出國報告（出國類別：其他國外會議）

出席第六屆即時模擬技術國際研討會

服務機關：國立聯合大學
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出國期間：102 年 6 月 25 日~102 年 6 月 27 日
報告日期：102 年 8 月 27 日

摘要（200-300 字）

第六屆即時模擬技術國際研討會提供國際產學界彼此交換應用於電力系統、汽車、航空、工業製造等領域之電機、電力電子及機械系統即時模擬技術之研究成果平台，研討會議議題專注在即時模擬與硬品迴路驗證。此次會議共計來自國際百餘篇論文投稿，審查通過數十篇文章安排在 3 天的會議時間進行，本人在會中作論文發表，將台灣在此一方面的研究成果與世界其他產學界專家分享，意義重大。多位參與學者針對本人研究相關議題提出問題交流，彼此分享成果經驗獲益良多。

關鍵字：微電網、即時模擬系統

目次

一、 目的

即時模擬技術國際研討會提供國際產學界彼此交換應用於電力系統、汽車、航空、工業製造等領域之電機、電力電子及機械系統即時模擬技術之研究成果平台，研討會議議題專注在即時模擬技術與硬品迴路驗證。本次研討會是第六屆舉辦，以往曾在亞洲、美洲、歐洲等地舉辦，今年又回到歐洲舉辦，地點爲法國巴黎，會議從 2013 年 6 月 25 日至 6 月 27 日止。本人參加此會議能將台灣在此一方面的研究成果與世界其他產學界專家分享，意義重大。

即時模擬技術的發展大約在 15~20 年前起步，最早起源於航空工業，而今，即時模擬技術已廣泛應用在各種工業中，主要是因爲此技術可以加快產品上市時程以及可以處理高複雜度的實體驗證能力。

本次與會目的如下：

一、發表論文，增進即時模擬技術專業知能之分享與交流。
二、參與相關論文研討，學習及交流，建立友好關係。
三、參觀即時模擬技術設備展示，了解使用經驗。

二、 過程

此次會議共計來自國際百餘篇論文投稿，審查通過數十篇文章安排在 3 天的會議時間進行，研討會議議題專注在即時模擬與硬品迴路驗證，本人在會中作論文發表，將台灣在此一方面的研究成果與世界其他產學界專家分享，意義重大。多位參與學者針對本人研究相關議題提出問題交流，彼此分享成果經驗獲益良多。

由於本人的研究主題乃將即時模擬技術應用於智慧電網運轉與能源管理系統之整合，由於智慧電網中有許多再生能源(風力、太陽能等)，這些電力的產生因受氣候因素影響，致使發電是間歇性的，對於系統的電壓或穩定度來說，均有嚴重的影響，所以需要搭配蓄電池來作能源的管理與調節，然而，不恰當的電池能量管理，不僅會使電池過充或過放電，影響電池壽命，也會造成系統的不穩定，以及經濟效益不佳，因此，電池使用於微電網的動態效應必須要藉由即時模擬技術來得知，而電池何時該充電、何時該放電，這一經濟上的效益分析就必須藉助於能源管理系統的決策，二者間的整合研究工作，較少人進行。

本次發表論文乃提出以 Opal-RT Technologies(OPAL-RT)之數位即時模擬器(RT-LAB)爲基礎，以非同步(UDP)架構與另一台電腦上的 EMS 程式進行互動，驗證動靜態系統模擬架構可行性及模擬系統真實動靜態響應變化。其中 RT-LAB 是由加拿大 OPAL-RT 公司所開發之即時模擬系統，它提供 PC-based 平台高性能分散式運算之即時模擬與控制系統軟體與硬體。RT-LAB 具開放性架構，可支援

Matlab/Simulink/SimPowersystems 所建構之模型，使用者可以 Simulink/SimPowerSystems 作爲系統層的設計(System-level design)與模擬的平台，然而在 Simulink 底下的模擬並非即時(real-time)的，若要進行即時的應用，微軟的作業系統平台相對有困難，因此選用 QNX 即時作業系統（RTOS），作爲實現即時應用的作業系統。QNX 是一種商用、遵循 POSIX 規範、類似 Unix 的即時作業系統，其標的市場主要是以嵌入式系統爲主。這種作業系統可以安裝在 PC 上並搭配 I/O 介面卡。使用者可以利用 RT-LAB 提供的 Blockset 在 Simulink 視覺化建模的環境做系統設計、開發與模擬，然後利用 Matlab 的家族產品 Real-time Workshop (RTW)將 Simulink 的原始模型檔轉成 ANSI-C 的程式碼，再透過網路將程式碼傳送到另一台(Target)有即時核心(Real-time Kernel)的電腦做編譯，這個即時運算核心是建構在 QNX 作業系統下，編譯完成後的執行檔會回傳至 Matlab 端電腦，當需要執行時只需透過 RT-LAB main control 的軟體介面，再次將執行檔傳送到 QNX 作業平台下即可執行。另外，在 QNX 模擬的結果也可以利用網路回傳至 Matlab 端的電腦，利用 Simulink 下的 scope 功能觀察，或是利用 Simulink 內的模塊作參數調整。

