Predictive functional control for photovoltaic system optimization

1st Nassima OUALI
déptartement de génie electrique,
Laboratoire de Technologie
Industrielle et de l'Information (LTII),
Université de Bejaia,
Bejaia, Algérie
nassima.ouali@univ-bejaia.dz

2nd Hocine LEHOUCHE
département de génie électrique,
Laboratoire de Technologie
Industrielle et de l'Information (LTII),
Université de Bejaia,
Bejaia, Algérie
hocine.lehouche@univ-bejaia.dz

3rd Abdelhakim BELKAID
déptartement de génie electrique,
Laboratoire de Technologie
Industrielle et de l'Information (LTII),
Université de Bejaia,
Bejaia, Algérie
abdelhakim.belkaid@univ-bejaia.dz

4th Ilhami COLAK
Departement of Electrical-Electronics
Engineering,
Nisantasi University
Istanbul, Turkey
ilhcol@gmail.com

5th Cylia IBAOUENE
déptartement de génie electrique,
Laboratoire de Génie Electrique
(LGEB),
Université de Bejaia,
Bejaia, Algérie
cylia.ibaouene@univ-bejaia.dz

6th A.yazid ACHOUR
déptartement de génie electrique,
Laboratoire de Technologie
Industrielle et de l'Information (LTII),
Université de Bejaia,
Bejaia, Algérie
abdelyazid.achour@univ-bejaia.dz

***Abstract*— Photovoltaic systems have earned recognition as incredibly interesting renewable energy sources, due to simplicity of supply. These systems have a nonlinear characteristic which causes them a low energy conversion. However, it necessity for control systems capable of outperforming conventional controllers and overcome the existing operational instabilities. The main objective of this paper is to design a predictive functional control to the photovoltaic generators, to make it follow a desired trajectory and to generate a maximum power. A predictive functional control is defined as advanced control which exploit the future behavior of process, and its consists in using of discretized model of the photovoltaic system. The simulation results prove the highest tracking efficiency of this algorithm which are evaluated by means of efficiency, stability and robustness under different scenarios of varied metrological condition.**

Keywords—photovoltaic system, optimization, predictive functional control, maximum power tracking

I. INTRODUCTION

Climate change, among the most crucial issues affecting society this decades, is manufactured by greenhouse gas emissions, mainly from the excessive fossil fuel energy consumption such as oil, coal, and nuclear energy which have a negative impact on the environment. The primary energy consumption worldwide production is expected by over 60%, from 2002 to 2030,This growing demand for energy has allowed a remarkable development of renewable energies, particularly photovoltaic (PV), wind,.. [1,2] which are considered an alternative to fossil fuels. Photovoltaic energy is currently one of the most promising technological solutions, and production process of the PV module has definitely improved in terms of quality and cost [3]. In a photovoltaic system (PV), reaching the operational point of a PV cell to maximum power point (MPP) is critical because its constantly changing which is dependent on environmental factors vary at irregular intervals such as solar radiation and temperature [4].

Consequently, various approaches have been developed in literature to increase the dynamic performance of PV system, namely the perturb and observe (P&O) algorithm and the Incremental Conductance (IC) algorithm which are extensively implemented due to their simplicity [5,6] and other intelligent methods [7,8] According to [9], the conventional algorithms have a critical disadvantages specifically the oscillation of photovoltaic power around the maximum power tracking (MPP) leading to significant energy losses from the photovoltaic array. And it provides a poor and slow tracking of the MPP during the variation of weather conditions.

To overcoming this major problems of the techniques described above in terms of speed convergence and robustness. A model predictive control (MPC) is proposed in literature, [10,11] and [12], his main benefit are this implicit form, adaptability, and the explicit usage of model. Predictive Functional control (PFC) technique has been used extensively in the process industry due to all these benefits, particularly as a readily adjustable and more highly efficient controller for nonlinear processes [13, 14] and [15]. The main objective of this work is to keep the PV system at the maximum power efficiency point under variation of weather conditions despite the nonlinear dynamic of the system behaviour. To achieve this purpose, the predictive functional control (PFC) is used which is based on utilization of the model of the process to anticipate the future behavior of the system, in this instance allows predicting the output power of PV arrays to optimize the efficiency of the PV model.

