

# Power Management and Simulation of Renewable DC Power System

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**Abstract**—This paper presents a method to manage the Independent renewable power source DC system, such as a stand alone solar/fuel cell system, to achieve the maximum using efficiency of the system. The system includes the power generation, energy storage, power bus and Power electronics parts. Scenarios, modes, loads and power sources decide the different control status and load priority. The MATLAB simulation shows not only the achievement of maximum energy efficiency but also a high level performance of the power system.

**Keywords**- Power Management; DC; efficiency; MATLAB

## 1. Introduction

Independent renewable power systems, such as solar power, fuel cell power and DC generator power become more and more popular in the near future. One of our biggest environmental problems to solve in the future is to avoid a huge increase in environmental pollutions and the greenhouse effect. Many new ideas and concepts need to be developed; so renewable power systems play important roles in that field. It is important and timely to find a control it more efficiently.

With power management capacity, throughput and battery lifetime could be increased, and latency could be reduced. This also is help to improve the environment.

Usually the DC power management system includes following components:

1. Power generation, which include solar panel, fuel cell generator or generator that can convert chemical, electrochemical, mechanical and other forms of energy into electrical energy.

2. Energy storage, which provide readily available electric power when no sufficient power output is available. Examples include batteries, ultra-capacitors, etc. Ultra-capacitors are energy storage devices, but they have a much greater power and energy storage capability compared to conventional capacitors. They are ideal for applications which demand quick release and absorption of energy.

3. Power bus, usually two DC power buses include high voltage (for high-power loads) and low voltage (for low-power loads). Both power suppliers and loads are connected to power bus. In this paper, only one 42V DC power bus is considered.

4. Electrical loads, two classes include high priority loads and low priority loads.

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5. Power electronics, which include power converters and power control units that control the power flows between the power sources, loads and power buses.

The stand alone system diagram is shown in Figure. 1.

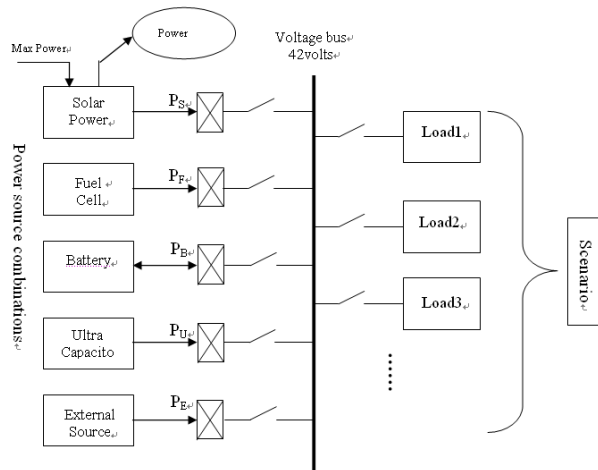


Fig.1. stand alone DC power system

Power management strategies for standalone DC power system can be roughly classified into three categories.

The first one employs heuristic control techniques such as control rules method [1] for estimation and control algorithm development [2], these strategies can offer a significant improvement in energy efficiency and are suitable for real-time control strategy.

The second one is based on static optimization methods. Commonly, electric power is translated into an equivalent amount of (steady-state) sun light or fuel rate in order to calculate the overall solar panel area or fuel cost [3]-[8]. The optimization scheme then figures out the proper split between the two energy sources using steady-state efficiency maps. Because of the simple point-wise optimization nature, it is possible to extend such optimization schemes to solve the simultaneous fuel economy and emission optimization problem [7].

The third one of control algorithms considers the dynamic nature of the system when performing the system optimization [7]. Furthermore, the optimization is with respect to a time horizon, rather than for an instant in time. In general, power split algorithms resulting from dynamic optimization approaches are more accurate under transient conditions, but are computationally more intensive [9]-[12].

In hardware, today's typical standalone dc power system can easily have many power loads. Much of those loads have steady-state currents of less than 10 A and power consumption levels below 500 W. Several loads will consume over a kilowatt and would have steady-state current levels in excess of more currents. To improve their efficiency, one method is to improve the power bus voltage. The voltage level addresses safety issues for higher voltages and minimizes the cost of components that will be required in these systems. Coping with increased power requirements higher bus voltages will need higher-voltage-rated power MOSFETs, power ICs, and other semiconductors that connect directly to the higher-voltage bus. The higher voltage level can significantly improve the efficiency of dc power system.

