Use of Petri Nets for maximum power point tracking in photovoltaic power generation system

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Abstract

Maximum power-point tracking is used to take full use of solar energy. The main object of this paper was to find a simple efficient technique to let photovoltaic power generation system working near the maximum power point of the solar arrays. The way of finding the suitable method of detection of the maximum power point and the strategy, which forces the system to work near this point was discussed. This project proposes a new way to realize the incremental conductance method by using high level Petri nets which is capable of tracking global maximum power point under condition change. This model will be evaluated by using stateflow in MATLAB. The result showed that this model is effective.

Keywords: photovoltaic power generation, maximum power-point tracking, incremental conductance, high level, Petri nets

1 Introduction

In the recent years power generation systems have had great revolutionary changes in terms of the integration of Renewable Energy Sources (RES) as alternatives to reduce the emissions and new intelligent control algorithms, which increase the efficiency in the grid are provide at the same time. The Smart Grid concept and the use of power electronics has been extended to Microgrids (MG), providing reliability, protection and efficiency with the grid interconnection. Control applications in this area have become more relevant due to the necessity to achieve minimum requirements, such as frequency voltage regulation, coordination and protection system [1-3].

In addition, the impact of Distributed Power Systems (DPS) on the Smart Grid requires the use of distributed processes control architectures according to the characteristics of Distributed Generation (DG) like the multiple conversion stages [4-6]. Therefore, several control techniques have been proposed in order to provide some smartness to the grid which is also needed in self-autonomous behaviour [7, 8]. Petri nets are well known to be good at modelling discrete-even systems which given an approach to multi-agent systems and used in distributed control problems [9, 10].

Photovoltaic (PV) Generation System performance depends on solar irradiation and operating temperature. Technique is use to track the maximum possible power from the PV array. Algorithm that included in charge controllers is used for extracting maximum available power from PV module under different conditions.

The voltage, at which PV module can reach maximum power, is called 'maximum power point' (or peak power voltage). The present study aims to evaluate performance and enhance accuracy for maximum power-point tracking. The proposed method is established model, which used a high level Petri nets to realize the incremental conductance method. The performance of proposed models shows that this algorithm tracks the maximum power solar energy effectively.

2 High level Petri nets

2.1 PETRI NETS

The control network of a described system by High Level Petri nets (HLPN) is an extension of Ordinary Petri nets (OPN). OPN are graphic and mathematic formalism. It can represent and describe systems in which concurrence and parallelism concepts are present. An OPN is a tuple. In which, let R={P, T, Pre, Post, m0}, where P is a non-empty set of places, T is a non-empty set of transitions, Pre is predecessor application and Post is a successor application of m0. Places of Petri nets can be marked by tokens; the application of tokens in the places of Petri net indicates the marking of the network. The graph is constructed with two types of nodes: the places and transitions. The rule is that two places cannot be directly linked and two transitions neither. High-level Petri nets (HLPN) are improved in the base of OPN, which are a widely used in modelling and specification language for information system behaviour. Chang et al. used a Behavioural Browsing model based on HLPN, which was made for modelling and generating behavioural pattern of students [11]. Object oriented course modelling based on High level Petri net (HLPN) was proposed by Su et al. [12]. Liu et al. proposed an

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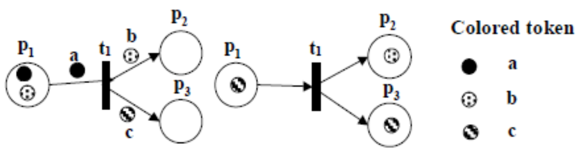
approach based on Petri net for controlling learning path among learning activities [13].

2.2 COLOURED PETRI NETS

In the following years later extensions of Petri net such as Coloured Petri net and timed Petri net are proposed and both of them are called High level Petri net (HLPN). The following will give the description of Coloured Petri nets (CPN) [14].

In Coloured Petri net a value so called colour is allocated to each token. The colour of input tokens which is used by transitions to determine the colour of output tokens. Relation between input tokens and output tokens is presented by colour consumption function or arc function which is depicted by H. For example in Figure 2, E functions are described as Hf(p1, t1) = a, Hf(t1, p2) = b. If a transition is fired, coloured tokens removed from input places and new colour tokens are produced and placed in output places. In Figure 1a, place p1 is marked with two coloured tokens a, b from a colour set {a, b, c}, denoted m(p1) = {a, b}. t1 is enabled as its input arc only requires one coloured token which is available in place p1. If fired, token a is removed from p1, two new coloured tokens b and c are generated by t1's output arcs and deposited in p2 and p3, respectively, as shown in Figure 1b.



1a Before t1 fires 1b After t1 fires

FIGURE 1 Colour Petri nets

In this work it is proposed to use Coloured Petri net approach.

3 Maximum power point tracking

Maximum power point tracking (MPPT) is a technique that grid connected inverters, solar battery chargers and similar devices use to get the maximum possible power from one or more photovoltaic devices, typically solar panels [15]. Solar cells have a complex relationship between solar irradiation, temperature and total resistance that produces a non-linear output efficiency which can be analyzed based on the I-V curve (which is shown in Figure 2) and P-V curve(which is shown in Figure 3).

