Narimani, Afsaneh, Nourbakhsh, Ghavameddin, Ledwich, Gerard, & Walker, Geoff
(2016)
Storage optimum placement in distribution system including renewable energy resources. In
Australasian Universities Power Engineering Conference (AUPEC2016), 25-28 September 2016, Brisbane, Qld.

https://doi.org/10.1109/AUPEC.2016.7749325

Storage Optimum Placement in Distribution System Including Renewable Energy Resources

A. Narimani, *Student Member, IEEE*, G. Nourbakhsh, *Member, IEEE,* G.F. Ledwich, *Senior Member, IEEE*, G.R. Walker, Member, *IEEE*
School of electrical engineering and computer science
Queensland University of Technology
Brisbane, Australia
afsaneh.narimanizamanabadi@qut.edu.au

***Abstract*—The inclusion of bulk Electric Energy Storages (EES) in distribution system offers a number of benefits to utilities to improve reliability and efficiency of the network. However high investment costs of EES installation should be justified for the utilities. Benefits such as system upgrade postponement and cost of energy purchased reduction in the network as well as reliability and efficiency improvement have made utilities persuaded to afford storage investment and maintenance costs. In this regard, optimal sizing and siting of storages has become the focus of the recent researches to provide a tradeoff between investment costs and expected benefits from storages. In this context, this paper proposes a strategy to optimize the size of EESs in the network while minimizing the cost of purchased energy and investment/maintenance cost of the storage. A case study is presented to evaluate this approach and examine the results.**

***Index Terms*—Electric energy storage, genetic algorithm, optimization, renewable energy resources.**

I. INTRODUCTION

DISTRIBUTION system are faced several changes due to addition of distributed generation. Conventional network with a centralized generation connected to the transmission network has upgraded into a network with small distributed generators with the ability of connecting directly to the load points. Distributed generators such as Renewable Energy Resources (RER) addition to the network are expected to improve reliability and efficiency of the distribution system. On the other hand, such resources have stochastic output relating to weather changes. EESs as a promising technology can guarantee storing surplus energy of such renewable resources in off-peak periods to supply loads in peak hours. However, high investment and maintenance cost of EESs made customers reluctant to use such devices. Research literature proposes utility owned EESs to achieve the desired reliability and efficiency in the network with the following economic feasibility justifications [1]:

1. Direct benefit from storing energy with a low price during off-peak periods, and selling the energy stored back with a higher price at peak load periods.
2. System upgrades due to annual load growth can be postponed and reduced by peak load shaving in the network.
3. Energy losses in distribution network can be reduced by proper placement of the storages in the network [1].

Once the addition of EESs is justified, solutions for optimum size and location of the storages are required to minimize the costs of energy storages while increasing the benefits from these devices. Researches have been conducted in the area of optimum sizing and locating of EESs [1-4] and optimum charge/discharge scheduling of storage [5-8]. Each study has considered solution to find a tradeoff between some of the benefits from EES and required investment or other network constraints.

In [2] optimal placement of energy storage was investigated to minimize the hourly social cost and effective utilization of the transmission capacity for wind power integration while satisfying the transmission line constraints using genetic algorithm. In [3] a hybrid multi-objective particle swarm optimization was proposed to minimize the power system cost and improve the system voltage profiles by searching location and size of storage units under consideration of uncertainties in wind power production. In another approach in [4] a methodology was presented to determine the optimal size of EES integrated with thermal power system using Tabu Search (TS)-based technique for solving optimization problem. These analyses include economic cost benefit analysis of the installed EES for its entire life cycle and distribution network saving to ensure system reliability and stability. Finally in [1] a planning framework was proposed to find the most cost-effective siting and sizing of EES units in order to defer system upgrades by means of load management using genetic algorithm (GA) and linear-programming solver. On the other hand authors in [5-8] proposed various storage optimum scheduling strategies to minimize energy costs of the network in one hand and reduce the impact of load uncertainty and

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price spikes on load aggregators in dealing electricity with the utility. From the abovementioned citation, it can be concluded that many works have been conducted in the area of sizing, locating, and scheduling of EESs; however, few studies have considered a tradeoff between EES investment cost and cost of purchased energy during the life cycle of the EES.

