Maximum Power Point Tracking Control Employing Fibonacci Search Algorithm for Photovoltaic Power Generation System

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Abstract— **Photovoltaic generation systems need MPPT (Maximum Power Point Tracking) control because the output power depends on the operating voltage and current. Therefore, many researchers propose various types of MPPT control methods. A new MPPT control scheme is proposed in this paper in order to realize higher efficiency with simple calculation. The line search algorithm with fibonacci sequence which is one of the optimizing method is employed for the MPPT. The line search method is modified for real-time operation. The method is verified by simulations and experiments. It is concluded that the scheme can respond fast variation of irradiance.**

Keywords—**Photovoltaic power generator, maximum power point tracking, fibonacci sequence.**

I. Introduction

Photovoltaic (PV) power generation is expected as one of the key technologies to mitigate global warming. It is clean and renewable. It is suitable for distributed power generation, transportation and mobile applications. However, it has some disadvantages caused by the change of irradiance and temperature. One of the major problems is variation of output power. In addition, optimal operating voltage and current to obtain the maximum power is also varied owing to the I-V characteristics as shown in Fig. 1. To obtain larger power from solar panels is important, because the solar panels are still expensive and the energy used in the production of PV cells versus output energy during their life cycle is not neglectable.

The efficiency of photovoltaic generation systems is dependent on MPPT (Maximum Power Point Tracking) control techniques. Converters with power electronic techniques are often applied to PV systems in order to approach the operating point to the maximum power point. The voltage and current should be controlled to the optimal operating point. One of the well known algorithm is

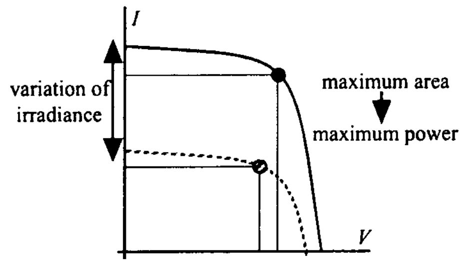


Fig. 1. I-V curve of a solar cell.

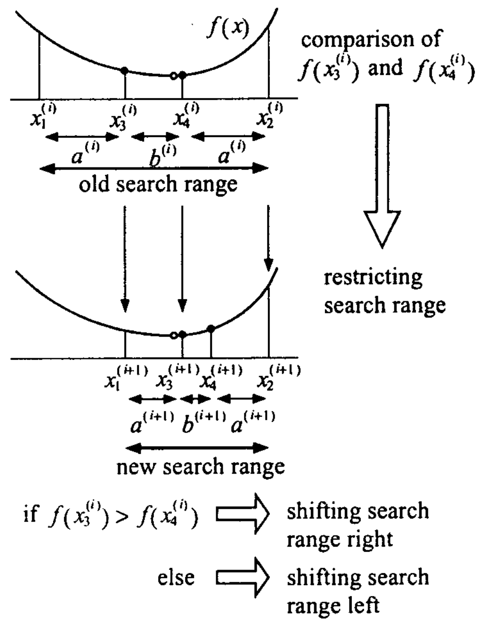


Fig. 2. Searching process of the line search technique in one operation.

the "perturbation and observation method". The change width of variable (voltage, current or duty factor) Δx is often fixed and the variable is increased or decreased by Δx in order to generate larger output power, just like climbing mountains. The method is simple but the convergence is slow. Therefore, many researchers have proposed various types of MPPT control methods, for example, [1]-[3]. Generally, most of the proposals realize faster response, but often need complicated calculation.

The authors propose a new MPPT algorithm with simple calculation and fast convergence. The line search method with Fibonacci sequence is employed for the proposal. It can be realized the following advantages;

1. simple algorithm,
2. realization of intuitive adjustment of control parameters, and
3. fast response with a small amount of calculation.

The change width Δx is not fixed but decided by the Fibonacci sequence. The proposed method can be applied to any types of DC-DC and DC-AC converters because it is simple and independent of the configuration of converters.

