DESIGN OF HOME POWER MANAGEMENT SYSTEM FOR ELECTRICAL APPLIANCES AND POWER RESOURCES USING MIXED INTEGER LINEAR PROGRAMMING (MILP)

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Abstract - Indonesia energy consumption has increased rapidly since early 2000s. Energy consumption grows by 4.2% per year over more than 15 years. The electricity energy consumption is growing so did the environmental pollution and the depletion of fossil sources. To solve these energy problems, conventional electrical system turns into smart grids. In the smart grid applications, there are some part to support the energy efficiency. Home power management system (HPMS) is one of the most important applications part of smart grids with renewable energy resources to improve the energy efficiency. With the application for residential central management power consumption to provides energy saving.
In this paper, HPMS is a tool used to minimize the electricity cost. The system is composed of smart electrical appliances, power units (grid and photovoltaic systems with energy storage), the main controller, web application, and communication network. At the beginning of the day, the main controller of user request electrical prices from the grid and by using a Mixed Integer Linear Programming (MILP) is purposed a smart and efficient operation for the appliance, electrical prices and power units. This solution will provides lower cost foe electrical energy usage by scheduling the power resources through web applications. Simulation result shows that the HPMS can reduce the electrical cost by 30% up to 80%.

Keywords - Home Power Management System, Smart Grids, Mixed Integer Linear Programming (MILP)

I. INTRODUCTION

The increase in the amount of electricity demand in line with the times has led to the demand for electricity energy providers to supply sufficient amounts of electrical energy. Fossil energy is widely used as a source of electrical energy to meet these energy needs. But because of the depletion of the amount, currently the use of fossil energy is reduced. With the development of science and technology, renewable energy is becoming an option for the community to reduce dependence on fossil energy.
Renewable energy is widely used and developed lately because of its abundant amount, its clean and environmentally friendly nature. Renewable energy sources such as wind, sunlight, and water are utilized in the form of scattered plants (microgrid) to meet load requirements, increase reliability, and so on. Because of its location in the distribution system, the use of microgrid is considered effective to utilize renewable energy in order to reduce economic losses because often the development of small to medium scale renewable energy plants is not a solutive investment. In reality, there is a problem in the application of renewable energy sources on the system because of its intermittent nature. This property causes generators from renewable energy sources to produce varying power depending on the availability of energy sources.
On the other hand, the amount of load on the system is dynamic or changes every time. In cases that often occur, the power produced by power plants with renewable energy sources is often not in accordance with the demands of changing loads. These plants tend to produce small power when high load demand (on peak) and produce large power when demand is low (off peak). So that the generated power is wasted in the on peak period, while in the off peak period, the system tends to lack power in meeting load demand.
To overcome the intermittent nature of renewable energy, energy storage technology is used. Battery-shaped energy storage provides a solution to the problem of integrating renewable energy generation. In this study, energy storage and microgrid are integrated into the system for energy management purposes. Energy storage has an input-output response that is fast enough that it can be used to store excess power and channel the power back to the system. Adding energy storage and microgrid to the system causes different energy management optimization techniques than before.
Household-scale energy management can contribute greatly to reducing peak loads so that they can save investment costs on electricity energy infrastructure. Effective household scale energy management can be done with active consumer participation in the household sector. Electricity allocation will set different rates for each hour and different prices for the cost of charging and discharging from a microgrid system with energy storage. In some literature a lot of research has been done on household-scale electrical energy management, most of which only examines energy management by regulating electronic equipment scheduling. For example in [1] the particle swarm optimization method is used to predict the energy needed and schedule electronic equipment. While [4] electronic equipment is scheduled according to the priority sequence with the maximum power consumption limit set, in [5] your energy

consumption is scheduled to use theoritic game approach to reduce the cost of electrical energy and peak load, and on [6] linear integer mix programming is used to schedule electronic equipment to get the most economical electricity costs.

Mixed Integer Linear programming is a calculation that is often used to find optimal system generation costs by considering the limits of system power flow and price considerations. With the ability of energy storage to store and distribute power, it is possible to dynamically calculate the changes in the level of load on the system with energy storage and solar-based renewable energy sources. In research [7], the use of energy storage in hybrid microgrid systems has been proven to reduce generation costs. In this study, energy storage was examined further by considering battery capacity and discharging on a microgrid system. By determining the cost of the grid and discharging the different batteries. From this study, it is expected to obtain cheaper generation costs in terms of electricity power providers and benefit from the owner of household-scale energy storage. The method used for system optimization is Mixed Integer Linear Programming.

