Journal of Science & Technology 120 (2017) 036-040

A Sensorless Vector Control for Stand-Alone Photovoltaic Water Pumping Systesms

Vu Hoang Phuong, Nguyen Tung Lam*

Hanoi University of Science and Technology – No. 1, Dai Co Viet Str., Hai Ba Trung, Ha Noi, Viet Nam

Received: March 02, 2017; accepted: June 9, 2017

Abstract

Stand-alone photovoltaic (PV) water pumping system is very important in rural areas and islands, where it is difficult or even impossible to reach electrical supply systems. This paper presents a sensorless vector control of an inductor motor (IM) and a hybrid maximum power point tracking algorithm to improve dynamic and robustness of the centrifugal pump in the stand-alone PV water pumping system. Analysis, simulation and hardware in the loop (HIL) experimental results are provided to demostrate advanced features of this proposed system.

Keywords: PV water pumping system, Hybrid MPPT, Sensorless vector control.

1. Introduction

Water is very importance element in agriculture based economies. Traditionally, electrical water pumping systems are used for feeding water into the agricultural areas. With renewable energy revolution, solar energy is applied widely in many applications, and it is a solution for rural areas where water pump system is required. The stand-alone solar pumping systems have received considerable attention in a field of applied science [1, 2].

Classically, two-stage inverters using DC/DC and DC/AC topology is applied. Maximum power point tracking process is carried out by an additional DC/DC converter. The structure decreases the total efficiency of the system and increases installation cost. This problem can be controlled by decreasing the number of power conversion stages and the number of components involved in each stage [3]. In a PV pumping system, DC voltage of PV array is directly converted into three-phase AC without DC/DC converter to drive the water pump. The single-stage inverter is complicated in control approach, but will increase in efficiency of the whole system and help to decrease investment [1, 2, 4].

For driving pumping motor, scalar control methods such as V/f control method is very popular with industrial applications. The main problem of the control scheme is its high inaccuracy performance [5]. Although, the PV pumping system does not require high dynamical performance but in many pumping applications, closely tracking reference speed is required. As a consequence, scalar control might be insufficient. Many researches use the closed loop vector control. However, this approach is costly and difficult to implement since the pumping system is totally submerged in water. In addition, the PV system need to be robust with perturbation, and be able to track the maximum power point (MPP) to improve efficiency of the system [6, 7]. The paper proposes a control solution for water pumping systems. The system comprises of an induction motor driven by a PV panel. The induction motor is control by sensorless vector scheme to gain a better speed tracking performance. An MPPT algorithm is also included in the PV system.

2. Control scheme for proposed system

System configuration is shown in Fig. 1 for the PV water pumping system. It consists of solar PV array followed by a Voltage Source Inverter (VSI) and a three phases IM. A novel hybrid MPP tracking algorithm searches for the MPP which decides the reference speed for the sensorless vector and maintain this state in a certain period.

2.1. Sensorless vector control

The vector control is based on the field-oriented control (FOC) method. The control structure comprises of two control layers is depicted in Fig. 1. The inner layer is designed for two current control loops and the outer layer is dedicated for speed and flux control. For the regulation of the main variables (current, flux, speed) to their reference values, regulators are of the PI type.

