Optimization of Configuration and Control of Energy Storage Systems Using ESWare™

FERRARA Marco : Ph. D., Vice President, Energy Storage Department, Project Division, IHI INC.
KOGUMA Yuji : Ph. D., Control & Communication Technology Department, Products Development Center, Corporate Research & Development

The number of distributed resources and renewable energy generators has increased dramatically in Europe and the US in recent years. In response to this trend, electric power players aim to build new business models based on flexible and optimal grid operation. Energy Storage Systems (ESS) such as rechargeable batteries, are have great potential to enable such models; however, the optimal configuration and operation of storage systems is complex. This article provides a comprehensive introduction to IHI's leading software platform ESWare, a powerful end-to-end environment for the optimal configuration and operation of energy storage systems in behind-the-meter and grid-based projects.

1. Introduction

The 20 largest European utilities have lost more than 500 billion dollars of market capitalization in just 5 years because of the shifting power industry landscape typified by the spread of renewable energy and dispersed power sources[(1)]. U.S. utilities are expected to face a similar challenge soon[(2)]. In anticipation, a new business model is needed for the integration and flexible operation of distributed resources and loads to harness renewable energy. Energy storage systems play a crucial role in the business model. However, sub-optimal configuration and operation can significantly compromise the economic viability of their deployment.

In order to address this challenge, American utilities, Independent System Operators (ISOs), and Independent Power Producers (IPPs) are allocating a considerable amount of time and manpower to optimize the configuration and operation of energy storage systems. Unfortunately, their trial-and-error method mostly relies on manual or spreadsheet analyses. This time-consuming and labor-intensive approach does not necessarily lead to adequate outcomes. There are analytical tools currently available for optimizing the operation of energy storage systems by predicting the demand and power output from renewable energy, but most of them assume perfect foresight. It is virtually impossible to take the difference in the actual demand and output from renewable energy into consideration to determine an operational schedule for actual control of an energy storage system. IHI's software platform ESWare addresses all the aforementioned shortcomings, and enables users to optimally configure and operate energy storage system.

This paper provides an overview of the ESWare software platform in **Chapter 2**. **Chapter 3** describes the optimization technology that plays the core role in ESWare. In **Chapter 4**, the ES/Analyzer and ES/Optimizer are introduced as software based on such optimization technology that respectively optimizes the configuration and the operation of an energy storage system. **Chapter 5** provides two examples of software application. More specifically, the ES/Analyzer is employed for peak shaving by determining the optimal configuration of an energy storage system. In another example, the ES/Optimizer is used for shaving the peak load. **Chapter 6** concludes this paper by summarizing the discussion.

2. Overview of ESWare

ESWare is software provided by IHI for controlling an energy storage system while optimizing the configuration and operation. It comprises the following three software environments that work in concert:

(1) The ES/Analyzer carries out an analysis before a project is built to identify the optimal configuration.
(2) The ES/Optimizer carries out consistent on-site optimization of the operational schedule for the system.
(3) The ES/Pilot robustly and securely controls the physical hardware.

The hierarchy of the tools in ESWare and the specific functions of each tool are illustrated in **Table 1**.

3. Optimization technology employed by ESWare

The core technology of ESWare optimizes the operational schedule for an energy storage system. ESWare derives the operational schedule for maximizing profit by using a nonlinear optimization algorithm for the optimization model while taking into account the projected demand, projected power output from renewable energy, electricity price, and other factors that directly influence the profitability of a power system. **Figure 1** schematically illustrates the optimization model used by ESWare.

The optimization model is employed both for optimizing the configuration and operation of an energy storage system. In this manner, the economic performance estimated from

Table 1　Software components and functions of ESWare

Hierarchy	Tool	Functions	Applications
As an analytical tool	ES/Analyzer	- Select services to monetize - Understand dispatch strategy - Identify optimal system specifications - Confirm project profitability/IRR/ROI	- Sales - Application - Engineering - Project planning - Project development
As a real-time optimizer	ES/Optimizer	- Implement the best strategy at the lowest cost of configuration - Dispatch the system in a way consistent with projections - Structure optimal O&M and warranty terms	- Asset management - Operation - Maintenance
As a low-level controller	ES/Pilot	- Optimized dynamic operations - Multi-vendor integration - Scalable	

