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DC / DC Converter for the conditioning of the photovoltaic energy - modeling and command strategy

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ABSTRACT: *Demand for energy, especially electricity, throughout the world, is increasingly growing rapidly. Renewable energy: wind, solar, geothermal, and hydroelectric and biomass provides substantial benefits for our climate, our health, and our economy. However it needs more investigations in terms of research. A special attention should be given on the optimization of energy production and its own integration in grids especially when the resources become multiple. The contribution of our researches is to study the technical and physical aspects to optimize the energy management in a multi-source system dedicated to rural area applications. The multi-source system is based on photovoltaic panels, wind turbine, solar PV and storage batteries. In this paper, we present the modeling and simulation of the part composed of photovoltaic source and its DC / DC converter.*

Keywords - *Renewable energy, PV generator, Chopper, MLI, Backstepping.*

I. INTRODUCTION

The introduction Demand for electrical energy, throughout the world, is increasingly growing rapidly. This demand must be satisfy within a framework that does not aggress the environment. So many researches has been developed. Most of these researches has been focused on the optimization of the renewable energy production and its integration with electrical systems [1]. In addition, to satisfy this energy need, research has taken many paths [1][2], especially when sources of renewable energy become multiple.

The contribution of this paper is to study a multi-source system composed by a wind, photovoltaic (PV) panels and the batteries in order to inject the energy produced in an island or rural electric network.

The proposed configuration is shown in Figure 1.

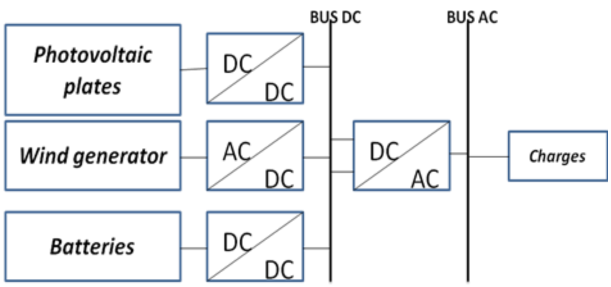

Figure 1: Configuration of global system.

Static charge represents common and fixed loads which are essential for a client. The dynamic charge represents additional loads to the usual ones, They have a fluctuating character. For the work conduct, we propose, as a first step, to consider separately the different blocks of the chosen structure, in a second step, to study the whole structure and how it can be affected by the integration of the blocks. Thus, we study in this article the floor composed of photovoltaic generator connected with the DC / DC converter. To command the switches (IGBTs) states, which are the heart of the DC / DC converter , the backstepping approach is used [3]. This approach control is non linear and can be adapted to the real functioning conditions, especially if we consider the variation of the output voltage of the photovoltaic field. Note that, an inverter (see fig. 1) is powered by the DC bus. Its output voltage value is given by $V_{AC\,eff} = \frac{\sqrt{2}}{2}.\alpha.V_{DC}$ and should be equal to 380V,with α is a variable coefficient of the command of the inverter and must be between 0 and 1.So, the DC bus voltage, noted V_{DC}, must be equal at least to 538V. our choice consists that α=0.4. This leads that we choose 800 V as a value of the DC bus voltage. After modeling the PV generator and the chopper, we use Matlab/Simulink software, to simulate different parts of the system.

II. MODELING SYSTEM

The studied system consists of a PV generator, a Boost chopper and a DC bus. Using the backstepping strategy, the chopper is controlled by a square signal with a varying duty cycle as a function of the measured output voltage of the PV. Figure 2 shows the block diagram of the floor.

