Optimal Scheduling of Battery Energy Storage for Grid-Connected Load using Photovoltaic System (PV) via Binary Particle Swarm Optimization (BPSO)

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Abstract

This paper presents an optimal dispatch of battery storage and its economic viability with a photovoltaic system. There are four modelled scenarios based on the combination of interruptible load program and the time-of-use scheme. The scenarios were modelled using a Binary Particle Swarm Optimization and were simulated using Matlab v6. In all the scenarios, this model successfully optimizes the battery dispatch scheduling while simultaneously minimizes the DU's penalty from exceeding the maximum allowable power demand. This algorithm also optimizes the linearly forecasted demand for the next six year for all the scenarios. Then, an economic analysis for the possible investment to the combined BESS and PV system is conducted through the comparison of the payback periods of each scenario. The first scenario is implemented without ILP and a ToU scheme and has 79.86 payback years. With ILP scheme only, the second scenario has 33.37 payback years. Then the third scenario with ToU scheme only has a 30.29 payback years. Finally, the fourth scenario, with both ILP and ToU schemes,shows the fastest recovery of the investment with 21.57payback years. Thus the combination of both ILP and ToU schemes provide the best economic benefit. Though the current proposed system is still not economically feasible, however, the foreseen positive trends on solar and battery technologies will make this system viable.

Keywords: Binary particle swarm optimization, battery energy storage system, photovoltaic system, interruptible load program, time-of-use scheme

Terminologies

λ_{demand}	Distribution electricity rate for demand in Php/kW
λ_{energy}	Distribution electricity rate for energy in Php/kWh
λ	Rate of Electricity cost in Php/kW
C_{Ah}	Battery bank capacity in ampere hours
C_{Ah_nom}	Nominal battery capacity in Ampere hours
C_{ch}	Charging cost in Php
C_{dis}	Electricity discharging cost in Php
C_T	Total cost in Php
DOD	Allowable depth of discharge
E_c	Backup Load daily requirement in kWh
η_{BI}	Overall battery and inverter efficiency
P_{ch}	Power needed to charge the battery in kW
P_{demand}	Penalties due to excess in maximum allowable demand in Php
P_{dl}	Power De-loaded in kW
P_{dis}	Power injected from the battery in kW
P_{energy}	Penalties due to excess in maximum allowable energy in Php
P_L	Demand in kW
P_{PV}	Power generated from the PV system in kW
SOC	State of Charge
V_B	Battery rated voltage
X_{ch}	Charging State (1 or 0)
X_{dis}	Discharging State (1 or 0)

1.0 Introduction

Background of the Study

Philippines faces the challenge of meeting the power supply with the growing demand. Demand side management (DSM) has been the well-studied field of this power supply mitigation (Fahriog lu & Alvarado, 200 0; Fahriog˜lu & Alvarado, 2001; Fotuhi-Firuzabad & Billinton, 2000; Gazze et al 2010; Malik, 1998; Nordell, 1987; Oren, 2001; Qureshi et al 2010; Strbac et al 1996). In addition, the emerging technologies such as battery energy storage system (BESS) and renewable energy sources subject DSM into a wider study (Y. Wang et al, 2012; Y. Wang et al, 2009). BESS appears to store energy during off-peak hours and release it during peak time ideal for load shredding application (Faranda et al, 2007; Rahman et al, 2004). To overcome high investment cost, pricing schemes such as interruptible load program (C. S. Chen & Leu, 1990; Gedra & Varaiya, 1993; Huang et al, 2004; Liao & Chen, 2010; Luo et al., 2007; Majumdar et al, 1996; Qi, Li, & Li, 2008; R. Wang, 2010; Y. Zhang et al, 2008; Ziaee et al, 2011) and Time-of-Use scheme have used (Dufo-López & Bernal-Agustín, 2015; Gedra & Varaiya, 1993). This study intends to optimize ESS with renewable energy source and conduct a feasibility case on the possible venture of this integration.

The battery storage system comes with complexity and investment. With the progress of battery storage system various solutions targets respective difficulty (H. Chen et al., 2009). The success depends on how feasible the system is. To address this, optimizing energy storage dispatch scheduling becomes one of the studied area of (Hida et al, 2010; Maly & Kwan, 1995). A range of algorithm has been studied extensively (Ahmadi & Pedrasa, 2012; Coello, Pulido, & Lechuga, 2004; Gaing, 2003; Jong-Bae Park et al, 2006; Pedrasa et al, 2008; Ponrani & Dhivya, 2012; Rodríguez-garcía et al, 2013; Selvakumar & Thanushkodi, 2007; J. Wang & Li, 2008; Yihong Wang et al., 2009; B. Zhang et al, 2008; Zhu et al., 2013). Every algorithm has designated application including the economic dispatch and incentives. The Particle swarm optimization (PSO), the binary PSO (BPSO) in particular, is the well-studied algorithm especially on the economic dispatch and battery dispatch scheduling. BPSO, a simple concept of function-optimization, leads the energy dispatch scheduling especially using battery energy storage systems (Pedrasa et al., 2008). On the partner renewable energy supply, the photovoltaic power generation system offers an attractive energy supply without heavily dependent on specified location (Virginia, 2010). Accordingly, grid-connected PV generation is subscribed more than stand-alone connection due to the profit generated from the net metering features. Hence, this paper presents a case of optimizing the scheduling dispatch of battery ESS in a grid-connected load with PV system integration using binary particle swarm optimization to address this high investment issue.

On the other side of high investment expense, the integration of battery ESS and PV system draw some supporting scheme. One support is the interruptible load program (ILP), a demand-side management scheme of generating profit out of de-loading energy from the maximum allowable energy. The load shredding functions of battery ESS appears to benefit in this program. Another support is the time-of-use scheme which provides lower electricity pricing during off-peak hours compared to peak hours. Both the load shifting of the battery ESS and the de-loading of peak energy demand due to PV system take advantage of this scheme. Lastly, the prevention of the distribution utilities' penalty due to the excess of energy usage out of the maximum allowable energy offers another benefit for the BESS-PV implementation. Though the ILP program appears to be new in the country's policy structure and with only some distribution utilities that avails ToU scheme, this study also considers the feasibility of using the two pricing schemes and prevention of DU's penalty scheme.

Problem Statement

This study ought to propose an optimized model using binary particle swarm optimization algorithm for battery storage scheduling combined with the prior studied PV system in the test subject. Then, an economic analysis is to be performed to determine the feasibility of this model. The Interruptible Load Program and Time-of-Use scheme are included in this analysis to verify their individual contribution to the positive contribution in this investment.

2.0 Materials And Methods

Binary Particle Swarm Optimization(BPSO)

Kennedy and Ederhart study(Kennedy & Eberhart, 1995)initiates the BPSO. It is described as an algorithm where the particles represent the position in binary space and particle's position vectors can take on the binary value 0 or 1 i.e. $x_{ij} \epsilon \{0,1\}$. A function *f* will map the binary space to the real B^n numbers, *R*.

In (1), a particle's velocity is connected to the possibility that the particle's position takes a value of 0 or 1.

$$v_{ij}^{t+1} = v_{ij}^{t} + c_1 r_{1j}^{t} \left[P_{Best,i}^{t} - x_{ij}^{t}\right] + c_2 r_{2j}^{t} \left[G_{Best,i} - x_{ij}^{t}\right]$$

Now, the bit of the jth particle u_{ij}^{t}, is updated by (2) where, u_{ij}^{t} is a random number selected from a uniform distribution in (0, 1), and s_{ij}^{t} is the sigmoid function, denoted by (3). The process flow of BPSO algorithm used in this study is presented in Fig. 2.

$$x_{ij}^{t} = \begin{cases} 1 \; if \; u_{ij}^{t} < s_{ij}^{t} \\ 0 \; if \; u_{ij}^{t} \geq s_{ij}^{t} \end{cases}$$

$$s_{ij}^{t} = \frac{1}{1 + e^{-v_{ij}^{t+1}}}$$

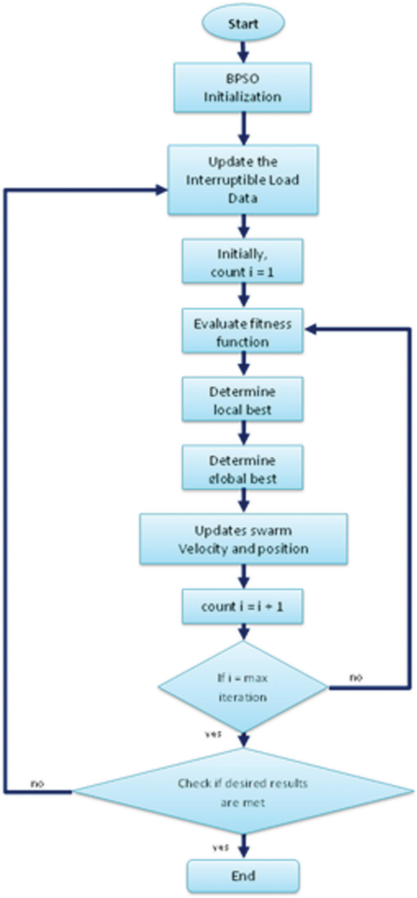


Figure 1. *BPSO Algorithm Pseudocode*

BPSO Initialization

The variables to initialize the BPSO are adjusted based on the(J. Liu & Fan, 2009; Pedrasa et al., 2008).

a. The Inertia Weight ω = 1;
b. Maximum Velocity Vmax = 5;
c. The Constriction Factor χ = 10;
d. The Swarm Size = 200;
e. The Acceleration Coefficients C1, C2 = 2 , 2;
f. Type = 'MAX';

BPSO Fitness Test

With the initialization variables, the fitness test determines the stability of the simulation. The higher the fitness value, the more stabilized the simulation results are. With the trials of 250, 500 and 750 iterations, the 500 iteration simulation shows the highest fitness value with the least elapsed time as shown in Table 1. This 500 iteration configuration with the BPSO initial values are to be used to simulate the proposed model.

