ICOTA '98

OPTIMIZATION

TECHNIQUES AND APPLICATIONS

VOLUME 2

Edited by

L. Caccetta[1], K.L. Teo[1], P.F. Siew[1], Y.H. Leung[2], L.S. Jennings[3], V. Rehbock[1]

[1] School of Mathematics and Statistics
Curtin University of Technology, Australia

[2]Australian Telecommunications Research Institute
Curtin University of Technology, Australia

[3] Department of Mathematics
The University of Western Australia

Use of a Fuzzy Logic Algorithm for the Power Generation Scheduling of a Remote Area Hybrid Energy System

V. Iyer, C.C. Fung and C. Maynard
School of Electrical and Computer Engineering
Curtin University of Technology
Perth, Western Australia

ABSTRACT

This paper deals with the optimisation of the operation of a hybrid energy system used in a remote area power supply. Remote area power supply (RAPS) systems are chosen as economic alternatives to the extension of grid supply to consumers in remote areas. A system consisting of a diesel generator, solar source and battery backup is investigated. A fuzzy logic algorithm is used to determine the diesel generator schedule and the battery charge/discharge strategy. The method is used to schedule the operation of the generator and the battery for the next 24 hours on an hourly basis. The simulation of the algorithm is tested on a system operating at a remote site in the Northern Territory in Australia. The results are found to be more cost efficient than the existing operation strategy.

1. Introduction

While the majority of the population in an industrialised country such as Australia have taken electricity supply for granted, there are many communities in remote locations that are deprived of such conveniences, as they are not connected to the main electricity supply grid. Examples are communities in the outback of Australia and residents living on the Asian-Pacific islands. Depending on the size of the community, the power consumption may vary from a few kWh to tens of kWh per day. In most cases one or more diesel generators will be required to meet the maximum load demand. This normally leads to oversizing of the generators. As load demand fluctuates during the 24-hour cycle, the generators will not be able to operate at the most efficient condition at all times. This reduces the efficiency and causes considerable wastage. Due to the remoteness, transportation costs of fuel and spare parts also add to the energy and maintenance bills. Improvement can be achieved by using a *Hybrid Energy System*. A hybrid energy system utilises energy from multiple sources. In conjunction with the diesel generators, solar cells and storage batteries are incorporated. The storage batteries are used to store the excess power from the diesel generators and the solar cells if load demand is low. When demand exceeds the capacity of the generators, the batteries will supplement the supply together with the output from the solar cells. This results in a reduction of fuel consumption and it allows the use of smaller-size generators. In order to operate the hybrid energy system in the most efficient manner, operation of the batteries and solar cells must be scheduled in accordance to the forecast load demand and solar radiation.

The recently published literature, in the area of optimisation primarily focuses on (a) design and sizing and (b) operation and dispatch strategies of the components. Some of the methods used previously for this optimisation problem are linear programming, dynamic programming and methods that come under the broad classification of artificial intelligence such as fuzzy logic and simulated annealing (Bakirtzis [1,2], Fung [3], Swaminathan [7], Wong [8]). In this paper, a fuzzy logic algorithm is used to schedule the diesel generator operation for a 24-hour period on an hourly basis.

2. A Fuzzy logic algorithm for RAPS scheduling

Though artificial intelligence methods are used in the unit commitment problems of conventional power systems, it is still a relatively new area as far as the scheduling of RAPS is concerned. This is mainly due to the complexity of operation of the battery bank. Fuzzy logic is emerging as a powerful tool to deal with systems which are characterised by uncertainty, random disturbances and ill defined problems. It is found suitable for applications involving dynamic, time-varying and non-linear systems.

Wong [8] describes a fuzzy algorithm developed based on a Simulated Annealing method. In this paper a fuzzy algorithm based on the heuristics of the RAPS system is proposed for the system scheduling. The RAPS system considered is similiar to the system operating at a remote site called Epenarra in the Northern Territory in Australia. Epenarra power station is a diesel/ battery hybrid system with a small PV array. The system consists of two diesel generators rated at 52kW and 80 kW, 1 kW solar PV and 100 kWh battery storage. Epenarra uses a control system that senses both the three-phase and single phase site load to arrange the diesel generator dispatch strategy. The 52kW generator is used alone on the majority of days to meet the load demand. The schematic of the system is as given in Figure 1.

