Photovoltaic Maximum Power Point Tracking without Current Sensor for Module Integrated Converter

Seong-Jin Kim [1], Sol Moon[1], Do-Hyun Kim [1], Joung-Hu Park[1], Chan-Su Chung[1]
[1]Dept. of Electrical Engineering, Soong-sil University, Korea
E-mail: jini4321@ nate.com

Abstract — In this paper, a simple maximum power point tracking (MPPT) method for series-connected DC-DC converter module of photovoltaic power conditioning systems (PCS) is proposed. This approach enables maximum power point (MPP) tracking control with the converter's output voltage information instead of calculating solar array power, which significantly simplifies the sensor network by removing current sensor. Furthermore, there is no multiplication process in the P&O algorithm to track the maximum power point because the power calculation is replaced by output voltage sensing. This simple MPPT control strategy can reduce the cost and size, and can be utilized with a low performance / low cost controller. For verification of the proposed control strategy, Zigbee (Xbee-pro) wireless communications and DSP's Series Communications Interface are utilized. Also series-connected hardware prototype with multiple photovoltaic modules was built and tested.

I. INTRODUCTION

Photovoltaic system presents fewer restrictions in terms of system organization cost and the installation areas compared to other renewable energy sources and it is receiving spotlight as the next generation's distributed power systems applicable to the urban areas. Photovoltaic systems have an optimal operating point (Maximum Power Point: hereafter referred to as MPP) where maximum power is generated due to the nonlinear variations in current and voltage of the solar cells. According to this, during the photovoltaic process to obtain maximum power from the solar cell, the technology to track the maximum power point (Maximum Power Point Tracking: hereafter referred to as MPPT) would be necessary. Currently representative algorithms for MPPT include constant voltage control method MPPT, Perturbation and Observation (P&O) MPPT and Incremental Conductance (IncrCon) MPPT, and among them, the P&O method which is easy for calculation and with good traceability is one of the most popular in use.

According to this trend, solar power systems, specially BIPV(Building Integrated Photovoltaic system) has increased. The past, solar power facilities, installed on the roof of the building, have exterior problems and limitations. To solve this problem, BIPV was used. However, in case of BIPV applicable to the building walls of the urban area, the volume of solar energy found in PV module would differ by partial shading, different local MPPs in the solar energy's characteristic curves. Thus, it becomes difficult for the central single PCS to track with the global MPP with the optimal efficiency due to the local MPPs, decreasing the performance of the MPPT. To resolve this, the study regarding the design technique for the system architecture using some small-sized DC-AC conversion device MIC (PV-Module-Integrated-Converter) in each PV module to increase efficiency has been in progress. MIC uses single power conversion circuit to deliver the generated power to load or storages (including DC-link capacitor), and in case of the occurrence of partial shading, each module generates the maximum power from its own solar panel, increasing the energy efficiency [1-6].

In addition, even with a solar array composed of multiple number of PV panels in different output characteristics from the complicated fabrication process, the maximum current can be tracked. However, each module utilizes the power conversion device, which leads to increase of the manufacturing cost. Thus, technical researches for reducing the manufacturing cost of MIC are necessary with the investigation of core operation algorithm of MPPT.

This study proposes a solution for removing the current sensor from power-measuring units to reduce the unit price per module, especially for the multiple number of MICs. If module's power increases/reduces due to the changes in insolation/temperature, the module's output voltage increases/ decreases. According to change As a result, without the current sensor, it can implement the existing MPPT algorithms.

Since the simultaneous MPPT operation of all the MICs in proposed scheme can confuse the normal operation of the algorithm, each module operates the MPPT algorithm sequentially. This paper analyzed the proposed MPPT method's operation principle in the theoretical perspective. Also introduced MPPT method is verified through experimental results including the proposed MPPT operation implemented with voltage sensor only.

II. PROPOSED MAXIMUM POWER POINT TRACKING METHOD

A. Operation principle

This study proposes new MPPT method based on P&O MPPT algorithm using a voltage sensor alone. The algorithm is applicable to PV power conditioning systems including cascaded dc-dc module integrated converters.