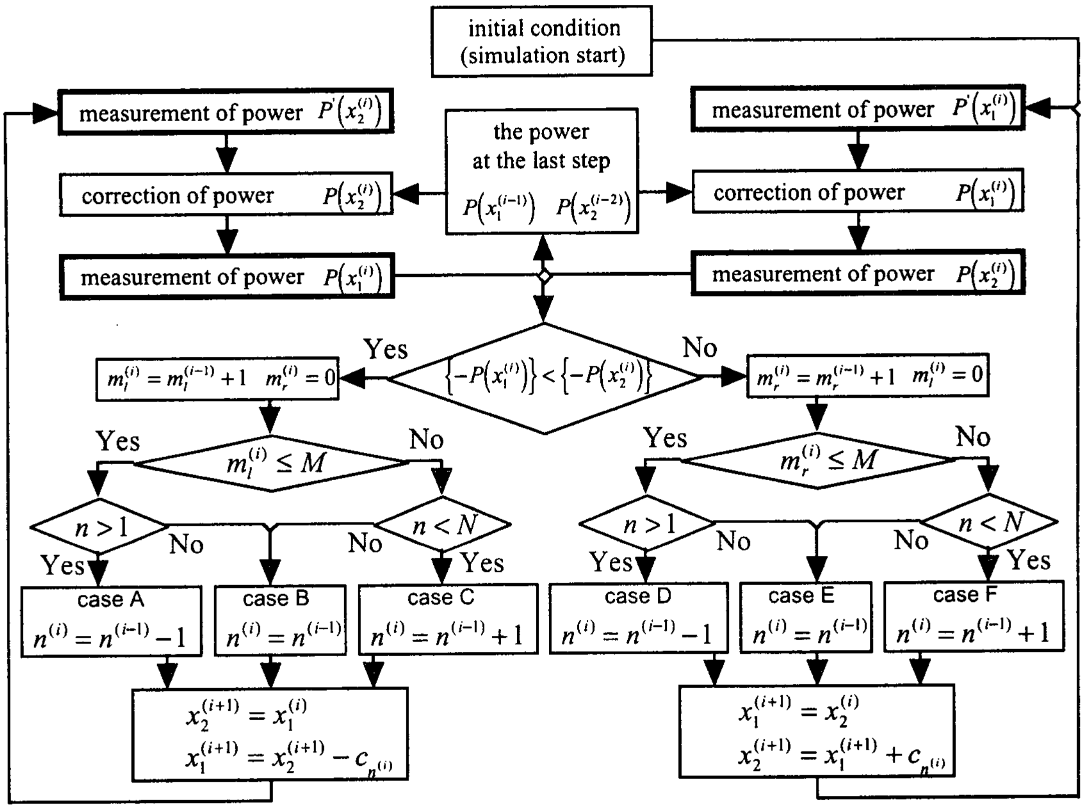


Fig. 3. The flowchart of the proposed MPPT control technique.

II. Line search method and its application to MPPT

The line search method is generally used for an optimization technique applicable to functions with one variable. The method iteratively restricts and shifts the searching range so as to contain optimal point in the range. The direction of the shift is decided by the value of function at two points in the range. The process of restricting and shifting is illustrated in Fig. 2.

Fibonacci sequence which is represented by (1) is used for setting the length of the range.

$$c_{n+2} = c_{n+1} + c_n, \quad c_1 = c_2 = 1 (n = 1, 2, \cdots) \quad (1)$$

The sequence is calculated as (2).

$$c_3 = 2, c_4 = 3, c_5 = 5, c_6 = 8, c_7 = 13, c_8 = 21, \cdots \quad (2)$$

There is another method which uses golden section ratio for the line search, however, it needs floating point operation because the golden section ratio is not integer. Hence, Fibonacci sequence is employed here for the proposed control.

The relation of $a^{(i)}$ and $b^{(i)}$ which are illustrated in Fig. 2 and c_n in (1) are expressed as (3).

$$a^{(i)} = c_{n+1}, b^{(i)} = c_n \quad (3)$$

In the next operation, $a^{(i+1)}$ and $b^{(i+1)}$ becomes (4).

$$a^{(i+1)} = c_n (= b^{(i)}), b^{(i+1)} = c_{n-1} \quad (4)$$

If c_n becomes zero, the search is terminated.

The variable x and the function $f(x)$ are regarded as voltage, current or duty factor, and output power respectively in the application of the method to PV control. However, the original search technique cannot be directly applied to time dependent function such as power-voltage characteristics of photovoltaic generators. Hence, the method should be modified for real-time optimization.

The authors propose an real-time and endless optimizing method whose flowchart is shown as Fig. 3. The Fibonacci sequence used in this method is limited between c_1 and c_N, where c_N is the last term of the sequence used in this method. The method is endless because the minimum shift width is kept to c_1. The range is shifting during every time step.

The search range is widen if the optimal point is assumed to go out of the search range owing to sudden change of weather. That is the reverse process of Fig. 2. The widening process is practically implemented when the range is shifted to the same direction more than M times and the Fibonacci sequence does not reach to c_N. $a^{(i+1)}$ and $b^{(i+1)}$ becomes (5) in the widening operation.

$$a^{(i+1)} = c_{n+2}, b^{(i+1)} = c_{n+1} (= a^{(i)}) \quad (5)$$

After all, the operation in a control cycle is classified into 6 cases as shown in Fig. 3. The change of range and the points of measurement in each case is illustrated in Fig. 4.

