Energy Management Optimization Techniques for Hybrid Renewable Energy Systems

N. Himabindu, Rajashekar P. Mandi

Abstract*: A Smart Grid is a reviving structure of traditional centralized power sector which incorporates smart software and hardware technologies. It provides communication among the prosumers and consumers to achieve sustainability and reliability in an economical way. A microgrid (MG) is a unit of smart grid which consists of distributed energy sources with renewable energy sources, energy storage units and variable loads. Because of stochastic nature of renewable energy sources to maintain balance between supply and demand a novel hybrid energy management controller need to be devised. This paper presents various operational objectives and constraints associated with energy management system of hybrid energy system. Also it compares and discusses various optimization algorithms in the literature.

Keywords*: Greenhouse gases (GHG), Hybrid Renewable Energy Sources(HRES) ,Information and Communications Technology (ICT), Smart Grid(SG), Optimization, Energy Management System (EMS)

I. INTRODUCTION

Energy consumption of any nation indicates increased activities in various sectors of country's economy. This leads to a better quality of life, in other terms- the percapita energy consumption of a country is an index of standard of living of the people in the nation. In this context globally there occurred an unprecedented increase in the demand for electrical energy.A traditional electric grid is centralized and makes use of fossil fuels[1] like coal, oil and natural gas as primary energy sources. Electricity production generates nearly 26% of the total global greenhouse gas (GHG) emissions which is a serious environmental concern with regards to global warming issue.With the dwindling of the fossil fuels, rise in the fuel prices, and increasing environmental concerns, Renewable Energy Sources (RES) which are the alternative sources for fossil fuels is gaining significant importance. However because of the variable and the intermittent nature of RES, two ormore forms of energy along with storage can be combined to form a hybrid power system which can alleviate the problem of stochastic renewable sources.On the other hand, with the advent of Information and Communications Technologies (ICTs) and the rapid growth in sensors and automation, an intelligent grid called "Smart Grid" is emerging to overcome the issues pertaining to traditional centralized grid. Also, Smart grid is the building blocks of MicroGrids. In this paper author emphasizes the importance of Energy Management System (EMS) with an intelligent controller which incorporates computational intelligent algorithms. The objective of thereview in this paper is to examine various parameters to be optimized to integrate Hybrid Renewable Energy Sources (HRES) and analyzing the various optimization techniques employed for Optimal EMS of HRES.

The organization of the paper is as follows: In Section II Hybrid Energy System is presented where the importance of microgrid and EMS is discussed. In Section III Optimization Techniques used for various mathematical objectives are discussed. Section IV reviews on various intelligent algorithms used to optimize the objective functions for EMS of Hybrid renewable energy System. Finally Conclusion and future work is presented in section V.

I. HYBRID ENERGY SYSTEM

A. MicroGrid

Microgrid is a combination of distributed generators including both Renewable energy sources and other micro energy sources,energy storage systems and the loads. Because of the stochastic nature of Renewable energy sources, in order to provide continuous uninterruptible power supply microgrids should be operated both in Grid connected and islanded modes. To achieve stable operation and ensure coordination between the various units an efficient energy management scheme is required.

B. Energy Management System

The energy management in microgrid is nothing but a strategy to determine the most economic dispatch of Distributed generators preferably renewable energy sources that should minimize the total operating cost and parallelly the load demand should be met satisfactorily.

Generation side:

In a common Hybrid energy system, where we have solar, wind, diesel, battery and utility grid on supply side, the role of EMS is to select the appropriate energy source which meets the desired demand with minimum cost. It should take care of reduced CO_2 emission which is nothing but selecting therenewable sources than the central grid wherever possible. To optimally select the discharging criteria if vehicle to grid (V2G) concept is present.

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Demand side:

On the demand side, the role of EMS is to reduce the customer electricity bill byoptimally selecting the energy producer if multiple generators and dynamicmarket pricing scheme is existing. To optimally select the charging and dischargingpatterns if Grid to Vehicle (G2V) and V2G concepts are introduced into the market.Both generation and consumption sides are to be optimized parallelly inorder to achieve optimal operation of the entire microgrid.However this leads to complexity in objective functions of the energy management problem in view of mathematical terms.In this context, computational intelligent algorithms are required to solve these mathematical objective functions.

Before expecting optimization we need to have proper load forecasting(fig.1) and generation capacity forecasting. Load characteristics should be studied if Demand Side Management (DSM) is to be implemented.

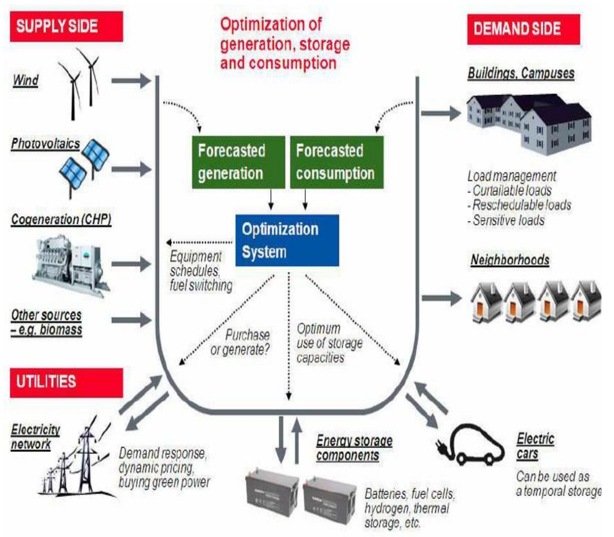

Fig 1: Schematic Microgrid system

II. OPTIMIZATION TECHNIQUES

Optimization algorithms are designed to compute maxima or minima of mathematical functions. To design a system for optimization various constraints and objectives should be considered. To solve complex mathematical functions Optimization Techniques and methods are very helpful. Variousoptimization objectives in EMS of HRES include maximizing the efficiency of the system, reliability,sustainability, user comfort level in case of DSM and minimizing the cost of its generation, GHG emissions, cost of electricity bills, Peak to Average (PAR) ratio.

