Optimization of Combined Energy Usage: A Case in Healthcare Industry

Shruti Khairnar[1], Milind Sakhardande[2]
[1] PG Scholar, Mechanical Engineering Department, Goa College of Engineering (Affiliated to Goa University), Goa, India
[2] Associate Professor, Mechanical Engineering Department, Goa College of Engineering (Affiliated to Goa University), Goa, India

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ABSTRACT

Implementing strategic Energy Management techniques based on energy hub modelling and demand side management approach has grabbed the attention, in the recent past. Government has enforced various policies/ laws to optimize the energy usage. Laws and policies addressing water and air pollution, chemical and oil spills, smog, drinking water quality, land conservation and management, wild life protection, etc. are implemented. While attaining energy efficiency, it is also important to minimize the capital cost and operating/ maintenance cost. Energy hub is one of the promising methods in a system where diverse energy carriers are involved. Having a closed system in which energy source and energy demand communicating through control/ feedback network further improves the efficiency of the system. Hence, devising an effective demand side management method, also plays critical role in attaining energy efficient system. Instead of optimizing one process/ system, it is proposed to link various systems together and then implement optimization technique.

This review paper showcases the advantages of implementing energy hub model and demand side management together, on single entity having varied energy source and diverse energy demand. This energy management approach is explained based on real world health care unit having huge energy demand and diversified usage. Constraints for optimizing demand side usage are more stringent than any other usual building as demand cannot be compromised since it is involving the risk to life. This paper describes the methodology to be used for implementation of this energy management approach. Possible results are interpreted for different conditions.

Keywords: ***- Energy hub model, Integrated energy management, Demand side management, Cost function, Optimization***

1. INTRODUCTION

Improving general performance of the systems and achieving the environmental and commercial goals is globally trending. In most of the systems, units it consists of, are of complimentary and conflicting nature. Hence, operating the entire system very efficiently has become an important issue. In various literatures, energy dispatch problem is defined as hardship in dealing with set of dissimilar components, technologies and constraints so as to adopt to these requirements and schedule a power generation in a distributed generation network.

2. LITERATURE REVIEW

Energy hub model was proposed by M. Favre-Perrod in 2005 [1], that can further be used to optimize the power exchange and coupling between different energy carrier systems in a combined manner. The author has also highlighted that when power is transformed from input to output of the hub, it involves relative transformation of marginal prices of the energy carriers. It takes information related to tariffs and availability of energies, forecast of renewable energies, specification of conversion units and storage devices present in the system and load demand as input to optimize the energy consumption and utilization of available technologies.

Conventionally, it has been always assumed that the load demand is fixed and then the utilization is optimized. In recent past, in various research work, efforts are made in omitting this assumption and treating the load demand as variable, which brings the term demand side management (DSM). In DSM, load is considered to be dynamic and not static, within specified limits. Making load as variable, adds further flexibility to energy management approach.

In the paper presented by H.-M. Groscurth et. al. [2], one of the first model was proposed for optimizing conventional energy demand, emissions and operational costs of municipal system. Numerous approaches published so far deals with evaluating the proposed optimal design and then planning the system. However, in this paper the existing system is considered for optimization. A new methodology for analysis of complex energy service systems with multiple energy carriers was proposed by B.H. Bakken & A.T. Holen [3], which is based on specific component modules with a standard interface combined in an energy system. This methodology was devised with the intension to carry out comprehensive analysis of their energy service system and to enable public decision makers to study energy system scenario in regards to the environmental impacts and consequences of difficult regulating regimes. A linear programming was used for cost minimization model by A.D. Hawkes & M.A. Leach [4], for optimizing high level system design and corresponding unit commitment of generators and storage within the micro-grid.

J. Vetterli and M. Benz [5] has determined the cost optimal design for ice storage cooling system in commercial building for various electricity tariff schemes using mixed integer linear programming. H.M. Khodra et. al. [6] aimed at minimizing the active power losses, by optimally scheduling the micro-grid in a virtual laboratory set up. Mixed integer linear programming was used by H. Ren & W. Gao [7] for minimizing annual energy cost.

Parallelly, numerous literatures have analyzed demand side optimization. For example, C.-H. Kung et. al. [8] developed load forecasting scheme for load management purpose, based on decision support information system using genetic algorithm embedded artificial neural network. G. Platt [9] introduced a technique which is based on concept of decentralizing the control of demand side resources. It states that there should not be a centralized hierarchal control system for the devices. He has proposed a system of agents, wherein each device is controlled by its agent; and system of agents negotiate within themselves to attain the targets. Scheduling of direct load control strategies was optimized using modified genetic algorithm by L. Yao et. al. [10]. A.-H. Mohsenian-Rad [11] has proposed game theory for energy management system having autonomous and distributed demand side.

