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MPPT control for photovoltaic pumping system based on perturb and observ alghorithm

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***Abstract*— With the increased use of water pumping systems, more attention has been paid to their design and optimum utilization in order to achieve the most reliable and economical operation. The size of the convenient PV array for the pump–motor–hydraulic system characteristics are varied to achieve the optimum performance for the proposed system. Simulations on a DC motor interfaced directly and through a buck converter driven centrifugal pump are presented. Other network components, photovoltaic panels are implemented, modeled and simulated using Matlab/Simulink. In this paper, the direct and indirect DC pumping methods are compared under the energy production and dynamics performance point of view.**

***Keywords*—Photovoltaic, DC Motor, Photovoltaic, perturb and observ.**

I. Introduction

Water is the primary source of life for mankind and one of the most basic necessities for rural development. The rural demand for water for crop irrigation and domestic water supplies is increasing. The water requirement increases during hot weather periods when the solar radiation levels are highest and the output of the solar array is at a maximum. Photovoltaic water pumping systems (PVPS) are particularly suitable for water supplies in remote areas where no reliable electricity supply is available.

Photovoltaic-powered livestock watering is gaining in popularity with electric utilities [1]. A photovoltaic (PV) panel is one of the cleanest and environment-friendly non-conventional energy sources. A PV panel directly converts solar energy into electrical energy. The electrical energy produced by the PV panel can be extracted over time and used in the form of electric power. This electric power can be used to drive electric devices [2], [6]. Under constant uniform irradiance has a current–voltage (I–V) characteristic there is a unique point on the curve, called the maximum power point (MPP), at which the array operates with maximum efficiency and produces maximum output power. Direct pumping system consist of PV arrays, a centrifugal pump, a tank with high and low level, indirect pumping system have the same components plus a buck converter controlled with P&O algorithm to extract maximum power. When a PV array is directly connected to a load (a so-called 'direct-coupled' system), the system's operating point will be at the intersection of the I–V curve of the PV array and load line [3]. Maximum power point trackers (MPPTs) play an important role in photovoltaic (PV) power systems because they maximize the power output from a PV system for a given set of conditions, and therefore maximize the array efficiency. In this paper, the direct and indirect DC pumping are compared under the energy production and dynamics performance point of view.

II. The Controlled pumping system

The two configurations of the PV pumping system considered in this work are shown in fig. 1. It consists of PV arrays, DCM, a centrifugal pump, electronic equipment to adapt PV arrays to the load.

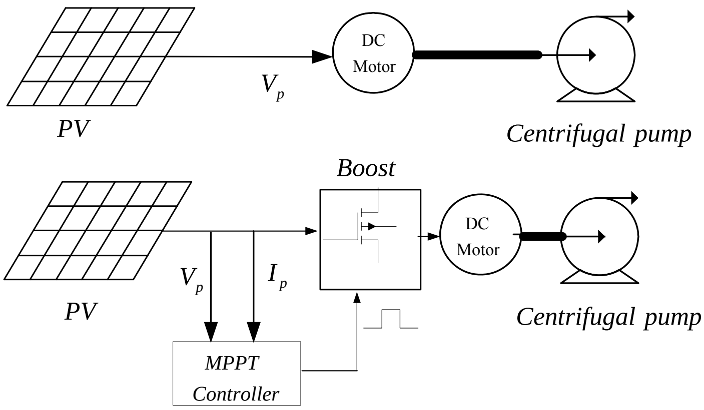

Fig. 1 The proposed PV pumping system

Provision for storage electricity is not provided in thus systems. Instead if desired provision can be made for storage water, this may be more cost effective than having a storage battery. In direct-coupled pumping systems, electricity from the PV modules is sent directly to the pump, which in turn pumps water through a pipe to where it is needed, in the second scheme PV panel fed the PMDCM coupled to the centrifugal pump through the buck converter with MPPT controller.

A. DC motor model

A DC Motor is a mechanism which converts electrical power to mechanical power via magnetic coupling. The electrical power is provided by a voltage source. This latter can be used in PV pumping system. The equivalent electrical circuit of a DC Motor can be represented by a voltage source V_a across the coil of the armature. The equivalent electrical circuit of the armature coil can be described by an inductance L_a in series with a resistance R_a in series with an induced voltage which opposes the voltage source. The differential equation given in (1) for the armature current and the angular velocity which describe the DC motor system can be rewritten as (2) putting the differential equations into state space form.

