International Journal of Electrical, Electronics and Computer Engineering 3(2): 7-12(2014)
ISSN No. (Online): 2277-2626

Methodology for Optimal Sizing & Power Management of Hybrid Energy System

Pallavi Gajbhiye and Payal Suhane***
**M. Tech. Scholar, Department of Electrical and Electronics Engineering, NRI Institute of Information Science and Technology, Bhopal, (MP), INDIA.*
***Professor, Department of Electrical and Electronics Engineering, NRI Institute of Information Science and Technology, Bhopal, (MP), INDIA.*

(Corresponding author: Pallavi Gajbhiye)
(Received 05 June, 2014 Accepted 30 July, 2014)

ABSTRACT: This paper proposes a Hybrid Energy System (HES) which combines solar Photovoltaic (PV) and Wind Turbine (WT) as a small-scale alternative source of electrical energy for the problem of optimal sizing and economic assessment such that the demand of residential area is met. It also uses Diesel Generator (DG) and battery bank to cover the emergency loads energy. Covering the load demand under varying weather conditions is the main constraint in this study. The main objective of this paper is to address the Power Management Strategy and cost optimization for HES. Algorithm has been suggested to evaluate the optimal sizing of components in HES and load demand is fulfilled at every instant. In this, the electrification costs like capital, replacement, operation and maintenance cost and fuel cost are considered for optimal design. Proposed study would be feasible solution for distributed generation of electric power for stand-alone applications at remote locations.

Keywords: Hybrid Energy System, Renewable Energy Sources, Optimization, PV array, Wind Turbine, Battery Bank and Diesel Generator.

I. INTRODUCTION

As traditional energy resources are exhausting and concern of environment is increasing, renewable and clean energy is attracting more attention all over the world to overcome the increasing power demand [1]. Some projections indicate that the global energy demand will triple by 2050 [10]. Therefore, there is an urgent need of renewable energy resources and it has formulated as national strategy for the development of renewable energy applications and Energy Conservation Measures (ECM). For this purpose, continuous and fast effort to develop more attracting systems with low-cost, high-performance and multifunction’s are required. From all Renewable Energy Sources (RES), Wind energy and Solar energy are world's fastest growing and available free energy sources, also most environment-friendly type of energy sources [2]. They are uncontrollable sources and are converted into electricity and then sent to load or easily stored in battery bank or Energy Capacitor System (ECS), and they meet the daily load fluctuations [8][2].
Renewable energy generation has disadvantage that the change in output characteristic is intense because the output greatly depends on climatic conditions which includes solar irradiance, wind speed and temperature. Therefore, solar and wind can be integrated together as an HES for more reliable power production. This system not only provide a bargain of low cost, but also more economical than a single PV or wind power generation in terms of both the cost and the protection of energy storage components [1].
A hybrid energy conversion system combines RES and conventional energy (diesel) as a small scale alternative source of electrical energy where conventional generation is not practical. For example - remote villages in developing countries or ranches located far away from main power lines [2]. In other words, a system in which two or more sources of energy brings together is called a hybrid system. Hybrid wind-solar systems using battery banks, found an optimal control strategy model to operate the hybrid system. The optimal sizing method calculates the optimal system configurations which achieve a given Loss of Power Supply Probability (LPSP) and at the same time it minimizes the annualized cost of the system [4]. To give optimal power, optimization techniques are used which may be deterministic techniques or stochastic techniques.

In most isolated and remote areas, electric power is often supplied to the local community by DG. It causes significant impacts on environment because every litre of diesel releases about three kilograms of CO_2. Moreover, it is often expensive to transport diesel to remote areas. In most remote areas, RES like solar and wind are available. But, they are not fully controllable and their availability depends on daily and seasonal patterns. Therefore, conventional energy source like DG and also energy storage system are used in conjunction with renewable energy for reliable operation [3].

II. MODELING OF HES

The proposed structure of HES comprises of PV array, variable speed WT, battery and DG as shown in Fig.1 In this, the components are integrated and complement each other, in order to meet the load requirements in optimal manner. Battery chargers which are connected to DC bus, charges the battery bank from the respective PV, WT and DG input power sources, which are usually configured in multiple generation blocks according to the devices nominal power ratings and the redundancy requirements. From the designing point, optimization of size of a hybrid plant is important which gives good ratio between the cost and performance [7].