II. DETAILS EXPERIMENTAL

In this final project the energy management system has a diagram as shown inFig.1.

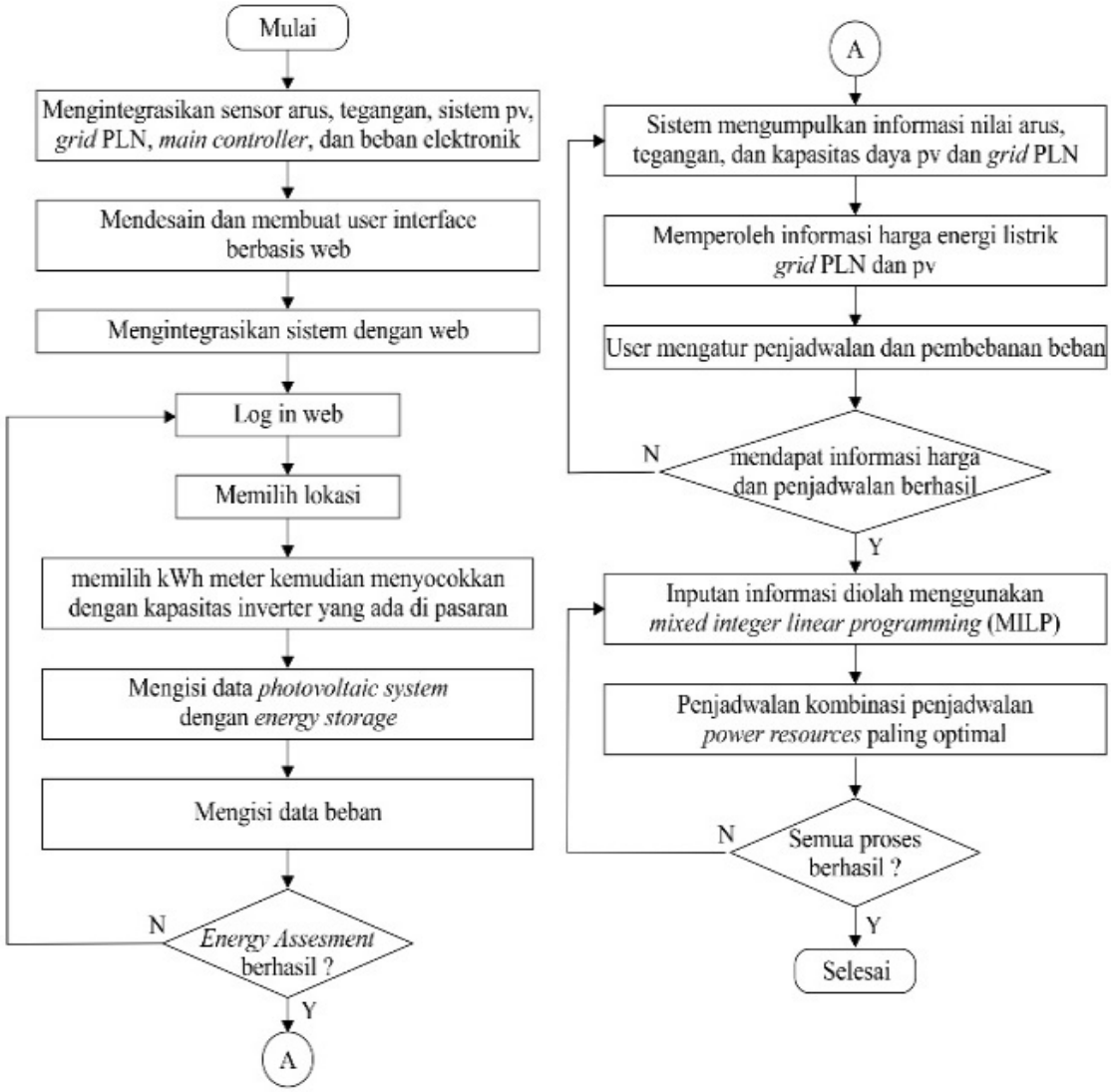

Fig.1. Research Flowchart

2.1. Power Units

The State Electricity Company (PLN) acts as a grid in the household-scale microgrid system in this final project. PLN can provide unlimited power. The generation cost of PLN is assumed to be the price of electricity sold to customers. Every day, PLN is assumed to issue electricity prices sold every hour in 24 hours with an hourly interval. While the photovoltaic system with energy storage functions as an independent energy system on a household scale.

