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Fotovoltaik Uygulamalar İçin Alternatif Akım Tarafında Maksimum Güç Noktası Takibi

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Özet

Bu çalışmada yenilikçi maksimum güç noktası takip (MPPT) yöntemi sunulmuştur. Alternatif Akım (AC) tarafında maksimum güç noktası takibi olarak adlandırılan bu yöntemde, eviricinin çıkış tarafında (AC) kontrol işlemi yapılmaktadır. AC tarafta kontrol işlemi için değiştir ve gözlemle (P/O) algoritması kullanılmıştır. P/O algoritması ile AC çıkış geriliminin genliği, nominal gerilimin ±% 20'si oranında değiştirilerek gerçekleştirilmektedir. Bu yolla, güneş panellerinin (PV) gerilimi maksimum güç noktası bulunana kadar arttırılmakta ya da azaltılmaktadır. AC tarafta kontrol yöntemi ile DC/DC dönüştürücü MPPT işlemi yapmayacağından dönüştürücünün tek işlevi evirici giriş geriliminin düzenlenmesi olacaktır. DC/DC dönüştürücünün çıkış gerilimi her zaman sabit 800 V_{DC} değerine sahiptir. Bu sayede, MPPT kontrolü ve anahtarlamadan kaynaklanan gerilim dalgalanmaları oluşmamakta ve buda küçük boyutlu (büyük W/cm^3 oranı) yarı iletken ve pasif devre elemanlarının kullanımına yol açmaktadır. Sürücünün diğer güç elektroniği modülleri, büyük W/cm^3 oranına sahiptir. AC tarafta MPPT yöntemi, bu amacın gerçekleştirilmesine hizmet eden araçlardan biri olacaktır.

Anahtar kelimeler
MPPT; Transformatörlü İnverter; AC Taraf MPPT; Değiştir ve Gözlemle (P/O)Metodu

Maximum Power Point Tracking on the Alternative Current Side for Photovoltaic Applications

Abstract

This paper represents an innovative Maximum Power Point tracking method. In this method which is named as “AC Side MPPT” as understood from the name control and switching will be realized at the AC side of the inverter. At the AC side a Perturb and Observe (P/O) method is implemented. Perturbation is realized as changing the amplitude of the AC output voltage with a ratio of ±20% of the nominal value. By this way the voltage of the solar panels is increased or decreased until the Maximum Power Point is captured. By means of this method, DC/DC converter does not deal with MPPT process, so the only function of the converter will be the regulation of the input. The output of the DC/DC converter always has a constant voltage value (800 VDC). By this way voltage ripples caused by the MPPT control and switching are not formed and this leads to utilizing of small sized semi conductor and passive components. Small sized components mean large W/cm^3 ratios. Other power electronic modules of the inverter have the large W/cm^3 ratio objectives. AC Side MPPT Method will be one of the tools which serve the realization of this purpose.

Keywords
MPPT; Inverter with Transformer; AC Side MPPT; Perturb and Observe (P/O)Method

1. Introduction

The cost of the energy produced by the PV systems has been decreasing in the recent years. The feed in tariffs for PV electricity has also been falling parallel to decreasing solar electricity costs. In many countries the feed in tariffs and grid rates are nearly getting equal. And this fact is making the solar more competitive compared to other energy technologies. There are many reasons underlying this steady downward trend. The most important reason is constantly falling module prices with ever – increasing production capacity. But the decline in the module prices has been coming to end. Different ways for decreasing the cost of energy produced by PV systems must be investigated. Still there may be some cost reduction opportunities in the other components rather than solar modules like module mounting systems and inverters. Inverters are one of the biggest cost factors of the PV systems. The decline in the prices and the increases in the performance of the inverters significantly contribute the fall in the cost of the energy produced by PV systems.

The PV systems display an inherently nonlinear current-voltage relationship, requiring an online identification of the optimal operating point for maximum power extraction. Continuous tracking of this operating point, called the maximum power point (MPP), is necessary to maximize the utilization of the solar array for a given insulation and temperature [1]. Maximum Power Point Tracking (MPPT) is utilized by inverters in order to make the system operate with maximum efficiency. The main mission of the MPPT is to adopt the operating point of a module or array usually modifying the output voltage to different irradiance conditions and also temperature variations. Therefore in theory and practice a great number of MPPT methods have been developed such as Hill Climbing [2], Perturb and observe (P&O) [3], Incremental Conductance (IC) [4], Fractional open-circuit voltage (FVOC) [5], fractional short circuit current (FSC) [6], Neural network [7], Fuzzy logic control [8], and Particle Swarm Optimization (PSO) [9]. Among the methods investigated, much focus has been on Hill Climbing and Perturb and Observe methods [10]. In the Hill Climbing method the duty cycle of the power converter is altered, while in the Perturb and Observe Method perturbation is achieved by altering the operation voltage of the module array [11]. Hill climbing method is suitable in rapidly changing atmospheric conditions because this algorithm oscillate around the maximum power in slowly changing atmospheric conditions. This oscillation causes loss [13]. The perturbation of the duty cycle of a module means the perturbation of the voltage of the module array. Therefore Hill Climbing and Perturb and Observe are different versions of the same method.

