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Development of novel MPPT algorithm of PV system considering radiation variation

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Abstract: This paper proposes a novel maximum power point tracking (MPPT) control algorithm considering radiation to improve efficiency of PV system. The proposed algorithm is composed perturb and observe (PO) method and constant voltage (CV) method. PO method is simple to realize and CV method is possible to tracking MPP with low radiation. Response characteristics of proposed algorithm are compared to conventional MPPT algorithm such as PO method, IC method and CV method with radiation variation. This paper proves the validity of proposed algorithm through the analysis result.

Keywords: Photovoltaic, MPPT control algorithm, PO method, IC method, CV method, Efficiency

1. INTRODUCTION

In 1997, the Kyoto Protocol fermented, since then the greenhouse gas emission standard of an earth was regulated according to the universal. In addition, alternatively the study of the various alternative energy including a photovoltaic, wind force and fuel battery, and etc. gets accomplished of the future energy according to the fossil energy exhaustion. The photovoltaic generation is similar to the peak power consumption part due to summer season air cooling and the time slot developing the maximum power can cancel the unbalance of income and outgo of electric power. However, the density of solar energy is low about 1[kW/m^2], and the direct current-alternative current power conversion device for the common electricity is needed. In addition, there is a problem that as to the photovoltaic generation, the output characteristic is unstable due to the change according to the environment condition including the solar radiation and temperature, and etc. and the photo electricity efficiency of the solar cell is low for 16.9% and the initialization period investment cost is high. The investigation of the PV generation is classified into the side that is material and the power conversion aspect. The latter, in the power conversion aspect, it is researched concentrated putting a concern on the power conversion efficiency and high performance conversion. Therefore, the study on the maximum power control obtaining the maximum power from a solar cell array and minimization of the energy loss are actively in progress.

The maximum power point control of the photo voltaic generating system says as maximum power point tracking (MPPT) and generally the research result of the various methods is reported by the paper which is many about the control method. Recently, there is perturbation and observation (PO), incremental conductance (IC), constant voltage (CV) method, and etc. in the method being much most applied in order to control the maximum power of the light power generation.[1]-[6] PO method is the algorithm which tracks MPP after measuring periodical the solar cell voltage and current and calculating the electricity by using the power value. The IC control method is the algorithm that measures the solar cell voltage and current and the power variation rate about the change of the terminal voltage of an array is 0 values as possible. The CV control method is the algorithm controlled by fixed V_{ref} regardless of the operating voltage or the electric power of the solar cell array.

However, each control methods have an advantage and disadvantage about the parameter change including the solar radiation change, and etc.[7][8] Therefore, this paper proposes the new MPPT algorithm considering the solar radiation change in order to solve and analyze the problem of the conventional MPPT algorithm. The proposed a novel algorithm is mixed the reciprocity PO and CV, that is the conventional MPPT control method. In not only the high solar radiation but also low solar radiation, this method performs the MPPT control and can increase the generated energy and improve the efficiency. Also, the validity of the proposed a novel MPPT control method is proved with the performance result about the solar radiation change.

2. MODELING OF THE SOLAR CELL

Fig. 1 shows the equivalent circuit of a solar cell where the short current I_{sc} is equal to the photo current I_c. The open voltage of the solar cell is decided by the diode saturation current I_o and is expressed as follows [9][10]:

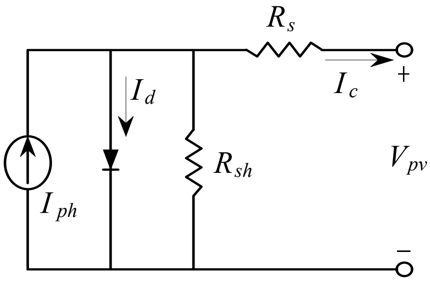

Fig. 1 Equivalent circuit of PV array

$$V_{oc} = \frac{kT}{q} \ln\left[\frac{I_c}{I_o} + 1\right] \tag{1}$$

where V_{oc} is the open voltage, k is the Boltzmann constant, q is the electric charge, I_o is the diode saturation current and T is the operating temperature of the solar cell. In addition, a related equation for the short current and open voltage is expressed as follows:

$$I_{sc} = I_o\left[e^{\left(\frac{qV_{oc}}{kT}\right)}\right] \tag{2}$$

The PV module is connected to a number of solar cells in series and parallel to get the desired voltage and current. In addition, the PV array is connected to a number of PV modules. An equation to obtain the current-voltage characteristic curve of the solar cell is expressed as follows:

