change in power output of the panel, and optimally iterates the elevation position angle of the PV panel. Fig. 1 shows the resulting tracking error vs. the solar elevation angle. In Fig. 2, the corresponding output power achieved by the proposed algorithm, in comparison to a panel fixed at 30^0 position angle is illustrated. The convergence speed, in terms of number of iterations required to converge for each value of solar elevation angle, is plotted in Fig. 3.

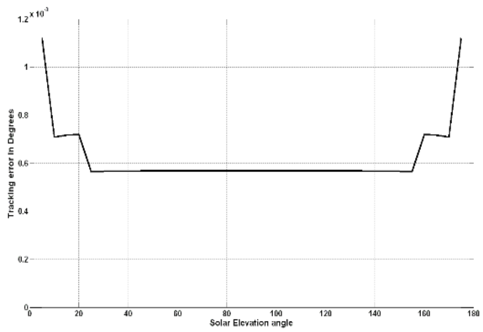


Figure 1: Tracking Error vs. Solar Elevation Angle

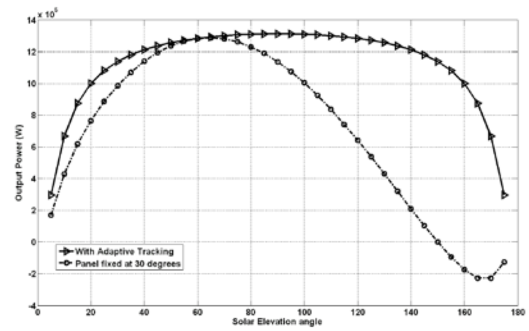


Figure 2: Output vs. Solar Elevation Angle

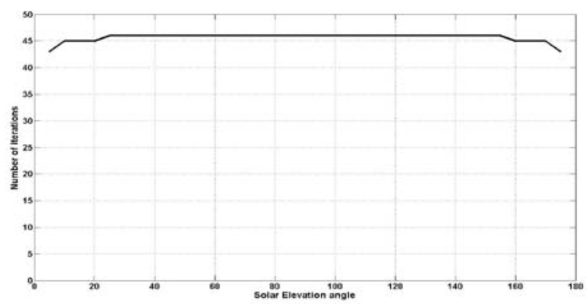


Figure 4: Number of iterations vs. solar elevation angle

A block diagram of the proposed prototype sun tracking system has been developed as shown in Fig. 4. The prototype sun tracking system consists of the following components:

1. Microchip dsPICDEM MCSM Stepper motor development board with a 100 pin dsPIC33FJ323MC204 Digital Signal Controller Plug In Module (PIM) mounted on it.
2. A Soyo 6V 2A 361 oz-in unipolar stepper motor controlled by Pulse Width Modulation (PWM) signals.
3. A HQRP 85 Watt (Size of 80 Watt) Solar Panel Power 12V Monocrystalline PV Module, with necessary mounts.
4. A Texas Instruments INA 209 high-side current shunt and power monitor with an Inter Integrated Circuit (I^2C) interface.

The INA209 sensor monitors the voltage and current output of the PV module, consequently computing the PV power output, and transmits that information to the dsPIC33FJ32MC204 microcontroller through the I^2C protocol. The developed adaptive sun tracking algorithm is implemented on the dsPIC33FJ32MC204 microcontroller, which executes the algorithm in conjunction with the inputs from the sensor INA209, and sends the appropriate PWM control signals through its PWM module to the Soyo 6 V stepper motor. The stepper motor moves the PV module through a series of steps on the elevation and/or azimuth axis until the incident solar radiation on the PV panel is maximized, and the INA 209 sensor power readings do not show a significant change in value. This process is continued to track the changes in the elevation and/or azimuth of the sun throughout the day and/or year.

The past few months were spent in testing the composite embedded code on the dsPIC33FJ323MC204, consisting of the adaptive sun tracking algorithm, motor control algorithm for controlling the stepper motor, and embedded code for I^2C communication between the INA209 power sensor and the dsPIC33FJ323MC204. Presently, the team is involved in the development of mounts, frame, support structures, etc. for the solar panel, and system integration of the complete sun tracking system.