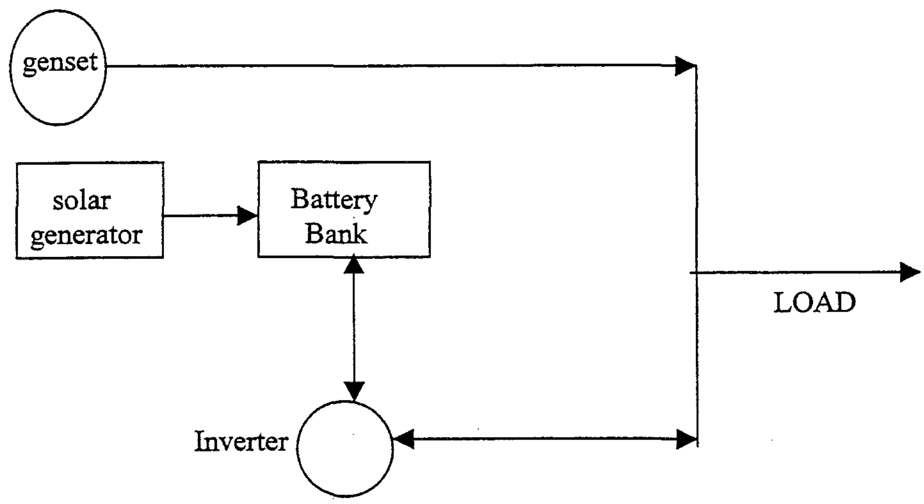

Figure 1 Schematic of a RAPS system

The system is operated to meet the load demand to a maximum of 40kW. As the actual load demand can be sufficiently met by a single generator, only a single diesel generator of 40kW rating, with a battery bank of 100kWh capacity is considered for simulation.

The fuzzy logic algorithm has three major stages as shown in Figure 2. The fuzzification unit interprets the inputs as linguistic values. The three input parameters used are load, time and battery. The generator output, which is the power level at which the diesel generator should be set at for the current simulation time interval, is used as the single output. Each of these parameters is fuzzified into different levels, with linguistic variables used to describe each level. Then the fuzzy membership functions are defined for each linguistic variable, as given in Figure 3. Fuzzification involves dividing each input variables' universe of discourse into ranges called fuzzy sets. A function applied across each range determines the membership of the variable's current value in the fuzzy sets. The value at which the membership is maximum is called the peak value. The width of a fuzzy set is the distance from the peak value to the point where the membership is zero. The knowledge base comprises a *rule base* that provides linguistic rules that express the relationship between the three input variables. All the possible combinations of the inputs are considered for the rules. In total, 80 rules have been derived. The system constraints are used for arriving at suitable rules. The heuristic knowledge used to construct the rule base is as follows:

The diesel generator is inefficient at low power output settings.
The diesel generator should be turned off at lower load levels.
The battery should not be discharged below 20% of its maximum capacity.
At the end of the day, battery should be charged to nearly 90% of its full capacity.
The loss of load probability should be minimised.
The load increases after midday.

Tuning of the knowledge base was carried out by running a number of simulations of the algorithm using the actual load data of the site. These rules are in the form of IF-THEN conditional statements as given by the rules below.

IF load is low and time is morning and the battery is xhigh THEN the Gen is off.
IF load is low and time is night and the battery is low THEN the Gen is optimum.

In the above example, the linguistic terms, *low, xhigh, off* and *optimum* are used to describe the input and output variables. Definitions of these variables are shown in Figure 3.

The Inference engine determines the rules that are fired and the resultant fuzzy set for the output variable. Finally, the defuzzification unit uses the output of the inference process to derive a single crisp output value. The centre-of-area method is used for defuzzification to obtain a singleton, which is a representative point for the resulting fuzzy set of the output.