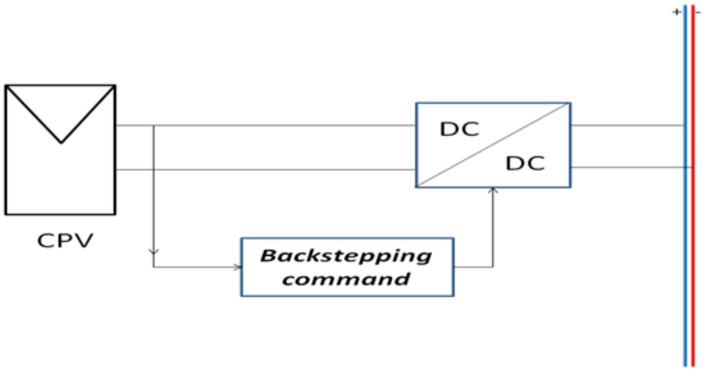

Figure 2. Studied floor structure

1- Model of photovoltaic plate

There are many models of PV which vary in complexity and accuracy [4][6]. For our study we use The model presented in Figure 3. This can faithfully reproduce the dynamic behavior of a photovoltaic generator

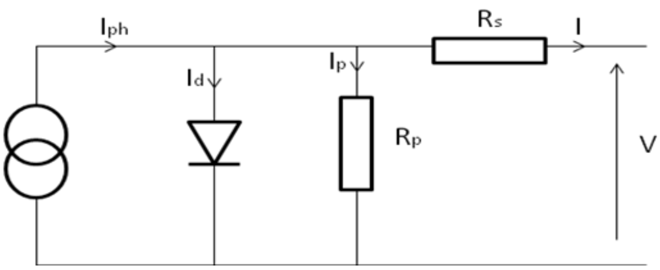

Figure 3. Model of photovoltaic plate

The electrical current output of the used model is mathematically described by:

$$I_d = I_{cc}\left(e^{\frac{qV}{nkT}} - 1\right) \qquad (1)$$

Where: Icc is the current in the reverse bias diode, q is the electron charge (1.6 10-19C), K is the Boltzmann constant (1.38 10-23J / K), n is the diode ideality factor it is between 1 and 2, T is the temperature in K of the junction.

The electrical current output of the used model is:

$$I = I_{PH} - I_{cc}\left(e^{\frac{V+I.R_S}{nV_T}} - 1\right) - \frac{V+I.R_S}{R_P} \qquad (2)$$

To increase the current value of the PV output; we use a mixed combination of several plates in series and parallel. This forms a matrix with Ns lines and Np columns; we connect the plates in a way to have Np groups of Ns PV. The Np groups are connected in parallel and the Ns are connected in series. This configuration leads to a global model presented in Figure 4.

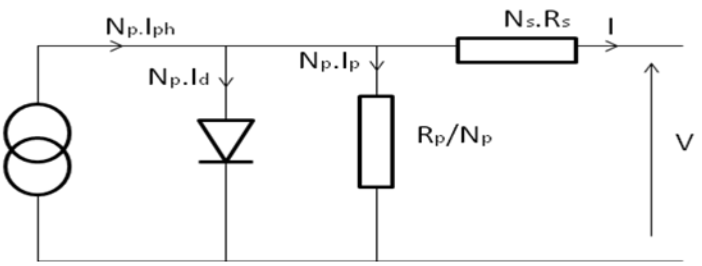

Figure 4. Model of photovoltaic fieled (CPV)

Finally, the expression of the PV field current is written as follows:

$$I = N_p.I_{ph} - N_p.I_d - N_p.N_s\left(\frac{V + I.R_S}{R_p}\right) \qquad (3)$$

2- Model of the boost chopper

The static converter chosen for this application is the boost chopper because of the voltage generated by the photovoltaic field value is lower than the voltage supplied by the DC bus. To achieve this, several structures can be used. Based on the performance criteria, the structure chosen for this study[6], is mounted around a double boost as shown in the figure below.

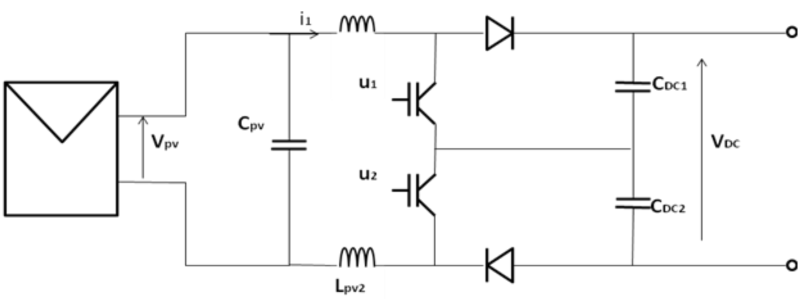

Figure 5: Structure of double boost.