To explain this method in detail, specify the first module's output voltage as V_1, the second voltage as V_2 as shown in Figure 1.

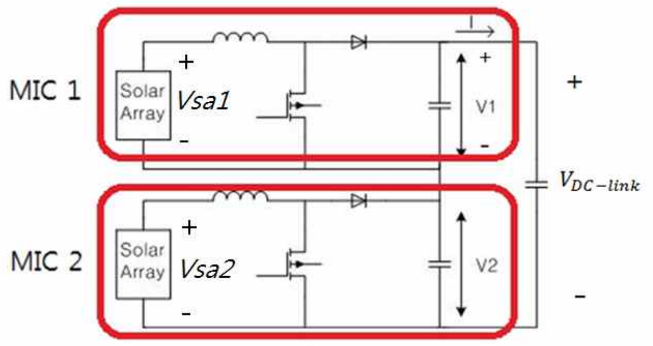


Fig. 1. Boost-type module-integrated converter (MIC) with series-connected outputs for PV power generation system

Sum of the output voltage in MIC connected in series is adjusted by post-stage regulator constantly maintaining the voltage through the voltage feedback controller. In Fig. 1, each module performs MPPT movements in a sequential order. When the first module's controller starts to do MPPT operation, the module1's power(P_1) generated from the solar cells increases in a few sampling period. Because P_1 are transmitted to DC-link through the converter, the output V_1 and the output current(I) increase. Due to the series connection of the outputs, the second module's output current(I) also increase. Since there is no MPPT operation in the second module whose operating point is fixed at constant PV power (P_2), So V_2 is decreased. From the fixed DC-link voltage control, V_1 increases. Likewise, when second module takes turns of MPPT operation, the change of the power brings about the changes of the output voltage of both modules, V_1 and V_2. In such process, the voltage change can replace the change in the PV power especially for P&O algorithm.

B. *Theoretical verification*

The operation principle with proposed P&O algorithm is as follows:
Output power of module1 is expressed equation (1).

$$P_1 = V_1 \times I,\ P_2 = V_2 \times I,\ V_1 + V_2 = V_{DC-link} \tag{1}$$

where , Vdc-link voltage is constant.
Variation of module 1's Power is like equation (2).

$$P_1 + \Delta P_1 = (V_1 + \Delta V_1)(I_1 + \Delta I_1) \tag{2}$$

Likewise, variation of module 2's Power is like equation (3).

$$P_2 = (V_2 - \Delta V_1)(I_1 + \Delta I_1) \tag{3}$$

Equation (4) is obtained as insert (3) into (2) to remove the current.

$$P_1 + \Delta P_1 = (V_1 + \Delta V_1)\left(\frac{P_2}{V_2 - \Delta V_1}\right) \tag{4}$$

Then, P_2 and V_2 are expressed by module 1's parameter, like equation (5).

$$P_1 + \Delta P_1 = (V_1 + \Delta V_1)\left(\frac{\frac{V_2}{V_1} \times P_1}{V_{DC-link} - V_1 - \Delta V_1}\right)$$

$$= (V_1 + \Delta V_1)\left(\frac{\frac{V_{DC-link} - V_1}{V_1} \times P_1}{V_{DC-link} - V_1 - \Delta V_1}\right) \tag{5}$$

From equation (5), ΔP_1 is summarized as :

$$\Delta P_1 = \left(\frac{\frac{V_{DC-link}}{V_1} \times P_1 \times \Delta V_1}{V_{DC-link} - V_1 - \Delta V_1}\right)$$

$$= \frac{V_{DC-link} \times P_1}{V_1} \times \left(-1 + \frac{V_{DC-link} - V_1}{V_{DC-link} - V_1 - \Delta V_1}\right) \tag{6}$$

Where $\frac{V_{DC-link}}{V_1} \times P_1$ and $V_{DC-link} - V_1$ are constant factors. So, it is possible to displace K_1, K_2. Finally we get equation(7).