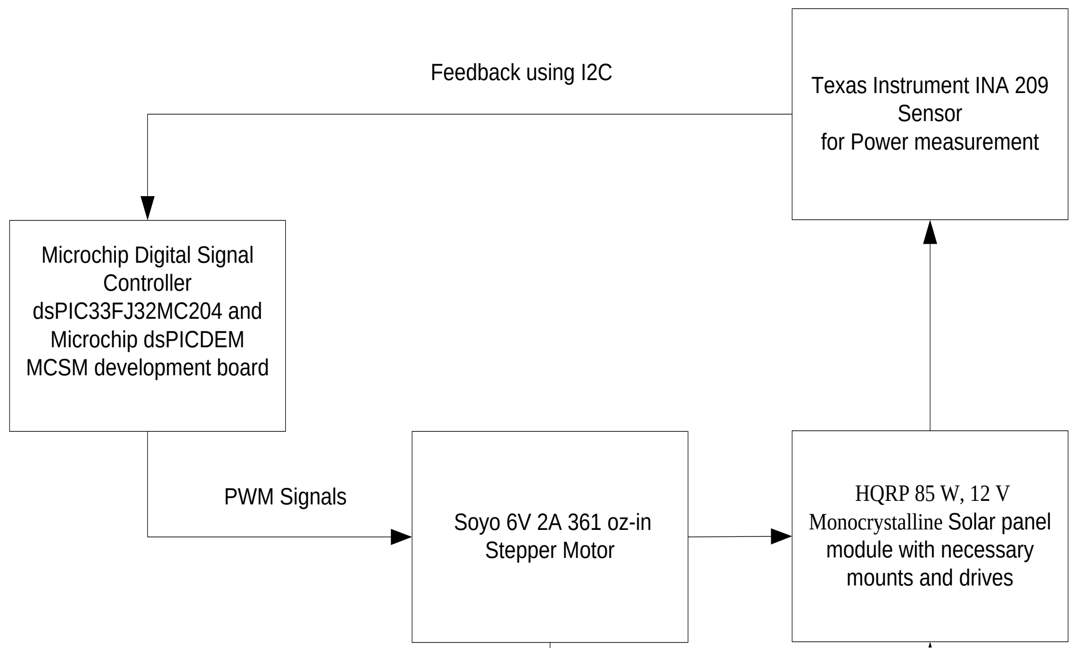


Figure 4: Block Diagram of the sun tracking system

b. Pulse Skipping control strategy development

Two new ideas came up during this research. We dug into these ideas with mathematical analysis, simulation and experimental verifications. The first idea that uses the pulse skipping control strategy to improve the efficiency of the inverter at low input power levels comes from the fact that the efficiency of a grid-tied inverter drops dramatically when the input power is relatively low. As shown in Fig. 5, the efficiency curves are greatly improved to above 90% by employing a pulse skipping strategy at light loads. The best efficiency curve corresponds to 140W pulse power level, while the lowest efficiency curve corresponds to a pulse power level of 49W. One can notice a slight difference in the efficiency curves corresponding to pulse power levels of 140W and 90W indicating

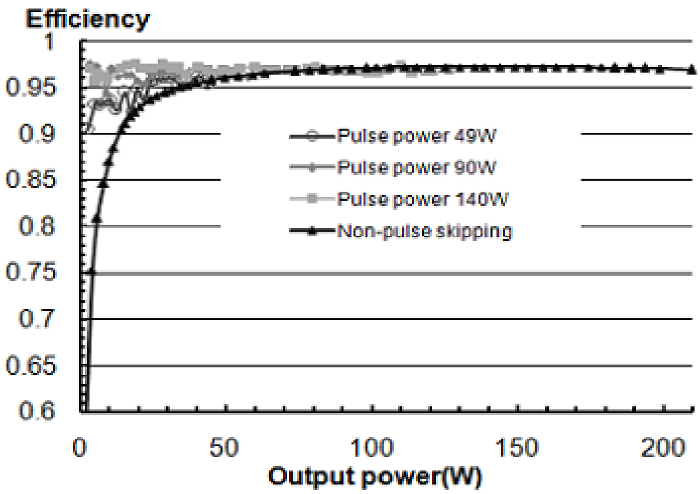


Figure 5. Efficiency improvement with pulse skipping with different pulse powers

that the optimal pulse power level can vary within this range without impacting the efficiency improvements attained.

The second idea is that most of grid-tied inverters are operating in continuous current mode(CCM), in which it is hard to achieve the soft switching without additional circuitry, while in discontinuous current mode(DCM), it is relatively easy to achieve the soft switching. There exists a big opportunity: can we gain the efficiency benefits from DCM over CCM? A comparison study was carried out and a conclusion was drawn. The two efficiency curves in CCM and DCM modes are compared as shown in Figure 6. From this figure, the efficiency in DCM mode at light load is much lower than that in CCM, while at heavy load the efficiency in DCM mode will slightly overtake that in CCM. Figure 7 shows the power loss comparison with the increase of the output power. From this figure, in CCM mode the power loss will increase steadily with the output power, while in DCM mode the power loss is much higher even at very light load.