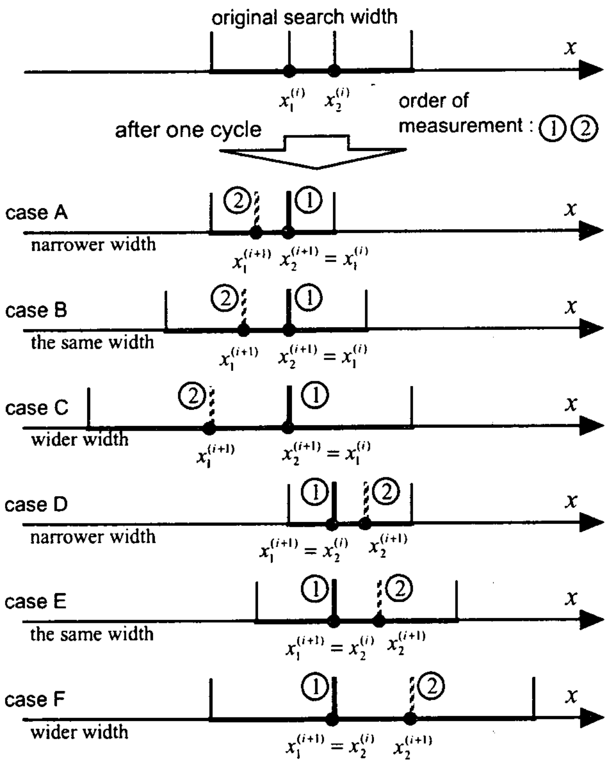


Fig. 4. The shifts of search range.

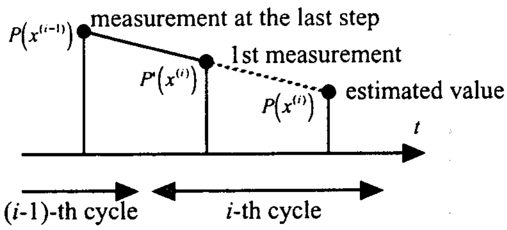


Fig. 5. The correction of measured power.

The output power is measured twice at the different timing during one control cycle. The timing should be essentially the same, because the irradiance may change between the measurement. Therefore, the power measured firstly is corrected by using the power measured at the last cycle as shown in Fig. 5. The correction uses (6) in the cases A, B and C, and (7) in the cases D, E and F.

$$P(x_1^{(i)}) = 2P'(x_1^{(i)}) - P(x_2^{(i-1)}) \quad (6)$$

$$P(x_2^{(i)}) = 2P'(x_2^{(i)}) - P(x_1^{(i-1)}) \quad (7)$$

The adjustment of control parameters is done with M and N. M and N influences speed of response and oscillation at the steady state.

This algorithm has a disadvantage that it may find a local maximum which is not always the same as the global maximum. It causes problem when the part of PV array is shadowed and the P-V curve has two or more maximum points. However, we are not concerned here with the problem, because most of the MPPT controls has the same problem.

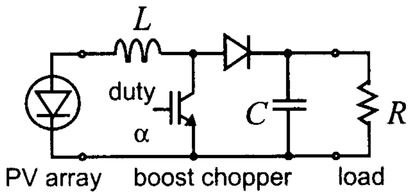


Fig. 6. The circuit with boost chopper used in simulations and experiments.

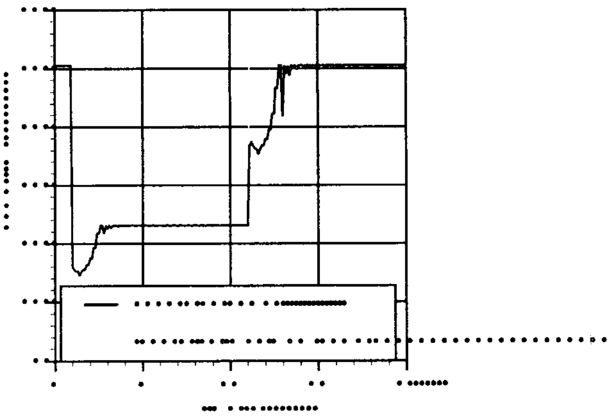


Fig. 7. A simulation result of the step input of irradiance.

III. Simulation Results

The simulated circuit is shown in Fig. 6. A PV array and a DC load are connected with a boost chopper which controls the operating point. The PV module (Fuji Electric Co. ELR-615-160Z) is represented as

$$I = -8.66 \times 10^{-5} \exp(0.482V) + 3.281 p_p \quad (8)$$

where I[A] and V[V] are the current and voltage of the array respectively, and p_p[kW/m^2] is the energy density of irradiation.

