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Efficiency Optimization Of Combined Heat And Power System Integrated With Renewable Energy For A Hospital

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Abstract – The demand of energy is getting higher with the developing technologies and increase of world population. Recently most of the energy demand is providing from the fossil fuels. The global greenhouse gas (GHG) emissions from fossil fuels are a threat for the world. The combustion of fossil fuels such as coal, oil and natural gas causes the GHG emission. Since fossil fuels are the greatest part of production of electricity and thermal steam, most of the research is making on clean, economical and reliable energy sources. Between the renewable energy sources, photovoltaic arrays get importance since photovoltaic Panel (PV) converts sunlight directly into electricity is a good option to produce electrical energy. Photovoltaic panels do not directly emit GHGs while energy conversion. However, PV cells have limitations because of inherent intermittency of solar irradiation and cloudy weather conditions. One of the greatest advantages of renewable sources is being integrated with other renewable energy sources to form a hybrid system. Therefore, to provide reliable and continuous energy, it is suggested that PV can be hybridized with other sources such as co-generation (CHP-Combined Heat and Power) system.
Combined Heat and Power technology is one of the efficient energy conversion way since it provides twice or more times of the useful energy from the same amount of fuel. The places need both electrical and thermal loads such as hotels, residential buildings and especially hospitals are good option to use CHP systems are coupled with solar photovoltaic (PV) arrays, reduces GHG emissions further. By adding battery systems to a PV+CHP system, total system efficiency will be getting higher by reducing CHP runtime. For simulation and optimization of renewable energy systems a lot of software have been developed. One of the most successful software is the Hybrid Optimization Model for Electric Renewable (HOMER) with the Pro Microgrid Analysis tool is to simulate PV+battery+CHP hybrid systems. In this paper, a hybrid system is simulated for a hospital and it is observed that the electricity produced by each component of the hybrid system can be integrated to meet the hospital load demand. Thermal load demand is supplied with a boiler and CHP unit. A sensitivity analysis of this hybrid off grid systems is depended on a function capacity factor of both the PV and CHP units. As a result of this study, it is found that PV + battery + CHP hybrid system is one of the most effective system to reduce energy related emissions while increasing energy efficiency.

Keywords – Hybrid Energy Systems, Renewable Energy Sources, Optimization, PV+Battery+CHP systems, HOMER software

I. INTRODUCTION

The effect of human being over the climate system is obvious, and the emissions of greenhouse gases which caused by human is at its top level. Changes in the climate system also influences the lives on the earth and natural system around us. If the emission of greenhouse gases continues, people and ecosystem will face to harsh, irretrievable and widespread impacts. To avoid the dangers of climate change and its harmful effects, the spreading of GHGs will be under control for human and nature welfare [1]. Researchers take consideration about renewable energy sources. The International Energy Agency (IEA) Sustainable Development Scenario (SDS) sees the share of fossil fuels in energy supply investment falling to 40% by 2030.There is an upgoing tendency to the clean and reliable energy supply investments in the energy sector [2]. The production of both electricity and heat from a single generator is called “cogeneration” or combined heat and power (CHP). Due to the production of two separate energy forms from one generator using the same energy consumption, cogeneration system provides energy management more efficiently than separate production. [3].

Photovoltaic (PV) technology is one of the most ascending renewable energy technologies, because of the not emitting any harmful gases. It also has large implementation area. Photovoltaic arrays produce electricity by absorbing sunlight which makes it environment friendly.[4]. Unfortunately, PV cells are not continuous power supply due to the daily solar cycle and undesirable weather conditions. Cooperating with a cogeneration unit, PV panels and CHP unit can overcome the eachothers deficits. Adding battery system, total system efficiency can be getting higher by reducing CHP runtime. The size and operation of such renewable systems planned carefully for satisfying the load demand [5].