This paper aims at providing complete concept for optimizing both source and demand side to have finest possible operating condition within given limits so energy management can be attained at its best. P. Ahcin & M. Sikic [12] has presented energy hub model which integrates load responses along with storage and conversion of energy for evaluation of costs towards energy distribution infrastructure. M. Almassalkhi and I.A. Hiskens [13] proposed that energy flows in simulated interconnected networks have been optimized using energy hub model but without considering DSM.

Approach adopted for this paper is conceptually similar to [12], [13] and [14], wherein supply and demand energy of the selected building was optimized together. However, the parameters and conditions are different from these. Also, the building considered for optimization has very huge energy demands.

3. METHODOLOGY

In order to optimize the given system following approaches are followed which explained in brief.

3.1 Optimization of energy supply

Concept of energy hub modelling mainly provides framework which can be used to model the energy flow of any infrastructure. This model can be used for formulating optimization problem as well as solving it. The model requires information about the available energy sources, efficiency of conversion units and capacity of storage units (if present). The figure -1 below shows the schematics of model under reference:

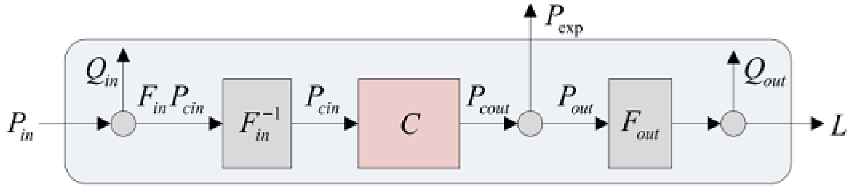

Fig -1: Schematic representation of energy hub model [14]

The schematic represents the sequence of stages through which the energy flows, namely: input stage, conversion stage and output stage. The energy P_{in} enters the energy hub model at input stage wherein it can be either stored as Q_{in} or dispatched further. F_{in} is a dispatch matrix through which energy P_{in} is dispatched as P_{cin}, which is input to the conversion block C. After conversion block, energy can be exported as P_{exp} and the remaining energy flows as P_{cout} to the next dispatch matrix F_{out}. Portion of output is stored as Q_{out} and remaining suffices the load L.

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3.2 Optimization of load demand

Load can be optimized in various ways. However, these methods can be broadly classified in two ways. First is reducing the load. This can be achieved by avoiding wasteful consumption. Also, replacing all the load side devices with energy efficient ones, so that the same outcome is achieved with less consumption of energy. This approach is not presented in this paper as hospital considered for the experimental set up is vast and has huge range of varied devices and study of which demands much more time.
Second way is to spread out the load over a time scale in such a way that peak load demand is reduced. This can be achieved by operating some loads during period when the load consumption is less. For example, normal OPD timings in any hospital are between 9:00 am to 4:00 pm. Hence, this is the period when load demand is at its peak. One if the measure that can be adopted by the hospital is pre-cooling of the rooms/ clinics. Hence, switching on air conditioning at 8:30 am would be economical as load demand is less at this time. This will help in cutting down the maximum demand during peak hours. This approach is adopted in this paper for optimizing the load demand. Also, this paper provides means to investigate maximum demand for the hospital such that cost towards maximum demand is reduced. Hence, DSM measures can be defined as deliberate modification in the load or modification in the load profile over a time scale without disturbing the functioning of the system.
Objectives of demand side management could be either/ all of the following: decreasing operational cost of the user; decreasing energy losses at generation, transmission and distribution; reducing impacts on ecology and environment. Depending on the objective, DSM can be framed in several ways such as altering cumulative load, shifting load on time profile and reducing instantaneous loads. To achieve this, load has to be classified into following categories:

- Critical load which cannot be changed
- Curtailable load which is allowed to alter within specified limits
- Reschedulable load which can be scheduled at different hours of day

3.3 Combined Energy Management

Objective of this paper is to merge the two methodologies and gain the advantages of both. It is aimed at devising a technique which could merge energy hub modelling and demand side management so that the expenditure towards the energies can be minimized. It may be noted that energy hub modelling itself can bring down the expenditure to great extent. Performance of the system can be further improved by adopting demand side management. As a mathematical viewpoint, the methods are integrated by changing loads to variable from parameter.

4. CASE STUDY

The energy hub is modelled based on real time institute which is a medical college and hospital. Data is obtained based on the log books maintained by the operation team. Also, energy bills of this institute are referred for clearer picture.

