CHEMICAL ENGINEERING TRANSACTIONS
VOL. 35, 2013
A publication of AIDIC
The Italian Association of Chemical Engineering
www.aidic.it/cet
Guest Editors: Petar Varbanov, Jiří Klemeš, Panos Seferlis, Athanasios I. Papadopoulos, Spyros Voutetakis

ISBN 978-88-95608-26-6; **ISSN** 1974-9791
DOI: 10.3303/CET1335096

Integrated Biomass and Solar Town Concept for Smart Eco-Village

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Integrated biomass solar town concept is a concept which encourages local community to utilize biomass waste comprehensively with strong ties between community and local stakeholders. This paper discusses about an Integrated Biomass Solar Town for eco village with and without load shifting (LS). On the other hand, the energy storage (ES) is also incorporated which could help cut electricity demand during peak periods and smoothing variations in power generation by variable solar power. A substantial technical and economic benefit was achieved through the implementation of integrated (LS) and ES. In this study, LS is used mainly to increase demand during periods of high supply and also shift the load to interval with low demand hence reduce the size of ES significantly. The concept is one of the great initiatives to spur economic growth and environmental protection through energy efficiency improvement and deployment of low-carbon technologies.

1. Introduction

Resources of renewable energy for power generation are usually restricted and limited to specific locations around the World. For instant in Malaysia, renewable energy that is available is commonly from biomass resources. However, sole utilization of biomass resources in an isolated energy system may cause adverse health effects on locals due to emissions of nitrogen oxides (NOx) if left unchecked. As a solution, solar energy, an inherently cleaner power generation technology which does not involve any combustion process is proposed resulting in a town relying on an integrated biomass and solar (IBS) energy system, IBS town. IBS town is an intentional community that emphasizes on sustainability, by utilizing local biomass resource and solar energy to power the energy system. It is envisaged that IBS town should be self-sufficient in fulfilling its own energy demand without relying on centralized system, thus saving up cost of transmission or distribution line extension and fitting the concept of an isolated energy system which is beneficial for rural electrification.

IBS energy system is deemed to be a cleaner power generation scheme, at the expense of higher capital cost expenditure on solar (Gallardo et al., 2011). Also, the integration of such system might be a challenging task due to the differences in process condition (Martínez-Patiño et al., 2012). Thus to further improve the economic performance, demand side management (DSM) techniques (Iglesias et al., 2012) such as load shifting (LS) via manipulation of demand loads, and supply loads using an energy storage (ES) (Tora and El-Halwagi, 2010) might be incorporated into the IBS energy system. In recent years, in order to study the effect of DSM and integrated energy system, numerous studies have been conducted. Kumaravel and Ashok (2012) performed an economic analysis to evaluate the economic performance of a hybrid energy system for a rural village in India by using HOMER, an established software. Mohanty et al. (2012) developed an optimal planning model for distributed energy generation (DEG) micro-grid system that considers photovoltaic (PV), small wind electric generator, biomass gasifier system, diesel generator and battery storage. Ho et al. (2012), developed a numerical approach known as Electricity System Cascade Analysis (ESCA), to identify the optimal configuration of a DEG system that consists of biomass

Please cite this article as: Hashim H., Ho W.S., Lim J.S., Macchietto S., 2013, Integrated biomass and solar town concept for smart eco-village, Chemical Engineering Transactions, 35, 577-582 DOI:10.3303/CET1335096

power generator and ES. As for LS, Dietrich et al. (2012) formulated load shifting procedures into a mathematical model and applied it on a wind energy based isolated energy system, to determine the effects of load shifting on operation cost. Gudi et al. (2012) performed load shifting for a set of household appliances that are powered by different energy sources by using Particle Swarm Optimization algorithm. In another study, Lujano-Rojas et al. (2012) proposed a novel load management strategy for the optimization of a RE system by predicting the wind speed and its corresponding power. However, limited study has been reported on the optimization of an IBS energy system that considers load shifting at demand side. Thus the objective of this study is to use an optimization modelling approach to design a cost optimal IBS energy system and subsequently evaluates the economic performance for incorporating ES and load shifting over such system.