$$PI(s) = K_p\left(1 + \frac{1}{T_i s}\right) \qquad (1)$$

* Corresponding author: Tel.: (+84) 989998384
Email: lam.nguyentung@hust.edu.vn

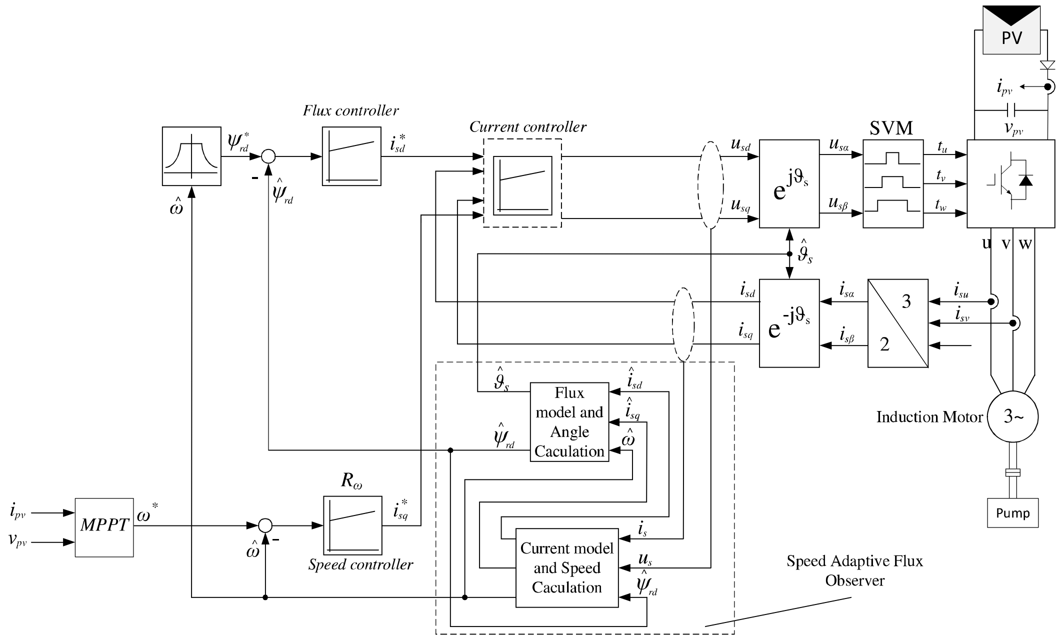

Fig. 1. A sensorless vector control and MPPT algorithm with the stand-alone PV water pumping system

The aforementioned control scheme does not require speed sensor, so information of rotor speed is supplied by the Luenberger observer as depicted in Fig. 2 [8].

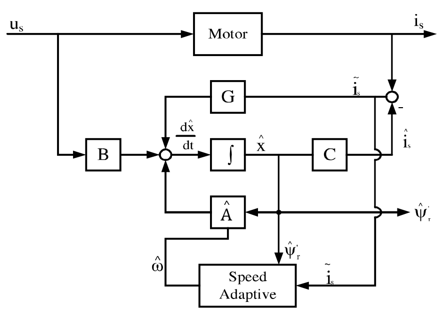

Fig. 2. Block diagram of speed adaptive observer

2.2. The novel hybrid MPPT control method

The novel hybrid MPPT control method is proposed to improve the stability and dynamics of system. This hybrid MPPT control strategy include two parts: the judgment of speed-up or speed-down speed references and the selection of step size [6] and [7].

a) The proposed algorithm

The system with the hybrid method is basically controlled in CV method while its V_{ref} is period updated by Multi-Criterion method (MC).

MC method bases on same principle of INC criterion, however, it does not use division as in INC method and it also checks the signs of ΔP, ΔV directly to track the MPP. Moreover, a new variable ΔI is used to judge the change of the solar radiation to improve the system dynamics.

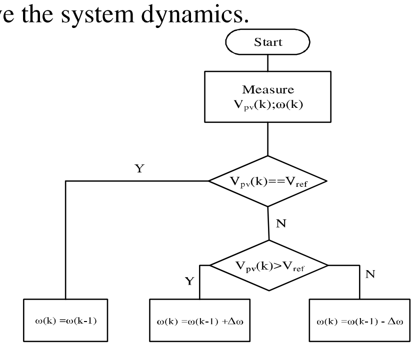

Fig. 3. Speed references according to the CV algorithm.