Hospitals are one of the biggest consumers of energy since it has both electric demand like lighting and appliances and thermal demand such as domestic hot water, space heating and cooling. Thus, it is a good option to use hybrid energy systems for both energy efficiency and reducing the GHGs emission. Different computer models are designed for the optimization of hybrid systems until now. The Hybrid Optimization Model for Electric Renewable (HOMER) Pro software is used for simulating cogeneration system with photovoltaic panel and storage equipment for a hospital. The generated electricity and thermal energy by each component are integrated to fulfill the necessity demand. The capacity factor of photovoltaic arrays and combined heat and power unit is investigated and energy

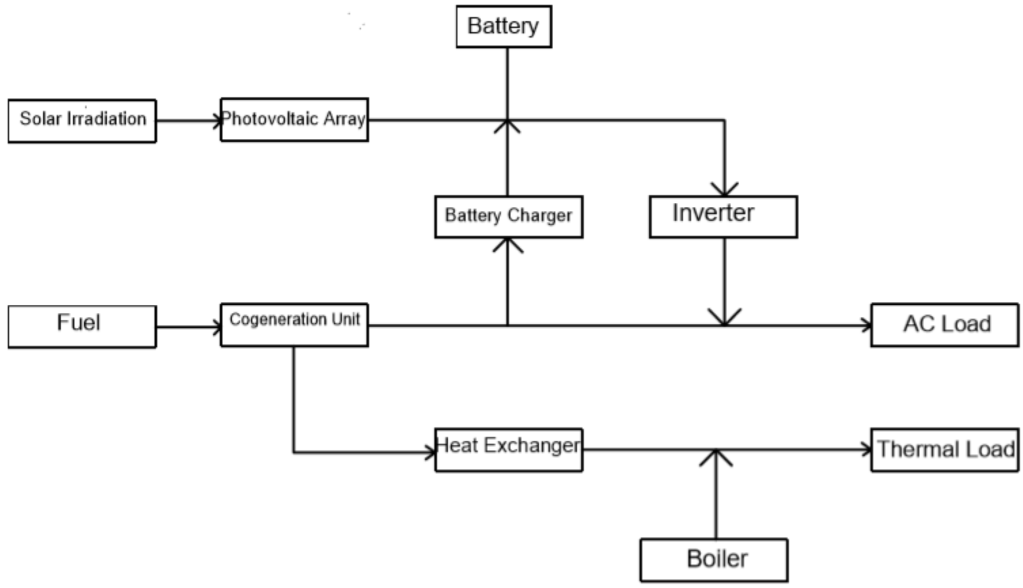

Fig.1. Hybrid energy system schematic

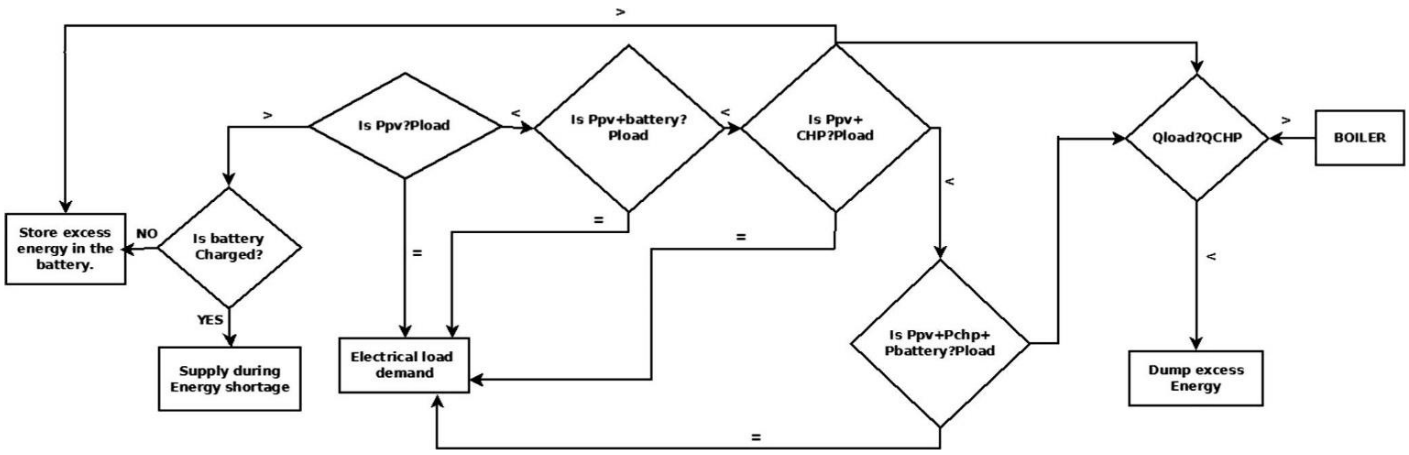

Fig.2. Control method of hybrid system

related GHGs emission is discussed.

II. Materials and Method

A. Hybrid System Component

The modelled renewable energy system is as shown in the figure 1. Just AC loads are considered for electrical consumption. PV arrays converts sunlight into electricity. PV panels and battery system have DC outputs. The DC output of both PV arrays and batteries transformed AC output by an inverter.

Cogeneration and photovoltaic panels are hybridized to supply energy to the load which rises system efficiency. After matching the demand, the remaining AC output from CHP unit is sent to battery via a battery charger to store the energy. Adding a heat exchanger to thermal output of co-generation system, thermal load demand is completed.

Thermal load which is not met by the output of CHP system, it is completed by the natural gas fired boiler.

Parallel topology is applied among the hybrid system topologies.

B. Control Strategy

The control strategy is aimed to satisfy the load demand by accomplishing reliability and efficiency of the undergoing process as illustrated in figure 2. Since the system have a boiler, meeting electrical load requirement is taken place in priority. When designing an optimum hybrid system, it is crucial that representative load profile not considered any extraordinary anomalies which causes unmet load.