Perturb and Observe method is the most preferred method due its implementation simplicity and small number of parameters needed. In this method, the output voltage of the module array is perturbed periodically (increased and decreased) and, after each perturbation the output power of the module array is compared with power generated during preceding period. If the output power keeps increasing, the perturbation is continued in the same direction; otherwise the direction of the perturbation is reversed [12]. Despite its prevalence, this method has many drawbacks. Its slow response to changes in ambient temperature and solar irradiation, the lack of capturing the Maximum Power Point (MPP), oscillations around the MPP and reacting to sudden environmental changes in the reverse direction are the most important disadvantages [14].

The conventional MPPT techniques perform the control and execution processes on the DC side of the inverter. For all of the MPPT techniques in which processes are executed on the DC side, due to output of module arrays are perturbed, oscillations on the output power are generated. In all of those methods, the number of perturbations is increased to capture the Maximum Power Point. This action increases the oscillations around the Maximum Power Point. In case the frequency of perturbation is chosen so high, excessive amount of ripples is generated which reduce the efficiency especially cloudy and windy weather conditions. Beside those, control and execution processes of MPPT on the DC side increase the stresses on the components [15].

Ripples on the DC side are transferred directly to AC side causing harmonic distortions and AC ripples. As the share of solar energy in the energy mix of grids increases, grid quality concerns that may be originated by those systems are increasing [16]. Therefore new MPPT methods which do not contribute to the grid quality problems should be investigated. Those new methods should also find new ways to reduce the stress on the components of implementation circuits, thus providing less and smaller sized components. Because of above – mentioned disadvantages of conventional MPPT methods which perform the control and perturbations on the DC side, a different method which performs control and perturbation functions on the AC side of the inverter were investigated. Casaro and Martins [17] proposed a "Behavior Matching" method in which the PV array I – V characteristics is reproduced in the DC stage output terminal. The DC-AC stage, responsible for MPPT and the grid current control, consists of the three-phase PWM voltage source inverter, VSI. Using this MPPT strategy and the Behavior Matching technique, a minimum amount of sensors are required for the dual-stage inverter. The justification is simple. The variables needed for MPPT are already available by the grid-current control [17]. The perturbation is processed in the output terminals of the DC – DC converter, so in the input of the DC – AC stage. This causes ripples in the output of the inverter. Modified dual stage inverter's block diagram is shown Figure 1.

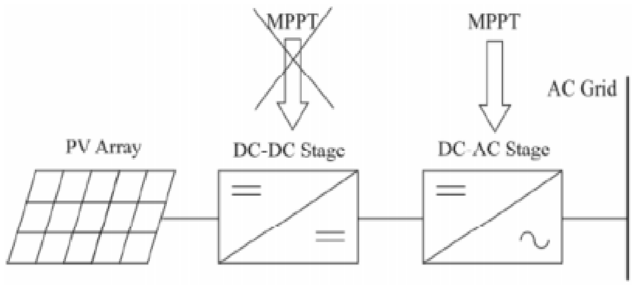

Figure 1. Modified dual stage inverter [17]

The topic of this paper focuses on an innovative MPPT technique called as "MPPT on the AC Side" which was developed within the scope of a 10 kW inverter with galvanic isolation. By means of this method, DC/DC converter does not deal with MPPT process, so the only function of the converter will be the regulation of the input. The output of the DC/DC converter will always have a constant voltage value (800 VDC). By this way voltage ripples caused by the MPPT control and switching will not be formed and this leads to utilizing of small sized semi conductor and passive components. Small sized components mean large W/cm^3 ratios. Other power electronic modules of the inverter have the large W/cm^3 ratio objectives. AC Side MPPT Method will be one of the tools which serve the realization of this purpose.

2. Grid-Tie inverter with galvanic isolation

In the literature there are many different grid – tie inverter designs with transformer which realize the isolation between the DC and AC side with high frequency transformers. Among those designs the one of the most notable one is a two stage inverter [14]. In this design a three phase DC – DC converter is utilized. Some of the most important advantages of this design:

- It enables the use of high frequency transformers.
- It allows high input and output frequencies, thus the size of the components in the filters decreases.
- The losses are distributed more orderly.

In this design, controls of the MPPT are realized at the output of the DC – DC converter concerning the current data read at the AC grid connection point. In this method, the input voltage of the DC – AC converter is perturbed by constant step sizes. Because there is no perturbation or other operations relating the MPPT in the DC – DC converter, the linearity between the input and output of this stage is not deteriorated due to MPPT operations. That provides less stress on the components of that stage, thus the numbers and the sizes of the components are decreased.