The remained of this paper is organized as follows. Section 2, describes the photovoltaic system, Section 3 discusses the development of predictive functional control; the 4th section is devoted to the application of PFC control approach to this system after presenting the identification of PV system. Conclusions and perspectives are drawn in the last section.

II. PV SYTEM MODEL

Certain power performances can be reached by using photovoltaic arrays, which are generated by connecting numerous PV panels in a series-parallel configuration. The system under study in this paper includes the PV module, DC–DC boost converter, and load resistance, as shown in Fig. 1 [16].

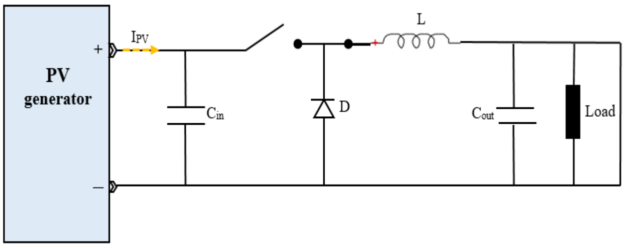

Fig.1. PV system.

A. *Model of the PV system*

First, The most basic Photovoltaic cells model, composed mainly of a current source I_{ph} connected in parallel to a diode D, provides an output current I_{PV} that is directly proportionate of irradiance. The idealized PV cell is mathematically described by the basic equations.

$$I_{pv} = I_{ph} - I_D \tag{1}$$

$$I_{ph} = \left(I_{ph,STC} + K_i \Delta T\right)\frac{G}{G_{STC}} \tag{2}$$

$$I_D = I_0\left[\exp^{\frac{V}{VT1}} - 1\right] \tag{3}$$

$$I_{PV} = \left(I_{ph,STC} + k_i \Delta T\right)\frac{G}{G_{STC}} - I_0\left[\exp^{\frac{V}{VT1}} - 1\right] \tag{4}$$

The PV module parameters used in this paper are shown in Table 1.

Table.1. SUNPOWER SPR-414 PV Module

Characteristic of PV module	**Values**
V_{OC}	85.3
I_{SC}	6.09
V_{mp}	72.9
P_{mp}	414.801

B. *Model of the boost converter*

The PV array is connected to a load. A boost converter is incorporated as shown in fig.1. The inductance value is $0.5mH$, and the condenser input output value are $150\mu F$ [17].

III. PREDICTIVE FUNCTIONAL CONTROL

Predictive functional control was developed to solve control issues in medium-complexity processes. It uses a process linear model that allows for the prediction of future outputs throughout a finite horizon. The objective is to bring the process output to the reference. The main characteristics of PFC are [18]:

- ✓ Internal model of the process.
- ✓ Reference trajectory.
- ✓ Coincidence horizon.
- ✓ Control law form

.

A. *Design of PFC for a higher order models*

The PFC for the first order model is described in [19], in this paper we will describe for a higher order models, a transfer function based on parallel representation is given by.

$$H(p) = \sum_{i=1}^{m} \frac{K_i}{1+\tau_i p} = \frac{y_M(t)}{u_p(t)} \tag{5}$$

The output of the model discretized is given by

$$y_M(k) = y_1(k) + y_2(k) + \cdots + y_m(k) \tag{6}$$

Where:

$$y_i(k) = a_i y_i(k-1) + K_i(1-a_i)u(k-1) \tag{7}$$

Noting that, $\alpha = e^{-T_{st}/\tau_i}$ where τ represent the constant time, T_{st} is the sampling time.