透過 RT-LAB target 端電腦的 Ethernet 可以將即時模擬的數據以非同步(UDP)方式傳送到另一台裝有 EMS 程式的電腦上，進行互動。

本人將上述這一方面的初步研究成果於會議中發表，引起諸多討論，有來自美國的華人學者提出她的看法，看是否可以用動態規畫的方式看結果如何，與本人的結果進行比較。也有學者對於微電網的各元件的模擬模組感興趣，問到動態響應取樣時間可以到多快，等等的問題讓 Q&A 時間比預計時間長，長達十多分鐘。雖然有延遲到下一位的發表，不過，個人覺得過程中相互獲益許多。

進行口頭報告發表論文

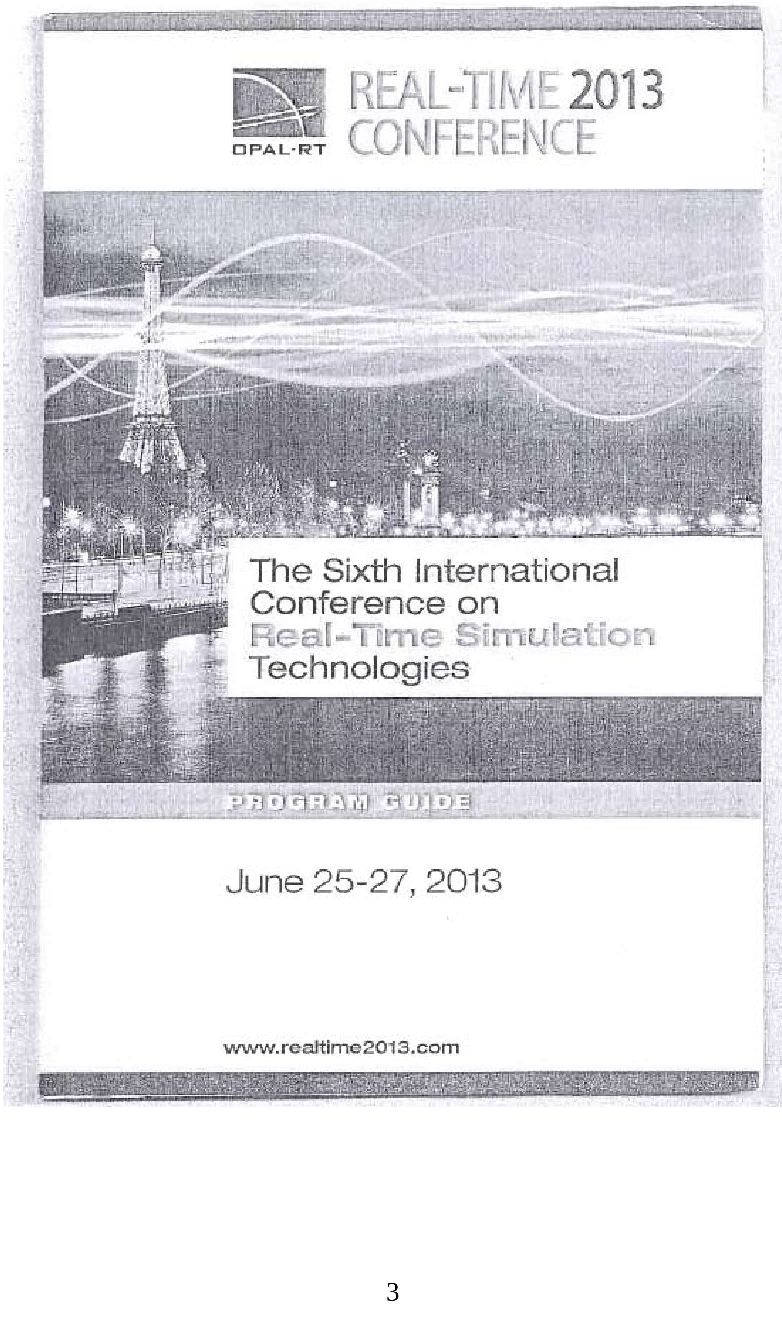
三、 心得及建議事項

此次會議地點法國巴黎，由於距離遠以及旅費昂貴，自台灣來的學者除了筆者外，並無他人，這是較爲遺憾的地方。另外，由於大陸開放人才留學的政策，多數學成後留在當地國的學者多數都已嶄露頭角，此次，就有多位來自大陸已入籍美國或加拿大的學者與會，他們所展現的研究能量不容小覷，這是我們台灣得注意及加強努力的。

幾天下來參與會議，與許多歐洲及美洲學者共同就即時數位模擬、硬品迴路驗證技術交流，獲得一些新知，而他們對於本人的研究成果，也多表肯定與贊同。

四、 攜回資料名稱

會議論文摘要集，會議投影片線上下載。



OPAL-RT

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STEM FOR TCU VALIDATION

n, Hyundai Motor Company, South Korea

ION OF DISTRIBUTED SYSTEM FOR SOLUTION OF PLANNING AND 'CHING PROBLEMS IN EUROPEAN

ME OPTIMIZATION AND SIMULATION FOR HYBRID POWER SYSTEMS

University of Michigan, USA

wer systems, exemplified by all-electric ships (AES) and hybrid electric vehicles (HEV), nultiple heterogeneous power sources to achieve high system efficiency and superior mission ess. To leverage the complementary features of different power sources, their control strategies ploit the dynamic coupling of subsystems while respecting physical and operational constraints. rch team at the University of Michigan RACELab (Real-time Adaptive Control Engineering devoted their efforts in recent years to hybrid power system optimization. In conjunction with ptimization algorithm development, researchers in the RACELab have been exploring real-time as one of the design, analysis, and evaluation tools.