$$\begin{cases} \frac{d}{dt} i_a = -\frac{R_a}{L_a} i_a - \frac{k_v}{L_a} \Omega_a + \frac{v_a}{L_a} \\ \frac{d}{dt} \Omega_a = \frac{k_t}{J} i_a - \frac{f}{J} \Omega_a - \frac{T_L}{J} \end{cases} \quad (1)$$

$$\begin{bmatrix} \dot{i}_a \\ \dot{w}_a \end{bmatrix} = \begin{bmatrix} -\frac{R_a}{L_a} & -\frac{k_v}{L_a} \\ \frac{k_t}{J} & -\frac{f}{J} \end{bmatrix} \begin{bmatrix} i_a \\ \Omega_a \end{bmatrix} + \begin{bmatrix} \frac{1}{L_a} & 0 \\ 0 & -\frac{1}{J} \end{bmatrix} \begin{bmatrix} v_a \\ T_L \end{bmatrix} \quad (2)$$

B. Cell and PV Models

Solar cells consist of a p-n junction fabricated in a thin wafer or layer of semiconductor.When exposed to light, photons with energy greaterthan the bandgap energy of the semiconductor are absorbed and create an electron-hole pair. These carriers are swept apart under the influence of the internal electric fields of the p-n junction and create a current proportional to the incident radiation . In order to prove their research work, many authors proposed different models for the solar cell [5-10]. the equivalent circuit of a solar cell is a current source in parallel with a diode. The output of the current source I_{ph} is directly proportional to the light falling on the cell. The diode D determines the I-V characteristics of the cell. Increasing sophistication, accuracy and complexity can be introduced to the model by adding in turn:

- Series resistance R_{sc} , which gives a more accurate shape between the maximum power point and theopen circuit voltage.
- Shunt resistance R_{pc} in parallel with the diode.

The electric model of a solar cell is shown in figure 2 [6-8].

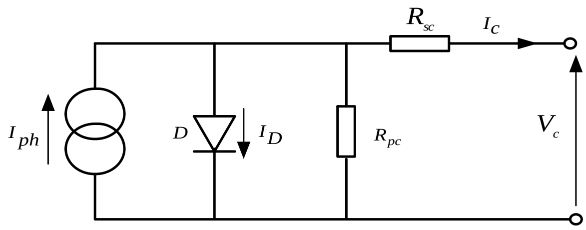

Fig. 2 Equivalent solar cell’s electric circuit

The equations which describe the I-V characteristics of the cell are where cell junction temperature T_{c_ref} , the insulation G_{ref} , the photocurrent I_{ph_ref} , the reverse saturation current I_{sc_ref} . , cell junction temperature T_c and the ambient insulation G , K_{SCT} the short circuit current temperature coefficient E_g , q , k and β represent respectively the band gap energy of the semiconductor, the electron charge, the ideal factor off the solar cell and the βoltzman constant.

The cell photocurrent I_{ph} can be deduced from the reference data condition given by equation (3)

$$I_{ph} = \frac{G}{G_{ref}} \left(I_{sc\_ref} + K_{SCT} \left(T_c - T_{c\_ref} \right) \right) \quad (3)$$

The desired reverse saturation current I_{rs} is also obtained from the reference condition according to relation (4), where

$$I_{rs} = I_{rs\_ref} \left(\frac{T_c}{T_{c\_ref}} \right)^3 \exp\left[\frac{qE_g}{\beta k} \left(\frac{1}{T_c} - \frac{1}{T_{c\_ref}} \right) \right] \quad (4)$$

Many others express the characteristic equation relating the cell’s current I_c to its voltage V_c as represented in (5).

$$I_c = I_{ph} - I_{rs} \left(\exp(\frac{q}{\beta k T_c} \left(V_c + R_{sc} I_c \right) - 1 \right) - \frac{\left(V_c + R_{sc} I_c \right)}{R_{pc}} \quad (5)$$

The solar panel can be composed of N_p array of modules assembled in parallel; each one can be composed of N_s modules assembled in series. A module can also contain n_s cells associated in series configuration. the relations between the panel’s and the cells parameters, relation is (6).

$$\begin{cases} I_p = N_p I_c \\ V_p = n_s N_s V_c \\ R_{sp} = \frac{n_s N_s}{N_p} R_{sc} \\ R_{pp} = \frac{n_s N_s}{N_p} R_{pc} \end{cases} \quad (6)$$

The equation related the panel current I_p to its voltage V_p is shown in (7)

$$I_p = N_p I_{ph} - N_p I_{rs}\left(\exp\frac{q}{\beta k T_c}\left(\frac{V_p}{n_s N_s}+\frac{R_{sc} I_P}{N_p}\right)-1\right) - \frac{N_p}{R_{pc}}\left(\frac{V_p}{n_s N_s}+\frac{R_{sc} I_P}{N_p}\right) \qquad (7)$$