However, there are some disadvantages of that design. Continuous perturbations of the DC – DC converter cause the duty cycles to stay under 40% of their maximum values which induces lower DC – DC converter efficiencies (under 97%). Moreover, ripples in the input of the DC – AC converter decrease the general efficiency of the inverter. The other drawback of the system is that; PV string voltage and current data are not read directly. Instead a transformation is utilized for PV string current and voltage values which increases the risk of error.

Considering those phenomenons the designed inverter has the following specifications:

- The inverter has a two stage (DC – DC and DC – AC) topology and in the DC – AC stage three phase converters are utilized.
- In the DC – AC stage three phase inversion is used. In this topology there are 12 switching and 6 clamping diodes.
- For MPPT, Perturb and Observe (P/O) method is applied. In order to react to sudden changes in solar

irradiation and temperature, variable perturbation step sizes are used.

- For the MPPT operation, perturbation is processed on the AC side and PV string current and voltage data is read directly on the output of the string.

3. The Proposed MPPT Technique

The proposed technique which is shortly called as “AC Side MPPT” performs the perturbation operations on the AC side of the inverter instead of the DC side. During the design of the inverter, the need for such an innovative method originates from the excessive dependence of the MPPT accuracy of the three phase DC – DC converter to the “dead time” and “switching period” of the PWM signals. As a product of the researches and theoretical studies for finding a solution of that problem; a “dual stage” design is reached that is comprising an inverter stage that is responsible for MPPT and grid current control and a DC – DC converter stage that is operating with constant duty cycle and frequency. The block diagram of that design can be seen on Figure 2.

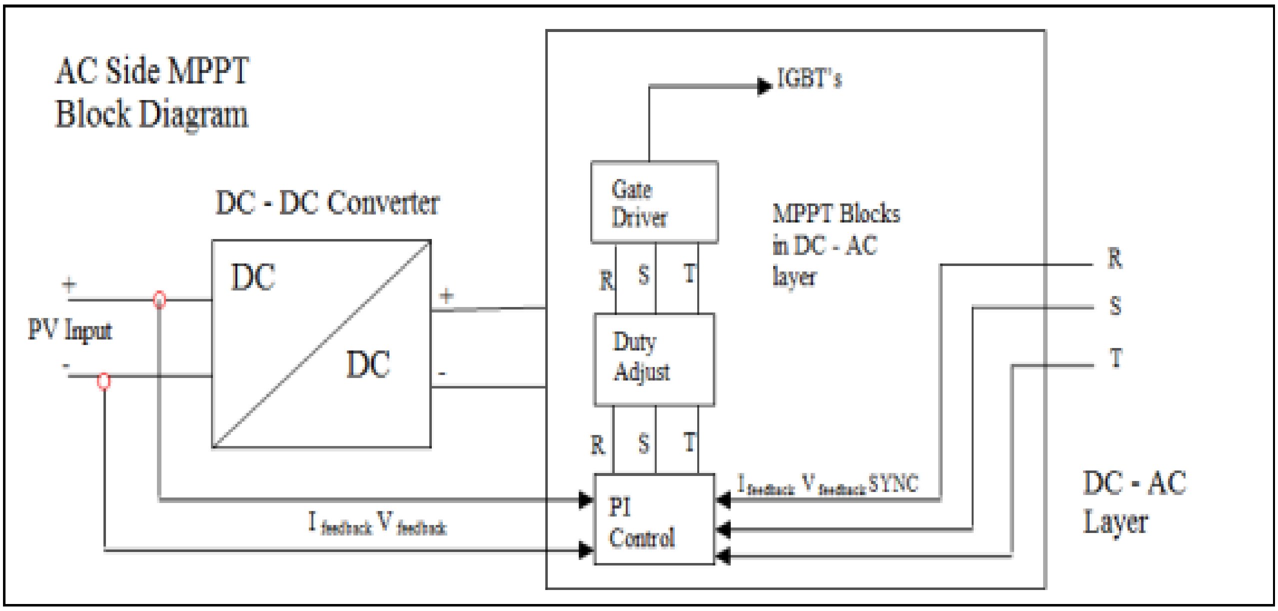

Figure 2. The block diagram of the AC side MPPT

In the Figure 3, the algorithm of the proposed MPPT technique is shown. In this method, first of all the PV voltage and current are meaured. Than the instantaneous PV power is calculated using voltage and current values. This instantaneous power compares with the previous output power. If the differance between previous power and recent power is not equal to zero, this algorithm will increase or decrease voltage or curerent to find the optimal point of maximum power. The maximum power is obtained when the differance between previous power and recent power is equal to zero. In order to achive this condition, If the output power increases by increasing the voltage, then the operating voltage is further perturbed in the same direction until it reaches the point of MPP. If the output power decreases by increasing the voltage, the operating point is in the negative slope region of the PV curve. Then the operating voltage is perturbed in the reverse direction to track the MPP [18].