For getting a higher system efficiency, the dispatch strategy first gives the priority photovoltaic panels then battery afterwards co-generation units. And this priority reduces GHGs emission. If the produced energy from PV panel satisfy the electrical load demand it will fulfil the AC load. When the output of PV panel is greater than the load demand, residuary energy is sent to the battery matching the load. The stored energy in the battery will be used when it is needed. If the PV panel does not match the demand, then both PV and battery unit will be started up. When the PV+battery system is not enough for the demand, then battery is deactivated for a while and CHP unit is activated. If the power produced by photovoltaic and cogeneration unit is equal to electrical load demand, then the thermal load demand will be fulfilled. When the PV+CHP system output energy is more than the load, excess output is dispatched to battery for storage. First the storage unit is charged, and thermal load is supplied then co-generation unit is turned off. If PV+CHP system is insufficient for the load, then both PV+battery+CHP system will be activated to match the electrical demand and thermal demand is provided by the co-generation. Once the electrical load is supplied then CHP unit is deactivated. During all the stages of process, thermal load is not supplied by the co-generation, it is supplied by the boiler unit [7].

C. Simulation

Many software programs have been developed for the hybrid energy systems until now. Hybrid Optimization Model for Electric Renewable (HOMER) Pro which was developed by NREL is one of the most succesful software to simulate PV+battery+CHP hybrid energy systems [8],[9].

HOMER shows the system architecture of optimized system and simulates the energy systems.

Using sensitivity analysis, HOMER evaluates uncertain inputs like prices, weather.

The block diagram is simulated for a hospital in Ankara. The database uses load datum for a hospital among the references buildings in U.S. HOMER will attempt to match the climate zone of the location defined by using datum from a matching climate location, based on the Koeppen Geiger Climate Classification System from open el database.

The Solar Global Horizontal Irradiance (GHI) is obtained form NASA Surface meteorology and Solar Energy database [10].

The energy produced by each component is distinct and sized to fulfill the load.

