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Optimization of a PV fed water pumping system without storage based on teaching-learning-based optimization algorithm and artificial neural network

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ABSTRACT

In this paper an optimal performance of three phase induction motor drives a centrifugal water pump and fed from photovoltaic (PV) system without storage elements during starting and running is presented. A three level three phase inverter is used to convert the DC voltage from the PV array to a variable voltage and frequency to supply the three phase induction motor. The output voltage and frequency of the inverter are controlled to extract the maximum power from solar panel during running at different levels of irradiance and temperatures using a Teaching Learning Based Optimization (TLBO) algorithm with minimum motor losses. The ratio of voltage magnitude and frequency is held within rated values to avoid saturation and motor overheating. The rating of PV array is chosen to develop the rated power of the pump at normal irradiance and temperature. The output voltage of the inverter is controlled during starting to prevent an excessive current from PV and to develop a torque larger than pump torque. An artificial neural network (ANN) is developed to give an optimal inverter voltage and frequency to extract maximum power from the PV array. The complete model is simulated using MATLAB/Simulink. The simulated results emphasize the significance of the proposed method to attain the maximum power from PV with minimum motor losses.

1. Introduction

Due to increase in demands for energy around the world and the expected end of fossil fuel; renewable energy sources gained a great attention as alternatives. PV is one of the most important clean energy sources. A PV system composes PV cell which produces a direct current in case of falling solar radiation on its surface. The PV can be used for water-pumping application in remote areas (Masters, 2004), it raises water from a well or spring and stores in a tank for irrigation purpose. The PV-water pump system operation differs from that of the AC Mains powered pump, as they work under varying input power conditions.

Many previous studies in the point of optimal operation of the PV-water pump system have been presented and literature as follows.

An optimal strategy for operating the PV pumping system composes an induction motor driving a centrifugal pump has been introduced in Betka and Attali (2010) and Betka and Moussi (2004); it has been achieved by maximizing the motor efficiency and minimizing the machine losses. A hybrid GA-ANN algorithm has been introduced in Kulaksız and Akkaya (2012) for minimizing the converter losses inserted in a PV system coupled with an induction motor. The matching of an induction motor driven water-pumping system to PV array in order to transfer maximum energy has been given in Akbaba (2007); a double step-up converter and six-step voltage source inverter have been embedded in this work. In Benlarbi et al. (2004), a fuzzy optimization approach to improve the global efficiency of a PV water pumping system and maximize the speed of drive then increasing water discharge rate has been presented. The optimal performance of the PV-water pump system driven by DC motor at different patterns of solar radiation and ambient temperature has been analyzed in Ghoneim (2006) and Jaziri and Jemli (2013). An optimization approach based on the detection of the optimal power flow between the PV system and water pump through the usage of maximum power point tracker has been given in Badoud et al. (2013). Takagi-Sugeno fuzzy approach has been developed in Ouachani et al. (2013) to extract the maximum power from the PV system feeding a water pump via DC motor. The usage of DC and induction motor as a part of multi and single

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Nomenclature

I_{ph}	photon current
I_o	saturation current of the diode
V	cell voltage
I	cell current
R_s	cell series resistance
R_p	cell parallel resistance
α	ideality factor of the diode
V_T	thermal voltages of the diode
N_{ss}	number of series modules
N_{pp}	number of parallel strings
R_{sarr}	PV array series resistance
R_{parr}	PV array parallel resistance
V_{LLrms}	the fundamental line voltage of the inverter
m	the modulation index
V_{ds}	d-axis stator voltage
V_{qs}	q-axis stator voltage
i_{ds}	d-axis stator current
I_{qs}	q-axis stator current
R_{st}	stator winding resistance
λ_{ds}	d-axis stator flux linkage
λ_{qs}	q-axis stator flux linkage
ω_s	synchronous speed
i_{dR}	d-axis referred rotor current
I_{qR}	q-axis referred rotor current
R_R	referred rotor winding resistance
λ_{dR}	d-axis rotor flux linkage
λ_{qR}	q-axis rotor flux linkage
ω	rotor speed
L_s	self-inductance of stator winding
L_R	referred self-inductance of rotor winding
M	mutual inductance
Te	electromagnetic torque
J	moment of inertial
B	friction coefficient
TL	load torque
TLBO	teaching learning based optimization
ANN	artificial neural network
PV	photovoltaic

