

Solar Powered PV Stand-alone Based DC Motor Drive Using Fuzzy Logic Control

H. A. Mohamed¹, Maged N. F. Nashed²

¹Electrical Power and Machines Department, Division of Media Engineering,

International Academy For Engineering & Media Science, Six of October City, Giza, Egypt.

²Dept. of Power Electronic and Energy Conversion, Electronics Research Institute, Cairo, Egypt.

¹tamann2004@gmail.com, ²maged@eri.sci.eg

Abstract— Due to rapidly aging electric transmission power and distribution infrastructure, increased demand for energy, awareness of climate change and greenhouse gas pollution, and increased cost of fuel there is a need to produce and deliver energy more efficiently power. This paper attempts to provide a solution to these constraints through advancements in DC power architectures. The simulation study of PI controller for boost converter are presented in a stand alone photovoltaic energy scheme. Moreover the simulation for a DC motor is presented in photovoltaic generator. The complete system consists of an array of solar panels, a boost converter with PI and DC shunt motor with Fuzzy Logic controller (FLC) – as a voltage regulator. The Fuzzy Logic Controller is designed to deal with the system nonlinearity and its associated uncertainty. DC-DC converters are used to convert the unregulated DC input into a regulated DC output at desired voltage level. The duty cycle (D) of the converter is adjusted to obtain a constant level of voltage or a variable voltage rout in case of voltage regulator or maximum power respectively.

Keyword— PV, Boost Converter, DC shunt motor, PI and FL Controller.

I. Introduction

With the increasing concerns on air pollution and global warming, the clean green renewable sources of energy are expected to play more significant role in the global energy future [1-2]. Photovoltaic (PV) units are the most promising technologies for supplying load in remote and rural regions. The rapid depletion of fossil fuel resources on a worldwide basis has necessitated an urgent search for alternative energy sources to cater to the present day demands.

PV system refers to any array of cells containing PV material that converts solar radiation into direct current electricity. PV systems work by converting light into electrical power. This is achieved using a thin layer of semi-conducting material, most commonly silicon, enclosed in a glass or plastic casing. When exposed to sunlight the semi-conducting material causes electrons in the materials' atoms to be knocked loose. The electrons that are knocked loose then flow through the material to produce an electric current known as a DC, [3-5].

The use of PV systems as a power source for electrical machines is considered a promising area in PV applications due to the ongoing growth of PV-market. The dynamical and steady-state characteristics of PV-powered DC shunt motors at different solar

intensities, different loading conditions and different system controllers and configurations have been proposed. In this study, PV array are designed to provide their maximum power at the rated conditions of the DC shunt motors when the PV array is fully illuminated. The average value of the output voltage of the DC-DC converter is controlled by its duty ratio with an aim of keeping fixed voltage across the terminals of the motors at all realistic loading conditions and solar illuminations.

II. PV model

PV arrays are built up with series/parallel connected combinations of solar cells. PV cell equivalent circuit can be represented by a current source with a shunt diode D, shunt resistor R_{sh} and series resistor R_s as illustrated in Fig.1. Based on the Shockley diode equation, the electrical characteristic equation of the PV panel is given by the next eq. (1), [6-8].

$$V_{pv} = -0.411383 I_{pv} + \frac{1}{0.8083 T_r} \ln \left(1 + \frac{4.82 * \Phi - I_{pv}}{2.35 * 10^{-8}} \right) \quad (1)$$

where,

I_{pv} : Current of the PV cell.

V_{pv} : Voltage of the PV cell.

Φ : Solar insolation in watt/m².

T_a : Is equal to 273.15 °C.

T : Ambient temperature in °C.

T_r : Is equal to $(T_a + T) / T_a$

I_{ph} : Photocurrent

I_D : diode current.

