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MPPT Control for PV Generation System Based on an Improved Inccond Algorithm

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Abstract

Maximum power point tracking (MPPT) is one of the key technologies in photovoltaic generation system. Incremental conductance (IncCond) method is recognized as theoretically concise and effective among existed classic tracking algorithms, but the application of which was hindered by the rigid requirements upon the precision of hardware. Aim to solve this, an improved IncCond algorithm significantly reduces these requirements was presented in this paper and related experiments have been carried out to verify its effectiveness.

Keywords: MPPT, IncCond, PV system, duty cycle

1. Introduction

Currently, the power changing efficiency of photovoltaic (PV) panel is still restricted by material property and technologies in manufactory. Various weathers and unstable local sun zenith and azimuth angles also lower the average output electricity power and its quality as well. Therefore the maximum power point tracking (MPPT) technology was necessarily introduced in PV generation system.

MPPT control module and DC-DC converter of PV generation system commonly work in combine. Without changing the parameters of hardware circuit, the possible way to control the system is by regulating duty cycle of semiconductor switch or the load. Since the load depends on grid, tracking maximum power point (MPP) by changing duty cycle is more reliable and more appropriate.

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Classical MPPT control algorithms are: constant voltage control (CVT), perturbation observation (P&O) and incremental conductance method (IncCond) [1]. Others featured real-time control step adjustment [2] or combination of classical methods [1] [3] were presented in recent years. Among them, CVT using an constant voltage measured beforehand to fix the power point near the MPP, stable but actually lose the ability of tracking; P&O continuously scans the input and output which definitely achieve tracking and at the same time the added perturbations produce harmful high order harmonics; IncCond is theoretically concise and effective, but its application relies on high precision hardware circuitry, which is very difficult to get up to [4]. An Improved IncCond was introduced for the reason, and verified via platform TMS320F2812 of Texas Instruments.

2. Improved IncCond method

The equivalent mathematical model of PV panel is:

$$i = I_{ph} - (u + R_S i)/R_{SH} - I_S\{\exp[(u + R_S i)q/AkT] - 1\} \tag{1}$$

In which, I_{ph} is light-generated current, I_S is the diode saturation current, R_S and R_{SH} are the series and shunt resistances and A is the diode quality factor [5]. The characteristic function (1) was analyzed in order to prove the effectiveness of MPPT algorithm.

$$di/du = -\{1/R_{SH} + I_S \exp[(u + R_S i)/M]/M\}/\{1 + R_S + I_S R_S \exp[(u + R_S i)/M]/M\} \tag{2}$$

Where

$$M = AkT/q \tag{3}$$

With approximation decided by PV cell characteristics $R_s \to 0$, $R_{SH} \to \infty$, we get

$$-1/R_S < di/du < 0 \tag{4}$$

Its working area is limited in the first quadrant and with the relation between *i* and *u* given, we know the u-i curve begins at (*umin, imax*) and ends at (*umax, imin*), in which *umin* and *imin* equal to zero.

In *u-P* panel, power function *P*(*u*) is continuous on the closed interval [*umin, umax*], differentiable on the open interval (*umin, umax*), and *P*(*umin*)=*P*(*umax*)=*0*. Rolle's theorem told us there exists a *ummp* in the interval that satisfies

$$dP/du\big|_{u=umpp} = 0\,. \tag{5}$$

The denominator of the second part of the second derivative is constantly positive. The numerator is

$$-I_S \exp[(u + R_S i)/M](1 + R_S di/du)/M^2 < 0 \tag{6}$$

From equation (4) and (6), we get

$$d^2P/du^2 < 0 \tag{7}$$

Hence P(u) is convex and that declared the existed point where *dP/du=0* is the only maximum point on the interval [*umin, umax*]. And this also suggests *dP/du* is monotonic decreasing. So we can simply search the maximum point through small-step adjustment on voltage in a certain direction which is determined by comparing the derivative with zero. We define *sgn(x)* as the sign function of *x*. Using constant *deltau>0* as adjustment step, the IncCond algorithm is described as

$$u_{k+1} = u_k + deltau \cdot \mathrm{sgn}(2i_k u_k - i_k u_{k-1} - i_{k-1} u_k) \qquad k \in N \tag{8}$$

When using non-ideal ADC, the sampling results of *u* and *i* would not take fixed values but follow Gaussian distributions. We express them with the help of random variables *X, Y, which are in standard normal distribution*.

$$u = \bar{u} + \sigma X, \qquad i = \bar{i} + \sigma Y \tag{9}$$

The error induced by nonideality is

$$error1 = \sigma X(\overline{du} + 2\bar{u}) + \sigma Y(\overline{di} + 2\bar{i}) + 2\sigma^2 XY \,. \tag{10}$$

$$E(error1) = 2\sigma^2 \neq 0 \tag{11}$$

The nonzero variance-related expectation of *error1* shows why IncCond algorithm highly depends on the precision of ADC. This error made the discriminant calculated by derivatives ineffective when using usual ADC. Using excellent ADCs can only reduce not eliminate this error. To solve this, the improved IncCond algorithm was introduced by adding *Check*(*u,i*) function. The *Check*(*u,i*) must have the same monotonicity with power *P*, for it is designed to screen out wrong instructions due to random error. And the statistical error should be zero, hence the decision of voltage adjustment unbiased. By hooping former results with new constraint, the error could be eliminated through a proper selected a *Check*(*u,i*). For example, we have identities:

$$u + i \geq 2\sqrt{ui} = 2\sqrt{P} \tag{12}$$

Expression (18) shows (*u*+*i*) meets the above requirements of *Check*(*u,i*). And its statistical error

