A Decentralized Energy Management for A Multiple Energy System with Fault Tolerance Analysis

He Yin, Chen Zhao, and Amro Alsabbagh
Univ. of Michigan-Shanghai Jiao Tong Univ. Joint Institute,
Shanghai Jiao Tong University,
Shanghai, P. R. China
Email: yyy@sjtu.edu.cn
chenzhaosjtu@gmail.com
amro.alsabbagh@hotmail.com

Chengbin Ma*[1,2]
1. Univ. of Michigan-Shanghai Jiao Tong Univ. Joint Institute,
2. School of Mechanical Engineering
Shanghai Jiao Tong University,
Shanghai, P. R. China
Email: chbma@sjtu.edu.cn

***Abstract*—This paper discusses a decentralized energy management for an engine-generator/battery/ultracapacitor (UC) hybrid energy system with fault tolerance analysis. The energy management problem among the energy suppliers and the load is formed into a non-cooperative power distribution game where the engine-generator, the battery pack, the UC pack, and the load are modeled as independent and related players. Each player has an unique objective, i.e., reducing fuel consumption, prolonging battery cycle life, maintaining UC state of charge and satisfying the load demands, represented by different second order polynomial function based utility functions. In this game, a Nash equilibrium is reached at each control instant to give a balanced solution among players. The weight coefficients in the utility functions can be determined through the parato optimal solution a multi-objective genetic algorithm. The fault tolerance analysis based simulation shows that the proposed energy management has a flexible and reconfigurable performance under six different case studies.**

***Index Terms*—Multiple energy system; Game theory; Nash equilibrium; Fault tolerance analysis;**

I. Introduction

Thanks to the rising interests in the renewable energy vehicles, i.e., hybrid electric vehicles (HEVs) and electric vehicles (EVs), hybrid energy systems (HESs), serving as the main energy supplier, are widely discussed [1]. The applications of HESs can also be extended to smart houses, micro grids, and smart grids [2]. A typical HES consists of multiple energy suppliers such as fuel cells, batteries, and internal combustion engines together with assistive devices, e.g., ultracapacitors (UC) and flywheels [3]. Due to the complicated characteristics of each energy suppliers, it is a challenging task to model and manage the energy flow inside a HES. This paper focuses on the energy management and fault tolerance analysis of an engine-generator/battery/UC pack HES.

The energy management problems of HESs have been widely discussed in recent years. Basically, there are two kinds of energy management, i.e., the centralized energy managements and the decentralized energy managements. For centralized energy managements, [4] applies a rule based energy management for a series-parallel plug-in hybrid electric bus. The parameters in the rules-table is optimized by dynamic programming. [5] discusses the fuzzy-logic energy management together with the rule based control applied on EVs with battery and UC HES. An adaptive fuzzy logic controller is applied to tune the membership function based on the previous driving conditions. [6] solves the energy management problem for a battery and UC HES through Karush-Kuhn-Tucker (KKT) conditions. This paper tries to optimize the battery cycle life and maintain the UC capacity. [7] applies an optimal control through using Neural Networks for a HEV. In addition to the centralized energy managements, decentralized energy management, on the other hand, can also be applied on HESs [8]. Among the decentralized managements, game theory is a famous approach to solve the trade-offs among self-interested players and predict their choices which is also widely discussed in the energy management problem in HESs. [9] discusses a game theoretic energy management on an engine-generator/battery/UC HES. The Nash equilibrium is determined at each control instant to solve the power distribution problem. [10] also discusses a game theoretic energy management for a HES together with renewable energy system. It focuses on the coalition among the energy suppliers. Comparing with the centralized energy managements, decentralized energy managements are more flexible, reconfigurable, and fault-tolerant [11]. Since the application background of this paper is a series electric vehicle, the fault tolerance should be considered for safety purposes [12]. The fault tolerance analysis for two five-phase permanent magnetic synchronous machines (PMSM) in a fuel cell/ultracapacitor HES has been discussed [13]. Their strategy focuses on dealing with the situation that one or two phases of the PMSM is failed. To the knowledge of the authors, there is a leak of research focusing on the fault tolerance analysis on multiple source energy system. In this paper, the situation that one or two energy suppliers are failed is discussed and analysed. A game theoretic energy management is discussed and analysed for an example decentralized energy management on an engine-generator/battery/UC HES with fault tolerance analysis.