## 2. Control Design

The control scenario, which is shown in Figure 2, is a mix of 10 modes. Each scenario is defined with different combination of 10 modes. The control program supports 3 scenarios, which are silence, combat, maintenance. the example of combat scenario is Combat (mode1) → Silence (mode2) → Planning (mode3) → Maintenance (mode4) → Forging (mode5) → Cold ops (mode7) → Protection (mode8) → Mopp (mode9) → Sustain (mode10).

A mode is defined by 32 loads with priority. Priority of one specific load is not consistent in different mode [7]. The simulator supports 10 modes (comprise of different loads): Combat, Silence, Planning,

Maintenance, Forging, Transit, Cold Ops, Protection, MOPP and Sustain. There are two additional modes in the system which are Off and Start.

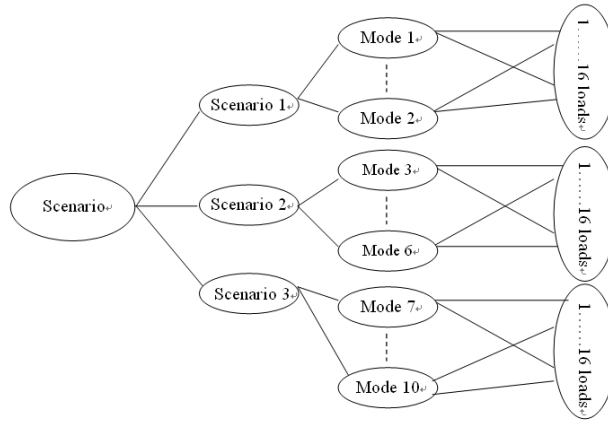


Fig.2. Control scenario of power system

In the simulator, all loads are predefined as “on” (1) or "off" (0) according to specific mode during the simulation. The status of loads is changed dynamically with different mode. However, since the controller of loads is applied automatically by controller, it does not work as predefined in the simulation. All loads are just turned on no matter what scenario and mode is, and all loads have the same priority. Thus, one work of this paper is to incorporate the control file of loads automatically according to current scenario and mode.

In the discrete-time format, a model of the DC power system can be expressed as:

$$x(t+1) = f[x(t), u(t)] \tag{1}$$

where  $u(t)$  is the vector of control variables.  $x(t)$  is the state vector of the system. The optimization goal is to find the control input,  $u(t)$ , to minimize a cost function, which consists of the weighted sum of solar/fuel consumption for a given working cycle. The cost function [1] to be minimized has the following form:

$$E = \sum_{t=0}^{N-1} f[x(t), u(t)] = \sum_{t=0}^{N-1} [S(t) + F(t) + \mu SOC(t) + vC(t)] \tag{2}$$

where  $N$  is the duration of the working cycle, and  $f$  is the instantaneous cost.  $S(t)$ ,  $F(t)$ ,  $SOC(t)$  and  $C(t)$  are corresponding instantaneous solar, fuel charge and other power cost.  $\mu$  and  $v$  are coefficients. For a solar power only system, the weighting factors are  $\mu = v = 0$ . The case of  $\mu > 0$  and  $v > 0$  represents a simultaneous fuel/charging problem. During the optimization, it is necessary to keep the battery state of charge and discharge inequality constraints to ensure safety of the system and smooth operation of the battery. Also keep the system the fast response.

Power loss represents the amount of power loss of all power sources during the simulation. It depends on the power delivery and bus voltage level. Total source loss is the sum of solar power loss, ultra capacitor loss, fuel cell total loss and battery loss.

Power consumed represents the power which is required by all loads. There is a burst of power consumption during the starting phase.

### 3. Performance Analysis

The working status of solar power, fuel cell, ultra capacitor and battery are indicated by the digit number, 1 is on and 0 is off. Assume the surge threshold value is 6000, worked in following 5 loops, figure 3 to figure 7 shows the MATLAB simulated surge current, which cause the big loss of system, the X-coordinate represents the time, unit is second and the Y-coordinate represents the current, unit is mA.