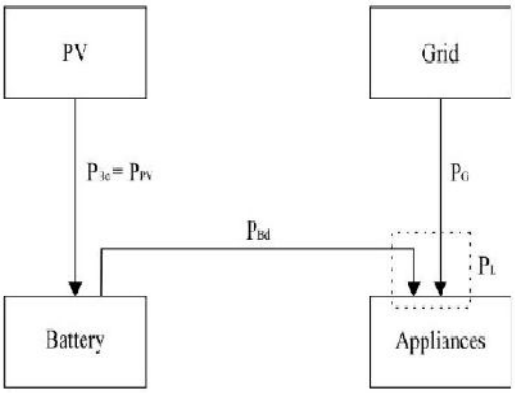

Fig.2. System Load Flow

The relationship between the power unit and the load in Figure 2.1 can be written with equation 1

$$P_G(t) + P_{PV}(t) + P_{Bd}(t) = P_L(t) + P_{Bc}(t) \quad (1)$$

On the left side of the equation is modeling from the source side, while on the right side is load side modeling. Where:

$P_G(t)$= Power that flows from the grid to the load

$P_{PV}(t)$= Power that flows from PV to battery

$P_{Bd}(t)$= Condition discharging, when the power flows from battery to load

$P_L(t)$ = The power consumed by the loadbeban

$P_{Bc}(t)$ = charging condition, when power flows from PV to battery

$$P_G(t) \leq P_{\lim}^{G}(t), \forall t \in \mathcal{T} \quad (2)$$

The PLN grid is a fundamental component in this system. The PLN grid functions as an electrical energy source that can supply unlimited power, the power that can be supplied to the system in a specific system is in equation 2.

$$P_{Bd}(t) \leq P_{\lim}^{Bd}(t), \forall t \ \mathcal{T} \quad (3)$$

While the power that can be supplied by a photovoltaic system with energy storage specifically is in equation 3.

$$x^{G}(t) \leq x^{Bd}(t), \forall t \ \mathcal{T} \quad (4)$$

Grid and photovoltaic systems with energy storage can supply the system at the same time. Specifically can be written in equation 4.

Where:

$x^{G} \in 0; 0.1; 0.2; 0.3; 0.4; 0.5; 0.6; 0.7; 0.8; 0.9; 1\}$

And

$x^{Bd}\{0; 0.1; 0.2; 0.3; 0.4; 0.5; 0.6; 0.7; 0.8; 0.9; 1\}$

is the mixed integer decision variable how much power limit is supplied to the system

2.2. B. Energy Storage

Energy storage used in this study is a battery that has charging and discharging capabilities. Charging is a battery charging process while discharging is a battery emptying process. With the battery storage capability, energy can be used to store excess power from the PV system when the load from the Grid is in a high period (on peak). Energy storage is modeled as a load condition when charging. While the PLN grid is modeled during the discharging process. As technology develops and market liberalization, energy storage can be used to generate profits. By setting the condition to be discharged more than charging, the owner of energy storage can benefit.

$$SOC(t) = {E^{B}(t)}/{E_{Cap}^{B}(t)} \quad (5)$$

storing power from PV requires energy storage or power storage, in this study batteries are used to store power from PV. The battery used is a battery with 12 V. The battery level is an important parameter called the State of Charge (SOC). The SOC is defined as a difference between the condition of the battery capacity and the total battery capacity so that it can be modeled in equation 5.

$E^{B}(t)$= Conditions of energy stored in the battery

$E_{Cap}^{B}(t)$= Total energy capacity that can be stored by the battery

$SOC(t)$=State of battery charge in time interval $tSOC(t) =$

$$SOC(t-1) + \frac{P_{Bc}(t)\,\eta_c \Delta t}{E_{Cap}^{B}(t)} - \frac{P_{Bd}(t)\Delta t}{E_{Cap}^{B}(t)\eta_{dc}} \quad (6) SOC(t) =$$

The battery can be calculated with the mathematical equation in equation 6.