Table 1. *Fitness Table without Interruptible Load Program*

Iteration	Elapsed Time (seconds)	Fitness
250	53.915611	-130984049.1
500	99.775988	40906.42
750	165.419705	40906.42

ECONOMIC ANALYSIS

Interruptible Load Model

Many published papers (Fahrioglu & Alvarado, 2000 ; Fahriog˜lu & Alvarado, 2001; Qi et al., 2008; Zhu et al., 2013) present the optimum model of ILP when certain considerations of the parameters were taken. Those significant works provide a relevant overview on the different literature and modelling techniques that are useful and significant. The interruptible load depends on the available capacity the energy storage stored during off-peak. This is to be released during peak hours to compensate the peak demand of the test subject. The remaining capacity is then estimated and maximum allowable to ILP for de-loading same capacity to the demand. The model is based to the ILP program performed by of (Fahrioglu & Alvarado, 2000). The model of (4) is a time-varying equation of the power to be de-loaded and t is in hours.

$$P_{dl}(t) = P_{dis}(t) + P_{PV}(t) - P_{ch}(t)$$

Pricing Functions

The charging (5) and discharging (6)rates depend on the electricity rate of the test subject. The electricity rate ((λ) depends on the four scenarios. This is fixed value for scenario 1 and 2 while scenarios 3 and 4 have different rates for peak and off-peak hours. The constraints are given to (7) and (8) where the binary value should always be either 0 or 1 and the constraints of the SOC with respect to time.

$$C_{ch}(t) = X_{ch}(i,t)P_{ch}(i,t)\,\lambda$$
$$C_{dis}(t) = X_{dis}(i,t)P_{dis}(i,t)\,\lambda$$
$$X_{ch_{i,t}} + X_{dis_{i,t}} \leq 1$$
$$40\% \leq SOC_i(t) \leq 100\%$$

The difference in off-peak and peak rates is the scheme of Time-of-Use (ToU) to encourage customers for their demand side management. The ToU pricing rates are sourced from Manila Electric Company (MERALCO) which is the country's leading distribution utility that uses this scheme(MERALCO, n.d.-b).

Distribution Utility Penalty Model

An estimate of ten percentage of the total excess energy is assumed over the maximum allowable energy and the same percentage for the total excess demand above the maximum allowable demand based on the electric bill (Iligan Light & Power Inc., 2015)of the test subject. Accordingly, the maximum allowable energy of the test subject is 888 kilowatt. (9) and (10) presents the power demand and energy penalty model due to excess in maximum allowable demand.

$$P_{demand} = 10\% * [(CurrentDemand - ContractedDemand) * \lambda_{demand}] \quad (9)$$

$$P_{energy} = 10\% * [(CurrentEnergy - ContractedEnergy) * \lambda_{energy}] \quad (10)$$

Cost Estimate of the BESS-PV System

Acquired from the same study of (Loreto & Serag, 2014), Table 2 shows the corresponding material cost of the potential installation of rooftop PV system using GP-100P-36 Polycrystalline Module with LithiumodTM 5.2 kWh, 48 V Lithium-Ion Battery Module. Table 3 also presents the overall expenses with ceiling percentages according to the study with Branker (2011).

Table 2. *Material Cost of Battery ESS and PV System*

Building	No. of Panel	Price Php (P2366.32 Per panel)	No. of Bat	Cost of Batteries Php (P137,280/ battery)	Inverter	Price Php (P13,218.00 per inverter)
Admin. Building	414	Php 979,656.48	200	Php 27,456,000.00	200	Php 2,643,600.00
Main Library Bldg	232	Php 548,986.24	175	Php 24,024,000.00	175	Php 2,313,150.00
New IACET Bldg	731	Php 1,729,779.92	250	Php 34,320,000.00	250	Php 3,304,500.00
COE Building	658	Php 1,557,038.56	250	Php 34,320,000.00	250	Php 3,304,500.00
CSM Building	1070	Php 2,531,962.40	250	Php 34,320,000.00	250	Php 3,304,500.00
CED Building	378	Php 894,468.96	225	Php 30,888,000.00	225	Php 2,974,050.00
Total	4333	Php 10,253,264.60	1350	Php 185,328,000.00	1350	Php 17,844,300.00

Table 3. *Total Investment (in Php)*

Total Material Cost:	Php 214,104,372.00
Installation Cost (9% of Material Cost):	Php 19,269,393.00
Shipping Cost for battery(15% of total cost)	Php 27,799,200.00
Handling Fee of battery: ($25)	Php 1,100.00
Drop-Ship Fee ; ($50)	Php 2,200.00
Total Investment:	Php 261,176,265.00
AnnualO&M Cost (0.12% of Investment Cost):	Php 313,411.52

Net Cost Function

The net cost function in (11) is a function that will determine the overall cost of the proposed system based on all the combined cost-benefit models(Luo et al., 2007)

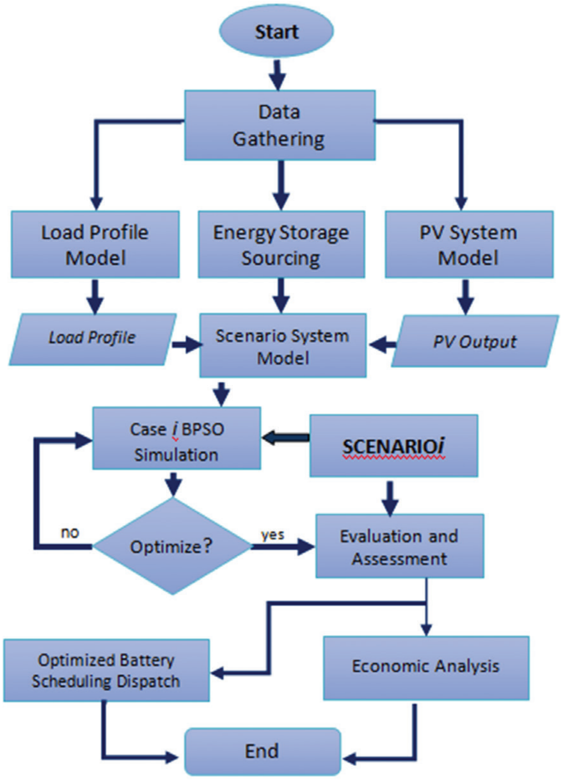
$$C_T(t) = \sum_{n=1}^{N}[P_{L,n}(t) + P_{ch,n}(t) - P_{dis,n}(t) - P_{PV,n}(t)](\lambda) \qquad (11)$$

Payback Period

The estimated possible investment and the annual savings generated from the reduction of annual energy or implementing ILP and ToU is sourced from (MERALCO, n.d.-a). In (12), the payback period is estimated.

$$\text{Payback period} = \frac{\text{Investment required for a project}}{\text{Net annual cash inflow}} \qquad (12)$$

Methodology



The optimized battery dispatch schedule and economic analysis begin with gathering of data as presented in Fig. 2. The data needed includes a 24-hour demand load profile, battery storage specifications, and 24-hour photovoltaic power output estimate. These data are sourced from the test subject. Combining all the necessary data and the sourced models, scenario system models (**SCENARIO *i***) are created.

All four scenarios implements BESS-PV system with the restriction according to DU's penalty scheme. SCENARIO 1 uses a fixed rate pricing without ILP scheme. SCENARIO 2 also uses fixed rate pricing with ILP scheme. SCENARIO 3 uses a ToU pricing without ILP scheme. And lastly, SCENARIO 4 uses ToU pricing with ILP scheme.

There are two sets of simulation. The first set is composed of SCENARIO 1 and SCENARIO 3 which have no ILP scheme. The second set composed of SCENARIO 2 and SCENARIO 4 includes ILP scheme. The two set are simulated for a six-year forecasted load demand from 2015-2020 using MATLAB R2011a. The forecasted load demand uses a linear annual growth rate of the country's load demand.

Once optimization is achieved, an evaluation and assessment of each scenario are performed respectively. Finally, the two set of simulations are the optimized battery scheduling dispatch while the economic analysis of each four model scenarios are presented through the analysis of the payback period estimate.

Test Subject

The test subject is the Mindanao State University – Iligan Institute of Technology campus which is already considered as a contestable customer with a peak demand reaching one megawatt as of January 2015 (Iligan Light & Power Inc., 2015). The test subject provides the needed demand load profile. The forecasted annual growth of load demand is assumed 4% according to the DOE (Department of Energy, 2013). The test subject provided a typical 24-hour weekday load profile with a 5-year forecasted period is tabulated in Appendix A. The new forecasted load profile (with interruptible load) is tabulated in Appendix B.

Battery Energy Storage Specifications

In an energy storage technology review of Bradbury (Chen et al., 2009), battery energy storage, especially, the Lithium-ion fits this study for grid-connected storage and load shredding. In comparing all Lithium-ion batteries of Elithion's Lithium-ion battery with inverter is used in this study. Table 4shows the specifications of the chosen battery.

Table 4. *Battery energy storage specs*

Battery data (Elithion)	
Battery input voltage(V):	48
Efficiency:	0.975
Nominal Energy(kWh):	5.2
DOD:	0.8
Nominal Ampere hours (Ah):	108.3333333
Inverter Data	
Efficiency	0.9
Input Voltage (Vdc)	48
Output Voltage (Vac)	230

Battery Energy Storage Model

In (Dufo-López & Bernal-Agustín, 2015; Pedrasa et al., 2008), the models for constraintsfor chargingare (13) and (15); for discharging are (14) and (16), for state of charge are (17) and (18); andfor the inverter efficiencyis (19).

$$P_{ch_T}(t) = \sum_{i=1}^{n} X_{ch}(i,t)\, P_{ch_i}(t)$$

$$P_{dis_T}(t) = \sum_{i=1}^{n} X_{dis}(i,t)\, P_{dis_i}(t)$$

$$0 \le P_{ch}(t) \le P_{ch}^{max}(t)$$

$$0 \le P_{dis}(t) \le P_{dis}^{max}(t)$$

$$SOC(t) = \frac{C_{sto}(t)}{C_{nom}(t)}$$

$$SOC(t+1) = SOC(t) + \frac{\eta_{out} I_{bat}(t)\Delta t}{C_{sto}(t)}$$

$$\eta_{inv}(t) = \frac{1}{1+\frac{\alpha_{inv}}{P_{load}(t)\varphi_{S_{inv}}}+\beta_{inv}+\gamma_{inv}P_{load}(t)\varphi_{S_{inv}}}\,\varphi_{S_{inv}} = \frac{S_{inv,ref}}{S_{inv}}$$

Battery Bank Sizing

The necessary battery bank sizing in ampere hours and the total number of batteries are determined by (20) and (21) from(L. Liu, Li, Wu, & Zhou, 2011).

$$C_{Ah} = \frac{E_c}{\eta_{BI} \cdot DOD \cdot V_B} \tag{20}$$

$$No.of\ Batteries = \frac{C_{Ah}}{C_{Ah\_nom}} \tag{21}$$

Table 5 presents the battery sizing resulted through implementing the acquired sizing models.