(Note)　IRR : Internal Rate of Return
ROI : Return on Investment

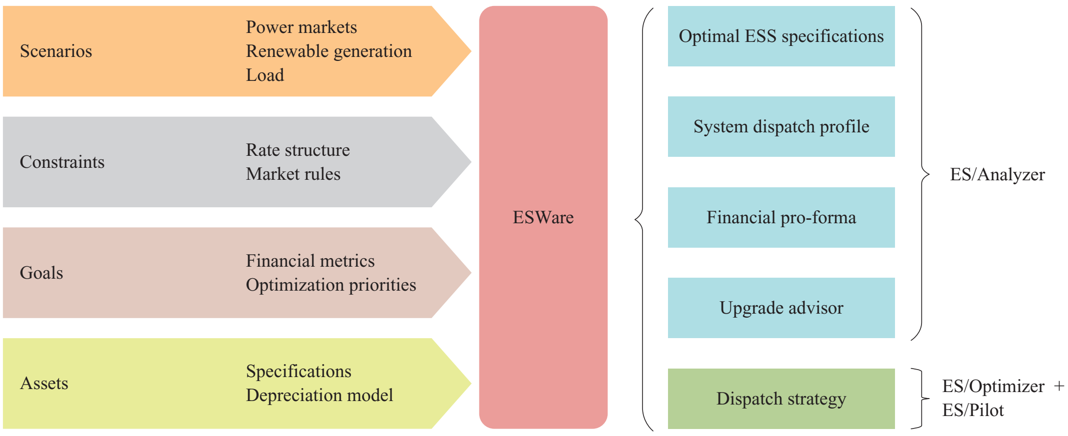


Fig. 1　Conceptual diagram of ESWare's optimization model

the optimization of the configuration can also be achieved during actual operation.

The optimization model of ESWare is so versatile that it can define various objective functions to suit individual projects and customers. **Figure 2** presents examples of objective functions used in different optimization cases. The ES/Analyzer is designed to take the complex balance of power supplied to micro-grids into consideration. It can take into account not only contract demand and flat electricity charge, but also frequency adjustment, incentives for selling power generated from renewable energy, and so forth.

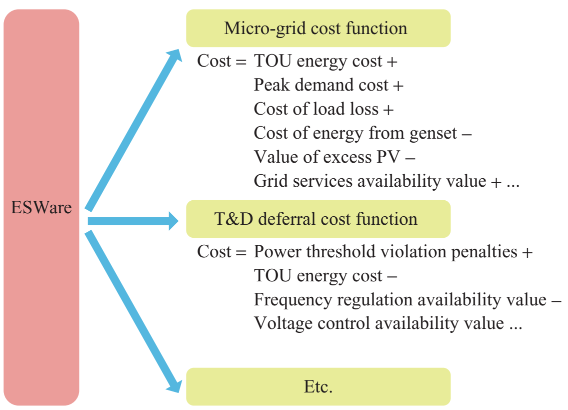


Fig. 2　Examples of ESWare's optimization cases and their cost functions

4.　ESWare — Software that provides optimization technology

4.1　The ES/Analyzer

The ES/Analyzer simulates offline grid operation. This software, incorporating the optimization technology as described in **Chapter 3**, can evaluate the economic performance of an energy storage system and optimize the system configuration based on the evaluation results.

(1)　User interface

Figure 3 presents the user interface of the ES/Analyzer, which comprises the input section on the left side of the panel and output section on the right side.

(2)　Loading a scenario

Prior to running the ES/Analyzer, a referenced scenario (load, power generated from renewable energy, energy charge, and other time-series data) for the simulation is specified by using the INPUT TIMESERIES button at the top of the user interface.

Figure 4 shows an example scenario being input to the ES/Analyzer. Once a scenario is read, the graphs of the load and power output from renewable energy are updated as shown on the right-hand side of **Fig. 5**.

(3)　Running a simulation

In order to evaluate the economic performance of a grid when the configuration of an energy storage system is given, specify the rated power and rated capacity in