Double boost is composed on two DC/DC converters connected in parallel, the output voltage is the sum of the voltages across each capacitor C_{DC1} and C_{DC2}.

u1 and u2 are the switches controls respectively (IGBT) forming the heart of the structure. Each command is moved from the other one by a half of the chopping period (T / 2)[7]. This configuration reduces the study of the control of the overall system to that of a single switch, since the command of one switch is derived from the other one by a simple shift of T / 2 . Therefore, the differential equations governing the DC/DC converter are [8]:

$$\begin{cases} L.\dfrac{di_1}{dt} = V_{pv} - (1-u)V_{DC} & (4.1) \\ C.\dfrac{dV_{DC}}{dt} = 2(1-u).i_1 - \dfrac{2}{R}.V_{DC} & (4.2) \end{cases} \quad (4)$$

With $L = L_1 + L_2$, $C = C_1 + C_2$ and i_1 and V_{DC} are respectively the input current and the output voltage for the system.

This system is nonlinear, it has a triangular form, where the V_{DC} Output has to follow the reference signal imposed by the DC bus and it is about 800V. Following the backstepping technique a controller is designed in two steps, since the controlled system (4) is a two-order [9][10][11].

- **<u>In the first step,</u>** we set $\varepsilon_1 = V_{DC} - V_{co}$ (5), with V_{co} the voltage setpoint. The derivative of the equation (5) takes the form:

$$\dot{\varepsilon}_1 = \dot{V}_{DC} - \dot{V}_{co} \qquad (6)$$

$$\dot{\varepsilon}_1 = \frac{2(1-u)}{C} i_1 - \frac{2}{RC} V_{DC} - \dot{V}_{co} \qquad (7)$$

Supposing that i_1 is the effective command of the system, and seeking the stability of the first lyapunov function which impose that $\dot{\varepsilon}_1$ takes the form $\dot{\varepsilon}_1 = -K_1 \varepsilon_1$, with $K_1 > 0$ is a design constant. Thus, the control law for the sub system (4.2) is given by:

$$i_1 = \alpha_1 = \frac{-K_1.C.\varepsilon_1 + \frac{2}{R}.V_{DC} + C.\dot{V}_{co}}{2(1-u)} \qquad (8)$$

To ensure the stability of the first sub-system described by (4.2), α_1 is considered as the desired value for i_1.

α_1 is called the first stabilization function.

- **<u>In the second step,</u>** Considering the overall system (4.1) and (4.2), the new error is defined as: $\varepsilon_2 = i_1 - \alpha_1$ (9).

We try, subsequently, to converge its value to zero just as ε_1. Replacing $i_1 = \varepsilon_2 + \alpha_1$ in equation (7) we obtain :

$$\dot{\varepsilon}_1 = -K_1.\varepsilon_1 + \frac{2(1-u)}{C}.\varepsilon_2 \qquad (10)$$

and :

$$\dot{\varepsilon}_2 = \frac{V_{pv}}{L} - \left(\frac{1-u}{L} - \frac{4}{R^2.C.(1-u)}\right).V_{DC} + \frac{C.K_1{}^2.\varepsilon_1}{1-u} + 2.K_1.\varepsilon_2 - \frac{4.i_1}{R.C} - \frac{C}{2(1-U)}.\dot{V}_{co} - \frac{\dot{u}.\alpha_1}{2(1-u)} \qquad (11)$$