η_c = charging efficiency

η_{dc} = dischargingefficiency

Pada penelitian ini baterai memiliki mode operasi yang dimodelkan pada persamaan 7.

$$SOC_{min} < SOC(t) < SOC_{max}, \forall t \in \mathcal{T} \quad (7)$$

$$SOC(t) < SOC_{min}, \forall t \in \mathcal{T} \quad (8) SOC(t) > (0.5) SOC_{max} \forall t \in \mathcal{T} \quad (10) SOC_{min} < SOC(t) < (0.5) SOC_{max} \forall t \in \mathcal{T} \quad (9) SOC_{min}$$

dan $SOC_{max}$is the minimum and maximum limit of battery operation, in this study$SOC_{min}$is 20% dan $SOC_{max}$is 99%. Where the operating modes are divided into three SOC conditions.

$$P^{Bd}(t) \leq P_{max}^{Bd}(t), \forall t \in \mathcal{T} (11)$$

The battery can supply power to the load to the maximum according to equation 11

2.3. System Integration

In this study there were two main controllers (MC). The first MC is used to extract and process analog data from current and voltage sensors on the grid and battery and control the relay on the grid and battery. While the second MC is the MC on the load side that is used to regulate and control the load.

The system in this study consists of two sources of electricity, namely 1 phase electricity source from PLN and a source of electricity from solar cells. The solar power system has a charge controller, a battery as storage energy and an inverter as a converter of dc current to AC current.

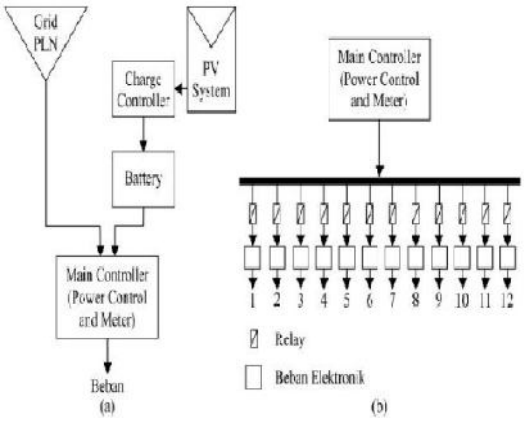

Figure 2 (a) Power control scheme and (b) control equipment scheme

The first MC uses a particle photon microcontroller with a 5 volt power supply, two ACS712 current sensors, a voltage divider, and a Current Transformer (CT), and two relays. The second MC uses a particle photon microcontroller with a 5 volt and 12 relay power supply. In this system also used Human Machine Interface (HMI) which uses Rasphberry Phi Model 3 B which is used as a mini personal computer (PC).

2.4. Data Distribution for Training and Testing

HPMS in this final project is designed to be monitored and controlled using a web application, HPMS in this final project consists of several menus namely solar assesmnet, dashboard, power monitoring, appliances monitoring, and energy saving

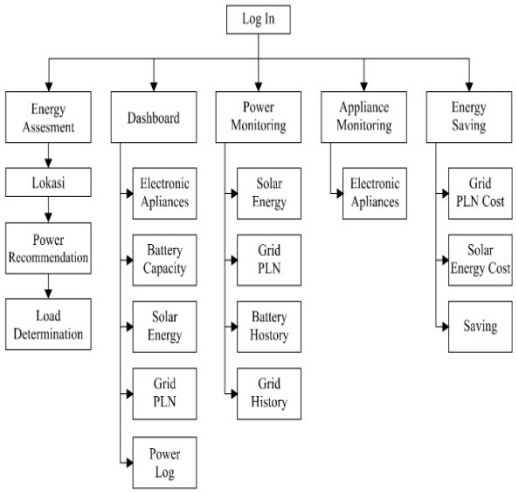

Figure 3 HMPS Architecture

2.5. Mixed Integer Linear Programming

In this simulation there are three battery conditions. If the full battery is assumed to be able to supply the system for 48 hours or have energy storage with a back up of two days. The purpose of this simulation is to get the lower bond and upper bond for mathematical calculations of Mixed Integer Linear Programming (MILP). In this final project the system will calculate every hour at one hour intervals, so that 24 optimum costs will be generated every hour. These conditions are as follows:

• If the battery capacity is <20% or low then the system automatically uses a source of electrical energy from the grid. Then the cost function:

$$Ft_{low} = P_G(t)C_G(t) \quad (12)$$

• If the battery capacity is between 20% -50%, the system will look for the minimum cost with formulas and combinations such as equation 13

$$Ft(n)_{med} = Ai * P_G(t)C_G(t) + Bj * P_{PV}(t)C_{PV}(t) \quad (13)$$

• If the battery capacity is> 50%, the automatic system uses electrical energy sources from solar energy sources

$$Ft_{up} = P_{PV}(t)C_{PV}(t) \quad (14)$$

Tabel 1 Kombinasi power resources (grid dan microgrid)