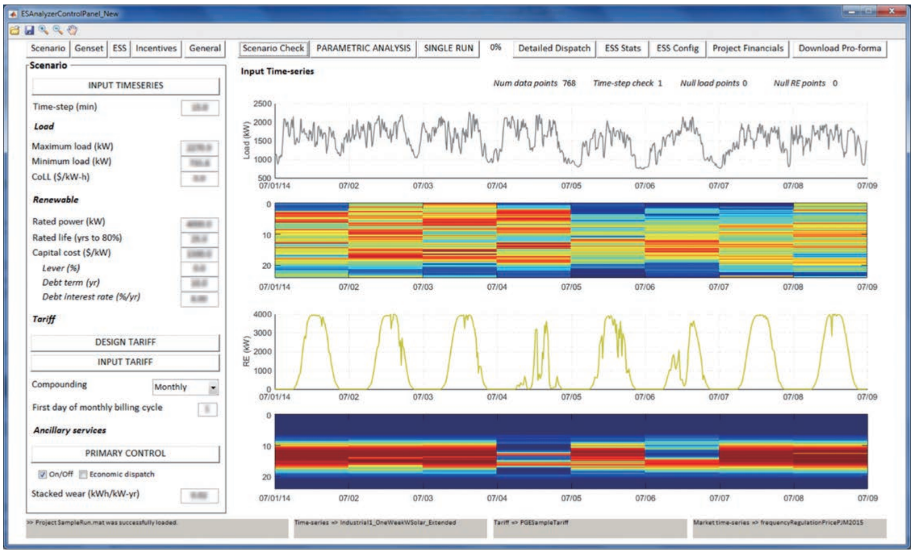
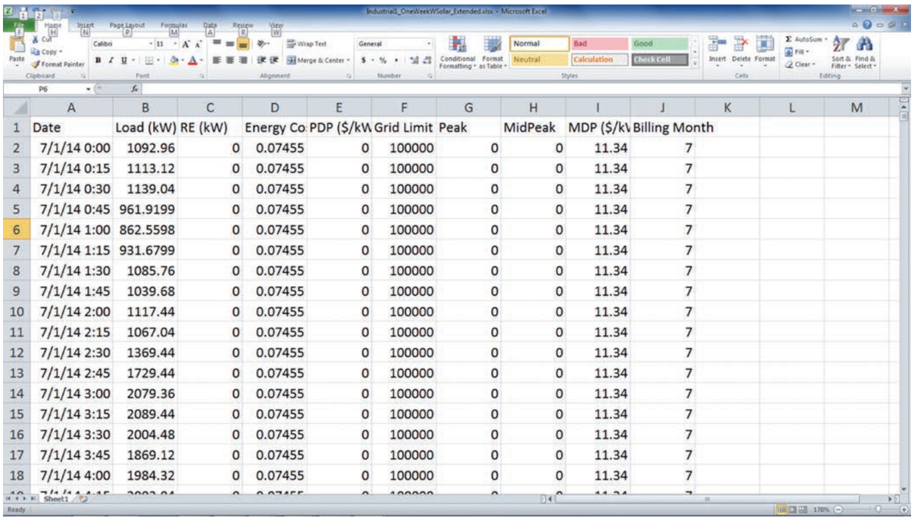


Fig. 3　User interface of ES/Analyzer



	Date	Load (kW)	RE (kW)	Energy Co	PDP ($/kW	Grid Limit	Peak	MidPeak	MDP ($/kV	Billing Month
1	Date	Load (kW)	RE (kW)	Energy Co	PDP ($/kW	Grid Limit	Peak	MidPeak	MDP ($/kV	Billing Month
2	7/1/14 0:00	1092.96	0	0.07455	0	100000	0	0	11.34	7
3	7/1/14 0:15	1113.12	0	0.07455	0	100000	0	0	11.34	7
4	7/1/14 0:30	1139.04	0	0.07455	0	100000	0	0	11.34	7
5	7/1/14 0:45	961.9199	0	0.07455	0	100000	0	0	11.34	7
6	7/1/14 1:00	862.5598	0	0.07455	0	100000	0	0	11.34	7
7	7/1/14 1:15	931.6799	0	0.07455	0	100000	0	0	11.34	7
8	7/1/14 1:30	1085.76	0	0.07455	0	100000	0	0	11.34	7
9	7/1/14 1:45	1039.68	0	0.07455	0	100000	0	0	11.34	7
10	7/1/14 2:00	1117.44	0	0.07455	0	100000	0	0	11.34	7
11	7/1/14 2:15	1067.04	0	0.07455	0	100000	0	0	11.34	7
12	7/1/14 2:30	1369.44	0	0.07455	0	100000	0	0	11.34	7
13	7/1/14 2:45	1729.44	0	0.07455	0	100000	0	0	11.34	7
14	7/1/14 3:00	2079.36	0	0.07455	0	100000	0	0	11.34	7
15	7/1/14 3:15	2089.44	0	0.07455	0	100000	0	0	11.34	7
16	7/1/14 3:30	2004.48	0	0.07455	0	100000	0	0	11.34	7
17	7/1/14 3:45	1869.12	0	0.07455	0	100000	0	0	11.34	7
18	7/1/14 4:00	1984.32	0	0.07455	0	100000	0	0	11.34	7

Fig. 4　An example input scenario of ES/Analyzer

(Note)　SOC : State of Charge

Fig. 5　An example simulation result of ES/Analyzer (Load, Purchased power, Charge/Discharge power of ESS, SOC, Energy breakdown) the panel, then press the SINGLE RUN button to run a simulation. The required time for completing a simulation depends on ① the length of the scenario, ② the time resolution, and ③ the convergence criteria of optimization. It takes a few minutes for a relatively fast computer to complete a simulation for a scenario lasting 1 year with a time resolution of 15 minutes.

If the optimal configuration of an energy storage system is unknown, the parametric analysis tool can be used by pressing the PARAMETRIC ANALYSIS button at the top of the user interface. This tool carries out the same simulation as the one mentioned with energy storage systems with various configurations. It can visualize the relationships between the battery configuration, rate of return, and Net Present Value (NPV). Based on the results, users can determine the configuration of the energy storage system that yields the best rate of return.