2. Mathematical model

The objective of the MILP model is to minimize the total cost, TC of the system. The formulation is shown in Eq(1). The details of each cost breakdown (annual operating cost, OC, and amortized investment cost, IC) are shown in Eq(2) and (3). Indices in this model include l for load, w for type of weather, and t for time intervals. The investment cost is amortized monthly for 30 years at an interest rate of 7%, the costing is however presented for a year).

$$TC = OC + IC \tag{1}$$

$$OC = \sum_{wt} BG_{wt}.W_w.(BVC + BH.BF) + \ Bcap.BFC \ + \ ESP.ESFC + \ Scap.SFC \tag{2}$$

$$IC \ = \ ESE.ESEC.A.M + \ ESP.ESPC.A.M + \ Scap.SCC.A.M + Bcap.BCC.A.M \tag{3}$$

where BG_{wt} is total energy generation of biomass system (kWh), W_w is number of weather occurrence in a year (day), BVC is biomass operating and maintenance (O&M) variable cost ($/kWh), BH is heat rate of biomass system (GJ/kWh), BF is cost of biomass ($/tonne), $Bcap$ is capacity of biomass system (kW), BFC is biomass fixed O&M cost ($/kW.yr), ESP is ES power-related capacity (kW), $ESFC$ is ES fixed O&M cost ($/kW.yr), $Scap$ is capacity of solar PV system, SFC is solar fixed O&M cost ($/kW), ESE is ES energy-related capacity (kWh), $ESEC$ is ES energy-related capital cost ($/kWh), A is amortized factor, M is number of months in a year (month), $ESPC$ is ES power-related capital cost ($/kW), SCC is solar PV capital cost ($/kW), and BCC is biomass system capital cost.

Loads are classified into two categories in this model, fix loads, FL_{wt} are loads that cannot be revised such as lighting loads at night, and shiftable loads, SL_l. Example of shiftable loads includes washing machine load and dish washing load. It is also noted that fix loads are presented as a load profile for each weather, w and time, t where shiftable loads will be added into the profile. LS technique is formulated as shown in Eq.(4), where demand, D_{wt} is equal to the addition of fix loads and shiftable loads with shiftable load being allocated at a specified time interval by a binary variable, xl_{wlt} and binary parameter, $FixTI_{lt}$. $FixTI_{lt}$ represent a range of time intervals that each shiftable loads can be allocated at. Table 1 shows an example of $FixTI_{lt}$. From the example, “Load 1” can be allocated from time interval, T1 to T3 while “Load 2” from time interval, T3 to T5. The model is to select only one time interval for allocation, formula shown in Eq.(5).

$$D_{wt} \ = \ FL_{wt} \ + \sum_{l} (SL_l \times xl_{wlt} \times FixTI_{lt}) \quad \forall w,t \tag{4}$$

$$\sum_{t} FixTS_{lt} \times xl_{wlt} = \ 1 \quad \forall w,l \tag{5}$$

Table 1: Example of load

Load, l	Time Interval, t				
	T1	T2	T3	T4	T5
Load 1	1	1	1	0	0
Load 2	0	0	1	1	1

Operation of ES devices on the other hand are formulated as a set of energy balances (equality constraints) shown in Eq(6) for load side energy balance, Eq(7) for biomass generation side energy balance, Eq(8) for solar side energy balance, and Eq(9) for ES side energy balance. In Eq(6), demands, D_{wt} are met by energy from biomass system, BD_{wt}, solar PV system, SD_{wt} and ES, ESD_{wt}. For Eq(7), total power generated from biomass system, BG_{wt} will be distributed to either the load, BD_{wt} or the ES, BES_{wt}. Similarly, in Eq.(8), total power generated from solar PV system, SG_{wt} will be distributed to either the load, SD_{wt} or the ES, SES_{wt}. For energy storage Eq.(9), cumulative energy at a specific time interval, CES_{wt} have to be equal to the cumulative energy from a previous time interval plus incoming energy from biomass system, BES_{wt} and solar PV, SES_{wt} minus outgoing energy, ESD_{wt}. During the formulation, energy losses will be allocated for any requirement of current inversion (due to inverter efficiency, IF), and charging and discharging of ES (due to charging/discharging efficiency, EF)

$$D_{wt} = BD_{wt} + SD_{wt} \times InvEFF + ESD_{wt} \times ESEFF \times InvEFF \quad \forall w,t \tag{6}$$

$$BG_{wt} = BD_{wt} + BES_{wt} \quad \forall w,t \tag{7}$$

$$SG_{wt} = SD_{wt} + SES_{wt} \quad \forall w,t \tag{8}$$

$$CES_{wt} = CES_{wt-1} + BES_{wt} \times IF \times EF + SES_{wt} \times EF - ESD_{wt} \quad \forall w,t \tag{9}$$