Introducing the equations (10) and (11), the derivative of the Lyapunov function shown in equation (12), on the one hand, and on the other hand, respecting the condition of stability of the system imposed by the method ($\dot{V}_2$ must be strictly negative) we obtain the relation (15) :

$$V_2 = \frac{1}{2}\varepsilon_1{}^2 + \frac{1}{2}\varepsilon_2{}^2 \qquad (12)$$

$$\dot{V}_2 = \varepsilon_1.\dot{\varepsilon_1} + \varepsilon_2.\dot{\varepsilon_2} \qquad (13)$$

$$\dot{V}_2 = -k_1\varepsilon_1{}^2 - k_2\varepsilon_2{}^2 + \varepsilon_2\left(k_2.\varepsilon_2 + \frac{2(1-u)}{C}\varepsilon_1 + \dot{\varepsilon_2}\right) \qquad (14)$$

With k1 and k2 two positive coefficients representing design constants.

$$k_2.\varepsilon_2 + \frac{2(1-u)}{C}\varepsilon_1 + \dot{\varepsilon_2} = 0 \qquad (15)$$

Finally we obtain the below equation managing the control of the overall system:

$$\dot{u} = \frac{2(1-u)}{\alpha_1}.\left(\frac{V_{pv}}{L} - \left(\frac{1-u}{L} - \frac{4}{R^2.C.(1-u)}\right).V_{DC} + \left(\frac{C.K_1{}^2}{1-u} + \frac{2(1-u)}{C}\right).\varepsilon_1 + (2.K_1 + K_2).\varepsilon_2 - \frac{4.i_1}{R.C} - \frac{C}{2(1-U)}.\dot{V}_{co}\right) \qquad (16)$$

When the errors represented by ε_1 and ε_2 tend to zero, the form of the differential equation of the command (16) becomes: $\dot{u} = \frac{R.(1-u)^2(V_{pv}-(1-u)V_{co})}{L.V_{co}}$ (17)

We are dealing with a system that has two equilibrium points (solutions): $u_1 = 1$ and $u_2 = 1 - \frac{V_{pv}}{V_{co}}$. Only the solution u_2 that might make sense in the command, since u_1 presents a unified duty cycle. This allows us to write the control law as follows:

$$\dot{u} = \frac{R.(1-u)^2(u-u_2)}{L} \qquad (18)$$

However u_2 is an unstable equilibrium point, as we can see from equation (18) [12]. this is due to the nature of the boost chopper.

2.1- Indirect output voltage control

As the control of the output voltage led to an unstable system. An indirect approach to command is on to control the input current i_1 with a setpoint current I_{co}. The latter can be calculated from Equation 4 in the steady state, it is written as follows: $I_{co} = \frac{V_{co}^2}{R.V_{PV}}$ (19)

Following the same steps described above for calculating the command law, we arrive at the following result :

$$\dot{u} = \frac{1-u}{\alpha}\left[\left(\frac{1-u}{L} - \frac{K_1^2.L}{1-u}\right)\varepsilon_1 + (-K_1 - K_2)\varepsilon_2 - \frac{2}{R.C}V_{DC} - \frac{2(1-u)}{C}i_1 + \frac{L}{1-u}\dot{I}_{co}\right] \qquad (20)$$

With :

$$\varepsilon_1 = i_1 - I_{co} \qquad (21)$$

$$\varepsilon_2 = V_{DC} - \alpha \qquad (22)$$

$$\alpha = \frac{K_1.L.\varepsilon_1 + V_{PV} - L.\dot{I}_{co}}{1-u} \qquad (23)$$

When, this time, the errors represented by ε_1 and ε_2 tend to zero, the form of the differential equation of the command becomes: $\dot{u} = \frac{2(1-u)}{V_{PV}.R.C}((1-u)^2.R.I_{co} - V_{PV})$ (24)

Equation (24) admits three equilibrium points which are : u_1=1, $u_2 = 1-\sqrt{\frac{V_{PV}}{R.I_{co}}}$ and $u_3 = 1+\sqrt{\frac{V_{PV}}{R.I_{co}}}$. only u_2 has meaning in the command, the Equation (24) in the vicinity of equilibrium u_2 becomes: $\dot{u} = \frac{4(u_2-u)}{RC}$ (25).