By inserting equation (7) in equation (6) , we obtain the output of the model as follow

$$y_M(k) = \sum_{i=1}^{m} a_i y_i(k-1) + \sum_{i=1}^{m} K_i(1-a_i)u(k-1) \tag{8}$$

a) *Define the reference trajectory form*

The set point is reached using a reference trajectory that is reset at each point on the process's actual output. the predicted output of the system is specified by the reference trajectory initialized on the real output of the process and the desired value.

$$y_R(k+H) = sp(k) - \lambda^H(sp(k) - y_p(k)) \tag{9}$$

With $\lambda^H = e^{-T_e * H * 3/T_{Bf}}$

At the coincidence horizon, the process's predicted output equals the reference trajectory

$$y_R(k+H) = \hat{y}_p(k+H)$$

At the point, $k+H$ we obain:

$$\hat{y}_p(k+H) = y_M(k+H) + (y_p(k) - y_M(k)) \tag{10}$$

By using the equation (8) of for y_M , we find:

$$\hat{y}_p(k+H) = \sum_{i=1}^{m} y_i(k+H) + (y_p(k) - \sum_{i=1}^{m} y_i(k)) \tag{11}$$

The increment of the output is expressed as follows:

$$\Delta_p(k) = (1-\lambda^H)(sp(k) - y_{ref}(k)) \tag{12}$$

The output increment for the model can be determined similarly to the process:

$$\Delta_M(k) = (1-\alpha^H)K_M u(k) - y_M(k)(1-\alpha^H) \tag{13}$$

Finnally, the control law of PFC is obtained by the eqaulity of (12) and (13):

$$u(k) = \frac{(1-\lambda^H)(sp(k) - y_p(k))}{\sum_{i=1}^{m} K_i(1-\alpha_i^H)} + \frac{\sum_{i=1}^{m} y_i(k)(1-\alpha_i^H)}{\sum_{i=1}^{m} K_i(1-\alpha_i^H)} \tag{14}$$

IV. APPLICATION OF THE PFC FOR THE SYSTEM PV

A. *Identification of the PV system*

The PV system is a nonlinear system that is difficult to control and adjust, necessitating the identification of a model based on the inputs/outputs that has the same behavior as the dynamic system that will be used for the application of the PFC algorithm. Using the recursive least squares method, we may extract the discrete representation of the continuous system and easily build the discrete controller [20].

$$G(q^{-1}) = q^{-d}\frac{B(q^{-1})}{A(q^{-1})} = \frac{b_0q^{-1}+b_1q^{-2}}{1+a_1q^{-1}+a_2q^{-2}} \qquad (15)$$

a) *Initialisation*

$$A(q^{-1}) = 1+0.5q^{-1}+0.5q^{-2}$$
$$B(q^{-1}) = 0.5q^{-1}+0.5q^{-2}$$

b) *the identification algorithm's parameters values*

- $F_0 = 1e^5$
- Forgetting factor $\partial = 0.999$
- Sampling time $T_{st} = 1\mu s$

The implementation of the recursive least squares algorithm presented in the previous chapter is used to approximate the system by a given second order model given by the following transfer function with $d = 0$: The parameters have been correctly identified, and they can be utilized to represent the model function.

$$G(q^{-1}) = \frac{2.0384e^{-5}q^{-1}+7.6740e^{-05}q^{-2}}{1-1.9323q^{-1}+0.9331q^{-2}}$$

The PFC's control law is generated by the following algorithm.