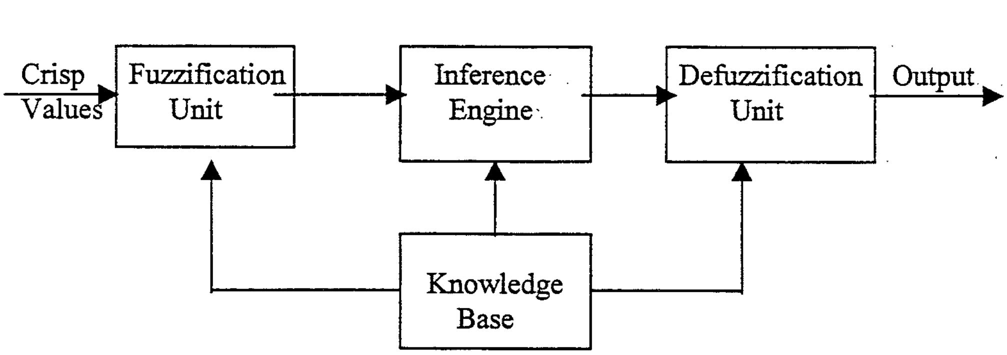

Figure 2 Block diagram of the Fuzzy Logic System.

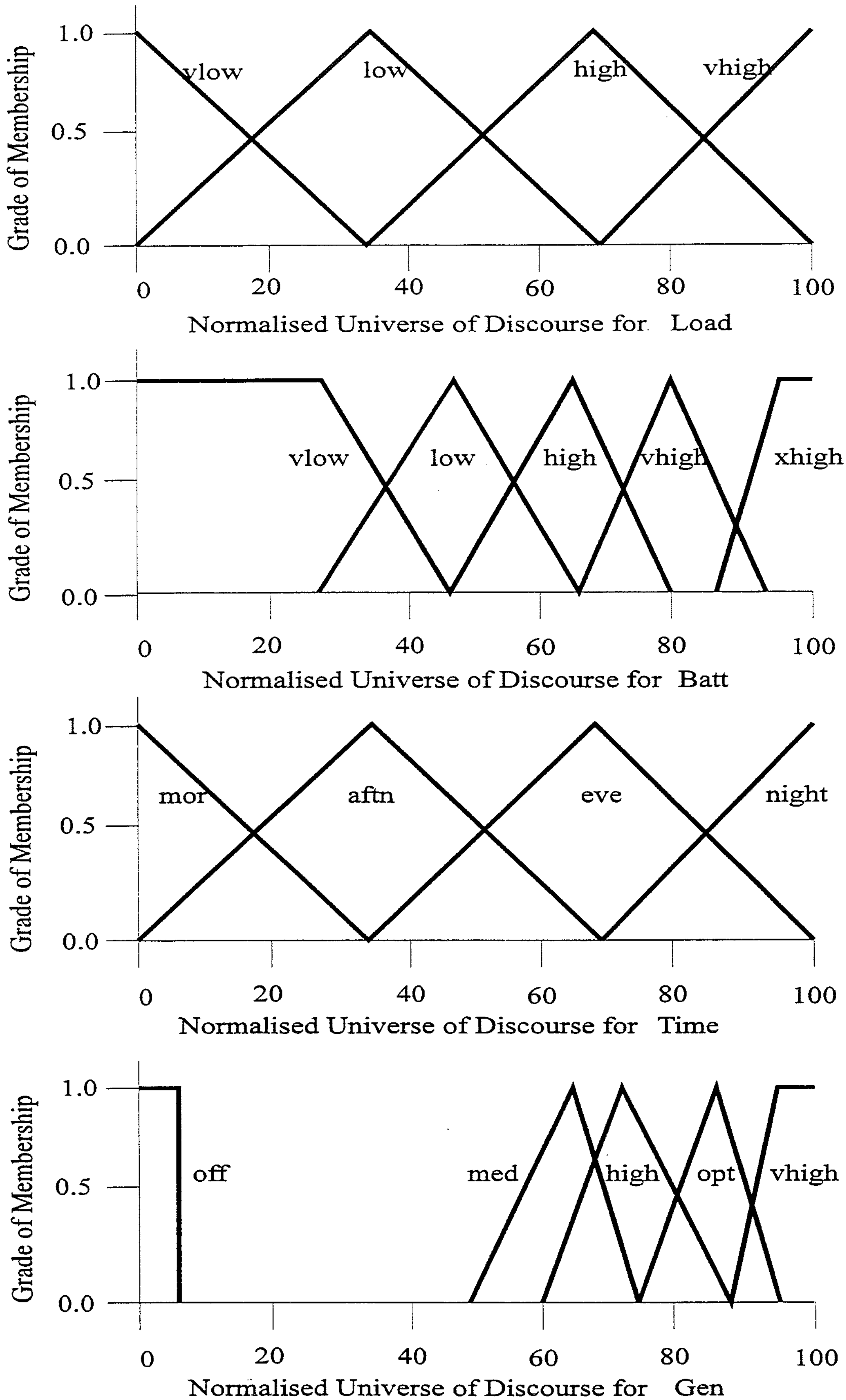

Figure 3. Grade of Membership for Load, Battery, Time and Generator Output

3. Problem Description

The overall aim in optimising the operation of the system is to determine the control strategy, which minimises the operating costs, subject to system constraints. The important costs of operating a diesel generator can be grouped into maintenance and fuel consumption costs. The other costs involve battery maintenance. The battery maintenance cost depends on the operation of the battery (as the battery life depends on the depth of discharge (DOD) of the battery in each cycle of its operation). The minimisation of fuel consumption cost, being the main component of the life cycle cost, is considered in the present study. The system constraints are as given below.

Diesel generator must be operated within the minimum and maximum allowable rating.
Fuel efficiency is low when the diesel is run at low load.
Total power generated must meet the load demand.
Minimum up and down times of the generator must be observed.
Battery charge/ discharge limits must be satisfied.

4. Simulations

The actual load profile from the site was used for the simulation. The battery bank is assumed to be fully charged at the start of the simulation. The battery state-of-charge is calculated by assuming a battery model with a constant charge and discharge efficiency. As the examination of the fuzzy logic algorithm for the optimisation is the primary objective of the present research, the detailed model analysis of the components is given less importance. The data from the site were recorded at 15-minutes duration but for the simulation purposes a time duration of one hour was considered. For each time interval, the generator