This solution clearly shows that u_2 is an equilibrium point asymptotically stable.

This command ensures satisfactory results only when the converter model and the DC bus are well known and with fixed parameters. The problem is that these conditions are encountered very little in reality, that's why an adaptive version of the command described above is required.

2.2- Adaptative command

Its mathematical formalism is based on the variable change shown by equation (26) : $\theta = \frac{1}{R}$ (26).

Where R is the resistance model symbolizing the DC bus. Thus the relation (19) becomes:

$$I_{co} = \frac{V_{co}^2}{V_{PV}}.\theta \quad , \quad \hat{I}_{co} = \frac{V_{co}^2}{V_{PV}}.\hat{\theta} \qquad (27)$$

The main aim of this command, which also obeys the same strategy as the previous one, is to find an optimal value for θ to stretch the value of an additional error rated $\tilde{\theta} = \theta - \hat{\theta}$ to zero, while treating the other two errors already studied. $\hat{\theta}$ is the estimated value of θ. the mathematical expressions of the two other errors which have be minimize are obtained by the same procedure as before.

- **<u>In the first step ,</u>** we are interested ,in first time , with the error defined by equation (21) .Thus, the first stabilizing function, denoted α_1 is obtained either: $\alpha_1 = \frac{K_1.L.\varepsilon_1 + V_{PV} - L\dot{I}_{co}}{(1-u)}$ (28)

  Then in a second time, we pay attention on the error described by equation (22).

- **<u>The aim of the second step</u>** is the introduction of the Lyapunov function with three errors ($\tilde{\theta}$, ε_1,ε_2) previously defined in order to properly calculate the command u and the estimated value denoted $\hat{\theta}$. This is translated by the function below. $V = \frac{1}{2}\varepsilon_1^2 + \frac{1}{2}\varepsilon_2^2 + \frac{1}{2.\gamma}\tilde{\theta}^2$ (29) , with γ is a positif coefficient.

let $\dot{V}$ derivated function of V : $\dot{V} = \varepsilon_1.\dot{\varepsilon_1} + \varepsilon_2.\dot{\varepsilon}_2 + \frac{1}{\gamma}\tilde{\theta}.\dot{\hat{\theta}}$ (30).

Calculation of $\dot{\varepsilon}_1$ and $\dot{\varepsilon}_2$ is based on the equations (21) and (22) and they are :

$$\dot{\varepsilon}_1 = -K_1.\varepsilon_1 - \frac{1-u}{L}.\varepsilon_2 \qquad (31)$$

$$\dot{\varepsilon}_2 = \frac{2(1-u)}{C}i_1 - \frac{2.\tilde{\theta}}{C}V_{DC} - \frac{2.\hat{\theta}}{C}V_{DC} + \frac{u.\alpha}{1-u} + \frac{L.\dot{I}_{co}}{1-u} - \frac{K_1^2.L.\varepsilon_1}{1-u} - K_2.\varepsilon_2 \qquad (32)$$

Introducing (31) and (32) into (30) we obtain:

$$\dot{V}_2 = -k_1\varepsilon_1{}^2 - k_2\varepsilon_2{}^2 + \varepsilon_2\left(k_2.\varepsilon_2 + \frac{2(1-u)}{C}\varepsilon_1 + \dot{\varepsilon}_2 + \frac{2}{C}V_{DC}.\varepsilon_2\right) + \tilde{\theta}(-\frac{2}{C}V_{DC}.\varepsilon_2 + \frac{1}{\gamma}\dot{\hat{\theta}}) \quad (33)$$

Then the insertion of the new expression (32) into (33) leads to the following equation:

$$\dot{V}_2 = -k_1\varepsilon_1{}^2 - k_2\varepsilon_2{}^2 + \varepsilon_2\left((K_1 + K_2)\varepsilon_2 + \frac{2(1-u)}{C}i_1 + \frac{2.\hat{\theta}}{C}V_{DC} + \frac{K_1^2.L}{1-u}\varepsilon_1 + \frac{u.\alpha}{1-u}\right) + \tilde{\theta}(-\frac{2}{C}V_{DC}.\varepsilon_2 + \frac{1}{\gamma}\dot{\hat{\theta}}) \quad (34)$$