$$I_{ph} = I_{sc}S_N + I_t(T_c - T_r) \tag{3}$$

$$I_d = I_o\left[e^{\frac{q(V_{pv}+I_cR_s)}{AkT}} - 1\right] \tag{4}$$

$$I_o = I_{or}\left[\frac{T_c}{T_r}\right]^3 e^{\frac{qE_g}{Bk}\left(\frac{1}{T_r} - \frac{1}{T_c}\right)} \tag{5}$$

$$I_c = I_{ph} - I_d - \frac{V_{pv} + I_cR_s}{R_{sh}} \tag{6}$$

where I_{ph} is the Photo-current, S_N is the radiation per area, I_t is the short current temperature coefficient, I_d is the diode current, R_s is the series resistance, R_{sh} is the parallel resistance, T_c is the temperature of solar cell$[K]$, T_r is the command temperature of the solar cell$[K]$, A, B are the manufacture constants, I_{or} is the reverse saturation current and E_g is the energy band gap.

Fig. 2 shows a PSIM model of a PV array and it is able to calculate the theoretical maximum power point of PV generation through a PSIM simulation.

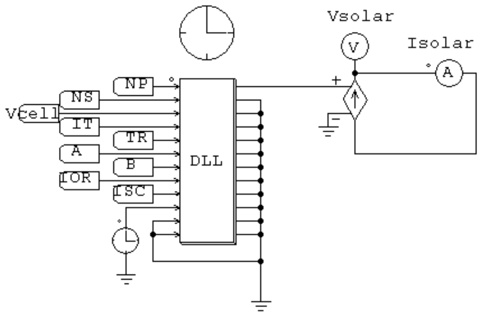

Fig. 2 PSIM model of solar cell array

Fig 3 shows the V-I characteristic curve of the solar cell array with the solar radiation and temperature change.

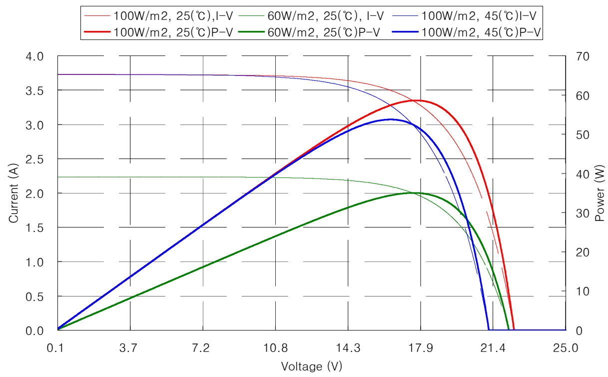

Fig. 3 Output characteristics of solar cell with radiation and temperature change

3. CONVENTIONAL MPPT ALGORITHM

The configuration diagram of the photovoltaic generating system for the maximum power point tracking control is as shown in Figure 4. It is composed of the PV module to convert solar energy into the electrical energy and the boost converter for step-up voltage the PV voltage. In the PV module, a voltage and current are measured and the power is calculated and the MPPT control is performed about the solar radiation change. By using V_{ref} outputted from the MPPT control, the boost converter is controlled through PWM.

As to the control method of MPPT, there is the analog method and digital method in the hardware phosphorus classification method and there is PO, IC and CV control method, and etc. in an algorithm aspect. The MPPT control method is outputted in V value to track MPP of the solar battery coming under the influence in the change of the solar radiation and surface temperature. MPP is because the electricity generated in the same solar radiation changes according to the output voltage, in case of doesn't make the MPPT control, the generation efficiency of the solar cell is decreased and loss is generated. Therefore, according to the change of the solar radiation condition and load condition, the MPPT control following the optimum operating voltage is needed.

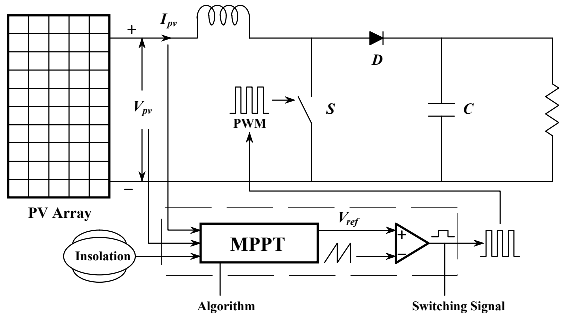

Fig. 4 system configuration diagram for the PV MPPT control

3.1 PO control method

Because of having the simple feedback structure and having a small number of calibration parameter, the PO control method is widely used. It operates by incrementing and reducing the sun voltage in periodically. The output power of an array is compared with the solar cell array output power for before period and consecutively MPP is traced. This control method operates by the flowchart as follow Fig. 5.

