International Journal of Scientific Engineering and Technology
Volume No.6 Issue No.6, pp: 181-184

ISSN:2277-1581
01 June 2017

Multi-Purpose HILS Design and Implementation for Optimal Operation Of Distributed Energy Resources with EMS

Chul-Sang Hwang[a]*, Yun-Su Kim[a], Jin-Hong Jeon[a], Changhee Cho[a], Minwon Park[b], In-Keun Yu[b]

a Smart Distribution Research Center, Korea Electrotechnology Research Institute, Republic of Korea
b Department of Electrical Engineering, Changwon National University, Republic of Korea
E-mail: hcs1006@keri.re.kr

Abstract : Multi-purpose hardware in-the loop simulation (HILS) design and implementation for optimal operation of distributed energy resources (DERs) with energy management system (EMS) were performed, and the operational performance of DERs is analyzed. The DERs which includes a photovoltaic power system, an energy storage system, load and utility grid is modeled and analyzed in real time digital simulator (RTDS). An optimal operation algorithm is implemented in connection with EMS, which is connected to the RTDS through interface cards. The results demonstrated the effectiveness of the HILS and the EMS. The proposed multi-purpose HILS method can be effectively utilized to validate and test operational schemes of DERs with EMS under the practical environment without a real system.

Keywords: hardware in-the loop simulation, optimal operation of distributed energy resources, real time digital simulator

1. Introduction

The electricity requirement is increasing at alarming rate and the power demand has been running ahead of supply. It is also widely recognized that distributed energy resources (DERs) such as distributed generation and energy storage system (ESS), presently being used for generation of electrical energy, are considered as some of the most important options to provide more secure, clean and efficient energy [1-3]. The benefits of DERs are seen to be higher reliability of service, better quality of power supply and efficient use of energy by utilizing ESS [4]. In order to confirm the optimal operation of DERs and related systems in advance, a closed loop type of test-bed such as hardware in-the loop simulation (HILS) is required. The HILS enables real time testing of devices in a controlled environment before they are connected to actual system. In this study, a multi-purpose HILS is designed and implemented for optimal operation of DERs with EMS in connection with real time digital simulator (RTDS). The HILS not only can perform operation of DERs, but also apply EMS with optimal operation algorithm, as well as analyze various algorithms through the HILS to verify the reliability of an integrated DERs system.

The DERs are composed of a photovoltaic (PV) power system, an ESS, load and utility grid which are modeled in RSCAD/RTDS for applying EMS using HILS, and the modeled DERs are simulated at real time by RTDS. The optimal control algorithm of the EMS is implemented using C# programing language in a computer. A communication between real time simulation and the optimal operation controller is also implemented through TCP/IP. The EMS includes a load forecasting and a peak shaving functions. The load forecasting is done by using the simple moving averages technique [6]. A peak load limit of the customer and charging and discharging schedules of the ESS are optimized on annual basis to minimize annual electric rates, which consists of peak load related base charge and energy charge [7-9].

The HILS results show the electric rates saving and optimal operation of DERs by the EMS. The performances of the DERs are also described when they are controlled by the EMS. Using the multi-purpose HILS, EMS functions can be effectively tested and validated under the practical environments without a real system.

2. Distributed Energy Resources model

Fig. 1 shows the configuration of an integrated DERs in distribution system which is installed at an elementary school in Korea. There is a large proportion of electricity demand during school hours and a maximum load of over 300 kW at day time and 50 kW at night time that is why it requires an optimal operation for saving electric rates. The DERs is a DC output type power source which consists of six PV arrays with a 100 kW capacity and two ESSs with 100 kW and 228 kWh capacities. They are linked to the common DC bus connected to utility grid through a bidirectional DC/AC converter. The rated voltages for DC and AC buses are 1,000 V and 380 V_{rms}, respectively. A three phase bidirectional DC/AC main converter provides stable DC bus voltage and exchange power between the AC and DC buses. The PV array is connected to the DC bus using a DC/DC boost converter which uses maximum power point tracking control mode to extract the maximum solar power. The bidirectional DC/DC converter interfaces the battery stack to the DC bus. The ESS output power is charged or discharged by control of the EMS. The specification of each system is shown in Table 1.