In the end, respect of the stability condition of the Lyapunov function requires the following:

$$\dot{\hat{\theta}} = \frac{2.\gamma}{C}V_{DC}.\varepsilon_2 \quad (35)$$

$$\dot{u} = -\frac{(1-u)}{\alpha}.\left((K_1 + K_2)\varepsilon_2 + \frac{2(1-u)}{C}i_1 + \frac{2.\hat{\theta}}{C}V_{DC} + \frac{K_1^2.L}{1-u}\varepsilon_1 - \frac{L}{1-u}\dot{I}_{co}\right) \quad (36)$$

When, this time, the errors represented by ε_1, ε_2 and $\tilde{\theta}$ tend to zero, the form of the differential equation of the command becomes : $\dot{u} = \frac{2.\theta.(1-u)}{C.V_{pv}}(\frac{(1-u)^2}{\theta}I_{co} - V_{PV})$ (37)

Note that the zero of this function is the same as that of the previous function, thus $u_2 = 1 - \sqrt{\frac{V_{PV}}{R.I_{co}}}$,

Hence the expression of the command : $\dot{u} = \frac{4.\theta(u_2 - u)}{C}$ (38)

III- SIMULATION AND DISCUSSION

The goal is, using a double-Boost converter controlled by the backsteeping strategy, to adapt the output of a photovoltaic field (CPV) to a fixed voltage of 800V imposed by the DC bus. In order to test the performance of the controller designed previously, we have applied a real signal measured from a (CPV), to a simulated model of a double boost chopper associated to the controller. This simulation is carried out under the Matlab / Simulink environment according to the experimental setting of figure 6.

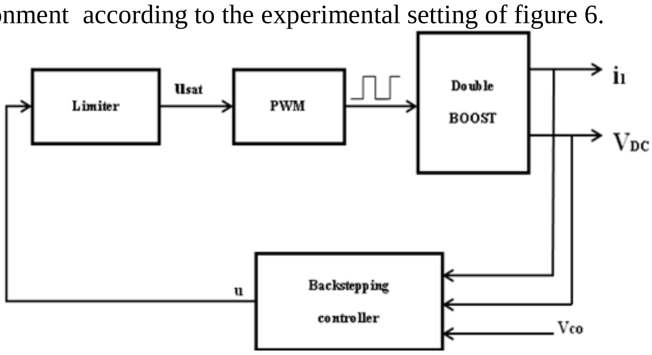

Figure 6: principle of the simulation

The (CPV) is composed of sixteen solar panels in series controlled by an MPPT algorithm (Maximum Power Point Tracking) called Perturb and Observ (P & O) that extracts the maximum power of each panel on the (CPV)[6][13]. The shape of the output (figure 7) of this (CPV), which is applied to our simulated model, was measured and recorded for a period of 10 hours (from 8 hours to 18 hours).

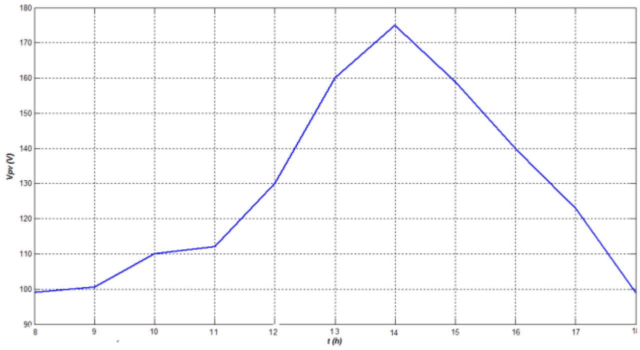

Figure 7 : Input Voltage Vpv

The parameters of the double boost, and the backsteeping controller used , for our simulation studies, are summarized in the table below

Variable	Valeur
C_1, C_2	600µF
L_1, L_2	100mH
F	20 kHz
R	10 Ω
K_1	20
K_2	40
γ	$10e^{-7}$
V_{co}	800V

Table 1 : parameters of the system.