C.1 PV Sizing

The size of PV panel is dependent to annual AC load demand, average daily peak sun hours and photovoltaic derating factor. The derate factor is the ratio of available AC power rating to DC power rating in the nameplate. Derate factor is taken 0.8 for the system.

$$P_s=E_L/(365xS_HxD_F)$$

where P_S is the power output of PV array in kW, E_L is the annual AC load demand in kWh, D_F is the derate factor and S_H average daily peak sun hours per day [11].

C.2 Battery Sizing

While many methods for battery sizing for off-grid systems are exist, a clear equation is shown.

$$E_{batt,tot} = \frac{N_{aut} \cdot E_{req,d}}{DOD_{max}}$$

where N_{aut} is the number of days of autonomy, DOD_{max} the maximum depth of discharge of the batteries. And the number of batteries N_{batt} is calculated [11].

$$N_{batt} = \frac{E_{batt,tot}}{E_{batt}} \left[\frac{kWh}{\frac{kWh}{battery}} = batteries \right]$$

C.3 CHP Sizing

For getting the highest overall system efficiency, cogeneration system is well sized. The factors which effects the CHP size are operating hours, thermal and electrical load demand, fuel and electricity prices.

C.4 Emissions

Primary GHG emissions during power generation include carbon dioxide, methane, and nitrous oxide and are characterized by their global warming potential (GWP). The strength of carbon dioxide is used as a reference for GWP as it is the main gas of interest in discussions surrounding global warming. Nitrous oxide and methane have GWPs of 298 and 25 by mass for a period of 100 years, respectively [6].

Emissions intensities vary according to the specific type of fuel used, the quality of that fuel, the conversion technology used and the efficiency of the combustion unit.

Emissions of these pollutants result from the production of electricity by generators. And production of thermal energy by a boiler.

III. Results

Optimized system configuration is shown in Table 1.

Table 1. Size of components

PV size(kW)	CHP size(kW)	Battery size (strings)
250	1250	3074

Every part of the system is greatly sized to satisfy the load demand. There is no unmet load since the building is a hospital. Figure 3 shows the electrical load demand of hospital. The generated energy from PV and CHP unit is shown the figure 4-6. Also state of charge of battery is graphed in figure 7.

It is obvious that from the figures, the electrical demand mostly is supplied by the co-generation unit. In the peak load times, PV panel and battery are incorporated to fulfil the demand.

Thermal load is mostly matched by the co-generation system. In case of any insufficiency, boiler unit is activated to fulfil the demand.

IV. Discussion

The energy generated by PV and CHP units investigated by changing the capacity factor of each. Capacity factor is the ratio of actual generated power overrated maximum power in a given period.