4.1 Physical layout and other details of the institute

The institute spreads over the plot area of 358 acres. It has 1000 (or more) bedded hospital which is partially airconditioned. Institute has dedicated buildings for OPDs, operation theatres, faculties, offices, lecture rooms, hostels, mortuary, auditorium, etc. Institute also has laboratories, blood bank, pharmacy, laundry, autoclaves, PSA plants, medical gas system etc. Some of the buildings are fully airconditioned and others partially. For all these buildings, energy supply infrastructure is common. Such as all the buildings draw power from common electrical power supply network. Steam required for kitchen, laundry and autoclave machines, is generated by common boilers. Airconditioning is provided to certain group of areas, by a common chiller system.
Institute receives its electrical power from Goa electricity department through two dedicated 33KV lines of which only one can be utilized at a time. Supply is fed to the booster transformer which takes care of voltage fluctuations of the incoming supply line. Supply is then stepped down at 11KV voltage from 33KV through two transformers. As the area of the institute is widely spread, 11KV ring is run through the campus. At each building, individual transformer steps down the voltage to 415V, which is then used for lighting, air-conditioning, heating and other machines/ equipment. In critical areas, electrical energies are stored in batteries through UPS systems, which provides uninterrupted power supply to these areas. In addition to electrical energy from power grid, electrical energy is also generated in the campus through diesel generator sets which provide power back up to the institute.

Hot water requirement of the institute is met through geysers installed in various locations in the institute. Further, institute also requires steam which is used for cooking, laundry and autoclave. Steam is produced by two furnace oil boilers, of which one works at a time.
Cooling is required for different purposes and are met through respective system. For example, for space cooling chiller system provides cooling in some areas. Other areas have VRV system and some areas have split air-conditioning units. For storing medicines, blood, chemicals, etc. cold storage units are there. And lastly for dead bodies mortuary cabinets are there.
All the systems are monitored by operators. All the logbooks maintained for energy consumption, operating conditions, etc. are manually noted by using various measuring tools/ instruments. Electricity tariff scheme in Goa for HT consumers, is determined by 11 parameters. Of these two important parameters which decides electricity billing are energy units consumed and maximum demand.

4.2 Energy hub model of medical college and hospital

This section gives the details of energy hub model and equations obtained here are used as constraints for solving cost function described in section 3.4. Energy hub model of medical college and hospital is shown in the fig.-2 below.

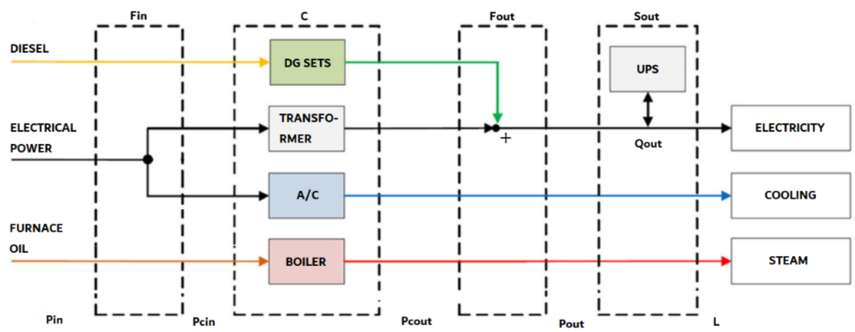

Fig -2: Energy hub model of medical college and hospital

In the above fig.2, P_{in} is the unput to the model which consists of P_e - electrical power expressed in KVA, P_d - power equivalent for amount of diesel consumed expressed in KVA and P_f - power equivalent expressed in KVA for amount of furnace oil burnt. These entities are then dispatched to the Converters as power converter input P_{cin}. Converter then converts these inputs to power converter output P_{cout}. These outputs are combined and then dispatched further through dispatch matrix F_{out}. Steam and cooling energies are immediately consumed whereas electrical energy is served as well as stored through UPS systems. Hence, P_{out} is partially stored as Q_{out} and partially used for load L.
Equations which can be formulated from this model, are detailed as follows. For all variables, k is the discrete time at which variables have been sampled. Sampling interval is set as T. The energy which enters the model is dispatched as follows:

$$P_{in}(k) = F_{in} P_{cin}(k) \qquad (1)$$

Where,

$$F_{in} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Dispatch matrix is the representation of input energies are dispatched to converters. Row of the matrix indicates energy carriers (diesel, electricity and furnace oil). Each column represents input to the converter units. Output of the converter block is in accordance with the following equation:

$$P_{cout}(k) = C\, P_{cin}(k) \qquad (2)$$

Where converter C is the diagonal matrix and its coefficients represents efficiency of each converter

$$C = \begin{bmatrix} 0.4 & 0 & 0 & 0 \\ 0 & 0.79 & 0 & 0 \\ 0 & 0 & 0.7 & 0 \\ 0 & 0 & 0 & 0.87 \end{bmatrix}$$