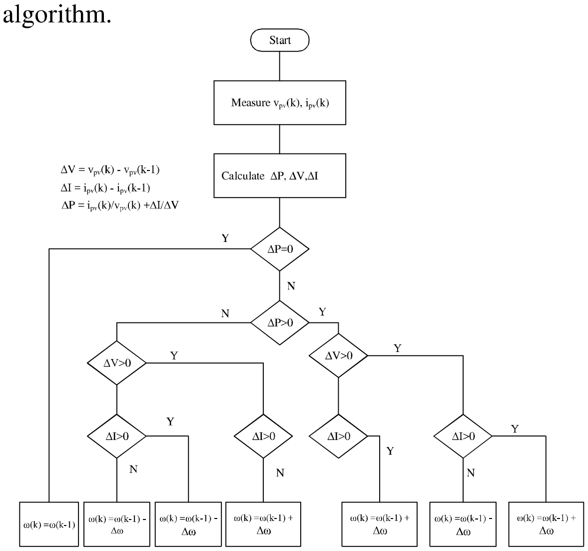

Fig. 4. Speed references according to the MC algorithm.

The overall system efficiency is as good as the MC method and the stability can be compared to that of CV method.

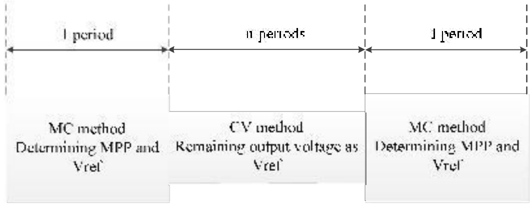

Fig. 5. The novel hybrid MPPT method.

b) Selection step size of the output speed reference

Step size of output speed reference (Δω) is very important during controlling periods, it affects dynamics and stability of the hole system. A large step size leads to quick dynamic response but a large oscillation around the MPP. A small step size leads to a good stability, but it takes a long time to approach the MPP. In order to combine the merits of large and small step size, the step size is selected, it base on the voltage of the PV array:

$$\Delta\omega = \begin{cases} k(V_1 - V_{ref}) + \Delta\omega_{\min} & Vref < V_1 \\ \Delta\omega_{\min} & V_1 < V_{ref} < V_2 \\ k(V_{ref} - V_2) & V_{ref} > V_2 \end{cases} \quad (2)$$

In order to reduce the vibration oscillation around the MPP, the minimum step size is selected when the voltage is within V_1 and V_2. Outside (V_1; V_2), the operating point of the system is away from the MPP, the larger the step size is selected. Due to this technique, the convergence time to the MPP is shortened.

$\Delta\omega_{min}$ is determined on the basis of system parameters and digital signal processing (DSP) capabilities [6]. The optimization value of Δf_{min} is calculated by (3):

$$\Delta\omega_{\min} = 2\pi \times \max\left[\frac{2^{-N}.f_{rate}.V_{ad}}{K_I.I_{mpp}} \quad \frac{2^{-N}.f_{rate}.V_{ad}}{K_V(V_o - V_{mpp})}\right] \quad (3)$$

With system parameters in this paper and the used DSP capabilities, we selected $\Delta\omega_{min}$= 2π0.01(rad/s).

2.3. Torque-Speed Characteristic of the Centrifugal Pump

The centrifugal pump load torque M_c is assumed to be proportional to the square of the rotor speed:

$$M_c \approx \left(\frac{M_n}{\omega_n^2}\right)\omega^2 \quad (4)$$

Where M_n is the nominal torque of induction motor and ω_n is the rotor nominal speed.

3. Simulation results

The proposed configuration for pump extracting power from PV arrays is modeled and simulated in MATLAB/SIMULINK. In this section, performance of the drive is analyzed in varying solar radiation, temperature based on the simulated results. Simulated results show that the systems has a good performance.

3.1. Characteristics of the System with varying temperature

In Fig. 6, the temperature is increased from 25^0C to 50^0C at 6 second, radiation remain G= 1000 (W/m^2) in all time.

