MODELLING AND SIMULATION OF SOLAR PV ARRAY FED BRUSHLESS DC MOTOR DRIVEN WATER PUMP USING FUZZY LOGIC CONTROLLER

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ABSTRACT- According to this project deals with the use of photovoltaic (SPV) energy in the brushless DC (BLDC) motor driven water pump using of fuzzy logic controller. A dc-dc boost converter, used as an intermediate power controller unit plays a vital role in improving the efficiency of SPV array and soft starting of the BLDC motor with the fuzzy controller. Fuzzy controller is advance controller which is mostly suitable for the human decision making mechanism which also provided the operation of an electronic system with the expert decision. For the speed control of BLDC motor is operated by PWM technique of the voltage source inverter using DC link voltage control. No other control or current sensing element is required for speed control. The output waveforms analyzed through MATLAB/simulink based simulation study.

INTRODUCTION

Solar energy is the most important, most effective and least expensive over other renewable energy source. Solar energy conversion can be achieved using either by thermal or photo voltaic effects. Many applications can use such renewable source of energy such as: water pumping, air conditioning, light sources electric vehicles, refrigeration systems. Standalone photovoltaic (PY) systems are widely used in military and space applications .

The evolution of life has been possible thanks to the presence of water. Using photovoltaic generators to operate the water pumps is now a technology in development that is characterized by gradual decrease in cost. Since the first installation of photovoltaic pumping system in the late seventies, these systems provide human domestic needs, livestock and irrigation water in rural areas, and have gained considerable acceptance in terms of reliability and performance and today they are considered to be the most significant applications of photovoltaic energy conversion. On the other hand, fuzzy logic is an intelligent control method that has been used recently for improving the efficiency of PY installations by giving the maximum power point tracking (MPPT) algorithm the ability to track effectively the maximum power point of a photovoltaic system under variable irradiation conditions.

In this paper, an intelligent control technique using fuzzy logic control is associated to an MPPT controller in order to improve energy conversion efficiency of a PY standalone water pumping system.

CONFIGURATION OF PROPOSED SYSTEM

Fig.1 shows a detailed schematic of proposed PV array fed BLDC motor driven water pump. This system constitutes a SPV array, boost DC-DC converter, VSI, BLDC motor and water pump. An incremental conductance (INC) MPPT method is applied for efficiency enhancement of PV array through boost converter operation. On the other hand, the speed control of BLDC motor and electronic commutation are performed by PWM control of the VSI. An inbuilt encoder, mounted on the BLDC motor itself, provides three Hall signals following the rotor position which are further converted into six pulses.

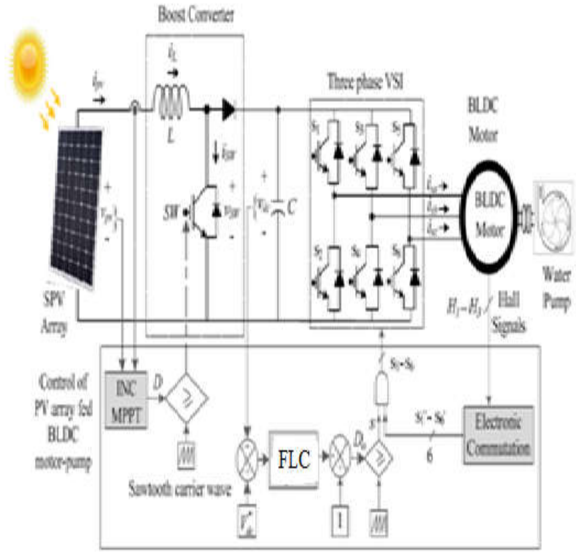

Fig.1 Configuration of PV array fed BLDC motor-pump.

PROPOSED SYSTEM DESIGN

The design of proposed water pumping system is based on the selection of BLDC motor and pump. A BLDC motor with 1.8 kW power rating is selected, as indicated in Table I, and the other stages viz. PV array, boost DC-DC converter and water pump are accordingly designed. The estimation of various parameters are elaborated in following sections.