For CHP and PV unit the generated energy is formulated as

$E_{PV}=365 \text{ x } 24 \text{ x } S_{PV} \text{ x } C_{PV}$ and

$E_{CHP}=365 \text{ x } 24 \text{ x } S_{CHP} \text{ x } C_{CHP}$

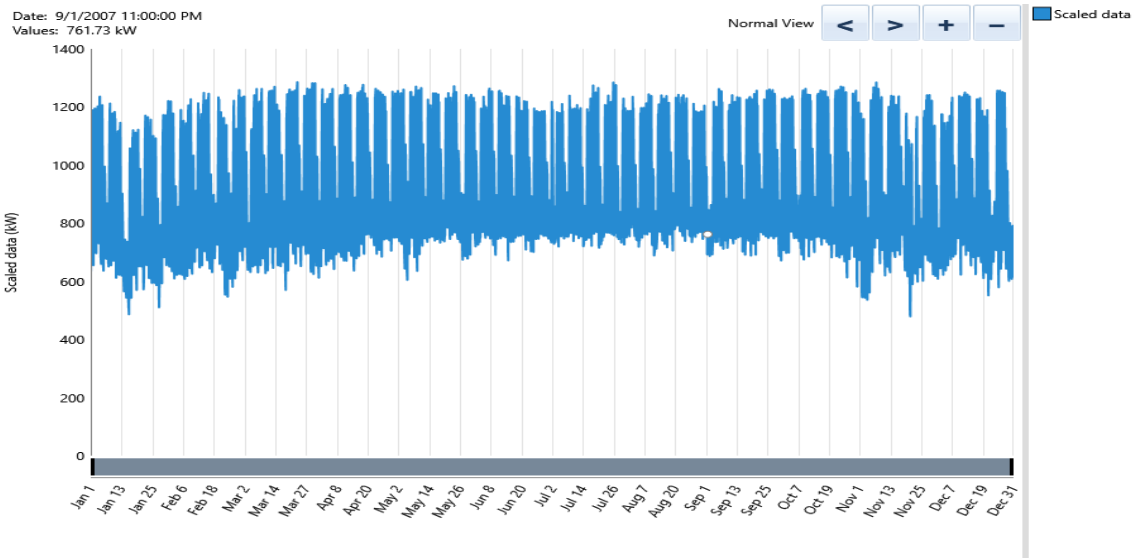

Fig.3.Electrical load demand

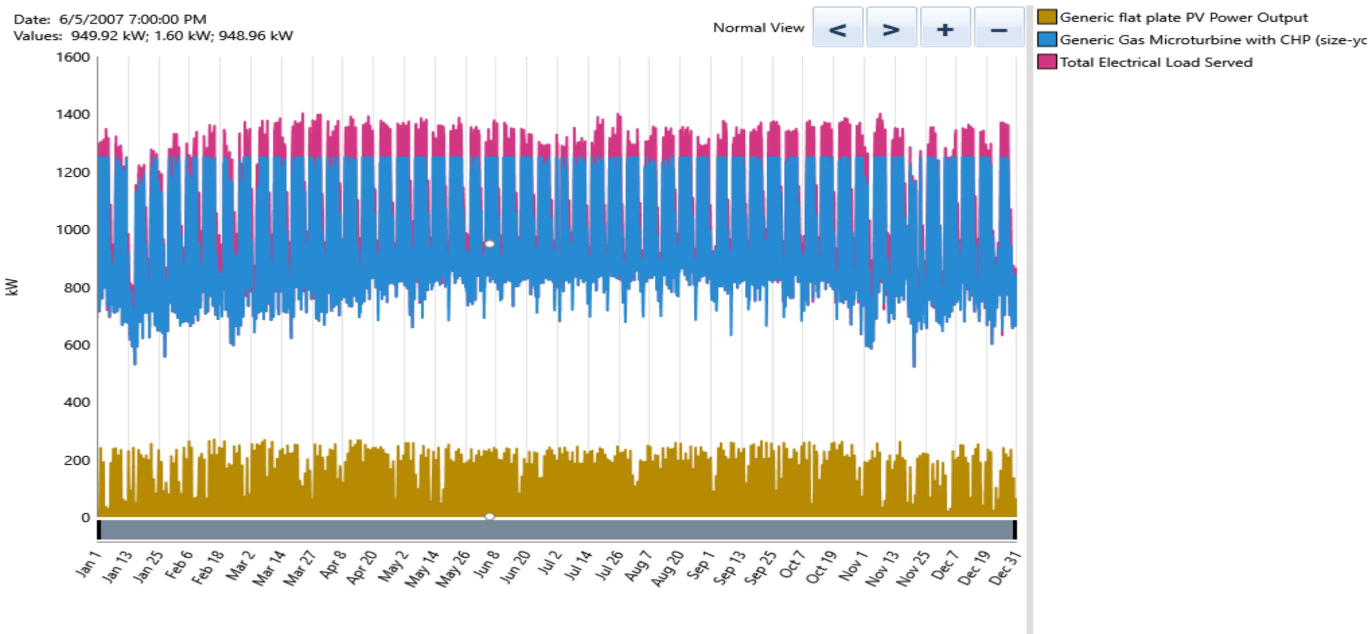

Fig.4.Power output energy of PV and CHP unit

where E_{PV} and E_{CHP} are annual energy generated by CHP and PV (kWh), S_{PV} and S_{CHP} are the size of PV and CHP in kW and C_{PV}, C_{CHP} are the capacity factor of PV and CHP (%).

