Characteristic Of Photovoltaic Generator For The Electric Vehicle

Naoui Mohamed, Flah Aymen, Mouna Ben Hamed

Abstract: Photovoltaic recharge systems were merged into different domains. In this work, the relation of the photovoltaic system and the electric vehicle is exposed and studied. The corresponding mathematical equations were exposed and explained. The efficiency of this recharge scheme is tested and compared for various external weather conditions. Two cases were simulated, one is related to the case where the vehicle is always in motion and the second case for the situation where the vehicle stop in several points in the running trajectory. A statistic for the system efficiency in relation to the car situation if it is in motion or stopped was given at the end of this study. The obtained results confirmed the benefit of using photovoltaic recharge application.

Index Terms: estimation, efficiency, electric vehicle, power, photovoltaic, renewable energy, simulation.

1. INTRODUCTION

Researchers were elaborated in order to use natural sources like solar, wind, geothermal, hydraulics and other natural and renewable sources. the exploitation of these sources was started firstly for feeding isolated houses by electric power was generally the first objective for using renewable energies as sources. different solutions and examples were exposed into the literature, which exploits solar energy, the wind energy or the hydraulic energy for feeding houses and isolated locations [1][2][3]. the efficiency of those systems was proved that it is possible to reduce the national factor of consuming the combustible energies as fuel and gas. effectively, the major of electrical energy suppliers in the major of the country in this world were desired to intercalate the renewable energies as other sources for given power [2],[4]. wind stations and photovoltaic stations were the two primary sources using renewable energies for those suppliers. some country as china can produce more than 110 gigawatts from solar power [5], [6] until 2020. also, Germany, Canada, and other countries can reach 1.5 % of the needed power from photovoltaic stations the best case is related to china where it is possible to touch 3% off the needed power from the photovoltaic stations.Also, the electric vehicle field was evolved using renewable energies. Solar energy was the best and the primary using a renewable energy source in this field. This due to the vehicle dimension and especially to the quick evolution of electronic devices, which make using the photovoltaic system more easy and rentable [7], [8].

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In the other hand, wind energy cannot be used for this system and this due especially to the unstable vehicle speed, which make the wind system for this case is not efficient. Also, the vehicle exigence weight, which is generally fixed and limited, make using this system difficult. Effectively, the relationship between the electric vehicle and solar energy was started in the recharge station and various examples were exposed as [8]and [9]. Well, various recharge station in the word were supplying by photovoltaic systems and a success story were proved the efficiency of this system for this phase. However, researchers found a solution for supplying electric vehicle using a photovoltaic system even the car is in motion. Special photovoltaic cells were installed on the vehicle in a various position in order to extract the maximum of solar power from all the possible vehicle surface especially, the vehicle roof, the doors of the vehicle and the bonnet of the VEHICLE [10].Various examples were exposed in the literature in which vehicle was covered by photovoltaic cells for producing energy. Toyota and Sono Motors were two automotive industry who commercialize hybrid electric vehicle using photovoltaic cells. However, the efficiency of this system was not proved only for some experimental versions with specific characteristics related especially to the vehicle weight and the vehicle aerodynamic system. In this context, this work exposes an analysis for the efficiency of the photovoltaic system in an electric vehicle and test its performance face various external effects in relation to the vehicle weight, the external climate, and the vehicle size. Therefore, this paper continent is divided into four sections. After a general introduction, the mathematical equations in relation to the electric vehicle were exposed. Then, the photovoltaic system is exposed and explained. Finally, and before the conclusion, the related results were exposed and interpreted.

2 ELECTRIC VEHICLE AND BASIC COMPONENTS

2.1 Modeling the MSAP motor

In order to arrive at a simpler formulation and to reduce the complexity of the model, we opt for the following hypotheses:

- Iron losses are neglected.
- The permeability of magnets is considered to be close to that of air.
- The excitation flux of the permanent magnet is considered constant.