The perturbation of the output AC signal is completed in 20 ms (10 ms in the positive alternance, 10 ms in the negative alternance) for 50 Hz grid frequency.

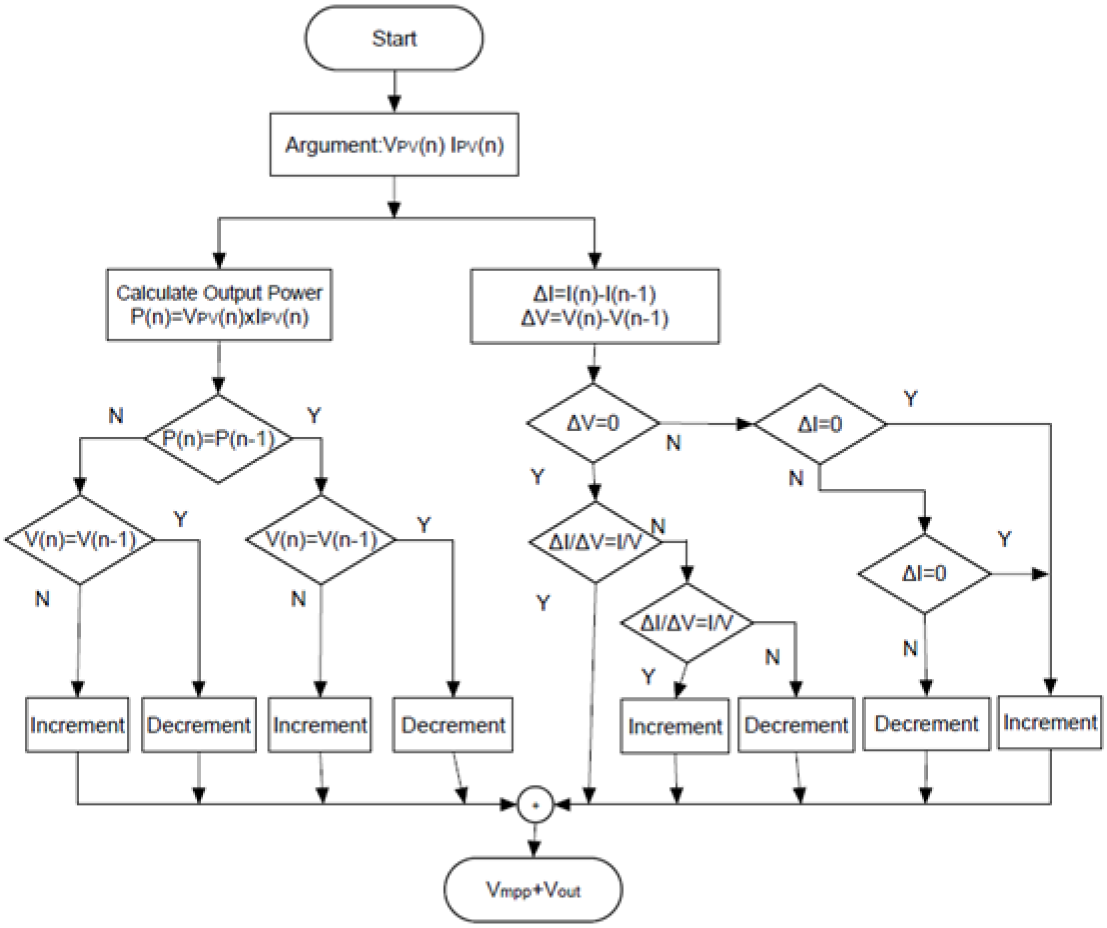

Figure 3. The block diagram of the AC Side MPPT Algorithm

The perturbation of PV strings is performed by altering amplitude the three phase AC output. The voltage (V), current (I) and power (P) values of the PV strings are read from the Analog Digital Converter (ADC) and transferred to microprocessor of the DC – DC block. As shown in the Figure 4. relating to the direction of the rate of change of the power each amplitude of the output will be increased or decreased by variable Perturbation Step Sizes (PSS). For this purpose negative alternance will be inverted to positive alternance.

