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Intelligent Control Of A Hybrid Energy Source Based On Solar Energy And Battery

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Abstract-- A dynamic modeling of a hybrid source system composed of a photovoltaic source and a battery source is presented herein. The proposed hybrid structure is composed by a PV array as a main source, a PV DC-DC boost converter, a DC bus, a Battery and its bidirectional DC-DC converter and a RLE load modeling the electric motor. The DC bus is powered by the PV system through its DC-DC boost converter that keeps the bus voltage to the value of its reference. The Battery is connected to the DC bus through its bidirectional DC-DC converter.

The role of the PV Panel is to provide power to the load; the Battery has the role to provide the extra power required by the load during transients and to recover the energy generated by braking.

A fuzzy logic system has been used as stand-alone controller, based on the flatness property for dc grid voltage regulation. Fuzzy logic has been utilised mainly to adapt the controller parameters to improve overall system robustness while maintaining stability in the control. This is the key innovative contribution of this research paper.

Index Terms— Fuzzy logic, Flatness, Hybrid source, Photovoltaic,

I. INTRODUCTION

The whole world is increasingly choosing to replace fossil fuels with renewable energy sources. Among the factors driving people to pre-emptively seek out different sources of energy are fears about a reliance on fossil-fuel imports, resource depletion, and anthropogenic climate change. [1] However, renewable energy sources such as photovoltaic (PV) solar energy rely heavily on the climate and weather condition. As a consequence, the available power is intermittent and stochastic. So, multiple renewable energy sources that are mutually complementary could be combined to maintain continuous power delivery to the load. Such a system is referred to as a hybrid power system. [2]

One application for this combination is hybrid vehicle. A combination of Photovoltaic (PV) and Fuel Cell (FC) sources forms a good pair with promising features for hybrid vehicles applications.

Obviously, the slow response of the FC needs to be compensated with a battery. [3] The battery system provides power to the vehicle during periods of peak power demand such as vehicle acceleration or travelling at a high constant speed. [4]

In this work, a hybrid power generation system is studied, consisting of the following main components: a PV array as a main source, a PV DC-DC boost converter, a DC bus, a Battery and its bidirectional DC-DC converter and a RLE load modeling the electric motor.

The PV Panel supplies the base energy while battery supplies peak power for fast acceleration and captures the braking energy for regeneration.[4], [5], [6]

Moreover, the work presented here also extended the mentioned system by proposing a novel framework using intelligent fuzzy logic-based flatness control approach.

The rest of the paper is structured as follows: Section II describes the hybrid energy system, an overview of the problematic in question and modeling of the power plant that is studied in this work. Section III presents the proposed design of integrated fuzzy logic controller. Section IV presents simulation results for the proposed system. Finally, the paper ends with concluding remarks in the same section.

II. SOLAR/HYDROGEN POWER PLANT

A. DYNAMIC MODELING

The converter topology for the renewable hybrid system is depicted in Fig.1 and Fig.2.

Fuel cell (FC) technologies are expected to become a suitable substitution for conventional power generators and grid utility for residential applications, as they are more efficient and environmentally friendly in comparison with other conventional power generators. Nevertheless, in order to provide power demand of a residential load, it may be required to over design fuel cell power module which is not economically advisable. Furthermore, due to the sluggish dynamic response of fuel cell in transient events, there will

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be load following problem. Not to mention diesel fuel consumption and energy costs that makes FC less effective. [7] In such cases, a renewable energy, such as PV Panel, has been incorporated instead of FC in order to overcome these problems