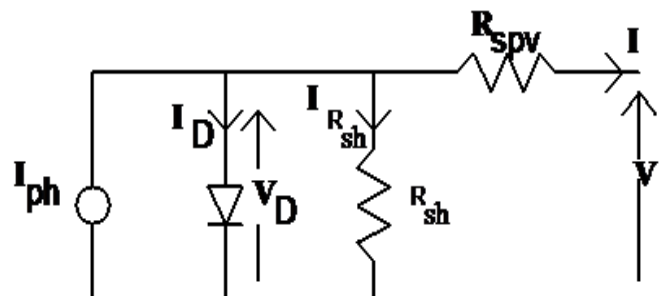


Figure (1): PV cell equivalent circuit

The Matlab/Simulink block model of the PV panel has been used. PV panels are connected in series/parallel. In this study, thirty six series cells have been connected to build up the PV panel and six series PV panels have been connected to build up

the PV array. Current (I) versus voltage (V) curves of the PV panel are depicted under different temperature level in Fig.2. While, Fig. 3 is shown the PV array under different insolation. In Fig. 4, the voltage-power characteristic of PV array is shown.

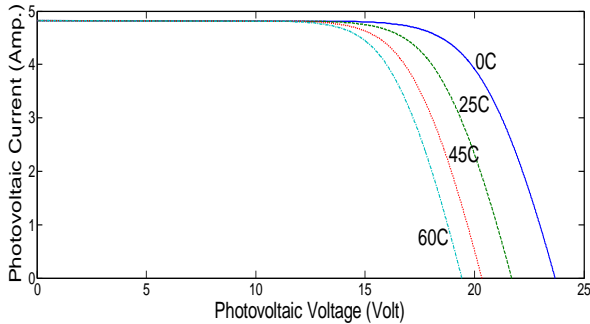


Figure (2): The PV panel I-V curves for various temperature levels at 1000W/m² irradiation level.

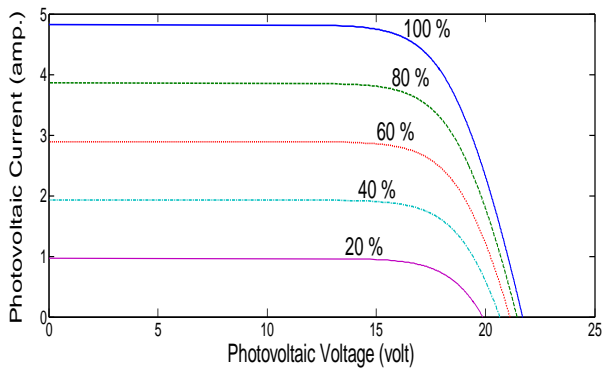


Figure (3): Relation between voltage and current of PV array at different insolation.

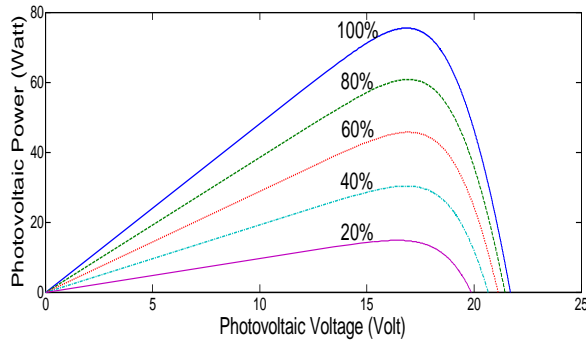


Figure (4): Relation between voltage and power of PV array at different insolation.

III. Modulation of the System

The system is consists of the PV array feeding a DC shunt motor via DC-DC boost converter. The motor are controlled by FLC in two loops (one for speed and other for current). Fig. 5 shows the PV array feeding a DC shunt motor via DC-DC boost converter.