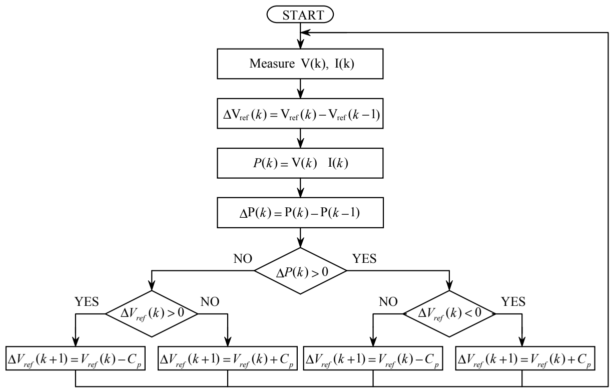

Fig. 5 Flowchart of PO MPPT Method

If the power increases, a disturbance will increase to the same direction and then for the next cycle. If not,, the direction of a disturbance will be opposed. This means that the array terminal voltage is disturbed for all MPPT cycles. Therefore, when reaching MPP, the PO control method will take the self-excitation vibration in the rapidly changing environment condition and consequently the loss is generated in the solar cell array. The reduction of the disturbance step could be reduced the power loss with another solution. However, as to this method, when the environment condition changes rapidly, decision of a step is important since the MPP tracking velocity is delayed.

3.2 IC control method

The IC MPPT method is called as the impedance comparison method or the increment conductance method. This method is that tracking the MPP through comparing the conductance of the solar cell array output with increment conductance. When comparing with the PO control method, this method is added the algorithm that the fluctuation range of voltage is '0' considering the temperature change and can be said more improved control algorithm. Particularly, there is the method being effective in the rapidly changing solar radiation and the output power of the solar cell array is stable in case of reaching MPP. IC control method for improving the PO control method measure the voltage and current and calculates the slope of the power versus voltage, and after the reference numeral of a slope is determined and it is tracked the MPP with the reference voltage is increased or decreased. Particularly this method is the control method that is good for the rapidly solar radiation change and it operates by the flowchart as follows Fig. 6.

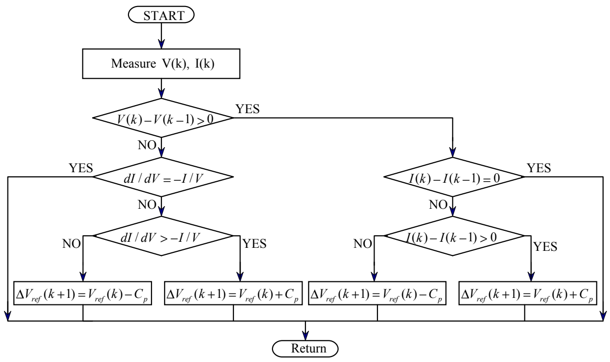

Fig. 6 Flowchart of IC MPPT Method

Since MPP being the case where $\dfrac{dP}{dV} = 0$ becomes, as follows.

$$IdV + VdI = 0 \tag{7}$$

$$\frac{V}{I} = -\frac{dV}{dI} \tag{8}$$

In the maximum power curve about MPP, the left of MPP gets the increase of the output power and the right of MPP shows the reduction of the output power. It is as follows if it shows with the solar cell current and voltage.

$$\frac{dP}{dV} = \frac{dIV}{dV} = I\frac{dV}{dV} + V\frac{dI}{dV} = I + V\frac{dI}{dV} \tag{9}$$

The equation below satisfying the MPP condition ($V = V_{mp}$) can be obtained.

$$\frac{dI}{dV} = -\frac{I}{V} \qquad (10)$$

The MPPT performance of the IC control method is very good in the fast environmental change. But, there is the disadvantage that the high effectiveness CPU is needed due to many computational complexities and it increases the system unit cost.