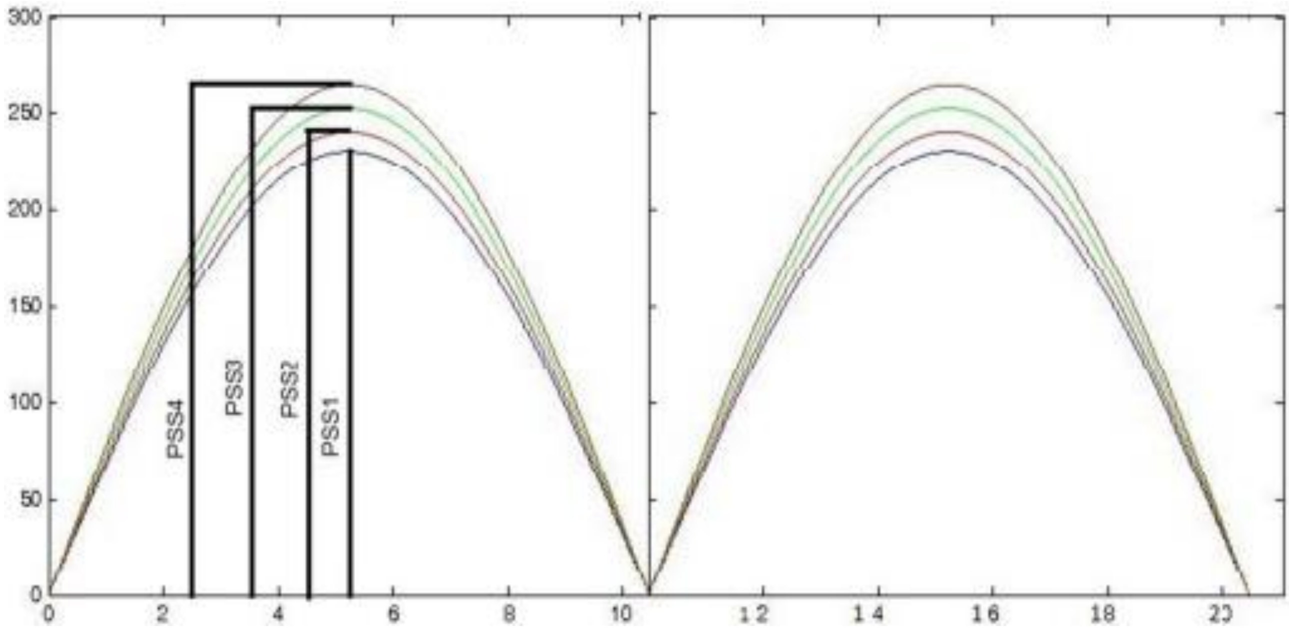

Figure 4. Perturbation step sizes

4. Experimental Results

Within the implementation stage of the method, the prototypes of DC – DC and AC – DC stages were produced. Each prototype can be seen in Figure 5.

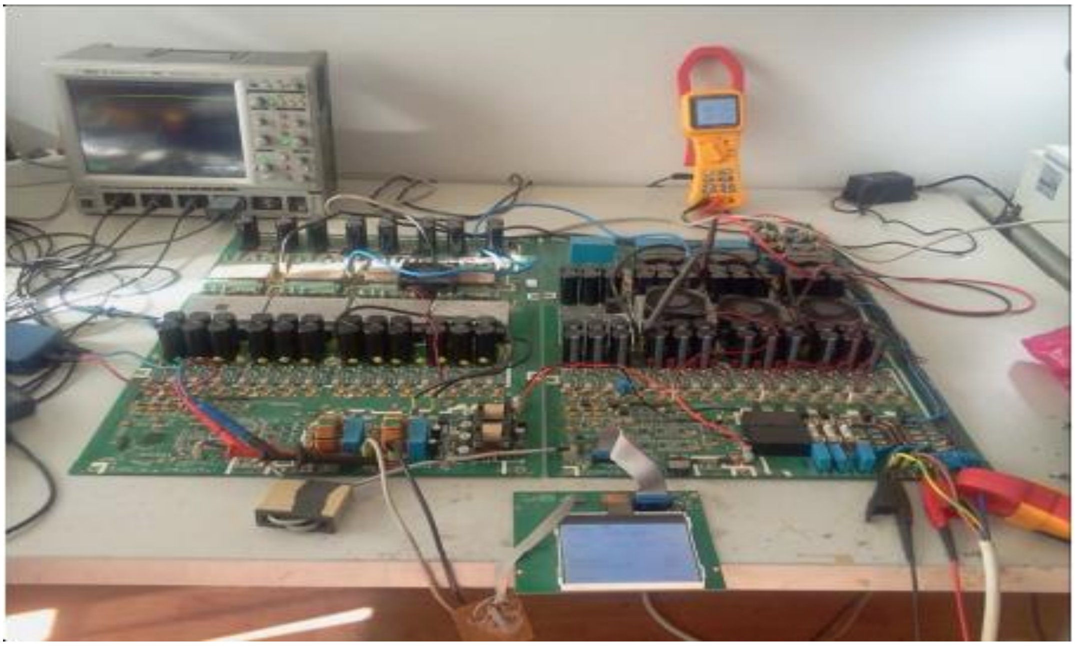

Figure 5. Laboratory prototypes of 10 kW DC – DC and DC – AC stages

The dimensions of each PCB are 608 mm x 429 mm and the thickness is 70 µ. A Texas Instruments C28 type 300 Mhz microprocessor is used in the design. The microprocessor was programmed as per to MPPT algorithm developed.