Table 5. *Battery Sizing Results*

Daily Energyof Test Subject (kWh)	16, 103.531
Backup Load daily requirement(kWh)	4, 928.02
Battery bank Capacity (Ah):	146, 249.4065
Total # of Batteries:	1,350

Photovoltaic Model

The study of (Loreto & Serag, 2014)conducted within the produced a financial cost estimate of potential installment of photovoltaic system within the test subject.(22) presents the 24-hour data vector for output power of PV system.

kwPV = 0.95*[0;0;0;0;0;0;0;0;0;100.040;120.084;121.985;124.484;106.584;...

86.216;53.888;0;0;0;0;0;0;0;0;0] (22)

3.0 Data And Results

Optimized Battery Dispatch Scheduling

The resulting schedule is presented in a discharging and charging dispatch of grouped batteries according to their respective building location to the test subject. The number 0 indicates no action taken by the battery while 1 indicates the respective dispatch either discharging or charging. Hour column indicates the start of time from 12AM to 12MN. The complete MATLAB codes is in (Piedad, 2015).

SET 1 Simulation

Table 6. *SCENARIO 1, 3 for 2015 Load Demand*

HOUR	DISCHARGING						CHARGING					
	Admin	Main Lib	IACET	COE	CSM	CED	Admin	Main Lib	IACET	COE	CSM	CED
12	0	0	0	0	0	0	0	1	1	0	0	0
1	0	0	0	0	0	0	1	1	0	1	0	0
2	0	0	0	0	0	0	1	0	1	0	1	0
3	0	0	0	0	0	0	0	1	1	0	1	1
4	0	0	0	0	0	0	0	1	0	1	0	1
5	0	0	0	0	0	0	0	0	0	1	0	1
6	0	0	0	0	0	0	1	0	0	0	1	0
7	0	0	0	0	0	0	1	0	0	0	0	1
8	0	0	0	0	0	0	0	0	1	1	1	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	1	0	0	0	0	0	0	0	0	0	0	0
11	0	1	1	1	0	1	0	0	0	0	0	0
12	1	1	0	1	1	0	0	0	0	0	0	0
13	0	0	0	1	1	0	0	0	0	0	0	0
14	0	0	0	0	0	1	0	0	0	0	0	0
15	1	1	0	0	0	1	0	0	0	0	0	0
16	1	0	1	0	1	1	0	0	0	0	0	0
17	0	0	1	0	1	0	0	0	0	0	0	0
18	0	1	1	1	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0

Table 7. *SCENARIO 1, 3 for 2016 Load Demand*

HOUR	DISCHARGING						CHARGING					
	Admin	Main Lib	IACET	COE	CSM	CED	Admin	Main Lib	IACET	COE	CSM	CED
12	0	0	0	0	0	0	0	0	1	1	0	0
1	0	0	0	0	0	0	0	1	0	0	1	1
2	0	0	0	0	0	0	1	0	0	0	1	1
3	0	0	0	0	0	0	1	0	1	0	0	1
4	0	0	0	0	0	0	1	0	1	1	0	0
5	0	0	0	0	0	0	0	1	0	1	0	0
6	0	0	0	0	0	0	1	1	0	0	1	0
7	0	0	0	0	0	0	0	0	0	0	0	1
8	0	0	0	0	0	0	0	1	1	1	1	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	1	0	1	0	0	0	0	0	0	0	0	0
11	0	1	0	0	0	0	0	0	0	0	0	0
12	0	1	0	1	0	1	0	0	0	0	0	0
13	0	0	1	1	0	0	0	0	0	0	0	0
14	0	0	0	1	1	0	0	0	0	0	0	0
15	1	1	0	0	1	0	0	0	0	0	0	0
16	1	1	1	0	1	1	0	0	0	0	0	0
17	0	0	0	1	0	1	0	0	0	0	0	0
18	1	0	1	0	1	1	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0

Table 8. *SCENARIO 1, 3 for 2017 Load Demand*

HOUR	DISCHARGING						CHARGING					
	Admin	Main Lib	IACET	COE	CSM	CED	Admin	Main Lib	IACET	COE	CSM	CED
12	0	0	0	0	0	0	1	1	0	1	0	0
1	0	0	0	0	0	0	1	1	1	0	0	1
2	0	0	0	0	0	0	0	0	0	1	0	1
3	0	0	0	0	0	0	1	0	1	0	1	0
4	0	0	0	0	0	0	0	0	1	1	1	0
5	0	0	0	0	0	0	0	0	0	0	1	0
6	0	0	0	0	0	0	0	1	0	0	1	1
7	0	0	0	0	0	0	1	1	0	0	0	1
8	0	0	0	0	0	0	0	0	1	1	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	1	1	0	0	0	0	0	0	0	0	0
11	1	0	0	1	0	0	0	0	0	0	0	0
12	0	0	0	1	1	0	0	0	0	0	0	0
13	0	1	0	0	1	0	0	0	0	0	0	0
14	0	0	1	0	1	1	0	0	0	0	0	0
15	1	1	0	0	0	1	0	0	0	0	0	0
16	1	0	1	1	0	1	0	0	0	0	0	0
17	1	1	0	0	0	0	0	0	0	0	0	0
18	0	0	1	1	1	1	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0

Table 9. *SCENARIO 1, 3 for 2018 Load Demand*

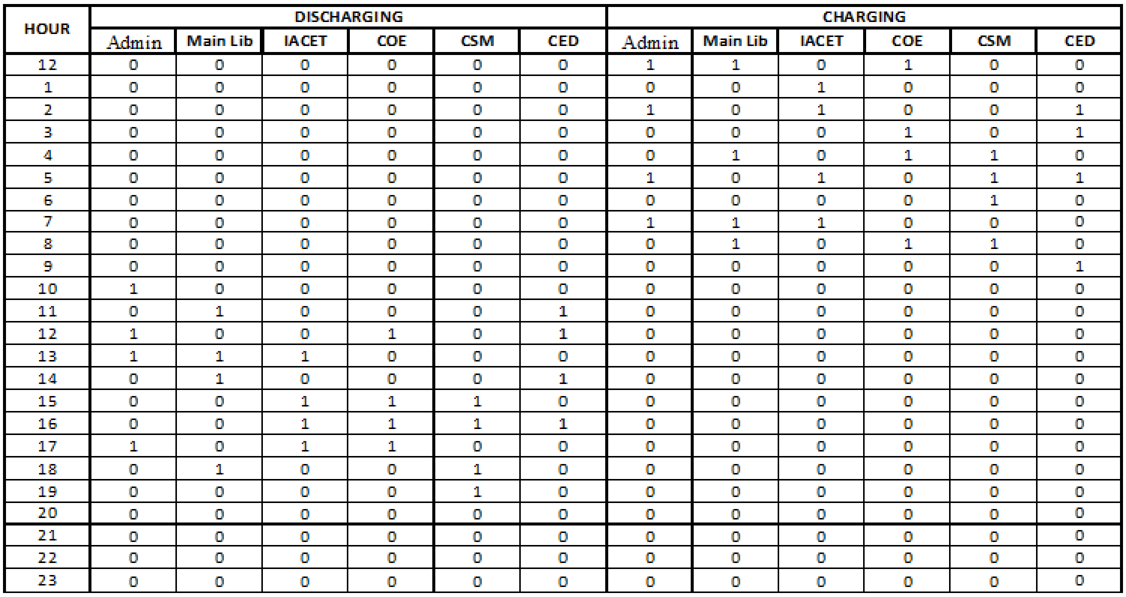
HOUR	DISCHARGING						CHARGING					
	Admin	Main Lib	IACET	COE	CSM	CED	Admin	Main Lib	IACET	COE	CSM	CED
12	0	0	0	0	0	0	0	0	0	1	1	1
1	0	0	0	0	0	0	1	0	1	1	0	1
2	0	0	0	0	0	0	0	0	1	1	1	0
3	0	0	0	0	0	0	0	1	0	1	0	0
4	0	0	0	0	0	0	0	1	1	0	0	0
5	0	0	0	0	0	0	1	1	1	0	0	0
6	0	0	0	0	0	0	1	1	0	0	1	0
7	0	0	0	0	0	0	1	0	0	0	1	1
8	0	0	0	0	0	0	0	0	0	0	0	1
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	1	0	1	0	0	0	0	0	0	0
11	0	0	1	1	0	0	0	0	0	0	0	0
12	0	1	0	1	0	0	0	0	0	0	0	0
13	1	1	0	1	0	1	0	0	0	0	0	0
14	0	1	0	0	0	1	0	0	0	0	0	0
15	1	0	1	0	1	1	0	0	0	0	0	0
16	1	0	1	0	1	0	0	0	0	0	0	0
17	0	0	0	1	1	1	0	0	0	0	0	0
18	1	1	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0

The difference in energy capacity of respective battery group allows the difference in charging and discharging dispatch time in Table 6 to Table 11. The algorithm optimizes which battery groups are going to be charged and discharged with respect to the assigned constraints.