3.3 CV control method

The output voltage of the solar cell array has the constant voltage characteristic having the little bit of vibration amplitude about the solar radiation change. Therefore, it can be said to the CV control method in which it sets as $V_{ref} = 0.76V$ and it controls by the constant voltage. This method is not needed the calculated power value for an output. The duty of the Boost converter is determined by the control circuit and the DC voltage of the output terminal is consistently maintained by V_{ref} value. The CV control method has the disadvantage that is unable to track the MPP in solar radiation rapidly change and the power efficiency is reduced. However, there is the advantage of reducing the sensor of an array and DC part and Fig. 7 shows the flowchart of the CV MPPT control method.

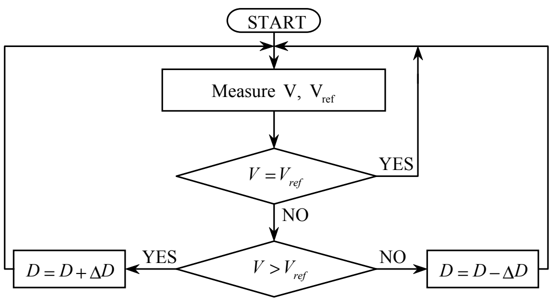

Fig. 7 Flowchart of CV MPPT method

4. PROPOSED MPPT ALGORITHM

The proposed MPPT algorithm is the method for maximizing the efficiency of the output power of the solar cell array with the solar radiation change. The algorithm performed MPPT with the solar radiation change is different. One case the solar radiation is low, the CV control method is performed and the other case the solar radiation is high, the conventional PO control method is performed. Efficiency is not higher than the CV control method in the solar radiation in which the PO control method is low. Therefore, the operation mode is changed in the low solar radiation to the CV control method. The flowchart about this control algorithm is equal to Fig. 8. By using the radiation meter, this control method can change the operation mode in the program. Until the output power of the solar cell array reaches the maximum power point, the proposed control method increases or reduces the reference of the solar cell output voltage as the same direction and it can be tracked the MPP. The fixed α value (less than 1) is multiplied a P_{max} value by and the minimum output power is determined. The output voltage of the solar cell tracks until it becomes same with the minimum power. When the output voltage is decreased than the minimal output value, the flag is changed and the output voltage of the solar cell is increased to the opposite direction.

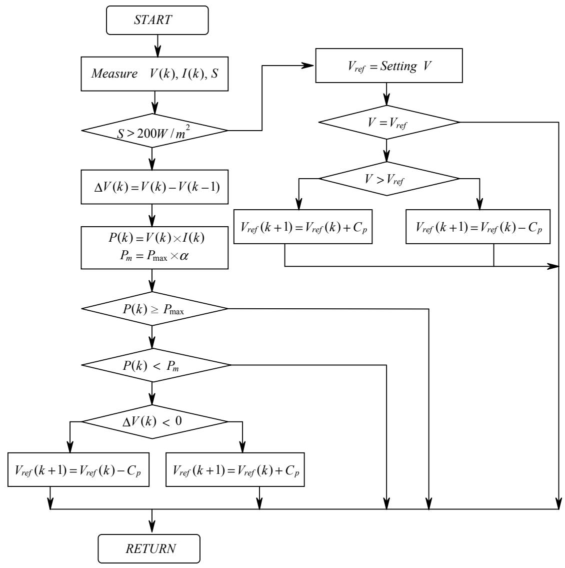

Fig. 8 Flowchart of proposed MPPT algorithm

5. PERFORMANCE RESULT OF SYSTEM

Fig. 9 shows the PSIM circuit diagram for the MPPT control. The MPPT control composed of C language program using the dynamic link library (DLL). DLL used in the circuit diagram was comprised of three parts. Max.dll is designed for the modeling of the solar cell and insol.dll is designed to simulate with solar radiation change. And EX.dll was programmed in order to apply PO, IC and CV method that is the conventional MPPT control method.

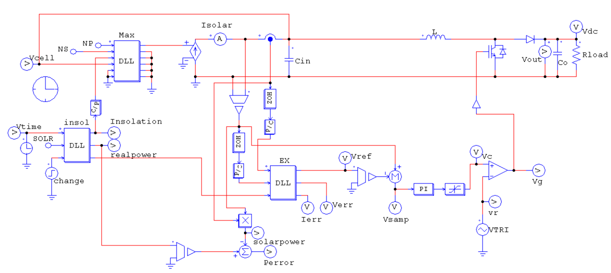

Fig. 9 PSIM circuit for MPPT control

4.1 MPPT control method comparison.

Fig. 10 ~ 13 shows the output waveform of a simulation composed of PSIM. The parameter of system is constant that solar radiation of an array is $1000[W/m^2]$, temperature is 45[℃] and it shows the maximum power error and V_{ref} generated in the array with load. The PO control method of Fig. 10 is generated the power loss because V_{ref} value vibrates the output power through the continued increment or decrease in the steady state. The IC control method of Fig. 11 tracks the MPP rapidly and maintains the constant output in MPP of the steady state. Therefore, the loss occurs a little bit in comparison with the PO control method relatively. Fig. 12 shows the response characteristics of the CV control method and it tracks MPP as V_{ref} value of 76 [%] of the open circuit voltage. This control can be simple and implement easily but the tracking performance is low and the loss is many in MPP of steady state.