C. Centrifugal pump model

Pump selection depends on the water consumption profile and the hydraulic head, any pump is characterized by its absorptive power, which is obviously a mechanical power on the shaft coupled to the pump which is given by [11], [12]

$$P = \frac{\rho g H Q}{\eta} \qquad (8)$$

The power consumed of the absorptive power and the developed pump torque are respectively given by (9) and (10).

$$P_u = \rho g H Q \qquad (9)$$

$$T_L = a_0 + a_1\omega + a_2\omega^2 \qquad (10)$$

D. Boost Converter Model

Fig. 3 shows the structure of the boost converter used in this research work.

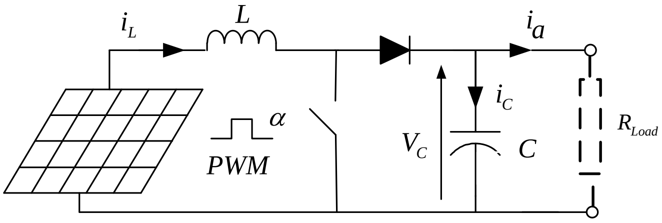

Fig. 3 Structure of the boost converter

As an assumption, the power devices are considered to be ideal. This idea leads to the consideration that when the ideal key is open, the current equals zero, and when it is closed, the voltage is zero as well. Also, both capacitive and inductive losses are neglected.

Relatively to the boost-converter command, the key state is defined by the PWM signal that is characterized by the duty cycle α and the operating period T.

During the considered operating time period T, the key is switched on in αT and switched off in $(1-\alpha)T$ intervals.

The average's boost converts model is given by (11) and (12) where the control term designate the duty cycle indicating the converter action in the global model:

$$\begin{bmatrix} \dot{i}_L \\ \dot{V}_C \end{bmatrix} = \begin{bmatrix} 0 & -\frac{1-\alpha}{L} \\ \frac{1-\alpha}{C} & 0 \end{bmatrix}\begin{bmatrix} i_L \\ V_C \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} V_{panel} + \begin{bmatrix} 0 \\ \frac{-1}{C} \end{bmatrix} i_a \qquad (11)$$

$$V_{dc} = \begin{bmatrix} 0 & 1 \end{bmatrix}\begin{bmatrix} i_L & V_C \end{bmatrix}^t \qquad (12)$$

E. The P&O MPPT algorithm

Many algorithms have been developed for tracking maximum power point of a solar cell. Among them, the most commonly used methods are perturb & observe (P&O) and incremental conductance algorithm. The P&O method measures the derivative of power (dp) and the derivative of voltage (dv) to determine the movement of the operating point. If is increased by some amount of value or inversely. The other method, for example the incremental conductance method can track the maximum power point voltage accurately than P&O method, by comparing the incremental conductance and instantaneous conductance of a PV array, in this paper we use P&O algorithm fig. 4, [14]. A drawback of P&O MPPT technique is that, at steady state, the operating point oscillates around the MPP giving rise to the waste of some amount of available energy. Several improvements of the P&O algorithm have been proposed in order to reduce the number of oscillations around the MPP in steady state, but they slow down the speed of response of the algorithm to changing atmospheric conditions and lower the algorithm efficiency during cloudy days [11].

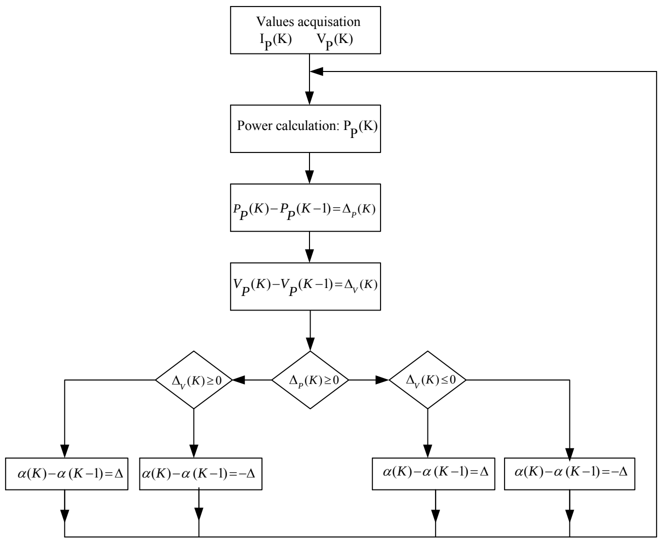

Fig. 4 Perturb and Observe Algorithm

F. The Photovoltaic panel sizing

The nominal size of the PV array should be chosen based on the load size, the water pump power demand is depending upon the volumetric flow rate requirement of the installation'' Q_a '', the pressure head '' h_a '' and the corresponding efficiency ' n_a '',[12]:

