TAF
Journal of Advances in Technology and Engineering Research
2015, **1**(1): 35-39
JATER

Piecewise affine modelling of hybrid control systems in solar cell-battery-supercapacitor

Novan Agung Mahardiono [1, *], Imam Djunaedi [2]

[1] Technical Implementation Unit for Instrumentation Development-Indonesian Institute of Sciences Kompleks LIPI-Jl Sangkuriang, Gd 30, Lt 3, Bandung, Jawa Barat 40135, Indonesia

[2] Research Center for Physics–Indonesian Institute of Sciences, Kompleks LIPI-Jl Sangkuriang, Gd 60, Lt 3, Bandung, Jawa Barat 40135, Indonesia

Index Terms:
Battery
Hybrid
Piecewise Affine
Solar Cell
SuperCapacitor
Modeling

Received: 28 September 2015
Accepted: 3 October 2015
Published: 15 October 2015

Abstract—This paper presents a piecewise affine (PWA) modeling of hybrid control systems in Solar Cell-Battery-Super capacitors. This model aims to design continuous dynamics and discrete dynamics of hybrid systems using PWA, a special model. A hybrid system is a combination of a continuous and discrete system that consists of a continuous interaction between the dynamics represented with differential equations and discrete dynamics represented by automata or network Petri. Current research is about developing a hybrid control in which the hybrid system is viewed as a graph, where edges represent discrete transition and vertices represent continuous activity. In contrast, discrete dynamics occur when there is a transition between the vertices. A hybrid control invariant set for the PWA model of the system is computed. At the PWA, models have been developed through the modeling program MATLAB using the languages HYSDEL (Hybrid Systems Description Language). This guarantees that the proposed model always provides safe evolutions of the system.

I. INTRODUCTION

The development of hybrid system is currently quite significant. The hybrid system is a combined system of continuous and discrete. The system has been developed since 1966 by Witsenhausen [1]. In the paper, Witsenhausen studies continuous systems that interact with elements of discrete relay. Great interest to develop models, methods of analysis, and hybrid system control method has generally emerged in the early '90s and pioneered the science community and control systems with computer science community who needed a new framework to analyze the complex systems. The resulting models were developed separately and used for different applications. Analysis method and control design have also been developed for each model, in terms of both theoretical and numerical computation. Hybrid systems can be found in many applications, especially in devices that use switching component and computer algorithms in its regulation [2]. In this paper, Piecewise Affine (PWA) is one of the models of the hybrid system that is designed to run energy management Solar Cell-Battery-

*Corresponding author: Novan Agung Mahardiono
E-mail: nova001@lipi.go.id

Supercapacitor in which continuous and discrete dynamics occurr.

Hybrid system of Solar Cell-Battery-Supercapacitor is the development of energy resources to produce high power and is able to change suddenly according to the high load on the application as shown in Figure 1.

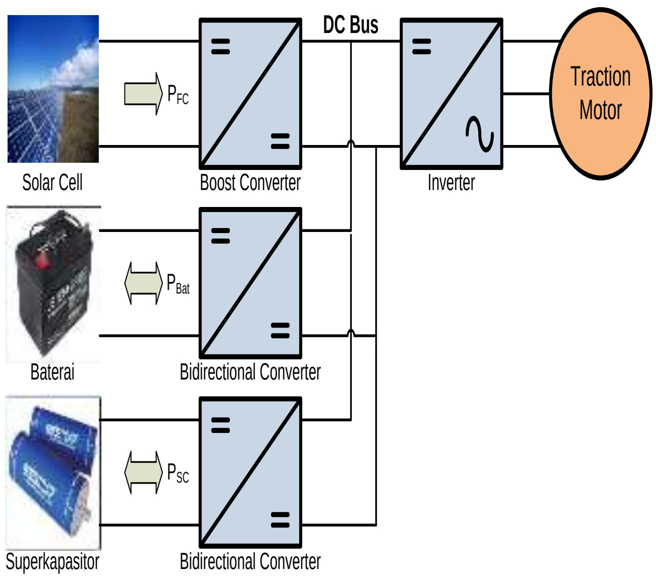

Fig. 1. Block diagram of a hybrid system of solar cell-battery-supercapacitor.