Table 10. *SCENARIO 1, 3 for 2019 Load Demand*

HOUR	DISCHARGING						CHARGING					
	Admin	Main Lib	IACET	COE	CSM	CED	Admin	Main Lib	IACET	COE	CSM	CED
12	0	0	0	0	0	0	1	0	0	1	0	1
1	0	0	0	0	0	0	1	0	0	0	0	1
2	0	0	0	0	0	0	0	0	1	0	1	1
3	0	0	0	0	0	0	1	1	1	0	0	0
4	0	0	0	0	0	0	1	0	0	1	1	0
5	0	0	0	0	0	0	0	1	0	1	0	0
6	0	0	0	0	0	0	0	1	1	0	0	1
7	0	0	0	0	0	0	0	1	0	0	1	0
8	0	0	0	0	0	0	0	0	1	1	1	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	1	0	0	0	0	0	0	0	0	0
11	0	1	1	1	0	0	0	0	0	0	0	0
12	0	0	0	0	1	1	0	0	0	0	0	0
13	0	0	0	1	1	0	0	0	0	0	0	0
14	1	0	0	1	0	0	0	0	0	0	0	0
15	1	1	1	0	0	0	0	0	0	0	0	0
16	0	1	0	1	0	1	0	0	0	0	0	0
17	0	0	0	0	1	1	0	0	0	0	0	0
18	1	1	0	0	0	0	0	0	0	0	0	0
19	1	0	1	0	1	1	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0

Table 11. *SCENARIO1, 3 for 2020 Forecasted Load Demand*



HOUR	DISCHARGING						CHARGING					
	Admin	Main Lib	IACET	COE	CSM	CED	Admin	Main Lib	IACET	COE	CSM	CED
12	0	0	0	0	0	0	1	1	0	1	0	0
1	0	0	0	0	0	0	0	0	1	0	0	0
2	0	0	0	0	0	0	1	0	1	0	0	1
3	0	0	0	0	0	0	0	0	0	1	0	1
4	0	0	0	0	0	0	0	1	0	1	1	0
5	0	0	0	0	0	0	1	0	1	0	1	1
6	0	0	0	0	0	0	0	0	0	0	1	0
7	0	0	0	0	0	0	1	1	1	0	0	0
8	0	0	0	0	0	0	0	1	0	1	1	0
9	0	0	0	0	0	0	0	0	0	0	0	1
10	1	0	0	0	0	0	0	0	0	0	0	0
11	0	1	0	0	0	1	0	0	0	0	0	0
12	1	0	0	1	0	1	0	0	0	0	0	0
13	1	1	1	0	0	0	0	0	0	0	0	0
14	0	1	0	0	0	1	0	0	0	0	0	0
15	0	0	1	1	1	0	0	0	0	0	0	0
16	0	0	1	1	1	1	0	0	0	0	0	0
17	1	0	1	1	0	0	0	0	0	0	0	0
18	0	1	0	0	1	0	0	0	0	0	0	0
19	0	0	0	0	1	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0

Table 6 shows the first set of simulation result for SCENARIO 1 and 3 for the year 2015.This set is implemented without the ILP scheme. Table 7, 8, 9, 10, and 11 show the same simulation result but using the forecasted load until 2020. It can be seen from all the tables that the battery charges only during off-peak hours from 12AM to 9AM and discharges only at peak hours around 10AM to 7PM.

