A Discrete Event Simulation Approach for Modeling and Simulation of Hybrid Renewable Energy System

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Abstract: With penury natural resources, rising energy costs, increasing traffic congestion, and environmental pollution, many cities. hybrid energy systems hold the potential for increasing energy efficiency, decreasing costs of energy use, decreasing the carbon footprint by including renewable resources, and trans-forming the role of the occupant. At the crux of the hybrid system is an efficient electric energy management system that is enabled by emerging technologies in the electricity grid and consumer electronics. In this paper, we will propose a methodology for the management and control of energy that we are proposed a discrete event system for modeling based on Petri Nets approach capable to management via calls of public Network in the case of need and manage the surplus of renewable energy.

Keywords: Energy management system, smart girds, solar energy, hybrid energy systems, discrete event system, Petri net.

1. INTRODUCTION

The depletion of fossil resources, more or less long term, crude prices soaring and the fight against greenhouse gas emissions make urgent control of consumption and diversification of energy sources, a fact that calls more than ever the development of renewable energies. And to mitigate the randomness of a given renewable energy field, we can multiply the sources of different types. then obtained a multi-source system. the renewable energy based generators (photovoltaic panels, wind turbines.) have a random electric production, which is directly dependent upon the weather conditions (wind speed, illumination, temperature.). Consequently, the adequacy between the required power (for the consumers) and the electrical PV production must be provided by conventional generators. Actually this compensation power is given by the fossil based generators. In islanded electrical networks and micro-grids this situation is more critical as fossil based generator have a limited power capacity. Therefore, the development of renewable energy based generators is quite naturally limited with a penetration ratio of about 30%.

Unfortunately, in addition to their important solution, they are dynamic, stochastic and complex systems, this makes their modeling and analysis very complicated. Hybrid systems, more or less complex, requiring an adapted control strategy to operate in the best conditions the different sources and use energy efficiently. In this context our research will concentrate to develop a mathematic methodology of hybrid energy management system of hybrid systems in a distribution network with integrated high rate of renewable. The proposed system will be based on photovoltaic array (PVA) generation, electrochemical storage, and grid connection; it is assumed that EV have a direct access to their DC charger input, the strategy of power management will be proposed allows self-consumption according to PVA power production and storage constraints, and the public grid is seen only as back.

Renewable and distributed electricity production is now steadily increasing so that their grid integration associated with an energy management system is more necessary than ever [Cunty G. 2001], [Aisa A. et al. 2023]. In urban areas, there is a significant development of small plants of decentralized photovoltaic (PV) power production, therefore associated or integrated to buildings. PV energy purchase conditions lead quite naturally these applications to a grid-connected system with a total and permanent energy injection. However, due to the technical constraints related to the absence of the smart grid which should integrate energy management, this development could be restrained by the power back grid capacity. In response to these technical constraints, research works are being currently carried out on grid integration of renewable energy generation, by developing new supervision strategies like a high level energy management control. In Ref. [Masotti et al., 2023] [Zidani C. et al. 2003] a distributed energy management solution by means of multi-agent systems is proposed as an application for hybrid power sources. Other studies like Ref. [El Moudden A et al, 2015] propose an energy management following some operating modes whose design is based on interpreted Petri Nets (PN). In Ref. [Ricaud A. 1997], a PV active generator producing power according to the smart grid demand is proposed, but high-speed communication is necessary for a real-time power balancing. The authors of Ref. [Dahbi M. Et al. 2007] [] propose an optimal power flow management with predictions, which separates the rule based energy management strategy and optimal management. An improvement can be achieved as multi-layer control structure, each layer with a different function. Rule-based energy management strategy, interfaced in the basic layer, can develop advanced energy management control with more flexibility.

In this context, for buildings equipped with PV power plant, an alternative solution is the multi-source power local generation, whose produced energy is intended primarily for self-feeding, with a grid connection for further supply in case of need and for sale of excess energy. By means of a smart grid communication device, this system takes into account the availability, needs and vulnerability of the electric grid. This paper focuses on energy management modeling based on interpreted PN for a multi-source power generation with smart grid interaction. This system is designed for tertiary buildings equipped with local renewable electricity sources. Firstly, the overview of the global system is presented as a multi-source power system coupled with a supervision system dedicated to energy management. Then, the behavior modeling of the supervision and the power system components behavior modeling (PV generator, storage, public grid and load) are proposed. Finally, numerical simulation results confirm the relevance of such integrated energy management.