The system was tested with a Solar Array Simulator (SAS). From the result read on the screen of the SAS (Figure 6.), MPPT efficiency was calculated.

String Open Circuit Voltage (Voc) = 409,20V
String Short Circuit Current (Isc) = 3,2A
Module Maximum Power Voltage (Vmp) = 326,7V
Module Maximum Power Current (Imp)=3,1A
Calculated Maximum Power (EQ_PMP)=1033,2W
Calculated Maximum Power Point Voltage=338,42V
Calculated Maximum Power Point Current=3,053
Power Output of the String=1027,9
MPPT Efficiency=1027.9/1033,3=99,49%

Figure 6. The screen of SAS

In the Figure 7., the power produced by the modules and power drawn by the MPPT can be seen.

The green signal and red signal are described the string voltage and current of PV and the peak value of this voltage and current are 338 V., 3.29 A respectively. According to the operating voltage and current values, the PV power is drawn and in the fgure.7 power describes with orange signal. As seen in figure. 7 the peak output power is found as 1027W. the blue signal describes the power which is produced by the PV modules. This peak power is found as 1033W. in figure 7, x axis represent the time (10sn).

As the solar irradiation is stable, when the output power is increased or decreased, the capturing period for Maximum Power Point can be seen on the graph. The capturing period is around 30 seconds.

The power value of the solar simulator is set to 3000W and 2500W to test and find the efficiency of the inverter. The test results of inverter for 3000 W and 2500 W can be seen in the Figure 8 and 9 respectively. When the solar Simulator set to 3000 W, the open circuit voltage, short circuit current, maximum power point voltage, and maximum power point current are measured as 464.04 V, 7.919 A., 400 V and 7.5 A. respectively. When the solar Simulator set to 2500 W, the open circuit voltage, short circuit current, maximum power point voltage, and maximum power point current are measured as 469.04V, 6.611A A., 400 V and 6.250 A. respectively. In both figures (figure 8 and 9) it can be seen that the MPPT efficiency is between 99.80 – 99.99.