ATION FOR UAV NAVIGATION

ppe LEBRAT, Sagem (groupe Safran), France

n and verification of signal processing functions related to Navigation systems require ated environment models. In order to verify accuracy and integrity performances, the off-line in an appropriate way for a statistical properties demonstration; for example, the verification of integrity requirements leads to simulation of millions of hours. The compliance of software activities to the DO-178 recommendations not only requires representative environments rigorous control of interfaces. Contact: jean-philippe.lebrat@sagem.com

IG LITHIUM-ION BATTERY MANAGEMENT SYSTEMS FOR HYBRID LECTRIC VEHICLES

irth, IAV Automotive, USA

g concern over climate change has led the Environmental Protection Agency(EPA) onal Highway Traffic Safety Administration(NHTSA) to establish new standards for fuel y and limits for carbon dioxide emissions from cars and light trucks. A viable solution to these new standards is by implementing partial or full electrification of vehicle powertrains. nd electrical vehicles utilize a battery to power a motor which subsequently provides emissions, or emission-free propulsion. A key challenge is to optimize functionality and n. Battery Management Systems (BMS) are required to control and manage the electrical stored in the battery. The validation of the BMS is equally important to ensure their proper ility and safety. A key step in the testing involves [illegible] real-life phenomena using

MULTIPHASE PWM CURRENT SOURCE INVERTER FED FROM THREE PHASE PWM CURRENT SOURCE RECTIFIER

Mahmoud I. Masoud – ECE dept. : College of Engineering, Sultan Qaboos University, Oman

Many industrial applications require high power ratings with quick response to adapt the load requirements or to cover faults. The real time system as a control tool engaged with multiphase converters could be a candidate to achieve fault tolerant, reliability, or even load variations. A rectifier-inverter system requires real time to drive the switches especially in medium voltage, (MV), applications where fault tolerance is required. The switching pattern to the converter could be DSP implemented using real time simulators. This paper introduces multiphase PWM current source inverter (CSI), fed from three-phase PWM current source rectifier (CSR) with controlled dc-link current. As a case study, MV three-phase rectifier controls the dc-link current which is the input to a seven phase PWM-CSI inverter to supply power to a static load taken as a case study. Simulation Results uses MATLAB/SIMULINK platform. Contact: m.masoud@squ.edu.om, m.masoud@ieee.org

PRESENTATION TO BE ANNOUNCED

Billings Chan, Aviyatech, USA

THE STUDIES OF REAL-TIME SIMULATION OF A MICRO-GRID WITH ENERGY STORAGE SYSTEM AND ITS OPTIMAL ENERGY MANAGEMENT SYSTEM

Yu-Chi Wu, Taiwan

CREATION OF DISTRIBUTED SYSTEM FOR SOLUTION OF PLANNING AND DISPATCHING PROBLEMS IN EUROPEAN INTERCONNECTION

Vasily Makeechev, Oleg Soukhanov, Russia

According to the practice, existing at the present time in large power interconnections, system operators of each of power systems within interconnection are encharged with a task of planning and dispatching in their power systems. The most important defect of the existing organization of power systems control in large interconnections lies in inability to assure global optimality of operation of interconnection as a whole. Practicable and most promising way for enhancement of economical efficiency in these interconnections lies in addition of one more layer to the existing structure of power systems control centers in UCTE, USA, Canada and CIS. The function of this layer should be calculation of optimal power flows between large power systems of these countries. Main advantage of this system compared with existing control systems is that this system can assure global optimality of operation in large interconnection as a whole without centralization of its control system.

五、 論文全文或摘要

The Studies of Real-Time Simulation of a Micro-Grid with Energy Storage System and Its Optimal Energy Management System

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Abstract

Several energy management strategies integrated into a micro-grid system with battery energy storage system (BESS) are proposed in this paper to decrease the impact from intermittent renewable energy sources (RES) (wind power and PV) and to increase the overall system economic benefit using a real-time digital simulator. The mathematical models of RES are first addressed, and then functions of energy management to microgrid systems are discussed. The proposed energy management strategies for the microgrid system with BESS considers not only the time of use rates but also several other operational constraints related to BESS, and they are tested to provide optimal hourly battery state-of-charge (SOC) through a real-time digital simulator, elevating the economic benefit and subsiding the impact from intermittent RES.

Keyword: Microgrid, Energy Management, Time of Use Rates, Real-time Simulation.

I. Introduction

The emission of CO_2 is the key factor causing global warming. In recent years, as the environmental considerations rise and the crisis of resource exhaustion is recognized in the world, the application of energy sources has already become a popular subject, and the development of new energy sources and energy saving have already become nonnegligible. However, as people's environmental considerations rise, the cost in building large-scale centralized power plants and transmission and distribution lines increases continuously, and the construction is increasingly difficult, so that the power companies have to look for other solutions. In order to increase the service efficiency of electric energy, the loss of electric energy in the transmission process shall be reduced [1], and the transmission loss can be reduced effectively by setting distributed power generation nearby the load center [2]. Therefore, the distributed power generation microgrid develops, the present power system network is complexer than ever, and its running operation is more difficult.