B. *internal model structure*

The decomposition of the system's model: consedering the equation as an internal model of the process then, that will be simplified into simple fractions of two main sub-models M_1, M_2

$$G(p) = \frac{K_1}{1+T_1p} + \frac{K_2}{1+T_2p} \qquad (16)$$

With model's parameters values:

$K_1 = 0.0574$ $\quad T_1 = 1.9531e^{-5}$

$K_2 = -0.1692$ $\quad T_2 = 5.814e^{-5}$

In order to incorporate the model in the controller, it must first be transformed into discrete form. Therefore, the parallel model combined with the Zero Order Hold (ZOH) and a sample period results in:

$$M_1(z^{-1}) = \frac{K_1(1-\alpha_1)z^{-1}}{1-\alpha_1z^{-1}}$$
$$M_2(z^{-1}) = \frac{K_2(1-\alpha_2)z^{-1}}{1-\alpha_2z^{-1}} \qquad (17)$$

With $a_1 = e^{-T_{st}/T_1}$ $\quad a_2 = e^{-T_{st}/T_2}$

The model's overall output y_M is obtained:

$$y_M(k) = y_1(k)+y_2(k) \qquad (18)$$

$$y_1(k) = a_1y_1(k-1)+K_1(1-a_1)u(k-1) \qquad (19)$$

$$y_2(k) = a_2y_2(k-1)+K_2(1-a_2)u(k-1) \qquad (20)$$

C. *Reference trajectory form*

$$y_R(k+H) = sp(k)-\lambda^H(sp(k)-y_p(k)) \qquad (21)$$

D. *output prediction:* The model's predicted output is provided by:

$$y_p(k+H) = \sum_{i=1}^{2} y_i(k+H) + (y_p(k) - \sum_{i=1}^{2} y_i(k)) \qquad (22)$$

E. *PFC control law*: The control law's form is determined as follows:

$$u(k) = \frac{(1-\lambda^H)(sp(k)-y_p(k))}{\sum_{i=1}^{2} K_i(1-\alpha_i^H)} + \frac{\sum_{i=1}^{2} y_i(k)(1-\alpha_i^H)}{\sum_{i=1}^{2} K_i(1-\alpha_i^H)} \qquad (23)$$

F. *Selection of PFC's parameters*

The value of the parameter λ is proportional to the required closed-loop time response T_{Bf} which is the PFC's crucial settings parameter because it directly influences the system's dynamics; for that, the appropriate range of λ is between $0 < \lambda < 1$, in this case $\lambda = 0.97$. Note that the low value of T_{Bf} ensures a fast convergence of the controller with $T_{st} = 1e^{-6}$, other parameter values of PFC are defined as: $F_{ac} = 2$ and $H = 110s$