Bus voltage desired in this hybrid system is 12 Volt, whereas, the solar cell itself has a slow response to rapid load changes and the resulting power density is not high enough. Therefore, solar cells require another energy source to improve the response. An additional energy source that is currently considered effective enough to meet the above requirements are supercapacitors and batteries.

II. LITERATURE REVIEW

A. *Hybrid System Models*

As a combination of continuous and discrete systems, the interaction between the dynamics of continuous and discrete of the hybrid system should be represented in mathematical models. Hence the behavior of the system can be analyzed and control strategies can be designed. In the last ten years, several models of hybrid systems have been developed by researchers. At [3], Alur, and colleagues developed a model of Hybrid Automata, in which the hybrid system can be viewed as a graph, where edges are representing discrete transition and vertices are representing continuous activity. Meanwhile, the discrete dynamics appear if there are transitions between vertices. An example of Hybrid Automata model can be seen in Figure.

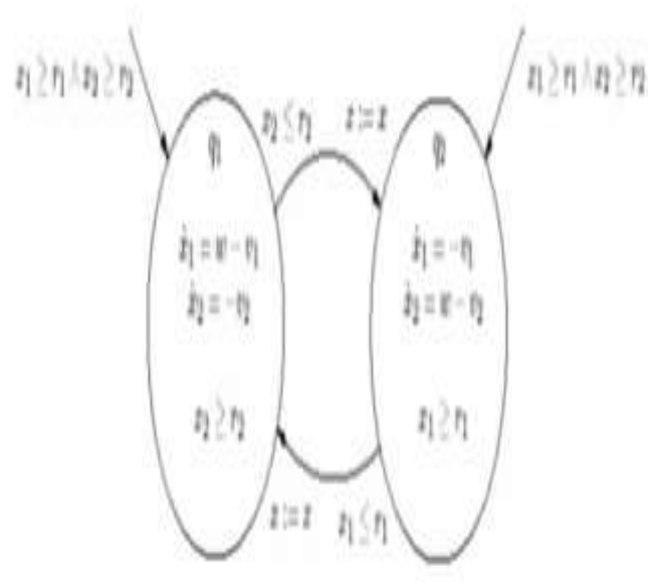

Fig. 2. Example of hybrid automata.

Another modeling framework is continuous plant supervised by digital automata [4]. This model can be shown in Figure 3.

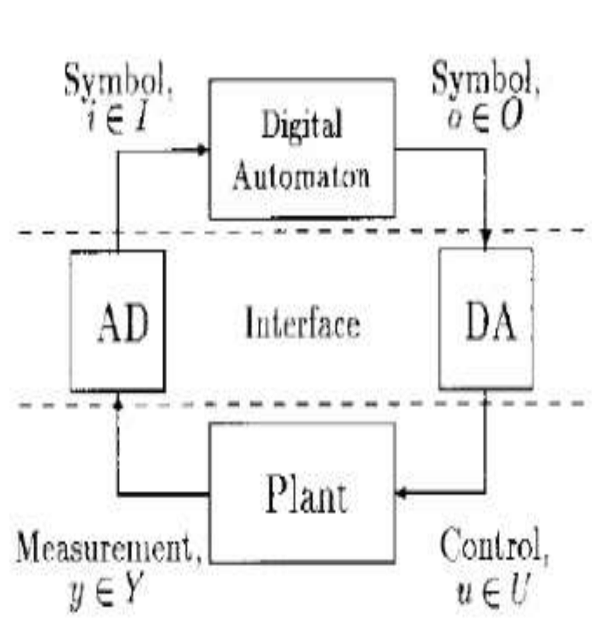

Fig. 3. Continuous plant supervised by digital automata [4].

ISSN: 2414-4592
DOI: 10.20474/jater-1.1.5

Similar to this model, [5] proposed Discrete Hybrid Automata (DHA) as shown in Figure 4.