In order to reduce the CO_2 emission, most of distributed power sources use green energy, but the output characteristic of green energy may be influenced by climatic factor, resulting in intermittent power generation that causes puzzles in control and protection coordination [3]. Take wind turbine as an example, the variance in the wind field, such as wind direction and wind speed, makes the output power of the wind turbine instable. This characteristic influences the power quality, especially when the penetration rate of wind turbine power generation increases [4-6]. In order to guarantee the safety, economy and high efficiency of the operation of power system, there shall be an energy storage system to smooth the power fluctuation of green energy output under weather effect, and to keep the dynamic balance between power generation and load to stabilize the voltage and frequency. When the battery capacity of the equipped energy storage system is large enough, the effect on smoothing the wind power output fluctuation is better, but the investment cost increases accordingly, meaning the economical requirement cannot be met in certain cases. Therefore, the optimal control improving energy storage system technology and economic performance becomes an important topic of microgrid system. In order to analyze these puzzles, there shall be a real-time simulator for power system to analyze the stability of new system and the microgrid operation [7].

The real-time simulation technology for power system is very important; however, the application of real-time simulation technology for power system to microgrid and energy management system is seldom studied and discussed, especially in Taiwan. Therefore, in order to solve the influence of microgrid system on power consumers and the problems in on-site testing, and to popularize the green energy, this paper applies the real-time simulation technology for power system to a simulated microgrid system, simulates and analyzes the steady-state characteristics and dynamic response by constructing a microgrid model, and proposes energy management strategies to improve the effect of intermittent power generation of renewable energy on the power system, so that the microgrid system can use energy more effectively and the economic benefit of the system can be increased.

This paper proposes using the interaction between asynchronous (UDP) architecture and the EMS program in another computer based on the digital real-time simulator (RT-LAB) of Opal-RT Technologies (OPAL-RT) to validate the feasibility of dynamic and static system simulation architecture and to simulate the changes in real dynamic and static responses of the system. The RT-LAB is a real-time simulation system developed by Canada OPAL-RT company, it provides real-time simulation of PC-based platform high performance distributed computing and controls the system software and hardware. The RT-LAB has open architecture, it supports the models built by Matlab/Simulink/SimPowersystems, the user can use Simulink/SimPowerSystems as the system-level design and the platform for simulation, however, the Simulink-based simulation is not real-time, the operating system platform of Microsoft is relatively difficult for real-time application, so the QNX RTOS is used as the operating system for implementing real-time application. QNX is a commercial RTOS similar to Unix following POSIX specifications, its target market is mainly embedded systems. This operating system can be installed in PC with I/O adapter card. The user can use the Blockset provided by RT-LAB to perform system design, development, and simulation in Simulink visual modeling environment, and then uses the series product Real-time Workshop (RTW) of Matlab to convert the original model file of Simulink into ANSI-C program code, and the program code is transmitted via network to another (Target) computer with real-time kernel for compilation, this real-time operation kernel is built on QNX operating system. The compiled execution file will be sent back to the Matlab-side computer, it can be executed only by sending the execution file via the software interface of RT-LAB main control to the QNX operating platform again. In addition, the result of QNX simulation can be sent back via network to Matlab-side computer, observed by the scope function of Simulink, or the parameters can be adjusted by using the module inside Simulink.

The real-time simulation data can be transmitted in UDP mode via the Ethernet of RT-LAB target-side computer to another computer installed with EMS program for interaction.

Section II of this paper will introduce the microgrid system architecture. Section III introduces the energy management system for microgrid. Section IV introduces the microgrid system simulation conditions. Section V introduces the modified planning of microgrid energy management system. Section VI introduces the simulation results. Section VII discusses the conclusions.

II. Microgrid system architecture

As shown in Figure 1, the microgrid system consists of energy storage component VRB battery, renewable energy solar cell/wind turbine and energy management system. The output voltage of solar power system and wind power generation system is increased to the same voltage level DC BUS, this architecture can reduce the number of converters, so as to increase the overall efficiency of the system [8]. The constructed system model can be used to analyze various dynamic responses and controls among VRB battery, solar power generation and wind turbine, so as to know the impact of using VRB battery to buffer the intermittent power generation characteristic of solar power generation or wind turbine on the system, as well as the economic benefit of the energy management system to the microgrid operation.

Microgrid system simulation:

The microgrid system model is built by using SimPowerSystems of Matlab, Figure 2 shows the microgrid system module structure, the microgrid system is separated into one SM_Subsystem and three SS_Subsystems, the calculations are integrated for different kernels to shorten the computing time for real-time synchronization, and the SC_Subsystem is in charge of monitoring the microgrid system module.