$$\Delta P_1 = -K_1 + K_1\left(\frac{K_2}{K_2 - \Delta V_1}\right) \tag{7}$$

$$\text{Where } \left(K_1 = \frac{V_{DC-link}}{V_1} \times P_1,\ K_2 = V_{DC-link} - V_1 \right)$$

At equation (7), if $\Delta V_1 > 0$, then $\Delta P_1 > 0$, If $\Delta V_1 < 0$, then $\Delta P_1 < 0$. It means that the increase or decrease in ΔV_1 indicates an increase or decrease in ΔP_1. In case of MIC2, the same equation is applied.

C. *MPPT tracking algorithm without current sensor*

In order to implement the perturbation and observation algorithm, current and voltage sensors are needed for power calculation [7-9]. In this MIC scheme Changes in power of each module can be determined by changes in voltage. In this paper, to reduce development cost, expensive current sensor was removed and only voltage sensor was used to implement P&O algorithm. Variation in power of module on sequential MPPT operation of each module causes changes in each module's voltage. The voltage of each module was measured and the algorithm was implemented by replacing power variation to the measured voltage changes. MPPT operation begins from the first module. When the first module gets to the MPP point, maintain this point and the second module's MPPT operation is started. When the second module gets to the MPP point, the first module's MPPT operation is started again. This process is repeated so, each module will operate MPPT sequentially. Therefore, each module MPP operation can be realized as each module's voltage variation. Actually, before arriving at the MPP, MPPT operation continues to increase or decrease in monotonic patterns. But, when each module has reached MPP point, the power's variation is repeated increase or decrease around this point. Consequentially, this case is recognized that this module has reached its maximum power point. So, if successive mark in increase or decrease is counted more than three or five times, it is considered that this module has reached MPP point. After that, communications systems or other devices will be used to announce the start signal to other modules. The overall algorithm flowchart is shown in Fig. 2.

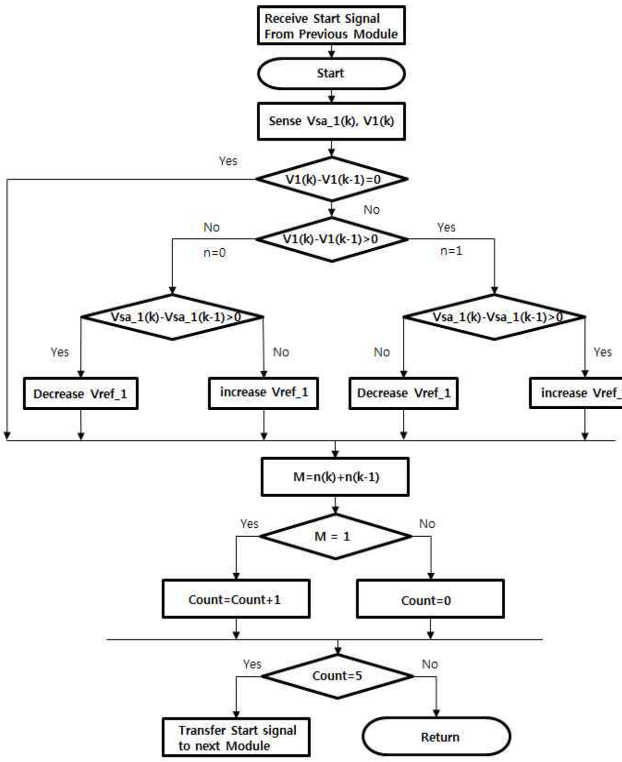


Fig. 2. MPPT algorithm without current sensor.