A. PV System Modeling

Output of PV panel includes the impact of geographic location like solar radiation and temperature [6]. Output power of module is given by [5]

$$P_{PV} = P_{STC}\,\frac{G_{I\,NG}}{G_{STC}}\,[1 + k(T_c - T_r)]$$

where,

P_{PV} = output power of module at irradiance

$G_{I\,NG}$ and P_{STC} = maximum power of module at standard test condition

T_c and T_r = cell and reference temperature

k = temperature coefficient of power

G_{STC} = irradiance at standard test condition

P_{STC} = 25 KW and k = 0.45 % / °C

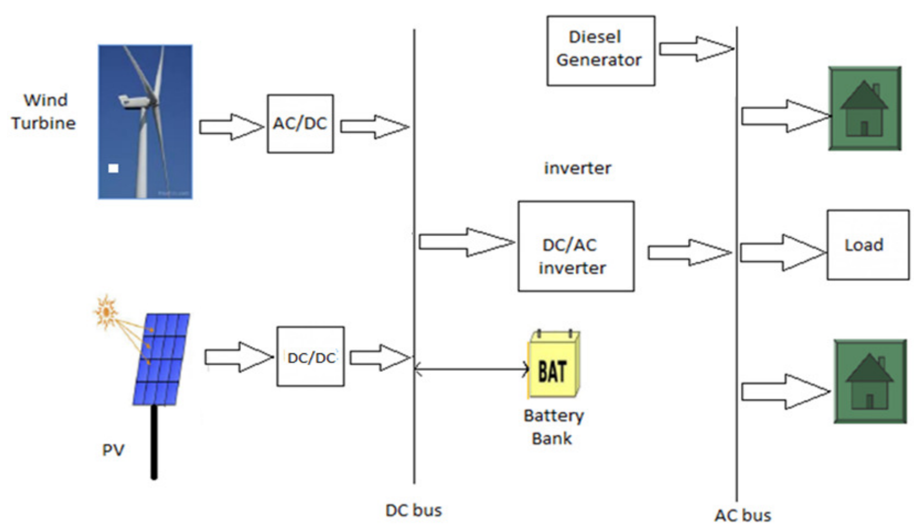

Fig.1. Block Diagram of HES.

B. Wind System Modeling

WT converts kinetic energy from wind into mechanical energy and then the mechanical energy is used to generate electricity [5]. The energy and current output of WT for each time instant is calculated on the basis of local weather conditions and actual installation height of turbines [6].

Fundamental equation governing the mechanical power capture of rotor blades of WT, which drives the electrical generator, is given by [2]

$$P = \frac{1}{2}\rho A C_p V^3$$

where,

ρ = air density (kg/m^3)

A = area swept by the rotor blades

V = velocity of air (m/sec)

C_p = power coefficient of WT, it is often expressed as function of the rotor tip-speed to wind-speed ratio (TSR)

C. Diesel System Modeling

A governor and an engine combine to form a diesel engine and the governor is a combination of a speed regulator and an actuator [3]. DG power is related to fuel consumption means DG is characterized by its efficiency and its fuel consumption ie. hourly and specific fuel consumption [12][14]. Specific fuel consumption (l/kWh) is defined as the fuel consumption needed to produce 1 kWh of energy and it is equal to hourly fuel consumption (l/h) to supply a given load during 1h. Hourly fuel consumption is given by [14]-

$$q(t) = a.P(t) + b.P_r$$

where,

a = constant in l/kW for typical DG

b = constant in l/kW for typical DG

P_t = power generated by DG in kW

P_r = rated/nominal power of DG in kW

Fuel cost of power system is expressed as a function of its real output power and modeled by a quadratic polynomial. The total $ /h DG fuel cost $C_{DG,i}$ is given by [5]-

$$C_{DG,i} = \sum_{i=1}^{N} (d_i + e_i P_{DG,i} + f_i P_{DG,i}^2)$$

where,

N = number of generators

d_i , e_i and f_i = coefficients of generator ie. constants given by manufacturer (d_i= 38, e_i= 26.7 and f_i=0.0008)

P_{DG} = output power (KW) of DG i

i = 1, 2…..N are assumed to be known

Maximum power of DG = 90 KW

D. Battery System Modeling

Battery stores the excess energy generated by HES and supply that energy during low generation period [6].