on/off state, the power generated and the battery discharge/charge and the state of charge are outputs produced from the fuzzy algorithm. The fuel consumption of the generator for each time interval is then calculated and used as a comparison with the actual consumption at site. The model described in Skarstein [6] is used to calculate the fuel consumption.

$$FC = 0.246*Popr+0.08415*Pr \qquad l/hr \qquad (1)$$

where,

FC is the fuel consumption
Popr is the operating power of the generator
Pr is the rated power of the generator, which is 40kW for the simulation
l/hr is the units in litres/hour.

The fuel cost per hour is given by

$$C= FC * Cf \qquad \$/hr \qquad (2)$$

where,

C is the fuel cost per hour
Cf is the cost of fuel per litre

The recorded information from the site operation indicated that the solar power was not used, hence the simulation was also done without the solar input. The simulation was carried out for a period of three months and the results were compared with the actual operation. The comparison done for three typical days is as given in Table.1. The load pattern for the day as given in case-1 is shown in Figure 4. The results indicate that the operational scheduling using the fuzzy method is more efficient than the existing operation method.

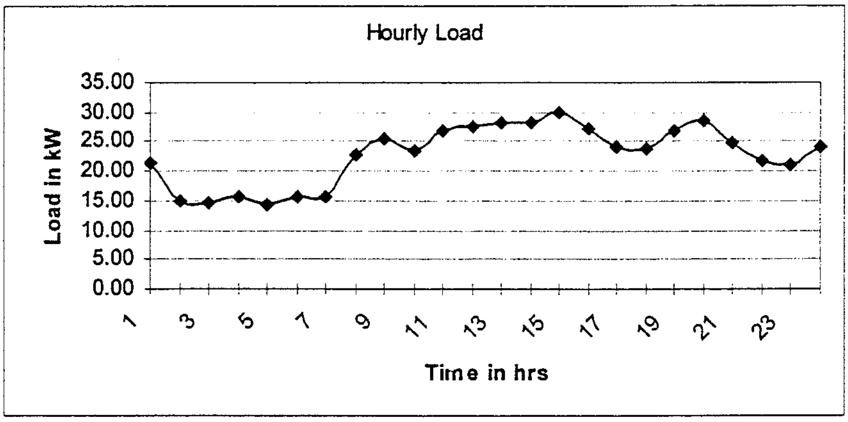

Figure 4 Load pattern for a typical day

The data available was for the years 1995-96. Hunter [4] states that manufacturers recommend that diesel generators should not normally be allowed to operate below a minimum acceptable power level (typically 40% of the rated power). So the program sets the generator output to zero if the generator output given by the algorithm output is below 45%. This generally happens on rare days when the loads are unusually low. The program also ensures that the battery is not charged beyond 95%.