In this context, this paper proposes a strategy to optimize sizing and siting of EESs in the network in order to minimize the total investment and maintenance cost of EES in one side and cost of purchased energy from the utility in the other side using genetic algorithm.

This paper is organized as follows: Section II describes the problem formulation and methodology of this approach. Section III presents a case study for this approach. And finally conclusion is presented in section IV of this paper.

II. PROBLEM FORMULATION AND METHODOLOGY

The purpose of utilizing EES in the distribution network is to shave peak load and postpone the system upgrades due to load growth to later time. On the other hand EES can reduce cost of purchased energy from utility by storing low price electricity in off-peak periods and dispatching during peak load periods or peak price time to the network. The purpose of this study is to investigate the optimum size and location of storage in the network in order to minimize the investment and maintenance cost of storage while maximizing the total financial benefit from storage as an alternative supply in the network. In this strategy EES charge and discharge as a function of EES rated capacity inversely affect total cost of purchased energy. It means that more EES rated capacity leads to spend less cost for purchasing electricity from utility. On the other hand, more EES capacity needs more investment and maintenance cost for storage.

In this work genetic algorithm is used to find optimum solution for EES size and location that minimizes both operation and investment/maintenance costs. The reason for using GA is that the output of this optimization method is improved by increasing the number of iteration. Moreover by adding some settings to this method it is possible to avoid local minimum point in using this strategy. Hence GA is suitable for large number of variables and complex constraints.

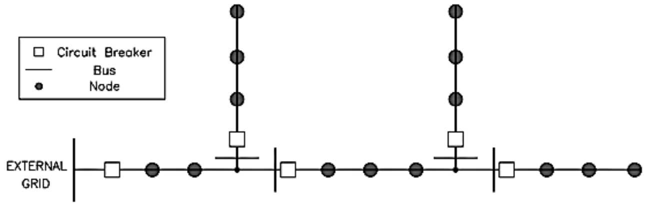

Fig. 1. Five-bus network

Suppose that the distribution network of Fig.1 is a five bus distribution system. The aim is to find out that addition of EES to which bus and with what size will be the optimum solution to minimize both cost of purchased energy from utility and investment/maintenance cost of the storages. The electricity supplier is responsible for the installation and maintenance of EESs. It is assumed that some of the residential customers in the network own Photovoltaic (PV) units in their places. In this paper historical data of load and PV is used to find a series of data representing a typical year data. Backward reduction technique proposed in [9] is used to find arbitrary non-overlapping clusters which represent multiple states model for PV and load. As load and sun radiation data have some correlation to each other since both are related to the time of the day, season, and weather conditions, in this paper load data and PV output clusters can be an accurate representative for calculations. The backward scenario reduction in brief can be summarized as follows[10]. More details can be found in [9-11]

1. Obtain historical hourly load and PV data that form the main scenario. The data of each hour is considered as a vector. The probability of each scenario should be obtained for annual calculation at the end.
2. Compute Kantrovich distance matrix[11] of scenarios.
3. Find the scenarios with the smallest distance to scenario n.
4. Delete the scenario with smaller probability.
5. The probability of remaining scenario is sum of scenarios probability.
6. Repeat the above steps until the required scenario number is achieved.

Then the load and PV states are divided into two categories of:

1) Load demand greater than PV generation or high price of electricity that are assumed as the discharging state for EES.

2) Load demand less than PV generation or low price of electricity that is counted as charging state for EES.