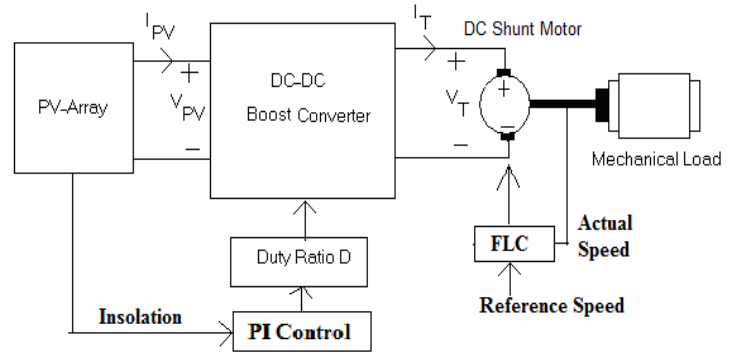


Figure (5): Block diagram for the system under study

a) DC Shunt Motor

In shunt motor, the field circuit is connected in parallel with the armature. Adjustable resistor R_{adj} is normally connected in series with the field circuit for speed control. DC shunt motor has the following dynamical model:

$$L_F \frac{di_F}{dt} = V_T - (R_F + R_{adj})i_F \quad (2)$$

$$L_a \frac{di_a}{dt} = V_T - R_a i_a - K\phi\omega \quad (3)$$

$$J \frac{d\omega}{dt} = K\phi i_a - T_L \quad (4)$$

Where L_F : field winding inductance,

i_F : field current,

V_T : terminal voltage

$R_F + R_{adj}$: total field resistance,

L_a : armature winding inductance,

i_a : armature current,

R_a : armature resistance,

K : constant related to the design of the machine,

ϕ : flux per pole,

ω : rotational speed of the rotor,

J : rotor and load moment of inertia

and T_L : load torque.

Eqs. (2), (3) and (4) represent the nonlinear dynamical behavior of a DC shunt motor including the nonlinearity of the magnetization curve of the ferromagnetic material of the machine.

b) Boost Converter

The boost converter is capable of providing an output voltage that is greater than the input voltage. It is also known as a step up converter and one switch is used. For which the continuous-time state-space-averaged representation, we used equation, [5]:

$$\begin{bmatrix} \dot{X}_1 \\ \dot{X}_2 \end{bmatrix} = \begin{bmatrix} 0 & -(1-D) \\ \frac{1-D}{L} & -\frac{1}{RC} \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} + \begin{bmatrix} \frac{1}{L} & 0 \\ 0 & \frac{1}{C} \end{bmatrix} \begin{bmatrix} U_1 \\ U_2 \end{bmatrix} \quad (5)$$

Where D is duty cycle
 X_2 is output voltage
 R, C, and L are the element part of boost converter.

Fig. 6 shows, the simulation blocks diagram of the boost converter analysis by MATLAB-SIMULINK. The Dynamic performance of boost converter with step change in PV insolation is shown in Fig. 7. The insolation changes from 0.6 to 1 at time 5 sec. Figure 8 is shown PV with change in ambient temperatures. The ambient temperatures changes from 25 to 35°C at time 5 sec.