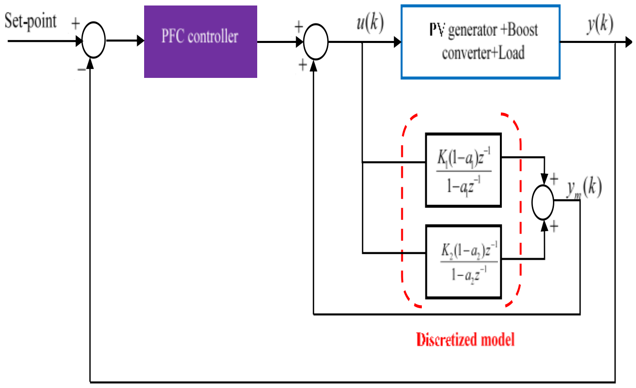

Fig. 2. Predictive functional control applied to PV system

V. SIMULATION RESULTS

The following figures show the simulation results

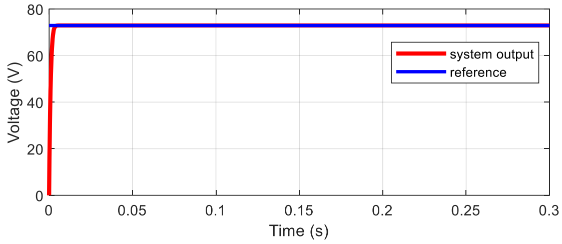

Fig. 3. the output of the system and the reference

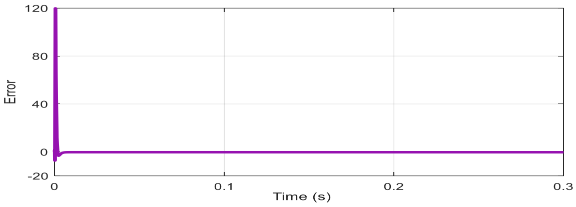

Fig.4. error between the output of the system and the reference

To assess the efficacy of the proposed controller design method, Three scenarios are considered in this study. The first simulation assumed a constant irradiance and temperature of 1000W/m^2 and 25°C, respectively. In the second simulation, the irradiation profile is changed throughout six time intervals with irradiation levels of 800 W/m^2,1000 W/m^2 , 600 W/m^2, 1000 W/m^2, 400 W/m^2 and 1000 W/m^2, the ambient temperature is considered constant (25 °C). In the final simulation, a temperature profile change is applied also over six time intervals 40°C, 25°C, 10°C, 25°C, 10°C and 30°C, with irradiation levels of 1000W/m^2.

A. *First scénario:* The following figures show the simulation results with an irradiation of 1000W/m^2 and a temperature of 25°C.

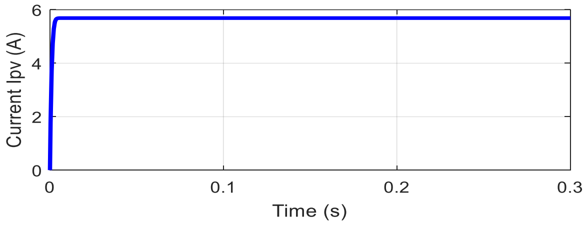

Fig. 5. The current of the PV panel

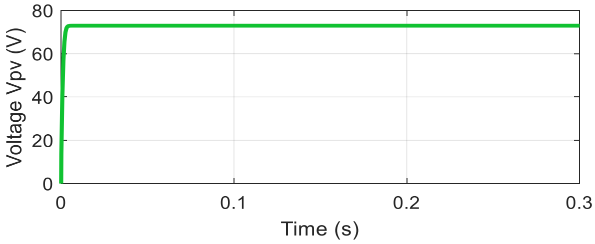

Fig. 6. The voltage of the PV panel

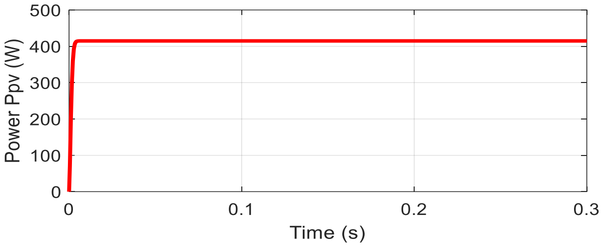

Fig. 7. The power of the PV panel

B. *The second scénario:* The simulation results of change temperature profile, irradiance constant, are shown in the figures below.

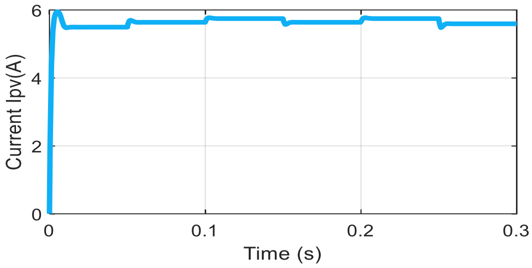

Fig.8. The current of the PV panel

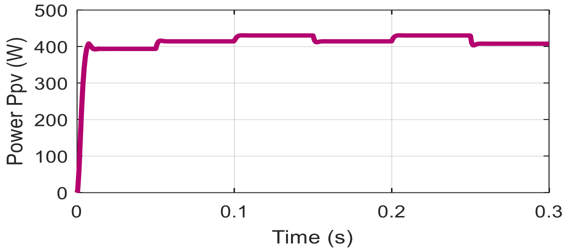

Fig.9. The power of the PV panel

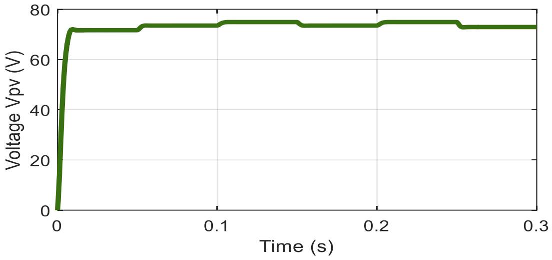

Fig.10. The voltage of the PV panel

C. *The last scénario:* The following figures show the simulation results of change irradiance profile, temperature constant..