If total output power of turbine and PV cell is greater than load power, then battery is in state of charging and the charged quantity of battery at the moment of (t) is given by [7]

$$P_b(t) = P_b(t-1).(1-\sigma) + [P_Z(t) - P_l(t)/\eta_{inv}] .\eta_{bc}$$

If total output power of turbine and PV cell is less than load power, then battery is in state of discharging and the charged quantity of battery at the moment of (t) is given by [7]

$$P_b(t) = P_b(t-1).(1-\sigma) + [P_l(t)/\eta_{inv} - P_Z(t)] /\eta_{bf}$$

where,

$P_b(t)$ = battery charged quantity at time (t)

$P_b(t-1)$ = battery charged quantity at time (t-1)

σ = self-discharge rate per hour

$P_Z(t)$ = total output power of turbine and PV cell in the time interval (t-1, t)

$P_l(t)$ = total load power in the time interval (t-1, t)

η_{inv} = inverter efficiency

η_{bc} = battery charging efficiency

η_{bf} = battery discharging efficiency

III. POWER MANAGEMENT STRATEGIES

They manage the power flow between HES and the battery to fulfill the load demand means it controls the proper active power flow from and to the battery storage system. Power Management System (PMS) improves the power quality of HES and controls the power distribution among the power generating system. It controls the power flow of energy of individual power generating system and battery (it controls the charging/ discharging of the battery bank). It is designed such that the use of battery is as low as possible. The combination of HES with battery and efficient PMS makes the best use of the advantages of each power generating system [13]. If load demand change, then power supplied by hybrid system must be properly changed ie.the power delivered from the PV array, WT as well as from the DG must be coordinated to meet load demand [8].

If total power generation of hybrid system (ie. combination of PV array and WT system) is higher than the load demand, then excess power is used to charge the battery and to feed the power to the load of selected area. As wind and PV systems are intermittent in nature, therefore the variation in power generation will be according to seasonal variation. Therefore, it is not needed that HES may fulfill the required load demand.

If total power generation of hybrid system (ie. combination of PV array and WT system) is not able to fulfill the load demand, then the battery is allowed to share the required real power. Power management of HES depends on State of Charging (SOC) of battery; accordingly, the battery can be charged or discharged. To get efficient power distribution, battery should operate in high efficiency region and battery SOC should be maintained at a reasonable level ie. between 40% and 80% [13].

Battery Energy Storage System (BESS) is made up of a bi-directional DC/DC converter, control system and a battery bank. This system should be able to operate in two directions ie. battery can be charged to store the extra energy and also can discharge the energy to loads.

In other words, it can charge and discharge to balance the power between PV generation and load demands and thus improve the stability of the entire system. PV array system and BESS has its independent control objective, and by controlling each part, the entire system is operating safely [10]. Life of a battery is more if it is kept at near 100% of its capacity, or returned to that state quickly after a partial or deep discharge [15]. If the renewable resources and the batteries are not able to satisfy the load demand then only DG is used [6].

IV. OPTIMAL SIZING OF HES

The aim of this study is to achieve HES, which should be optimally designed in terms of economic, reliability and environmental measures subject to physical and operational constraints/strategies. There are many ways to find the economic viability of distribution generation and energy efficiency projects [5].

The economic viability of a proposed system is influenced by many factors which contributes expected profitability. In economical analysis, all costs must be considered like-

- Capital cost
- Replacement cost
- Operation and maintenance cost
- Fuel cost (just for DG)

For optimal design the total annualized costs is defined as-

Total annualized cost = Sum of annualized cost of each hybrid system components

where,

Annualized cost = annual capital cost + annual replacement cost + annual operation and maintenance costs + annual fuel cost (just for DG) [12].