(4) Outputting simulation results

The following examples show how ES/Analyzer simulation results are output from the evaluation of the economic performance of a grid when the configuration of the energy storage system is given. **Figure 5** presents the load, purchased power, charged and discharged power of an energy storage system, SOC, and energy breakdown. **Figure 6** shows statistical information. The configuration of the energy storage system and the evaluated economic performance are respectively shown in **Figs. 7** and **8**. These graphs can be zoomed in and out to view trends in detail. Detailed information can be output as a report for spreadsheet software. Results from evaluation of the economic performance are converted into annual figures regardless of the time span of the input data by assuming that any input scenario represents the trend for an entire year.

Figure 9 shows an example of a charge-discharge

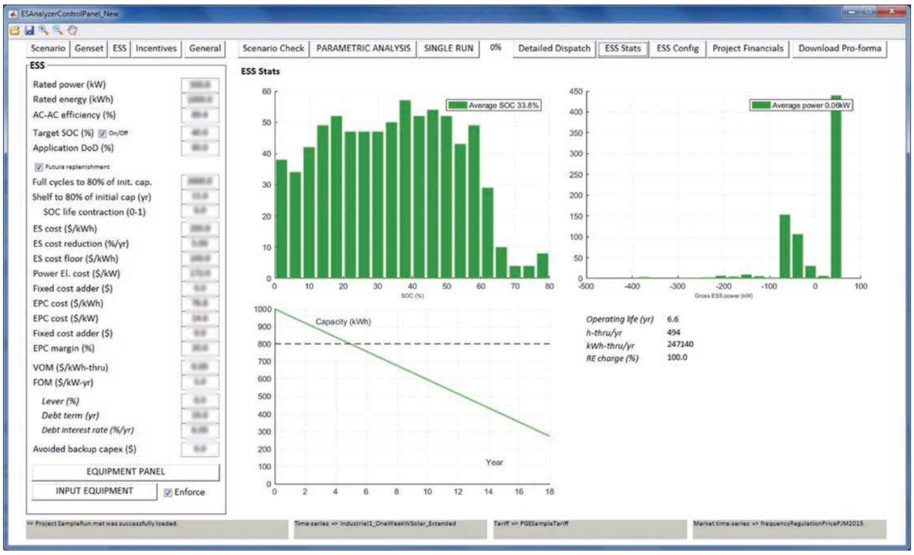


Fig. 6 An example simulation result of ES/Analyzer (Statistics information)

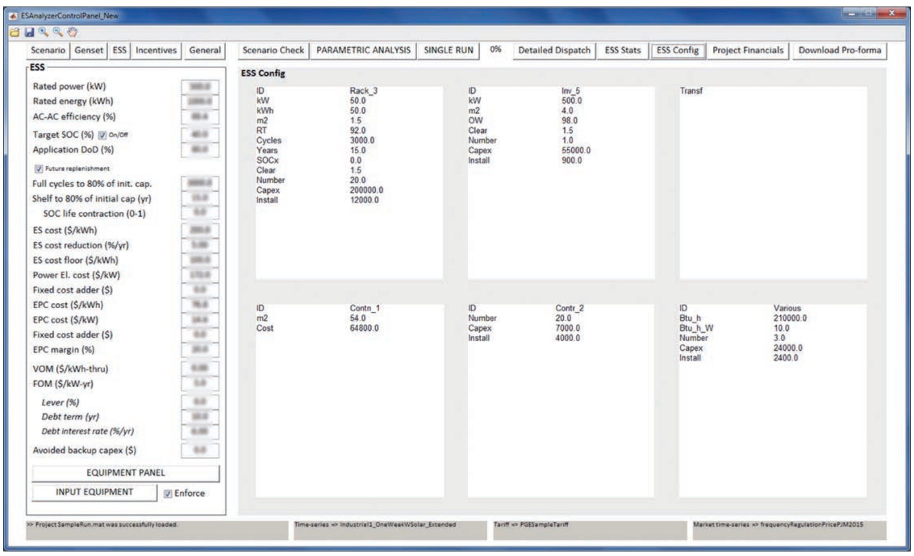


Fig. 7 An example simulation result of ES/Analyzer (ESS configuration)