Any change in the capacity factor of photovoltaic array varies the rated output of the PV module. Thus, the output of the cogeneration unit is also changed. The whole generated energy is fulfilled the demand.

If the capacity factor of PV panel decreases, the capacity factor of CHP panel will increase. The change of capacity factor is seen in the Table 2.

Table.2 Capacity factors and power production

C_{pv} (%)	C_{CHP} (%)	Production /CHP(kWh/yr)	Production /PV(kWh/yr)	Total kWh/year
21.1	76.1	8328	461	8789
19.3	76.4	8368	422	8790
10.3	78.2	8564	225	8789

As the increasing capacity of PV unit, the generated energy from PV array also gets higher. Since the energy conversion in panel does not emit any GHGs, the emission of system is decreasing with the increasing capacity factor of PV. Table 3 shows the results.

Table.3 Emission values

Pollutant	%21.1 C_{PV}	%19.3 C_{pv}	%10.3 Cpv	Unit
Carbon Dioxide	5,720,357	5,742,564	5,852,351	kg/yr
Carbon Monoxide	19,021	19,095	19,460	kg/yr
Particulate Matter	536	538	549	kg/yr
Nitrogen Oxides	39,909	40,064	40,830	kg/yr

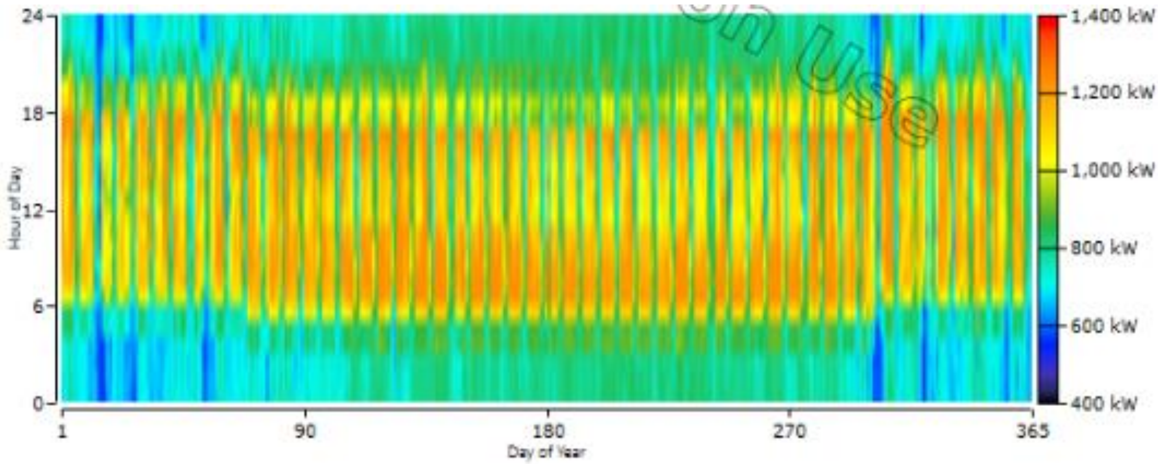

Fig.5.Output of CHP unit