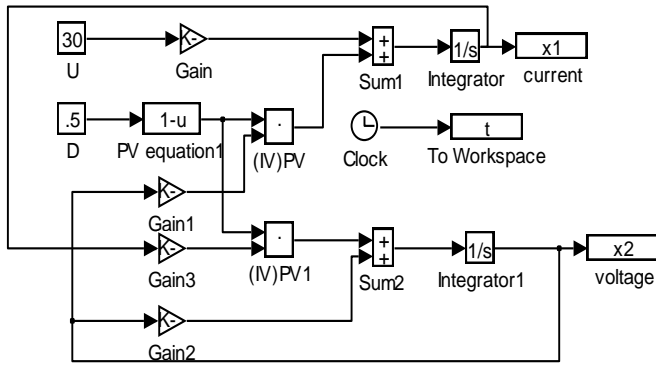


Figure (6): Simulation blocks diagram of the boost converter analysis

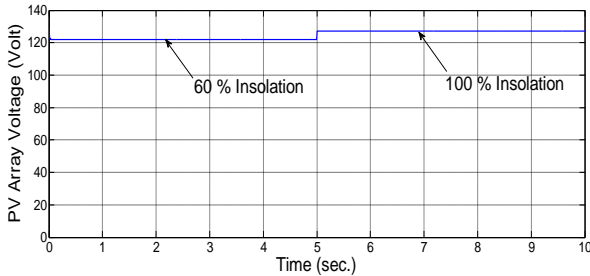


Figure (7): Output of PV array voltage with change in insolation levels

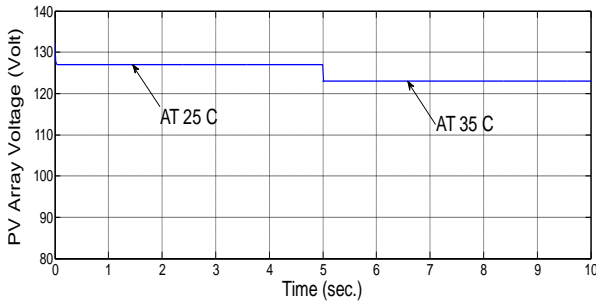


Figure (8): Output of PV array voltage with change in ambient temperatures

c) Fuzzy Logic control

The structure of the controller in FL in MATLAB Toolbox is presented in Fig. 9, [9, 10]. The FLC surface rules of input and output of control are shown in Fig. 10. Table 1 shows the Assignment Matrix/Table used for the fuzzy rules of FLC-controller. While, Fig 11 is shown the output value of rule during run simulation.

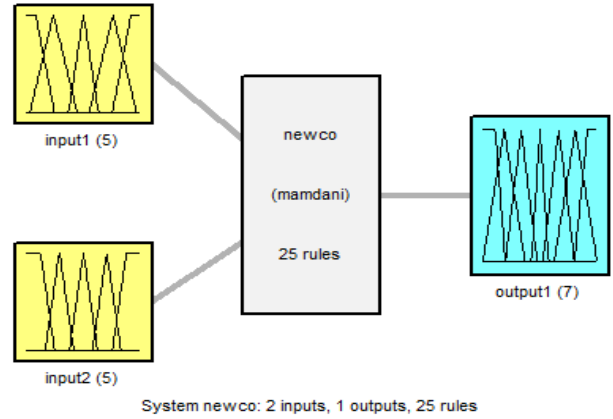


Figure (9): Structure of FLC in Matlab software program.

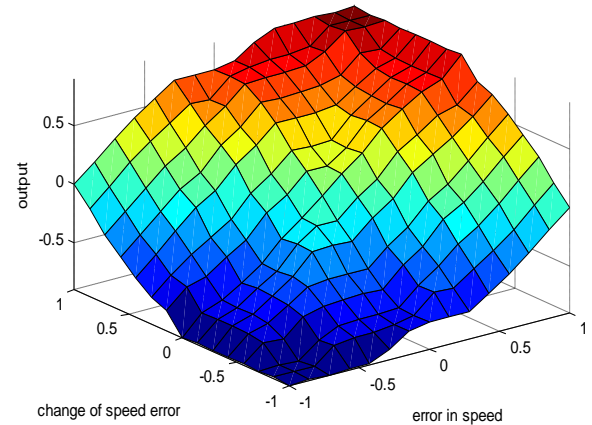


Figure (10): FLC surface rules for control motor, input1 is the error of speed or current output, input2 is the change of speed or current error, and output1 is the change of voltage of motor switching.

Table I: Rules of FLC

Error /Δ error	hn	ln	ze	lp	hp
hn	hn	hn	mn	ln	ze
ln	hn	ln	ze	ze	lp
ze	mn	ln	ze	lp	mp
lp	ln	ze	lp	lp	hp
hp	ze	lp	mp	hp	hp

Where: hn = negative high, mn = Medium negative, ln= negative low, lp = positive low, mn = Medium positive, hp = positive high, and ze = zero

