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Design of a standalone hybrid power system and optimization control with intelligent MPPT algorithms

Bağımsız bir hibrit güç sisteminin tasarımı ve akıllı MPPT algoritmaları ile optimizasyon kontrolü

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Design of a Standalone Hybrid Power System and Optimization Control with Intelligent MPPT Algorithms

Highlights

- *Modeling of photovoltaic generator (PVG), Permanent magnetic synchronous generator (PMSG),*
- *Space vector pulse width modulation (SVM), Direct current boost converter DC/ DC, lithium type Battery.*
- *Using two Maximal Power Point Tracking (MPPT's), Perturb and observed (P&O), and gradient method.*
- *Genetic algorithm (GA's),for optimization the fuzzy logic controller MPPT (FLC).*
- *Wind Energy Conversion Systems (WECS),Synchronization to grid by high transformer 5.5 KV.*

Graphical Abstract

Schematic diagram of Hybrid System proposes robust control of wind-solar hybrid system by two methods, MPPT (P&O) by the fuzzy controller (FLC) optimized by GA's for PVG, and MPPT (gradient method) for PMGS, the both energy redundant by lithium type battery, connected to grid by inverter controlled by SVM.

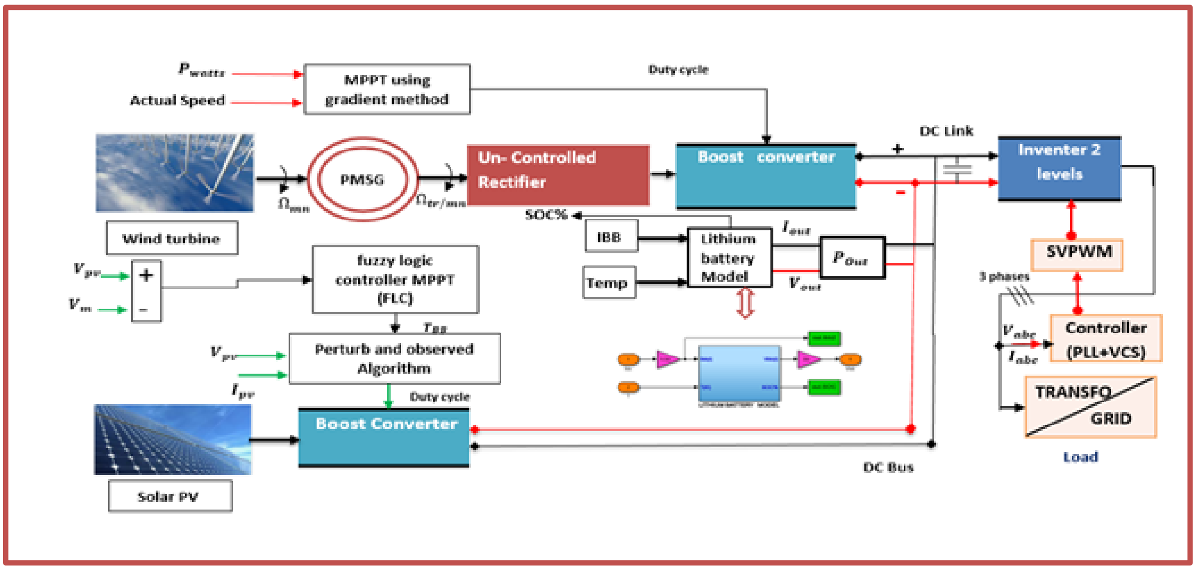

Figure. Schematic diagram of Proposed Hybrid System

Aim

This paper proposes a method for control and modeling of hybrid solar –wind system and optimization.

Design & Methodology

we use two algorithms, one is fuzzy MPPT (P&O) for PVG optimized by GA's, and the other is MPPT by gradient method for PMSG.

Originality

Despite the diversity of control and the non-linearity of the overall system, the robustness of the controllers ensures the feasibility of synchronization and reliability of the redundancy for two energy sources per battery system.

Findings

The framework allows optimization of the performance of system PV and wind power plants connected to the grid.

Conclusion

The simulation results obtained by MATLAB / Simulink proved the effectiveness of this strategy with encouraging performance which is manifested clearly when the suggested controllers employed and shed light on the performance of the hybrid system in an isolated network.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Design of a Standalone Hybrid Power System and Optimization Control with Intelligent MPPT Algorithms

Araştırma Makalesi / Research Article

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ABSTRACT

In this paper, a stand-alone hybrid power system has been proposed using both: photovoltaic generator (PVG) and permanent magnets synchronous generator (PMSG), integrated with a lithium-type battery connected to the DC bus. The improvement of performance and reliability of the overall system are guaranteed. For this aim, the efficiency of the PVG system can be enhanced firstly by using two MPPT's techniques, such as the Perturb and Observe (P&O) method and the Fuzzy Logic Control (FLC) approach. The Genetic Algorithms (GA's), using the principles of evolution, natural selection, and genetic mutation, are then introduced to address difficulties in the adjustment of the FLC gains. A lithium-ion battery model is presented to ensure stability and energy storage. Furthermore, the model of the wind energy conversion system (WECS) based on PMSG is presented. Hence, the control by the gradient method, allowing designing an MPPT based on the delivered power and mechanical speed of the generator. Both sources are connected to the grid via a two-level voltage source inverter controlled by Space Vector Modulation (SVM) technique. Finally, simulation results obtained using MATLAB / SIMULINK software proved the effectiveness of proposed control strategies with high performance which is manifested clearly when the suggested controllers employed and shed light on the performance of the stand-alone hybrid system.

Keywords: Photovoltaic generator (PVG), Permanent magnet synchronous generator (PMSG), MPPT (P&O) & gradient method's, SVPWM, Fuzzy logic controller (FLC).

Bağımsız Bir Hibrit Güç Sisteminin Tasarımı ve Akıllı MPPT Algoritmaları ile Optimizasyon Kontrolü

ÖZ

Bu yazıda, her ikisini de kullanan bağımsız bir hibrit güç sistemi önerilmiştir: fotovoltaik jeneratör (PVG) ve Sabit Mıknatıslı Senkron Jeneratör (PMSG), DC veriyoluna bağlı lityum tipi bir batarya ile entegre edilmiştir. Genel sistemin performansının ve güvenilirliğinin iyileştirilmesi garanti edilir. Bu amaçla öncelikle Perturb ve Observe (P&O) yöntemi ve Bulanık Mantık Kontrolü (FLC) yaklaşımı gibi iki MPPT tekniği kullanılarak PVG sisteminin verimliliği arttırılabilir. Evrim, doğal seleksiyon ve genetik mutasyon ilkelerini kullanan Genetik Algoritmalar (ga'lar) daha sonra FLC kazanımlarının ayarlanmasındaki zorlukları ele almak için tanıtılır. Stabilite ve enerji depolama sağlamak için bir lityum-iyon pil modeli sunulmuştur. Ayrıca, pmsg'ye dayalı rüzgar enerjisi dönüşüm sistemi (WECS) modeli sunulmuştur. Bu nedenle, gradyan yöntemiyle kontrol, jeneratörün teslim edilen gücüne ve mekanik hızına dayalı bir MPPT tasarlamaya izin verir. Her iki kaynak da, Uzay Vektör Modülasyonu (SVM) tekniği ile kontrol edilen iki seviyeli bir voltaj kaynağı invertörü vasıtasıyla şebekeye bağlanır. Son olarak, MATLAB / SİMULİNK yazılımı kullanılarak elde edilen simülasyon sonuçları, önerilen kontrolörler kullanıldığında açıkça ortaya çıkan ve bağımsız hibrit sistemin performansına ışık tutan yüksek performansla önerilen kontrol stratejilerinin etkinliğini kanıtlamıştır.

Anahtar Kelimeler: Fotovoltaik jeneratör (PVG), Sabit mıknatıslı

1. INTRODUCTION

In our modern society, energy has become a fundamental element due to our different demands in many domestic and industrial arias. This encourages us to always think of a new production of this energy. In a little over a century, energy with electricity as a modern form has taken a prominent place. Its production covers a third of the world's energy consumption, which is mainly concentrated in thermal machines where combustion is on a large scale with the direct emission of millions of tons of CO_2 causing high levels of pollution and global warming; and reduction of nature reserves [1].Renewable energy production techniques have evolved in terms of power and performance over the past decades. It has been used all over the world, especially in remote areas [2]. For economic reasons, the recent increase in oil prices obliges each country to choose the strategy of electric energy production, with an acceptable blow

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according to the possible wealth, and to exploit the sources of energy to the maximum. Renewables exist because its energy sources are the best means of meeting energy demand and reducing the price of energy produced by fossil sources. It also contributes to the reduction of CO2 emissions [1].

Wind and solar power are developed by many countries and were experiencing very strong growth. These are the largest and most promising renewable energy sources used in the world. Mainly because they are considered to be non-polluting and economically viable sources, which solar panels and Aero-generators can be used for conversion to Electric energy [1,3].