2. STRUCTURE OF THE MULTISOURCE POWER STATION

The proposed hybrid system is based on a photovoltaic array (PVA) constituted of several panels is connected to the continuous bus via a DC/DC converter. This converter controls the panel working and thereafter the generated power, wind system is constituted of a wind turbine coupled to a multi-polar MPMSG and controlled converter AC/DC. The control of the converter permits to control the voltage of the MPMSG and indirectly the power working point of the wind turbine. The current produced by the wind conversion system are injected in the continuous bus, electrochemical storage, and grid connection; and it allows self-consumption according to PVA production and storage constraints, while the public grid is seen only as a back-up. Therefore the energy required for the load is superior to the hybrid energy produced by renewable sources, at the time it called on electric network to complete the production and satisfy the need. These resources are connected to a common DC voltage bus through their dedicated DC/DC chopper (see the Fig. 1). The grid connection is performed by a three-phase inverter.

This hybrid system should allow supplying a small community a region where the weather is similar to the Shelli region. Using standard estimates based on an average consumption of a house, the average community consumes nearly *4 kW* which is about *35Mwh* per year. An excerpt from the consumption profile of a week is presented Fig. 2 and it come standard data available [Déruelle O. 2002]. Note that the load profile is not the same throughout the year and especially changes in the seasons.

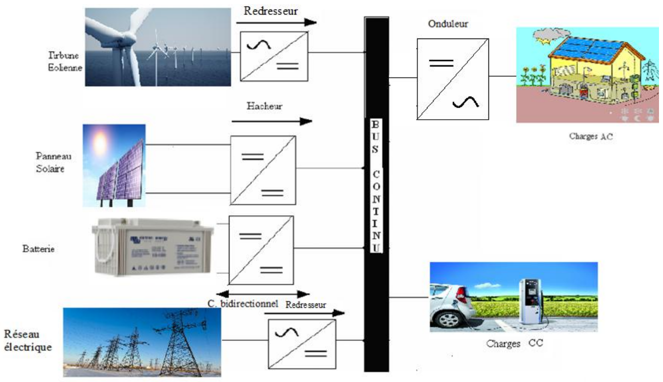


Figure 1. Hybrid energy system

In our work, the charge represents the energy demand of a house in Algeria. To determine the power needs, we conducted investigations into this house with the seasons and time of day. The application consists mainly of lighting, and appliances (refrigerator, washing machine, electric water heaters, microwave oven, mobile phone chargers, plasma TV, laptop, etc.). The results of the survey are summarized in the following table 1:

Table 1. electrical household appliances Synthesis

Device types.	power consumption W/h	Number	Operating time in 24 h (h)	Total power consumption for 24 h (W)
lamp	75	40	15	750
Pl. TV	10	4	5	50
fridge	80	1	24	1920
eletric water heaters	1500	1	2	3000
microw	800	1	0.5	400
Phone charger	5	5	20	100
Lap-top	20	3	10	200
The maximum power consumption for 24 hours				6795

Estimated demand: we can establish the following assumptions

- From 0h to 6h: no professional activities, only the yard lights and refrigerators, portable chargers for power P = 950W,
- From 6 am to 16h: economic and educational activities, only the refrigerator and electric water heaters, a power P = 410W,
- From 16h to 20h: end of school activities and end of work for workers, and PC are on the refrigerator, microwave, electric water heaters, the power P = 4950W
- From 20h to 23h: dusk and no professional activity takes place, almost all the electrical equipment is working, the power consumption is at its peak and is about P = 6100W.

3. MODELING OF A HYBRID SYSTEM BASED ON PETRI NETS

Among the formalisms used to model the dynamic systems, Petri nets are one of the graphical and formal specification techniques for the description of the operational behavior of the systems [Benarbia T. 2013][Benfekir A. 2013].