$$P_e = \frac{\rho g Q_a h_a}{n_a} \quad (13)$$

The installation under investigation is used to cover an electricity consumption needs to pump water. The electricity consumption of the water pumping system, operating usually between 8 pm and 6 am to pump the water to the pump is:

$$P_e = U_a I_a = C_m \Omega_m \quad (14)$$

The require PV module area A_{PV} (m²) can be calculated from the chosen nominal PV power using the formula (16), [13]:

$$A_{PV} = \frac{P_e}{n_{PV}} \quad (15)$$

n_{PV} : is the efficiency of the modules at STC

III. Simulation results

The simulation in this work has been developed in Matlab /Simulink environnement.

Initially, the DC motor is at stopped, at t = 0, the insulation is equal to 1 Kw/m2 the DCM is supplied by the maximum power voltage from the photovoltaic panel through the MPPT controlled boost converter.

The nominal DCM voltage is used as a base value voltage; fig. 5 and fig. 6 give respectively the panel voltage and the output boost converter voltage.

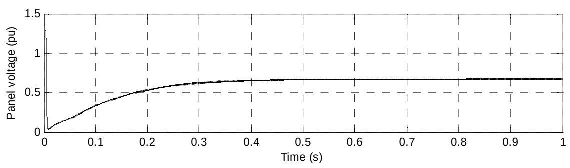

Fig. 5: Panel voltage

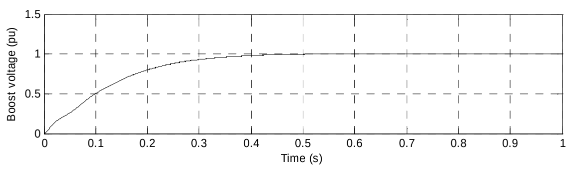

Fig. 6: Output Boost converter voltage

Fig. 7 gives the motor power response; the generated power is more important when the MPPT is used.

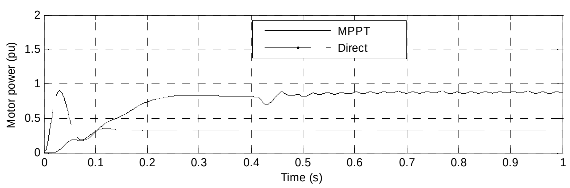

Fig. 7: Motor Power

Fig.8, fig.9 and fig.10 give respectively the motor current and the motor torque responses; they compare the pumping performance with and without MPPT.

It is shown that, when the MPPT is used, the current and electromagnetic torque responses converge towards their target ones (rated values) but the dynamics of the motor current and the motor torque are influenced.

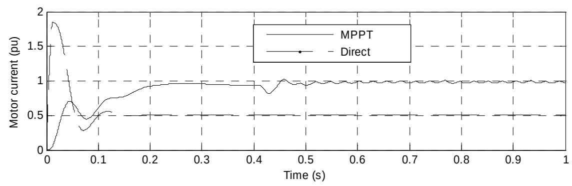

Fig. 8: Motor current

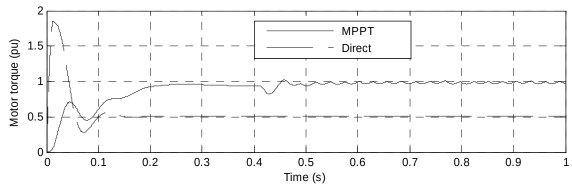

Fig. 9: Motor torque

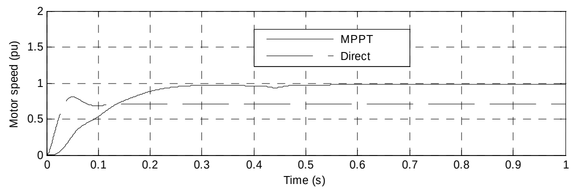

Fig. 10: Motor speed

IV. Conclusion

This work presented leads to the development of an overall dynamic model for a controlled photovoltaic–pumping system. The steady-state and dynamics performances of DC motor with MPPT controlled boost converter are obtained. From the simulation studies it is observed that the use of converter will have the influence both on the dynamic and steady-state behavior.

The direct motor supply from the PV generator occurs in special cases, when the load is adapted to PV generator. The used power is often weak when compared with the extracted power which weakens clearly the efficiency of the system and it is possible to combine the two solution to improve the dynamic of the system with direct coupling and the efficiency of the system by using MPPT controller.