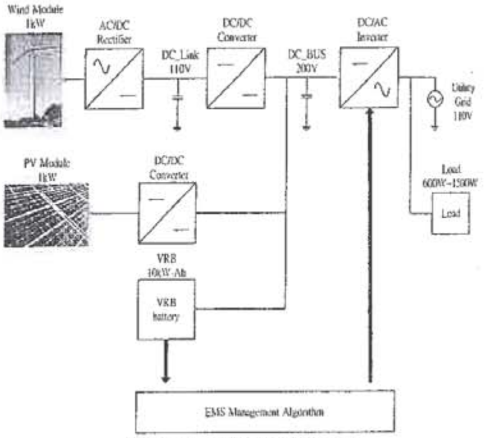

Figure 1 Microgrid system

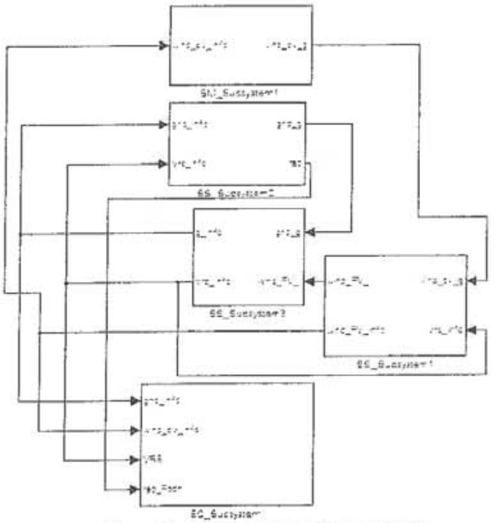

Figure 2 Microgrid system module

III. Energy management system of microgrid: mathematical model of economic dispatch

The power dispatching of microgrid system shall not only determines the optimal power generation scheduling of various decentralized power supplies, but also coordinates the optimal energy storage and energy release strategies of accumulator and the optimal time for power grid electricity buying and selling, the minimization of the operating cost of overall microgrid system depends on the cost or profit of buying electricity from or selling electricity to the electric supply, meeting the microgrid load requirement at the minimum cost.

The energy management system proposed in this paper is applicable to any microgrid architecture. The energy management system aims to minimize the cost of electric energy of overall system by dispatching the VRB battery SOC. Figure 3 is the schematic diagram of microgrid system power flow. PF is the renewable energy power (sum of solar energy power and wind power generation power), PB is the VRB battery output power (positive or negative), and PG is the power flowing to the electric supply.

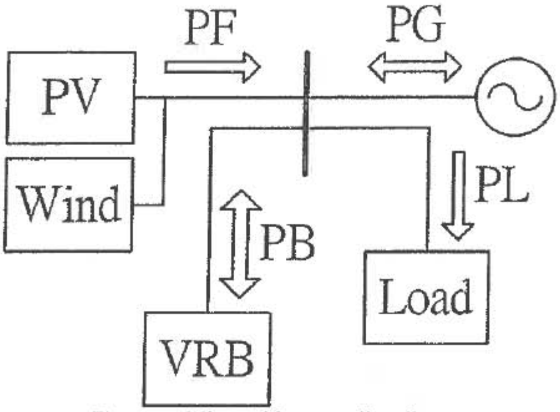

Figure 3 Microgrid system line diagram

The energy management system shall maintain the required load in microgrid and the battery SOC between the upper and lower limits to avoid overcharge or overdischarge to prolong the battery lifetime. Using the energy management system to dispatch VRB battery SOC can reduce the cost of microgrid system, so that the system meets the economic benefit better. The economic dispatch of microgrid is expressed by the mathematical model of 24-hour planning as follows.

$$\text{Min } F = \sum_{i=1}^{24}(PG_i)f_i \quad (1)$$

s.t.

$$SOC_j = \sum_{j=1}^{j}(PB_j)\eta_{soc_j}/PB_{base} + SOC_{j-1} \quad \forall j = 1,2,\dots,24 \quad (2)$$

$$PF_k + PG_k + PB_k = PL_k \quad \forall k = 1,2,\dots,24 \quad (3)$$

$$SOC_k^{min} < SOC_k < SOC_k^{max} \quad \forall k = 1,2,\dots,24 \quad (4)$$

$$PG_k^{min} < PG_k < PG_k^{max} \quad \forall k = 1,2,\dots,24 \quad (5)$$

Where PG_i is the power delivered from the microgrid system to the electric supply side in time interval i, f_i is the time of use rates function (please refer to three-phase time of use rates introduced by Taiwan Power Company [9]), SOC_j is the SOC value of VRB battery in time interval j, PB_j is the output power of VRB battery in time interval j, η_{soc_j} is the efficiency of VRB battery in time interval j, PF_k is the total power of renewable energy power generation in time interval k, PL_k is the capacity in time interval k, SOC_k^{min} and SOC_k^{max} are the lower and upper limits of SOC of VRB battery respectively in time interval k, PG_k^{min} and PG_k^{max} are the lower and upper limits of the power delivered from the microgrid system to the electric supply side in time interval k. According to the above mathematical equation of microgrid, the optimal power dispatching of microgrid system can be obtained by linear programming.

Figure 4 is the schematic diagram of interconnection between RT-LAB and EMS PC. The communication bridge is built through network Hub, the Host and Target of RT-LAB are connected by Ethernet for data transmission, the RT-LAB Target is connected to EMS PC through Ethernet UDP communication protocol to transmit the execution data of both systems. The Host monitors the microgrid system state. The data transmitted from RT-LAB to EMS PC is the SOC value of the system, EMS PC executes energy planning and works out the optimal power dispatching according to SOC value, delivers the power flowing to the electric supply side in each time interval calculated by the energy management system to the microgrid system for connection, forming the energy management system for real-time monitoring of the microgrid.

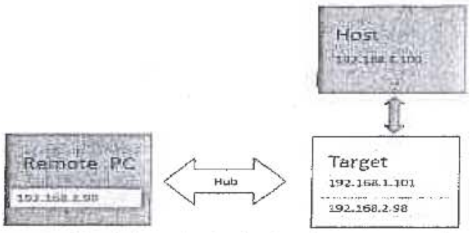

Figure 4 Real-time simulation hardware connection structure

IV. Microgrid system simulation conditions

This paper uses 1-second real-time simulated operation of microgrid system to represent 4-minute system operation, thus, as long as the real-time simulated microgrid system runs 6 hours in the real-time simulation system, the changes in the microgrid system within 24 hours can be analyzed. Although this method reduces the simulation time, the instantaneous time of microgrid system is short, such a simulation has slight influence on transient response.