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Futher, the energy is dispatched as follows:

$$P_{out}(k) = F_{out} P_{cout}(k) \quad (3)$$

Where,

$$F_{out} = \begin{bmatrix} 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

In matrix F_{out}, rows represent load stage and represent output of the converter block. Further, stored energy at the output is expressed as follows:

$$Q_{out}(k) = S_{qout} q_{out}(k) \quad (4)$$

Where S_{out} represents the number of storage units available and q_{out} indicates energy flow to these units.

$$S_{out} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

Finally, the load is expressed as,

$$L(k) = P_{out}(k) - Q_{out}(k) \quad (5)$$

Further, the stored energy cannot be available throughout the time. Hence, it becomes necessary to express variation in stored energy over the time, which is done as follows:

$$E(k+1) = q_{out} T + \kappa E(k) \quad (6)$$

Where E is the stored energy at the k^{th} time and κ coefficient for charging/ discharging. Following are the more constraints, which are set based on history of the energy requirement of the system and are self-explanatory:

$$P_{in}(k) > 0 \quad (7)$$
$$P_{cin}(k) \geq 0 \quad (8)$$
$$P_{cout}(k) \geq 0 \quad (9)$$
$$P_{out}(k) \geq 0 \quad (10)$$
$$0 \leq E \leq E_{max} \quad (11)$$

Where E_{max} is the maximum energy that can be stored by the storage unit

$$-Q_{outmax} \leq Q_{out} \leq Q_{outmax} \quad (12)$$

Where Q_{outmax} is the maximum energy supplied/consumed by the storage units

$$P_e \leq P_{emax} \quad (13)$$

Where P_{emax} is the maximum electrical energy supplied by grid

4.3 Load model/ Demand side management of medical college and hospital

As stated earlier, in case of demand side management the load is considered as variable instead of fixed value. However, the range of variation has to be defined in such a way that the overall functioning of the hospital is not hampered. This can be defined as follows:

$$-\Delta L_{max}(k) \leq \Delta L(k) \leq \Delta L_{max}(k) \quad (14)$$

Where $\Delta L(k)$ represents variation in load at the k^{th} time

Boundary values are obtained based on study of history of load pattern profile.

4.4 Cost Minimization

To minimize the cost towards energy following cost function is defined where R is the cost which has to be minimized. $\alpha(k)$ is the cost for per unit of energy and β is the cost towards maximum demand of energy.

$$R = \sum_{K=1}^{N} \alpha(k)\, Pin(k) + R_{maxdemand} \quad (15)$$

$R_{maxdemand}$ is the cost towards maximum demand which varies with the maximum demand and as per tariff scheme it takes three values.

$$R_{maxdemand} = 212.5\, P_{cd} \qquad \text{if } 0 \leq P_{emax} \leq 0.85 P_{cd} \qquad (16)$$

$$= 250\, P_{emax} \qquad \text{if } 0.85\, P_{cd} \leq P_{emax} \leq P_{cd} \qquad (17)$$

$$= 500\, P_{emax} \qquad \text{if } P_{cd} < P_{emax} \leq 1.2\, P_{cd} \qquad (18)$$

Where, P_{cd} is contract demand load.

The optimization requires data such as Tariff scheme for the electricity, Cost of diesel, Cost of furnace oil, Electricity load, Steam load and Cooling load. For obtaining the best possible solution data has to be sampled over a month, as the energy billing is done for a month. If the sampling interval is kept small the data will be very huge. And also, since data is maintained manually it is cumbersome process. Hence, sampling interval of 4 hours is set which sets the value of N=180.

5. CONCLUSIONS

This paper presents the technique which can be implemented for functional infrastructure so as to minimize its monthly cost towards energy requirement. In this paper, energy hub and DSM has been modelled for the medical college and hospital. Also, the cost function has been defined considering all possible variables which can minimize the cost. After implementing optimization, it would be interesting to know whether the operating DG sets during peak hours can minimize the monthly energy cost. Also, results will suggest about feasibility of utilization of stored energy during peak hours. However, the main purpose of energy storage is having uninterrupted power supply for critical loads and not for energy optimization.

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