Equations of voltages and flows:

$$[v_s] = [R_s][i_s] + \frac{d}{dt}[\varphi_s] \quad (1)$$

$$[\varphi_s] = [L_{ss}][i_s] + [\varphi_f] \quad (2)$$

$$[\varphi_f] = \varphi_{sf} \begin{bmatrix} \cos(\theta) \\ \cos(\theta - \frac{2\pi}{3}) \\ \cos(\theta - \frac{4\pi}{3}) \end{bmatrix} \quad (3)$$

Equation (3) being the flux expression generated by the magnets and the peak (constant) value created by the magnet through the stator windings.Note that equation (1) is non-linear and coupled, to eliminate this problem we adopt variable changes and transformations that reduce the complexity of the system. In this case we proceed to the transformation of Park, which consists in transforming the immobile windings (a, b, c) by windings (d, q) which turns with the rotor. Using Park's transformation, we pass real stator quantities (voltage, current flow) to their dummy components called the d-q components [11].

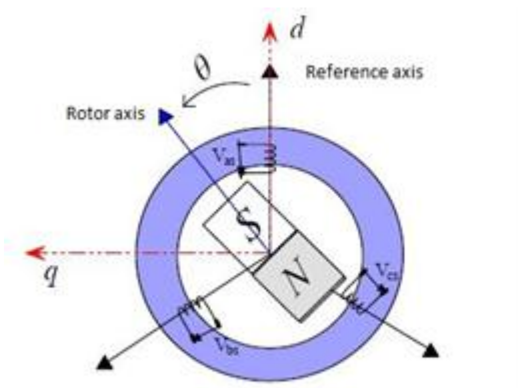

Fig. 1. *Diagram of a synchronous machine with permanent magnet*

$$[P(\theta)] = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos(\theta) & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ -\sin(\theta) & -\sin(\theta - \frac{2\pi}{3}) & -\sin(\theta + \frac{2\pi}{3}) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \quad (4)$$

$[P(\theta)]$ the matrix of the Park transforms which allows the passage of the stator quantities $[v_s]$, $[\varphi_s]$ and $[I_s]$ to their relative components $[V_{dq}]$, $[I_{dq}]$ and $[\varphi_{dq}]$. The application of Park's transformation to equation (1) gives after development:

The electric equations:

(5)
$$\frac{d}{dt} i_d = \frac{1}{L_d}\left(v_d - R i_d + L_q \omega_e i_q\right)$$

(6)
$$\frac{d}{dt} i_q = \frac{1}{L_q}\left(v_q - R i_q - L_d \omega_e i_d - \varphi_f p\Omega\right)$$

Electromagnetic torque expression:

$$C_e = p((L_d - L_q) i_d i_q + \varphi_f i_q) \quad (7)$$

Mechanical equations:

$$\frac{d}{dt}\Omega = \frac{1}{J}(C_e - f\Omega - C_r) \quad (8)$$

$$\frac{d\theta}{dt} = p\Omega \quad (9)$$

2.2 Battery Model

In the literature, various battery models were exposed each type can be presented by several methods as it is exposed in [12] and to [13]. The lithium-ion battery model given in Figure (2), in this figure, E0 is the standard voltage (V), Ebatt is the nominal voltage (V), Sel(s) is the battery mode and Exp(s) is the exponential dynamic voltage.

With:

$$\begin{cases} Sel(s) = 0 & \text{when discharging} \\ Sel(s) = 1 & \text{when charging} \end{cases}$$

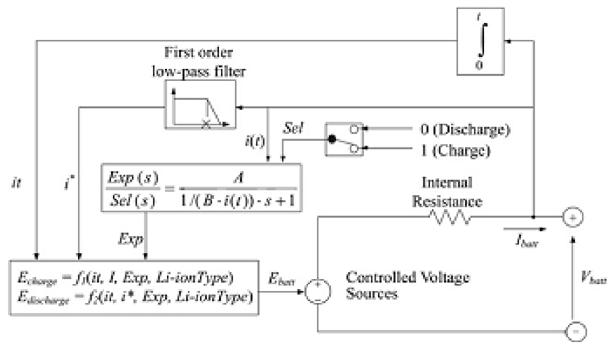

Fig. 2. *Equivalent electrical diagram of a battery element*

The charge/discharge model for the lithium-ion battery[14] can be described as follows:
Charge model (i* < 0):

$$E_{discharge} = E_0 - K_b \cdot \frac{Q}{0.1 \cdot Q + it} \cdot i^* - k_b \frac{Q}{Q - it} \cdot it + A \cdot e^{(-B \cdot it)} \quad (10)$$