This paper discusses a game theoretic energy management for an engine-generator/battery/UC HES. Due to the nature of a decentralized control, the energy suppliers and the load demand are modeled as independent players. The objective of each players are represented by utility functions that the engine-generator tries to rise the fuel efficiency; the battery pack tries to prolong the cycle life; the UC pack tries to maintain the capacity; the load demand tries to satisfy the load demand. Then a non-cooperative power distribution is set up to solve the energy management problem through reaching a Nash equilibrium at each control instant. The weight coefficients in the utility function will be optimized under each different situations (i.e., one or two energy suppliers are failed.). Finally, the simulation with fault tolerance analysis under six different cases is discussed and the performance of the proposed energy management is shown.

II. Configuration and Modeling

A. Overall System Configuration

In this paper, a three energy system, i.e., an engine-generator/battery/ultracapacitor HES, is used as an example system for a multiple energy system. As shown in Fig. 1, the major components, i.e., the engine-generator, the battery pack, the UC pack, the load, and two bidirectional DC-DC converters apply a parallel-active topology. This is because that the parallel-active topology has a higher flexibility and reliability than other topologies [14]. Besides, the DC-link voltage can be maintained in a stable range which is one of the requirement of the electric vehicle application. i_g, i_b, and i_c represent the current for the engine-generator, the battery pack, and the UC pack.

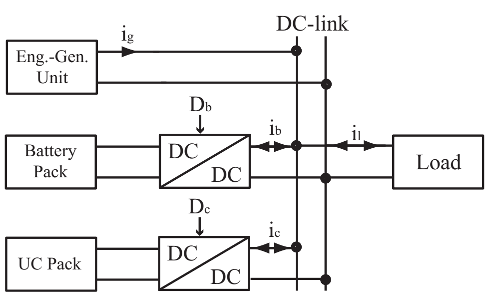

Fig. 1. The model of the engine-generator/battery/ultracapacitor HES.

B. Engine-generator

The engine-generator model here uses the data from a series connected hybrid electric vehicle, provided in the AVL CRIUSE 2010. The relationship between the engine torque and the velocity can be concluded in Fig. 2(a). The operating line can be written in a six-order polynomial function as follows,

$$T_E = u \sum b_i W_E^i, \tag{1}$$

where u is the engine throttle, W_E is the engine velocity, b_i $(i = 0, ..., 6)$ are the coefficients for a sixth-order curve fitting. On the other hand, the efficiency map of a generator is shown in Fig. 2(b).

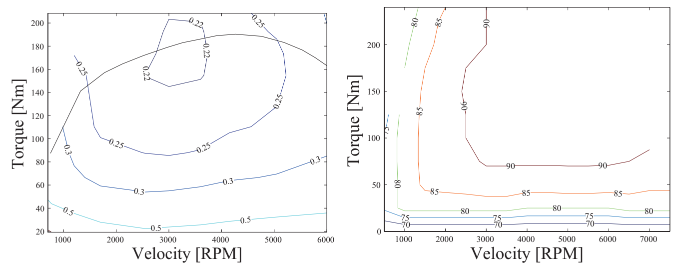

Fig. 2. (a) Engine efficiency map. (b) Generator efficiency map.

C. Battery and Ultracapacitor

The detail models for the battery pack and the UC pack are shown in Fig. 3. The battery pack is modeled by its open circuit voltage (OCV), internal resistance (R_b), and two RC networks. The OCV and R_b are modeled by six-ordered polynomial functions. Meanwhile, the RC networks are included with different time constants to describe the transient response of the battery pack in second and minute range [15]. On the other hand, the UC pack is modeled by a capacitor (C), a series resistance ($R_{c,s}$), and a parallel resistance ($R_{c,l}$) [16]. Notice that DC-DC converters are chosen as bidirectional buck-boost converters. The DC-DC converter on the battery pack side is designed to control the battery current (i_b) through tuning D_b while the DC-DC converter on the UC pack side is designed to control the UC current (i_c) through tuning D_c.