Energy Hybridization using two energy storage devices makes the system robust and efficient with perfect control and optimal management, thus the cost has been amortized for many years. Celik et al [4] proposed a technique to estimate the feasibility of a hybrid PV/wind system using synthetic weather data. Ding et al [5] showed that the hybrid energy system consisting of two or more renewable energy sources has the advantage of significant stability; the objective of their study is to provide lighting in a site where they have achieved it using wind and solar sources. Local data on wind and solar potential indicate that a feasible hybrid energy system could be planned. In-depth data analysis is fundamental to planning the desired system structure. Many fields are concerned with the applications of hybrid renewable energy production. Research [6] focused on the analysis of system performance and the development of efficient power converters, such as two-way inverters and maximum power point trackers [7,8].

Further research has focused on storage devices and battery management units [9]. Hybrid electric systems combine solar-wind systems to get the most out of the region's seasonal wind and solar resources; since wind is relatively more available during the winter months and at night, on the other hand, the sun is available especially during the summer months and the sunny winter days [10].

However, the energy storage system must have a power supply continuity to cover any shortfall in electricity generation from renewable energy sources. The available energy storage devices, such as, batteries, super capacitors, cannot simultaneously meet the high specific energy demand. Considering the current global energy mix, of renewable energy sources, such as solar and wind. Power, is ranked among the most popular sources, but the major drawback of this type of renewable energy lies in the design and construction of expensive energy park installations. However, the development of power electronics, which plays a main and very important role in the control and mastery of energy production, and in view of the availability of solar and wind resources, this makes it possible to exploit these energies to the maximum [11].

In particular, the cost of photovoltaic panels is reduced, which encourages investors to take charge. In particular that the availability of two sources of wind and solar energy, this gives us a sufficient argument to implement a hybrid source technology sufficiently mastered and managed to take major steps in the field of various applications and energy consumption, whose optimization of these systems will surely lead to a better use of solar and wind energy, in order to ensure the optimization control and operation of these systems which will surely lead to a better use of solar-wind energy [2].

A comparison has been made for many hybrid system optimization techniques [12] witch have been reported that could be applied to achieve a technologically optimal hybrid renewable energy system [13-16]. But these energies have a major drawback by the conversion rate of the energy source which acts directly on the site; the higher the cost is compared to the different forms of energy. Also, that PVG and PMSG behave like non-linear generators. This problem affects the optimum operating point called the MPP which is linked to two factors which are the temperature and the solar radiation and the variation of the load for the first and the second depends on the kinetic speed of the wind, and Beltz limits. Typically, in a variable speed wind power system, below rated wind speed, the electrical torque is controlled to drive the system at an optimum speed for maximum energy conversion [1,2].

In order to transfer the maximum energy supplied by the two wind-solar generators to the load, a MPPT is used. For the remedy of power fluctuation, and the redundancy of the two hybrid system sources, due to the load demand, the energy storage in the continuous bus (DC) is provided by lithium type battery. P&O technique is the most popular MPPT algorithm; however, the oscillation of the operating point of the system around its optimal position and a long its transient period limits this method. Therefore, several artificial intelligence techniques such as fuzzy logic, the artificial neural network are used to size these autonomous systems. The FLC is one of the very efficient controls used to control a mathematically unmodellable system [8]. Especially, in case of complexity of the non-linearity systems, considered as a black box due to the stochastic variations of the Control parameters. In particular, FLC remains a very good choice in terms of high dynamic response and better disturbance rejection. Which offers us a contribution in order to control a complex system without knowledge of its mathematical model and to adapt with as the model is to identify and to make the system more controllable. The only drawback of the FLC controller is the determination of the range of its inputs and outputs. The range of each input or the output differs from PVG to another. One effective intelligent search technique, a GAs [5] is used to optimize the FLC tuning gains MPPT for PVG. GA's are an adaptive algorithm for searching the global optimum solution for an optimization problem based on the mechanisms of natural selection process that mimics biological evolution. GA is used to calculate the optimal gains of each input and output, such an optimal FLC in the case of using a GA method to tune the FLC gains to achieve the desired in MPPT for PVG control loop and could provide ideal control performance.

In this paper, we use the boost for the hybridization of two sources taking into account the punctual monitoring of the MPPT in unfavorable climatic conditions (high temperature and in insufficient radiation). To ensure redundancy and perfect energy quality for the variable speed and Beltz limits for wind power, a passive filter connected to the AC network via a two-level inverter controlled by SVM is applied. Such ways to ensure the synchronization of two sources in the HTA network (load) [1].

Considering the spot tracking of the MPPT on the PVG side improve by two techniques to achieve an improvement control of the P&O and FLC tuning gains by the AGs in climatic conditions When converting variable voltage and variable frequency electricity to fixed frequency and fixed voltage power, the most common WECS configurations used with PMSG machines are three. A WECS PMSG with an appropriate gradient MPPT controller is created and built for the converter control, which depends on the converter configuration. For PMSG WECS, the MPPT controller algorithm is often implemented using one of three techniques. The gradient MPPT controller is a control system for controlling the rotor speed of a wind turbine by manipulating the control torque generated by the turbine.

The pitch drive of the blades causes a delay in response time, with the response acting in proportion to changes in wind conditions, such as turbulent and gusty winds, which impacts fuel efficiency and exerts mechanical stress on the wind turbine because of this delay. On the other hand, the speed of the generator rotor can be regulated electrically in order to maximize the amount of electrical energy produced. The development of MPPT-based control approaches was motivated by the goal of achieving the highest possible power coefficient. The output power of a generator in a variable speed wind power system is efficiently managed using converters based on power electronics in a very efficient manner. For both systems, the assembled regulators exhibit a good solution in terms of dynamic response and better disturbance rejection [1] the improvement of MPPT on the PVG side, we used two techniques to achieve an improvement control the P&O and FLC tuning gains by AG's. On the other hand, PMSG its MPP consists in the tracing the power of the turbine in other words gradient method. For both systems, the assembled regulators present a good solution in terms of dynamic response and better rejection of disturbances.

2. MODELLING OF GLOBAL HYBRID SYSTEM

The proposed configuration of hybrid power source (HPS) system in figure 1, which includes two renewable energy production subsystems, PV and Wind, and a battery storage system. The PV subsystem consists of photovoltaic panels and a DC/DC boost converter. The wind subsystem contains a wind turbine coupled to a permanent magnet synchronous generator (PMSG), AC/DC diode rectifier and DC/DC boost converter. The storage system is based on lithium-ion batteries and a bi-directional buck-boost converter. To optimize the system energy production, an MPPT and FLC controllers are developed based on two algorithms that allow controlling the two boost converters of both subsystems.

2.1 Modelling of Pvg

In this paper, we use two-diode model to simulate the photovoltaic cell, a PVG composed of 576 cells in series and 8 columns in parallel. The equivalent circuit of a (PVG) is given by Figure 2.

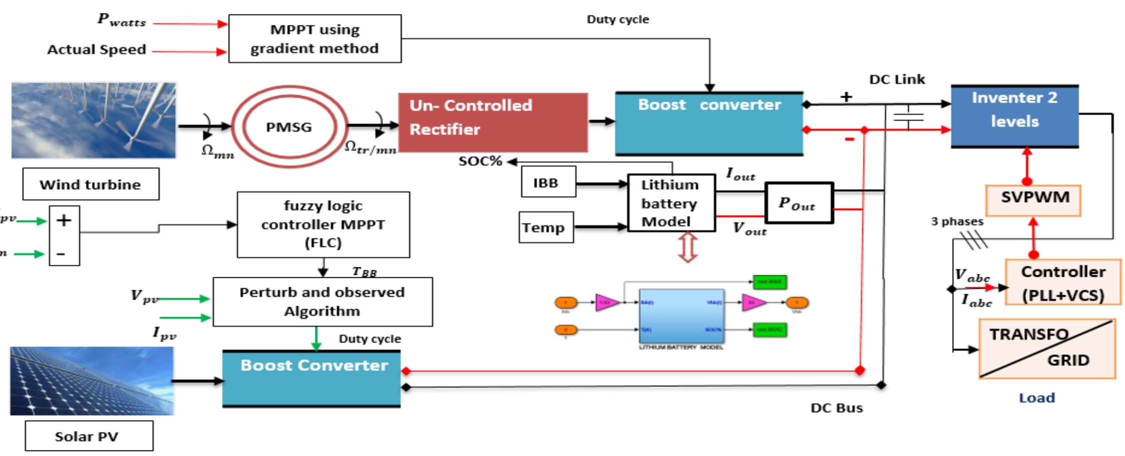


Figure 1. Hybrid power source (HPS) system.

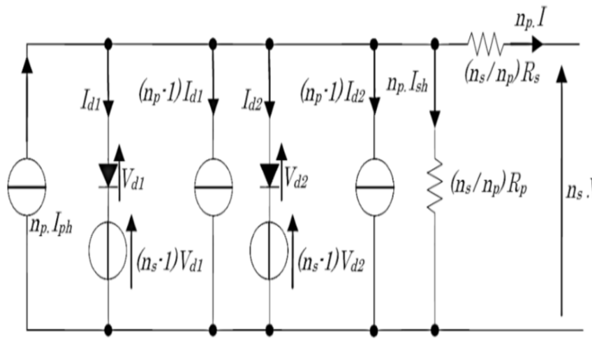


Figure 2. Equivalent circuit of a photovoltaic generator.