Other boundary constraints implied in the model are shown in Eq(10) for biomass generation (BG_{wt} must be less or equal to $Bcap$), Eq.(11) for solar PV generation (SG_{wt} must base on solar radiation intensity, SR_{wt}), Eq.(12) for energy-related ES capacity (CES_{wt} must be equal or less than ESE with consideration over the depth of discharge, DOD), Eq.(13) and Eq.(14) for power-related ES capacity (charging/discharging of ES at a specific time interval must be equal or less than ESP). Eq.(15) is formulated to bound the operation of the ES between charging and discharging state (only on state at a time interval), where binary yl_{wt} for charging of energy (1 charging, 0 otherwise) and binary zl_{wt} for discharging of energy (1 discharging, 0 otherwise). Eqs.(16) and (17) are formulated to avoid non-linear terms in the model where Q is a very large value (Mirzaesmaeeli et al., 2010). Lastly, Eq.(18) to ensure the total amount of biomass consumed is equal or less than its availability, AB.

$$BG_{wt} \leq Bcap \quad \forall w,t \tag{10}$$

$$SG_{wt} = Scap.SR_{wt} \quad \forall w,t \tag{11}$$

$$CES_{wt} \leq ESE.DOD \quad \forall w,t \tag{12}$$

$$ESD_{wt} \leq ESP \quad \forall w,t \tag{13}$$

$$BES_{wt}.IF + SES_{wt} \leq ESP \quad \forall w,t \tag{14}$$

$$yl_{wt} + zl_{wt} \leq 1 \quad \forall w,t \tag{15}$$

$$ESD_{wt} \leq Q.zl_{wt} \quad \forall w,t \tag{16}$$

$$BES_{wt}.IF + SES_{wt} \leq Q.yl_{wt} \quad \forall w,t \tag{17}$$

$$\sum_{wt} BG_{wt}.W_w.BH \leq AB \tag{18}$$

3. Case Study

This study involves the designing of an IBS energy system for a village of 100 residential houses. The typical load profile without load shifting but illustrating the two categories of load and solar radiation for weather patterns are shown in Figure 1. Day of occurrence for clear weather is 60 days, cloudy weather is 255 days and remaining 50 days is rainy weather. The shiftable loads power rating, usage duration, energy demand, and range of time interval for shifting are shown in Table 2.

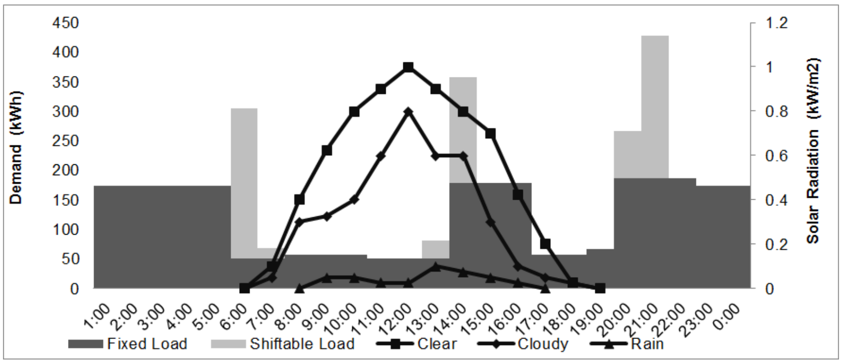

Figure 1. Typical load profiles and solar radiation profiles in Malaysia

Table 2: Shiftable loads

Shiftable Load	Power Rating (kW)	Duration of Operation (h)	Energy Consumption (kWh)	Time Interval Range	
				Begin from (h)	End at (h)
Shower Heater	3.6	0.5	1.8	6:00	7:00
Electric Kettle	2	0.25	0.5	6:00	7:00
Toaster	0.7	0.25	0.175	6:00	7:00
Washing Machine	0.24	1	0.24	6:00	10:00
Iron	1.2	0.5	0.6	9:00	22:00
Shower Heater	3.6	0.5	1.8	11:00	15:00
Microwave	1.2	0.25	0.3	12:00	14:00
Shower Heater	3.6	0.5	1.8	17:00	22:00
Rice Cooker	0.6	0.5	0.3	18:00	20:00
Electric Kettle	2	0.25	0.5	18:00	20:00
Shower Heater	3.6	0.5	1.8	6:00	7:00