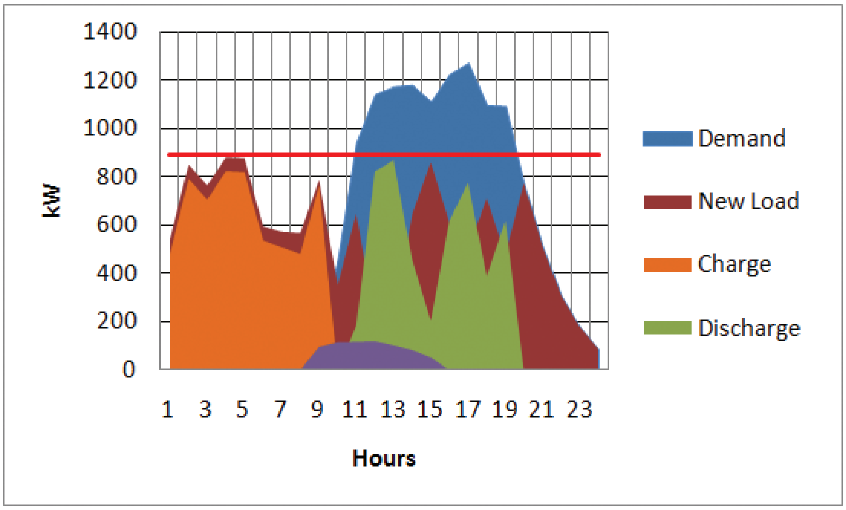


Figure 3. *2015 Daily Load Curve w/o ILP*

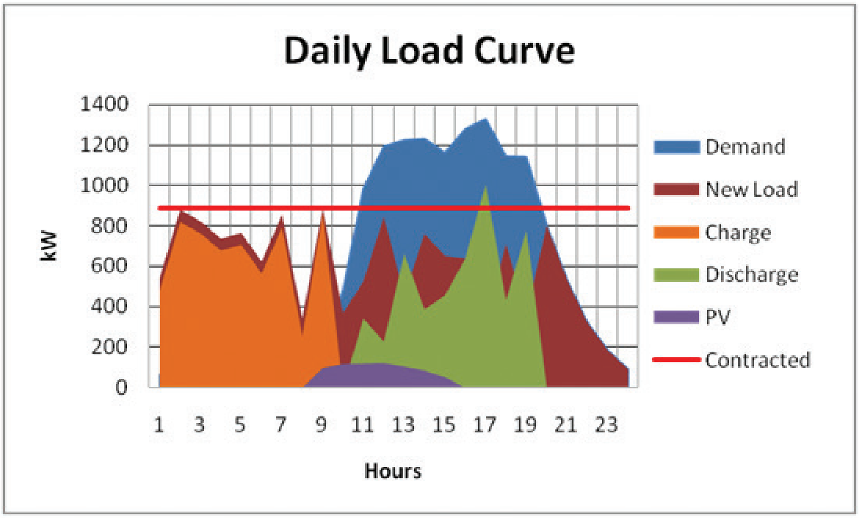


Figure 4. *2016 Daily Load Curve w/o ILP*

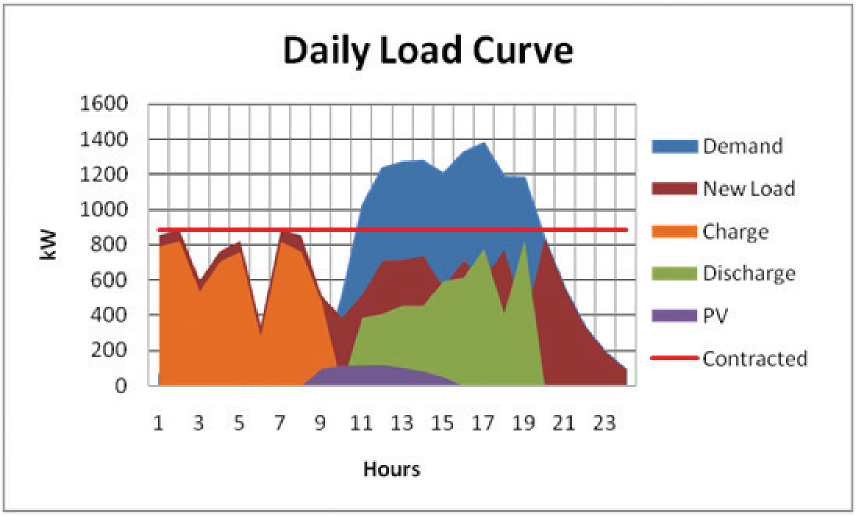


Figure 5. *2017 Daily Load Curve w/o ILP*

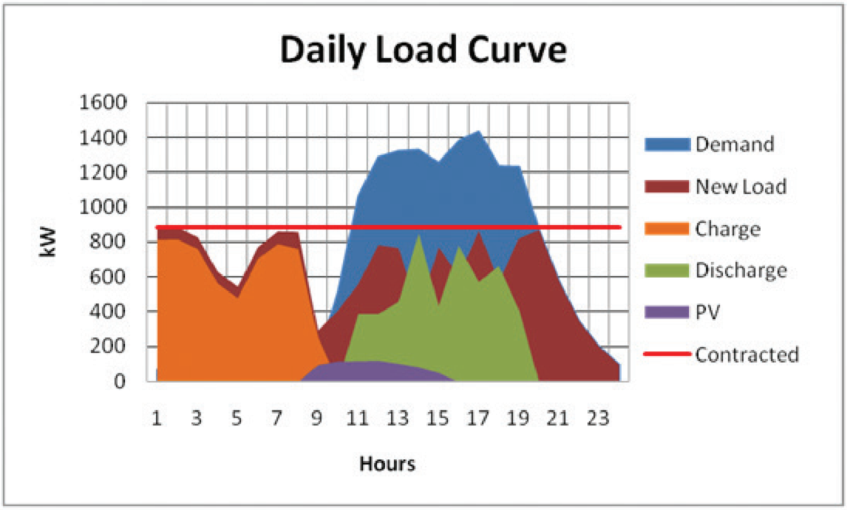


Figure 6. *2018 Daily Load Curve w/o ILP*

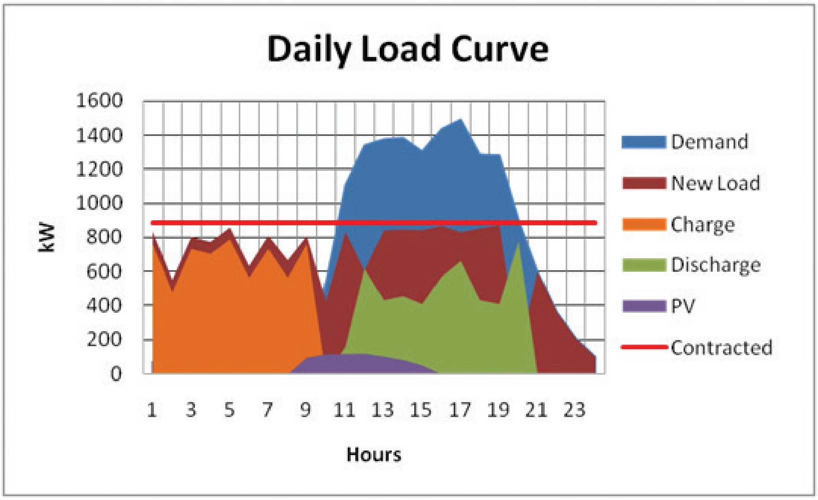


Figure 7. *2019 Daily Load Curve w/o ILP*

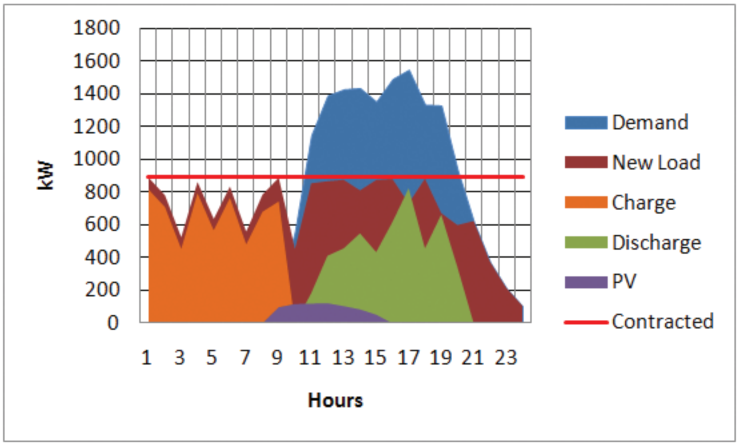
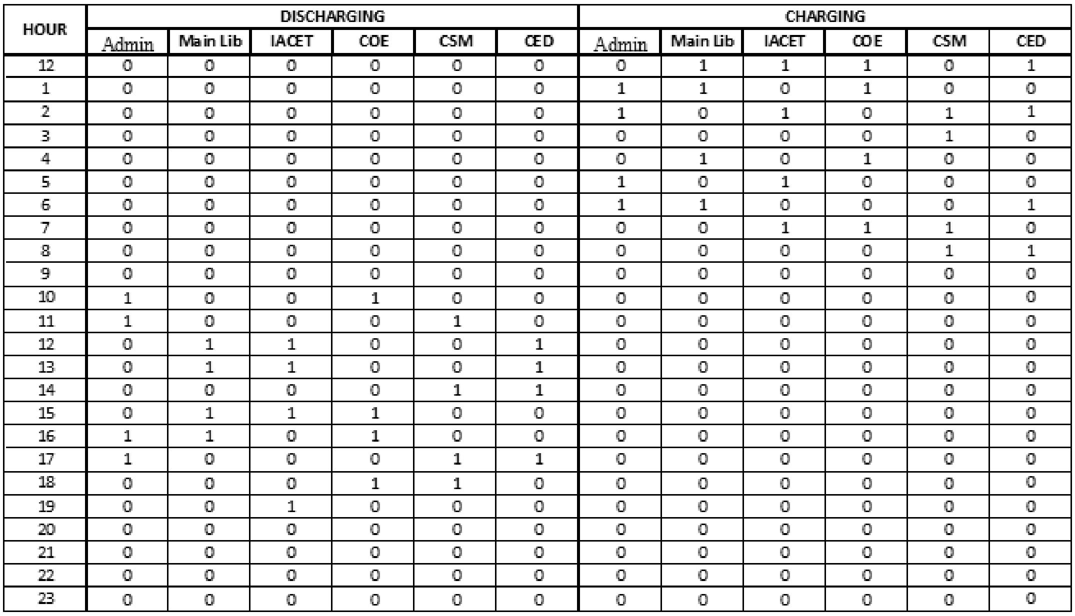


Figure 8. *2020 Daily Load Curve w/o ILP*

Fig. 3 – Fig. 8present the changes in the load profile resulted from the optimized dispatches of Table 6 – Table 11respectively. Accordingly, the original demand of the test subject, in blue gradient, exceeds the line red line which is the maximum allowable contracted demand. With the optimized scheduling, the new load with gradient of brown, is now restricted to the maximum allowablecontracted demand after the simulation. The PV system in violet gradient has lower power capacitycontribution. This, however, helps in de-loading the load demand during peak hours. On the other hand, the charging dispatch occurred during the off-peak hours. The discharged energy in green happened during peak hours that compensate most of the excess demand energy. These situations occur in all six scenarios in Fig. 3 to Fig. 8.

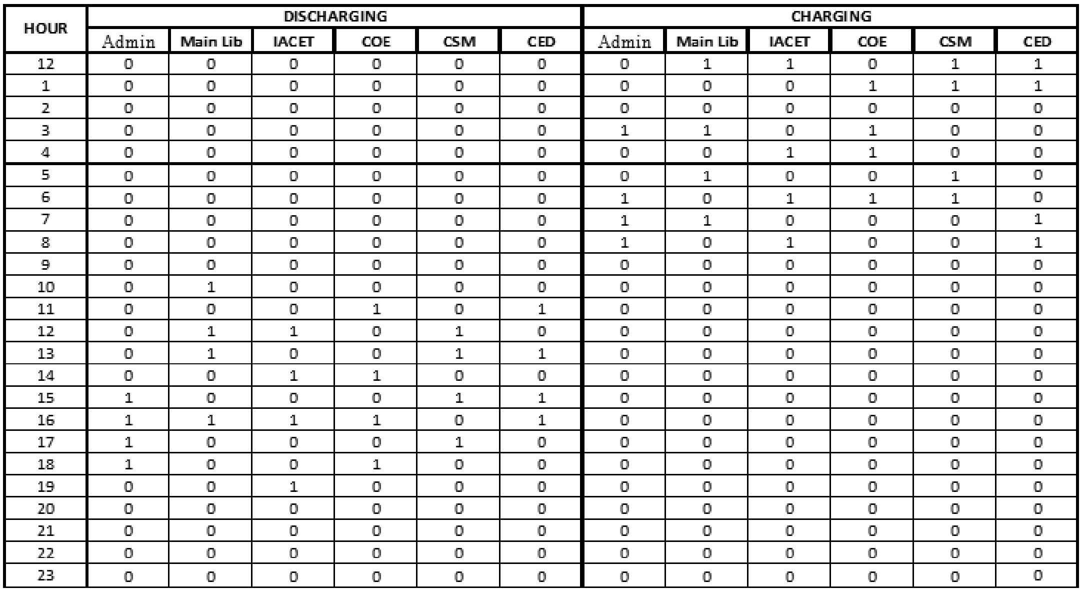
SET 2 Simulation

Table 12. *SCENARIO 2, 4 for 2015 Load Demand*



HOUR	DISCHARGING						CHARGING					
	Admin	Main Lib	IACET	COE	CSM	CED	Admin	Main Lib	IACET	COE	CSM	CED
12	0	0	0	0	0	0	0	1	1	1	0	1
1	0	0	0	0	0	0	1	1	0	1	0	0
2	0	0	0	0	0	0	1	0	1	0	1	1
3	0	0	0	0	0	0	0	0	0	0	1	0
4	0	0	0	0	0	0	0	1	0	1	0	0
5	0	0	0	0	0	0	1	0	1	0	0	0
6	0	0	0	0	0	0	1	1	0	0	0	1
7	0	0	0	0	0	0	0	0	1	1	1	0
8	0	0	0	0	0	0	0	0	0	0	1	1
9	0	0	0	0	0	0	0	0	0	0	0	0
10	1	0	0	1	0	0	0	0	0	0	0	0
11	1	0	0	0	1	0	0	0	0	0	0	0
12	0	1	1	0	0	1	0	0	0	0	0	0
13	0	1	1	0	0	1	0	0	0	0	0	0
14	0	0	0	0	1	1	0	0	0	0	0	0
15	0	1	1	1	0	0	0	0	0	0	0	0
16	1	1	0	1	0	0	0	0	0	0	0	0
17	1	0	0	0	1	1	0	0	0	0	0	0
18	0	0	0	1	1	0	0	0	0	0	0	0
19	0	0	1	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0

Table 13. *SCENARIO 2, 4 for 2016 Load Demand*



HOUR	DISCHARGING						CHARGING					
	Admin	Main Lib	IACET	COE	CSM	CED	Admin	Main Lib	IACET	COE	CSM	CED
12	0	0	0	0	0	0	0	1	1	0	1	1
1	0	0	0	0	0	0	0	0	0	1	1	1
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	1	1	0	1	0	0
4	0	0	0	0	0	0	0	0	1	1	0	0
5	0	0	0	0	0	0	0	1	0	0	1	0
6	0	0	0	0	0	0	1	0	1	1	1	0
7	0	0	0	0	0	0	1	1	0	0	0	1
8	0	0	0	0	0	0	1	0	1	0	0	1
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	1	0	0	0	0	0	0	0	0	0	0
11	0	0	0	1	0	1	0	0	0	0	0	0
12	0	1	1	0	1	0	0	0	0	0	0	0
13	0	1	0	0	1	1	0	0	0	0	0	0
14	0	0	1	1	0	0	0	0	0	0	0	0
15	1	0	0	0	1	1	0	0	0	0	0	0
16	1	1	1	1	0	1	0	0	0	0	0	0
17	1	0	0	0	1	0	0	0	0	0	0	0
18	1	0	0	1	0	0	0	0	0	0	0	0
19	0	0	1	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0