$$error2 = d(\bar{u} + \sigma X + \bar{i} + \sigma Y) - d(\bar{u} + \bar{i}) = \sigma X + \sigma Y \tag{13}$$

$$E(error2) = 0 \,, \; D(error2) = 2\sigma^2 < D(error1) \tag{14}$$

And we conclude (14) from (11) and (13). It is clearly the variant of derivative of *Check*(*u,i*) has no relation with current *u* and *i*, unbiased judge to the status of system, and smaller range of random values. We define *bln(x)* equals 0 when *x* less than 0, and 1 if else. The improved IncCond method is described as

$$u_{k+1} = u_k + deltau[\mathrm{bln}(u_k - u_{k-1} + i_k - i_{k-1})\,\mathrm{sgn}(2i_k u_k - i_k u_{k-1} - i_{k-1} u_k)] \qquad k \in N \,. \tag{15}$$

In common way, duty cycle of controllable device is used to control the voltage. We used Thevenin's theorem to equal the system in steady state as a voltage source *E* with internal resistance *r* and resistance load *R* connected in parallel with an ideal switch whose duty cycle denoted as D. From KVL, we get

$$u = (1/t)\{\int_0^{Dt} 0dt + \int_{Dt}^{t} [RE/(R+r)]dt\} = (1-D)RE/(R+r) \tag{16}$$

The duty cycle D is inversely proportional to u. So when being coded practically, the recursive formula with constant step *deltaD* should be:

$$D_{k+1} = D_k - deltaD[\mathrm{bln}(u_k - u_{k-1} + i_k - i_{k-1})\,\mathrm{sgn}(2i_k u_k - i_k u_{k-1} - i_{k-1}u_k)] \qquad k \in N \tag{17}$$

3. System structure

Fig. 1. PV generation system prototype

Common PV generation system consists of PV arrays, DC-DC converter, inverter, controller, protection circuits and filter [6]. A prototype of above system was set up in laboratory, Fig. 1. Supplying by low-power mono crystal silicon PV panel, controlled by TMS320DSP2812f, the built system ran on the load 100 Ohm. In a 1000W per square meter, 25 Celsius degree environment the rated voltage is 17.28V and rated current is 1.16A.

4. Experimental verification

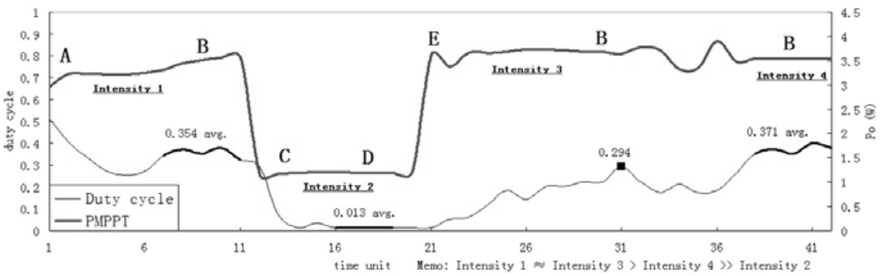

Fig. 2. Output power and duty cycle

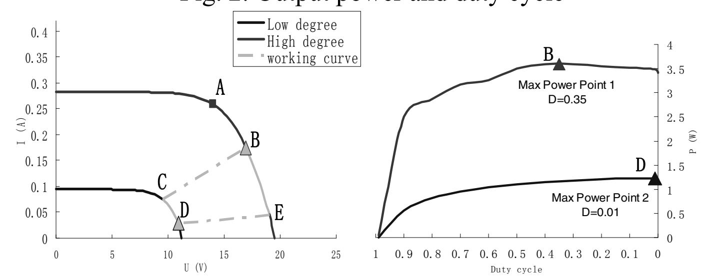

Fig. 3. (a)MPPT control process; (b) MPP of the system

In order to verify the solid effectiveness of the improved IncCond algorithm, we observed the operation of the system under precipitously changed light intensities. The output power PMPPT of the prototype and the duty cycle of the boost switch were shown in Fig. 2. We logged duty cycle instead of power was because it's more intuitive and accurate when load is constant and power is low.

Information in Fig. 2 shows the system was shifting within A, B, C, D, E five status. As results of MPPT, the duty cycle stabilized in Intensity 1, Intensity 2 and Intensity 4 at 0.354, 0.013 and 0.371 respectively. When outside light intensity remains unchanged in large scale, the algorithm would stabilize the system eventually despite the process would be interrupted or delayed by small-ranged intensity variation, which is proved by the output of the last period.

The whole process of experiment in Fig. 2 was mapped into PV panel's characteristics curves plane in Fig. 3(a). The status changes of system mean the operation point jumping between two curves or moving along one of them. The A, B, C, D, E stand for the same operation point in each chart. The B and the D stand for the final operation point tracked by MPPT algorithm. Their duty cycle values accorded the maximum power point tested in Fig. 3(b), with relative errors less than 6 percent. And the actual output power's error was under 0.1 percent. This proved that the improved IncCond algorithm have the capability to track MPP effectively in varied light environment, while original IncCond algorithm can not rightly track MPP based on the same TMS320DSP2812 hardware.

5. Conclusion

In this paper, an improved IncCond algorithm was presented to lower the hardware threshold made by the origin method. Experiments show even if sunlight changes rapidly and sharply, the improved algorithm can work effectively. Moreover, it doesn't require extra hardware such as sensors or external circuitry. Theoretically, the nature of MPPT control was clarified. Not only the fundamental cause of the failure of original method was revealed, but also new functions were built solving this.

Acknowledgements

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