to adjust the duty cycle is totally based on the theory of load matching

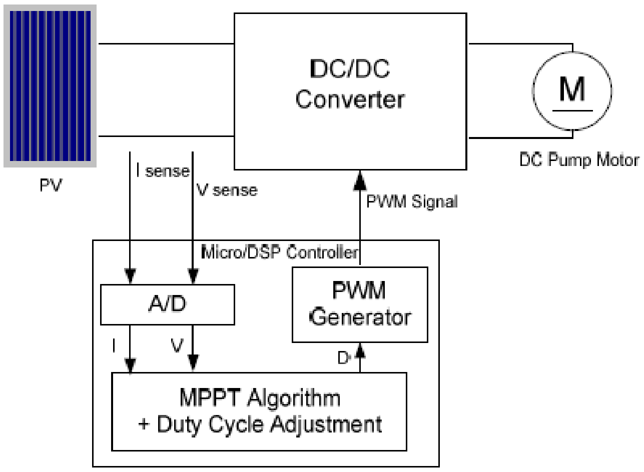

Figure 8: Block diagram of MPPT with the direct control

The impedance seen by PV is the input impedance of converter. Using the example of the Cúk converter , the relationship to the load is:

$$R_{in} = \frac{V_s}{I_s} = \frac{(1-D)^2}{D^2} \cdot R_{load} \quad (7)$$

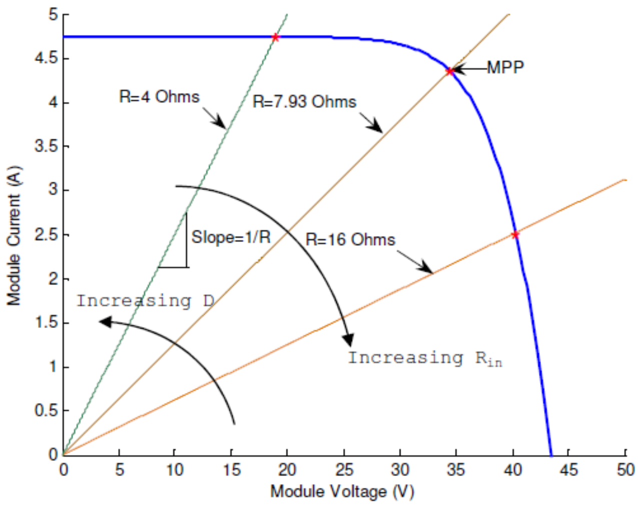

Figure 9: Relationship of the input impedance of Cúk converter and its duty cycle

where: *D* is the duty cycle of the Cúk converter. As shown in Figure 6, increasing *D* will decrease the input impedance (*Rin*), thus the PV operating voltage moves to the left. Similarly, decreasing *D* will increase *Rin*, thus the operating voltage moves to the right. The tracking algorithm (P&O, incCond, or variations of two) makes the decision how to move the operating voltage. The time response of the power stage and PV source is relatively slow (10~50*msec* depending on the type of load) [8]. The MPPT algorithm changes the duty cycle, then the next sampling of PV voltage and current should be taken after the system reaches the periodic steady state to avoid measuring the transient behavior [8]. The typical sampling rate is 10~100 samples per second. The sampling rate of PI controller is much faster, thus it provides robustness against sudden changes of load. The system response is, however, slow in general. The direct control method can operate stably for applications such as battery equipped systems and water pumping systems. Since sampling rates are slow, it is possible to implement with inexpensive microcontrollers [7].

4. Design and Simulations

4.1 PSpice Simulations

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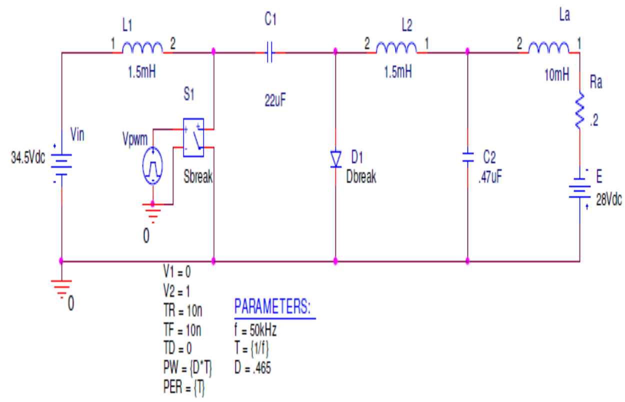


Figure 10: Schematic of the Cúk converter with PMDC motor load

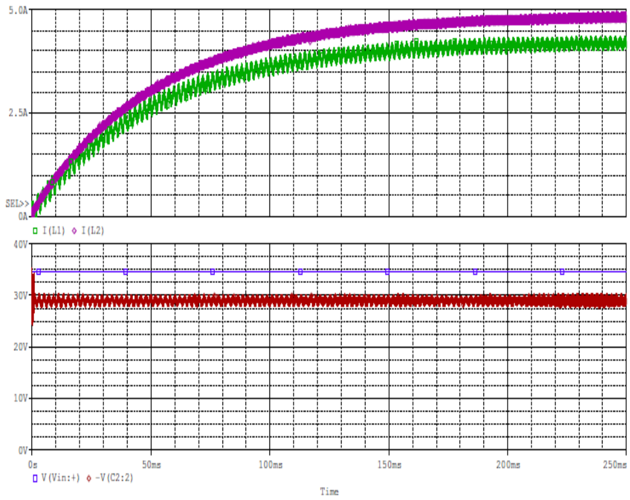


Figure 11: PSpice plots of input/output current (above) and voltage (below)