According to the aforesaid mathematical model of microgrid, the power grid cost function can be set referring to the three-phase time of use rates, as shown in Eq. (6) and Figure 5.

$$f(x) = \begin{cases} 1.35 & x < 7;\ 22 \le x < 24 \\ 2.7 & 7 \le x < 10 : 12 \le x < 13 : 17 \le x < 22 \\ 4.26 & 10 \le x < 12 : 13 \le x < 17 \end{cases} \quad (6)$$

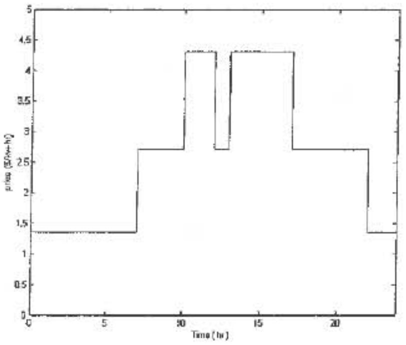

Figure 5 Three-phase time of use rates cost function

As there are three phases of electricity price, including high electricity price, moderate electricity price and low electricity price, integrating the renewable energy output, the daily power generation of microgrid system can be divided into six states, as shown in Figure 6. The energy management system will coordinate the optimal energy storage and energy release strategies of accumulator and the optimal time for buying electricity from or selling electricity to the power grid from the aforesaid conditions, so as to reduce the microgrid system cost and to prove that the microgrid with energy management system can increase the economic benefit of overall system and improve the influence of intermittent power generation of renewable energy.

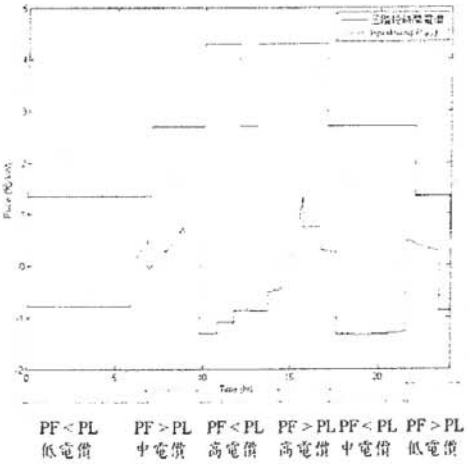

Figure 6 Relation between renewable energy and load in various time intervals

Experimental situation of microgrid system

The microgrid system with energy management is shown in Figure 7, the modified OPF is executed once according to the updated predicted value hourly.

Simulation procedure

The constructed microgrid system module is separated into several subsystems for parallel computing to accelerate the simulation, so that the microgrid system implements real-time simulation calculation, the 24-hour energy dispatching value after current time is calculated according to the updated predicted value hourly, and adding in weight mode referring to the planning value of previous time interval, to correct current energy planning, the PG commands in different time intervals are transmitted to the microgrid system via Ethernet for optimal power dispatching and analyzing the system economy improvement efficiency.

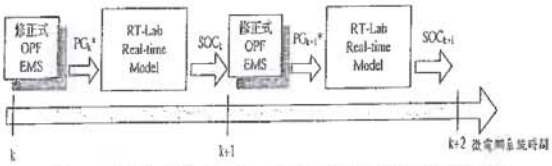

Figure 7Modified planning calculation of energy management system

V. Modified planning strategy for microgrid energy management system

Hourly energy planning for microgrid system can improve the effect of the errors in the predicted renewable energy power generation of microgrid system or in the predicted value of load demand, but there may be differences in the future electricity selling or buying time point planned at different time points, so that the overall economic benefit of microgrid system is not optimal. Figure 8 shows the modified energy planning calculation sequence for improving this phenomenon, the PG command value of current microgrid in each time interval is the sum of the planning value calculated at current hour and the value planned one or two hours ago in weight proportional mode, the applicable equation is shown in Figure 8. Figure 9 is the operational flowchart of modified planning of energy management system.

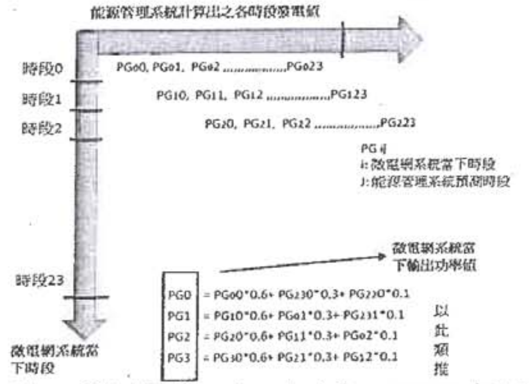

Figure 8Modified planning calculation sequence chart of energy management system

VI. Simulation results

The VRB battery is applicable to distributed power generation for its high response speed, the intermittent power generation of renewable energy has adverse effect on the microgrid system, so this paper proposes using VRB battery to absorb the renewable energy output fluctuation and using energy management system to supply stable power to the electric supply side or to supply the required power for the load.

The microgrid system without energy management is simulated, the VRB battery absorbs the fluctuation of the renewable energy output, and provides firm power for the load. The timing of selling electricity to or buying electricity from the electric supply of the microgrid system depends on the SOC value of VRB battery. In order to avoid over-discharge and over-charge of VRB battery, when the VRB battery SOC is lower than 20%, the electric supply charges the VRB battery till the VRB battery SOC exceeds 30%; on the contrary, when the VRB battery SOC is higher than 80%, the VRB battery is discharged till the VRB battery SOC is lower than 70%. Two battery capacities are considered here: 10kW-Ah and 6kW-Ah for analyzing and discussing the effect of battery capacity on economic benefit.