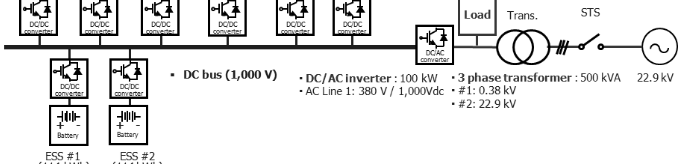


Fig. 1: Configuration of an integrated DERs in distribution system

DOI : 10.5958/2277-1581.2017.00015.8

International Journal of Scientific Engineering and Technology ISSN:2277-1581
Volume No.6 Issue No.6, pp: 181-184 01 June 2017

Table 1: Specifications of each system

	DC/AC converter	PV array	ESS	Load
Rated power	100 kW	17 kW x 6	50 kW / 114 kWh x 2	Under 400 kW
Connection	Grid connection	DC bus connection	DC bus connection	DC bus connection
Converter type	Bidirectional	Unidirectional	Bidirectional	Unidirectional
Control method	DC voltage control	MPPT	Charge and Discharge	variation

2.1 Modeling of DERs in distribution system

In this paper, the distribution system is modeled in RSCAD/RTDS. Figure 2 represents the configuration of the distribution system in RSCAD/RTDS

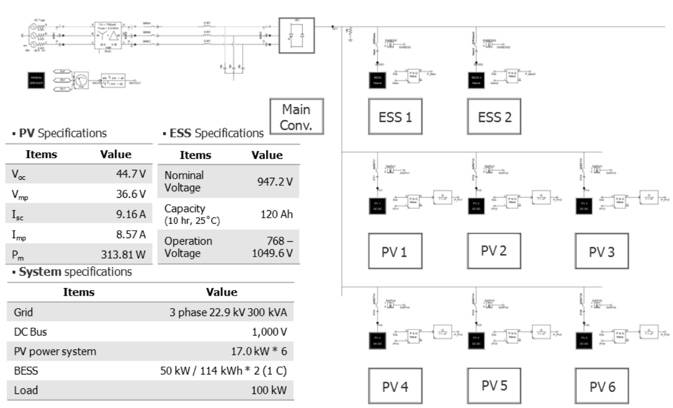


Fig. 2: Configuration of the modeled DERs in RSCAD/RTDS

3. Design and Implementation of Hardware In the Loop Simulation for optimal operation of DERs with EMS

3.1 HILS setup

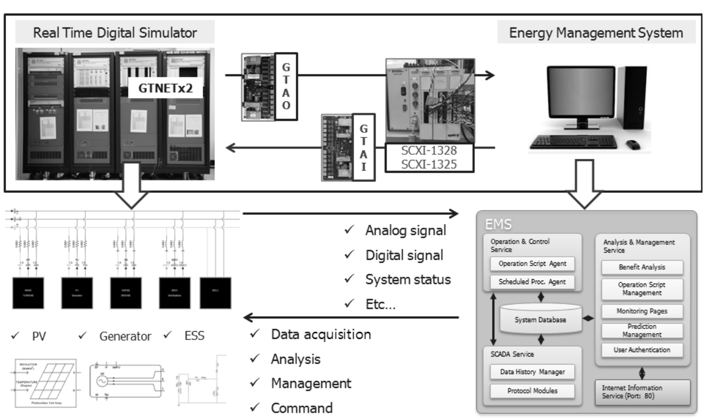


Fig. 3: Configuration of the HILS setup for optimal operation of DERs with EMS

The configuration of HILS setup for optimal operation of DERs with EMS is shown in Fig. 3. The HILS system consists of hardware, software and interface parts. The hardware part includes an actual EMS with several functions. The DERs are modeled in RTDS. Two parts are connected by the interface card in a real time simulation environment. The EMS is able to optimize the system operation including allocation of energy produced by PV power system and ESS. EMS is interfaced to the RTDS using SCXI devices. For the HILS, giga-transceiver input/output card is needed for communication between RTDS and EMS. Through giga-transceiver analog input card, the EMS sends the load power signal to RTDS. The EMS receives a power reference signal of each component from a giga-transceiver analog output card in RTDS.