Discharge model (i* > 0):

$$E_{charge} = E_0 - E_b \cdot \frac{Q}{Q - it} \cdot i^* - k_b \frac{Q}{Q - it} \cdot it + A \cdot e^{(-B \cdot it)} \quad (11)$$

Where i* is the current of low-frequency dynamic (A), it is the available capacity (Ah), Kb is the polarization constant (V (Ah)-1) or polarization resistance (Ω), Q is the maximum battery capacity (Ah), A is the exponential voltage (V), and B is the exponential capacity ((Ah)-1). The State of Charge (SOC) charge state is the ratio of the amount of electricity remaining at time t ($Q(t)$) to its nominal capacity (Q_{MAX}). SOC is often given in%.

$$SOC(t) = \frac{Q(t)}{Q_{MAX}} \cdot 100 \quad (12)$$

The capacity of the battery at time t is given by the equation below:

$$Q(t) = Q(0) - \int_0^t \eta_b \cdot I_b dt \quad (13)$$

2.3 Photovoltaic System and Its Components

As it is exposed in this paper, solar energy is used as the main power source for the electric vehicle model. Therefore, identifying the related components is necessary. So, the photovoltaic generator, the corresponding electronic converter, and the control method were exposed and detailed in this section.

In general, the Photovoltaic generator composes various photovoltaic cells placed in parallel and series. This photovoltaic cell can be represented by a simple equivalent circuit model as shown in Figure (3) [15]. We can observe that a photovoltaic cell behaves like a current source shunted by a diode.

The overall corresponding model consists of photocurrent, diode, shunt resistor, and series resistor as shown in figure (1).

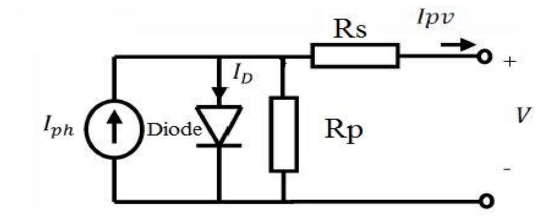

Fig. 3*. Circuit equivalent of a photovoltaic cell*

We can express the related mathematical equation for the current diode and the photocurrent as it is exposed in equation (14). We indicate by Rs and Rp the serial and parallel resistor respectively. VT is the thermal voltage. V is the outputted voltage.

$$\begin{cases} I_{pv} = I_{ph} - I_D \\ I_D = I_o \left[\exp\left(\frac{V + R_s I}{V_t a}\right) - 1 \right] - \frac{V + R_s I}{R_p} \end{cases} \quad (14)$$

After identifying the mathematical photovoltaic generator, the corresponding electronic converter will be shown and it is the corresponding scheme that will be presented. Several converters can be used as a boost and buck-boost converters. Each scheme is characterized by numerous advantages and problems [9]. Figure (4), exposes the relationship between those converters and the vehicle components as the electric motor, the photovoltaic system and the system of battery.

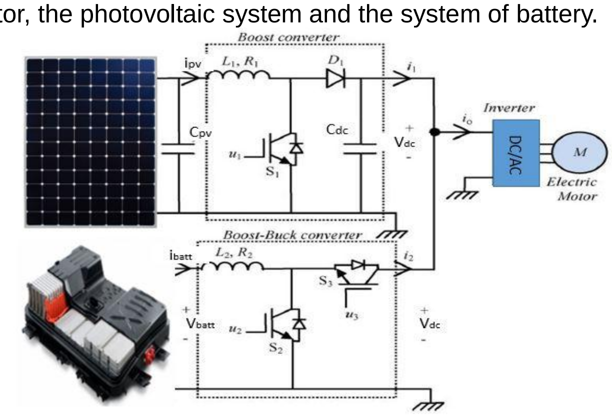

Fig. 4*. DC:DC converters inside the photovoltaic electric vehicle [16]*

The corresponding mathematical equations for the Boost converter can be exposed in equation (15) and (16). U1 is the control input coming from the PWM signal.