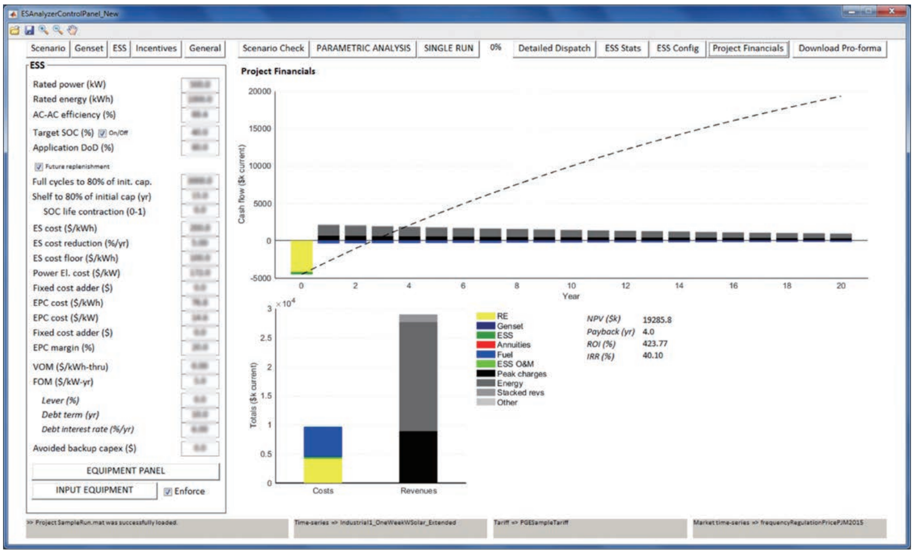


Fig. 8　An example simulation result of ES/Analyzer (Financial performance)

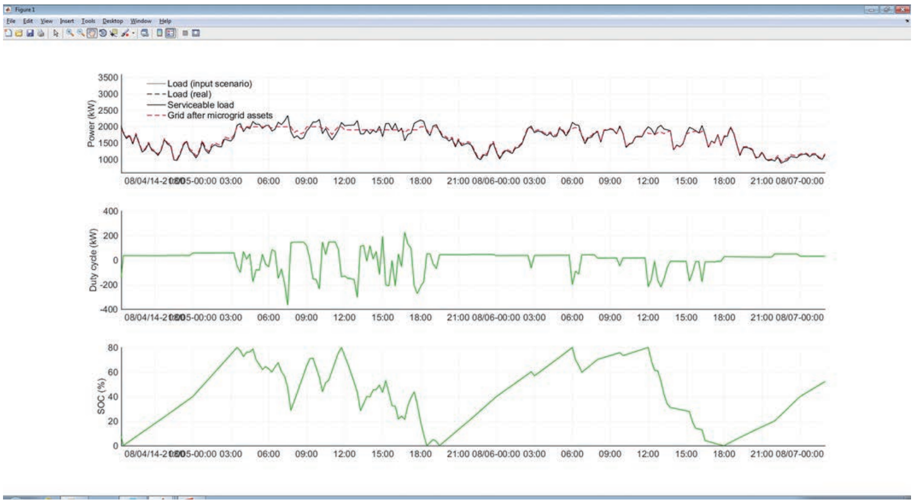


Fig. 9　An example simulation result of ES/Analyzer (An example of charge/discharge plan of ESS for peak-shift)

plan for an energy storage system when the peak of purchased power leveled. The charge-discharge plan of an energy storage system was optimized with the ES/ Analyzer to reduce the electricity tariff that is determined based on the maximum level of purchased power in a certain period (e.g., over a month or a year). The peak of purchased power is leveled in the resulting plan. In general, an energy storage system is charged at night when the power charge is lower to avoid the higher charges during day; nevertheless, charging can take place during the day when greater benefits can be obtained by leveling off the peak. Since the electricity tariff is determined based on the maximum level of purchased power in a specified period, the electricity tariff cannot be reduced by shaving off the peak from the charging and discharging operations when the power consumption is lower than that maximum level in the same time period. The optimization by the ES/Analyzer can provide a plan to avoid unnecessary charging and discharging operations during such periods. Charging and discharging operations became less frequent on the second day in **Fig. 9** thanks to this function.

4.2　The ES/Optimizer

The ES/Optimizer derives the optimal operational schedule for an energy storage system under real-time control while using the same optimization framework as the ES/Analyzer. This software can bring the economic performance of actual operation of an energy storage system closer to the level estimated by the ES/Analyzer.

The ES/Optimizer is built on the Simulink® language. **Figure 10** is a Simulink block diagram of the ES/Optimizer. Like the ES/Analyzer, the ES/Optimizer optimizes the operational schedule of an energy storage system based on the forecasts of power demand, output from renewable energy, and so forth. Still, under the real-time control, the optimized economic performance of the actual energy storage system can be different from the estimated one due to the difference in these forecast values and reality. In order to address this problem, the ES/Optimizer employs a neural network to make a forecast. The differences between forecasts and actual