3.2 Optimal operation of DERs

a. Load forecasting

The moving average method consists of computing an average of the most recent n data values for the series and uses this average for forecasting the value of the time series for the next period. Therefore, the load forecasting is calculated as (1) [10].

$$MAL_i = \frac{1}{n}\sum_{k=1}^{n} x_{ki}, \quad i = 1 \cdots 24 \qquad (1)$$

Where, i : time [hour]

n : period

k : number of days

xi : load data

b. Peak shaving limit

The contracted electric power of an elementary school is 500 kW. The peak shaving is limited to 30% of the contracted electric power by Korea Electric Power Corporation (KEPCO) [10]. Therefore, the maximum value of peak shaving power is 150 kW.

c. Electric rates calculation

A total monthly electric rate is being applied by policy of KEPCO. The total electric rates are composed of base charge and energy charge. The unit price of base charge and energy charge vary depending on the power supply method by contracted type such as resident, general purposes, industries, education, and agriculture etc.. Therefore, the monthly electric rates are calculated as (2)-(4) [11].

$$Energy\ charge\ [KRW] = [\sum_{i=1}^{24} (P_i \times C_i)] \times n \times 1.137 \qquad (2)$$

$$Base\,charge = Demand\ charge \times Peak\,load \times 1.137 \qquad (3)$$

$$The\ monthly\ electric\ \ rate = (Energy + Base)charge \qquad (4)$$

where, i : time [hour]

n : the number of days

P_i : energy in i^{th} hour [kWh]

C_i : energy charge in i^{th} hour [KRW/kWh]

d. Control procedure with EMS

The HILS operation procedure with EMS and the optimal operation plan of EMS procedure are shown in Fig. 4. The EMS calculated the optimal operation plan of the ESS that follows the

ISSN:2277-1581
01 June 2017

optimal operation of EMS plan procedure. The load is generated and transmitted from EMS to RTDS. Therefore, the simulation is operated.

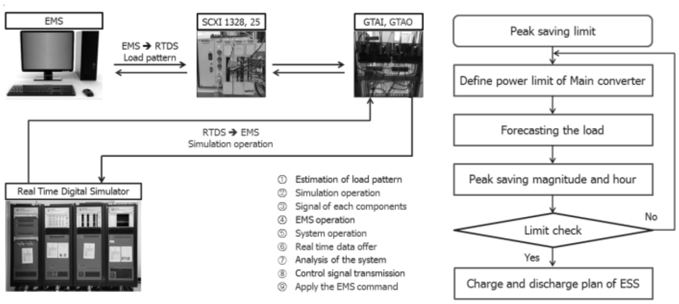


Fig. 4: HILS operation procedure with EMS (a) and optimal operation steps of EMS (b)

4. Hardware In the Loop Simulation Results

In the simulation, the load demand is controlled under 150 kW. The EMS calculated the reference of the ESS output power. The analysis of peak load pattern from 2014 to 2016 is shown in Fig. 5. The peak load of surveyed load data in 2014, 2015 and 2016 were 287.0 kW, 361.16 kW and 381.4 kW respectively. Figure 6 represents the simulation result that indicates the resulting power of optimal operation of the DERs. The peak load was detected by EMS. The DERs were controlled reflecting the peak shaving and electric rates reduction.