III. Simulation Results

For simulation of the proposed MPPT method, numerical analysis has been done using PSIM software. Solar array model and MPPT algorithm were implemented with provided DLL files, and also the boost converter in each PV module was controlled by a PI controller. Two module's output voltage was connected in series for boosting the output voltage by summing up the each of the output DC-link voltage to the following post-stage power conditioner. DC-link was set to 160[V] by the voltage feedback controller of the post conditioner. The MPPT control is performed in sequential order from MIC1 to MIC2, and is MPPT returns to MIC1 when MIC2's MPPT operation has finished. For determination of the timing on transferring MPPT control priority to the next module, counting action is done in the DLL file of the MPPT. If the up/down fluctuation of power variation is detected more than 5 times in a row, then MPPT controller in P&O algorithm is determined that the module is in steady-state of the MPPT operation and then transfers the priority to the next module. Fig. 3. is the simulation circuit.

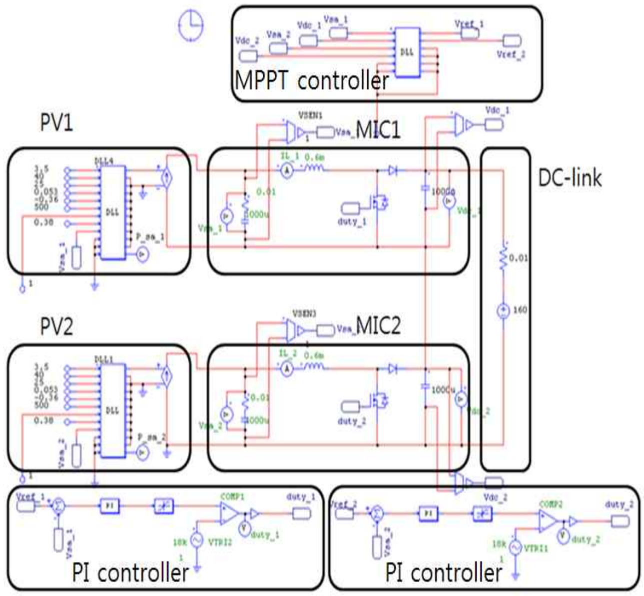
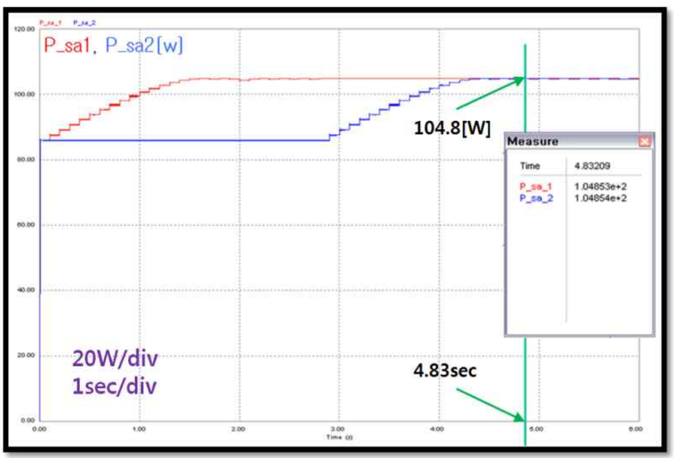
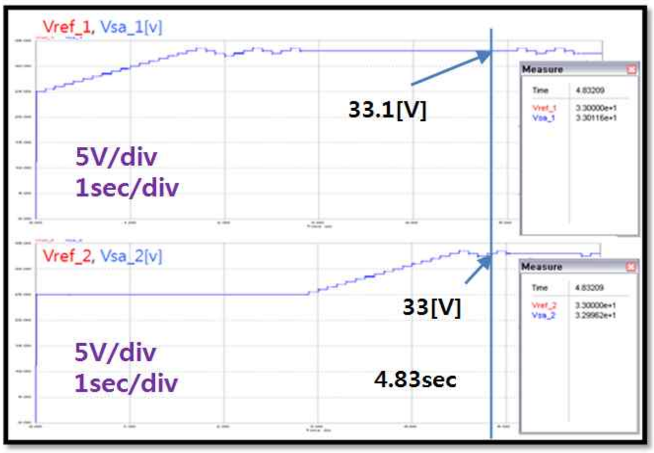