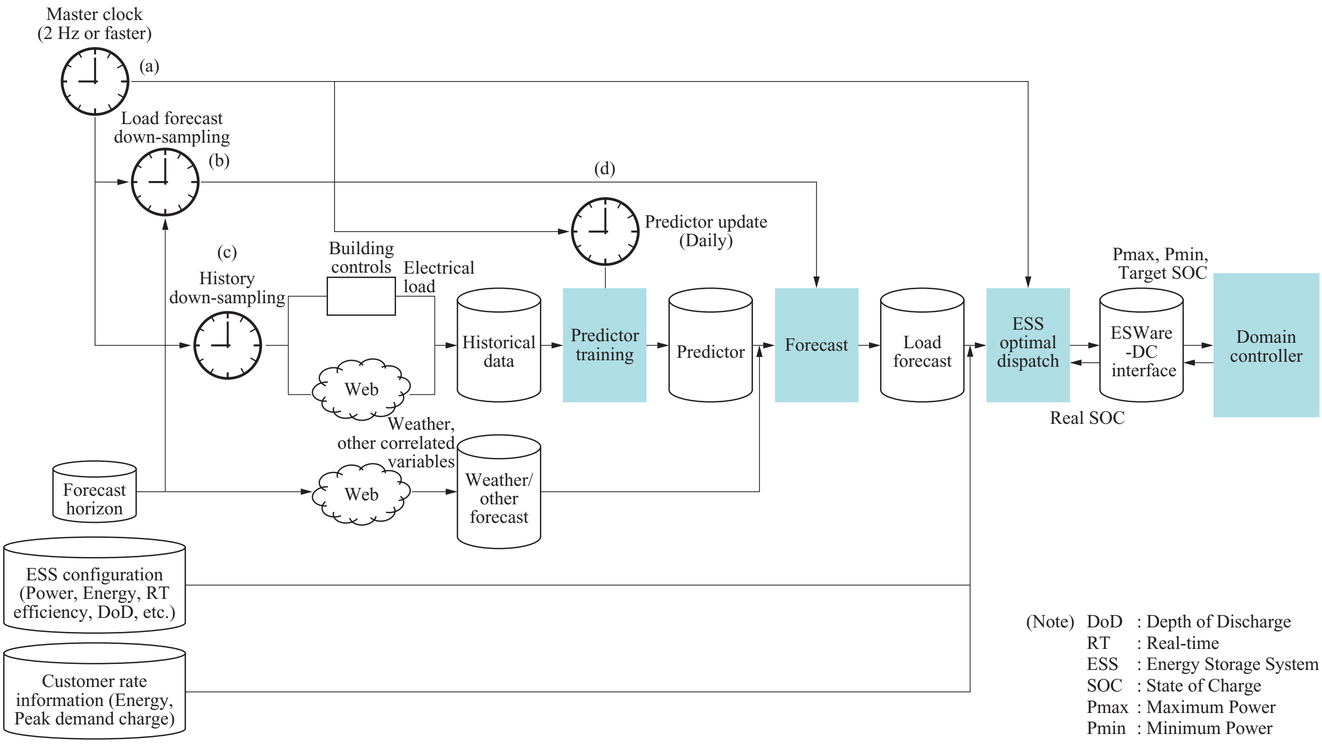


Fig. 10 Simulink block diagram of ES/Optimizer

figures are taken in account by the learning of the predictive model and correction of predictions. Functions for reliably addressing such differences include feed-forward correction for directly activating the power demand for energy storage, and feedback control for reacting to the difference resulting from a change in the intended SOC.

5. Application

5.1 Optimization of battery configuration for peak shaving with the ES/Analyzer

An example of a practical application of the ES/Analyzer is optimization of battery configuration for peak shaving at an industrial facility in northern California, the United States. The customer used to pay a high electricity tariff, and it sought to reduce the charge by installing an energy storage system to shave off the peak.

Figure 11 shows the yearly load profile of the customer's industrial facility where the ES/Analyzer was employed. **Figure 12** presents the load profile during one day in September and the electricity tariff. This customer used to pay an additional charge of \$18.15/kW during the maximum peak hours, \$3.79/kW during the medium peak hours, and \$11.34/kW for the maximum monthly demand. These added up to a huge operational cost every year.

The parametric analysis tool determined the configuration of the energy storage system for maximizing the NPV to address this problem (rated power of 500 kW and rated capacity of 1 000 kW·h). **Figure 13** presents the analysis results of the parametric tool. The economic performance was then simulated by using "SINGLE RUN" assuming introduction of an energy storage system with this optimal

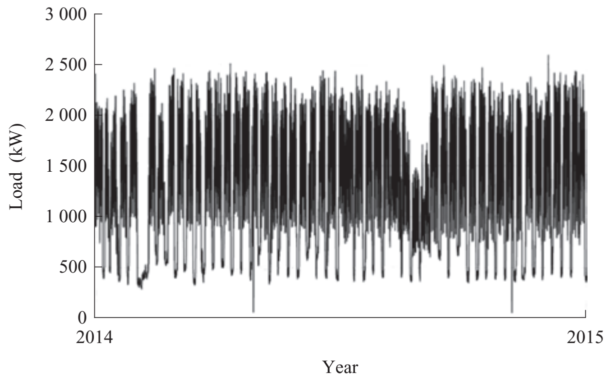


Fig. 11 Yearly load profile of the target industrial customer

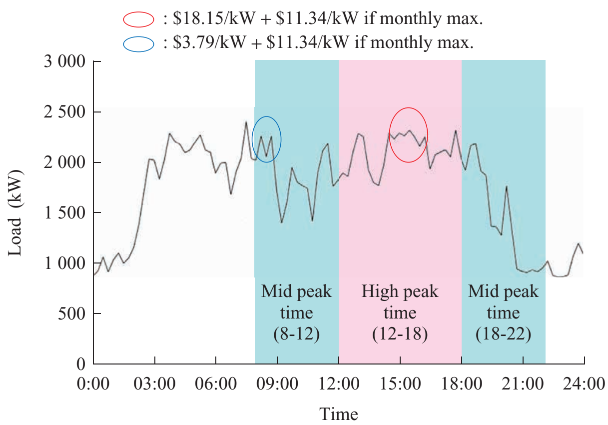


Fig. 12 Daily load profile and electricity tariff of the target industrial customer