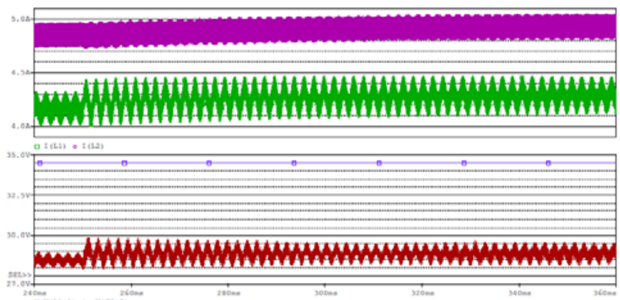


Figure 12: Transient response when duty cycle is increased 0.35% at 250ms

4.2 MPPT Simulations with DC Pump Motor Load

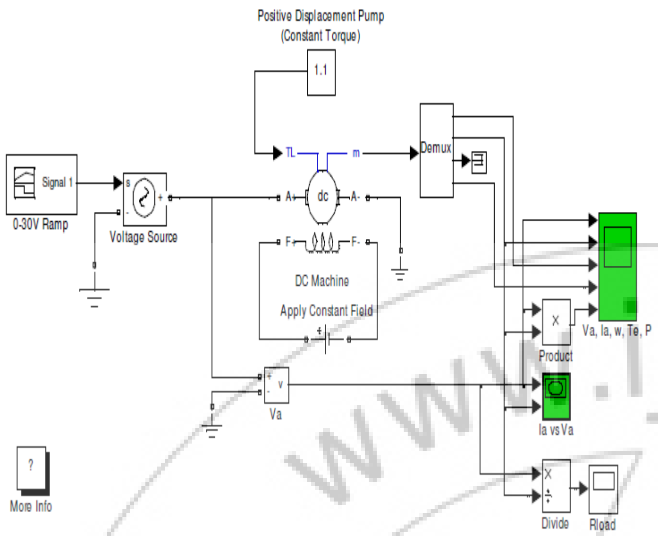


Figure 13: SIMULINK model of permanent magnet DC pump motor

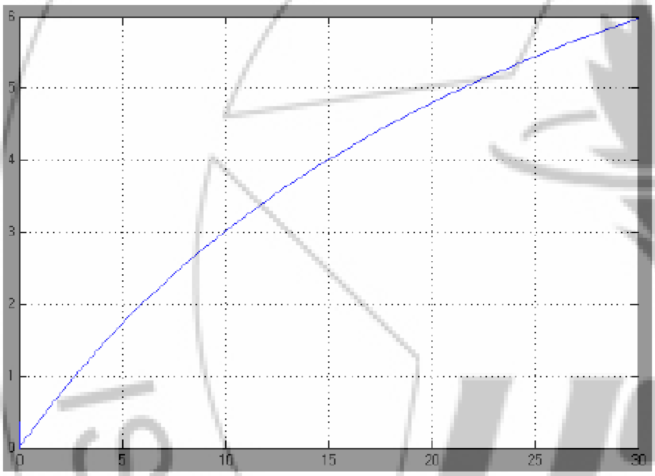
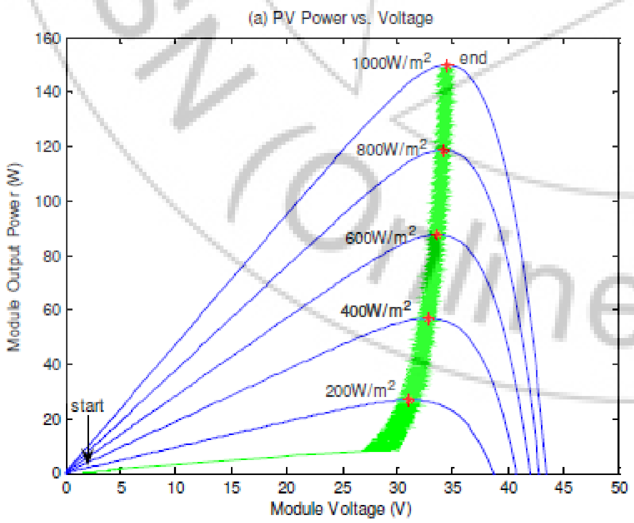


Figure 14: SIMULINK plot of Rload (Ω)