They are widely used in a number of different disciplines including engineering, manufacturing, business, chemistry, mathematics, and even within the judicial system. A Petri net with inhibitor arcs can be defined as: *PN = (P, T, Pré, Post, Inhib, M0),* where: *P = {p1, p2, ..., pn}* is a finite and non-empty set of places represented by circles; *T = {t1, t2, ..., tm}* is a finite and non-empty set of transition

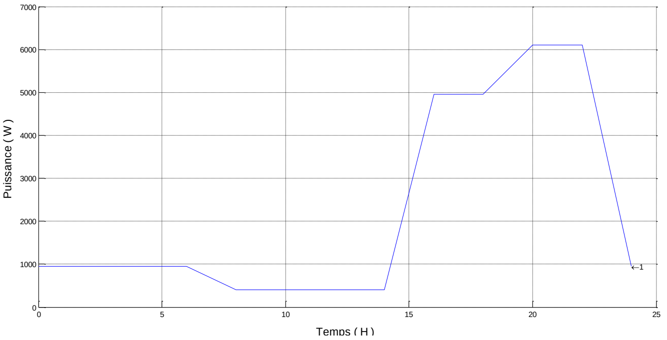


Figure 2. Evolution of the power required by the load with time.

Pre: *(P×T)→N* is an input function that defines directed weighted arcs from places to transitions, where *N* is a set of nonnegative integers, *Post*: *(P×T)→N* is an output function which defines directed weighted arcs from transitions to places, *Inhib*: (*P*×*T*)→*N* is an inhibition function that defines inhibitor weighted arcs (circle-headed arcs), and M_0 represents the initial marking (initial distribution of the tokens in the places). The set of input places and the set of output places of a transition t_j are denoted by ${}^{\bullet}t_j$ and $t_j{}^{\bullet}$, respectively, and ${}^{\circ}t_j$ represents the set of places connected with t_j by inhibitor arcs. The weights of an input arc and of an output arc are respectively denoted by $Pre(p_i,\ t_j)$ and $Post(p_i,\ t_j)$, and the weights of an inhibitor arc is denoted by $Inhib(p_i,\ t_j)$.

- A transition t_j is said to be enabled if and only if:

$$\forall p_i \in {}^{\bullet}t_j, M(p_i) \geq Pre(p_i, t_j) \qquad (1)$$

- A firing of an enabled transition t_j in marking M' results in a new marking M':

$$\forall p_i \in P, M'(p_i) = M(p_i) - Pre(p_i, t_j) + Post(p_i, t_j) \quad (2)$$

- *Inhibitor arcs:* Graphically, an inhibitor arc is represented by circle-headed arcs. It can be used to stop a transition from being enabled if the place contains one or more tokens. Consequently, the inhibition function, noted *Inhib* (where *Inhib*(*pi, tj*) is the weights of the inhibitor arc from *(pi* to *tj)* modifies the enabling rules of the Petri net. Thus, in addition to the enabling condition (1), a transition *tj* is said to be enabled if and only if:

$$\forall p_i \in {}^{\bullet}t_j, M(p_i) \leq Inhib(p_i, t_j) \qquad (3)$$

The energy management model takes into account the hybrid nature of the system, the system consists of the wind source, PV, electrochemical storage and the grid. Management of sources is a function of the power demanded by the load, the energy produced by the hybrid system and the battery level.
The behavioral modeling of power system components is proposed by means of PN formalism. By identifying possible physical states of the system, this step allows the subsequent design of energy management.
In our paper we will present three models, of management switch between the public network and the hybrid system, the objective is to modeling the switching of the moments of call of *GP* in function of the energy demanded by the load and the flow of the hybrid energy produced, the second model is focused on the switching mode between the power supplied by the *PG* to complete the lack of hybrid power and the power to be stored and to inject to the *PG*.

3.1 Switching model between the public grid and the hybrid system

Because of the intermittent nature of renewable energy sources the generated power is not always sufficient available at the appropriate time. Two scenarios can be imagined, this model describe the switching inter the public grid power and the hybrid power according the demand power of load and the availability of renewable sources energy. Graphically, an inhibitor arc is represented by circle-headed arcs. It can be used to stop a transition from being enabled if the place contains one or more tokens. Consequently, the inhibition function, noted *Inhib*, modifies the enabling rules compared to an ordinary Petri net (without inhibitor arcs).