The equation of the current-voltage characteristic of a PVG can be written as follows [2], [17]:

$$I_g = I_{phg} - I_{s1g}\left[\exp\left(q\frac{(V_g+R_{sg}.I_g)}{n_s n_1 KT}\right) - 1\right] - I_{s2g}\left[\exp\left(q\frac{(V_g+R_{sg}.I_g)}{n_s n_2 KT}\right) - 1\right] - \frac{(V_g+R_{sg}.I_g)}{R_{pg}.I_g} \quad (1)$$

Figures 3 represent respectively the current and power characteristics in function of voltage, with T = 298K and E = 1000W/m2.

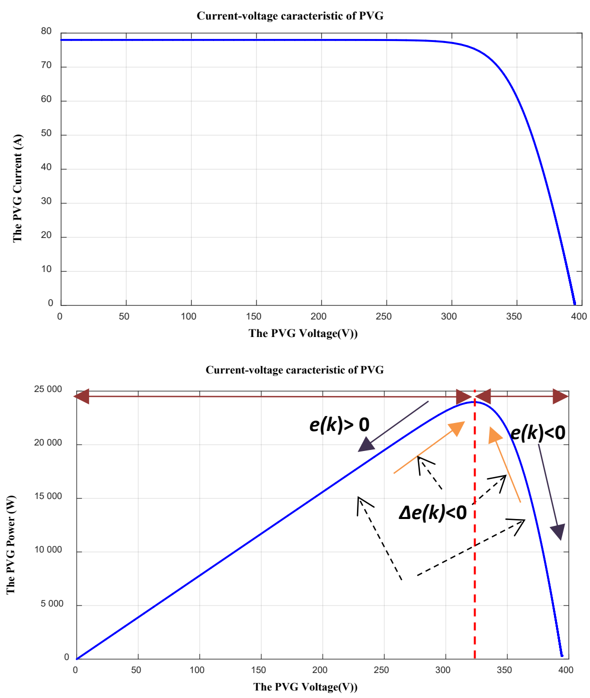


Figure 3. Current-voltage and Power-voltage characteristic of PVG.

This characteristic shows the progress of the power in function of the voltage [18]. The (MPP) we talked about above is very clear to recognize in this characteristic. This point is situated on the "knee" of this curve. It is noted that under partial shading conditions, in some cases it is possible to have multiple local maxima, and only one global maximum [19].

2.2 MODELLING OF THE WIND CHAIN

The wind generator consisting of a horizontal axis turbine coupled directly to PMSG connected to a DC bus via a rectifier [20] is shown in Figure 8. The modeling of these different organs will be examined in the following.

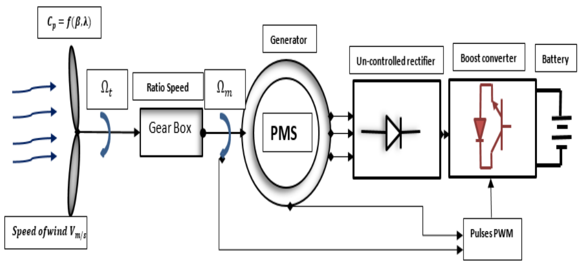


Figure 4. Wind turbine conversion chain.

CP power of the wind turbine is specific to each wing. This coefficient links wind power to wind speed [20].

$$Cp(\lambda,\beta) = A_1 * \left[\left(\frac{A_2}{\lambda_i}\right) - A_3 * \beta - A_4\right] * e^{\frac{A_5}{\lambda_i}} + A_6 * \lambda \quad (2)$$

With:

$\frac{1}{\lambda_i} = \frac{1}{\lambda+0.008*\beta} - \frac{0.035}{\beta^3-1}$, $A_1 = 0.5, A_2 = 116, A_3 = 0.4, A_4 = 5,\ A_5 = -21, A_6 = 0.0068$

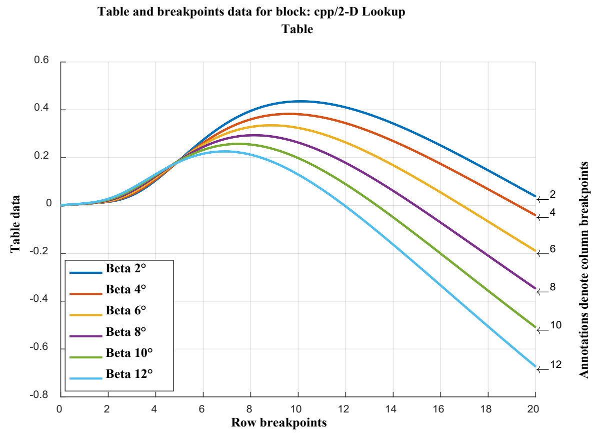


Figure 5. $Cp(\lambda,\beta)$ model choice, model choice with lockup table graph, model choice with lockup table data.

By the equation (2), the mechanical power C_p available on the shaft of an aero generator can be expressed by:

$$P_m = \frac{1}{2}.C_p(\lambda).\rho.\pi.R_t^2.V^3 \quad (3)$$

With $\lambda_n = \frac{\Omega_t.R_t}{V}$. Hence the expression of the couple is the following:

$$T_t = \left(\frac{P_m}{\Omega_t}\right) = \frac{R_t.P_m}{\lambda.V} = \frac{C_p}{\lambda}.\frac{1}{2}\rho.\pi..R_t{}^2.V^2 \quad (4)$$

The value of the torque coefficient is determined by the following formula [21]:

$$C_m = \left(\frac{C_p}{\lambda}\right) = \frac{2T_t}{\rho.S_t.R_t.V^2} \quad (5)$$

T_t : Torque of the wind turbine (Nm).

- **MODEL OF THE MACHINE SHAFT**

The model that characterizes the mechanical behavior of the wind chain is given by the following differential equation [21]:

$$C_{eol} = J_t \frac{d\Omega}{dt} + C_{em} + f_m \Omega \tag{6}$$

With

f_m: Coefficient of friction of the machine

J_t: Inertia of the turbine

C_{eol}: Static torque by the wind turbine.

C_{em}: Electromagnetic torque of the generator.

- **THE PMSG MODEL**

The PMSG is a nonlinear system; Park's transformation changes the stator windings into equivalent electric and magnetic windings, arranged along the axes d and q. The PMSG is modeled by the following equations [22]:

$$\begin{aligned} \frac{d\varphi_{ds}}{dt} &= u_{ds} + R_s i_{ds} - \omega_e \varphi_{qs} \\ \frac{d\varphi_{qs}}{dt} &= u_{qs} + R_s i_{qs} + \omega_e \varphi_{ds} \\ \frac{d\varphi_0}{dt} &= u_0 - R_s i_o \\ \frac{d\varphi_r}{dt} &= u_r - R_r i_r \end{aligned} \tag{7}$$

With:

$$\begin{aligned} \varphi_{ds} &= L_{ds} i_{ds} - \varphi_m \\ \varphi_{qs} &= L_{qs} i_{qs} \\ \omega &= \frac{d\theta}{dt} \end{aligned} \tag{8}$$

Where: U is the voltage, R is the resistance, i is the current, ω_e is the electrical angular stator speed, ω is the base angular speed in rad/sec, φ is the flux linkage, φ_m is the exciter flux of the PMSG, d and q indicate the direct and quadrature axis components. The instantaneous electrical power of the machine is [22]:

$$p(t) = {}^3/_2 \left(U_d i_d + U_q i_q \right) + 3\, U_0 i_0 - U_r i_r \tag{9}$$

Mechanical energy is therefore:

$$dw_{mec} = {}^3/_2\, \omega \left(\varphi_d i_q - \varphi_q i_d \right) dt = T_{em} \theta dt \tag{10}$$

With $d\theta = \frac{\omega}{P} dt$.

The electromagnetic torque is finally worth:

$$T_{em} = {}^3/_2\, P \left(L_d - L_q \right) i_d i_q + L_{ra} i_r i_q \tag{11}$$

- **THREE-PHASE RECTIFIER MODEL**

We consider a rectifier powered by a voltage source, charging on a battery assumed ideal. In the assumption of zero source impedance, the current is instantaneously set to its i_{dc} value when a diode becomes conductive (see figure 6) [23].

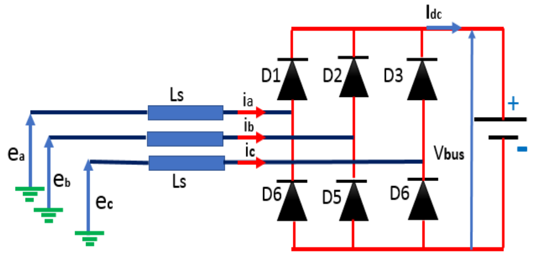


Figure 6. Diagram of a diode bridge three phases uncontrolled.