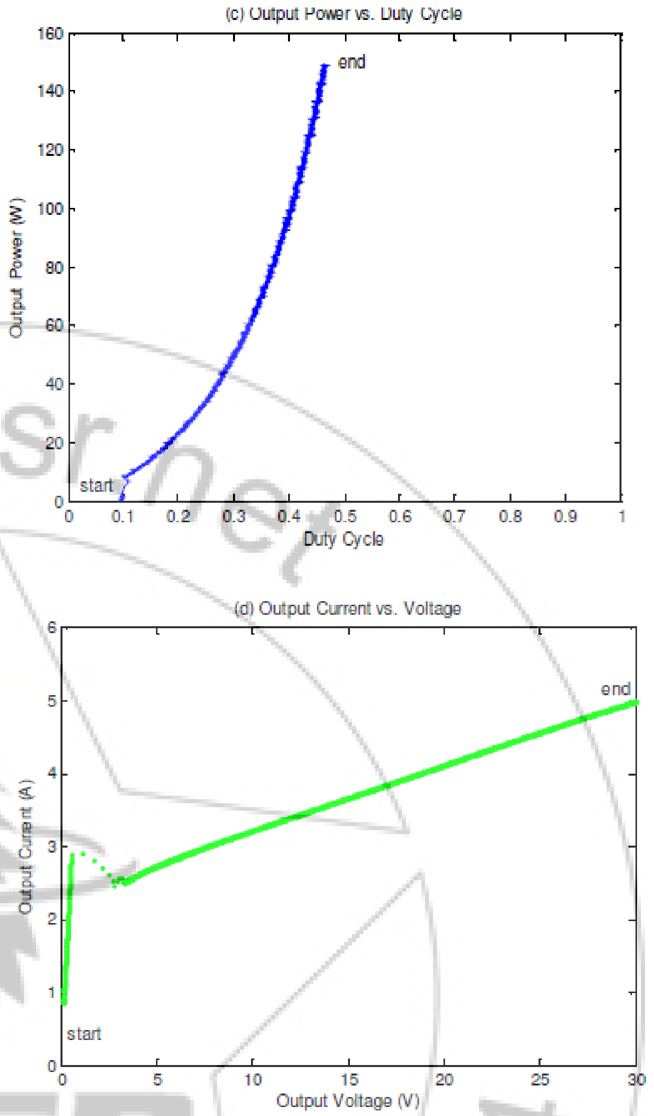


Figure 15: MPPT simulations with the DC pump motor load (20 to 1000W/m2, 25oC)

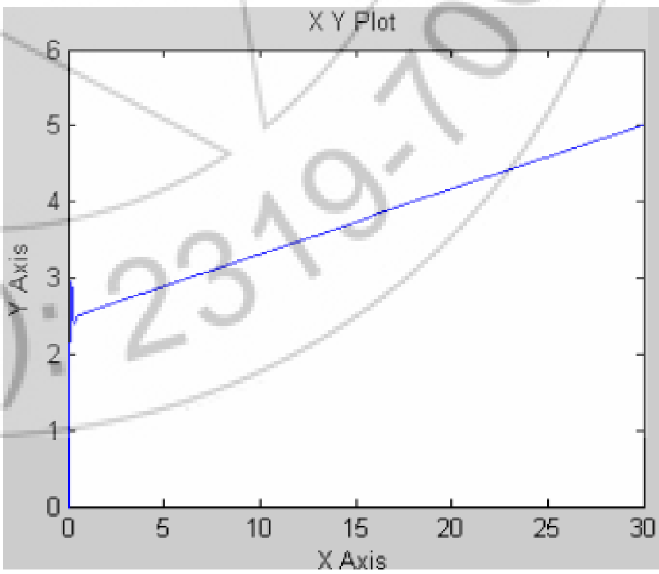


Figure 16: SIMULINK plot of DC motor I-V curve

5. Conclusion

This study presents a simple but efficient photovoltaic water pumping system. It models each component and simulates the system using MATLAB. The result shows that the PV model using the equivalent circuit in moderate complexity provides good matching with the real PV module. Simulations perform comparative tests for the two MPPT algorithms using actual irradiance data in the two different weather conditions. The incCond algorithm shows narrowly but better performance in terms of efficiency compared to the P&O algorithm under the cloudy weather condition. Even a small improvement of efficiency could bring large savings if the system is large. However, it could be difficult to justify the use of incCond algorithm for small low-cost systems since it requires four sensors. In order to develop a simple low-cost system, this thesis adopts the direct control method which employs the P&O algorithm but requires only two sensors for output. This control method offers another benefit of allowing steady-state analysis of the DC-DC converter, as opposed to the more complex state-space averaging method, because it performs sampling of voltage and current at the periodic steady state. Simulations use SimPowerSystems in SIMULINK to model a DC pump motor, and then the model is transferred into MATLAB. It performs simulations of the whole system and verifies functionality and benefits of MPPT. Simulations also make comparisons with the system without MPPT in terms of total energy produced and total volume of water pumped a day. The results validate that MPPT can significantly increase the efficiency of energy production from PV and the performance of the PV water pumping system compared to the system without MPPT.

6. Future Research

Physical implementation of the system remains for future research. It may involve implementation of: a DSP or a microcontroller, a method of supplying power to the controller, signal conditioning circuits for A/D converters, a driving circuit for Power MOSFET, a Cúk converter, and a water level sensor that detects when the water reservoir reaches full. It may also involve performance analysis on the actual system and comparisons with simulations.

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