Fig. 3. Schematic of the proposed MPPT method in PSIM

Fig. 4(a) has two module's power waveforms. P_{sa1} is MIC1's output power and P_{sa2} is MIC2's output power. First module traced the MPP successfully to 104.8[W]. Afterward second module tries to find the MPP after several perturbation cycle of MIC1. Fig. 4(b) shows the voltage waveform of each module during the MPP tracking process. First, the first module approaches to the MPP voltage when the second module is under the standby operation mode. Then, after the perturbation of the PV voltage in the steady-state operation, the second voltage starts to perturb the operating point of MIC2. Both of the steady-state voltage is 33[V], which is the nearby operating of the PV MPP, 33.1[V]. From the results, the operating principle of the proposed MPP algorithm is validated successfully. It seems that the method is simply implemented and well performed for the series-output multiple MICs.



(a) PV power trace of each module



(b) PV voltage traces of each module
Fig. 4. Simulation results of PV power system with the proposed MPPT method

IV. EXPERIMENTAL RESULTS

To verify the proposed MPPT algorithm, an experimental prototype set-up and system structure is configured in Figure 5 and 6. Power Supply(60V supply on each module)with a series PV-equivalent resistor, two MIC modules, electronic load to simulate the DC-link Voltage, and Zigbee wireless module were used. The parameter using the experiment is shown in Table I.

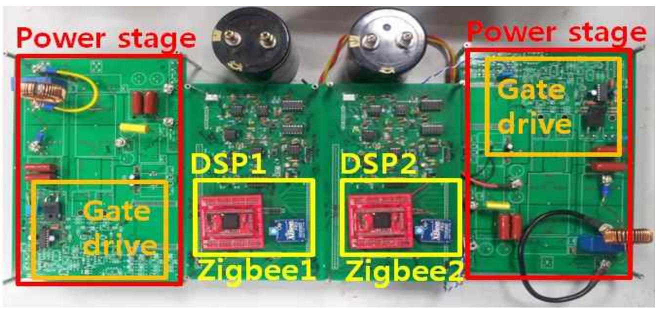


Fig. 5. Experimental setup of the series connected MIC

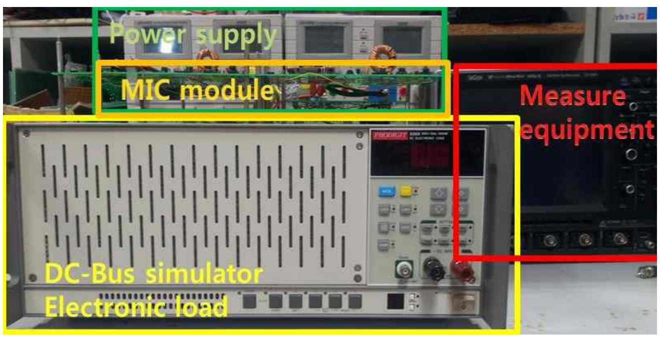


Fig. 6. The overall experimental setup.

TABLE I. Parameter used in the experiment.

Input Voltage	60[V]
Total DC-link	120[V]
Input Capacitor Capacitance(Vsa)	1000[uF]
Output Capacitor Capacitance	2200[uF]
Filter Inductance(L)	0.8[uH]
Switching Frequency	20[KHz]
Wireless Communication	Zigbee XBee-pro
Controller	TMS320F28335

The experimental results are shown in Fig. 7. Each of the MIC's MPP voltage is 30V and reference voltage starts of 15V. At first, MIC1 transmit MPPT starting signal to MIC2 by using Zigbee, then MIC2's MPPT work is started. If MIC2's MPPT work finished, keep the reference voltage and send MPPT starting signal to MIC1. Then MIC1 also find the 30V MPP successfully.