The capital and replacement cost, the operation and maintenance costs are combined therefore a comparison may be made.

$$\min C_t(P_w,\ P_{PV},\ P_B,\ P_{DG}) =$$
$$\min\left(C_w + C_{PV} + C_b + C_g + C_r\right)$$

where,

C_t = total cost of the system

$P_w,\ P_{PV},\ P_B,\ P_{DG}$ = capacity of WTG, PV panel, battery, and DG

$C_w,\ C_{PV},\ C_b,\ C_g,\ C_r$ = total cost of WT system, PV panel, battery, DG and total cost of considering the power- supply reliability [6].

A. Design Constraints

In target system, there are physical or operational limits, so there are also the set of constraints that should be satisfied throughout the operation, it means to solve the optimization problem, all of the below constraints have to be considered [6][12].

Power balance constraint: Total power supply from HES, for any period t must supply total demand with certain reliability criterion and it is given by [6]-

$$P_W(t) + P_{PV}(t) + P_b(t) + P_g(t) \geq (1-R)\,P_d(t)$$
$$P_W(t) + P_{PV}(t) + P_b(t) + P_g(t) \leq P_d(t)$$

where,

P_W, P_{PV}, P_b, P_g and P_d = wind power, solar power, charged/discharged battery power, DG power and total load demand

R = ratio of maximum permissible unmet power wrt total load demand at each time instant.

Battery capacity constraint: It is given by [6]

$P_{b_{min}} \leq P_{b_{SOC}} \leq P_{b_{max}}, 0 \leq P_{b_{cap}} \leq P_{b_{cap\,max}}$, $P_{bt} \leq P_{b_{max}}$

where,

$P_{b_{SOC}}$ = SOC of storage battery

$P_{b_{cap}}$ = capacity of storage battery

$P_{b_{min}}$ = minimum permissible storage level

$P_{b_{cap\,max}}$ = allowed storage capacity

P_{bt} = hourly charged or discharged power

$P_{b_{max}}$ = hourly inverter capacity

No. of WT, PV cell and battery constraints: It is given by [6]-

$$0 \leq S_n \leq N_{PV,P_{max}}, 0 \leq W_n \leq N_{W,P_{max}}$$
$$0 \leq B_n \leq N_{BAT,P_{max}}, 0 \leq H_n$$

where,

$N_{PV,P_{max}}$ = maximum capacity of PV panel

$N_{W,P_{max}}$ = maximum capacity of WT

$N_{BAT,P_{max}}$ = maximum capacity of battery panel.

V. OPTIMAL SIZING TECHNIQUES OF HES

Suresh *et al.* [1] proposes HES which combines PV and WT and uses Perturbation and Observation (P & O) Maximum Power Point Tracking (MPPT) technique, which works well if irradiation does not vary quickly with time, but fails to quickly track the maximum power points. Ahmed *et al.* [2] proposes HES which combines solar PV and WT and uses Incremental Conductance (IncCond) MPPT technique which offers good performance under rapidly changing atmospheric conditions and has two divisions and structure is similar to P & O algorithm because condition, dP/dV = 0, rarely happens.

Osman Haruni *et al.* [3] proposes voltage and frequency stabilization methods of hybrid Wind-Diesel (WD) Power System (PS) to obtain maximum contribution of wind resource in local power generation, in which a technique for power sharing between a Wind Energy Conversion System (WECS) and a DG system is also addressed during the WD hybrid operation.

Keyrouz *et al.* [4] address MPP tracker in PV, wind and fuel-cell HES by using the algorithm which is based on Bayesian information fusion combined with swarm intelligence. Javadi *et al.* [7] apply a novel intelligent method to optimal sizing problem and economic assessment in PV, WT and lead acid battery bank to minimize the total cost of the stand alone hybrid system by Artificial Bee Colony (ABC) optimization method. Shahirinia *et al.* [12] presents an optimized design for wind farm, PV array, DG and battery bank for standalone hybrid PS based on Genetic Algorithm (GA) and also economical costs like capital, replacement, operation and maintenance cost and fuel cost and economic aspects like capital recovery factor, interest rate, inflation, sinking found factor is expressed for each power source. Govardhan *et al.* [5] address the issue of optimal operating strategy and cost optimization scheme for a Microgrid (MG) by evolutionary techniques like Particle Swarm Optimization (PSO), Craziness based Particle Swarm Optimization (CRPSO) and ABC algorithms and uses a MG with WT, PV array, DG, fuel cell and microturbine. Bansal *et al.* [6] proposes Biogeography Based Optimization (BBO) algorithm to predict optimal component sizing of Small Autonomous Hybrid Power System (SAHPS) in remote areas, which finds operational strategy by reducing total cost of SAHPS and guarantees the availability of energy and applied to design wind/PV/hydro HES to supply a varying load. BBO is applicable to majority of problems, where GA and PSO are applicable and its results are compared with Hybrid Optimization Model for Electric Renewable (HOMER), GA, PSO, Comprehensive Learning Particle Swarm Optimization (CLPSO) and EPSDE. He also presents system configuration, characteristics of main components, overall sizing, control and Power Management Strategy (PMS) for HES.