$$(15) \quad \frac{dI_{pv}}{dt} = -(1 - u_1)\frac{V_{dc}}{L_1} - \frac{R_1}{L_1} I_{pv} + \frac{V_{pv}}{L_1}$$

$$\frac{dV_{dc}}{dt} = (1 - u_1)\frac{I_{pv}}{C_{dc}} - \frac{1}{C_{dc}} i_1 \quad (16)$$

Where V_{pv} is the PV voltage, V_{dc} is the dc bus voltage, I_{pv} and i_1 are respectively, the inductor input current and the output current of the boost converter.For the Boost–Buck Converter, two modes can be operated. If (i_{batt} <0) this corresponding to the recharge mode. The discharge mode is for (i_{batt}> 0). The related mathematical equations are as follow.

$$\frac{di_{batt}}{dt} = -\left[k(1-u_2)+(1-k)u_3\right]\frac{V_{dc}}{L_2} - \frac{R_2}{L_2} i_{batt} + \frac{V_{batt}}{L_2} \quad (17)$$

$$i_2 = \left[k(1-u_2)+(1-k)u_3\right] i_{batt} \quad (18)$$

The constant K is calculated inside the power management algorithm and the principle of calculation is presented as follow:

$$k = \begin{cases} 1 & if\ i_{battref} > 0\ (Boost\ \text{mode}) \\ 0 & if\ i_{battref} < 0\ (\text{Buck mode}) \end{cases}$$

In this case, we concentrate on the boost converter as it is directly in relation with the photovoltaic system. The boost converter is also known as a step-up converter. It is typically used in the conversion of a low input voltage into a high output voltage. It transforms an input voltage source noted by V_A from continues form through an inductance L_1 placed in series, a controlled switcher and it is chosen a MOSFET here. A diode and two capacitors C_{pv} and C_{dc} placed in the input and the output of this scheme as it is exposed in figure (4), to another DC output signal with the highest voltage than the input one noted V_O.Refers to figure (4), a principle bloc noted MPPT placed on the gate input of the switcher MOSFET. This bloc is necessary, for controlling the overall converter. Several methods can be implemented inside this programmed bloc and the Disturbance and Observation (P&O) method is the widely used approach in the MPPT's[17]. This is due to its simplicity. It requires only measurements of tension and photovoltaic field current "V" and "I" respectively. This method makes it possible to find the maximum power point even during variations of illumination and temperature. Figure (5) shows the P&O algorithm principle.

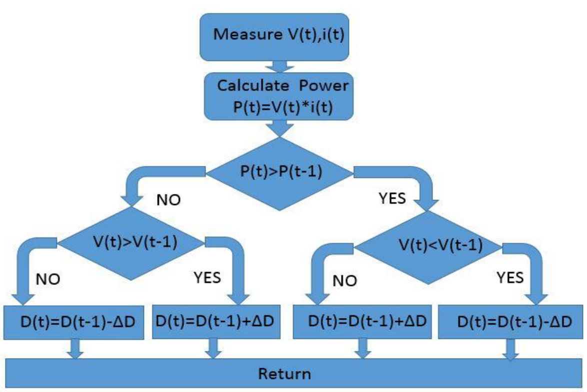

***Fig. 5**. P&O Algorithm structure*

3 SIMULATIONS RESULTS

In this part, we desire to expose the efficiency of solar system and the obtained results for various solar weather condition, for showing the photovoltaic system efficiency for an electrical vehicle case. Therefore, we desire firstly cite the simulations conditions applied in this work. The battery and the used PV system characteristics are summarized in table (1). In this simulation, we try to expose the different results related to the battery state of charge and the battery injected power for various acceleration form.

TABLE 1 CHARACTERISTICS OF BATTERY AND PV SYSTEM

Symbol	Quantity
Nominal discharge current	6.4A
Nominal voltage	200 v
Rated Capacity	26.5Ah
Internal resistance (R)	0.3Ω
Fully charged voltage	180v
Maximum of Power	390W
Maximum of voltage	4.2V
Maximum of current	5.96A
Serial cells	5
Parallel cells	3

The simulation phase was started under those conditions, the photovoltaic system contains five serial panels and 3 parallel lines. The outputted power can touch 5Kw. We have supposed that the panel temperature is 25°. The irradiation factor is between 1000 and 500.In this simulation, we try to expose the different results related to the battery state of charge and the battery injected power for various acceleration form. Two cases were exposed-Case 1 the case where the vehicle is always in movement.-Case 2 the case where the vehicle is stopped.Figure (6) presents the first case “case 1”, the battery SOC is always decreasing, however, we can observe that we have three decreasing forms. The best-case corresponds to the highest irradiation factor and the worst case is for the lowest irradiation factor.