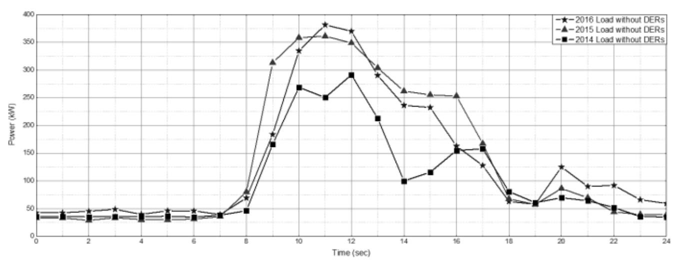
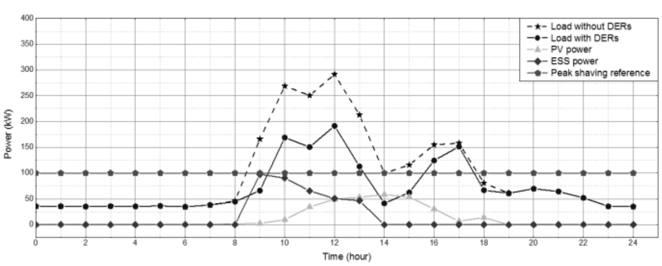
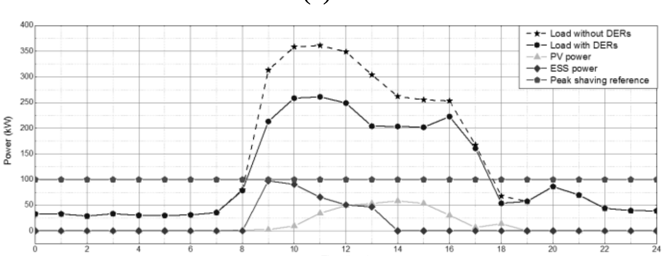


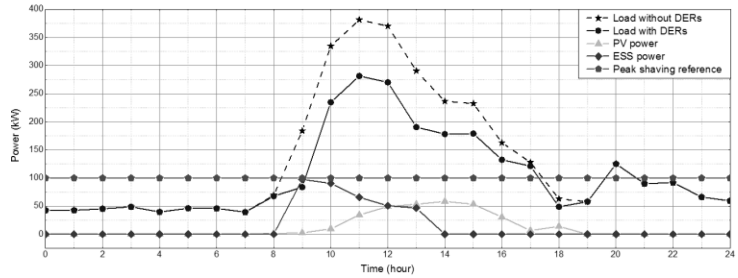
Fig. 5: Analysis of peak load pattern from 2014 to 2016



(a) 2014



(b) 2015



(C) 2016

Fig. 6: Output power of DERs and load with Peak shaving in 2014(a), 2015(b) and 2016(C)

The comparison of the electric rates reflecting the ESS control has been performed using (2)-(4) as represented in Table 2.

Table 2: Total electric rates from 2014 to 2016

		2014	2015	2016
Peak load (kW)		287.0	361.16	381.4
After peak shaving		187.0	261.16	281.4
Base charge (KRW/ KW)	Without Peak-shaving	1,706,648	2,147,642	2,267,999
	With Peak-shaving	1,111,997	1,552,991	1,673,348
	Cost saving / month	594,651	594,651	594,651

5. Conclusions

In this paper, an HILS was designed and implemented for optimal operation of an integrated DERs with EMS. The DERs in distribution system were modeled in RSCAD/RTDS. The HILS for implementation of the optimal operation of DERs with EMS was setup at Changwon National University in Korea. The EMS calculated load forecasting using simple moving averages method for the optimal operation of DERs. Furthermore, The EMS regulates output power of the ESS for electric rates reduction. The operation characteristics including load forecasting and peak shaving were investigated. The base charge was saved about 594,651 KRW/month. The proposed HILS in this paper can be effectively utilized to test and develop variable control schemes under a practical environment without real DERs.