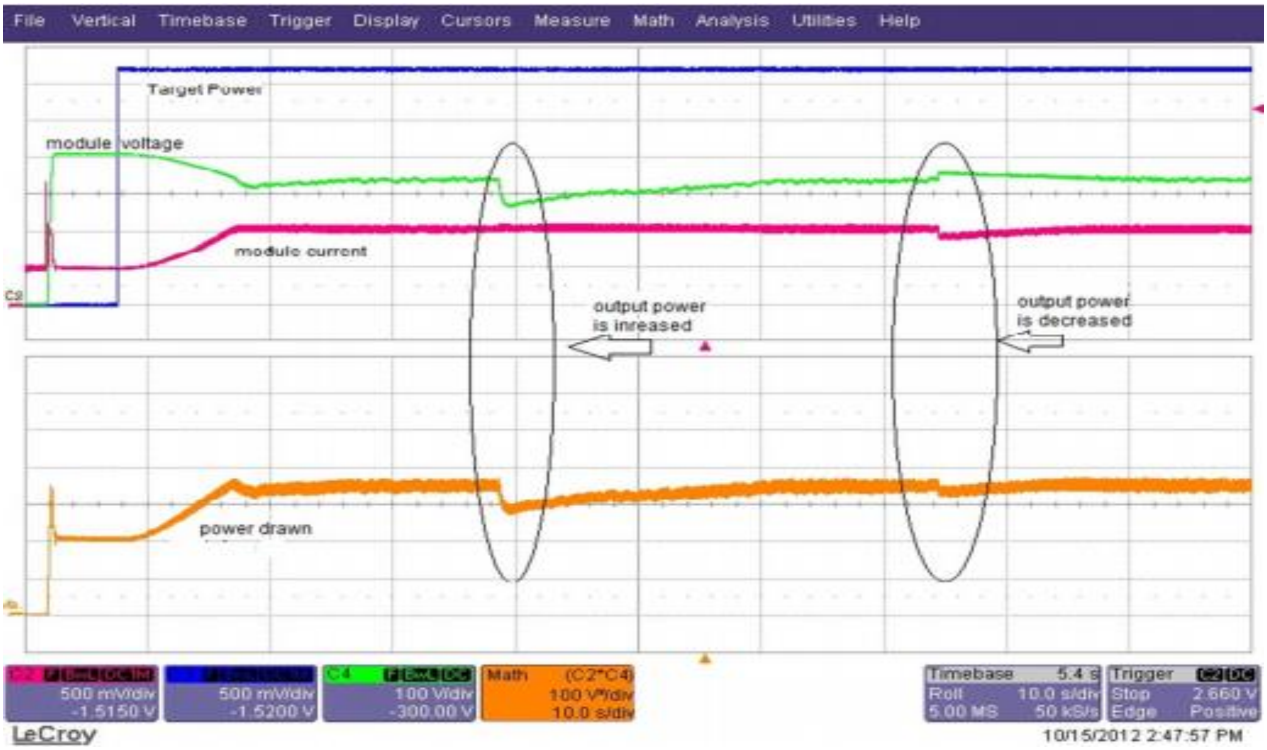

Figure 7. Target power and power drawn from the modules

Figure 8. SAS measurement results for 3000 Watt input

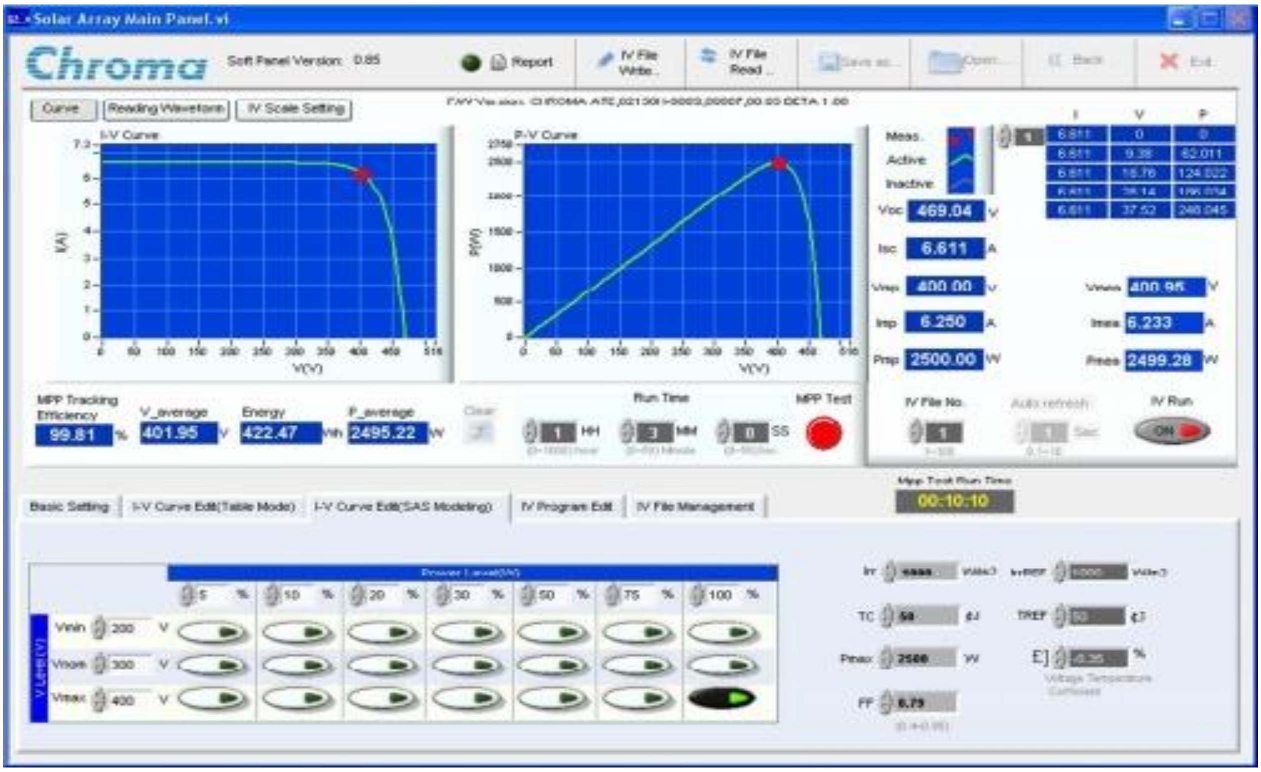

Figure 9. SAS measurement results for 2500 Watt input

5. Conclusion

For all of the MPPT techniques in which processes are executed on the DC side, because the output of module arrays is perturbed, oscillations on the output power are generated. In all of those methods, the number of perturbations is increased to capture the Maximum Power Point. This action increases the oscillations around the Maximum Power Point. In case the frequency of perturbation is chosen so high, excessive amount of ripples is generated which reduce the efficiency especially cloudy and windy weather conditions. Beside those, control and execution processes of MPPT on the DC side increase the stresses on the components.

Ripples on the DC side are transferred directly to AC side causing harmonic distortions and AC ripples. As the share of solar energy in the energy mix of grids, grid quality concerns that may be originated by those systems are increasing. Therefore new MPPT methods which do not contribute to the grid quality problems should be investigated.