VI. PROPOSED TECHNIQUE

On the basis of most relevant papers on design, modeling, control and optimization of hybrid system, the proposed technique is “Ant Colony Optimization (ACO) algorithm”. It is applied in many fields and achieved a rapid development.

.

It was recently proposed algorithm by Marco Dorigo in his doctoral dissertation in 1992, and idea was from the activities that ants can explore when they are searching food. It is an intelligent bionic and probability algorithm which searches the optimization paths and a kind of simulated evolutionary algorithm [2][1]. In this, ants construct the solution of optimization problem by multi stage decision-making process [6]. It is a fruitful paradigm to design metaheuristic algorithm for combinatorial optimization problems. Metaheuristic part allows the low level heuristic to get solutions better than those it could have achieved alone, even if iterated. Essential trait of this algorithm is combination of priori information and posteriori information. Priori information is about the structure of promising solution and posteriori information is about the structure of previously obtained good solutions [11]. It has strong robustness, good distributed calculative mechanism and it is easy to combine with other methods. Generally, TSP problem is taken as example to introduce the basic principle of ACO [1].

If this algorithm is applied on function optimization problem then result gives gain optimization value very quickly, therefore it is viable and feasible method [1]. To improve convergence time of ACO and to avoid falling in local best, a novel ant colony-genetic hybrid algorithm is used which gives higher convergence speed, better escape capability from local best and preferable quality of optimal solution [8]. To improve the basic ACO algorithm in two aspects: next region selection and pheromone updating, this improved algorithm is applied to multi-terminal wire to get better solution in short period. It shortens the searching time, prevents the algorithm running into local optimal value, and gets short wire length. Finally, it is an effective method to solve difficult NP wire issues [9]. If the pheromone updating method is adjusted, the parameter control is added in local pheromone update rule and global update rule then the direct blind signal detection is possible [10].

In ACO, there are many improvements like - improvement of algorithm in self-adaptive, improvement of increasing the diversity of various groups, improvement of enhancing local search, combine with global optimization algorithm, and also with deterministic local optimization algorithm [2].

A. Applications of ACO

Novel effective three-step optimum configuration strategy for adjustable parameters is beneficial to the application and the development of ACO algorithm in various kinds of optimization problems [7].

Other applications- Bus route, delivery route and garbage collection, Products composition, Protein folding, Personnel placement in airline companies, Lacquering machine feeding, Online optimization in telecommunication network, Machine scheduling: Transport time minimization in distant production location.

VII. CONCLUSION

In order to utilize RES efficiently and economically, one optimum sizing method is developed i.e. HES- combine PV, wind, diesel and BESS feeding a load. Wind and PV generation systems are main power generation devices, and the battery acts as a storage device for excess power. PV generation gives many benefits like it needs no fuel costs, nonpolluting, needs little maintenance, and emitting no noise when compared to others. Solar panel has standard value of insolation and temperature. Design, control, and optimization of HES are very complex task. Main purpose of this designing is reliable supply of load under varying weather conditions, with minimum cost. In this, all economical costs like capital, replacement, operation and maintenance cost and fuel cost (just for DG) for all modules have been considered. The system configuration, characteristics of the main components, overall sizing, control and PMS for HES has also been presented.

Because of variety of system's constraints, to solve the optimization problems, ACO algorithm has been suggested, which minimizes the total operating cost of a practical system. More expensive and complex control algorithms are not required. Proposed algorithm is used for operations in which accuracy, cost and time are important.