The states of the microgrid system without energy management are shown in Figure 10. P_{grid} plus sign means the microgrid system buys source power from electric supply, P_{grid} minus sign means the microgrid sells source power to electric supply, the VRB battery of microgrid system absorbs the fluctuation of intermittent power generation of renewable energy, and supplies the required power for the load. The electric supply selling and buying timing is determined by whether the VRB battery SOC value reaches the upper and lower limits. According to the aforesaid waveforms of various modules of the microgrid system, the underload is supplied by VRB battery, the microgrid system maintains the power PG delivered to the electric supply side at zero, till the SOC value reaches the lower limit, the electric supply charges the VRB battery, the daily total cost of microgrid system is NTD 0.923.

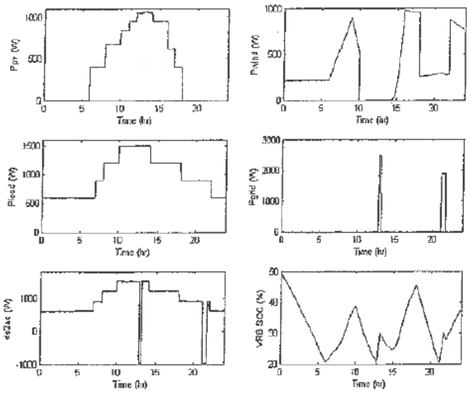

Figure 10System operation without energy management system in Case I (VRB battery capacity 6kW-Ah)

When the microgrid system increases the VRB battery capacity to 10kW-Ah, as shown in Figure 11. Although the data show that with this capacity, the overall cost of microgrid system on the day is zero, the battery SOC value is reduced at 24 hr, so that the initial value of SOC of the new cycle on alternate day is low, therefore, only increasing the VRB battery capacity cannot keep the overall cost of system at zero in long-term operation of the microgrid, in order to maximize the efficiency, the energy management system shall be used to determine the optimal time for buying electricity from and selling electricity to the power grid, and to control the VRB battery SOC value instantly to make optimal power dispatching of microgrid system meet the economic benefit better.

As mentioned above, the microgrid system cannot supply the required energy for the load by increasing the VRB battery capacity to keep the long-term expenditures of microgrid system at zero, the energy management is required to plan optimal power dispatching for the microgrid system. According to Section III, the established mathematical equation of economic dispatch of microgrid can be solved by linear programming to obtain the optimal power dispatching of microgrid system VRB battery.

The energy management system modified planning calculation adds the planning value in previous one (or two) time interval and current planning value in weight mode, there are two weights, as shown in Eq. (7) and Eq. (8), the planning effect after ten times of simulation is shown in Table 1.

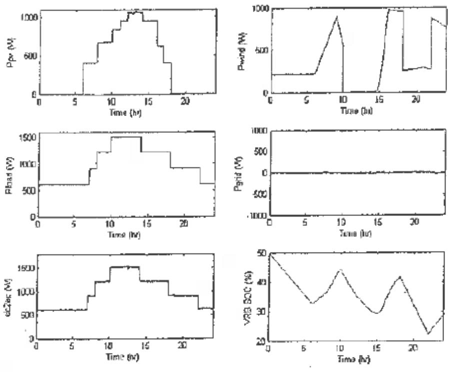

Figure 11System operation without energy management system in Case I (VRB battery capacity 10kW-Ah)

$$PG(t-1)\times 0.2 + PG(t)\times 0.8 \tag{7}$$
$$PG(t-2)\times 0.1 + PG(t-1)\times 0.3 + PG(t)\times 0.6 \tag{8}$$

Table 1Efficiency result of energy management system modified planning

No.	Weights 0.2 & 0.8		Weights 0.1 & 0.3 & 0.6	
	Final SOC(%)	Total cost (NTD)	Final SOC(%)	Total cost(NTD)
1	50.55	-2.14	48.07	-2.52
2	36.87	-4.00	48.12	-2.49
3	52.29	-1.90	48.10	-2.53
4	52.00	-1.87	49.27	-2.45
5	52.88	-1.79	48.31	-2.41
6	50.58	-2.13	40.77	-3.40
7	36.88	-3.98	48.82	-2.41
8	53.61	-1.63	50.33	-2.05
9	50.63	-2.12	48.67	-2.42
10	50.57	-2.14	50.77	-2.08
Average	48.69	-2.37	48.12	-2.48

According to Table 1, the overall economic benefit is stable when the weights are 0.1, 0.3 and 0.6, and the final residual capacity value approaches to 50% of initial, so the weight parameters of this energy management system are 0.1, 0.3 and 0.6. Figure 12 shows the operating states of the microgrid system in this mode, the daily overall cost is –NTD 2.03 (income), and the VRB battery residual capacity is 48.5%.

Battery capacity selection of energy management

This section discusses the selection of the energy storage component VRB battery capacity in the microgrid system. The battery capacity is also one of important factors determining the economic benefit of microgrid and energy management system. Section II has introduced that the VRB is characterized by long life and low cost maintenance. The VRB battery capacity cost is divided into maintenance cost and set-up cost. The maintenance cost is approximately NTD 0.264/kWh [10-11], and the higher the service power of VRB battery is, the higher is the maintenance cost. The set-up cost is approximately NTD 6,600/kWh [10-11], the set-up cost determines the operable capacity of the energy storage component VRB battery.