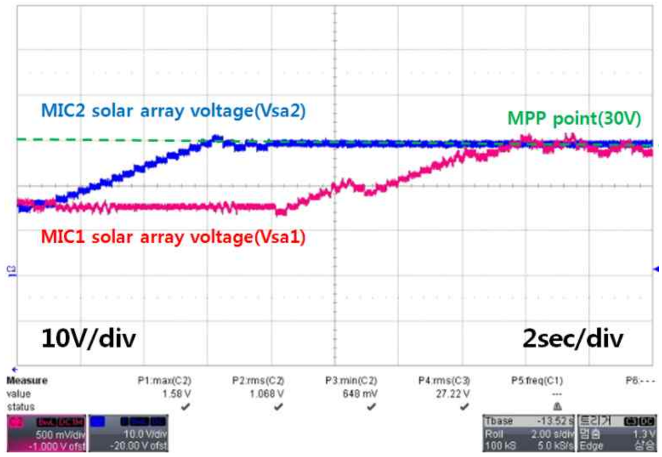


Fig. 7. Waveform of the each MICs input capacitor(Vsa).

If irradiation does not change, MIC will trace 30V alternately. The steady-state operating waveforms are shown in Fig. 8.

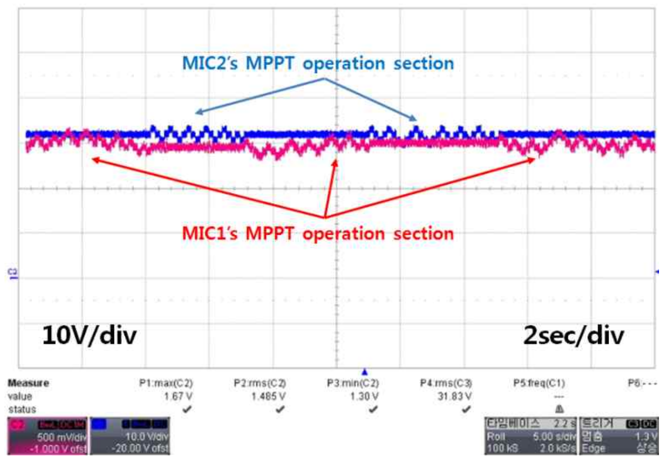


Fig. 8. Waveform of the each MICs input capacitor expected in steady-state of the MPPT operation

In another case, one of the MIC's solar radiation is decreased, and the MIC's MPP voltage and the power are also lowered. So the steady-state DC-link voltage is lowered according to the reduced power. But other module maintains 30V for MPPT operation. It can be found o.k. Fig. 9. MIC1's power supply was step changed from 60V to 50V. Then, MIC1 traces 25V like Fig. 9. That is point in Figure 9 That the solar array voltage is determined by sensed DC-link voltage's MPPT work. Fig. 10. is another experiment to illustrate proposed MPPT algorithm. MIC1's solar array(input) and DC-link(output) voltage on MPPT operation. DC-link voltage was retained at 120V and each of the solar array voltages was 15V. when starting signal sent to MIC1 by MIC2, reference voltage is increased up to 30V and MIC1's output power also increases. This causes an increase in output current. In this situation, MIC2 is not on MPPT operation but in State of constant power, so MIC2's output voltage is decreased and MIC1's output voltage is increased naturally. When MIC1 is reached, MIC2 start MPPT operation. At this point, opposite phenomena appear. This means that MIC1's output voltage is reduced like Fig. 10.

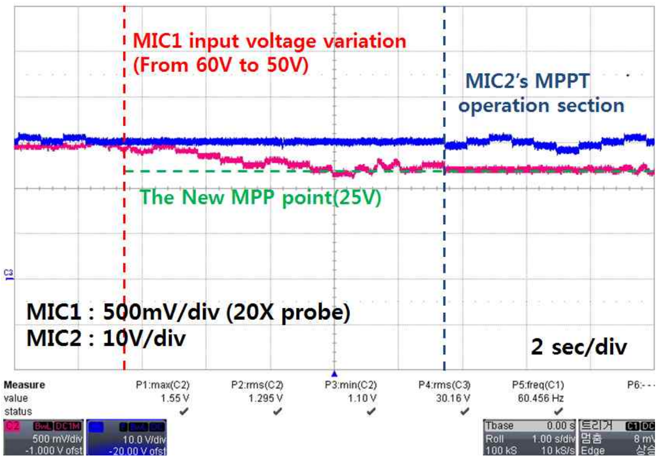


Fig. 9. Waveform of each MICs input capacitor in different solar radiation.