The equivalent scheme during a conduction sequence (eg, phases 1 and 2) is shown in figure 7. From the equivalent diagram, and applying the law of meshes and nodes, we can write:

$$\frac{dI_{dc}}{dt} = \frac{1}{2L_s} \left(V_a - V_b - V_{bus} \right) \tag{12}$$

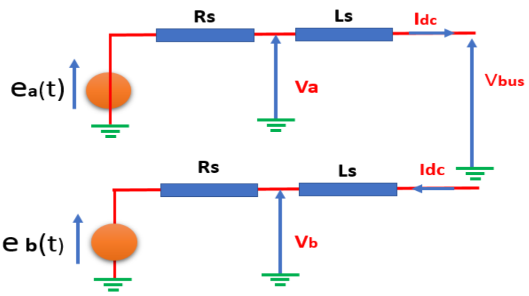


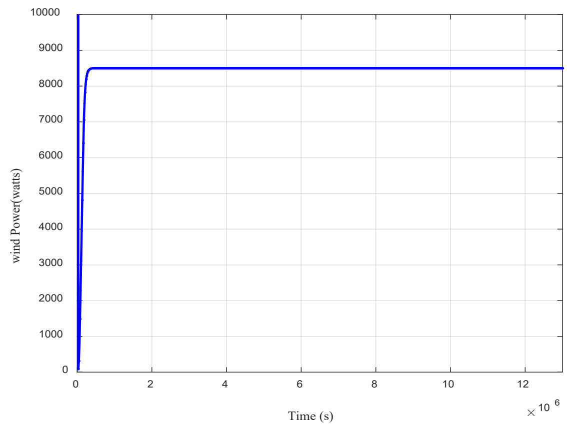
Figure 7. Equivalent diagram of a sequence in normal conduction.

- **WIND POWER PRODUCED**

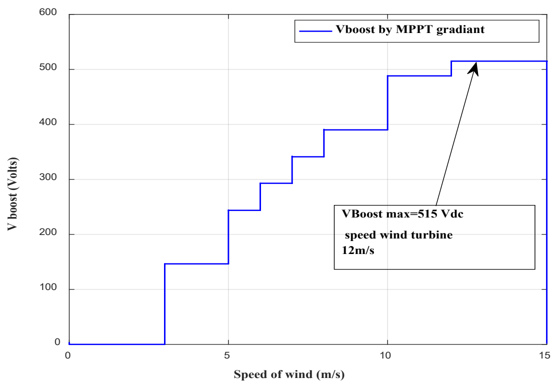
The wind turbine found at the market is characterized by its nominal power P_n , the electrical power at the output of the generator, this power is supplied when the wind blows at the nominal speed V_n Once the distribution functions of the wind speed are found. The average power produced by the wind turbine is given by [24]:

$$P_{A.wind\ turbine} = P_n \left[\frac{\left[e^{\left(-\left(\frac{V_d}{c}\right)^k\right)} - e^{\left(-\left(\frac{V_n}{c}\right)^k\right)} \right]}{\left(\frac{V_d}{c}\right)^k - \left(\frac{V_n}{c}\right)^k} - e^{\left(-\left(\frac{V_c}{c}\right)^k\right)} \right] \tag{13}$$

The variation of the power produced as a function of the wind speed and the variation of voltage Boost by speed wind turbine are shown in Figure 8.



(a)



(b)

Figure 8. (a): Power of the wind turbine depending on the wind speed, (b): Variation of voltage Boost by speed wind turbine.

2.3 BOOST CONVERTER MODEL

The power produced by a PV changes and depends heavily on two main factors: irradiation and temperature. The maximum power that a panel can produce changes too, and therefore a tracking system based on DC-DC converters is needed. The choice of Buck or Boost converter to track the MPP depends on the situation of the intersection to that of the MPP. In our system the boost converter is used as the intersection is situated on the right of the MPP [3]. The boost electric circuit is shown in figure 9.

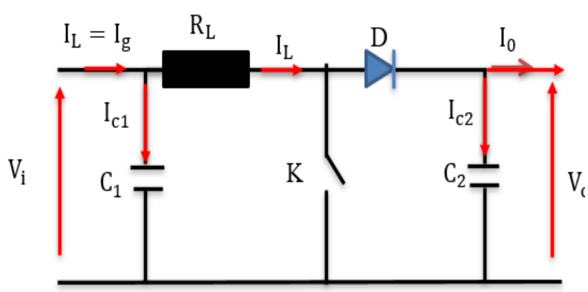


Figure 9. Electrical circuit of a boost converter.

The dynamic model of the Boost converter is:

$$\begin{cases} i_L = i_i - C_1 \dfrac{dv_i}{dt} \\ i_0 = (1-D)i_L - C_2 \dfrac{dv_0}{dt} \\ v_i = (1-D)v_0 + R_L i_L + L \dfrac{di_L}{dt} \end{cases} \tag{14}$$

- **STEADY-STATE STUDY**

Replacing the derivatives of signals with zeros, and the converter signals with their average quantities [25], we obtain:

$$\begin{cases} I_i - I_L = 0 \\ I_0 - (1-D)I_L = 0 \\ V_i - (1-D)V_0 - R_L I_L \end{cases} \tag{15}$$

- **CONVERSION RATIO**

Using the relations (15), we can calculate the conversion ratio ${V_o}/{V_i}$, [25].

$$M(D) = \frac{V_0}{V_i} = \frac{1}{(1-D) + \frac{R_L I_L}{V_0}} = \frac{1}{1 + \frac{R_L I_0 (1-D)}{(1-D)^2 V_0}} = \eta \frac{1}{(1-D)} \tag{16}$$

During the operation of a PVG, the MPP can be changed due to changes of weather or load; hence a controller is needed to follow the MPP. In fact, the research of this MPP must be done automatically. This is quite possible by using one of the approaches known as Maximum Power Point Tracking MPPT [25].

2.4 BATTERY BANK MODEL

The most commonly used for PV systems is the electrochemical storage battery. The Battery bank model used in our simulation is based on the kinetic model developed by the University of Massachusetts [26]. The capacity of battery is:

$$I_{MR}(t) = I_{BB}(t) - I_{GAZ}(t) \tag{17}$$

$$C_B(t) = \int_{t=0}^{t} I_{MR}(t) * dt + C_{B.i} \tag{18}$$

IMR : Main battery reaction current (A)
IBB : External battery current (A)
IGAZ : Battery gassing current (A)
TBB : Battery Temperature (K)
VB : Battery charging voltage (V).
CB : battery capacity (Ah)
CBI : Initial battery capacity (Ah)

The battery voltage as a function of SOC is given by [26]:

$$U_{bat} = U_{100\%} - \Delta U * (1 - soc) \tag{19}$$

$$soc = Q_{bat}/Q_{nom.bat} \tag{20}$$

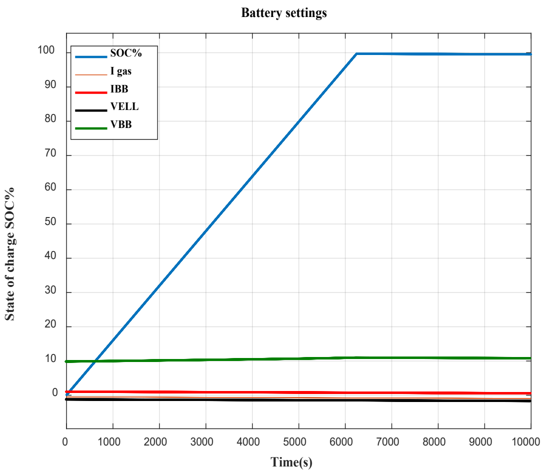


Figure 10. Battery settings.

3. MPPT CONTROL SYSTEM

3.1 Mppt Method For Pv System

For the PV system MPPT, we propose a hybrid strategy based on the combination of techniques figure 11: Perturb and observe (P&O), Fuzzy Logic Control (FLC) and FLC controller tuning using GA. The P&O algorithm track the MPP delivered by the system PV. It uses power-feedback control technique where the output power of the PVG is tracked continuously and compared with the previous power.

The power difference is then used as a parameter for the microcontroller to produce a PWM signal with a set of duty cycle. PWM signal is used to control the switch K in the boost converter DC/DC.

Figure 12 shows the flow chart of the power-feedback control technique.

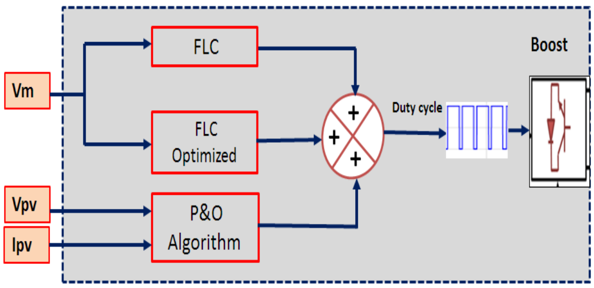


Figure 11. Block diagram of proposed MPPT approach for PV subsystem.