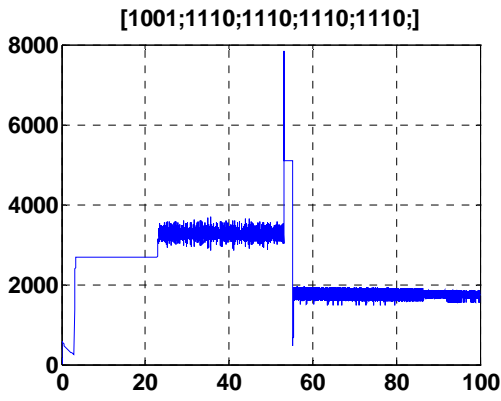


Fig.3. 1st loop, surge occurs during [40.60]

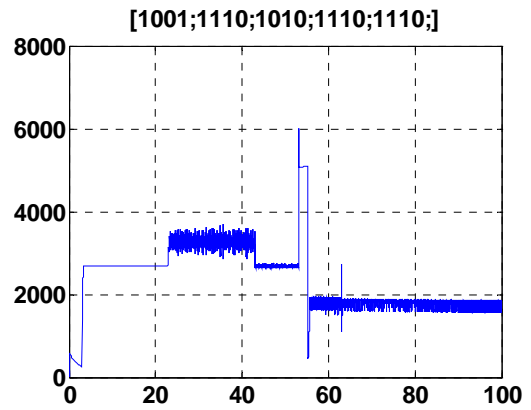


Fig.4. 2st loop, state change from 1110 to 1010, no surge

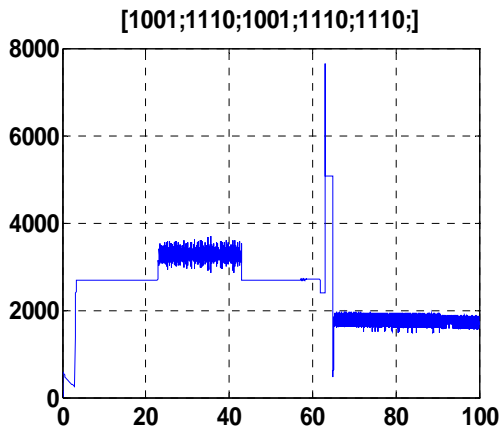


Fig.5. 3st loop, state change from 1010 to 1001, have surge

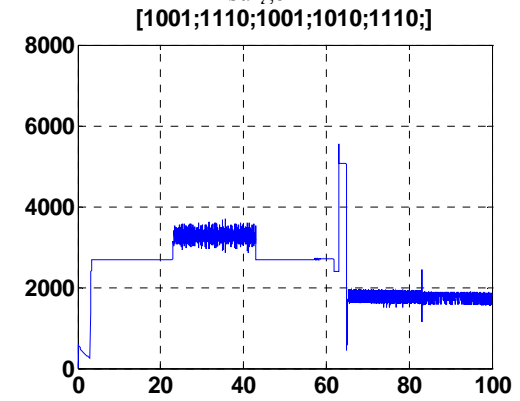


Fig.6. 4st loop, state change from 1110 to 1010, no surge

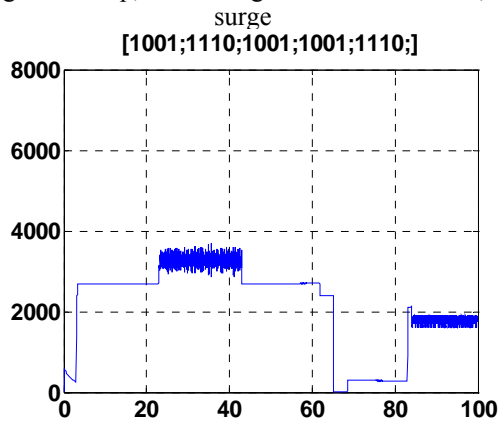


Fig.7. 5st loop, state change from 1110 to 1001, no surge

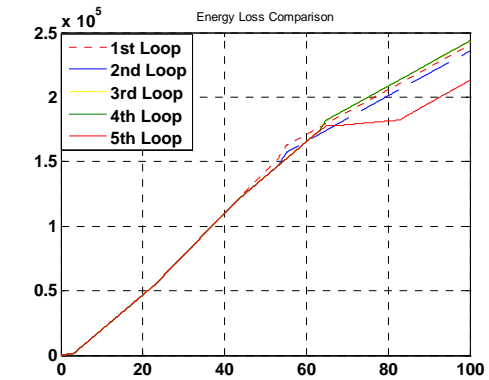


Fig.8. Energy Loss Comparison of 5 loops

Figure 8 shows the energy loss comparison of above 5 loops. The MATLAB simulation results show the 5<sup>th</sup> working loop has the smallest surge and the lowest loss.

#### 4. Loss Simulation Results

Figure 9 shows the MATLAB simulation results of instantaneous power loss under several working states. Also, the 4 digital numbers shows the working status of solar power, fuel cell, ultra capacitor and battery, 1 refers to on and 0 refers to off. And Figure.10 shows the simulation waveform of DC bus voltage. Figure 11 shows power loss comparison of optimized mode vs. all on mode (1111). Figure 12 shows the energy loss comparison of optimized mode vs. all on mode (1111).