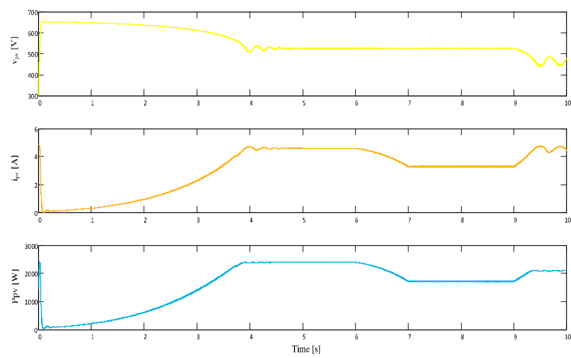

Fig. 6. Current, Voltage and Power of PV after tracking.

In this simulation, the system implement MC method for 5s at the first time, after that, the system will begin the process: implement CV tracking method for 4s to keep the PV at maximum power point, and MC method for 2s to determine MPP.

We can see that PV voltage is tracked to MPP voltage after 4.5s. This voltage is so accurate with MPP voltage in real. At t=6s, the temperature increase from 25^0C to 50^0C, so it makes the curve change a little of bit. According the theory, MPP voltage must be decreased. However, at this time, CV method activate, so it keeps MPP constant voltage. It also helps the frequency not to change so much when the weather change fast. After 9s, MC algorithm continuous activate, CV algorithm is stopped to determine new MPP.

At t=6s, the temperature increase from 25^0C to 50^0C, the speed, torque, stator current and frequency pump is reduced softly and not changed much at that time in Fig. 7.

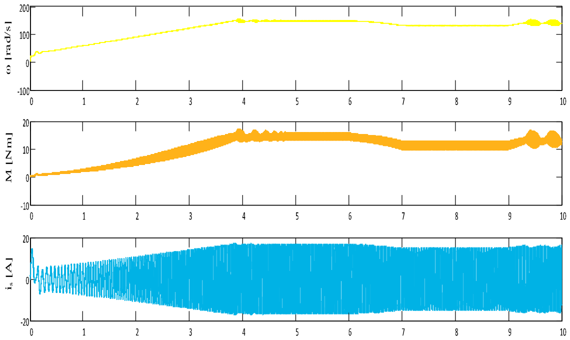

Fig. 7. Stator current, torque and speed of the pump.

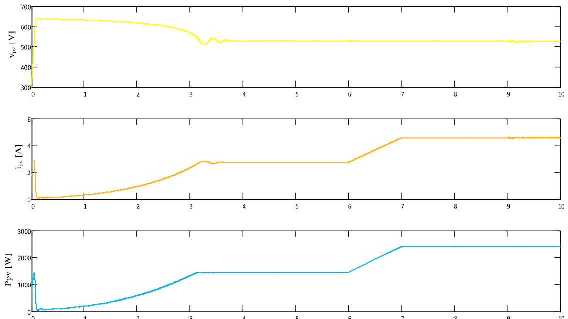

Fig. 8. Current, Voltage and Power of PV after tracking.

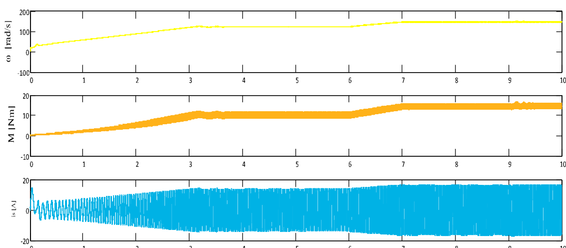

Fig. 9. Stator current, torque and speed of pump motor.

3.2. Characteristics of the System with varying Radiation

The radiation is increased from 600 W/m^2 to 1000 W/m^2 and temperature is hold T=25^{0}C

The tracking MPP time is about 4s. At t=6s, radiation increase from 600 W/m^2 to 1000 W/m^2, current, voltage is varied and is established quickly, the voltage value is hold at MPP which MC determine, and current increase follow the theory. The voltage, current, power simulation value is approximate value of the real MPP at the different weather conditions as **Error! Reference source not found.**

Fig. 9 show that stator current, torque and speed increase while radiation increase from 600 to 1000 W/m^2.