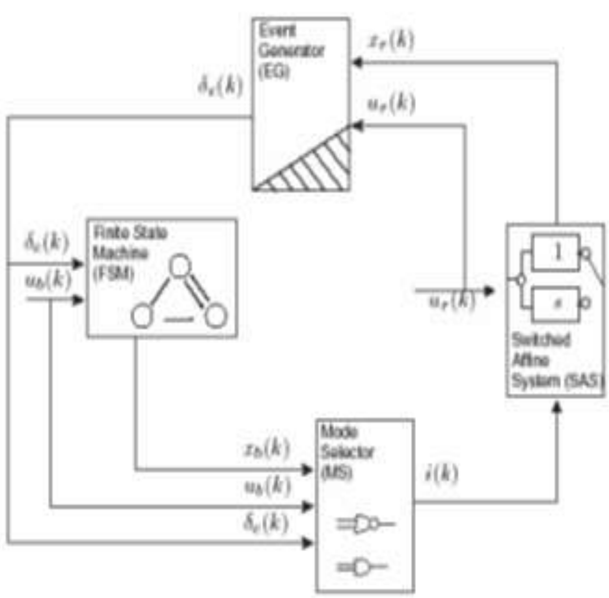

Fig. 4. Discrete hybrid automata [5].

Corresponding to continuous plant supervised by digital automata, DHA interface is viewed as Event Generator (EG) and Mode Selector (MS), automata is viewed as Finite State Machine (FSM) and continuous plant is viewed as Switched Affine System (SAS). Note that there is modeling program for DHA called HYSDEL (Hybrid System Description Language) [5]. HYSDEL program provides compiler to transfer DHA into another hybrid model for further computation. The above mentioned models are very general. The other hybrid system models are more specific where the theoretical and numerical computations have been developed. There were other models developed as well like Piecewise Affine (PWA), Beberapa model yang lain diantaranya adalah Mixed Logical Dynamical (MLD), Linear Complementary (LC), Extended Linear Complementary (ELC), Max-Min-Plus-Scaling (MMPS). Several studies have been developed for these models including designing models equivalence hybrid system [6].

B. Piecewise Affine (PWA) Models

Piecewise affine (PWA) model is defined as [7]:

$$x(k+1) = A_i x(k) + B_i u(k) + f_i \quad (1)$$

$$y(k) = C_i x(k) + D_i u(k) + g_i \quad (2)$$

$$\forall i: \begin{bmatrix} x(k) \\ u(k) \end{bmatrix} \in \Omega_i$$

where $x(k) \in R^n$ is state, $u(k) \in R^m$ is input, $y(k) \in R^l$ is output, and $\Omega_i = \{H_{ix}x(k) + H_{iu}u(k) \leq K_i\}, i = 1,2,\dots,s$ are state/input partitions.

It can be shown that in PWA model, continuous dynamics $x(k+1) = A_i x(k) + B_i u(k) + f_i$ and $y(k) = C_i x(k) + D_i u(k) + g_i$ will correspond to index i that represents discrete state change. Furthermore, discrete dynamics occur if there is a change of index i to j, which is also dependent on the change of state/input continuous from $x(k)$, $u(k)$, at $\Omega_i = \{H_{ix}x(k) + H_{iu}u(k) \leq K_i\}$ into $x(k+1), u(k+1)$, at $\Omega_j = \{H_{jx}x(k) + H_{ju}u(k) \leq K_j\}$.

III. METHODOLOGY

By reviewing the fact that hybrid system is a combination of continuous and discrete modes, the DC-DC converter in the circuit of the Solar Cell-Battery-Supercapacitor can be modeled with PWA system. PWA forms are compiled based on the programming language HYSDEL (Hybrid System Description Languages). HYSDEL is a programming language that can be used to model a system with MLD. MLD models are obtained and then converted into PWA with a function namely MLD2PWA. Conversion method for the form of this model can be applied