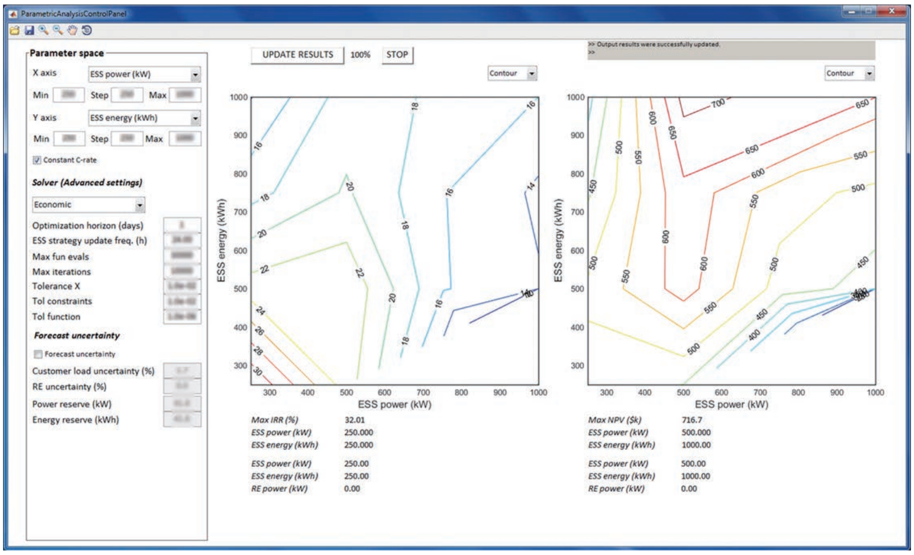


Fig. 13 Parametric simulation result

configuration. The result is presented in **Fig. 14**.

Figure 15 presents the simulated economic performance with the same configuration when Self-Generation Incentive Program (SGIP) incentives were assumed. These figures suggest that the initial investment can be recovered in 6 years even without SGIP incentives, and in just 4 years with SGIP incentives.

5.2 Peak shaving test with the ES/Optimizer

A test was conducted in a pilot project with IHI's energy storage system at a water supply company in northeastern Missouri, the United States. One ES-500 unit with a rated power of 500 kW and a rated capacity of 500 kW·h was tested to examine the real-time control of peak shaving by the ES/Optimizer. **Figure 16** shows part of the test results. Blue lines, one on top and another at the bottom of **Fig. 16**, respectively indicate changes in power consumption, and purchased power after the control based on the optimized charging and discharging plan. The pink series in each graph shows the level of shaved peak as calculated by the optimization. As shown in the bottom graph of **Fig. 16**, control based on the charging and discharging plan optimized by the ES/Optimizer successfully kept the purchased power below the level of the peak that was shaved off.

6. Conclusion

The business model of the energy industry must continue to evolve to achieve the integration and flexible operation of distributed resources and loads to harness renewable energy and optimize grid planning and operations. In so doing, energy storage systems play a crucial role. Still, sub-optimal configurations and operation can significantly compromise the economic viability of their deployment. American utilities, ISOs, and IPPs are allocating a considerable amount of time and manpower to optimize the configuration and

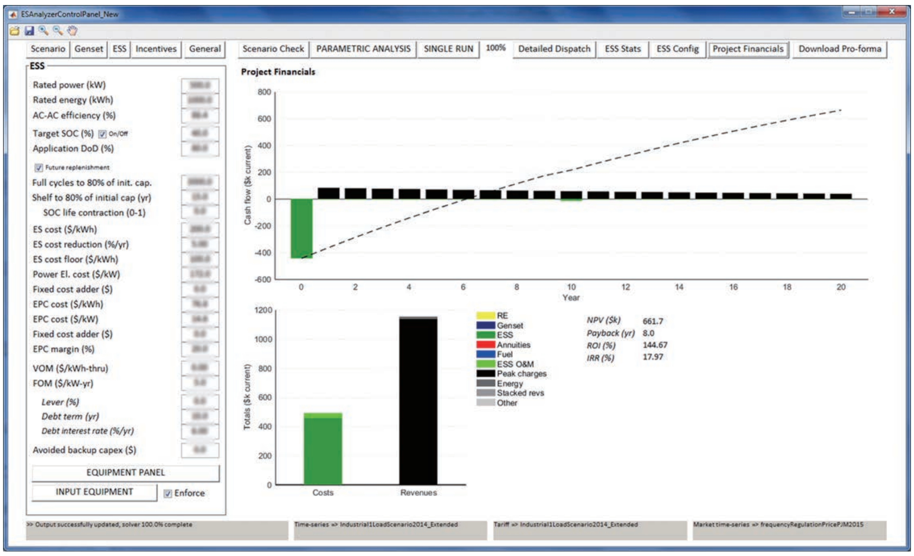


Fig. 14 Simulation result of ES/Analyzer for the target industrial customer (Financial performance under the optimal ESS configuration)