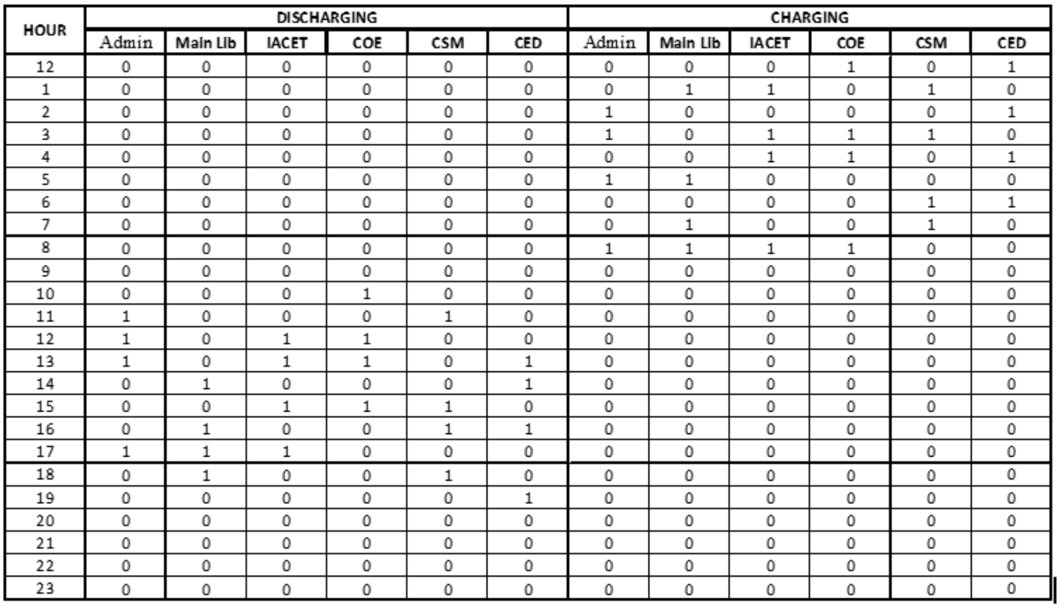
Table 14. *SCENARIO 2, 4 for 2017 Load Demand*

HOUR	DISCHARGING						CHARGING					
	Admin	Main Lib	IACET	COE	CSM	CED	Admin	Main Lib	IACET	COE	CSM	CED
12	0	0	0	0	0	0	0	1	0	0	0	1
1	0	0	0	0	0	0	1	0	1	0	1	0
2	0	0	0	0	0	0	1	0	1	0	0	1
3	0	0	0	0	0	0	0	1	0	1	0	0
4	0	0	0	0	0	0	1	0	0	0	0	0
5	0	0	0	0	0	0	1	0	1	1	0	0
6	0	0	0	0	0	0	0	0	0	1	1	1
7	0	0	0	0	0	0	0	1	0	1	1	0
8	0	0	0	0	0	0	0	1	1	0	1	1
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	1	0	0	0	0	0	0	0
11	0	0	0	1	0	1	0	0	0	0	0	0
12	0	1	0	1	0	0	0	0	0	0	0	0
13	1	0	1	0	1	0	0	0	0	0	0	0
14	1	0	1	0	0	1	0	0	0	0	0	0
15	1	1	0	0	0	1	0	0	0	0	0	0
16	1	0	1	1	0	1	0	0	0	0	0	0
17	0	1	0	1	0	0	0	0	0	0	0	0
18	0	1	1	0	1	0	0	0	0	0	0	0
19	0	0	0	0	1	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0

Table 15. *SCENARIO 2, 4 for 2018 Load Demand*

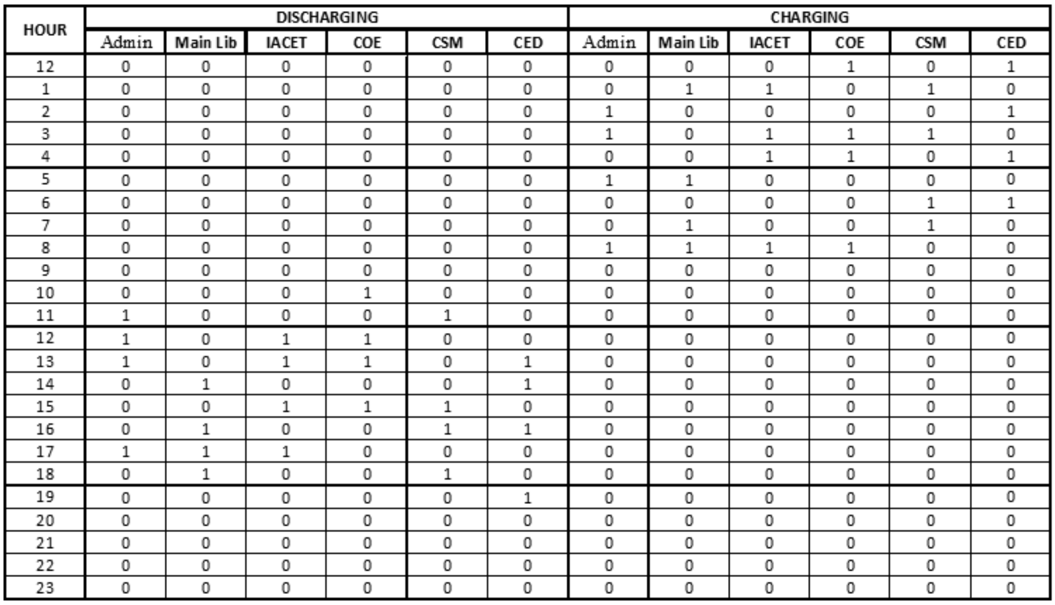
HOUR	DISCHARGING						CHARGING					
	Admin	Main Lib	IACET	COE	CSM	CED	Admin	Main Lib	IACET	COE	CSM	CED
12	0	0	0	0	0	0	1	1	0	0	0	1
1	0	0	0	0	0	0	1	1	0	1	0	0
2	0	0	0	0	0	0	0	1	0	0	1	0
3	0	0	0	0	0	0	1	0	1	0	0	0
4	0	0	0	0	0	0	0	1	0	0	0	1
5	0	0	0	0	0	0	0	0	1	0	1	0
6	0	0	0	0	0	0	0	0	0	1	1	1
7	0	0	0	0	0	0	0	0	1	1	0	1
8	0	0	0	0	0	0	1	0	1	1	1	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	1	0	0	0	0	0	0	0
11	1	0	0	0	0	1	0	0	0	0	0	0
12	0	0	0	1	1	0	0	0	0	0	0	0
13	1	0	1	0	1	1	0	0	0	1	0	0
14	0	0	0	1	0	1	0	0	0	0	0	0
15	0	1	1	1	0	0	0	0	0	0	0	0
16	1	1	1	0	0	1	0	0	0	0	0	0
17	0	1	0	1	0	0	0	0	0	0	0	0
18	1	0	1	1	1	0	0	0	0	0	0	0
19	0	1	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0

Table 16. *SCENARIO 2, 4 for 2019 Load Demand*



HOUR	DISCHARGING						CHARGING					
	Admin	Main Lib	IACET	COE	CSM	CED	Admin	Main Lib	IACET	COE	CSM	CED
12	0	0	0	0	0	0	0	0	0	1	0	1
1	0	0	0	0	0	0	0	1	1	0	1	0
2	0	0	0	0	0	0	1	0	0	0	0	1
3	0	0	0	0	0	0	1	0	1	1	1	0
4	0	0	0	0	0	0	0	0	1	1	0	1
5	0	0	0	0	0	0	1	1	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	1	1
7	0	0	0	0	0	0	0	1	0	0	1	0
8	0	0	0	0	0	0	1	1	1	1	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	1	0	0	0	0	0	0	0	0
11	1	0	0	0	1	0	0	0	0	0	0	0
12	1	0	1	1	0	0	0	0	0	0	0	0
13	1	0	1	1	0	1	0	0	0	0	0	0
14	0	1	0	0	0	1	0	0	0	0	0	0
15	0	0	1	1	1	0	0	0	0	0	0	0
16	0	1	0	0	1	1	0	0	0	0	0	0
17	1	1	1	0	0	0	0	0	0	0	0	0
18	0	1	0	0	1	0	0	0	0	0	0	0
19	0	0	0	0	0	1	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0

Table 17. *SCENARIO 2, 4 for 2020 Forecasted Load Demand*



HOUR	DISCHARGING						CHARGING					
	Admin	Main Lib	IACET	COE	CSM	CED	Admin	Main Lib	IACET	COE	CSM	CED
12	0	0	0	0	0	0	0	0	0	1	0	1
1	0	0	0	0	0	0	0	1	1	0	1	0
2	0	0	0	0	0	0	1	0	0	0	0	1
3	0	0	0	0	0	0	1	0	1	1	1	0
4	0	0	0	0	0	0	0	0	1	1	0	1
5	0	0	0	0	0	0	1	1	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	1	1
7	0	0	0	0	0	0	0	1	0	0	1	0
8	0	0	0	0	0	0	1	1	1	1	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	1	0	0	0	0	0	0	0	0
11	1	0	0	0	1	0	0	0	0	0	0	0
12	1	0	1	1	0	0	0	0	0	0	0	0
13	1	0	1	1	0	1	0	0	0	0	0	0
14	0	1	0	0	0	1	0	0	0	0	0	0
15	0	0	1	1	1	0	0	0	0	0	0	0
16	0	1	0	0	1	1	0	0	0	0	0	0
17	1	1	1	0	0	0	0	0	0	0	0	0
18	0	1	0	0	1	0	0	0	0	0	0	0
19	0	0	0	0	0	1	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0

Table 12 presents the outcome of the optimum scheduling for SCENARIO 2 and 4 which the ILP scheme is already implemented. Tables 13, 14, 15, 16, and 17uses the forecasted load demand until 2020,respectively, with the same simulation setting. Still, all tables show that the battery charges only during off-peak hours from 12AM to 8AM and discharges only at peak hours around 10AM to 7PM.