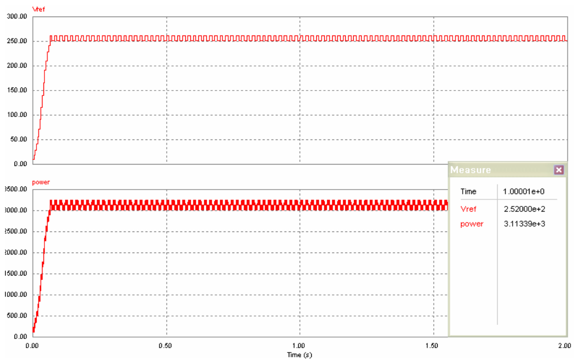

Fig. 10 Response characteristics of MPPT method (PO)

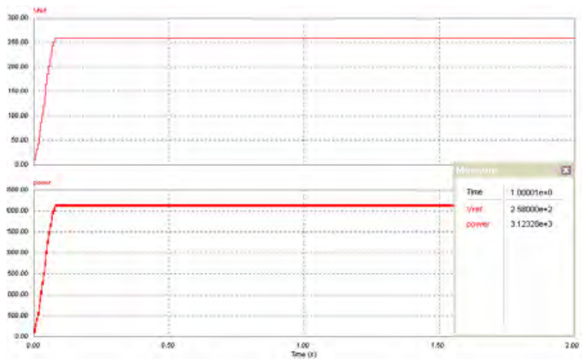

Fig. 11 Response characteristics of MPPT method (IC)

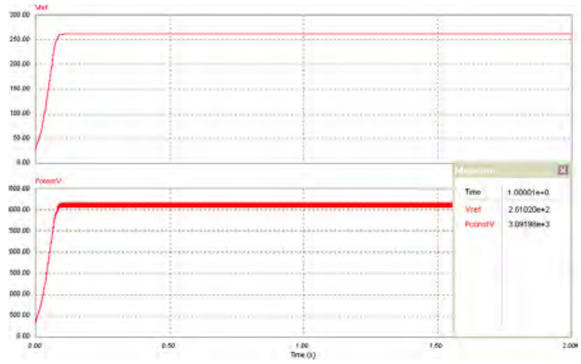

Fig. 12 Response characteristics of MPPT method (CV)

Fig. 13 shows the output waveform of the proposed MPPT control method in this paper. When comparing with the conventional MPPT control method, vibration of proposed method was reduced in MPP of the steady state and therefore the output error was decreased.

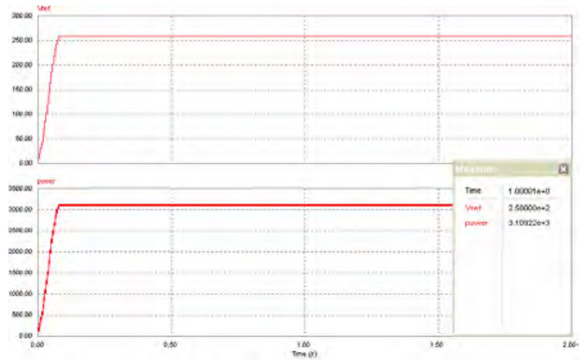

Fig. 13 Response characteristics of MPPT method (proposed algorithm)

4.2 Comparison with radiation change.

The photovoltaic generation is affected with the solar radiation and temperature. The tracking performance of each control method was compared in case of the solar radiation rapidly changing from $1000[W/m^2]$. The power error is calculated by using the real power through voltage and current sensor and theoretical power of solar module. The upper side waveform of Fig. 16 ~ 19 shows the change of the solar radiation and the lower side waveform shows the generated power error. The solar radiation value is changed to 1000 → 800 → 500 → 200 → 600 → $1000[W/m^2]$. Fig. 14 shows the response characteristics of the PO control method with the solar radiation change. It is shown that it fails in the MPPT control in the low solar radiation and power error increases. Fig. 15 shows the response characteristics of the IC control method. Performance of this control is excellent in the high solar radiation. However MPP is unable to be accurately tracked in low solar radiation and it shows that the output error is increased. Fig. 16 shows the response characteristics of the CV control method. This control method is that response characteristic is slow and error is generated but can trace MPP in the low solar radiation.