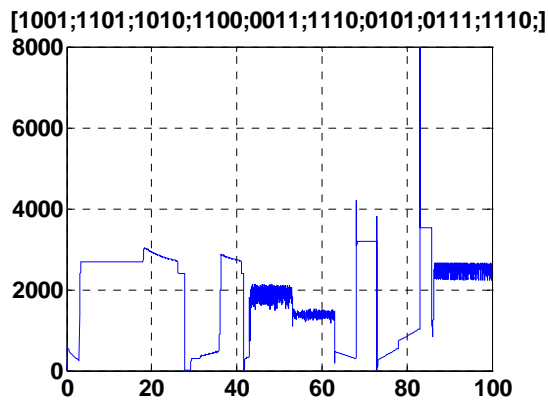


Fig.9. Instantaneous Power Loss

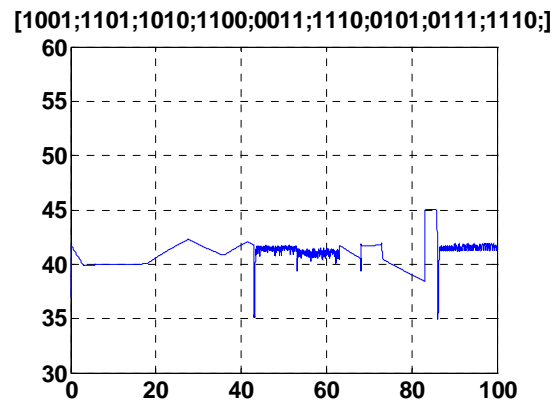


Fig.10. bus voltage

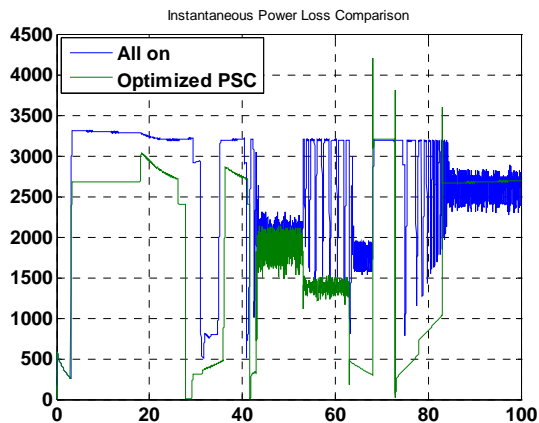


Fig.11. Power loss comparison of optimized mode vs. all on mode

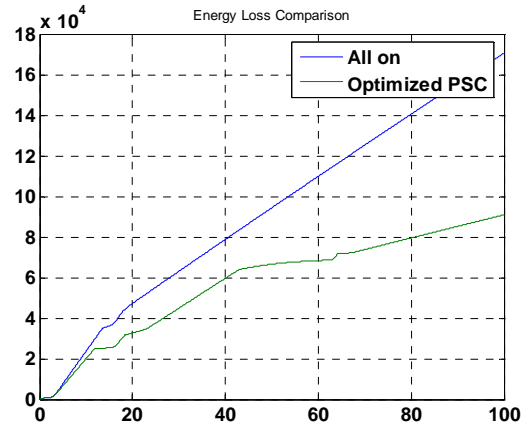


Fig.12. Energy loss comparison of optimized mode vs. all on mode

## 5. Conclusion

This paper discussed the power management for a renewable power system that has multiple power sources, including solar power, fuel cell, ultra capacitor and battery. A real-time control algorithm has been developed to learn about optimal power source combinations with respect to less surge and minimum power loss for all possible load requests and various system power states. The MATLAB simulation results show that the proposed control algorithm is a promising technology for standby multi source renewable power management. The simulation results of 5 modes shows the optimized control algorithm can avoid the surge current during the working conditions change and causes less ripple to voltage bus, also it is effective to improving the power loss of the system.

## 6. References

- [1] Chan-Chiao Lin, Huei Peng, "Power management strategy for a parallel hybrid electric truck," IEEE Transactions on Control Systems Technology, Vol.11, Issue 6,2003, pp.839 - 849.
- [2] Schupbach, R.M.; Balda, J.C.; Zolot, M.; Kramer, B.; "Design methodology of a combined battery-ultracapacitor energy storage unit for vehicle power management," IEEE 34th Annual Power Electronics Specialist Conference, 2003,vol.1, pp. 88-93.
- [3] Carrasco, J.M.; et al., "Power-Electronic Systems for the Grid Integration of Renewable Energy Sources: A Survey," IEEE Transactions on Industrial Electronics, 2006, Vol.53 Issue 4, pp.1002 - 1016.