TABLE I
Specifications Of BLDC Motor

Power, P	1.8 kW
Speed, N_r	3000 rpm
DC voltage, V_{dc}	310 V
Poles, P	4
Inertia, J	3.5 kg.cm^2
Current, I_s	5.64 A
Voltage constant, K_e	78 V/krpm
Torque constant, K_t	0.74 Nm/A
Phase resistance, R_s	2.3 Ω
Phase inductance, L_s	7.68 mH

A.Design of SPV Array

The SPV array of 2.24 kW maximum power rating is selected to feed the BLDC motor - pump of 1.8 kW power rating. The surplus power from SPV array is required to compensate the losses of converters and motor-pump. To estimate the other parameters, SPV array voltage is first considered according to the rated DC voltage of BLDC motor and optimum design of boost converter. It is selected such that the optimum duty ratio at MPP is at its minimum possible value, which results in a very good switch utilization, reduced voltage and current stress on power devices, reduced current rating of the inductor.

TABLE II
Design Of SPV Array

Solar PV Module	
Cells	36
Module voltage	21 V
Module current	5.6 A
Module MPP voltage, V_m	17 V
Module MPP current, I_m	4.75 A
Solar PV array	
MPP voltage, $V_{mpp} = v_{pv}$	238 V
Power at MPP, $P_{mpp} = p_{pv}$	2240 W
Current at MPP, $I_{mpp} = i_{pv}$	P_{mpp}/V_{mpp} = 2240/238 = 9.4 A
Numbers of modules in series, N_s	V_{mpp}/V_m = 238/17 = 14
Numbers of modules in parallel, N_p	I_{mpp}/I_m = 9.4/4.75 = 1.98 ≈ 2

B.Design of Boost DC-DC Converter

The MPP voltage of SPV array, v_{pv}= V_{mpp}= 238 V is boosted to the DC bus voltage of VSI, Vdc= 310 V. This offers a minimum duty ratio, D, resulting in the merits mentioned in previous section. Table III summarizes the estimation of inductor, L[4] and capacitor, C[1], where f_{sw} is the switching frequency of boost converter; I_L is the average inductor current; ΔI_L is ripple contents in the inductor current; ΔVdcis ripple contents in the capacitor voltage; I_{dc} is average current flowing through the DC bus of VSI; f and ω are the input voltage frequencies of BLDC motor in Hz and rad/sec. respectively.

TABLE III
Design Of Boost Dc-Dc Converter

Para-meter	Expression	Data	Value	Selected value
D	$\frac{V_{dc}-v_{pv}}{V_{dc}}$	v_{pv} = 238 V V_{pv} = 310 V	0.23	0.23
L	$I_L = N_p * I_m$ $L = \frac{D * v_{pv}}{f_{sw}\Delta I_L}$	D = 0.23 v_{pv} = 238 V f_{sw} = 20 kHz N_p = 2 I_m = 4.75 A ΔI_L = 10% of I_L	2.88 mH	3 mH
C	$\omega = 2*\pi*f = \frac{2*\pi*N_r*P}{120}$ $I_{dc} = P_{mpp}/V_{dc}$ $C = \frac{I_{dc}}{6*\omega*\Delta V_{dc}}$	P = 4 N_r = 3000 rpm V_{dc} = 310 V P_{mpp}= 2240 W ΔV_{dc}=2%of V_{dc}	309 μF	500 μF

C.Design of Pump

The water pump is designed on the basis of its power speed characteristics as,

$$K_p - \frac{P}{w_r^3}\frac{1800}{(2*\pi*3000/60)^3} = 5.8*10^{-5}W/(rad/sec)^3$$
(1)

PROPOSED SYSTEM CONTROL

The control techniques used at various stages of proposed water pumping system are divided into following three parts.

A.MPPT of Solar PV Array

In order to enhance the efficiency of a SPV array, MPPT is mandatory due to variable weather condition. The proposed system adapts an INC type of MPPT technique. This technique is less sensitive to the system dynamics and noise. The direct duty ratio control is used because it offers good stability characteristics and simplicity.

B.Electronic Commutation of Brushless DC Motor

The VSI which feeds the brushless DC motor is switched in a predefined sequence to perform the so called electronics commutation [1, 6]. It is a procedure of converting the three Hall signals into the six switching signals, s1….. s6 , . The three Hall signals are generated by the encoder, mounted on the shaft, according to the rotor position. The conduction of only two switches at a time results in a reduced conduction losses.

C.Speed Control of Brushless DC Motor-Pump

The speed control of BLDC motor-pump is accomplished by PWM switching of VSI while regulating its DC bus voltage. As illustrated in Fig. 1, the reference and sensed DC bus voltage, Vdc * and v_{dc} respectively, are compared and the error is passed through voltage regulator which is a PI (Proportional-Integral) controller. Further, the output value of voltage regulator is compared with the maximum possible value of duty ratio i.e. 1 to get the final duty ratio, Do. The comparison of Do and a high frequency carrier wave results in a PWM signal, s. Finally, the PWM switching signals for VSI are generated by modulating s1 , -s6 , with susing AND logic. The duty ratio of the switches of VSI, Do varies following the variation in weather condition, resulting in the BLDC motor-pump speed control. This proposed method of speed control completely eliminates the motor current sensing elements and requires only a voltage sensor at the DC link, resulting in a reduced complexity, cost and size.

