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作品名稱

以類比積體電路實現太陽能最大發電功率追蹤器
Analog Integrated Circuit Realization for Maximum Power Point Tracking of Solar Energy Systems

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作品摘要

近年來太陽能發電為綠色能源中較被廣為使用的方法，而太陽能光電板輸出端需接上控制器控制輸出阻抗才能長時間操作在最大功率輸出，但傳統使用微處理器及離散元件的實現方式會付出較大的成本、體積、功率消耗及暫態反應不夠快等代價，因此，本作品針對上述問題提出了全新的演算法及全新的積體電路實現方式，使最大功率追蹤轉換器能有良好的效能。

本作品提出精簡類比式電路設計結合低複雜度的最大功率追蹤演算法，不需另外增加演算法複雜度、硬體成本及運算量，即可同時達成高追蹤效率及快速暫態響應的效能。本作品所提出的最適合等效負載線斜率(Adaptive Load Line Slope, ALLS)技術，可依實際的太陽能電池輸出特性曲線決定最適合等效負載線和斜率，因此能與實際應用環境做可適應性的改變。本作品利用太陽能電池接收太陽光產生電流與電壓，經由偵測電路取得電壓與電流資訊並傳到所提出之類比乘法器做功率計算，再將目前的功率取樣值與前一取樣值做比較並將結果輸入到ALLS電路中並與偵測得到的太陽能電池輸出電壓做計算，進而控制閘極驅動器的責任週期(duty cycle)並推動功率電晶體使太陽能電池輸出達最大功率點。另外加入了快速暫態響應機制，可大大降低當太陽能電池輸出改變時的功率損耗並使太陽能電池快速達到穩態且操作在最大功率點。

本作品使用TSMC 0.35μm 2P4M 3.3V/5V Mixed Signal CMOS製程，就所知為全世界最先以類比積體電路實現的最大功率追蹤轉換器，晶片大小尺寸約為3mm^2，遠小於傳統實現方式的成本及體積。實際量測結果顯示其追蹤效率高達99.2%，其暫態響應參數為0.47ms/W，遠優於現有技術，功率轉換效率更可達91.2%以上。此晶片可直接輸出5V, 3W。外接高壓功率電晶體(power MOSFET)後可維持相同追蹤效率及達成更高的功率轉換效率(94%以上)，其結果可用於5V~200V左右高壓太陽能板且輸出功率達3W~1kW以上。

指導教授

郭泰豪　成功大學電機工程學研究所

- 郭教授於1988年和1990年於美國馬里蘭大學分別獲得電機工程碩士和博士學位。1992年加入成功大學電機系(所)迄今，並於2004~2007年借調集新科技及晶豪科技分別擔任總經理及副總經理。
- 專長領域：主要研究類比及混合信號積體電路設計，包含ADC、DAC、Delta-Sigma技術及class-D amplifier。近年來並致力於綠能積體電路設計，包含太陽能/風力發電之最大功率追蹤、市電併聯微型換流器、智慧型大功率馬達驅動器及變頻技術等。

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- 郭教授於2001年在成功大學獲得電機工程博士學位。2007年加入高雄第一科技大學電子系(所)迄今。
- 專長領域：包含太陽能轉換系統IC設計、電源管理IC設計、智慧型控制IC設計及電子設計自動化。近年來與郭泰豪教授合作，致力於綠能積體電路設計。

Abstract

In green energy, solar power has been increasingly used in recent years. Photovoltaic (PV) array can output maximum power for a extended periods of time when its output impedance is governed by a controller. Conventional implementation employs a microprocessor and discrete components, which have drawbacks like high cost, large volume, large power consumption and slow transient response. Therefore, this work proposes a novel algorithm and integrated circuit to compensate for the above problems to enable the maximum power point tracking (MPPT) converter to have superior performance. The combination of the analog circuit design and low complexity MPPT algorithm can achieve high tracking efficiency and fast transient response simultaneously without imposing additional algorithm complexity, hardware cost and computational load.

The adaptive load line slope (ALLS) technique, proposed in this work, is decided by the output characteristic curves of the real photovoltaic cells, and is optimal for real applications. First, this work uses PV array to produce current and voltage; then, sensing circuits are used to obtain current and voltage information which computes power by the proposed analog multiplier. Second, the current and last sample value are compared, the results are input to the ALLS circuit and are computed with the sensed PV array output voltage. Third, the duty cycle of gate drivers are controlled and drive the power MOSFETs to make the PV array output achieve the MPP. Moreover, adding the fast transient response mechanism can greatly decrease the power consumption produced when the PV array output changes, and allows the PV array to quickly achieve steady state and operate at MPP.

This work is fabricated with TSMC 0.35um 2P4M 3.3V/5V Mixed Signal CMOS process. To the best of our knowledge, this is the first MPPT converter which is implemented by analog integrated circuit. The total chip area is about 3 mm^2, which is far smaller than conventional types in cost and volume. The measured tracking efficiency can achieve 99.2% and the parameter of transient response (Transient Tracking Factor) is 0.47ms/W, the best ever recorded. The power conversion efficiency can achieve more than 91.2%. This chip can directly output 5V and 3W. With a high voltage power MOSFET outside, the same tracking efficiency can be maintained and achieve a larger conversion efficiency, higher than 94%. The results can be used with 5V~200V high voltage PV array with outputs achieving more than 3W~1kW.