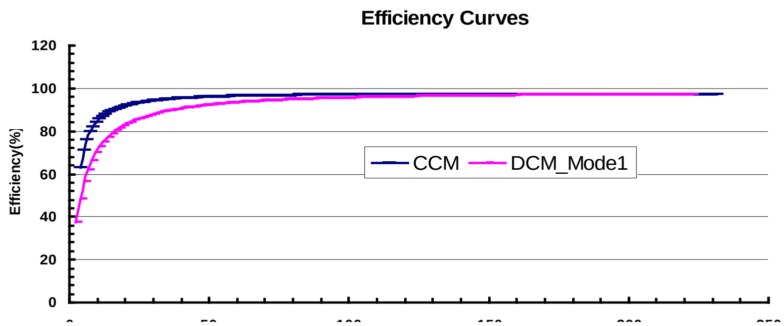


Figure 6. The efficiency comparison between DCM and CCM modes

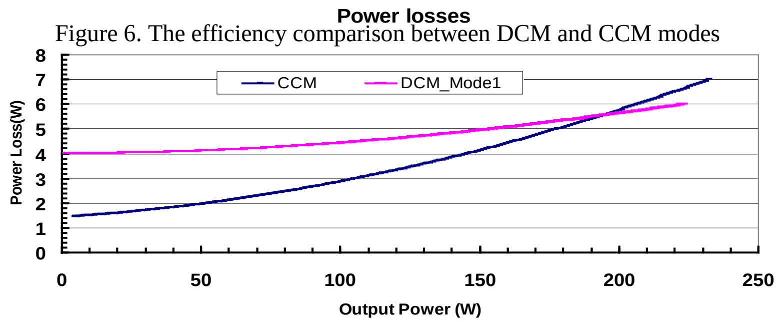
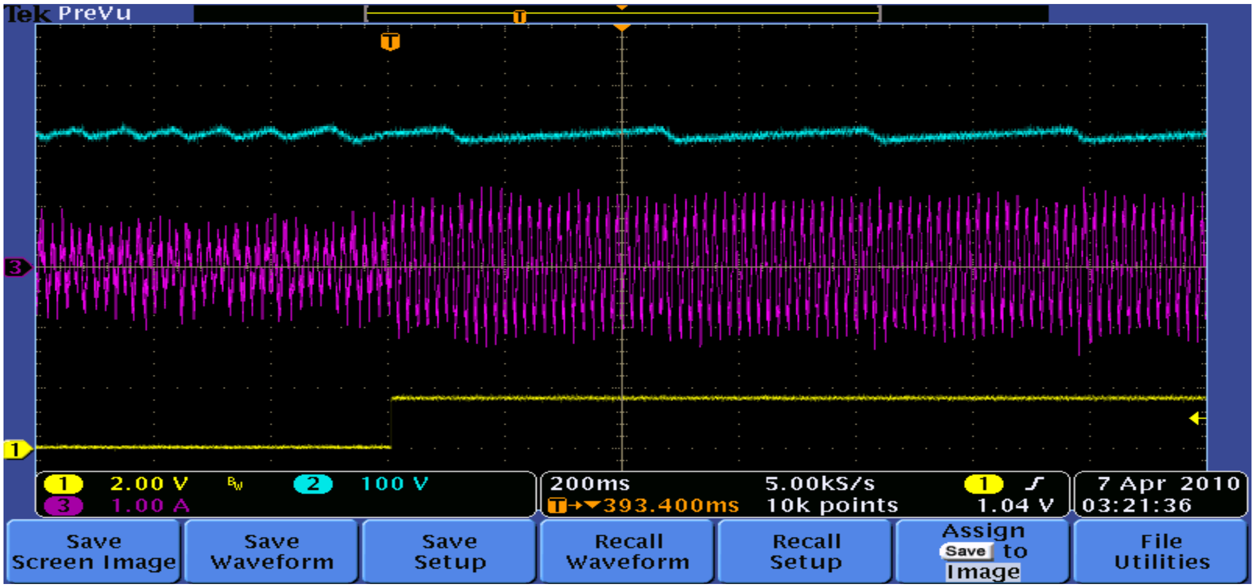


Figure 7: The power loss comparison between DCM and CCM modes

- **SmartTie Interface with the Utility Grid**

This research provided a novel control strategy that enables PV inverters to absorb little active power from the grid when the renewable source (e.g. sun) is not available to compensate for the inverters' internal losses, regulate the DC bus voltage to keep it within limits, and operate the inverters in VAR mode. This eventually extends the utilization of PV inverters beyond active power generation and helps improving grid stability and voltage regulation. Detailed design procedure was provided and validated by simulation and experimental results.



Patents:

Wasfy Mikhael, Raghuram Ranganathan, Nasser Kutkut, and Issa Batarseh "*Novel Adaptive Sun Tracking system for Incident Energy Maximization and Efficiency Improvement of PV Panels*", Invention Disclosure, filed Feb 10, 2010.

Journals:

R. Ranganathan, W.B. Mikhael, Nasser Kutkut and Issa Batarseh, "Adaptive Sun Tracking algorithm for Incident Energy Maximization and Efficiency Improvement of PV Panels", Special Issue Elsevier Journal on Renewable Energy (In Press, Accepted, April 2010).

Conferences:

R. Ranganathan, W.B. Mikhael, Nasser Kutkut and Issa Batarseh, "Novel adaptive sun tracking algorithm for energy maximization and efficiency improvement of PV panels", International Conference on Renewable Energy: Generation and Applications (ICREGA'10), United Arab Emirates, March 8-10, 2010 (Accepted, January 2010).