The results of the simulation is shown in Figures 8, 9 and 10.

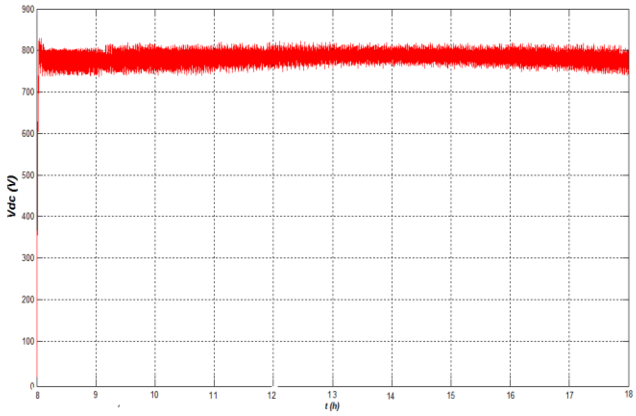

Figure 8 : output voltage of the double boost

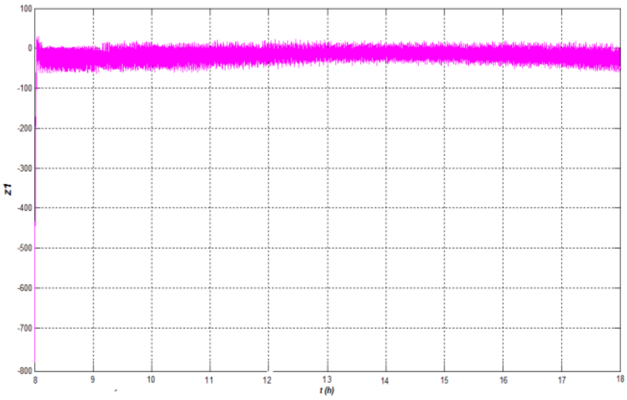

Figure 9 : representation of the evolution of the error z1

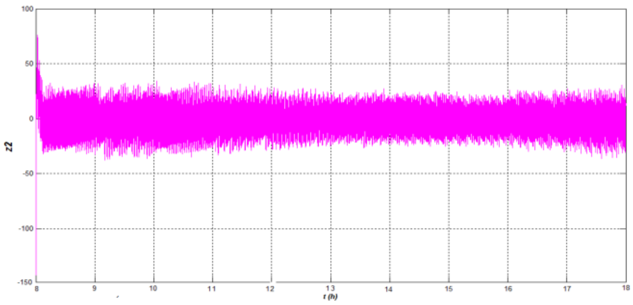

Figure 10 : representation of the evolution of the error z2

Figure 8 shows the voltage output of the chopper, which is the system output, and it is fixed, with a good stability, around the 800 V, despite the variation of the chopper signal input generated by (PV Field). Note that the 800 V is the desired value and represents the DC bus voltage, In addition, as we can see, the oscillatory phenomenon is mastered and understated, see disappeared; compared to the old structure of the chopper presented in [14].

Figures 9 and 10, respectively represent, the shape of errors ε_1 and ε_2 .Note that the actual trajectories converge to the desired trajectory and errors ε_1 and ε_2 tend to zero. These results lead us to consider the system as robust to adverse consequences, caused by changes in the input voltage from the (PV Field) depending on weather conditions.

IV- CONCLUSION AND PERSPECTIVE

Thanks to the adaptive command based on the backsteeping strategy, the voltage output of a double boost chopper is fixed with a good stability to a required value. The chopper is used to adapt and regulate the output of a PV field to a DC bus voltage. The set made up of the chopper, the controller and the PV field represents a mesh in a multisource system of renewable energy. the obtained results are encouraging and we plan to apply the same approach to control and adjust the output of a wind turbine to the DC bus.

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