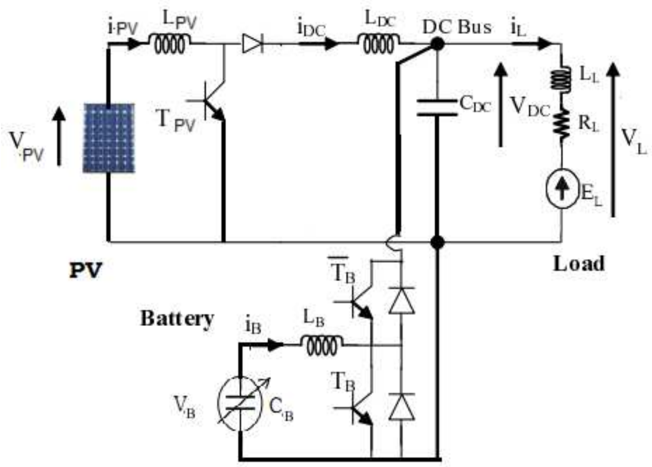

Fig.1 PV/Battery hybrid system configuration.

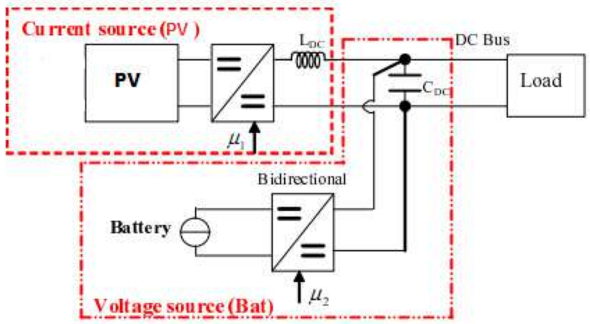

Fig.2 Hybrid sources structure.

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After the resolution of this problem, another one arises: PV Panel does not work properly under transient conditions. The sharp changes in the load power demand cause severe electrochemical and thermal non uniformities in PV Panel. These non-uniformities increase the degradation rate of PV Panel and reduce its expected life span. To mitigate these detrimental effects, a battery bank is used along with PV Panel[4], [5]. We obtain as a result a hybrid system of a PV Panel and battery shown in figures above.

B. COMMAND STRATEGY

The proposed hybrid structure given by Fig. 2 is composed by a PV array as a main source, a PV DC-DC boost converter, a DC bus, a Battery and its bidirectional DC-DC converter and a RLE load modeling the electric motor. The DC bus is powered by the PV system through its DC-DC boost converter that keeps the bus voltage to the value of its reference. The Battery is connected to the DC bus through its bidirectional DC-DC converter.

The role of the PV Panel is to provide power to the load; the Battery has the role to provide the extra power required by the load during transients and to recover the energy generated by braking.

Even with higher efficiency, the goal remains to maximize the power from the PV system under various lighting conditions.

Maximum Power Point Tracking (MPPT) is used to obtain the maximum power from this system. [4], [5], [8]

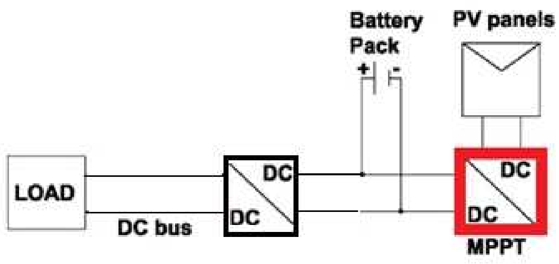

Fig. 3 Hybrid system for power generation from PV panels with an MPPT device

III. DESIGN OF INTEGRATED FUZZY LOGIC CONTROLLER

Fuzzy control algorithms offer many advantages over traditional controls because they give fast convergence, are parameter insensitive, and accept noisy and inaccurate signals. In recent years, it has been used in many control applications where the system is complex.

The control objective in this study is to regulate the dc bus $\boldsymbol{v_D}$ voltage or the dc bus energy $\boldsymbol{E_D}$.

A. CONTROL DESCRIPTION

The control objective is to regulate the dc bus voltage v_{DC} or the dc bus energy E_{DC}.