$Ft(n)_{med}$	Ai (%)	Bj (%)
$Ft(1)_{med}$	0	100
$Ft(2)_{med}$	10	90
$Ft(3)_{med}$	20	80
$Ft(4)_{med}$	30	70
$Ft(5)_{med}$	40	60
$Ft(6)_{med}$	50	50
$Ft(7)_{med}$	60	40
$Ft(8)_{med}$	70	30
$Ft(9)_{med}$	80	20
$Ft(10)_{med}$	90	10
$Ft(11)_{med}$	100	0

III. RESULTS AND DISCUSSION

3.1. First Scenario (Grid Cost = PV Cost)

The three battery state simulations in scenario one (grid price equals pv price) obtained lower bond and upper bond which can be summarized in table 4. lower bond and upper bond obtained in this simulation result will be used as min limits and max limits that can be supplied by power resources (grid and microgrid), with the limit of min and max, the user will get the cheapest electricity cost based on the price and the condition of the remaining energy storage. From table 4 shown that the battery capacity is less than 20% optimal system when supplied with a grid, between 20-50% is optimally supplied by a grid and energy storage combination with a ratio 4: 6, and above 50% found by the PV system.

Table 4. The lower bond and upper bond of first scenario.

Batas	<20%		20%-50%		>50%	
	Grid	PV	Grid	PV	Grid	PV
lb	0	0	0	0	0	0
up	1	0	0.4	0.6	0	1

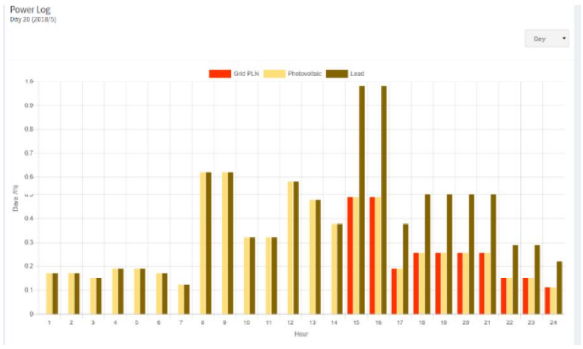

Figure 5. Power log of first scenario

In the experiment one the retrieved data is data on May 20, 2018. On that date the grid price is more expensive than the price of PV. From Figure 4.23 it can be seen that at 1 to 14 o'clock the system uses one source, PV because at that time the capacity of the battery used is still above 50%. While at 15 to 24 o'clock the system uses a combination of two energy sources, that are grid and PV, because the grid price is higher then both sources use the upper bond 50% of the load so that it can be seen in Figure 5 the two sources generate the same electrical energy.

3.2. Second Scenario (Grid Cost < PV Cost)

Table 5. The lower bond and upper bond of second scenario.

Batas	<20%		20%-50%		>50%	
	Grid	PV	Grid	PV	Grid	PV
lb	0	0	0	0	0	0
up	1	0	0.5	0.5	0	1

Of the three battery conditions in scenario one (grid price equals pv price) a lower bond is found and the upper bond can be summarized in table 5. From table 5 shown that the battery capacity is less than 20% of the optimal system when supplied with a grid, between 20-50% is optimally supplied by a grid and energy storage combination with a ratio 5: 5, and above 50% found by the PV system.

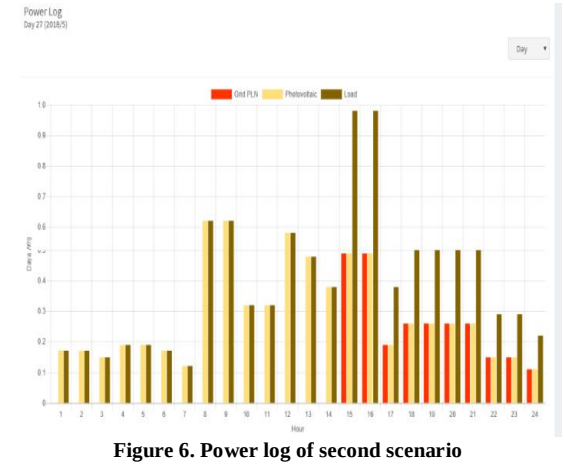

Figure 6. Power log of second scenario

The second experiment is when grid prices fluctuate and PV prices stagnate. From Figure 6 it can be seen that at 1 to 14 o'clock the system uses one source, that is PV because at that time the capacity of the battery used is still above 50%. While on 15 to 24 o'clock the system uses a combination of two energy sources, that are grid and PV, because the grid price is higher then both sources use upper bond 50% of the load so that it can be seen in Figure 6 the two sources generate the same electrical energy.