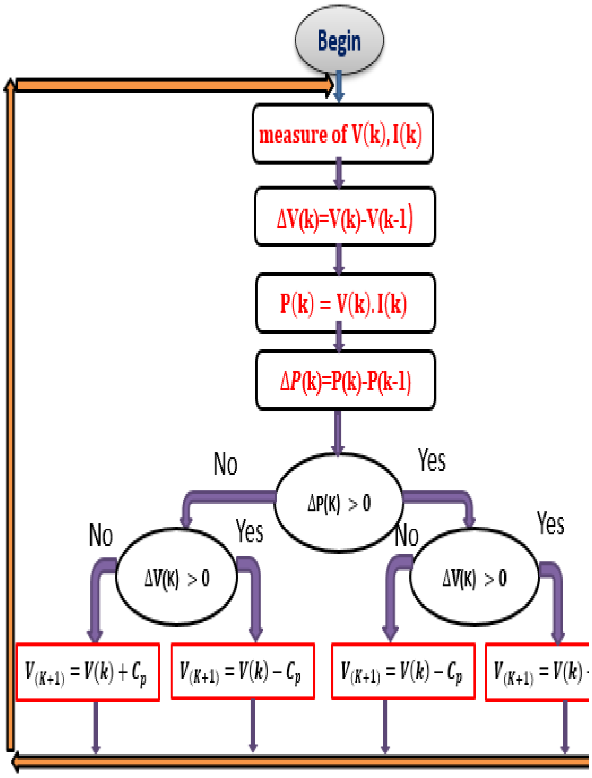


Figure 12. The P&O flow chart.

- **FUZZY LOGIC CONTROLLER**

This method uses a controller based on fuzzy logic applied to a boost converter. The structure of a FLC can be realized as a traditional PI controller, where the error e and its variation Δe are considered as input linguistic variables and the duty Ratio change Δe is considered as the output linguistic variable [27].

$$e(k) = \frac{P_{ph}(k) - P_{ph}(k-1)}{V_{ph}(k) - V_{ph}(k-1)} \tag{21}$$

$$\Delta e(k) = e(k) - e(k-1) \tag{22}$$

Where: $P_{ph}(k)$: PV Instantaneous power.
$V_{ph}(k)$: PV Instantaneous voltage.

The selected inputs and output memberships for the FLC are given in the figure 13; the method chosen for the calculation of the output variable is the centre of gravity for the défuzzification to that of the function of belonging, the rule base controlling the defuzzified output according to the fuzzified input is given in Table 1[18,19].

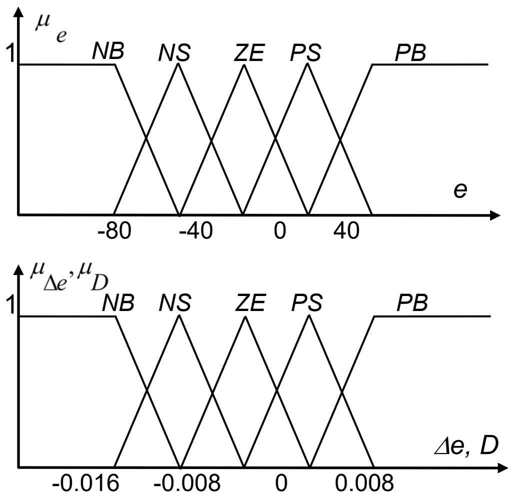


Figure 13. The memberships function with five fuzzy subsets.

Table 1. FLC Rules base.

e \ Δe	NB	NS	ZO	PS	PB
NB	ZO	ZO	PB	PB	PB
NS	ZO	ZO	PS	PS	PS
Z0	PS	PS	ZO	ZO	NS
PS	NS	NS	NS	ZO	ZO
PB	NB	NB	NB	ZO	ZO

- **FLC CONTROLLER TUNING USING GA**

In the case of using a GA method to tune the FLC gains in the speed control loop, the fitness function used to evaluate the individuals of each generation can be chosen to be the integral time of absolute error [27]:

$$\mathrm{ITAE} = \int e(t)dt \tag{23}$$

The GA searches for the optimal setting of the PI speed controller gains, which minimizes the fitness function (ITAE). This last is very important in order to evolve the GA factor. To reduce programming complications, we use GADS TOOLBOX in MATLAB to generate a set of initial random parameters [27]. According to a well-finished research, the parameters will be adapted to improve the perfect appearance of the response. Each chromosome represents a solution to the problem and therefore consists of three genes: $[K_p, K_i]$.

The following steps can summarize the optimization of the controller parameters procedure [27]:

- Randomly generate an initial population;
- Rate this population;
- Apply genetic operators (selection, crossover, mutation);
- Evaluate the new population created by the genetic operators;
- Repeat the procedure for a given number of generations;
- Choose the best individual of the last generation;
- Use a local search simplex method to complete the operation optimization achieved by the GAs.

Table 2. Summarizes the GA parameter setting

Population size	100
Maximum generation	200
Selection	uniform stochastic
Crossover probability	80%
Mutation probability	0.1%

3.2 MPPT METHOD FOR WIND SYSTEM

Ratio ΔP / ΔΩ = 0 if ΔP = 0, The MPPT by gradient technique calculates the reference speed by measuring the power output of the wind energy conversion system for the adjustment of the system operating point. The as the rotor speed is set to be proportional to the power change; that ΔP, ΔΩ ≈ 0. The flow chart of the proposed algorithm is as shown in Figure 16 [28].

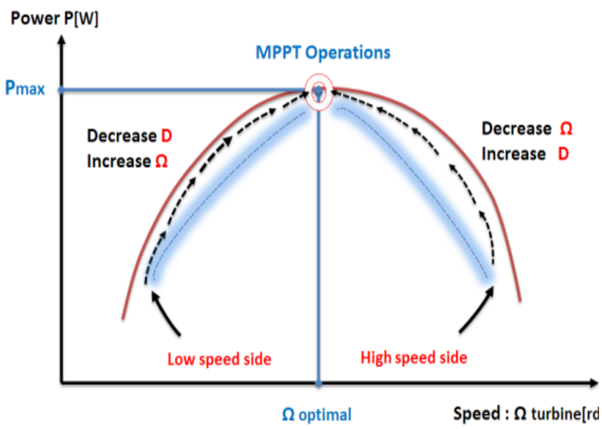


Figure 14. Wind power curve for an arbitrary wind speed.

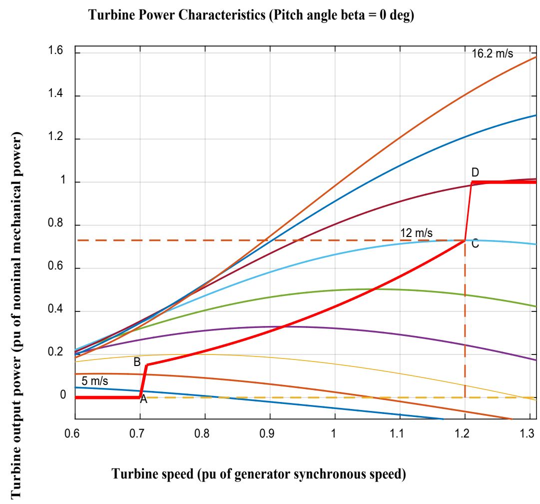


Figure 15. Turbine output power characteristics for the pitch angle beta (β).

The algorithm calculates the reference speed by measuring the power output of the wind energy conversion system for the adjustment of the system operating point. The ratio ΔP / ΔΩ = 0 if ΔP = 0, as the rotor speed is set to be proportional to the power change; that ΔP, ΔΩ ≈ 0. [28].

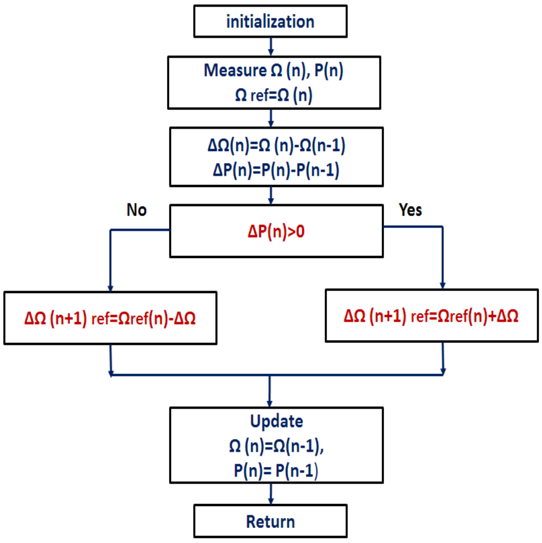


Figure 16. Flowchart of WECS algorithm.

4. CONTROL OF INVERTER TWO LEVEL'S USING SPACE VECTOR MODULATION

The commutations of the OCR's as follows: [1 0 0], [1 1 0], [0 10], [0 1 1], [0 0 1], [1 0 1], and the vectors inactive are [000] or [111].The three phase line voltages produced are V_{ab}, V_{bc} and V_{ca} and these three-line voltages are related to the switching vectors as given by [24]:

$$\begin{bmatrix} V_{ab} \\ V_{bc} \\ V_{ca} \end{bmatrix} = V_{dc} \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (24)$$

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = {}^{V_{dc}}/_{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (25)$$

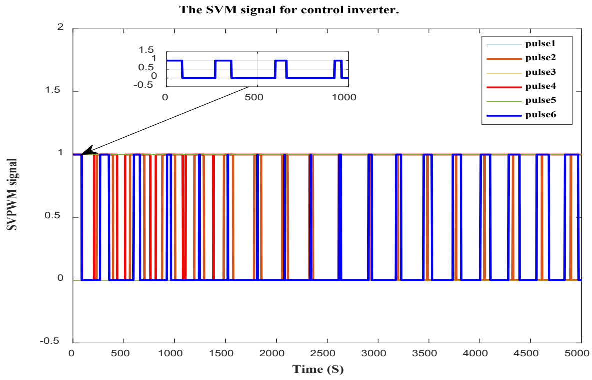


Figure 17. The SVM signal.