The purpose of the MPPT system is to sample the output of the Photovoltaic cells and apply the proper resistance (load) to obtain maximum power for any given environmental conditions. MPPT devices are typically integrated into an electric power converter system that provides voltage or current conversion, filtering, and regulation for driving various loads, including power grids, batteries, or motors.

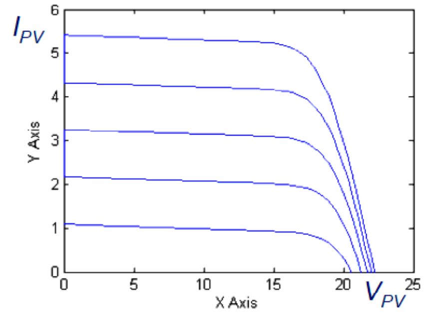


FIGURE 2 I-V Curves

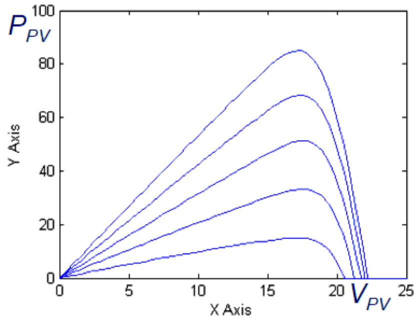


FIGURE 3 P-V Curves

Photovoltaic cells have a complex relationship between their operating environment and the maximum power they can produce. The fill factor (FF), is a parameter, which characterizes the non-linear electrical behaviour of the PV cell. It is defined as the ratio of the maximum power from the solar cell to the product of Open Circuit Voltage Voc and Short-Circuit Current Isc. It is often used to estimate the maximum power that a cell can provide with an optimal load under given conditions. The function to describe the relationship is that P=FF*Voc*Isc. For most purposes, FF, Voc, and Isc are enough information to give a useful approximate model of the electrical behaviour of a photovoltaic cell under typical conditions. For any given set of operational conditions, PV cells have a single operating point where the values of the current (I) and Voltage (V) of the cell result in a maximum power output. These values correspond to a particular load resistance, which is equal to V/I as specified by Ohm's Law. The power P is given by P=V*I. A photovoltaic cell, for the majority of its useful curve, acts as a constant current source [16]. However, at a photovoltaic cell's MPP region, its curve has an approximately inverse exponential relationship between current and voltage. From basic circuit theory, the power delivered from or to a device is optimized where the derivative dI/dV of the I-V curve is equal and opposite the I/V ratio (where dP/dV=0) [17]. This is known as the maximum power point (MPP) and corresponds to the "knee" of the curve.

Incremental conductance is used in this paper for MPPT. In the incremental conductance method, the controller measures incremental changes in array current and voltage to predict the effect of a voltage change. This method can keep up with changing conditions more rapidly than the perturb and observe method (P&O). This method utilizes the incremental conductance (dI/dV) of the photovoltaic array to compute the sign of the change in power with respect to voltage (dP/dV) [18]. The incremental conductance method computes the maximum power point by comparison of the incremental conductance (ΔI/ΔV) to the array conductance (I/V). When these two are the same (I/V=ΔI/ΔV), the output voltage is the MPP voltage and it reach the max power output. The controller maintains this voltage until the irradiation changes and the process is repeated. Figure 4 shows the process of incremental conductance method.

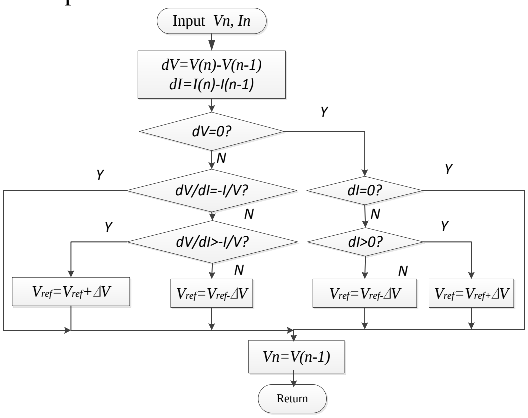


FIGURE 4 Incremental conductance method

4 Case study

Taking a photovoltaic cell as an example, we make test of maximum power point tracking with Coloured Petri net.

Simulation example: 1 PV cell with full sun (1,000 W/m2)

Tables 1 and 2 show the definition of places and transitions of this Coloured Petri net for MPPT.

TABLE 1 Definition of places and transition of the CPN

Places and transition	Description			
	Represent for	*Token=Color1*	*Token=Colour 2*	*Token=Colour 3*
P0	dV	=0	≠0	*NONE*
P2	*dI/dV*	＞-*I/V*	< *I/V*	= *I/V*
P11	*dI*	＞0	＜0	*NONE*

TABLE 2 Definition of places and transition of the CPN

Places and transition	Description
	Represent for
P1	*V=V(p=pMAX)*
T3	*dI≠0*
T4	*dI =0*
T5	*dV≠0*
T6	*Vref+△V*
T7	*Vref-△V*
T8	*dI/dV=I/V*

According to the task of MPPT and the incremental conductance model, which is showed as Figure 4, Figure 5 described the scheme of MPPT task based on Petri nets.