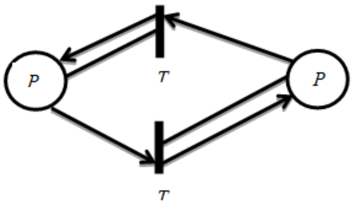


Figure 3. Petri net model of switching PG/HS

Our model (Figure 3) taking into account new decision parameters of the system and all specific situations:

Table2. Interpretation of the transition and place of model

Ph	Represents a state of system. Its marking *M(Ph$_i$)=1* corresponds that the power demanded by load Pl is satisfied by the hybrid system *HS=1* and does not call to *PG=0*.
Pg	Represents a state of system. Its marking *M(Pg)=1* corresponds that the load demand will be satisfied by the hybrid system and completed by *GP*, therefore appealed to *GP*.
Th	Decision of call of *Sh* if the load demand energy less than the energy product by hybrid *Ph≥ Pl.*
Tg	Decision of call of *GP* if the load demand energy great than the energy product by hybrid *Ph≥ Pl.*

The (Fig. 3)and the (Tab. 2) allow readers to quickly gain an understanding of the Petri net model. A closer look at this model shows tow place Pg represents the call of public grid and Ph represents the call of hybrid system.

- When $Ph \geq Pl$, then the demand will be satisfied by hat the hybrid system, hence the Switch state hybrid $HS = 1$ and the network provider $PG = 0$.
- When $Ph < Pl$, then the demand will be met mutually by the hybrid system and public network, where the state $HS = 1$ and $PG= 1$.

3.2 Switching model of power stoked and power demanded from PG

In this model we present the mode of switching between the power requested from the *PG* and the power stoked. When the energy provided by hybrid system is laisse than the energy demanded by load, the switching calls the supplement energy for complete the sufficient *Pdg* and stop the storage of energy, in the invers case the system stop the call of *Pdg* (supplement power) and storage the energy *Ps* in condition $Pl < Ph$ see the (fig.4) as below.

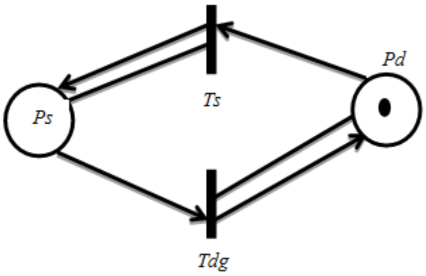


Figure 4. Petri net model of switching supplied Power / stored Power

The (Fig. 4) and the (Tab. 3) allow readers to quickly gain an understanding of the Petri net model. A closer look at this model shows tow place *Pdg* represent the call of supplement power and *Ps* represents the call of storage or buy of power.

Table3. Interpretation of the transition and place of model

Pdg	Represents the requested power from network, Its marking $M(Pdg)=1$ corresponds the call of supplement power from *PG* (the quantity of power needed to satisfied the load request).
Ps	Represents the power stored or buy. Its marking $M(Ps)=1$ corresponds the power stored or buy, in condition the power demanded by $load < Ph$ (help to calculate the stored power).
Ts	Decision of call for storage or buy of power if the $Pl<Ph$.
Tdg	Decision of call of supplement power *Pdg* if the load requested energy great than the energy product by hybrid $Ph \geq Pl$.

- When the power required $Ph \geq Pl$ is less than that produced by the hybrid system; we no longer need the power supplier and a resulting power Ps can be stored.

- When power required is greater than that produced by the hybrid system, we call a supplement power from network to meet demand.

4. SIMULATION AND ANALYSIS

The Matlab/Stateflow environment allows the graphical representation of the results (fig. 6), (fig. 7) and (fig. 8) ; the developed model provides all the parameters of operation of the components of the whole.

4.1 Petri Net model simulation of switching model between the PG and HS

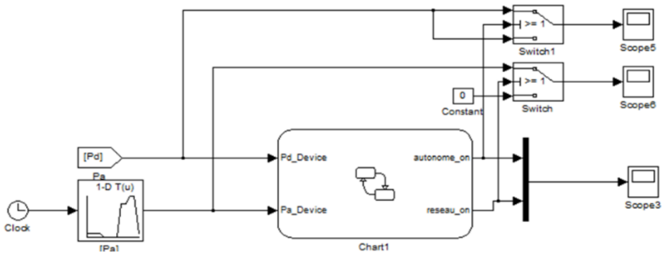


Figure5. Power model of Ph and Pl under Matlab/Simulink/Stateflow

This is due to the priority given to *HS*. There is always a certain production of *HS* but this production turns out to be less than the demand, at that time there will be a firing of transition *Tg* to call to the public grid network in order to Complement this production, and thus satisfy the demand. Otherwise, when this production is greater than the demand, only HS satisfy the demand.