3.3. Third Scenario (Grid Cost < PV Cost)

Table 6. Lower bond and upper bond scenario three

Batas	<20%		20%-50%		>50%	
	Grid	PV	Grid	PV	Grid	PV
lb	0	0	0	0	0	0
up	1	0	0.5	0.5	0	1

Of the three battery state simulations in scenario one (grid price equals pv price) obtained lower bond and upper bond which can be summarized in table 6. From table 6 it can be seen that the battery capacity is less than 20% optimal system when encountered by the grid, between 20- 50% is optimally supplied by grid and energy storage combinations with a comparison of 5: 5, and above 50% found by the PV system

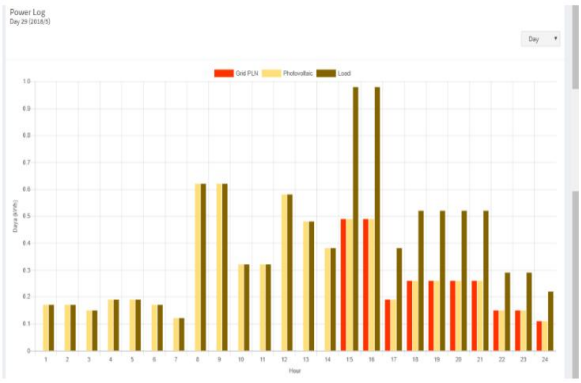

Figure 7. Power log third scenario

The results of a system calculation that contains the energy source used can be seen in Figure 7. The third experiment is when the grid price is equal to the price of PV. From Figure 7 it can be seen that at 1 to 22 hours the system uses one source, PV, because at that time the capacity of the battery used is still above 50%. While on the 13th to 24th hour the system uses a combination of two energy sources, namely grid and PV, because the grid price is the same as the two sources using different upper bonds, 60% for the grid and 40% for the PV system

3.4. Third Scenario (Grid Cost fluktuatif, PV Cost fixed)

Table 7. lower bound and upper bound scenario four

Batas	<20%		20%-50%		>50%	
	Grid	PV	Grid	PV	Grid	PV
lb	0	0	0	0	0	0
up	1	0	0.5	0.5	0	1

Of the three battery state simulations in scenario one (grid price equals pv price) obtained lower bond and upper bond which can be summarized in table 7. From table 7 it can be seen that the battery capacity is less than 20% optimal system when encountered by the grid, between 20- 50% is optimally supplied by grid and energy storage combinations with a comparison of 5: 5, and above 50% found by the PV system

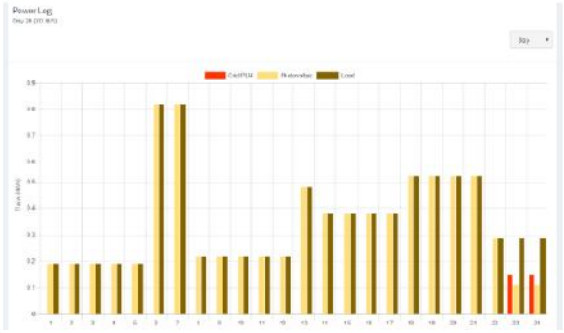

Figure 8. Power log fourth scenario

The second experiment is when the grid price is cheaper and the price of PV. From figure 8 it can be seen that from 1 to 14 hours the load is found by PV while 15 to 24 loads are supplied by two sources with a max limit of 50% of the total load

CONCLUSIONS

1. Mixed Integer Linear Programming can be used to solve problems in the Home Power Management System (HPMS)
2. Simulation results from four price scenarios and three battery capacity conditions indicate that when the price is the most optimal the cost is when the load is found to be 40% with a photovoltaic system equipped with energy storage when the battery is between 20-50%. Found 100% by a photovoltaic system that is equipped with energy storage when the battery capacity is above 50%, and is found 100% by the grid when the battery capacity is below 20%.
3. Three other scenarios show that the optimal price when the battery is below 20% is supplied by 100% of the grid. When the battery condition is 20-50% the load is found 50% PV 50% grid, and when the conditions are above 50% it is 100% covered by a photovoltaic system equipped with energy storage.
4. The HPMS in this final assignment can cost up to 30% -70%.

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