REFRENCES

[1]. M. Suresh and Yerra Sreenivasa Rao, "Maximum Power point Tracking in Hybrid Photo-voltaic and Wind Energy Conversion System", *Proceedings of International Journal of Engineering Research & Technology (IJERT)*, Vol. **1** Issue 5, July-2012.

[2]. Nabil A. Ahmed and Masafumi Miyatake "A Stand-Alone Hybrid Generation System Combining Solar Photovoltaic and Wind Turbine with Simple Maximum Power Point Tracking Control", *IEEE 2006*.

[3]. Abu Mohammad Osman Haruni, Ameen Gargoom, Md. Enamul Haque, and Michael Negnevitsky, "Voltage and Frequency Stabilisation of Wind-Diesel Hybrid Remote Area Power Systems", Centre for Renewable Energy and Power Systems, School of Engineering, University of Tasmania Hobart, TAS 7001, Australia.

[4]. F. Keyrouz, M. Hamad and S. Georges, "A novel unified maximum power point tracker for controlling a hybrid wind-solar and fuel-cell system", *Proceedings of Eighth International Conference and Exhibition on Ecological Vehicles and Renewable Energies (EVER), IEEE 2013.*

[5]. M. D. Govardhan and Ranjit Roy, "Artificial Bee Colony based Optimal Management of Microgrid", *IEEE 2012*.

[6]. Ajay Kumar Bansal, Rajesh Kumar and R. A. Gupta, "Economic Analysis and Power Management of a Small Autonomous Hybrid Power System (SAHPS) Using Biogeography Based Optimization (BBO) Algorithm", *IEEE Transactions On Smart Grid*, Vol. **4**, No. 1, March-2013.

[7]. Mohammad Reza Javadi, Abolfazl Jalilvand, Reza Noroozian and Majid Valizadeh, "Optimal Design and Economic Assessment of Battery Based Stand-Alone Wind/PV Generating System using ABC".

[8]. P.PRADEEP and B.KIRAN BABU, "Power-Management Strategies for a Grid-Connected PV-FC Hybrid System By Using Fuzzy Logic Controller", *Proceedings of International Journal of Modern Engineering Research (IJMER)*, Vol. **2**, Issue. 2, pp-358-364, ISSN: 2249-6645, Mar-Apr 2012.

[9]. Robert Cardenas, Ruben Pena, Jon Clare and Greg Asher, "Power Smoothing in a Variable Speed Wind-Diesel System", *IEEE 2003*.

[10]. B.K. Prusty, Dr. S M Ali and D.K. Sahoo, "Modeling And Control of Grid-Connected Hybrid Photovoltaic/Battery Distributed Generation System", *Proceedings of International Journal of Engineering Research & Technology (IJERT),* Vol. **1** Issue 9, ISSN: 2278-0181, November- 2012.

[11]. Sami H. Karaki, Riad B. Chedid and Rania Ramadan, "Probabilistic Production Costing of Diesel-Wind Energy Conversion Systems", *IEEE Transactions On Energy Conversion,* Vol. **15**, No. 3, September- 2000.

[12]. A.H.Shahirinia, S.M.M. Tafreshi, A. Hajizadeh Gastaj and A.R.Moghaddamjoo, "Optimal Sizing of Hybrid Power System Using Genetic Algorithm".

[13]. Sweeka Meshram, Ganga Agnihotri, and Sushma Gupta, "Power Management Strategy for Active Power Sharing in Hydro/PV/Battery Hybrid Energy System", *Chinese Journal of Engineering,* Hindawi Publishing Corporation, Vol. 2013, Article ID 723860, 7 pages, http://dx.doi.org/10.1155/2013/723860.

[14]. D. Yamegueu, Y. Azoumah, X. Py and N. Zongo, "Experimental study of electricity generation by Solar PV/diesel hybrid systems without battery storage for off-grid areas", *Renewable Energy*, Elsevier, 2010.

[15]. Bogdan S. Borowy and Ziyad M. Salameh, "Optimum Photovoltaic Array Size for a Hybrid Wind/PV System", *IEEE Transactions On Energy Conversion*, Vol. **9**, No. 3, September-1994.