Control cycle is set to 0.2 [sec] and p_p is an input which is varied between 0.5 and 1 [kW/m^2] in this simulation. Duty factor of the chopper α is controlled in this simulation for simple control algorithm, while the performance is assumed to be better if the voltage control of PV array is employed instead of duty control. The variable x operated with Fibonacci sequence c_n is converted to the duty factor α $(0 \leq \alpha \leq 1)$ as

$$\alpha = \frac{x}{256 - 1} \quad (9)$$

where 256 is the number derived from 8 bits and it decide the resolution of the duty factor. M and N are set to 1 and 8 respectively.

The result when p_p is step input is shown in Fig. 7. It can be observed in Fig. 7 that the change width of

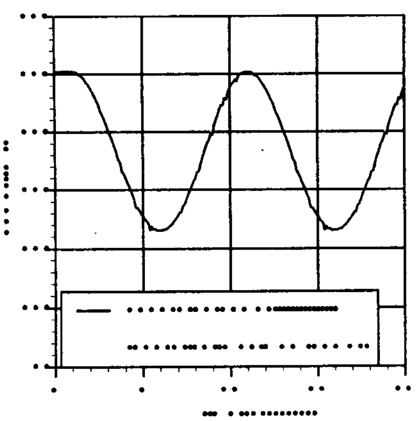


Fig. 8. A simulation result of the sinusoidal input of irradiance.

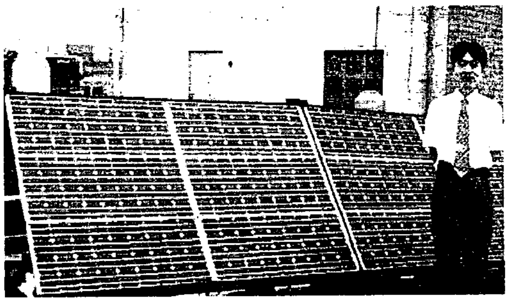


Fig. 9. Solar panels for experiments.

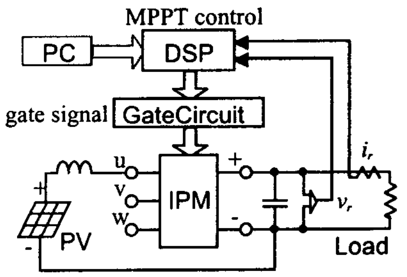
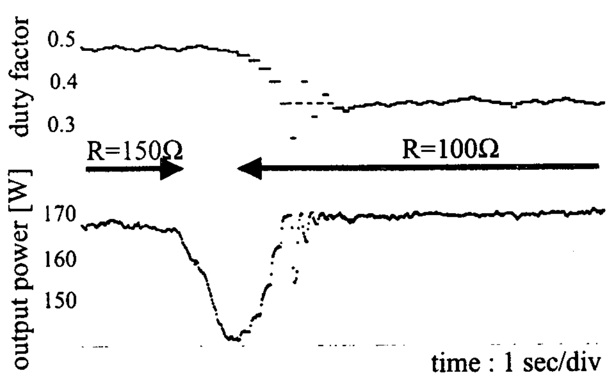


Fig. 10. Configuration of the experimental system.



conditions : 31 °C, fine.

Fig. 11. Experimental result.

duty in each control cycle is dynamically controlled by the proposed method. The simulation proved that fast convergence and very few fluctuation of output in steady state is realized by the method.

Another result of sinusoidal input is shown in Fig. 8. Fig. 8 indicates that the operating point can respond the continuous change of irradiance.

IV. Experimental results

Fundamental experimental system is the same as the simulated model in Fig. 6. The PV array for the experiments are shown in Fig. 9. Rated output power of the system is about 300 [W] per one unit which consist of 6 series PV modules.

The configuration of the experimental system is shown as Fig. 10. An IPM (Intelligent Power Module) is used as a boost chopper. Gate signals of the IPM are generated by a DSP (Digital Signal Processor). Output current and voltage of the IPM are measured instead of those of the PV array in order to include the power loss of the converter. The control program run on the DSP is developed with C compiler on a PC. A variable resistance is used in order to change the optimal operating point. R can change between 100 and 150 Ω. The other specifications are as follows : $C = 1000$ [μF] and $L = 60$ [mH].

Fig. 11 shows the result of the experiment. It indicates that the MPPT control works similar as the simulated control. However, slight oscillation of operating point is sometimes observed during the experiments. This oscillation seems to be caused by the change of irradiance and errors of current and voltage sensors. The resolution of α seems to be too high as compared with the oscillation of power caused by the sensors.

V. Conclusions

The authors propose a simple MPPT algorithm with fast response using Fibonacci search technique. The convergence and the fluctuation at the steady state is examined by simulations. It is proved that the algorithm has good performance. Experimental study is also reported. The power point is controlled well, however the influence of sensor error is also observed.

The authors will further improve the proposed method in order to make it more simple, faster and more stable. The authors will also study on applying the proposed PV system to practical apparatus, such as combining batteries, DC loads and AC loads.

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