Cost data for biomass system and solar PV system includes biomass system capital cost of 3,960 $/kW, biomass system fixed O&M cost of 217 $/kW.yr, biomass system O&M variable cost of 6.83 $/MWh, biomass system heating rate of 0.012 GJ/kWh, solar capital cost of 2,700 $/kW, and solar fixed O&M cost of 4 $/kW.yr (EIA, 2010). Biomass cost on the other hand is 15.41 $/GJ with availability of 12,900 GJ (Evald, 2005). For energy storage, charging and discharging efficiency of 92% (Steward et al., 2009), inverter efficiency of 90 %, ES energy-related capital cost of 300 $/kWh (Steward et al., 2009), ES power-related capital cost of 247 $/kW (Steward et al., 2009), and ES fixed O&M cost of 60 $/kW.

4. Results and discussion

The model was implemented in General Algebraic Modelling System (GAMS) and via CPLEX 12. The results are illustrated in Figure 2, 3, 4 and 5. Case 1 represents a case without integration of ES and LS, Case 2 represents a case with LS, Case 3 represents a case integrated with ES, and lastly, Case 4 represents a case integrated with ES and LS.

Figure 2 shows that through implementation of ES, LS or both, the total cost reduces. Among Case 2 and Case 3, the total cost is about the same with Case 3 being slightly lower. The operating cost of Case 3 is slightly higher than Case 2 due to additional energy losses from charging and discharging of ES thus requires slightly more energy to be produced. Amortized investment cost on the other hand reduces as Case 3 managed to reduce a greater amount of biomass capacity than Case 2.

Nevertheless, Case 4 which implements both strategies achieved lowest total cost and capacity of operating units. Another interesting observation from the results is that of the ES capacities between Case 3 and Case 4. It can be observed that with LS, the ES energy-related capacity reduces while ES power-related capacity increases, as energy-related cost is higher than power-related cost, the overall arrangement is more cost competitive. This thus shows that LS strategy did not only shift the loads to high generation periods (Dietrich et al., 2012) but also shift the load to interval that could benefit the ES in terms of sizing. Generally, the loads are shifted to periods where demand is low as shown in both Figure 3 and

Figure 4. Figure 5 on the other hand shows the operation of the ES during different weather patterns where its operation is similar for most cases.