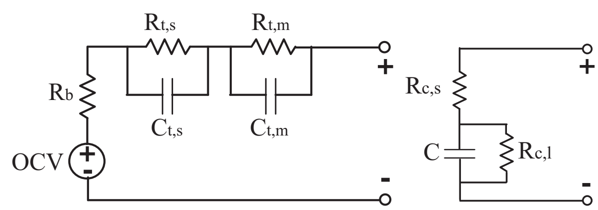

Fig. 3. (a) Battery model. (b) UC model.

D. Load

Since the application background of this paper is the HEV, the load in this paper chooses the New European Driving Cycle (NEDC) as example load shown in Fig. 4. The velocity profile is converted into a power profile through considering a HEV, i.e., NISSAN Leaf. Note that since the fault tolerance analysis is focused in this paper, the power profile may not be satisfied when one or two energy suppliers are failed.

E. Agent Based Modeling

In this paper, due to the nature of the decentralized energy management, an agent based modeling is applied in the engine-generator/battery/UC HES [17], [18]. As shown in Fig. 5, the engine-generator, the battery pack, the UC pack,

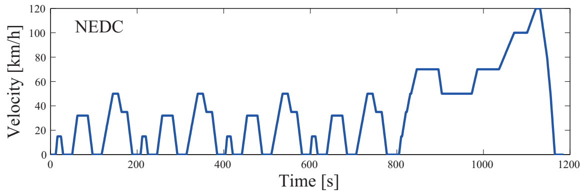

Fig. 4. The New European Driving Cycle.

and the load are modeled as independent agent. They only share the control variables, i.e., i_g, i_b, and i_c, with each other while the local information such as SOC will not be shared.

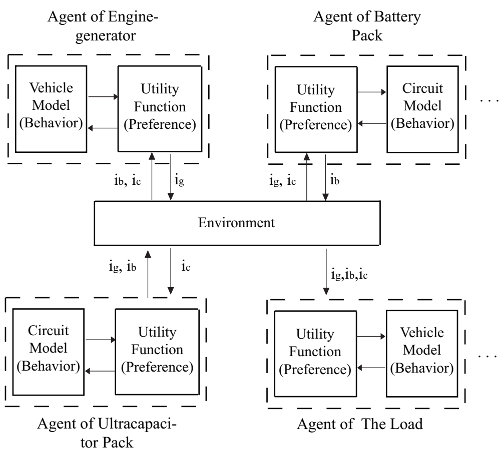

Fig. 5. The agent based model for the engine-generator/battery/UC HES.

III. Noncooperative Power Distribution Game

A. Utility Functions

In this paper, the three energy suppliers, i.e., the engine-generator, the battery pack, the UC pack, and the load are treated as four independent agents with different objectives as follows,

- Engine Generator:reduce the fuel consumption;
- Battery Pack:extend the cycle life;
- UC Pack:maintain the SOC level;
- Load:Satisfy the load demand.

The objectives of each agent are represented by utility functions with second order polynomial function for its convex property [19]. Note that the utility functions for energy suppliers have been discussed in previous works [6], [9]. Only the utility function for the load is newly defined.

1) Engine-Generator: As shown in Fig. 2, there exists a highest efficiency working point for the engine-generator system. The utility function for the engine-generator is used to represent the objective of the engine-generator as follows,

$$u_g = 1 - a(i_g - I_{g,opt})^2, \tag{2}$$

$$a = \frac{1}{I_{g,max}^2}, \tag{3}$$

where a is used to normalize the utility function and $I_{g,max}$ is the most permissible value.

2) Battery Pack: The utility function of the battery pack, u_b, consists of two parts, $u_{b,1}$ and $u_{b,2}$, as follows,

$$u_b = w_{b,1}u_{b,1} + w_{b,2}u_{b,2}, \tag{4}$$

$$u_{b,1} = 1 - b(i_b - I_{b,ave})^2, \tag{5}$$

$$u_{b,2} = 1 - c(i_b - I_{b,l})^2, \tag{6}$$

$$b = \frac{1}{I_{b,max}^2}, \tag{7}$$

$$c = \frac{1}{Max|i_b - I_{b,l}|^2}, \tag{8}$$

where $w_{b,1}$ and $w_{b,2}$ are weight coefficients for $u_{b,1}$ and $u_{b,2}$. $u_{b,1}$ aims to minimize the variation of the amplitude of the battery current. Meanwhile, $u_{b,2}$ aims to minimize the variation rate of the battery current. $I_{b,ave}$ is the average battery current so far while $I_{b,l}$ is the battery current at the last control instant. b and c have the similar definition and role as a.