stage water pump system has been reviewed in Periasamy et al. (2015); additionally the various techniques of MPPT have been introduced. A single stage water pumping system comprises PV array, six-step square wave inverter, induction motor and centrifugal pump has been presented in Muljadi (1997). The maximum power of the PV array has been obtained by operating the inverter as variable frequency; additionally the losses due to switching process have been minimized. An optimal design algorithm based on photovoltaic opportunity irrigation (POI) applied on several sub-models represented PV generator, variable speed centrifugal pump and olive orchard has been implemented in Luque et al. (2015). An optimized stand-alone solar pumping system has been implemented in Corrêa and Silva (2012); the objective of this algorithm is to maximize the PV array efficiency using maximum power point tracking algorithm and minimize the induction motor losses. A linear actuated water pump driven by solar system has been optimized in Wade and Short (2012) to suit the PV power characteristic and hydraulic requirements. An optimization process for maximizing the quantity of water pumped from the water pump system driven from an induction motor with improving the induction motor efficiency by obtaining an optimum voltage-frequency relation to control the motor has been introduced in Betka and Moussi (2005); additionally the impact of changing the PV array temperature has been studied. The performance of induction motor-pump system for irrigation purpose supplied from PV system has been studied in Gumus and Yakut (2015) and Belgacem (2012).

In this paper a Teaching Learning Based Optimization (TLBO) algorithm is used to have the optimal values of inverter voltage and frequency to obtain a maximum power from PV and to minimize the losses of three phase induction motor drives a centrifugal water pump. ANN is built up to have PV maximum power point at any solar radiation and temperature. This maximum PV power is used as an input signal for other ANN to give optimal inverter voltage and frequency after trained by data obtained from TLBO algorithm. The field weakening method of reduced voltage and constant frequency is used to start the induction motor to avoid high starting current from PV. The complete system of PV array, three level inverter, three phase induction motor and centrifugal pump is simulated by MATLAB/Simulink.

2. Mathematical model

The system under study consists of photovoltaic array that composed of a number of modules of type First Solar FS-64 272, formed by the interconnection of 8 series connected modules per string and 3-parallel strings, 3-level 65 three phase inverter, 1.1 kW three phase induction motor and water pump load. The mathematical model of each part is given in this section.

2.1. PV array model

The PV cell is simulated by a parallel current source represents the photon current connected in parallel with a diode and resistance, all in series with series resistance as shown in Fig. 1.

The PV cell output current is given as follows (El-arini et al., 2013; Fathy et al., 2013):

$$I = I_{ph} - I_D - I_p \quad (1)$$

$$I = I_{ph} - I_o\left\{\exp\left(\frac{V + IR_s}{\alpha V_T}\right) - 1\right\} - \left\{\frac{V + IR_s}{R_p}\right\} \quad (2)$$

where I_{ph} is the photon current which is generated by the sunlight strikes the PV cell surface, I_o is the saturation current of the diode, V and I are the cell voltage and current respectively, R_s and R_p are the cell series and parallel resistances respectively, α is the ideality factors of the diode and V_T is the thermal voltages of the diode. The PV array is formulated by connecting N_{ss} PV modules in series and N_{pp}

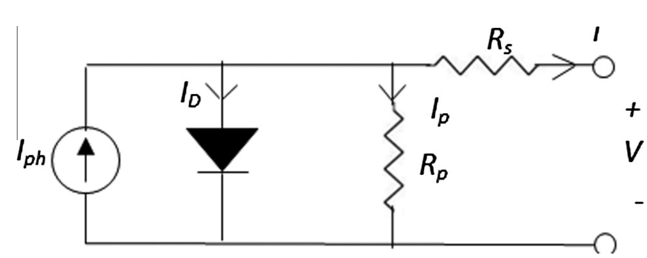

Fig. 1. PV cell equivalent circuit.