Considering the abovementioned states with the probability of each state, the objective of a sub problem optimization is to minimize total cost of purchased energy from utility. This can be achieved by managing charge and discharge of EES during all states considering electricity price at each state. The objective function can be defined as follow:

$$C_e = \sum_{i \in ch} \rho_i \times U_i \times \mathrm{Pr}_i + \sum_{i \in di} \rho_i \times U_i \times \mathrm{Pr}_i \tag{1}$$

where;

C_e: Total cost of purchased energy

di: Discharging states

ch: Charging states

Pr_i: Electricity price at period i (\$/kWh)

p: Probability of state i

i: State index

U: Total purchased electricity from utility (kWh)

For charging periods:

$$U_i = L_i - PV_i + ch_i \tag{2}$$

For discharging periods:

$$U_i = L_i - PV_i - di_i \times \eta \tag{3}$$

Subject to the following constraints:

$$SOC_{min} \le SOC_i \le SOC_{max} \tag{4}$$

$$0 \le ch_i \le ch_{max} \tag{5}$$

$$0 \le dis_i \le dis_{max} \tag{6}$$

From (1), (2), and (3) it is obvious that in order to minimize total cost of purchased energy in the network, discharge during peak price periods and charge during off-peak price should be increased and vice versa. The result of this sub problem optimization depends on the price of electricity and charging or discharging amount at each period *i*. On the other hand, investment cost and maintenance costs of EES can be expressed as following:

$$C_t = Rc \times (MC + IC) \tag{7}$$

where;

Ct: Cost of investment/maintenance of EES ($)

Rc: Rated capacity of EES (kWh)

MC: Maintenance cost of EES ($/kWh)

IC: Investment cost of EES ($/kWh)

In order to find a tradeoff between EES investment cost and cost of purchased energy, genetic algorithm is used in this paper. The objective function for this problem can be defined as follow:

$$F = C_e + C_t = Rc\times(MC+IC)+\Big(\sum_{i\in ch}\rho_i\times U_i\times Pr_i+\sum_{i\in di}\rho_i\times U_i\times Pr_i\Big)\times Lf\times 8760 \tag{8}$$

subject to the constraints in (4) to (6). *Lf* represents lifetime of EES.

As (8) shows, the cost of purchased energy has been calculated for total life cycle of EES in this paper. Load growth and interest rate have not been considered in these calculations. However; in future works it will be considered. By minimizing this function a tradeoff between investment cost for EES and total cost of purchased energy that can compensate investment costs partly is achieved.

The main part of this methodology is the chromosome encoding for genetic algorithm. In the proposed method in this paper, each chromosome consists of unit intervals that represent the size of EESs at each segment. The number of variables in each chromosome represents the EES capacity in a segment. The solution chromosome will present the size of storage in each segment and zero for each gene shows that no EES is required for the relevant segment. The location candidature of the storage is considered at the start of each feeder after the entry circuit breaker. This location consideration is to avoid any line current capacity deviation in the network.

The process of proposed optimization is shown in Fig.2. As the figure shows, first load, PV generation and price data are clustered to some charging and discharging scenario cases. Then GA operators perform the mutation and crossover and objective function is evaluated for the generated populations. The best populations are kept and finally after the defined number of iterations, the optimum solution is obtained.

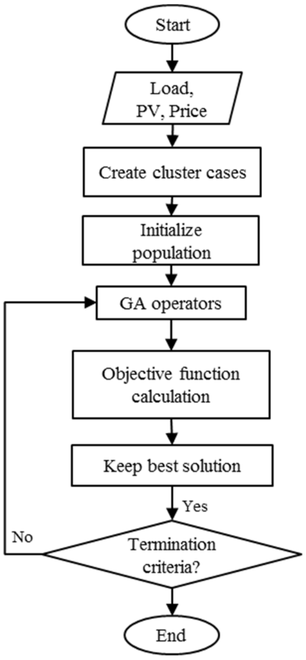

Fig. 2. Flowchart of proposed strategy

III. CASE STUDY

The proposed method is applied to the network of Fig.3. This network is divided into 5 parts and one EES is considered for each part at the entry of the segment. Each part starts with a circuit breaker. The load and PV data used in this application are actual annual data collected on hourly basis from Australian Climate Data Bank (ACDB) and data base of south east Queensland distribution network, Australia. It is assumed that each residential customer has a PV of 3 kW rating in their place. These data of load demand and PVs for a typical year is clustered into 10 non-overlapping clusters with the assigned probability of happening in a year.