6. Acknowledgment

This work was supported by the Power Generation & Electricity Delivery Core Technology Program of the Korea Institute of Energy Technology Evaluation and Planning (KETEP), granted financial resource from the Ministry of Trade, Industry & Energy, Republic of Korea. (No. 2013T100200060)

7. References

i. Tomislav Dragicevic, Xiaonan Lu, Juan C. Vasquez, and Josep M. Guerrero. DC Microgrids-Part 1: A Review of Control Strategies and Stabilization Techniques. IEEE Trans. on Power Electronics, vol. 31, No. 7, pp. 4879-4891, 2016

ii. *Tomislav Dragicevic, Xiaonan Lu, Juan C. Vasquez, and Josep M. Guerrero. DC Microgrids-Part 2: A Review of Power Architectures, Applications, and Standardization Issues. IEEE Trans. on Power Electronics, vol. 3, No. 5, pp. 3528-3549, 2016*

iii. *Daniel E. Olivares, Ali Mehrizi-Sani, Amir H. Etemaemayi, Claudio A. Canizares,Reza Iravani, Mehrdad Kazerani, Amir H. Hajimiragha, Oriol Gomis-Bellmunt, Maryam Saeedifard, Rodrigo Palma-Behnke, Guillermo A. Jimenez-Estevez and Nikos D. Hatziargyriou. Trend in Microgrid Control. IEEE Trans. on Smart Grid, vol. 5, No. 4, pp. 1905-1919, 2014*

iv. *Juan C. Vasquez, Josep. M. Guerrero, Alvaro Luna, Pedro Rodriguez, and Remus Teodorescu. Adaptive droop control applied to voltage-source inverters operation in grid-connected and islanded modes. IEEE Trans. Industrial Electronics, vol. 56, no. 10, pp. 4088–4096, 2009*

v. *Gilsung Byeon, Chul-Sang Hwang, Jin-Hong Jeon, Seul-Ki Kim, Jong-Yul Kim, Kisuk Kim, Bokyung Ko and Eung-Sang Kim. Complementary Power Control of the Bipolar-type Low Voltage DC Distirbution System. Journal of Electrical Engineering & Technology, vol. 10, no. 3, pp. 786-794, 2015*

vi. *Dan Wang, Shaoyun Ge, Hongjie Jia, Chengshan Wang, Yue Zhou, Ning Lu and Xiangyu Kong. A Demand Response and Battery Storage Coordination Algorithm for Providing Microgrid Tie-Line Sommthing Services. IEEE Trans. on Sustainable energy, vol. 5, no. 2, pp.476-486, 2014.*

vii. *Grayson Heffner, Charles Goldman, Brendan Kirby and Michael Kintner-Meyer. Loads providing ancillary services: Review of international experience. Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, USA, LBNL-62701, ORNL/TM-2007/060, 2007*

viii. *Gyeong-Hun Kim, Jong-Yul Kim, Jin-Hong Jeon, Seul-Ki Kim, Eung-sang Kim, Ju-Han Lee, Minwon Park and In-Keun Yu. Hardware-in-the-loop simulation Method for a Wind Farm Controller Using Real Time Digital Simulator. Journal of Electrical Engineering & Technology, vol. 9, no. 5, pp. 1489-1494, 2014.*

ix. *P. Mercier, R. Cherkaoui and C. Ohler. Optimizing a Battery Storage Energy System for Frequency Control Application in an Isolated Power System. IEEE Trans. on Power Systems, vol. 24, no. 3, pp 1469-1477, 2009*

x. *Kyeong-hee Cho, Seul-ki Kim and Eung-sang Kim. Optimal sizing of BESS for Customer Demand Management. Journal of Electrical Engineering & Technology, vol. 4, no. 1, pp. 30-36, 2014.*

xi. *Chul-Sang Hwang, Jongho Choi, Chang-Soon Kim, Dinh-Vuong Le, Minwon Park, In-Keun Yu, Jin-Hong Jeon and Changhee Cho. Development of a RTDS-based EMS Control Algorithm in connection with Demand Response. ISGC, 2015*