4.2 Petri Net model simulation of Switching model between power supplement Pdg and power stoked Ps

Text From the figure below indicates Stored power Ps / Required power to the public network Pgm we note that there are two moments:

- From 0 h to 16 h the power Ps reaches a value $Max\ Ps = 4290\ W$ and $Pgm = 0\ W$. by which $Ph > Pl$.
- From *16h to 23h* the power *Pdg* reaches a value $Max\ Pdg = 1400$ *and* $Ps = 0\ W$.

According to these results, it is concluded that the power stored for the whole day is greater than the power demanded by the supplier network and therefore our hybrid system is more reliable and more economical and permanent to satisfy the demand and to minimize the dependence on the public grid network.

6. CONCLUSIONS

This work is part of our larger project on dynamic modeling, simulation and performance optimization of hybrid energy systems. Our approach is the first one in the literature dedicated to these systems by using Petri nets with inhibitor arc. In this paper, we present a new model taking into account new decision parameters and all specific situations that arise during the control and the balancing of the bike stations. The authors believe that this new area of research has significant promise for the future to help planners and decision makers in determining how to implement, and operate successfully these complex systems.

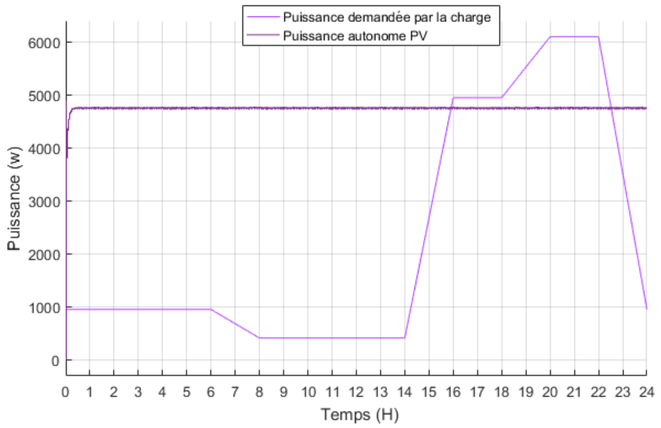
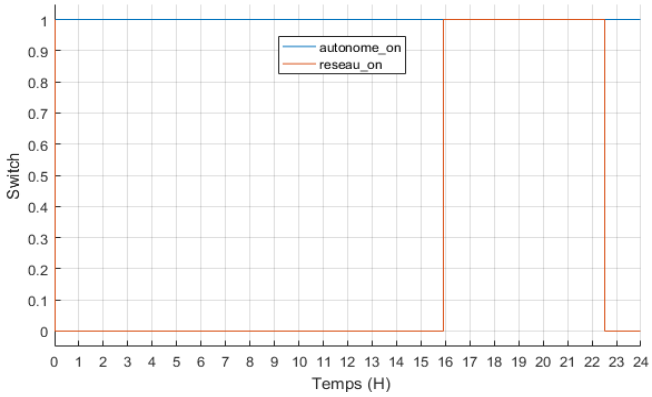
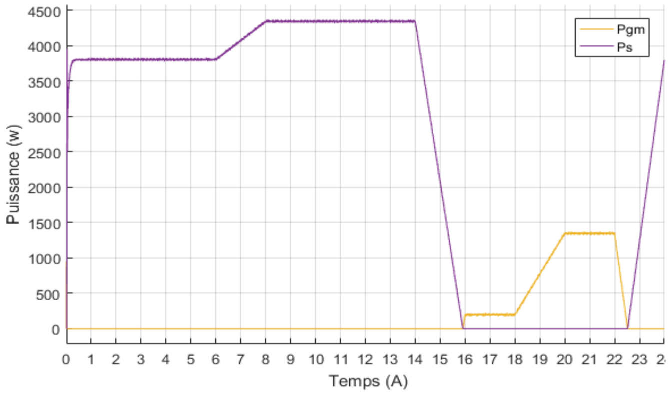


Fig 6: power demanded by load/ Power produced by hybrid system.



7: Switch between hybrid system HS and public grid PG.



Figire8. Power stored Ps / Required power to public network Pgm.

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