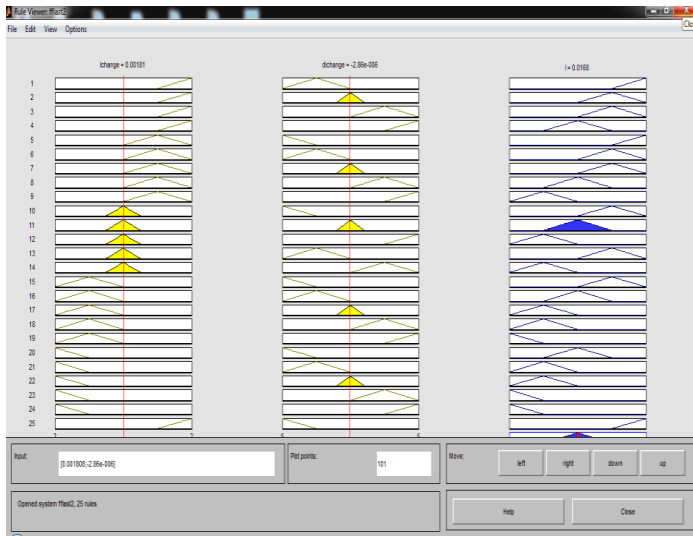


Figure (11): Output value of rule during run simulation.

The system under study consists of PV system acts as a voltage source for a connected DC shunt motor. The input of PV system is the ambient temperature and radiation, while the output is the DC voltage. The proposed controller based on Fuzzy algorithm is used to control the duty cycle of DC/DC converter and consequently the voltage and speed of DC shunt motor. Matlab/Simulink block model of overall system is shown in fig. 12.

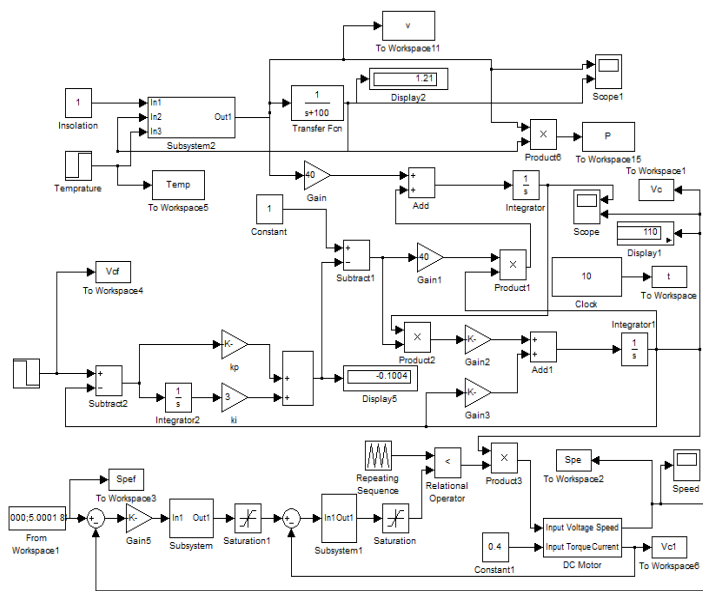


Figure (12): Matlab/Simulink block model of overall system

IV. Simulation and results

Fig. 13 shows the relation between actual and reference speed of DC shunt motor with change in reference speed from 1000 to 800 rpm. While, Fig. 14 shows DC shunt motor current with change in reference speed at 5 sec.

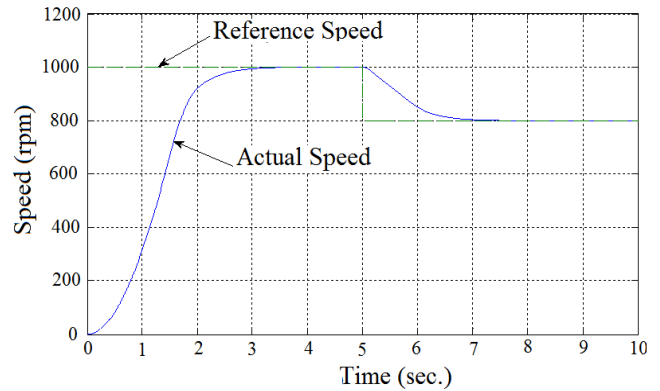


Figure (13): The relation between Actual and reference speed at change in reference speed.