A fuzzy control system can be considered as a real time expert system, which performs the control tasks in a human-like way and also can technically deal with the approximated information to control systems that have uncertain characteristics. The dc bus voltage is unstable. So, it is difficult to control it using simple PID controller. Because the parameters of the conventional PID controller are fixed during control, it cannot respond in various situations. For this reason, the PID method is not suitable with the dc bus voltage. Specially, fuzzy logic is useful to find optimum adjustments of the controller. Moreover, the fuzzy controller can improve the stability of dc bus voltage. [16]

The controller contains a Takagi–Sugeno (T-S) inference engine and two fuzzy inputs: the energy error e_1 ($= E_D - E_{DC}$) and the differential energy error $\dot{e}_1$, which are carefully adjusted using the proportional gain K_P and the derivative gain K_D, respectively. In addition, the fuzzy output level can be set by the proportional gain K_0(Fig. 6). [3]

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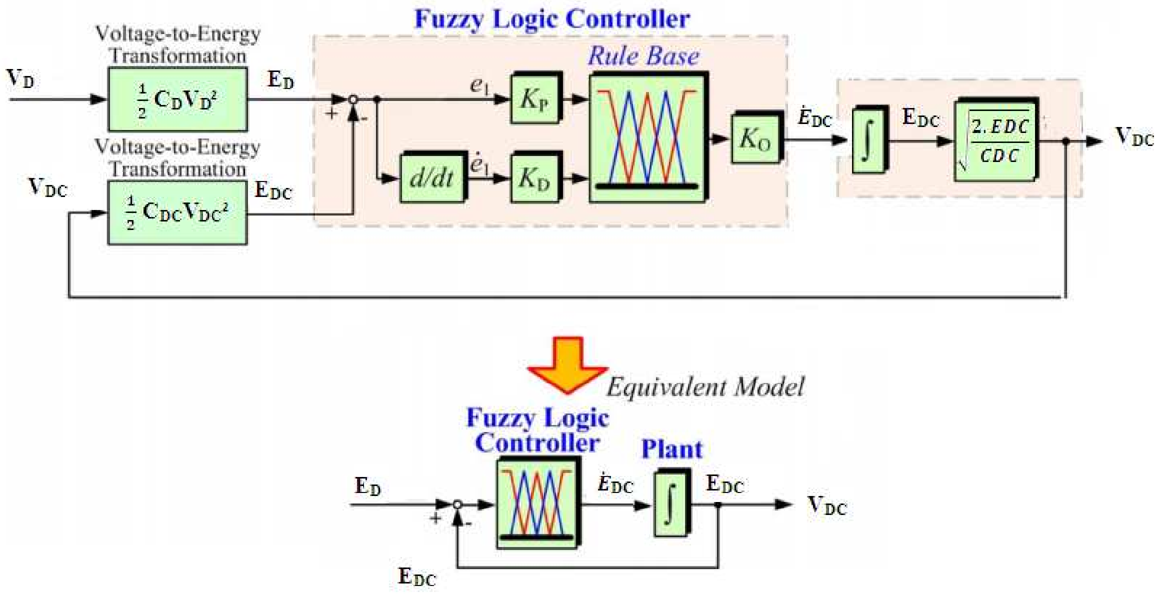


Fig. 6. Control law based on the differential flatness theory of the dc-bus energy regulation for Hybrid Energy Source based on Solar Energy

IV. PERFORMANCE VALIDATIONS

To authenticate the performance of the modeling and control system, a model was implemented in Matlab / Simulink.

We still do not forget that the main purpose behind this work was to improve the results that were obtained before without the use of fuzzy logic controller.

Therefore, and in order to give a rational comparison between the two processes, we show experimental results obtained for both methods.

Main numerical values used in the simulation are shown in the table below:

C_{BAT}	Battery's Capacity	125F
R_{BAT}	Battery's Internal resistance	0.01Ω
V_{DCRef}	Bus reference voltage	40V

Figure 8 shows the response of the system to the DC Bus voltage reference changes V_D&V_{DC}. The DC Bus voltage tracks well the reference. A very low overshoot and no steady state error are observed.

Figure 9 shows the battery voltage and current V_B& I_B response in presence of the DC Bus voltage variation. The battery supplies power to the load in the transient and in the steady state no energy is extracted since the battery current is null.