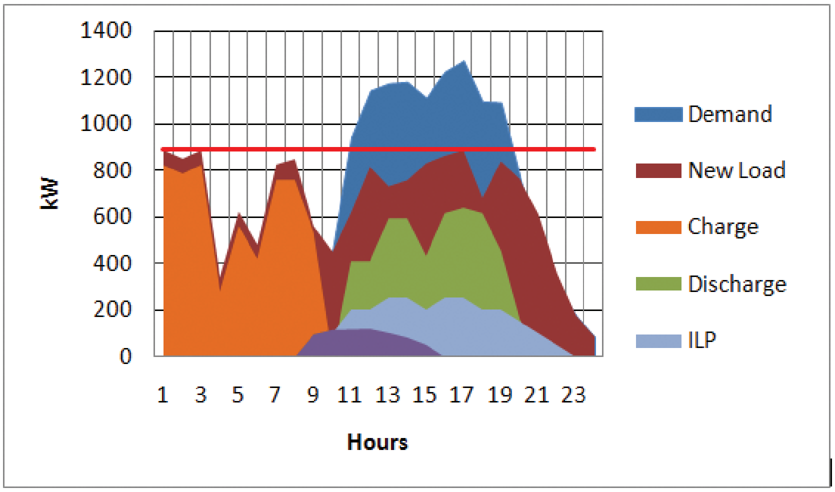


Figure 9. *2015 Daily Load Curve with ILP*

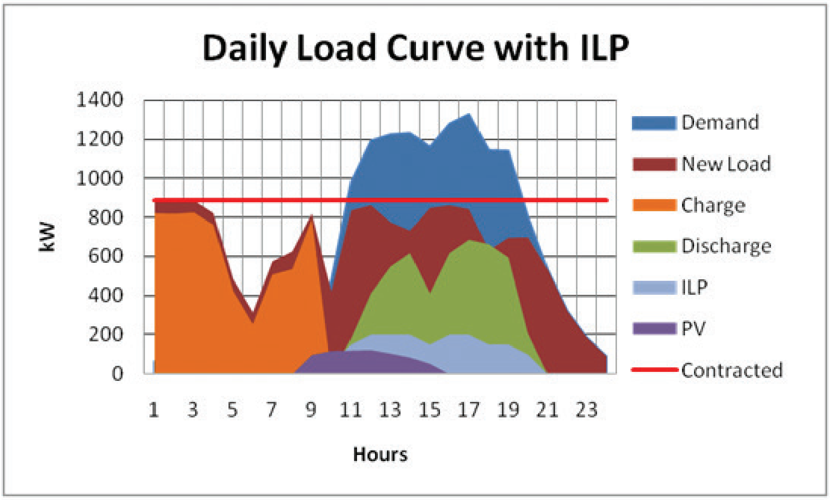


Figure 10. *2016 Daily Load Curve with ILP*

Table 12 presents the outcome of the optimum scheduling for SCENARIO 2 and 4 which the ILP scheme is already implemented. Tables 13, 14, 15, 16, and 17uses the forecasted load demand until 2020,respectively, with the same simulation setting. Still, all tables show that the battery charges only during off-peak hours from 12AM to 8AM and discharges only at peak hours around 10AM to 7PM.

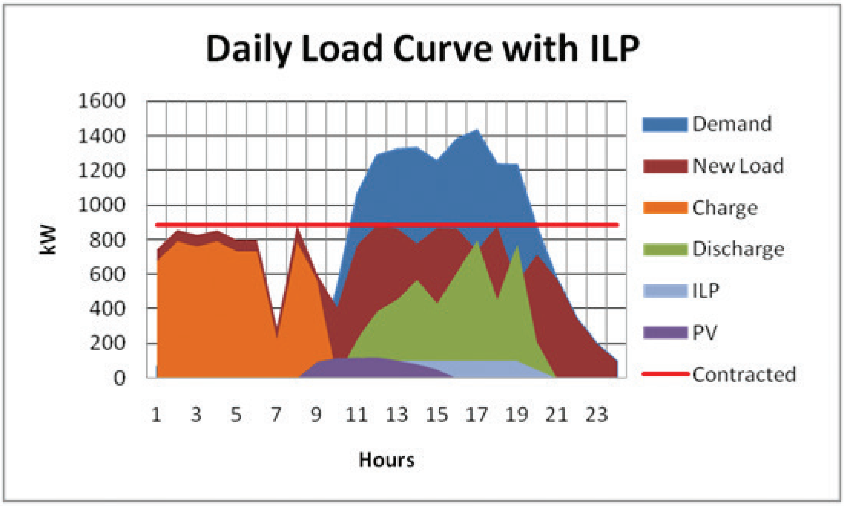


Figure 11. *2017 Daily Load Curve with ILP*

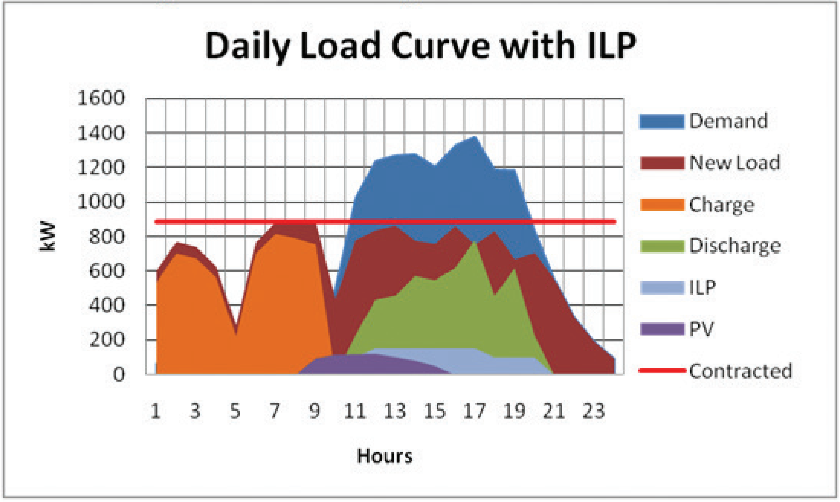


Figure 12. *2018 Daily Load Curve with ILP*

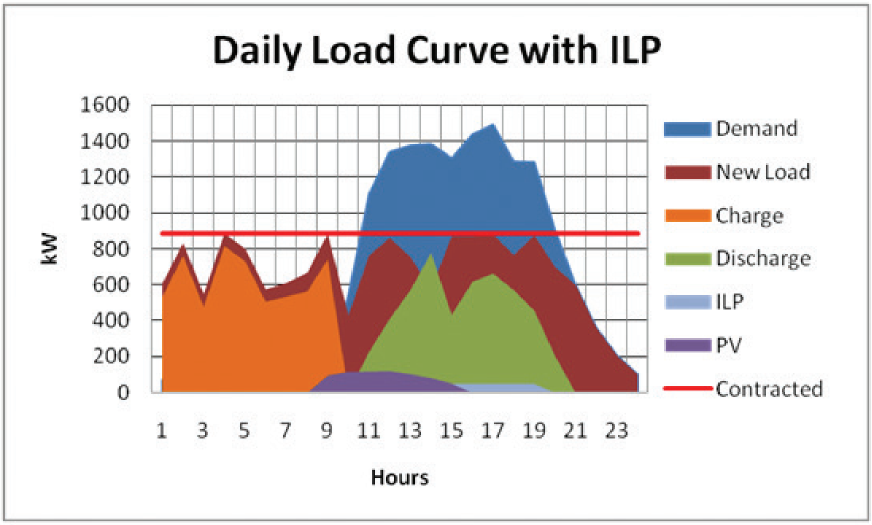


Figure 11. 2017 Daily Load Curve with ILP

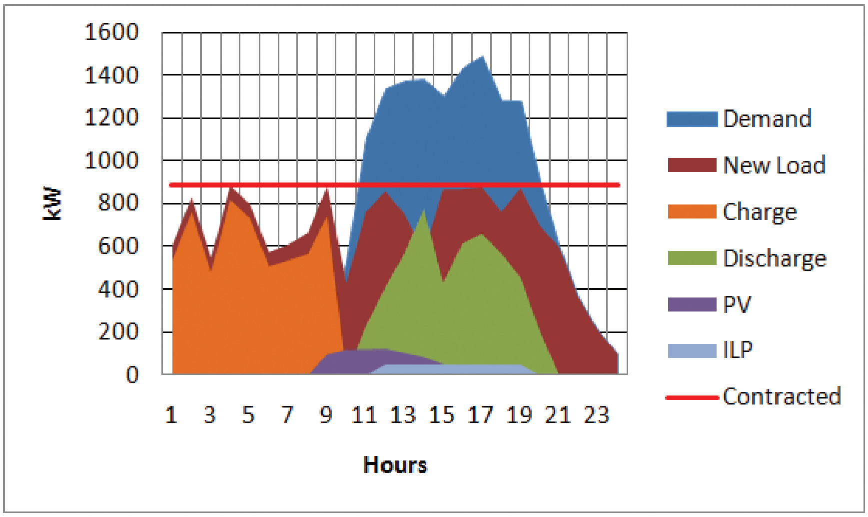


Figure 14. *2020 Daily Load Curve with ILP*

Fig. 9 – Fig. 14 present the changes in the 24-hour load profile based on the optimized dispatches of Table 12 – Table 17 respectively. The results show similar results with the SET 1 Simulations. Although the results were already included the interruptible loads from the ILP scheme, still the new load successfully restricted the maximum allow able contracted demand. The PV system in violet gradient still has the lower power capacity contribution. This, however, helps in de-loading the load demand during peak hours. On the other hand, the charging dispatch occurred during the off-peak hours. The discharged energy in green also happened during peak hours that compensate most of the excess demand energy. These situations occur in all the six scenarios in Fig. 9 – Fig. 14 similar to the previous simulation.

Economic Analysis

Savings

The optimized battery ESS scheduling dispatch and PV system changes the daily load profile of the test subject. These changes were calculated to produce the corresponding savings.

Table 18. *Peak Demand, Annual Energy and Difference of Annual Energy for Two Simulation Sets*

YEAR	Original		BPSO SIMULATION					
			SET 1: without ILP			SET 2: with ILP		
	Peak Demand	Annual Energy	Peak Demand	Annual Energy	Difference of Annual Energy	Peak Demand	Annual Energy	Difference of Annual Energy
	kW	kWh	kW	kWh	kWh	kW	kWh	kWh
2015	1275.86	4495460.81	880.90	4453649.93	41810.88	887.04	5295396.24	-799935.43
2016	1326.89	4675293.71	887.96	4633967.39	41326.32	886.90	5287299.36	-612005.65
2017	1379.97	4862304.19	887.89	4833056.35	29247.84	887.72	5397410.88	-535106.69
2018	1435.16	5056799.21	885.60	5022661.37	34137.84	886.88	5520136.08	-463336.87
2019	1492.57	5259067.17	871.45	5262104.13	-3036.96	885.97	5511229.20	-252162.03
2020	1552.27	5469436.08	887.10	5465942.88	3493.20	887.10	5690453.28	-221017.20

Table 18 shows that the new peak demand of both simulation sets is restrained from exceeding the maximum allowable demand of 888 kilowatt. The first simulation set, composed of SCENARIO 1 and 3, have reduced the annual energy consumption. This is due to the contribution of the PV system that appears to de-load some demand energy on the daily basis. In the second simulation set composed of SCENARIO 2 and 4, the difference in annual energy becomes significantly negative. The presence of the interruptible loads minus the energy output of PV system tends to increase the daily load demand.