3) Ultracapacitor Pack: Similar as the engine-generator and the battery pack, the utility function of the UC pack can be expressed as follows,

$$u_c = 1 - d(i_c - I_{c,fit})^2, \tag{9}$$

$$d = \frac{1}{I_{c,max}^2}, \tag{10}$$

where d has a similar as a, b, and c to normalize the utility function. $I_{c,max}$ is the most permissible value for the UC pack. $I_{c,fit}$ can be written as follows,

$$I_{c,fit} = (2\frac{v_c^2 - V_{c,emp}^2}{V_{c,max}^2 - V_{c,emp}^2} - 1)I_{c,max}, \tag{11}$$

where v_c is the voltage of the UC pack, $V_{c,emp}$ is the lower voltage limit of the UC pack, and $V_{c,max}$ is the upper voltage limit of the UC pack.

4) Load: The utility function for the load can be written as follows,

$$u_l = 1 - e(i_l - i_b - i_c - i_g)^2, \tag{12}$$

‘ where i_l is given by the NEDC at each control instant and e is used to normalize the utility function.

5) utility functions for players: Since the utility function for the load contains only the control variables for other energy suppliers, i.e., i_b, i_c, and i_g, it can not be treated as an independent player here. Note that the constraint, $i_g + i_b + i_c \leq i_l$, holds because of the one or two energy suppliers are failed. Thus, the utility function for the engine-generator, the battery pack, and the UC pack should be modified with the utility function of the load using weighted sum method,

$$u_{g,l} = w_g u_g + w_{l,g} u_l, \tag{13}$$

$$u_{b,l} = w_{b,1}u_{b,1} + w_{b,2}u_{b,2} + w_{l,b}u_l, \tag{14}$$

$$u_{c,l} = w_c u_c + w_{l,c} u_l, \tag{15}$$

where w_g, $w_{l,g}$, $w_{l,b}$, w_c, and $w_{l,c}$ are new weights coefficients and they will be determined in section III D.

B. Nash equilibrium

In the proposed paper, a noncooperative power distribution game is set up at each control instant to determine the power distribution among the energy suppliers and the load. As mentioned above, the three players in this game are the engine-generator, the battery pack, and the UC pack. Thus the noncooperative power distribution game can be represented as, $G = [(G, B, C), (i_g, i_b, i_c), (u_{g,l}, u_{b,l}, u_{c,l})]$. In this game, each player is treated as selfish and tries to maximize its own utility function. However, the utility function of each player is determined not only by its own control variable but also by control variables from other players. Thus players need to determine a so-called "Nash equilibrium" to determine their power distribution. Under this equilibrium, all the players' utility can not become larger if one of the players changes its strategy (i.e., i_g, i_b, and i_c.). The existence and uniqueness of a Nash equilibrium can be proved by solving the following equations,

$$\frac{\partial u_{g,l}}{\partial i_g} = 0, \frac{\partial u_{b,l}}{\partial i_b} = 0, \frac{\partial u_{c,l}}{\partial i_c} = 0. \tag{16}$$

Since $u_{g,l}$, $u_{b,l}$, and $u_{c,l}$ are all convex functions, there exists an unique solution for the above equations. This solution is the Nash equilibrium that balances the objective of each player. Note that since this paper focuses on the fault tolerance analysis of the proposed control, one or two energy suppliers may break during driving the HEV. The existence and uniqueness of the Nash equilibrium can still be proved because of the convexity of the utility functions. The detail proof are omitted here for avoiding redundancy.