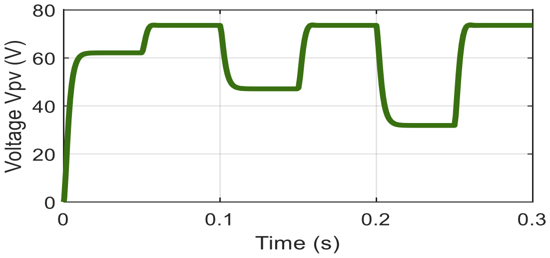

Fig.11. The voltage of the PV panel

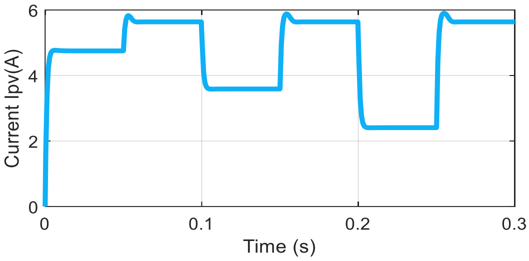

Fig. 12. The current of the PV panel

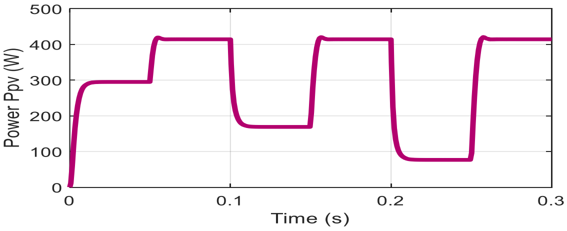

Fig. 13. The power of the PV panel

A. *Interpretation of the result*

Figure 3 depicts the system output, which indicates the voltage of the PV, and it can be seen that it satisfy its reference voltage with very zero error, as shown in Figure 4. Figures (5,6 and 7) shows that the different electrical quantities (power, voltage, and current) of the PV generator output converge to its optimal values. According to the obtained simulation results shown in figures (8,9 and 10) and figures (11,12 and 13)it is obvious that the current, voltage and power follow their ideal operating values throughout the whole irradiation and temperature change profiles.

VI. CONCLUSION

Optimizing photovoltaic energy involves creating a high-performance control system capable of adapting to climatic variations. In this study a predective functional control algorithm, has been applied to the PV system. In order to implement the controller, we must using the discretized model of the photovoltaic system which is obtained with the MCR algorithm's identification. The simulation results showed a good performance in terms of tracking of the maximum power delivered by the photovoltaic panel in standard and variable metrological conditions, and demonstrate that the PFC algorithm capable of tracking variations in irradiation and temperature in order to achieve the maximun power point.

REFERENCES

[1] TJ. Hammons, "Europe: transmission system developments, interconnections, electricity exchanges, deregulation, and implementing technology in power generation with respect to the Kyoto protocol," 39th Int. Univ. Power Eng. Conf. 2004. UPEC 2004, IEEE, p. 1251–7, 2005. https://doi.org/10.1109/PES.2004.1373048

[2] H. Wang and F. Xu,"Flexible global carbon pricing study: A new method to establish the international cooperation on reducing carbon emission," 10th Int Power Energy Conf IPEC:300–4, 2012. https://doi.org/10.1109/ASSCC.2012.6523282.