FUZZY LOGIC CONTROLLER

In FLC, basic control action is determined by a set of linguistic rules. These rules are determined by the system. Since the numerical variables are converted into linguistic variables, mathematical modeling of the system is not required in FC.

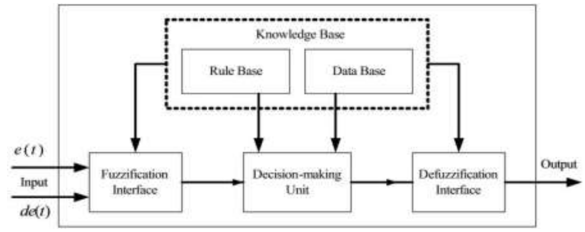

Fig.2 Fuzzy logic controller

The FLC comprises of three parts: fuzzification, interference engine and defuzzification. The FC is characterized as i. seven fuzzy sets for each input and output. ii. Triangular membership functions for simplicity. iii. Fuzzification using continuous universe of discourse. iv. Implication using Mamdani's, 'min' operator. v. Defuzzification using the height method.

Fuzzification: Membership function values are assigned to the linguistic variables, using seven fuzzy subsets: NB (Negative Big), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (Positive Medium), and PB (Positive Big). The Partition of fuzzy subsets and the shape of membership CE(k) E(k) function adapt the shape up to appropriate system. The value of input error and change in error are normalized by an input scaling factor.

TABLE IV: Fuzzy Rules

Change in error	Error						
	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PB	PM	PM	PS	Z
NM	PB	PB	PM	PM	PS	Z	Z
NS	PB	PM	PS	PS	Z	NM	NB
Z	PB	PM	PS	Z	NS	NM	NB
PS	PM	PS	Z	NS	NM	NB	NB
PM	PS	Z	NS	NM	NM	NB	NB
PB	Z	NS	NM	NM	NB	NB	NB

In this system the input scaling factor has been designed such that input values are between -1 and +1. The triangular shape of the membership function of this arrangement presumes that for any particular E(k) input there is only one dominant fuzzy subset. The input error for the FLC is given as

$$E(k) = \frac{P_{ph(k)} - P_{ph(k-1)}}{V_{ph(k)} - V_{ph(k-1)}} \quad (2)$$

$$CE(k) = E(k) – E(k-1) \quad (3)$$

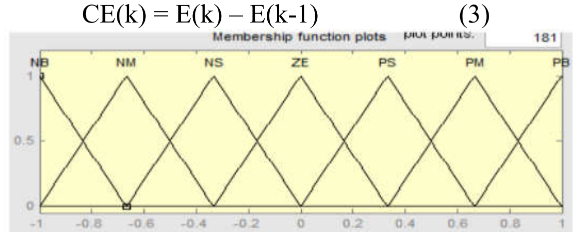

Fig 3 input error as membership functions

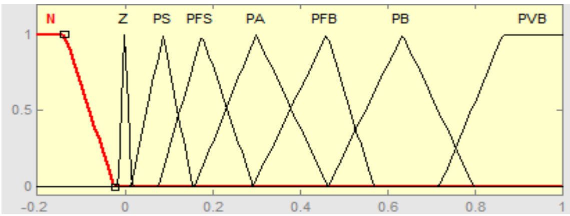

Fig 4 change as error membership functions

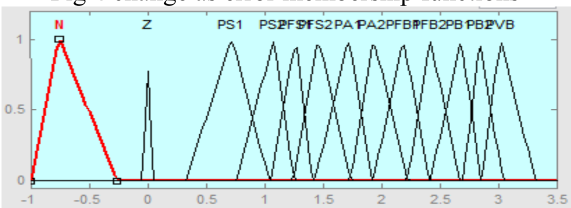

Fig.5 output variable Membership functions

Inference Method: Several composition methods such as Max–Min and Max-Dot have been proposed in the literature. In this paper Min method is used. The output membership function of each rule is given by the minimum operator and maximum operator. Table 1 shows rule base of the FLC.