- [4] Dimitris Ipsakisa, Spyros Voutetakisa, et al., "Power management strategies for a stand-alone power system using renewable energy sources and hydrogen storage," International Journal of Hydrogen Energy, Volume 34, Issue 16, 2009, pp.7081-7095.
- [5] E. Nogaret, G. Stavrakakis, "An advanced control system for the optimal operation and management of medium size power systems with a large penetration from renewable power sources," Renewable Energy, Volume 12, Issue 2, 1997, pp.137-149.

- [6] B. M. Baumann, et al., "Mechatronic Design and Control of Hybrid Electric Vehicles," IEEE/ASME Transactions on Mechatronics, 2000, vol. 5, no. 1, pp. 58-72.
- [7] Zhi Hang Chen; Abul Masrur, M.; Murphey, Y.L.; "Intelligent vehicle power management using machine learning and fuzzy logic," IEEE International Conference on Fuzzy Systems, 2008, pp.2351 - 2358.
- [8] Somporn Tanatvanit, Bundit Limmeechokchai, Supachart Chungpaibulpatana; "Sustainable energy development strategies: implications of energy demand management and renewable energy in Thailand," Renewable and Sustainable Energy Reviews, Volume 7, Issue 5, 2003, pp.367-395.
- [9] P. Rodatz, , G. Paganelli, A. Sciarretta and L. Guzzella; "Optimal power management of an experimental fuel cell/supercapacitor-powered hybrid vehicle," Control Engineering Practice, Volume 13, Issue 1, 2005, pp.41-53.
- [10] M.Muselli, G.Notton and A.Louche; "Design of hybrid-photovoltaic power generator, with optimization of energy management," Solar Energy, Volume 65, Issue 3, 1999, pp.143-157.
- [11] Amin Hajizadeh, Masoud Aliakbar Golkara; "Intelligent power management strategy of hybrid distributed generation system," International Journal of Electrical Power & Energy Systems, Volume 29, Issue 10, 2007, pp. 783-795.
- [12] Willett Kempton, et al., "Vehicle-to-grid power implementation: From stabilizing the grid to supporting large-scale renewable energy," Journal of Power Sources, Vol.144, Issue 1, 2005, pp.280-294.