Appendix

TABLE I. DC MACHINE PARAMETERS

DC supply voltage V_{DC}	400 V
Rated armature current I_{an}	25A
Rated torque CemN	57.5 Nm
Rated speed Ω_N	157 rad/s
Armature resistance R_a	1.5 Ω
Armature inductance L_a	47 mH

TABLE II. PARAMETERS OF PV CELL (POLLY-CRYSTALLINE SILICON)

Open circuit voltage: V_{oc}	$0.6058\ V$
Short circuit current : I_{sc}	$8.1\ A$
Parallel cell's resistance: R_{pc}	$0.833\ \Omega$
Series cell's resistance: R_{sc}	$0.0833\ m\Omega$
Solar cell's ideal factor : k	1.450
reverse diode saturation current I_{rs}	$3.047e-7\ A$
Short circuit current temperature coefficient K_{SCT}	$1.73e-3A/°K$
Reference cell's temperature: T_{c_ref}	$25°C$
Boltzmann's constant: β	$1.38e-23$
Band gap energy: E_g	$1.11ev$

TABLE III. PARAMETERS OF PV MODULE

Rated output power	$216W$
Open circuit voltage: V_{oc}	$36.35\ V$
Number of series cells: n_s	60

TABLE IV. PV ARRAY PARAMETERS

Open circuit voltage: V_{oc}	$254\ V$
Short circuit current : I_{sc}	$8.1\ A$
Number of series modules: N_s	7
Number of parallel modules: N_p	5

REFERENCES

[1] A.Mekeddem, A.Midoun, D.Kadri, S.Hiadsi, I.Raja, "Performance of a directly-coupled PV water pumping sysstem," Energy conversion and management, vol. 52, pp. 3089-3095, 2011.

[2] A. Elshefi, "Design and economic analysis of a stand-Alone PV system to electrify a remote area household in Egypt, "The open renewable energy journal, vol. 2, pp. 33-37, 2009.

[3] D. P. Hohm , M. E. Ropp. " Comparative Study of maximum power Point tracking algorithms," Progress in photovoltaics research and application Vol. 11, pp.47-62, 2003.

[4] J.K.Kalldeis, G.C.Spyropolous, K.A.Kavadias, I.P. Koronaki "Experimental validation of autonomous PV-based water pumping system optimum sizing," Renewable energy, vol.34, 1106-1113, (2009).

[5] R. Chenni, M. Makhlouf, T. Kerbache, A. Bouzid, "A detailed modeling method for photovoltaic cells," Energy, vol.32, pp. 1724–1730, 2008.

[6] N. Hidouri , L. Sbita, "A New DTC-SPMSM Drive Scheme for PV Pumping System, International Journal of Systems Control," vol.1.3, pp. 113-121, 2010.

[7] N.Hidouri, T.Mhamdi, S.hammadi, L.Sbita, "A new hybrid photovoltaic-diesel system control scheme for an isolated load," IJRRAS, vo1.9, issue 2, pp. 270-281, 2011.

[8] T. Mhamdi, N. Hidouri, L. Sbita "A fuzzy controlled-hybrid photovoltaic diesel system scheme for an isolated load," Renewable Energy vehicular technology (REVET), first conférence, pp.401-411, 2012.

[9] A.Saadi, A.Moussi, " Optimisation of Buck-boost converter by MPPT Technique with a Variable Reference Voltage Applied to Photovoltaic Water Pumping System under Variable Weather condition," Asian Journal of Information Technology, vol.6, issue 2, pp. 222-229, (2007).

[10] R. Chenni, M. Makhlouf, T. Kerbache, A. Bouzid, "A detailed modeling method for photovoltaic cells," Energy, vol. 32, pp.1724–1730, 2008.

[11] N. Femia , . G. Petroni,M.Vitelli. " Optimization of Perturb and Observe Maximum Power Point Tracking Method," IEEE transactions power electronics Vol. 20, No:1, pp.963-973, 2005.

[12] M, Arrouf , S. Ghabrour, , "Modelling and simulation of pumping system fed by photovoltaic generator within Matlab/Simulink programming environnment ," Desalination, Vol. 209, pp.23-30, July 2007.

[13] M.Abu-Aligah. " Design of Photovoltaic Water Pumping System and Compare it with Diesel Powered Pump ," Jordan Journal of Mechanical and Industrial EngineeringVol. 5, No:3,pp.273-280, 2011.

[14] B.Khiari,A.Sellami,R.Andoulsi, " MPPT control of Photovoltaic pumping system based on discrete Sliding mode ," International Renewable Energy Congress, pp.66-72, 2010.