It can be seen from Figure 10 that the battery supplies and absorbs the transient peak power.

Figure 11 shows results for both controllers (before and after using the fuzzy-flatness based control).

According to the results obtained and shown in figure 11, we can say that the proposed fuzzy-logic controller shows good stability and an optimum response (no oscillation and short settling time) for the regulation of the dc bus voltage to the desired reference of 40 V.

Indeed, PID technique gives high overshoot and settling time with zero steady state error. The Fuzzy Logic controller gives no overshoot, zero steady state error and smaller settling time than obtained using PID controller. The simulation results confirms that the proposed Fuzzy logic controller with simple design approach and smaller rule base can provide better performance comparing with the PID controller.[17] [18]

From these results, we conclude that fuzzy- control provides better performance than the initial model. Although dynamic response of the linear control law could be improved relative to that shown in the figures, this enhancement comes at the expense of a reduced stability margin (overshoot and oscillation).

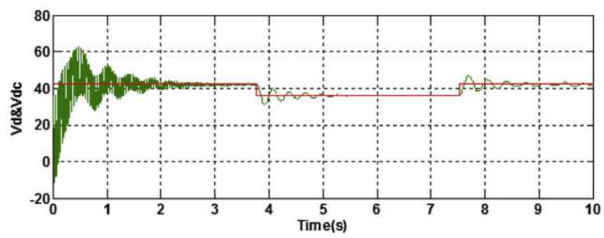
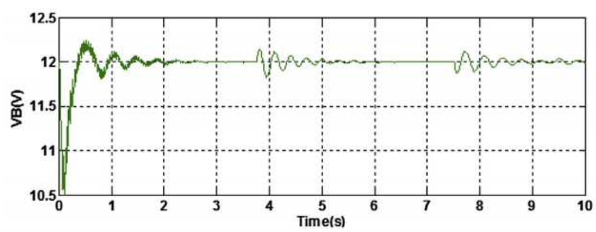


Fig. 8. DC Bus voltage and its reference.



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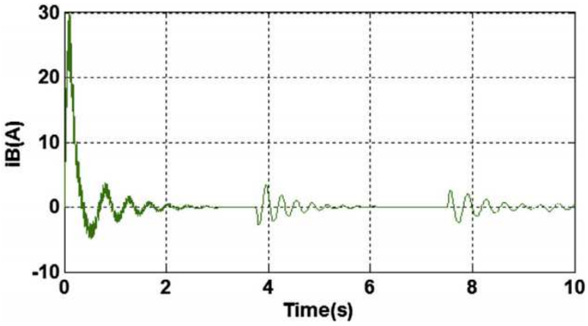


Fig. 9. (a) Battery voltage. (b) Battery current.

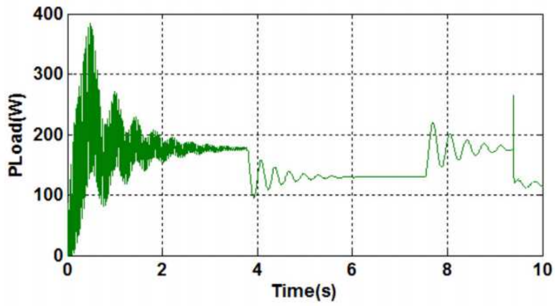
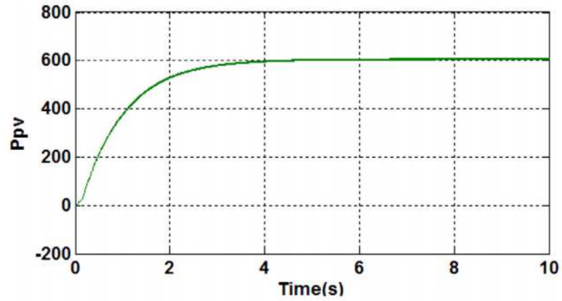
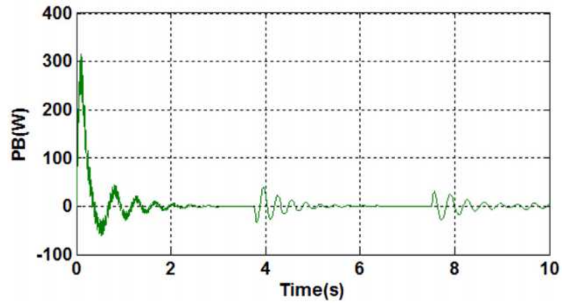