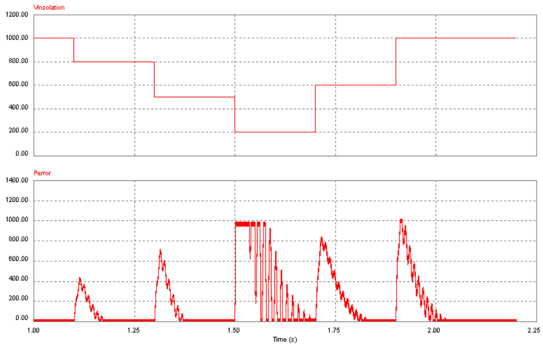

Fig. 14 Response characteristic with radiation changing (PO)

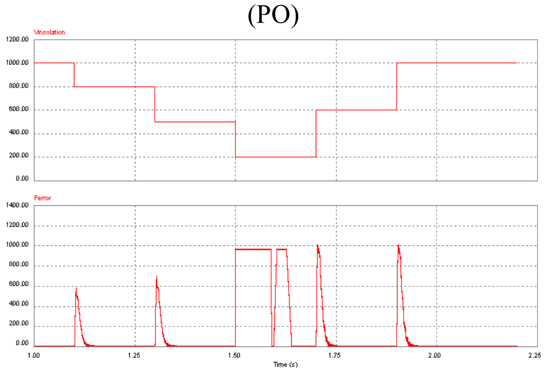

Fig. 15 Response characteristic with radiation changing (IC)

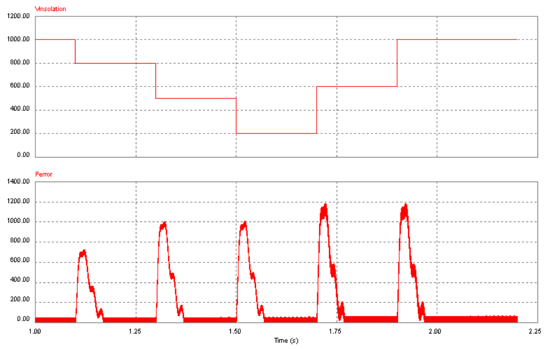

Fig. 16 Response characteristic with radiation changing (CV)

Fig. 17 shows the response characteristics of the proposed MPPT algorithm in this paper. The proposed control method shows that the output error is less than the conventional PO method. In addition, it is shown that the presented control method can track the MPP in the low solar radiation.

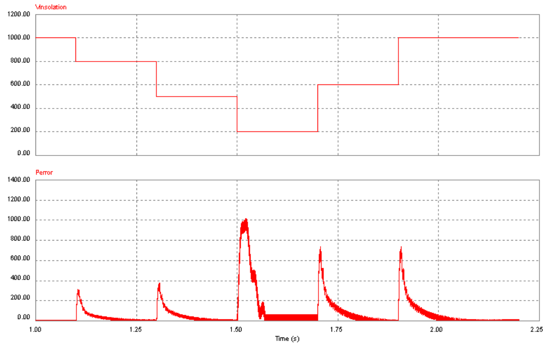

Fig. 17 Response characteristic with radiation changing (proposed algorithm)

6. CONCLUSION

This paper proposes the novel control algorithm which is combined PO and CV, to improve the problem of the conventional MPPT control. PO method is the simple feedback structure and the realization of a system is simplicity. And the CV control method is can be tracked the MPP in the low solar radiation. The proposed control algorithm is analyzed and compared with the result of the conventional MPPT control method using the PSIM program with following condition that both constant and changing of radiation. In case the solar radiation is constant, the generation efficiency is as follows that PO method is 97.3[%], IC method 97.5[%], CV method is 96.6[%] and propose algorithm is 97.6[%] in the steady state. And in case of the solar radiation changes, the generation efficiency is as follows that PO method is 88[%], IC method is 85[%], CV method is 73[%] and proposed method is 91[%]. This result shows that the proposed algorithm is generated stable power than conventional method and efficiency of system is improved. Therefore, the validity of the proposed algorithm is proved in this paper.

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