4. System performance verification using HIL

4.1. HIL Emulation

In this paper, the general hardware architecture of the HIL 402 emulator of Typhoon is shown in Fig. 10 to emulate for power electronics systems applications, it consists of 4 cores processor is connected to DSP Interface. The system provides 16 analog inputs, 16 analog outputs (AO), 32 digital inputs (DI), and 32 digital outputs. The system hardware is simulated in real time on the HIL platform with a time step of 1 μs by FPGA, since the pulsewidth modulation (PWM) carrier frequency is 5000 Hz. Control algorithms are realized using a control platform based on the fixed – point TMS320F2808 DSP.

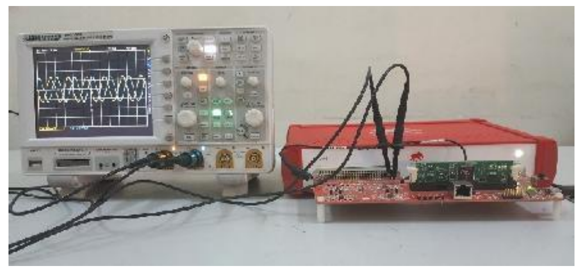

Fig. 10. HIL402 Emulation of stand-alone PV water pumping system.

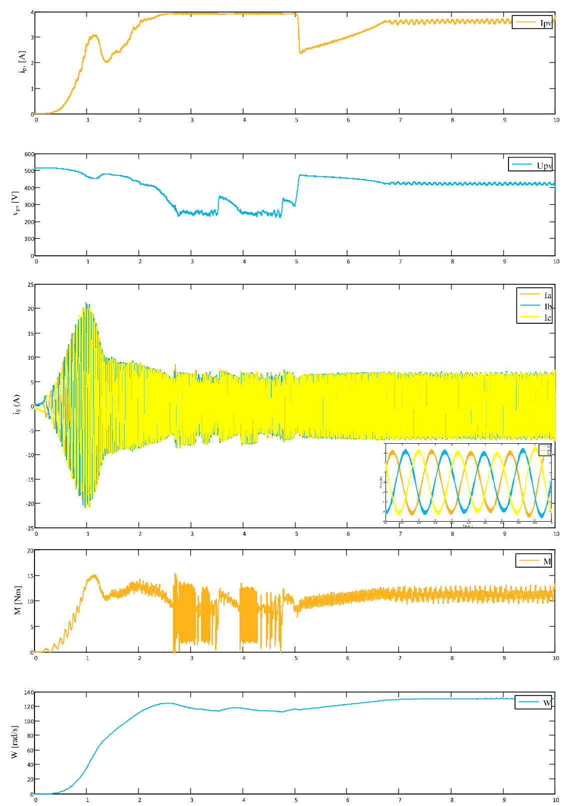

Fig. 11. HIL results at G = 800 W/m^2 and T=25^{0}C.