5. SIMULATION RESULTS

5.1 Performances Of Photovoltaic Generator

The figures that follow represent the performances of our photovoltaic generator using MATLAB/Simulink. All the characteristics are obtained using a fast-varying load. In order to view the robustness of the two control algorithms MPPT P&O and fuzzy, we vary the illumination suddenly and the temperature.

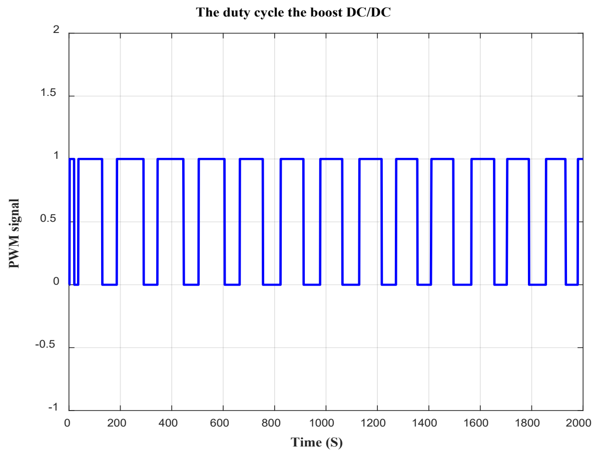


Figure 18. The duty cycle the boost DC/DC.

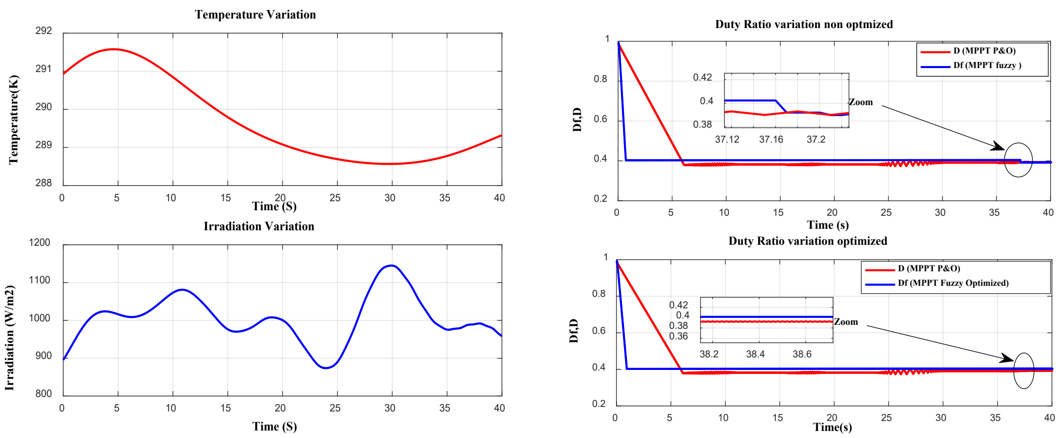


Figure 19. (a) . Variation of irradiation and temperature. **(b).** Duty Ratio Variation optimized.

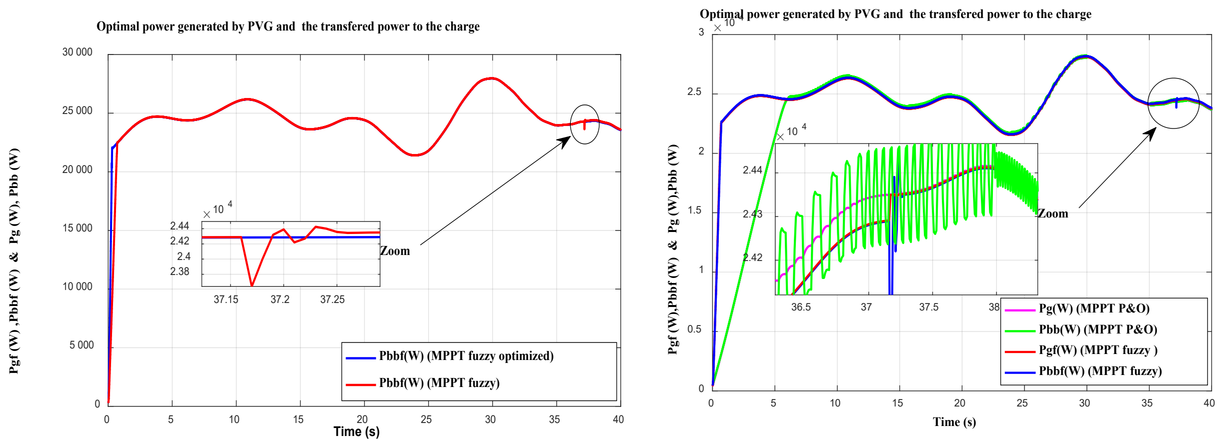


Figure 20. (a) . Power generated by PVG and the transformed power to the charge. **(b)** : Variations of the optimal power of PVG.

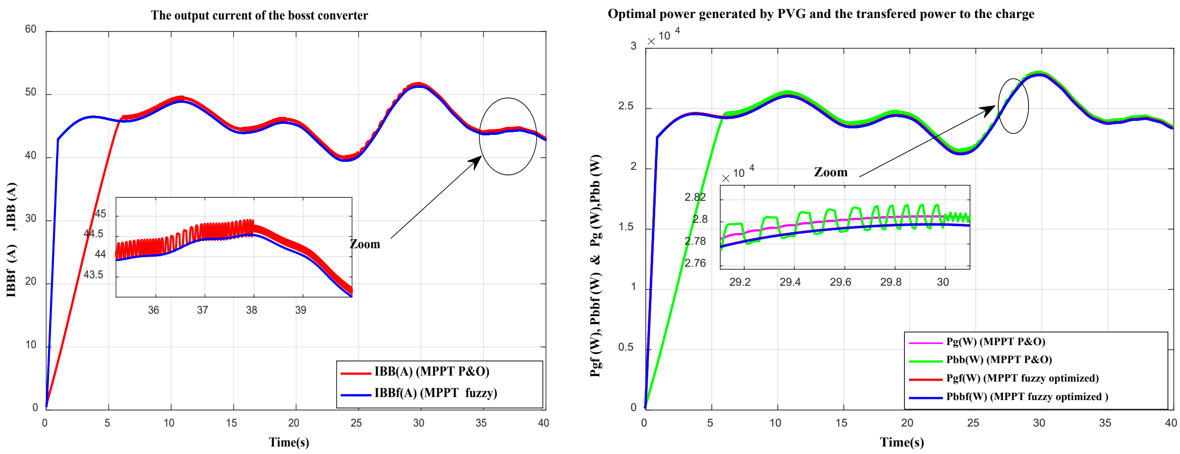


Figure 21. (a) . Charging current and voltage of battery. **(b).** Power of PVG transferred to the batteries issued by the FLC and FLC optimized

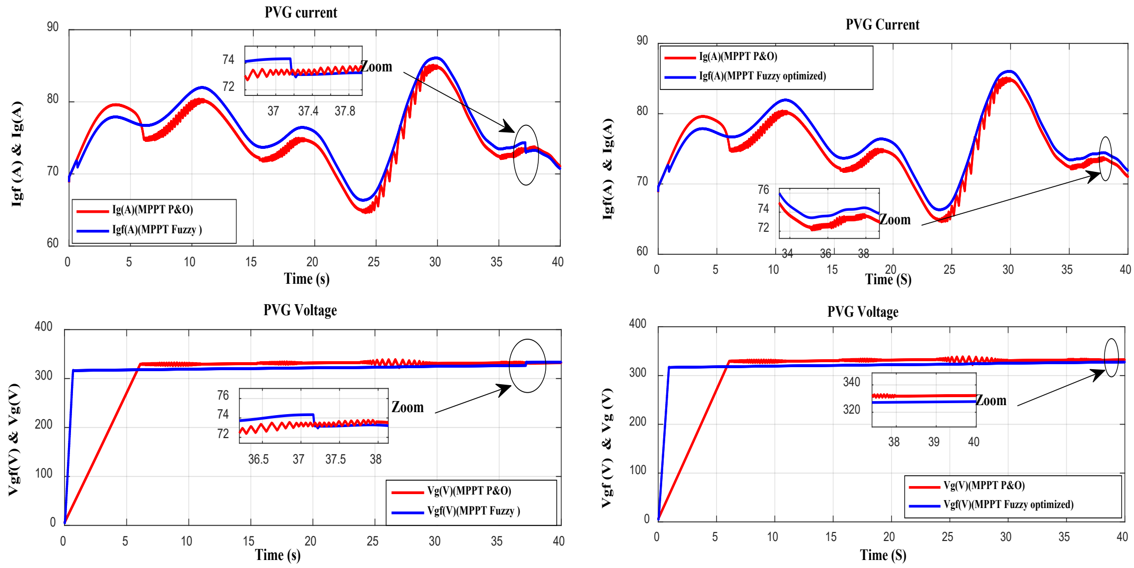


Figure 22. (a). Voltage & current of PVG with FLC. **(b).** Voltage & current of PVG with FLC optimized.