C. Learning Algorithm

Due to the nature of the decentralized energy management in this paper, there are individual controller for each energy supplier. Each player could only share their control variables, i.e., i_g, i_b, and i_c. Therefore, the Nash equilibrium could only be reached through a learning algorithm. In this paper, the best response function method is used to reach the Nash equilibrium. Note that due to the real-time implement of the proposed control, the simplest learning algorithm, best response function method is used here. For example, given an initial power distribution, the engine-generator could determine i_g by taking i_b and i_c as parameter. Then the battery pack and the UC pack will determine the i_b and i_c similar as the engine-generator. An example convergence of the control variables at a random control instant is shown in Fig. 6. It is clearly shown that i_g, i_b, and i_c converge to a stable value after thirty iterations.

D. Weight Coefficient Optimization

The fault tolerance analysis discussed in this paper focuses on the accidents that one or two energy suppliers are failed due to the unpredictable reason. Supposing that one of the energy supplier is failed, the HES should still work as usual. Supposing two energy supplier are failed, the HEV should work in a limp-home mode. Note that under this mode, the only energy supplier should not be the UC pack because the UC pack is only an energy buffer.

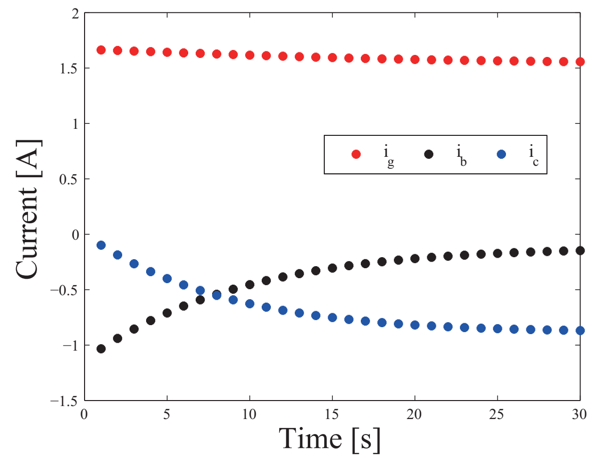

Fig. 6. Convergence for all control variables at a random control instant.

According to (13), (14) and (15), several weight coefficients need to be determined. Due to the fault tolerance analysis purposes of this paper, each different combination of the weight coefficients should be taken into consideration. The basic idea is that when no energy supplier is failed, $w_{l,g}$, $w_{l,b}$, and $w_{l,c}$ are treated as penalty factor (Therefore, $w_{l,g}$, $w_{l,b}$, and $w_{l,c}$ are chosen as a large value, e.g., 10 in this paper.) while w_g and w_c are chosen to be 1; $w_{b,1}$ and $w_{b,2}$ still need to be determined (optimized in Table. I). When accident happens, the hybrid electric vehicle has to work under a limp-home mode (i.e., only 40% of the original driving cycle can be achieved.). Under this circumstance, all the weight coefficients are required to be determined simultaneously. A simple multiple objective genetic algorithm is applied to find the optimal weight coefficients with the objectives to be the utility function of each player. Besides, a conmen constraint exists as follows,

$$w_g + w_{l,g} = 1, \tag{17}$$

$$w_{b,1} + w_{b,2} + w_{l,b} = 1, \tag{18}$$

$$w_c + w_{l,c} = 1. \tag{19}$$

Base on the above discussion, all the weights in each case can be concluded in Table. I. In this table, G represents the engine-generator, B represents the battery pack, and C represents the UC pack.

TABLE I
WEIGHT COEFFICIENTS FOR DIFFERENT CASES

	w_g	$w_{l,g}$	$w_{b,1}$	$w_{b,2}$	$w_{l,b}$	$w_{l,c}$	w_c
G,B,C	1	10	0.8	0.2	10	10	0.1
B,C	0	0	0.4	0.1	0.5	0.9	0.1
G,B	0.5	0.5	0.16	0.04	0.8	0	0
G,C	0.4	0.6	0	0	0	0.9	0.1
G	0.2	0.8	0	0	0	0	0
B	0	0	0.4	0.1	0.5	0	0

IV. Simulation Results

The simulation environment is the Matlab Simulink. Due to the hardware limitation of the future experiment test bench, a down scaled test bench is considered in this paper. Based on the utility functions, four criteria are determined to show the performance of the proposed control with different cases.

$$I_{b,norm} = \sqrt{\frac{\sum (i_b - I_{b,l})^2}{N}}, \tag{20}$$

$$E_{c,eng} = \frac{\sum C_u (v_c^2 - V_{c,min}^2)}{2N}, \tag{21}$$

$$C_{g,fuel} = \frac{\sum C_i}{N}, \tag{22}$$

$$I_{l,dif} = \frac{\sum |i_l - i_g - i_b - i_c|}{N}, \tag{23}$$

where $I_{b,norm}$ is the variation of the battery current, $E_{c,eng}$ is the average energy in the UC pack, $C_{g,fuel}$ is the fuel consumption., and $I_{l,dif}$ is the difference between the load current and the current provided by the energy supplier. N is the number of the control instant and C_i is the fuel consumption at the control instant.