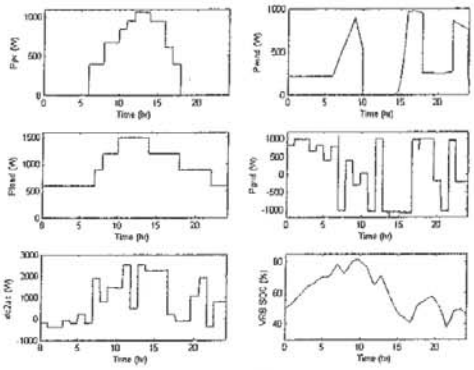

Figure 12Microgrid system operating states in Case IV

We use modified energy planning method, the influence of microgrid system with different VRB battery capacities on the economic benefit can be worked out by the aforesaid costs. The higher the VRB battery capacity is, the larger is the economic benefit of microgrid system, as shown in Figure 13 and Figure 14.

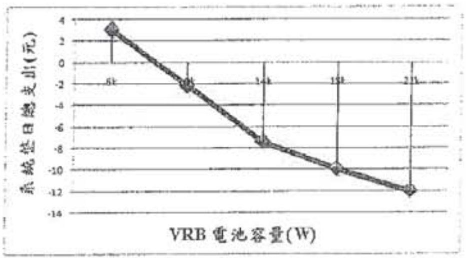

Figure 13Relationship between battery capacity and economic benefit of system

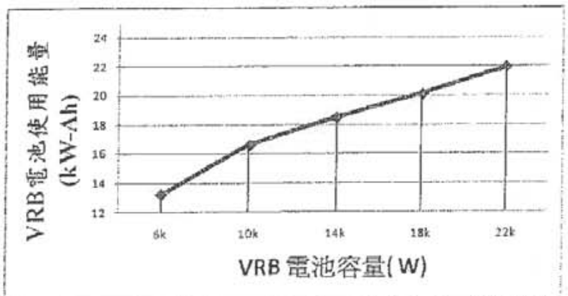

Figure 14Relationship between battery capacity and VRB battery service power

Table 2 shows the relationship between the battery capacity and cost of the microgrid system with energy management system. Data 0W-Ah means the microgrid has not been equipped with energy storage system, the system constraint is the result of the lower limit of power delivered to the electric supply side PG_k^{min} = --1000W and the upper limit of power delivered to the electric supply side PG_k^{max} = 1000W, the total daily expenditure value with plus sign represents the amount of expenditure, and the minus sign represents the amount of income, as the energy management system expects the VRB battery to absorb the fluctuation of intermittent power generation of renewable energy to supply stable power to the electric supply and the power for load, therefore, most of daily average power is consumed by VRB battery absorbing renewable energy power fluctuation. According to Table 2, under these conditions and limits, total daily income is negative only if the battery capacity exceeds 14kW, take 22kW-Ah as an example, the cost recovery period of VRB battery of the microgrid with energy management system is estimated at about 49 years.

Table 2Relationship between battery capacity and cost of microgrid system

VRB (kW-Ah)	Average daily power consumption (kW)	Average daily income (NTD)	Maintenance cost (NTD/day)	Set-up cost (NTD 1,000)	Total daily expenditure (NTD)
0	1.26	1.84	0	0	1.84
6	13.22	3.04	3.49	39.6	6.53
10	16.6	-2.16	4.38	66	2.22
14	18.49	-7.45	4.88	92.4	-2.57
18	20.11	-9.94	5.31	118.8	-4.63
22	21.96	-12.05	5.8	145.2	-6.25

If the limit parameters of microgrid system to electric supply side are changed to lower limit PG_k^{min} = --2,000W and upper limit PG_k^{max} = 2,000W, the result is shown in Table 3. The total daily income is negative when the battery capacity exceeds 14 kW, take 22kW-Ah as an example, the cost recovery period of VRB battery of the microgrid with energy management system is estimated at about 20 years. Therefore, the economic benefit of energy management system can be influenced by the battery capacity and the grid-connected power limitations.

Table 3Relationship between battery capacity and cost of microgrid system

VRB (kW-Ah)	Average daily power consumption (kW)	Average daily income (NTD)	Maintenance cost (NTD/day)	Set-up cost (NTD 1,000)	Total daily expenditure (NTD)
0	1.26	1.84	0	0	1.84
6	24.24	2.94	6.4	39.6	9.34
10	25.03	-4.01	6.61	66	2.6
14	27.23	-12.19	7.19	92.4	-5
18	29.11	-19.7	7.68	118.8	-12.02
22	32.14	-26.57	8.48	145.2	-18.09

VII. Conclusions

This paper mainly discusses the integration of optimal energy management system and microgrid with energy storage system, and uses real-time simulator to research the dynamic response and economic benefit of the system, the real-time simulation microgrid system can help the power engineers know the transient response of microgrid system and power system stability.

This paper proposes the energy management strategy algorithm, and analyzes the influence of energy management system under different battery capacity and grid-connected power limitation conditions, as well as considers the battery set-up cost and battery maintenance cost and works out the cost recovery period.

This paper uses real-time simulator to implement real-time simulation, the microgrid system integrated with energy management uses the energy management system to determine the power and flow direction to the electric supply side, so as to optimize the economic dispatch and improve the influence of intermittent power generation of renewable energy, so that the microgrid system can use energy more efficiently and the economic benefit of microgrid system is increased.

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