Figure 19 shows the variation of irradiance and temperature and the duty cycle of the MPPT, the variation of the duty cycle during start-up and steady states. It starts with an initial value (0.99) and then decreases around 0.38, which corresponds to the steady states in the P&O case. In figure 20 shows the variation of output power (Ppv). It can be seen that the steady state occurs after 5.3 seconds for the P&O MPPT, and 1 second for the FLC, due to the rapid variation of the load to reach both states.

Figure 21(a) shows the output voltage and current of the boost converter. We notice that there is no clear starting state in the output voltage curve is compensated by the batteries. We observe that despite the rapid variations and sudden changes in temperature and solar radiation, our tracker (controller) has achieved its objective of transferring the maximum power from the PV generator to the load. We also find that the results obtained by the fuzzy controller are better, in terms of resistance to changes in weather parameters, and in terms of increment step size than the variable in the case of a fuzzy controller. The performance of the MPPT based on the fuzzy optimized gain controller for a PV system is presented in Figures 21(b) and 22(b), it can be seen that the proposed FLC based GA can improve the dynamic and steady state performance of the PV system simultaneously.

5.2 Performances Of The Wind Chain

In this case we take the two principals values of turbine speed, the starting speed at 6m/s and nominal speed at 12m/s.

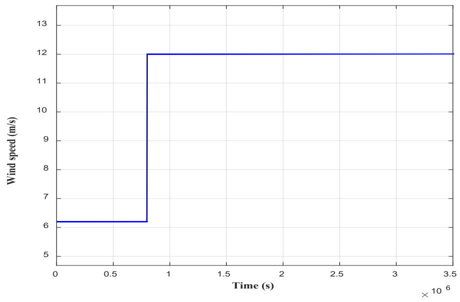


Figure 23. The wind speed.

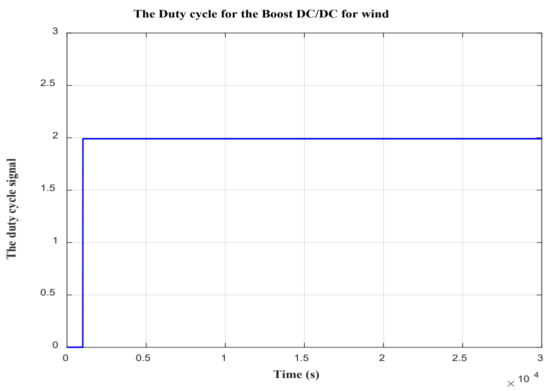


Figure 24. MPPT method of the wind turbine and its action on the duty cycle.

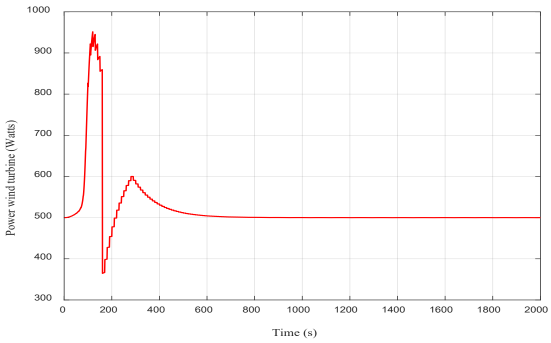


Figure 25. Variation of the power wind turbine.

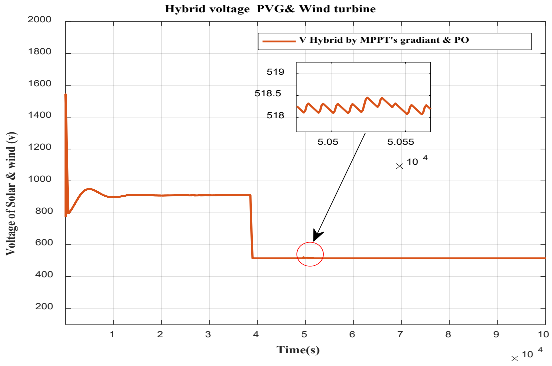


Figure 26. Variation of boost output voltage.

Figure 25 shows the operational control of a wind turbine with start-up and shutdown conditions, in particular the very short transient phase of 0.25, whose power takes a maximum value of 950w which corresponds to a speed of 12 m/s and the voltage 515V DC. In figure 26, the DC output voltage of both solar and wind sources is redundant at Vac=518.25V DC, and stable at 4s.

5.3 Simulations Of The Hybrid Pv-Wind System

In our case we chose the industrial frequency of 50Hz. Let us note here that the hybrid system synchronization is important with the frequency of the electrical network, this synchronism is ensured by the PLL loop which is integrated in the blocks of the chosen command SPS discrete of our system studied.

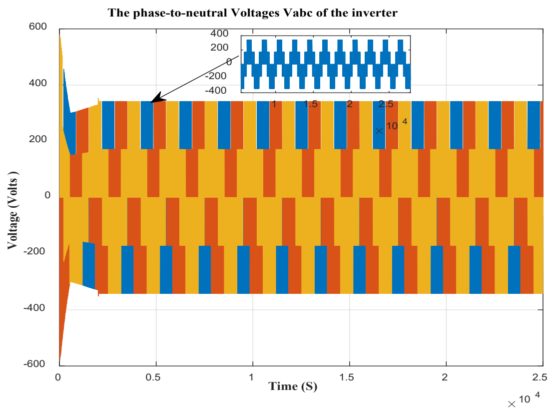


Figure 27. The phase-to-neutral Voltages V_{abc} of the inverter.

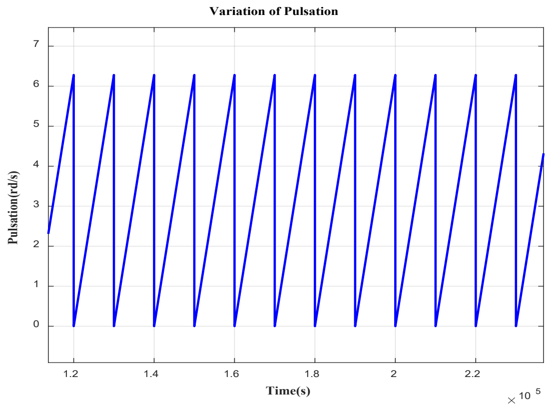


Figure 28. Variation of pulsation.

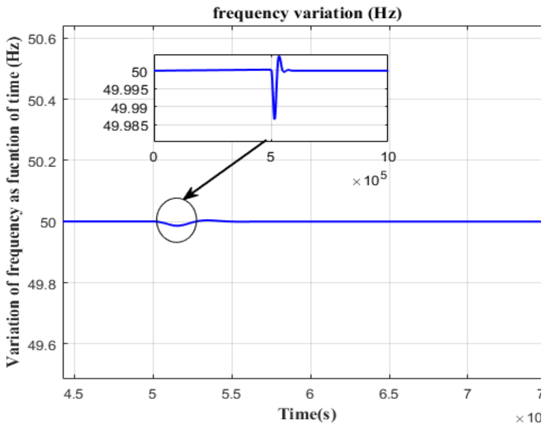


Figure 29. Variation of frequency as a function of time.

5.4 Connection Of The Hybrid System To The Industrial Network

The mains voltage is 5.5KV it is a medium voltage network by the transformer (elevator) the latter which will raise the voltage for a planned connection of our hybrid system to this distribution network [29].

The complete system consisting of the solar model, the wind model, and the energy distribution network is presented below simulating the optimal power outputs of the solar and wind systems.