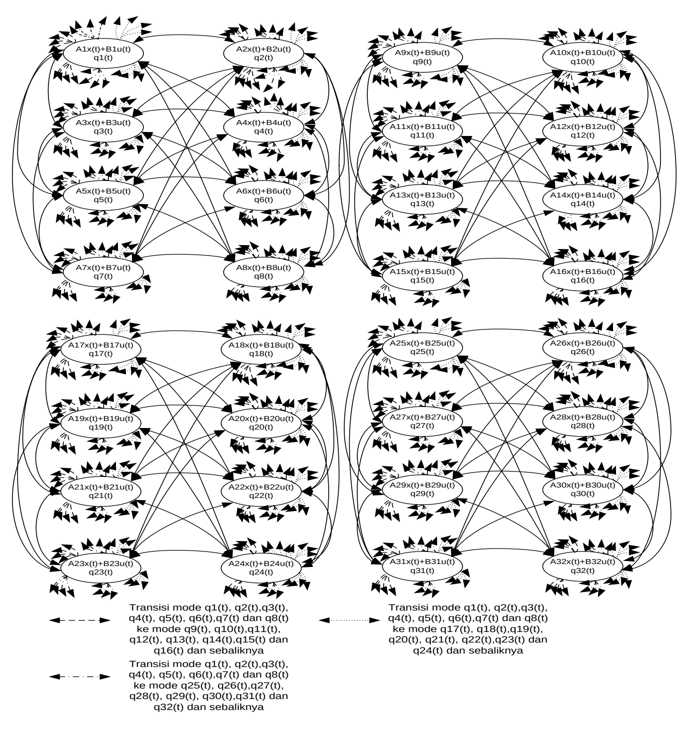

Fig. 5. Finite State Machine hybrid systems solar cell-battery-supercapacitor.

because both the models have an equivalence. Equivalence

ISSN: 2414-4592
DOI: 10.20474/jater-1.1.5

that can be established between the two forms of this model is a set of state variables and input pair ($x1(k)$, $u(k)$) where the inequality

$$E_2 \delta(k)+E_1 z(k) \leq E_3 u(k)+E_4 x(k)+E_5 \quad (3)$$

has a solution of $\delta(k) \in R^{rl}, z(k) \in R^{rc}$. Finite State Machine Hybrid Solar Cell-Battery-Supercapacitor is shown in Figure 4 where there are 32 states. 32 states are to represent the working mode hybrid system based topology with a series of DC / DC converters that are used for solar cells, batteries and supercapacitors.

Fig. 5: Finite state machine hybrid systems solar cell-battery-supercapacitor.

In case of stability properties of hybrid system, one cannot guarantee if overall system will be stable if each of its sub-systems is stable. An approach to analyze the stability of hybrid system is by adopting the wellknown Lyapunov stability theory. By viewing each sub-system for its particular stability properties, the idea is to combine each piece of Lyapunov function from each sub-system, and then observe the overall behavior of the combination. In hybrid system, the criteria for overall system stability cannot be seen only from the change of each Lyapunov function in each sub-system, but also depends on the change of Lyapunov function at *switching* time. This fact can be shown mathematically by:

IV. RESULTS AND DISCUSSION

Figure 6 shows the structure of control in a block Discrete Hybrid Automata (DHA).

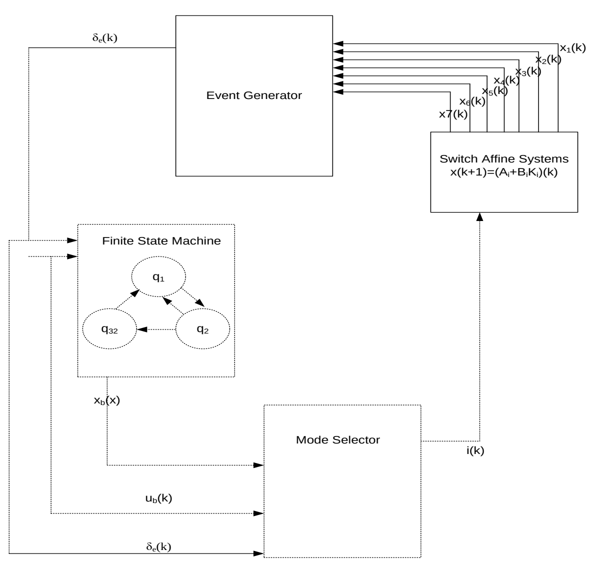

Figure 6. Block diagram of discrete hybrid automata.

The structure of HYSDEL consists of 2 parts: INTERFACE and IMPLEMENTATION. INTERFACE section contains declarations comprising STATE, INPUT, OUTPUT and PARAMETERS. IMPLEMENTATION section contains information on the relationship of the variables described. This section begins with variables Auxiliary which is a declaration of an internal signal system DHA. It will be explained in the following subsection of

V. IMPLEMENTATION

1. AD Section

AD section is to define a boolean variable of state variables statement. This section is described by the Event Generator (EG).