Defuzzification: As a plant usually requires a non-fuzzy value of control, a defuzzification stage is needed. To compute the output of the FLC, „height" method is used and the FLC output modifies the control output. Further, the output of FLC controls the switch in the inverter. In UPQC, the active power, reactive power, terminal voltage of the line and capacitor voltage are required to be maintained. In order to control these parameters, they are sensed and compared with the reference values. To achieve this, the membership functions of FC are: error, change in error and output

The set of FC rules are derived from

$$u=-[\alpha E + (1-\alpha)*C] \qquad (4)$$

Where α is self-adjustable factor which can regulate the whole operation. E is the error of the system, C is the change in error and u is the control variable. A large value of error E indicates that given system is not in the balanced state. If the system is unbalanced, the controller should enlarge its control variables to balance the system as early as possible. One the other hand, small value of the error E indicates that the system is near to balanced state.

SIMULATED RESULTS AND PERFORMANCE ANALYSIS

The proposed water pumping system is simulated in MATLAB environment to demonstrate its starting, steady state and dynamic behavior subjected to the rapid variation in weather conditions.

A.Starting and Steady State Performances of Proposed System at 1000 W/m 2

The starting and steady state behavior of various indices of solar PV array, boost DC-DC converter and brushless DC motor-pump are presented in Figs. 6-8 respectively. As shown in Fig. 2, MPP of the SPV array is properly tracked, hence the SPV array is operating at 2240 W. The boost converter is operating in CCM and the DC bus voltage of VSI is regulated at 310 V as shown in Fig. 7. The peak voltage stress on the switch is 310 V. Similarly the peak current stress on the switch is observed as 9.5 A. Fig. 8 exhibits that the motor current is limited to permissible range at starting and the motor is running at its rated speed of 3000 rpm, pumping the water with full capacity.