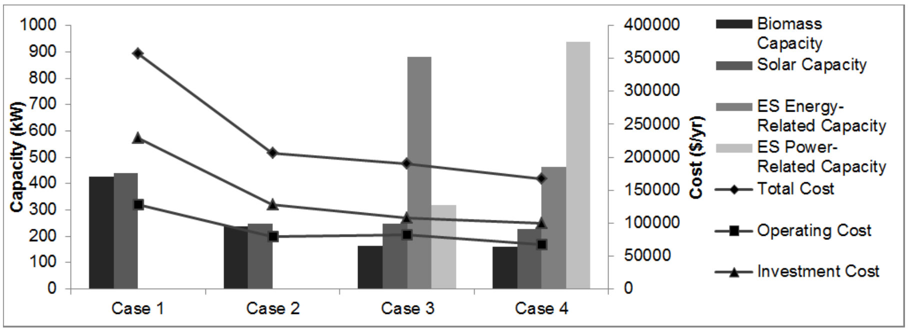

Figure 2. Cost and capacity of IBS energy system for different cases

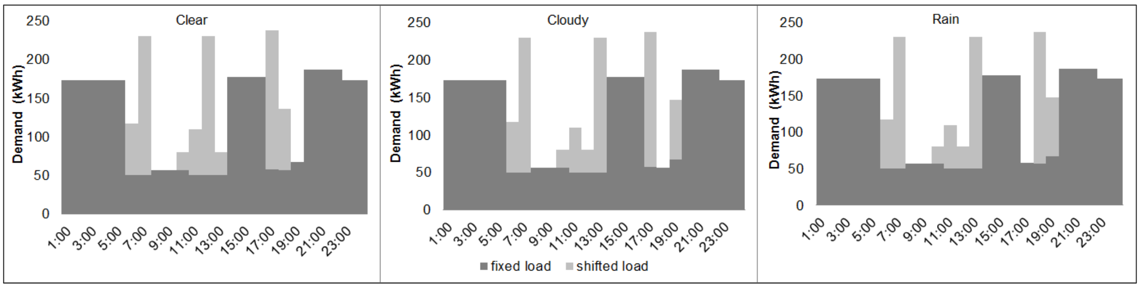

Figure 3. Load profile under different weather patterns for Case 2

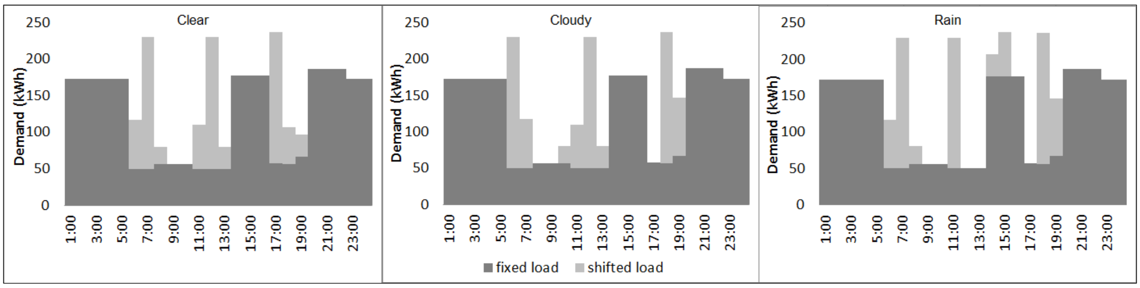

Figure 4. Load profile under different weather patterns for Case 4

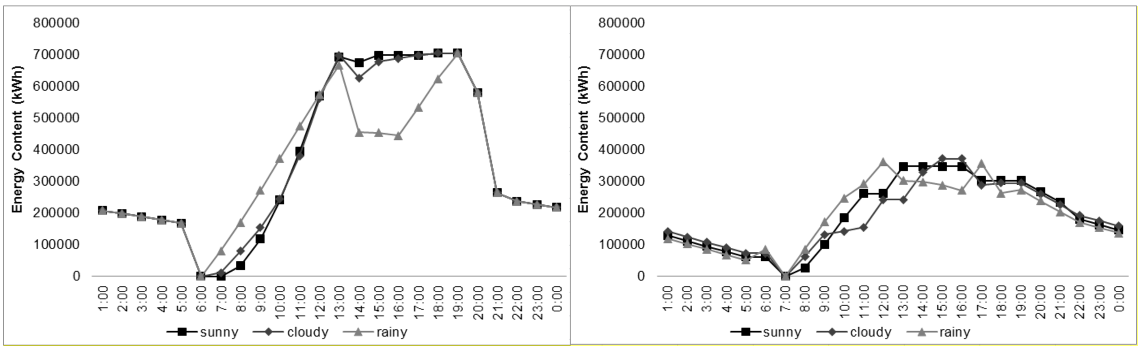

Figure 5. Energy content of ES for Case 3 (left) and Case 4 (right)

5. Conclusions

Model for integrated biomass and solar system equipped with LS and ES has been developed to satisfy the demand at the most competitive way. While the model takes into account effect of weather variation, further study will be conducted to include variation of daily house chores which are apparently especially during the weekday and weekend. Nevertheless, in this study, the MILP model is able to holistically shift the load to reduce the size of ES which provides cost-saving potential, secure high levels of energy supply flexibility and enhance RE power source for sustainable environmental impact. The approach has been successfully implemented on a smart eco-village case study. These concept will enable the acceptance of smart eco village, and therefore decisive on our progression towards a more efficient energy system.

Acknowledgement

The authors gratefully acknowledge the research grant and financial support provided by Ministry of Higher Education (MOHE) and University Teknologi Malaysia (UTM) under the GUP research grant of vot number Q.J130000.2525.01H52, Japan International Cooperation Agency (JICA) under the scheme of SATREPS (Science and Technology Research Partnership for Sustainable Development) for the project Development of Low Carbon Scenario for Asian Region, and the Commonwealth Scholarship Commission for providing financial support for collaboration with Imperial College London (ICL).

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