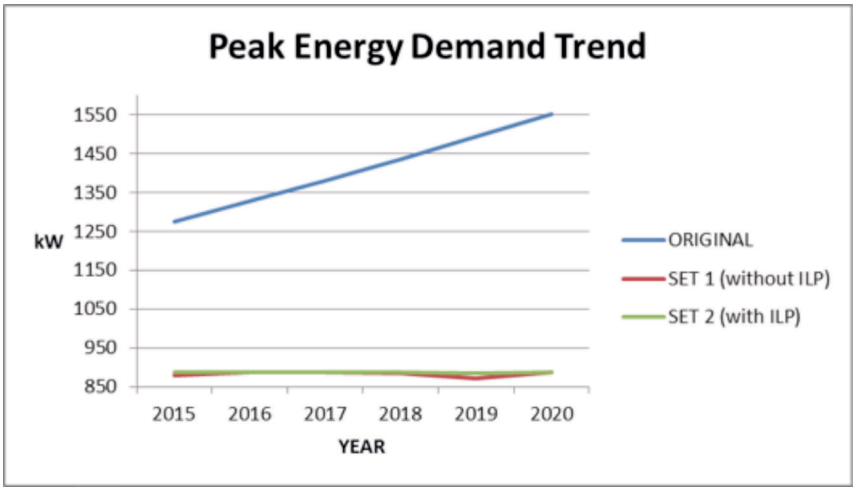


Figure 15*. Annual Peak Energy Demand Trend from 2015-2020*

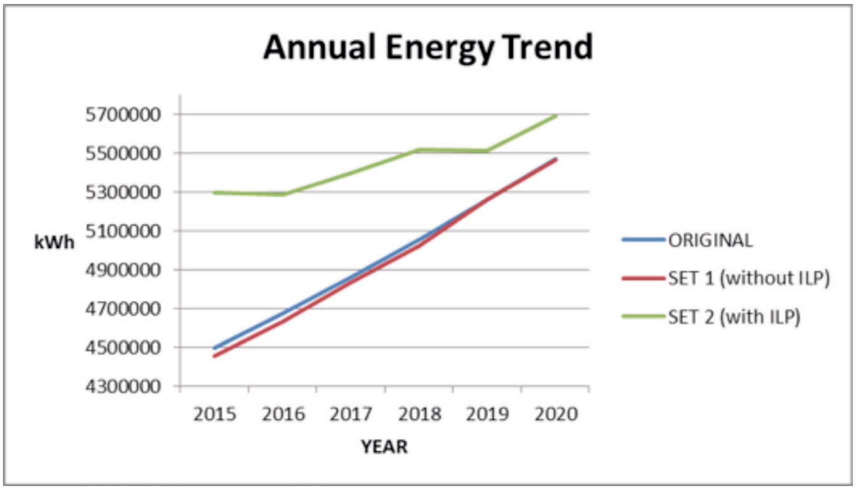
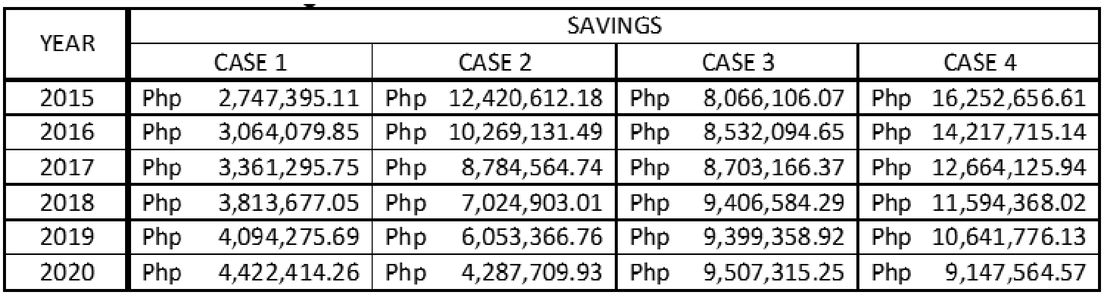


***Figure 16**. Annual Energy Trend from 2015-2020*

Fig. 15 and 16 show trends on annual peak demand and annual energy consumption. Fig.15 presents how the proposed application maintained the 888 kW contracted peak demand for the next six years. Fig. 16 however showed how annual energy rapidly increases due to the additional load consumed by energy storage.

***Table 19.** Annual Savings of Four Scenarios for Six Forecasted Years*



YEAR	SAVINGS			
	CASE 1	CASE 2	CASE 3	CASE 4
2015	Php 2,747,395.11	Php 12,420,612.18	Php 8,066,106.07	Php 16,252,656.61
2016	Php 3,064,079.85	Php 10,269,131.49	Php 8,532,094.65	Php 14,217,715.14
2017	Php 3,361,295.75	Php 8,784,564.74	Php 8,703,166.37	Php 12,664,125.94
2018	Php 3,813,677.05	Php 7,024,903.01	Php 9,406,584.29	Php 11,594,368.02
2019	Php 4,094,275.69	Php 6,053,366.76	Php 9,399,358.92	Php 10,641,776.13
2020	Php 4,422,414.26	Php 4,287,709.93	Php 9,507,315.25	Php 9,147,564.57

The negative difference on annual savings in the second simulation set of Table 18 may not generate savings for SCENARIO 2 and 4. However, Table 19 presents that the two scenarios have positive and even greater savings compared to their respective counterpart. These only show that the ILP and ToU schemes, regardless of the negative implications in annual energy, tend to benefit the test subject.

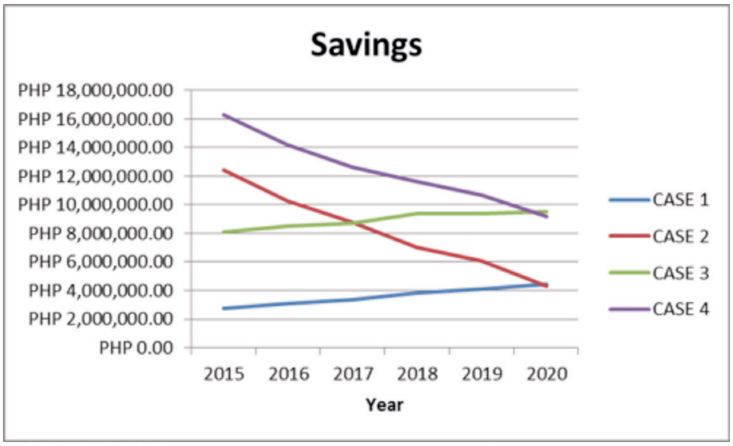


***Figure 17**. Annual Generated Savings from 2015-2020*

The negative difference on annual savings in the second simulation set of Table 18 may not generate savings for SCENARIO 2 and 4. However, Table 19 presents that the two scenarios have positive and even greater savings compared to their respective counterpart. These only shows that the ILP and ToU schemes, regardless of the negative implications in annual energy, tend to benefit the test subject. Fig. 17 shows the trend of every case. It can be seen that case 4 has the greatest savings but rapidly decreases every year due to the presence of energy storage system wherein a cost on additional energy is incurred.

Payback Period

With the savings of Table 19 and the total estimated investment cost of about 260 Million pesos from (Loreto & Serag, 2014) for the potential BESS-PV System in the test subject, a payback period calculation is performed for the four scenarios.

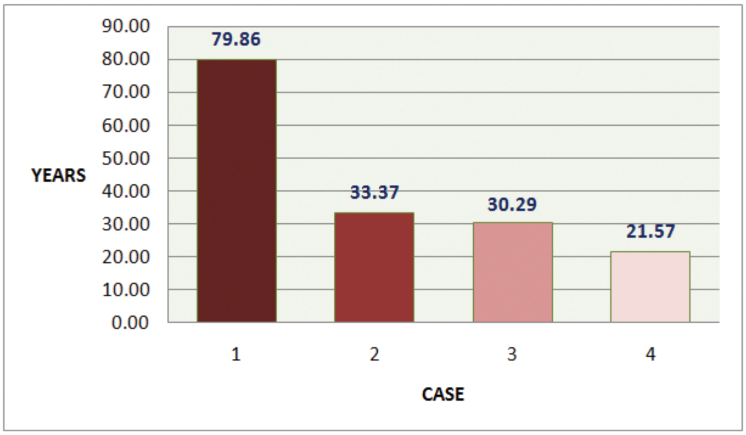


***Figure 18.** Payback Period of Four Scenarios*

Fig. 18 shows the payback period of each of the four scenarios. SCENARIO 4, which implements both ILP and ToU schemes when venturing BESS-PV system, appears to have the least period to recover the investment. SCENARIO 1 has the longest return of investment. This scenario is modelled with a fixed rate and without implementing ILP schemes. The SCENARIO 3 and 4 payback periods are shorter compared to their counterpart SCENARIO 1 and 2 in terms of applying Time-of-Use scheme. It only shows that the application of ToU scheme produces positive saving to the test subject.

4.0 Conclusion

Despite of the additional de-loading demand or the interruptible load for the ILP implementation, BESS model is seen to be regulated and is optimized in scheduling for charging and discharging dispatch. It also sustains the maximum allowable energy limit for the next sixth year.

Moreover, the positive contributions of implementing the ILP scheme and ToU schemes were realized. Another scenario that uses ILP scheme without ToU pricing tends to shorten the payback period. Likewise, the application of ToU scheme in without ILP also has good economic inclination. Moreover, combining both ILP and ToU schemes shows the best economic impact. However, though these payback periods may not be economically viable to venture battery ESS and PV system, the positive trends for solar and battery developments will lower the expenses, thus, shorten the payback period.

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