	Case-1		Case-2		Case-3	
Description	**Simulation results**	**Site operation**	**Simulation results**	**Site operation**	**Simulation results**	**Site operation**
Load energy kWh/day	525.7	525.7	547.28	547.28	264.54	264.54
Average power kW/h	21.9	21.9	22.8	22.8	11.02	11.02
Maximum power kW/h	30.9	30.9	29.76	29.76	14.34	14.34
Minimum power kW/h	13.68	13.68	14.22	14.22	8.52	8.52
Diesel generator size kW	40	52	40	52	40	52
Battery size kWh	100	100	100	100	100	100
Load provided by diesel kWh/day	457.28	512.08	480.66	502.61	159.04	180.34
Load provided by battery kWh/day	68.44	13.68	66.62	44.67	105.49	84.24
Diesel output energy kWh/day	558.03	546.24	579.5	577.5	306.75	287.58
Fuel consumption lts/day	218.06	239.39	223.3	247.08	156.24	175.76
Diesel run hours hrs/day	20	23	20	21	14	17

Table 1 Results of comparison for three typical days

From the results in Table 1, it can be observed that the system can be operated more efficiently using the fuzzy algorithm. Based on the simulation results, the fuel consumption can be reduced by 10% while the number of running hours of the generator is reduced by 13.6%. On the other hand, the Load delivered by the diesel is increased by 3% due to operation of the diesel generator at its optimal performance. The Load provided by the battery also increased by 150% by maximising the utilisation of the battery. Although solar power has not been used on site, availability of the additional energy source will further decrease the diesel generator usage, the fuel consumption and subsequently reducing the running hours of the generator. This will in turn reduce the maintenance cost. In addition, the generator size could be reduced from 52kW to 40 kW while meeting the load demand.

5. Conclusion

The paper has described the development and verification of a fuzzy logic algorithm to optimise the operation of a RAPS. The objectives of optimisation are the minimisation of fuel cost, the reduction in running time of the diesel generator and the maximisation of the use of storage and renewable energy. Work is currently being carried out to fine-tune the knowledge base of the fuzzy logic algorithm. The present research indicates that the fuzzy logic is suitable for the operational improvement of the RAPS. This proposed algorithm which is used for one-hour time intervals could also be shortened to 15-minute time span.

6. Acknowledgement

Vanaja Iyer is currently a recipient of the Alternative Energy Development Board (AEDB) scholarship. The authors are grateful for the support given by AEDB to this work.

7. References

[1] A.G Bakirtzis and P.S. Dokopoulos, 'Short term generation scheduling in a small autonomous system with unconventional energy sources' *IEEE Transactions on power systems* 3(3) (1988) pp.1230-1236.

[2] A.G Bakirtzis. and E.S. Gavanidou, ' Optimum operation of a small autonomous system with unconventional energy sources' *Electric power systems research* 23(2) (1992) pp.93-102.

[3] C.C. Fung, S.C.Y. Ho and C.V. Nayar, 'Optimisation of a hybrid energy system using simulated annealing technique' *IEEE TENCON 1993*, (1993) pp.235-238, Beijing China, October 1993.

[4] R. Hunter and G Elliot, G. *Wind- Diesel Systems* Cambridge (UK) : Cambridge univ. press. (1994)

[5] H. Li and M. Gupta, *Fuzzy logic and Intelligent systems* (Kluwer Academic publications, 1995)

[6] O. Skarstein and K. Uhlen, 'Design considerations with respect to long-term diesel saving in wind/diesel plants' *Wind engineering*, Vol.13, No.2, (1989) pp.72 -87.

[7] S. Swaminathan, K. Kottathra, S. Phillips and K. Teh, 'A MNLP Formulation for Power System Scheduling' *Solar 93 conference proceedings* Vol.2 (1993) pp.446-451.

[8] K.P. Wong, C.C. Fung and T. Eskamp, 'Development of a fuzzy-logic-based control algorithm for the commitment of energy sources in an integrated energy system' *Proc. ANZIIS-93*, (1993) pp.432-436, Perth Australia, December 1993.