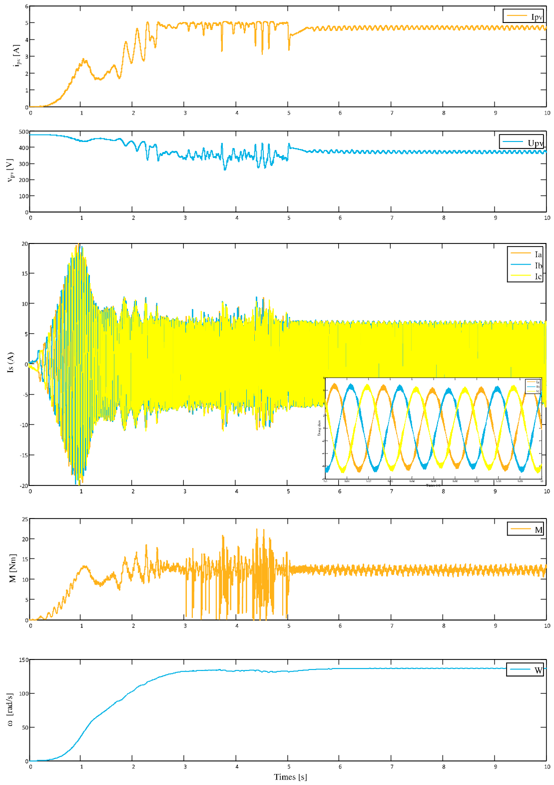

Fig. 12. HIL results at G = 1000 W/m^2 and T=50^{0}C.

4.2. HIL Experimental Results

In this section, the performance of the proposed HIL controller was verified comparing it with the simulation results shown in the previous section. Experimental results shown in Fig. 11 and Fig. 12 illustrate the performance of proposed controller. The first, MC is done in 5s to define maximum point and then CV is active to guarantee robustness for system. The period MPPT algorithm is 10s.

5. Conclusion

This paper has presented a control of stand-alone photovoltaic Water Pumping Systems. This system includes: a single stage scheme for solar PV array fed induction motor drive utilizing benefits of a sensorless vector control strategy has been proposed, a novel hybrid MPPT for determine reference speed corresponding the P-V characteristic of solar PV array and remain it for a long time. PV array has been operated at maximum power in the atmospheric conditions. The pump has been used affinity law and performance has been simulated. Simulation and HIL experiment results show that the induction motor drive performs satisfactorily during starting, dynamic and steady state conditions.

Acknowledgments

This research is funded by the Hanoi University of Science and Technology (HUST) under project number T2016-PC-183.

Appendix

a. Solar PV Array (SQ160): Single module V_{oc} of the Array = 43.5 V, I_{sc} of the Array = 4.9 A, V_{mp} = 35 V, I_{mp} = 4.58 A, Number of 15 series and 1 parallel module in PV Array.

b. Induction motor: 2.2 kW, Δ/Y: 230V/380 and 15.2A/8.8A, 50 Hz three phase, 1450 rpm, 4 pole.

References

[1] U. Sharma, S. Dwivedi, C. Jain, and B. Singh, “Single Stage Solar PV Array Fed Field Oriented Controlled Induction Motor Drive for Water Pump.” National Power Electronic Conference (NPEC) 2015.

[2] [2] M. A. Khlifi, “Study and Control of Photovoltaic Water Pumping System,” Journal of Electrical Engineering and Technology, vol. 10, no. 7, 2015.

[3] [3] M. A. Elgendy, B. Zahawi, and D. J. Atkinson, “Comparison of directly connected and constant voltage controlled photovoltaic pumping systems,” IEEE Trans. Sustain. Energy, vol. 1, no. 3, pp. 184–192, 2010.

[4] [4] M. Makhlouf, F. Messai, and H. Benalla, “Vectorial command of induction motor pumping system supplied by a photovoltaic generator,” J. Electr. Eng., vol. 62, no. 1, pp. 3–10, 2011.

[5] [5] W. Wareesri and S. Po-ngam, “A Three-Phase PV-Pump Inverter With Maximum Power Point Tracking (MPPT) Controller,” pp. 5–8, 2016.

[6] [6] S. Z. S. Zhang, Z. X. Z. Xu, Y. L. Y. Li, and Y. N. Y. Ni, “Optimization of MPPT step size in stand-alone solar pumping systems,” 2006 IEEE Power Engineering Society General Meeting, no. 1. pp. 1–6, 2006.

[7] [7] G. Heng, X. Zheng, Y. C. Li, and H. Wang, “A novel maximum power point tracking strategy for stand-alone solar pumping systems,” Proc. IEEE Power Eng. Soc. Transm. Distrib. Conf., vol. 2005, pp. 1–5, 2005.

[8] [8] N. P. Quang and J.-A. Dittrich, Vector Control of Three-Phase AC Machines, Spinger, 2008.