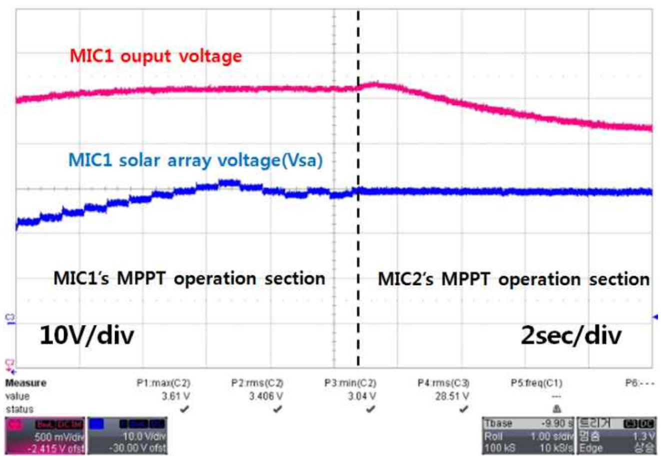


Fig. 10. MIC1's output DC-link side and solar array voltage(V_{sa1}) on MPPT operation

V. CONCLUSION

In this paper, a module-integrated PV converter in output series of solar power systems was studied to lower the unit price. Existing algorithms for tracking the maximum power point are needed both PV current and PV voltage information. In MICs, since the ouput voltage is monotonically proportional to the output power of each module, power measurement can be replaced with the voltage measurement. The proposed method can reduce the manufacturing cost by eliminating the current sensor. For the verification of proposed algorithm, a 80W boost-type experimental hardware of MIC was built, and through the MPPT tracking capability experiment, the proposed algorithm has been proved.

ACKNOWLEDGMENT

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(No. 2010-0025674).

REFERENCES

[1] Linares, L. Erickson, R. W. MacApline, S. Brandemuehl, M "Improved Energy Capture in Series String Photovoltaics via Smart Distributed Power Electronics" Power Electronics Conference and Exposition, APEC 2009, 24th IEEE.

[2] MIKE MEINHARDT, GUNTHER CRAMER, BRUNO BURGER and PETER ZACHARIAS, "Multi-string-converter with reduced specific costs and enhanced functionality" Solar Energy – SOLAR ENERG, vol. 69, pp. 217-227, 2001

[3] Frede Blaabjerg, Remus Teodorescu, Zhe Chen, Marco Liserre, "Power Converters and Control of Renewable Energy Systems" ICPE, 2004.

[4] G.R Walker and P.C Sernia, "Cascaded DC-DC converter connection of photovoltaic modules" IEEE Transactions on, vol.19, no.4pp. 1130-1139, July 2004.

[5] Geoffrey R walker and Jordan C Pierce, "PhotoVoltaic DC-DC Module Integrated Converter for Novel Cascaded and Bypass Grid Connection Topologies – Design and Optimisation", 37th IEEE, 2006

[6] Jatin Nathwani and Artie Ng, "PV Solar Energy Conversion Using The Behavior Matching Technique" InTech, December 2010.

[7] J.M. Kwon, K.H. Nam and B. H. Kwon "Photovoltaic power conditioning system with line connection", *IEEE Trans. Ind. Electron.*, vol. 53, pp.1048 2006.

[8] T. Esram and P. L. Chapman, "Comparison of photovoltaic array maximum power point tracking techniques", IEEE Trans. Energy Conversion, vol. 22, no. 2, pp. 439-449, June 2007..

[9] Youngseok Jung, Gwonjong Yu, Jaeho Choi, Juyeop Choi. "High-frequency DC link inverter for grid-connected photovoltaic system" 29th IEEE, 2002.