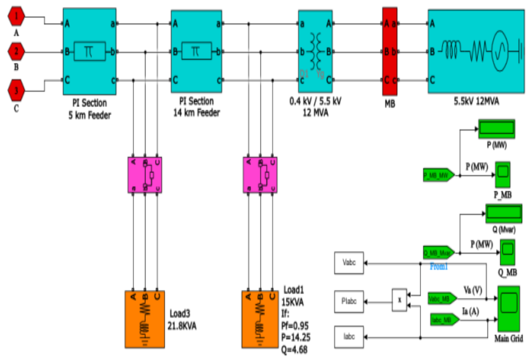


Figure 30. Model of the electrical network and these parameters

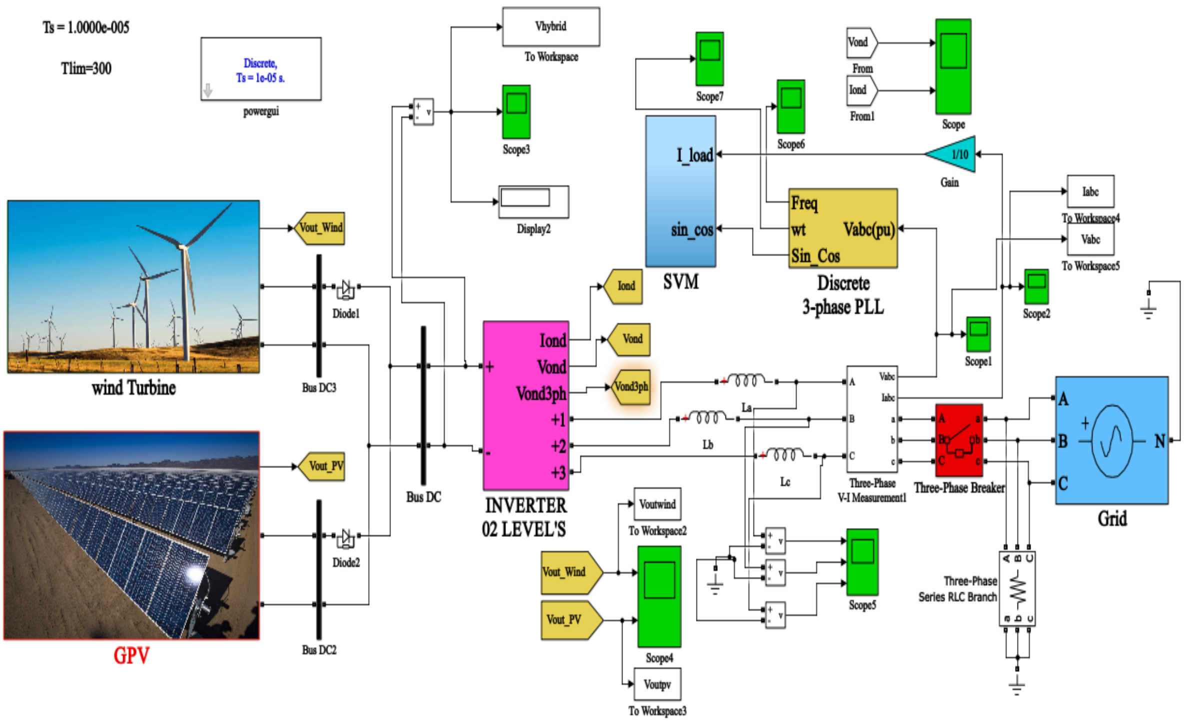
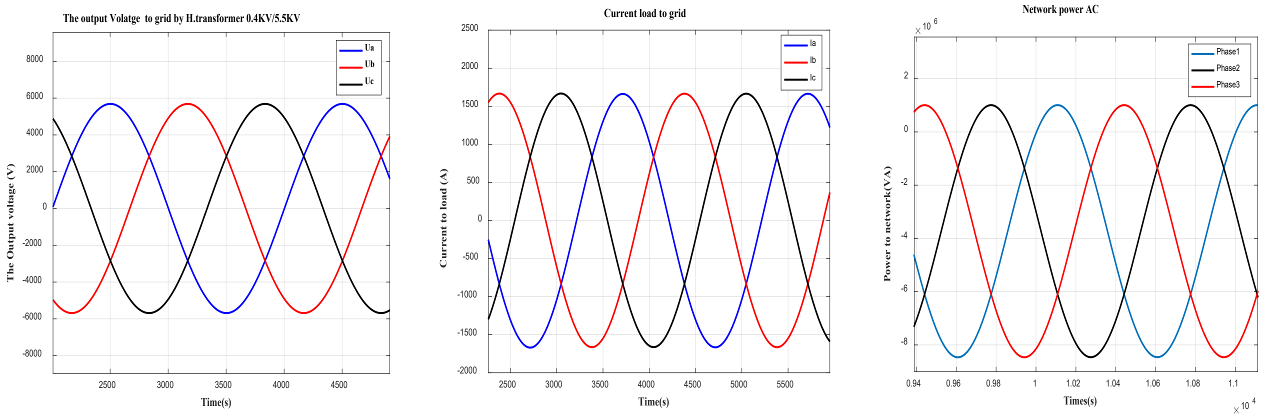


Figure 31. Scheme of the Hybrid System model connected to the distribution



(a) **(b)** **(c)**

Figure 32. (a). Three-phase voltage of the distribution network. **(b).** Three-phase current of distribution network., **(c).** Three -phases Power AC network.

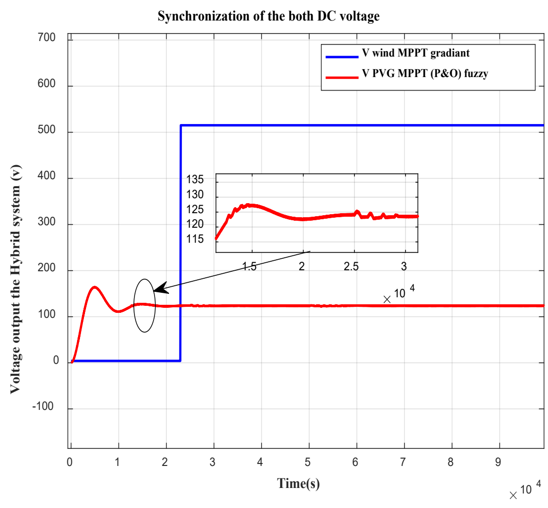


Figure 33. Synchronization of the both voltage DC.

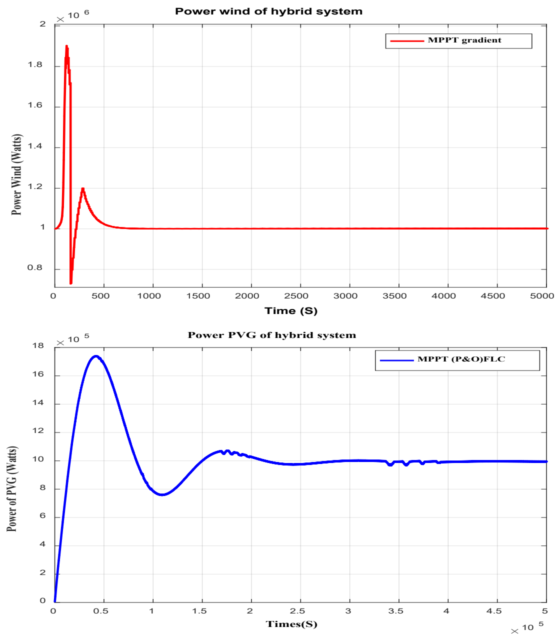


Figure 34. The curves of the global powers of the hybrid system.

Figure 32(a) shows that the system voltages are sinusoidal of 5.5 KV with the same frequency of 50 Hz, and are phase shifted from each other by 120°. Figure 32(b) shows that the system currents are sinusoidal of 1600 A with the same frequency of 50 Hz, and that they are phase-shifted by the same angle to each other. In figure 32(c), it is clear that the electrical system is 1 MW sinusoidal with the same frequency of 50 Hz, balanced.

Simulation results are performed taking into account the PVG and PMSG, after hybridization connected to a distribution grid figure 30. In figure 34 shows the curves of the overall power of the hybrid system. It should be noted that the regulation of the system PV power varies proportionally with the wind power P_{Wind}, each of which is controlled by its own MPPT controller, and the resultant of two powers follows the injection power to the grid.

We notice a total synchronism between the power of the hybrid system and that of the network, which is explained by the command provided by the discrete SPS command which controls the frequency connection by the phase loop locked (PLL) and also the voltage.

6. CONCLUSION

In this paper, we have proposed the sizing and control of a hybrid solar and wind energy conversion system, by the presented mathematical models of the PVG and PV system, and for the variable speed turbine coupled to the PMSG. In particular, the quality factor of the power supplied to the grids requires certain performance, depending on the efficiency and reliability of the overall system. It is essential to implement a developed battery model for this combined system, from which a suitable operation and control strategy has been proposed. Taking into account, that these autonomous plants produced power energy in isolated locations; especially, climatic instability. For this, it can be concluded that the hybrid system with the redundancy function meets the needs of the required optimal load at high quality.

The diversity of the used converters and their control modes, the non-linearity of the hybrid system, and the exogenous and endogenous conditions of the overall system can influence the control of the static converters, stability and reliability. In order to achieve maximum performance of the power produced by employing scalable algorithms, such as the maximum power point tracking technique known as MPPT (P&O), the (P&O) method for PVG. On the other hand, the use of the MPPT gradient method proves its effectiveness in controlling PMSG to produce energy with the variation of speed and power of the wind power system.

Artificial intelligence such as the optimized fuzzy approach accredits the robustness of the control and makes the behavior accurate and stable. In the end, with the combination of the two systems, the performance characteristics are quite acceptable and conclusive from the point of view of the validation of the proposed model.

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Mebrouk MENNAD: Performed the simulation by Matlab and analyse the results.

Abderrahim BENTAALLAH: Performed the simulation by Matlab and analyse the results.

Youcef DJERIRI: Performed the simulation by Matlab and analyse the results.

Aissa AMEUR Performed the simulation by Matlab and analyse the results.

Aicha BESSAS: Performed the simulation by Matlab and analyse the results.

Mebrouk MENNAD: Wrote the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

NOMENCLATURE

Nomenclature	Referred to
P&O	Perturb and Observe
DC-AC	Direct Current /Alternative
DC-DC	Direct Current/Direct
FLC	Fuzzy Logic Controller
GA	Genetic Algorithm
HPS	Hybrid Power Source
MPP	Maximal Power Point
MPPT	Maximal Power Point Tracking
NPC	Neutral Point Clamped
$P_{A.wind\ turbine}$	Average Power of the wind turbine
PI	Classic Controller
PLL	Phase Locked Loop
PMSG	Permanent Magnetic Synchronous Generator
PVG	Photovoltaic Generator
PWM	Pulse Width Modulation
SOC	State of Charge
SVPWM	Space Vector Pulse Width Modulation

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