2. LOGIC Section

LOGIC section is a boolean variable function described by Mode Selector.

3. DA Section

DA section defines a continuous variable according to the condition of the if-then-else at based on a boolean variable. This section is described by Switch Affine Systems (SAS).

4. Automata Section

Automata section is a transition state as a boolean function. This section is described by Finite State Machine (FSM).

Open-loop simulation is shown in Figure 5 where the model PWA is unstable with the largest overshoot in 10-25 seconds.

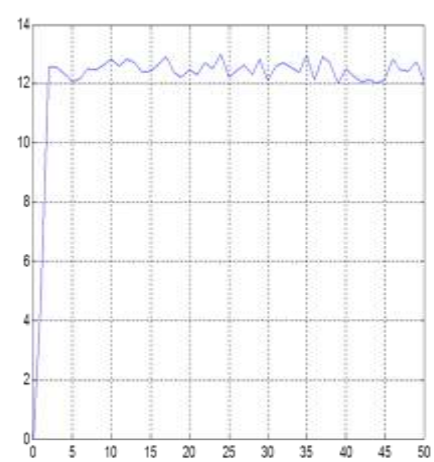

Figure 7. Open loop simulation.

While the close loop simulation is shown in Figure 5 where the level of stability of PWA models is found in 40-50 seconds.

Figure 8. Close loop simulation.

ISSN: 2414-4592
DOI: 10.20474/jater-1.1.5

VI. CONCLUSION

The conclusion of this paper is that the using of HYSDEL applied to the device can convert MATLAB, simulation, analysis and control of the hybrid system. In this case, the analysis method that is implemented is stability analysis of discrete-time PWA system with piecewise Lyapunov function where the stability of the close loop model of PWA was reached in 40-50 seconds so that the output of the system is expected. The function piecewise Lyapunov likely undergoes drastic changes and discontinued when switching from one region to another PWA partition.

ACKNOWLEDGEMENT

We wish to thank the Research Center for Physics-Indonesian Institute of Science for offering us an invitation and opportunity to do the research in Thematic Program. We would like to thank our colleague at Technical Implementation Unit for Instrumentation Development for making our research a pleasurable one.

REFERENCES

[1] H. S. Witsenhausen, "A class of hybrid-state continuous-time dynamic systems," *IEEE Transactions on Automatic Control,* vol. 11, no. 2, pp. 161-167, 1966. **DOI:** 10.1109/TAC.1966.1098336

[2] M. S. Branicky, V. S. Borkar and S. K. Mitter, "A unified framework for hybrid control: Model and optimal control theory," *Automatic Control, IEEE Transactions on,* vol. 43, no. 1, pp. 31-45, 1998. **DOI:** 10.1109/9.654885

[3] R. Alur, C. Courcoubetis, T. A. Henzinger and P. H. Ho, "Hybrid automata: An algorithmic approach to the specification and verification of hybrid systems, in Hybrid Systems," in *Lecture Notes in Computer Science*, New York, Springer-Verlag, 1993. **DOI:** doi.org/10.1007/3-540-57318-6_30

[4] P. Antsaklis, "Special issue on hybrid systems: Theory and applications. A brief introduction to the theory and applications of hybrid systems," in *Proc. of the IEEE*, 2000. **DOI:** 10.1109/JPROC.2000.871299

[5] F. Torrisi and A. Bemporad, "HYSDEL–A tool for generating computational hybrid models for analysis and synthesis problems," *IEEE Transactions on Control Systems Technology,* vol. 12, no. 2, pp. 235-249., 2004. **DOI:** 10.1109/TCST.2004.824309

[6] I. Kresno, "Perancangan perangkat MATLAB untuk ekuivalensi model sistem hybrid", dissertation, Bandung Inst. of Technology., Bandung, ID, 2005.

[7] H. Ye, A. N. Michel and L. Hou, "Stability theory for hybrid dynamical systems," IEEE Transactions on Automatic Control, vol. 43, no. 4, pp. 461-474, 1998. **DOI:** 10.1109/9.664149

— This article does not have any appendix. —