The MPPT method subject of this study processes the perturbation and control functions on the AC side. The output of the DC/DC converter will always have a constant voltage value (800 VDC). By this way voltage ripples caused by the MPPT control and switching will not be formed and this leads to utilizing of small sized semiconductor and passive components. Small sized components mean large W/cm^3 ratios. Other power electronic modules of the inverter have the large W/cm^3 ratio objectives. AC Side MPPT Method will be one of the tools which serve the realization of this purpose.

References

[1] Jain S, Agarwal V. A new algorithm for rapid tracking of approximate maximum power point in photovoltaic systems, IEEE Power Elec. Lett, 2004; 2: 16–19.

[2] Omair K, Samrat A. Hill Climbing Power Flow Algorithm for Hybrid DC/AC Microgrids, IEEE Transactions on Power Electronics, 2018; 33:7, 5532-5537

[3] Ahteshamul H. Z. Fast and reliable perturb and observe maximum power point tracker for solar PV system, Int J Syst Assur Eng Manag, 2017; 8: S773–S787

[4] Afshan I, Mohammad A, Rizwan M.K, Abhinandan J, Mohammed A. H. Realisation of incremental conductance the MPPT algorithm for a solar photovoltaic system, 2017; 1-12.

[5] Bharath K. R. Eenisha S. Design and Implementation of Improved Fractional Open Circuit Voltage Based Maximum Power Point Tracking Algorithm for Photovoltaic Applications, 2017; 7:3, 1108-1113.

[6] Hadeed A. Sher. Ali F. M. Abdullah N. Khaled E. A. Marcello C. An intelligent control strategy of fractional short circuit current maximum power point tracking technique for photovoltaic applications, 2015, Journal of Renewable and Sustainable Energy, 7: 013114-1, 013114-15

[7] Ramji T. Kumar K. Ramesh B. N. Sanjeevikumar P. Patrick W. W. Neural Network Based Maximum Power Point Tracking Control with Quadratic Boost Converter for PMSG—Wind Energy Conversion System, 2018, MDPI elektronics, 1-17

[8] Yaqin E.N. Abdullah A.G. Hakim D.L. Nandiyanto A.B.D. MPPT based on Fuzzy Logic Controller for Photovoltaic System using PSIM and Simulink, IOP Conf. Series: Materials Science and Engineering, 2017; 288: 1-12

[9] Kalaiarasi N. Subranshu S. D. Sanjeevikumar P. Paramasivam S. Pandav K. Morati. Maximum Power Point Tracking Implementation by Dspace Controller Integrated Through Z-Source Inverter Using Particle Swarm Optimization Technique for Photovoltaic Applications, MDPI Applied Sciences, 2018; 8: 1-18

[10] Qiang M. Mingwei S. Liying L. Josep M. G. A Novel Improved Variable Step-Size Incremental-Resistance MPPT Method for PV Systems, IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, 2011; 58:6

[11] Deepak V. SavitaN. Shandilya A.M. SoubhagyaK.D. Maximum power point tracking (MPPT) techniques: Recapitulation in solar photovoltaic systems, Renewable and Sustainable Energy Reviews, 2016; 54: 1018-1034

[12] Rahul R. Chandel S.S. Hill Climbing Techniques for Tracking Maximum Power Point in Solar Photovoltaic Systems- A Review, Special Issue of International Journal of Sustainable Development and Green Economics, 2013; 2: 90-95

[13] Bhukya K. N. Tarun K. C. Kalyan C. Performance Analysis of Maximum Power Point Tracking Algorithms Under Varying Irradiation, Int. Journal of Renewable Energy Development, 2017; 6: 65-74

[14] Søren B. K. Evaluation of the “Hill Climbing” and the “Incremental Conductance” Maximum Power Point Trackers for Photovoltaic Power Systems, IEEE TRANSACTIONS ON ENERGY CONVERSION, 2012; 27: 922-929

[15] Tuhin S. B. Suman M. Chandan C. A New Dual Inverter Based Solar PV System with Maximum Power Point Tracking Capability, IEEE 24th International Symposium on Industrial Electronics, 2015; Brazil, 172-177

[16] Hanif M. Basu M. Gaughan K. Novel AC Side P&O Maximum Power transfer control for Grid Connected Photovoltaic Systems, International Conference on Renewable Energies and Power Quality, 2010,Spain,

[17] Casaro M.M, Martins D.C.Grid - connected PV system using a three - phase modified dual - stage inverter, In: Power Electronics Conference, 27 September-01 October 2009; Brazil, pp: 163 – 167.

[18] Saravanan S. Babu R.N. Maximum power point tracking algorithms for photovoltaic system – A review Renewable and Sustainable Energy Reviews 2016; 57: 192–204.