The fault tolerance analysis is determined by six different case studies as discussed in previous section. Under these case studies, different combination of the players are tested and the performance of the proposed energy management are shown. The current responses for different cases are shown in Fig. 7. The criteria for each cases are summarized in Table. II. It can be clearly notice that for GBC combination, the performance is the best one, i.e., the engine-generator tries to provide a stable power; the battery pack covers the low dynamic power; the UC pack covers the rest high dynamic power. However, if one of the energy supplier is failed, i.e., shown in Fig. 7(b)(c)(d), the other two energy suppliers have to take the responsibility for the failed one. Thus, a relative low performance is shown in Table. II. Although the performance is relative lower, the basic functions of the energy system still work. Further more, if two of the three energy suppliers are failed, the left one should tries to change into limp-home mode. Thus, the load demand can not be fully satisfied as shown in Fig. 8. Meanwhile, the performance is the lowest. As shown in Fig. 9, the voltages of the UC cell in all six cases maintain a stable state.

For real-world application, when one energy supplier is failed, it can not be predicted. Therefore, a more real world simulation is given when the engine-generator is suddenly failed. As shown in Fig. 10, the engine-generator is failed at $2000s$. The original engine-generator/battery/UC HES becomes a battery/UC HES. However, due to the benefits of the proposed decentralized control, the HES still works well. The battery pack supplies more power to take charge of the engine-generator part while the UC pack has to cover more dynamic power. The only drawback is that the sum of the i_b and i_c is slightly lower than the load demand. The other cases are quite similar that will be omitted for avoiding redundancy.

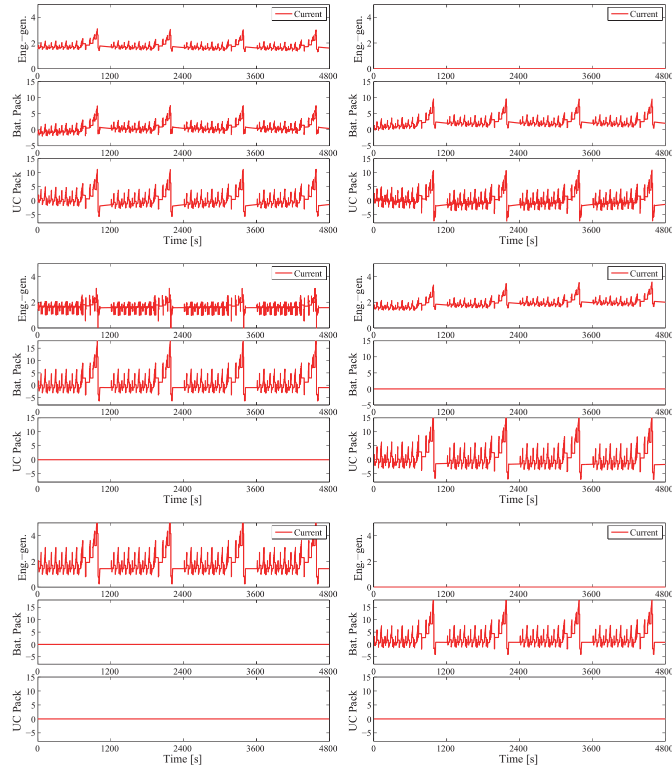

Fig. 7. Current map for i_g, i_b, and i_c(a) GBC combination. (b) BC combination. (c) GB combination. (d) GC combination. (e) G only. (f) B only.