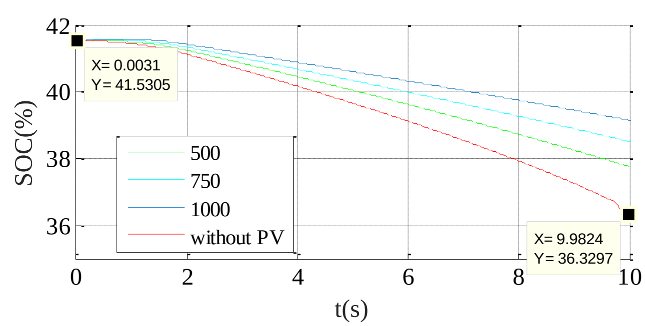

***Fig. 6**. Proportional Battery state of charge in three irradiation forms*

The efficiency of the photovoltaic system can be seen here. Basing on these results, we can save more than 0.3% of the battery SOC with this photovoltaic recharge system. The acceleration of the start starts immediately, the acceleration of the car changes on five acceleration 0.2, -0.1,0.5,0.3,0.5the corresponding motor power proportional to the acceleration also, however, we can observe that the generator power (PV) come decreasing only when the motor power passes 10000W. Figure (7) represents the variation of the generator power and motor power according to acceleration

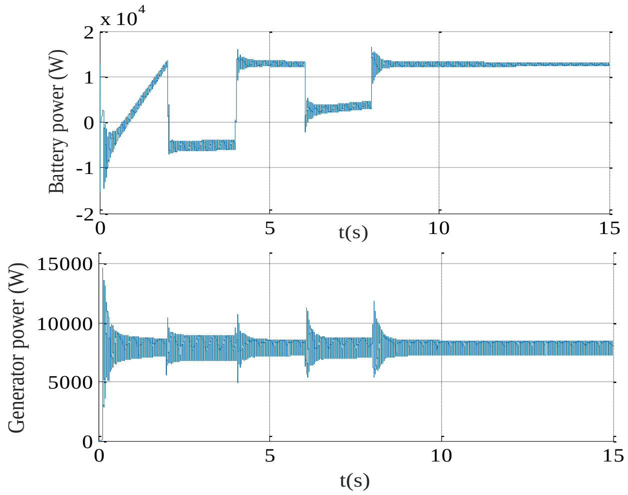

***Fig. 7**. the variation of the generator power and motor power*

The importance of the photovoltaic system when the car is in motion was seen in the first case, however, the situation will be different if the car is stopped, therefore, “case 2” presents the situation where the car is stopped and then it will be in movement.In the second case we have supposed that the car is stopped for 8 seconds, however, the photovoltaic recharge system is working. As it is exposed in figure (8), the car speed becomes different to zero only after height seconds. The efficiency of the photovoltaic recharge system can be seen in figure (9). The battery SOC increases rapidly and this is according to the irradiation factor. For the best weather case, we can guarantee 0.5% of battery SOC every 8 seconds if the car is stopped. For the low acceleration region, we can eliminate the injected battery power and using only the photovoltaic system for feeding the electrical motor and charging the battery at the same time. As it is exposed in figure (8) and figure (9), even the motor power is present, the SOC battery continues increasing. Here, we can observe that the worst case is for the less irradiation factor. The battery SOC comes decreasing before touching 5000W on the electric motor.