[3] G. Eason, S. Al-Janabi, AF. Alkaim and Z. Adel, "An innovative synthesis of deep learning techniques (DCapsNet & DCOM) for generation electrical renewable energy from wind energy. Soft Comput," 24(14):10943–10962, 2020. https://doi.org/10.1007/s00500-020-04905-9

[4] H. Delavari1 and M. Zolfi, "Maximum power point tracking in photovoltaic systems using indirect adaptive fuzzy robust controller," volV)(0123456789,-().volV)https://doi.org/10.1007/s00500-021-05823-0(0123456789.

[5] R. B. Bollipo, S. Mikkili and P. K. Bonthagorla, "Critical review on PV MPPT techniques: classical, intelligent and optimisation," *IET Renewable Power Generation*, *14*(9), 1433–1452, 2020.

[6] A. BELKAID, I. COLAK, A. BELKAID and I. COLAK, "A Novel Approach of Perturb and Observe Technique Adapted to Rapid Change of Environmental Conditions and Load," https://doi.org/10.1080/15325008.2020.1793842

[7] A. Belkaid, I. Colak, K. Kayisly and R. Bayindir, " improving PV System Performance using High Efficiency Fuzzy Logic," Control th IEEE International Conference on Smart Grid, 17-19, 2020, Paris, FRANCE.

[8] C. Aoughlis, A. Belkaid, I. Colak, O. Guenounou and M. AklI, Automatic and Self Adaptive P&O MPPT Based PID Controller and PSOAlgorithm," 10th International conference On renewable Energy Research and Application (ICRERA) https://doi.org/10.1109/ICRERA52334.2021.9598489

[9] M. Kermadi, Z. Salam, A.M. Eltamaly and J. Ahmed, " Recent developments of MPPT techniques for PV systems under partial shading conditions," a critical review and performance evaluation https://doi.org/10.1049/iet-rpg.2020.0454

[10] M. Schwenzer, M. Ay, T. Bergs and D. Abel, " Review on model predictive control: an engineering perspective," The International Journal of Advanced Manufacturing Technology july 2021. https://doi.org/10.1007/s00170-021-07682-3,

[11] JB. Rawlings, "Tutorial overview of model predictive control," IEEE Control Sys 20(3):38–52, 2000. https://doi.org/10.1109/37.845037

[12] A.A. Stoorvogel and T.J.J. van den Boom, "Model predictive control," DISC Course Lecture Notes, DISC Delft, The Netherlands, January 2010.

[13] J.A. Rossiter and R. Haber, "The Effect of Coincidence Horizon on Predictive Functional Control," Processes,3, 25-45. 2015 doi:10.3390/pr3010025.

[14] J. Zhang, " Design ofanew PID controller using predictive functional control optimization for chamber pressure in a coke furnace," http://dx.doi.org/10.1016/j.isatra.2016.11.006

[15] Li. Shihua, Liu. Huixian and Fu. Wenshu, "An improved predictive functional control method with application to PMSM systems," International Journal of Electronics, 2016. DOI: 10.1080/00207217.2016.1196743

[16] S.N. Yahayab and B. Singhc, " Single-diode model and two-diode model of the PV modules: A comparison," IEEE international conference on control system. Computing and Engineering, dec, 2013, penang, Malaysie.

[17] A. Dehghanzadeh, G. Farahani, H. Vahedi and K. Al-Haddad, " Model predictive control design for DC-DC converters applied to a photovoltaic system," Electrical Power and Energy Systems, 2018. https://doi.org/10.1016/j.ijepes.2018.05.004

[18] J. Richalet, and D. O'Donovan,"Predictive Functional Control: Principles and Industrial Applications," Springer Science & Buisiness Media, 2009.

[19] N. Ouali, H. Lehouche, Y. Belkhier, and A. Achour, "Indoor Temperature regulation and Energy Consumption inside a Working Office in Building System Using a Predictive Functional Control," Energy sources part A recovery utilization and environmental effects, December 2021. http://dx.doi.org/10.1080/15567036.2021.2017517

[20] L. D. Landau. "Introduction to adaptive control". Edition Springer. London. 1-33. 2011.