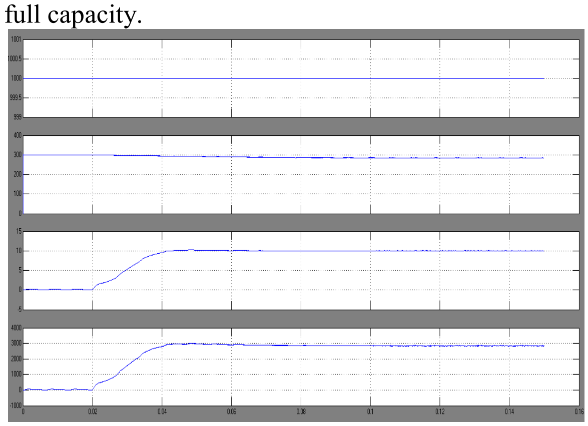

Fig.6 Starting and steady state performances of solar PV array

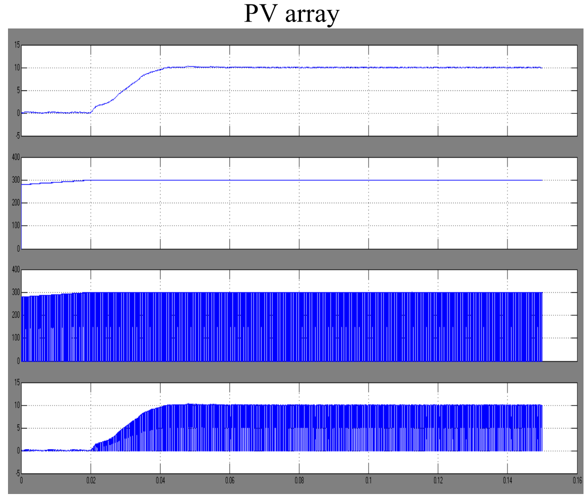

Fig.7 Starting and steady state performance of boost DC-DC converter

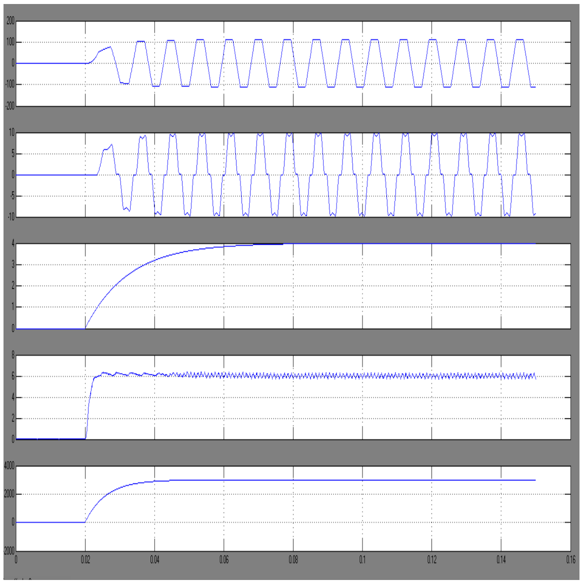

Fig.8 Starting and steady state performance of brushless DC motor-pump

B. Dynamic Performance of Proposed System

To demonstrate the dynamic behavior of proposed water pumping system, the irradiance is increased from 200 W/m 2 to 1000 W/m 2and reduced to 200 W/m 2 as shown in Fig. 9. The SPV array, irrespective of variation in irradiance, operates at its MPP. The boost converter operates in CCM and the DC bus voltage is regulated at 310 V as shown in Fig. 10. Following the variation in solar irradiance, speed of the motor is controlled and the motor draws corresponding current as presented in Fig. 11. The speed of motor at 200 W/m 2 is observed as 1310 rpm, a sufficient speed to pump some amount of water.

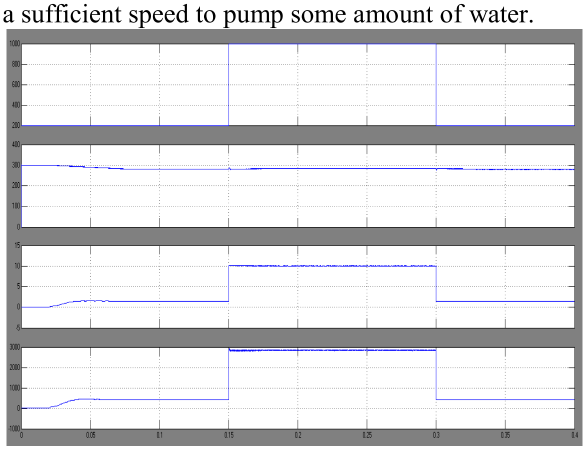

Fig.9 Dynamic performance of solar PV array

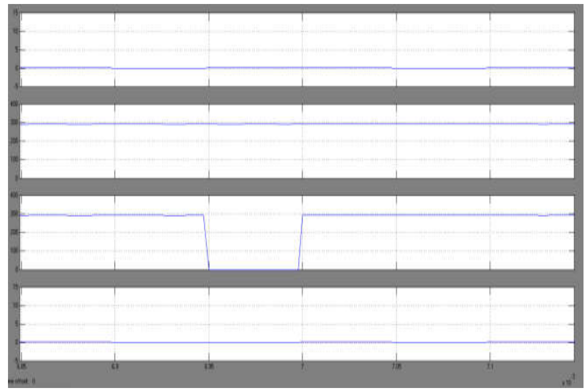

Fig.10 Dynamic performance of boost DC-DC converter

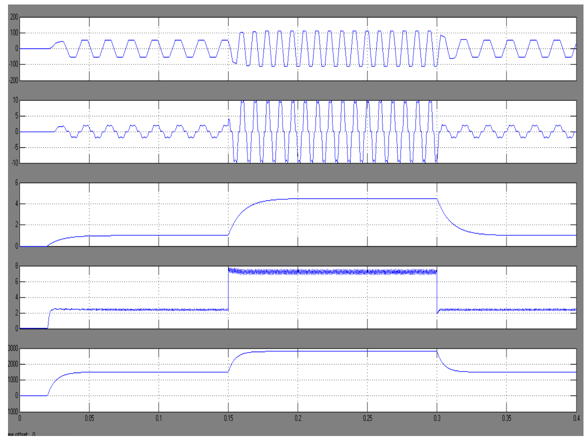

Fig.11 Dynamic performance of brushless DC motor – pump

CONCLUSION

The SPV Array sustained boost converter based BLDC motor driven water pump has been proposed and its appropriateness has been exhibited by analyzing its different performance indices utilizing MATLAB based simulation study. By using of Fuzzy logic controllers (FLC's) have the following advantages over the conventional controllers: they are cheaper to develop, they cover a wider range of operating conditions, and they are more readily customizable in natural language terms. A straightforward, proficient and efficient strategy for speed control of BLDC motor has been recommended, which has eliminate the total end of current sensing components. The best possible determination of SPV array has made the boost converter equipped for tracking MPP regardless of climate conditions. An ideal outline of the boost converter has been displayed. The sheltered beginning of brushless DC motor has been accomplished with no extra control. The coveted execution of proposed system even at 20% of standard solar irradiance has advocated it appropriateness for solar PV based water pumping.

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