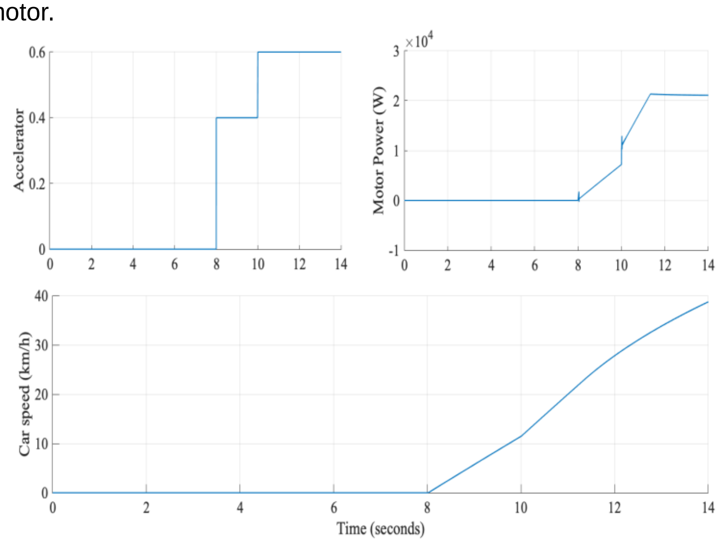

***Fig. 8.** Car speed and motor power parameters in relation to the acceleration reference form: “case 2”*

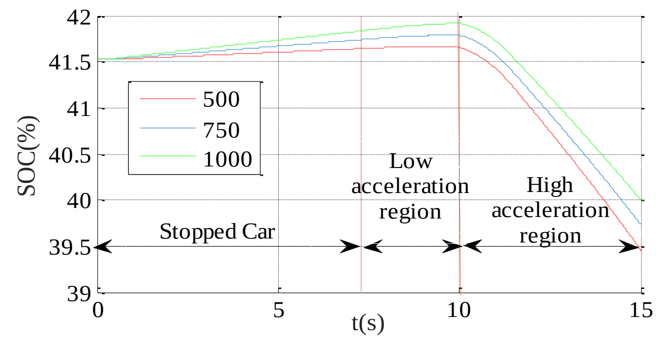

***Fig. 9.** Proportional Battery state of charge in three irradiation forms*

Refers to those results, we can conclude that the photovoltaic recharge system can increase the vehicle autonym. In figure (10), we expose the initial and the final battery state of charge in relation to the vehicle ruing mode. We can see that with this PV system, the energy gain is guaranteed and the vehicle autonym can be increased.

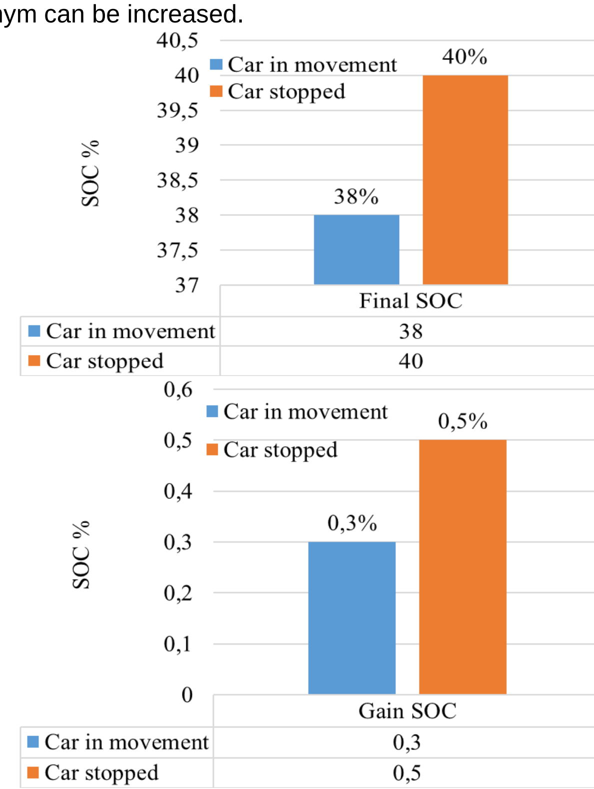

***Fig. 10.** State of charge status with and without PV system for the two cited cases*

4 CONCLUSION

The charging system for electric vehicles requires more and more researches for improving its efficiency and especially vehicle autonomy. The present contribution has a goal to confirm the efficiency of the photovoltaic system merged in an electric vehicle. The system efficiency applicate under various external weathers conditions. The obtained results affirm that the photovoltaic system can be efficacy only under the perfect weather condition. This makes high solar energy performance for normal electric vehicle very useful in a sunny country as the African countries.

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