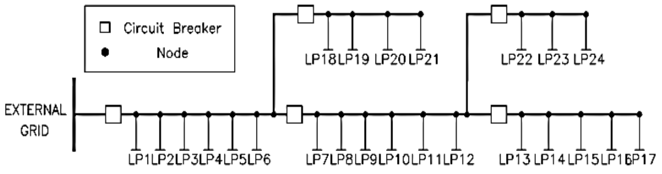

Fig. 3. Distribution system for case study

The centroids of the clusters for this work are shown in Table I. As the table shows, in four cases load demand is more than PV generation or price of electricity is high so those cases are considered as discharging periods. The other six cases are counted as charging periods where the load demand is less than PV generation or the price of electricity is low. Such charging and discharging period's categorization makes the storage supplier able to make decision in each real scenario to minimize costs of energy purchasing. The optimization is performed based on this charge and discharge categories. In this way the cost of energy to be purchased form utility will be minimized.

Table II provides the information of lead acid battery which is used in this work. Total investment and maintenance cost for EES lead acid type in this paper is considered 724 dollar per kWh as a rough amount for investment, maintenance, and power electronic devices that is converted from USD to AUD from table II [12].

Table III presents the average load and maximum PV generation of each segment. The life cycle of storages is considered equal to 5 years. Table IV shows the proposed genetic algorithm parameters that are used in this strategy. The stopping criterion of GA in this work is number of iterations which is 50. The number of populations is 100 in this paper. After running the GA, the optimal storage sizes are obtained for this case study as shown in Table V. The hours of storage is considered equal to 5 hours in this case study. Total cost of investment and purchased energy is $772,540 by using this strategy for 5 typical years.

TABLE I: CLUSTERS CENTROIDS (PER UNIT)

Load (P.U.)	PV (P.U.)	Price (cent/kWh)	Probability	State
1.01	0.00	21.52	0.02	dis
0.88	0.45	21.39	0.09	dis
0.83	0.73	21.24	0.15	dis
0.47	0.01	9.11	0.08	ch
0.50	0.25	10.78	0.13	ch
0.70	2.95	20.02	0.13	ch
0.84	0.96	20.81	0.12	ch
0.79	3.02	21.13	0.19	ch
0.63	2.01	15.45	0.08	ch
0.90	0.00	21.52	0.02	dis

TABLE II: LEAD ACID STORAGE VALUES[12]

Rated Output(kW)	2500
Efficiency	0.75
Unit Cost for Power Electronic(USD/kW)	175
Unit Cost for Storage Unit(USD/kWh)	305
Unit Cost for Balance of Plant(USD/kWh)	50
Fixed O&M Cost(USD/KW)	15
Number of Charge/Discharge Cycles in Life	3200

TABLE III: AVERAGE LOAD AND MAX PV GENERATION

Part	Average load(kW)	Max PV(kW)
1	28	35
2	30	36.5
3	26	33
4	25	30
5	27	25

TABLE IV: GA PARAMETERS

Population Size	Max Generation	Crossover Rate	Mutation Rate	Elitism Number
100	50	25%	20%	50

TABLE V: MAX ENERGY STORAGE LEVEL (KWH)

EES1	EES2	EES3	EES4	EES5
25	29	23	21	26

IV. CONCLUSION

In this paper, a new strategy for sizing and siting of EES in distribution system is proposed to minimize the total cost of storage investment in addition to total cost of purchased energy from utility. Genetic algorithm is used for this purpose and an objective function is defined as investment/ maintenance cost and cost of energy purchase as a function of EES rated capacity. Result of case study shows that the proposed strategy has a significant impact on reducing total costs including operation, maintenance, and investment. The proposed strategy can be used by load aggregators/retailers to provide optimal storage facilities for their network to achieve financial benefit in trading electricity between customers and utility.

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