Fig. 10. PV power, load power and battery power.





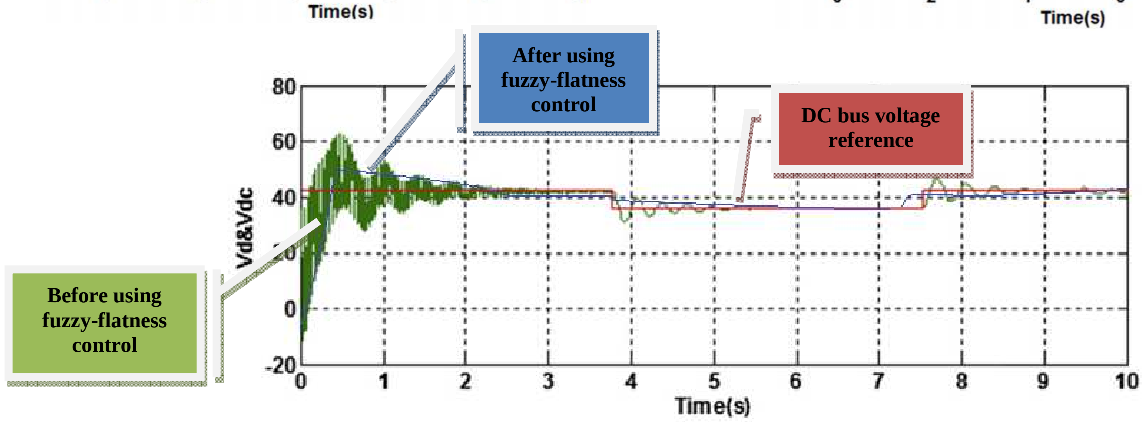


Fig. 11. Comparison between both controllers (before and after using fuzzy-flatness control).

V. CONCLUSION

Increasingly, hybrid energy systems are recognised as a viable alternative to reticulated grid supply or fuel-based remote area power supplies. Experience has shown that conventional diesel systems are often not flexible enough to respond to changing load demand and varying operating conditions. In contrast, renewable energy sources and batteries are inherently modular and can generally be upgraded when the long-term load demand increases, without changing the overall configuration of the system.

A dynamic modeling of a hybrid source system composed of a PV source and a battery source is presented in this work.

Its working principle, analysis, and design procedure were presented.

The PV generation is intermittent for depending on weather conditions. Thus, the battery energy storage is necessary to help get a stable and reliable output from PV generation system for loads and improve both steady and dynamic behaviours of the whole generation system; The PV is the main source, while the Battery serves as storage device (or an auxiliary source) to compensate for the uncertainties of the PV source in the steady state and transient state.

Another key contribution of this paper is to improve the quality of achieved results.

For this purpose, an intelligent fuzzy logic control is applied to the PV/Battery hybrid source. By using the intelligent fuzzy logic control for dc link stabilization, we proposed simple solution to the fast response and stabilization problems in the non linear power electronic system. This strategy is based on a standard dc link voltage regulation.

Fuzzy controller was implemented by using MATLAB/Simulink as an application tool which provides us the specialized tool boxes for Fuzzy Logic. Simulation results authenticated the validity of the adopted control

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algorithm. Indeed, fuzzy controller makes the tracking error sufficiently small enough to achieve lesser vibration and significantly improves the system performance without changing the controller algorithm or increasing the cost or complexity of the system.

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