Four places p0, p2, p11, p1 is used to describe the state of incremental conductance parameters of dV, dI/dV, dI, and the MPP voltage. The colours represent its properties.

T3, T4, T5, T6, T7, T8 is the condition for transition.

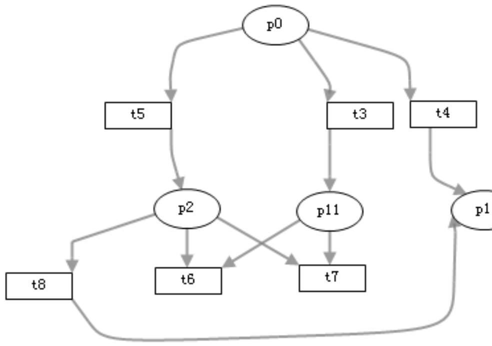


FIGURE 5 Maximum power point tracking scheme based on Petri nets

Figure 5 showed the Maximum power point tracking scheme based on Petri nets.

The simulation used Matlab simulink to establish the photovoltaic power generation system and stateflow to build the Petri net.

This system firstly detected the input voltage and current, and then the output of MPPT module is supplied to the PWM module. It adjusts the duty ratio (FF), and then adjusts the voltage to make the system working in the maximum power point.

The result is shown as Figures 6-9.

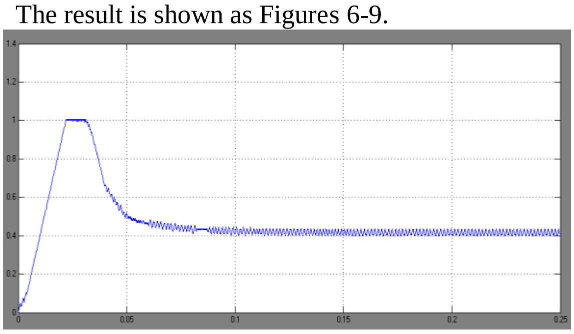


FIGURE 6 Output of MPPT

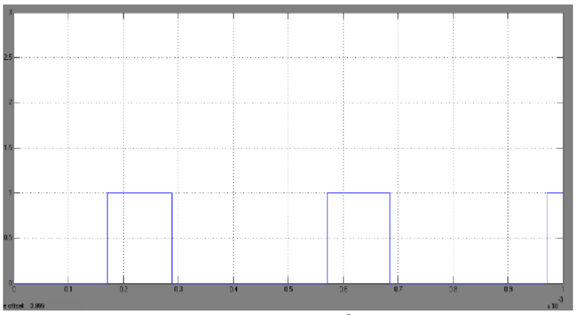


FIGURE 7 Output of PWM

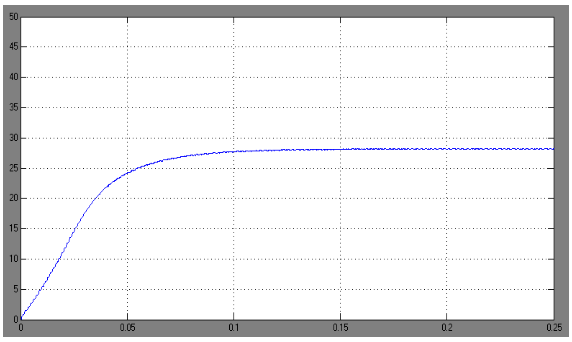


FIGURE 8 Voltage output curve

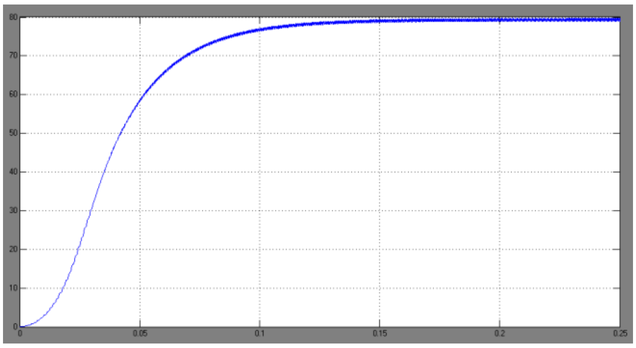


FIGURE 9 Power output curve

The input voltage of approximately stable at 18V, after DC-DC circuit, the output voltage is stable at around 28V as shown in Figure 8. Output power reaches the maximum value at about 0.15s. It is stable at around 80W. The simulation is successful.

6 Conclusions

Controllers with MPPT function increases the utilization efficiency of the solar panel and improves the net system maximum efficiency. On the basis of the analysis of the equal circuit for the solar cell, the paper provide the maximum power point tracking (MPPT) methods, and design a Petri net based on incremental conductance which controls the maximum power point. Trough testing we can track the maximum power point successfully. The experiment proves the improving of stability and reliability of the photovoltaic power generation system.

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