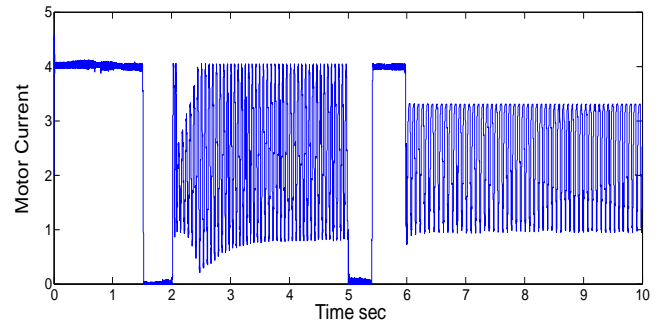


Figure (14): The curve shows the relation between DC shunt motor current and different ambient temperatures

V. Conclusions

During this paper, we have focused on the development of a stand-alone autonomous PV system. Modeling and simulation of PV isolated system are presented. The system is simulated in the Matlab/Simulink. The individual system performance of PV system is studied through simulation for solar insolation and temperature. The system is tested under different conditions at different level of insolation with change in load value. The proposed system performs well under different loading conditions. The duty cycle of this converter is decided by PI controller. This study presented speed control of DC Shunt motor fed directly through DC boost converter by PV generator. The control of speed and current are controlled by FLC. It was study voltage and current coupled with DC shunt motor at change in speed.

References

- i. H. Yang, W. Zhou, L. Lu, Z. Fang, "Optimal sizing method for standalone hybrid solar-wind system with LPSP technology by using genetic algorithm," *Solar Energy*, vol. 82, pp.354-367, 2008.
- ii. F. Ardakani, G. Dehkordi, M. Abedi, "Optimal sizing of a stand-alone hybrid system for south-west of Iran-case study," *24th International Power System Conference*, 2009.
- iii. Maged N. F. Nashed and Iman Edwar, "Wind/PV Hybrid of DC Electric Vehicle Charging Station with Bi-directional Converter" *World Engineering conference and Convention (WEEC 2015)*, Kyoto, Japan, 29 Nov. -2 Dec., 2015.
- iv. A. Kaabeche, M. Belhamel, R. Ibtouen, "Sizing optimization of grid in dependent hybrid photovoltaic/wind power generation system," *Energy*, vol. 36, pp.1214-1222, 2011.
- v. H. Suryatomo, T. Hiyama, A. Elbaset and M. Ashari: "Optimal design of wind-PV-diesel-battery system using genetic algorithm," *IEEJ Trans. PE*, vol., 129, pp.413-420, 2009.
- vi. H. A. Mohamed, "Approach Method to Evaluate the Output Voltage of Crystalline Silicon Photovoltaics at Different Cell Operating Temperatures" *International Journal of Engineering Research*, (IJER) <http://www.ijer.in/ijer/> Volume No.5, Issue No.5, May. 2016, pp: 411-414.
- vii. Abeer A. M. El-Hady, Shawky H. Arafa, Maged N. F. Nashed, and Salah G. Ramadan "Modeling and Simulation for Hybrid of PV-Wind system" *International Journal of Engineering Research (IJER)* <http://www.ijer.in/ijer/> Vol. 4, Issue No. 4, March 2015, pp: 178-183.
- viii. Maged N. F. Nashed, Mona Eskander, and Adel M Sharaf "A Stand Alone Robust PV-FC-Eleetrolyzer Utilization Scheme" *International Journal of Engineering Research (IJER)* <http://www.ijer.in/ijer/> Vol. 4, Issue No. 3, March 2015, pp: 145-150.
- ix. Maged N. F. Nashed "Transient Performance of a Hybrid Electric Vehicle with Multiple Input DC-DC Converter" *Journal of Power Electronics*, Vol. 3, No. 4, Korea, October, 2003 pp 230-238.
- x. Adel M Sharaf, Maged N. F. Nashed, and Mona Eskander, "A Switched Capacitor Compensator-Fuzzy Logic Controlled Scheme for Damping Load Excursions in PV-Powered DC Schemes" *International Electrical Engineering Journal (IEEJ)*, <http://www.ieejournal.com/>, Vol. 6, No. 9, Sept. 2015, pp. 1994-2002.