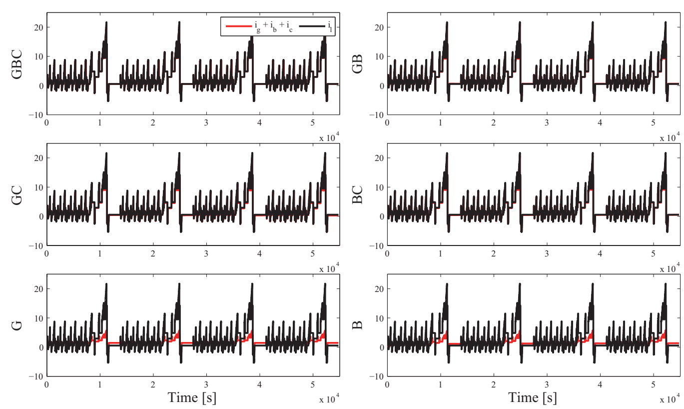

Fig. 8. Load current map for $i_g + i_b + i_c$ and i_l.

V. Conclusion

This paper develops and discusses a decentralized energy management for a engine-generator/battery/UC hybrid energy system with fault tolerance analysis. The energy management problem is converted into a non-cooperative power distribution game where the engine-generator, the battery pack, the UC pack, and the load are modeled as players in the power distribution game. Each player focuses on different utility functions, i.e., raising the fuel efficiency, prolonging the battery cycle life, maintaining the UC capacity, and satisfy the load demand. At each control instant, a Nash equilibrium is reached to

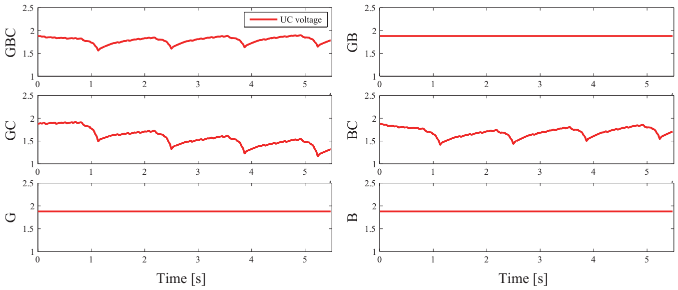

Fig. 9. UC voltage map.

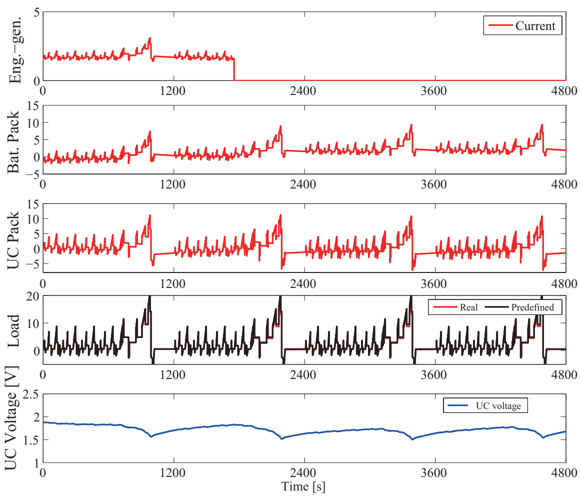

Fig. 10. Case when Engine-generator is failed.

give a balanced power distribution among players through best response functions based learning algorithm. The weight coefficients in the utility functions are determined through a generic algorithm. The fault tolerance based simulation discusses six different case studies to show the flexible and reconfigurable performance of the proposed game theoretic energy management.

TABLE II
CRITERIA IN DIFFERENT CASES

	$I_{b,norm}$ (A)	$E_{c,eng}$ (J)	$C_{g,fuel}$ (L/kWh)	$I_{l,dif}$ (A)
G,B,C	0.0121	5533.7	0.2574	0.0156
B,C	0.0407	4851.9	0	0.1230
G,B	0.2125	6199.2	0.2644	0.1220
G,C	0	4109.1	0.2626	0.2040
G	0	6199.2	0.3119	1.9890
B	0.1676	6199.2	0	0.4444

REFERENCES

[1] S. F. Tie and C. W. Tan, “A review of energy sources and energy management system in electric vehicles,” *Renew. and Sustain. Energy Rev.*, vol. 20, pp. 82–102, 2013.