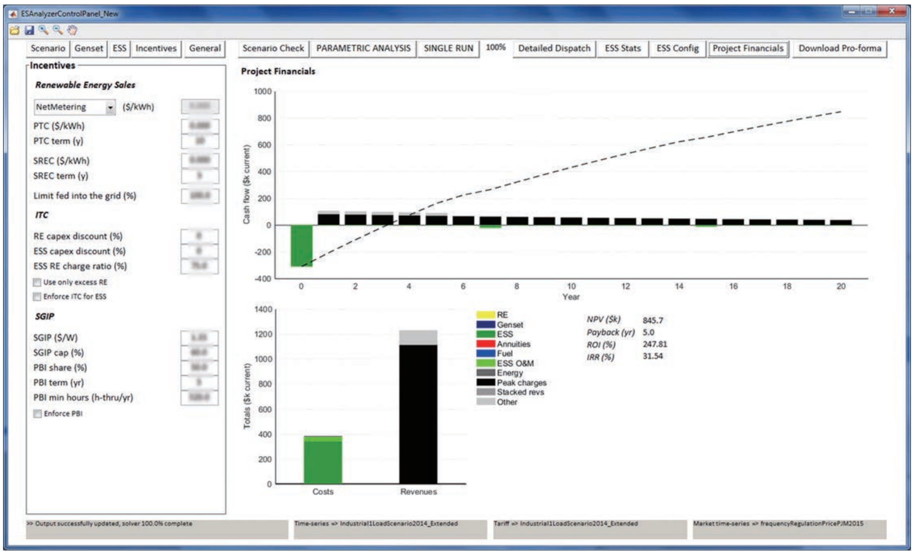


Fig. 15 Simulation result of ES/Analyzer for the target industrial customer (Financial performance under the optimal ESS configuration and SGIP incentives)

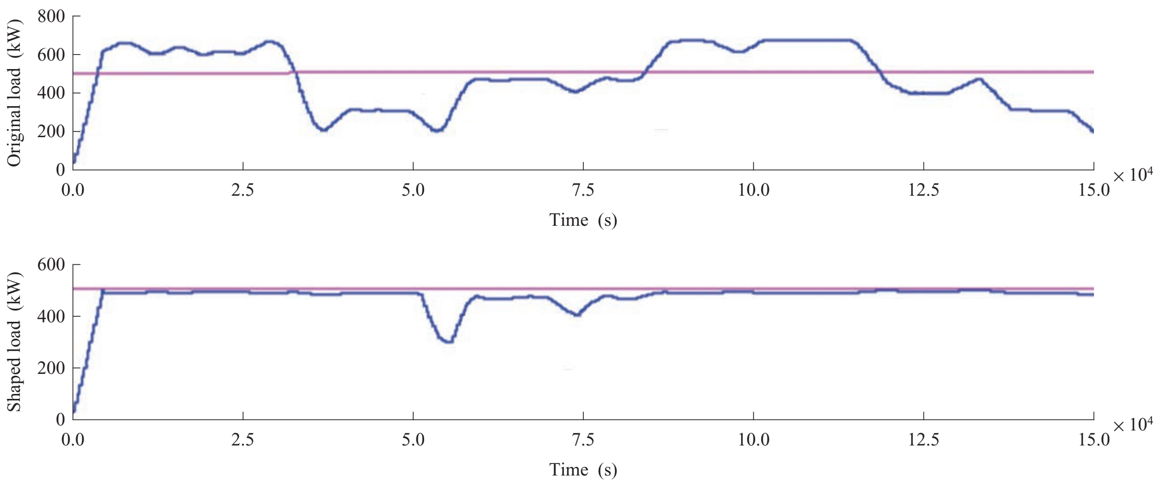


Fig. 16 Peak-shift experimental result of ES/Optimizer

operation of energy storage systems.

ESWare is a software platform that addresses the challenge by enabling users to optimally configure and operate energy storage systems.

The greatest advantage provided by ESWare is the handling of configuration and operation of energy storage systems in an integrated manner using the same optimization model and software platform. Thus, this software can bring the economic performance of actual operation of an energy storage system closer to the level estimated in the optimization of the system configuration, which makes it possible to seamlessly proceed from system configuration to actual operation.

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