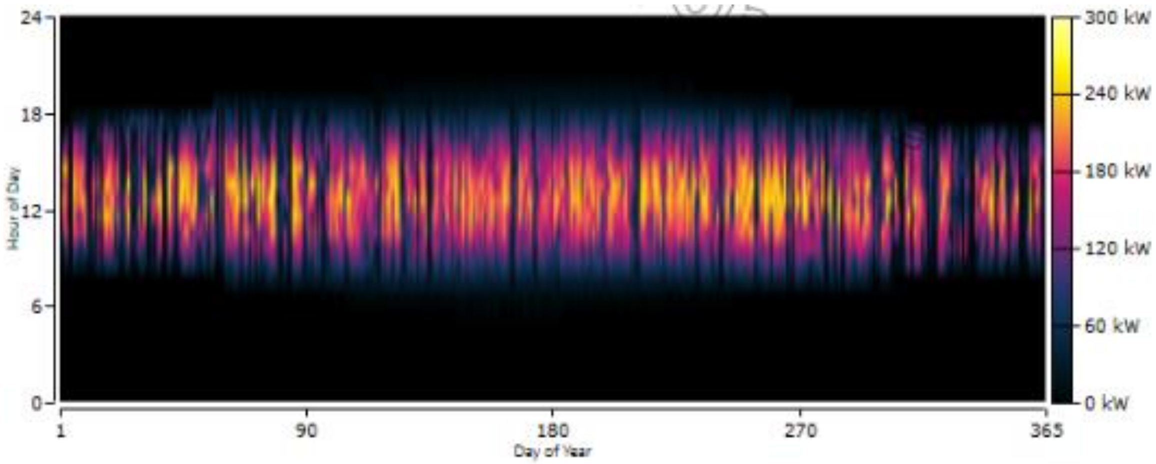

Fig.6.Output of PV panel

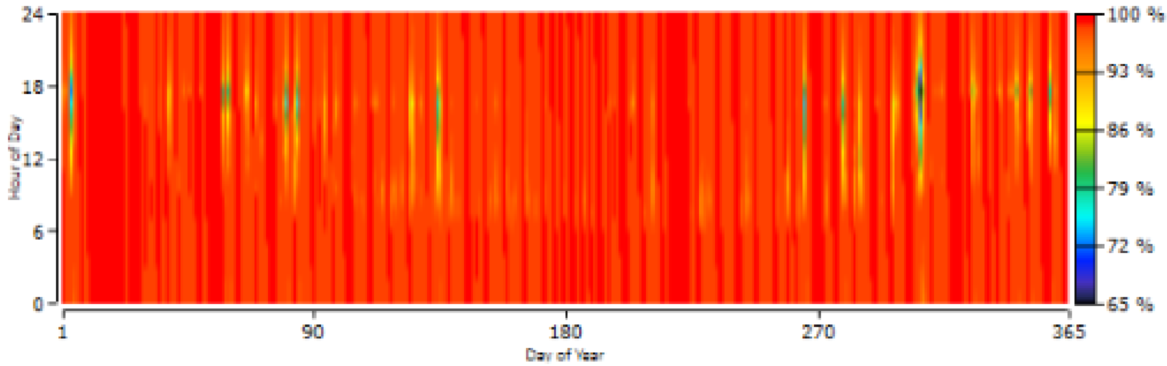

Fig.7.State of charge of battery

V. CONCLUSION

As a result, the renewable energy systems consisting of a cogeneration unit with solar photovoltaic array and back up equipment supplies continuous electrical and thermal power for a hospital. As an increase of capacity factor of PV array from 19.3 to 21.1, the capacity factor of CHP decreases, and the output of CHP also decreases 40 kWh/yr respectively.

Implementing a PV+CHP+battery energy system for buildings is a beneficial solution to overcome the reduction of emissions and weakness of solar photovoltaic technology. Since PV panel do not emit any GHGs emission, a rise in the capacity factor of PV panel from 10.3 to 21.1, the emission of total carbon dioxide and nitrogen oxide decreases nearly 132 kg/year and 1 kg/year respectively.

PV+battery+CHP hybrid system is a fine option for the buildings which needs both thermal and electrical load. In future, grid connected PV+battery+CHP systems can be investigated to reduction of costs and emissions.

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