[2] J. Aghaei and M.-I. Alizadeh, “Demand response in smart electricity grids equipped with renewable energy sources: A review,” *Renew. and Sustain. Energy Rev.*, vol. 18, pp. 64–72, 2013.

[3] S. Ashok, “Optimised model for community-based hybrid energy system,” *Renewable energy*, vol. 32, no. 7, pp. 1155–1164, 2007.

[4] J. Peng, H. He, and R. Xiong, “Rule based energy management strategy for a series–parallel plug-in hybrid electric bus optimized by dynamic programming,” *Applied Energy*, 2016.

[5] W. Zhou, M. Li, H. Yin, and C. Ma, “An adaptive fuzzy logic based energy management strategy for electric vehicles,” in *2014 IEEE 23rd International Symposium on Industrial Electronics (ISIE)*, Istanbul, Turkey, June 1-4, 2014, pp. 1778–1783.

[6] H. Yin, C. Zhao, M. Li, and C. Ma, “Utility function-based real-time control of a battery ultracapacitor hybrid energy system,” *IEEE Trans. Ind. Informat.*, vol. 11, no. 1, pp. 220–231, Feb 2015.

[7] W.-S. Lin and C.-H. Zheng, “Energy management of a fuel cell/ultracapacitor hybrid power system using an adaptive optimal-control method,” *J. Power Sources*, vol. 196, no. 6, pp. 3280–3289, 2011.

[8] J. M. Guerrero, M. Chandorkar, T.-L. Lee, and P. C. Loh, “Advanced control architectures for intelligent microgrids, part i: decentralized and hierarchical control,” *IEEE Transactions on Industrial Electronics*, vol. 60, no. 4, pp. 1254–1262, 2013.

[9] H. Yin, C. Zhao, M. Li, C. Ma, and M.-Y. Chow, “A game theory approach to energy management of an engine-generator/battery/ultracapacitor hybrid energy system.”

[10] S. Mei, Y. Wang, F. Liu, X. Zhang, and Z. Sun, “Game approaches for hybrid power system planning,” *Sustainable Energy, IEEE Transactions on*, vol. 3, no. 3, pp. 506–517, 2012.

[11] D. Fudenberg and J. Tirole, “Game theory,” *MIT Press Books*, vol. 1, 1991.

[12] A. Emadi, Y. J. Lee, and K. Rajashekara, “Power electronics and motor drives in electric, hybrid electric, and plug-in hybrid electric vehicles,” *IEEE Trans. Ind. Electron.*, vol. 55, no. 6, pp. 2237–2245, 2008.

[13] H. Aouzellag, K. Ghedamsi, and D. Aouzellag, “Energy management and fault tolerant control strategies for fuel cell/ultra-capacitor hybrid electric vehicles to enhance autonomy, efficiency and life time of the fuel cell system,” *International Journal of Hydrogen Energy*, vol. 40, no. 22, pp. 7204–7213, 2015.

[14] A. Kuperman and I. Aharon, “Battery–ultracapacitor hybrids for pulsed current loads: A review,” *Renewable and Sustainable Energy Reviews*, vol. 15, no. 2, pp. 981–992, 2011.

[15] S. Abu-Sharkh and D. Doerffel, “Rapid test and non-linear model characterisation of solid-state lithium-ion batteries,” *Journal of Power Sources*, vol. 130, no. 1, pp. 266–274, 2004.

[16] M. S. Chan, K. Chau, and C. Chan, “Effective charging method for ultracapacitors,” *Journal of Asian Electric Vehicles*, vol. 3, no. 2, pp. 771–776, 2005.

[17] S. D. McArthur, E. M. Davidson, V. M. Catterson, A. L. Dimeas, N. D. Hatziargyriou, F. Ponci, and T. Funabashi, “Multi-agent systems for power engineering applications part i: concepts, approaches, and technical challenges,” *Power Systems, IEEE Transactions on*, vol. 22, no. 4, pp. 1743–1752, 2007.

[18] ——, “Multi-agent systems for power engineering applications part ii: technologies, standards, and tools for building multi-agent systems,” *Power Systems, IEEE Transactions on*, vol. 22, no. 4, pp. 1753–1759, 2007.

[19] R. T. Clemen and T. Reilly, “Making hard decisions with decisiontools suite,” 1999.