To achieve the mentioned optimal objectives, many algorithms had been proposed by earlier authors like in [2], the author proposed a methodology for optimal wind and PV systems to minimize cost of the entire system which includes the battery chargers, PV modules, installation and maintenance costs. In [3] the hourly operation cost is considered and with the inclusion of battery storage using OptQuest tool in ARENA 12.0 software the sizing of hybrid wind PV system is optimized.

Linear programming model (LPM) is applicable in cases where the mathematical objective function is linear and the variables in design space are framed with linear equalities and inequalities. For optimization of HRE system, LPM model has been used in several cases [4-7]. Reliability and economicanalysis can be performed but it adversely affects the capacity of overall energy delivery if any one of the renewable fails to operate accordingly.Nonlinear programming (NLP) model is applicable in scenarios where the design of the objective functions or the constraints are nonlinear in nature. Some authors[8-9] applied this model which solved complex problems. The drawback of this technique is that the computational burden of the problem increases as the numbers of iterations are quite more.

In case of Dynamic Programming (DP) model, the problem will be split further into sub problems. Each stage can be optimized with this model. The presence of more related functions leads to complex coding and implementation.

In [10], the author proposes a mixed integer linear programming (MILP) design for optimization in wind–PV hybrid energy systems which can solve the placement of the wind–PV generators and the design of the micro grids. There are some other conventional methods like montecarlo-simulation [11], branch and bound [12], trade off [13] etc. that have been used by various researchers in a successful way.The cons of the above discussed traditional methods are that they often fall in local optima specifically when non-linear objective functions are existing. Tosolve this issue various modern intelligent computational optimal techniques are feasible to apply upon.

III. COMPUTATIONAL INTELLIGENT ALGORITHMS FOR HYBRID ENERGY SYSTEM

In paper [14], a model for demand side management is proposed with inclined block-rates and ToU tariff as a combined architecture. ACO optimization technique is being used for obtaining the solution. After the simulation is being done, the output indicates that the proposed model increases the sustainability rate of the selected grid. It also gives the minimum cost solution. The designed controller operates effectively with respect to minimization of - consumer electricity bill, peak to average ratio (PAR) and maximizing the consumer satisfaction than the controller without this technique.Refer fig.2.It was reported that using the controller with ACO technique reduced the energy bill from 267 cent to 115 cent.

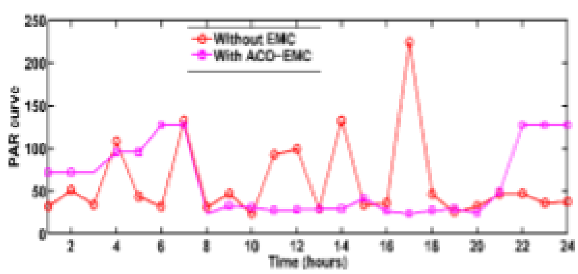

Fig.2.PAR Curve

In paper [15], to encounter the heating,ventilation and air-conditioning load, the author designed a model which includes generating by hybrid renewable resources and storage devices. The author used optimization method based on Genetic Algorithm with a two-point method to reduce cost and improve efficiency. For assessing the energy efficiency, the two constraints considered for calculation are maximum rating of storage device and surplus energy. The simulation output indicates that there is negotiation between the reliability in terms of meeting the demand and economics of wind and PV generation levels.

In paper [16] firstly a day-ahead DSM(Demand Side Mnagement) optimization problem is formulated, which includes demand, generation, storage and cost models. Three typical scenarios of pricing and regulation are studied, i.e. “Real time pricing scheduling”, “ToU with FiT”, “Real time pricing plus FiT”. A distributed algorithm is used to optimize DSM problem, which can preserve the user’s privacy and is also scalable in both time domain and sample size.

The result shows(fig.3) that DSM could reduce the PAR under all three scenarios, to 1.7534, 1.8243 and 1.8298 in the sequence of Scenario 1 to 3 from the original PAR of 2.0740. This DSM system has reduced the direct dependence on the grid down to 70%.

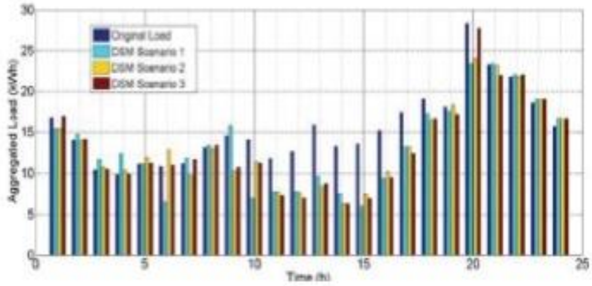

Fig.3. Actual aggregated load that is DSM less compared with the aggregated load after optimization withDSM under three different scenarios in 24-hour time slot.

A two dimensional particle swarm optimization was introduced for the DSM of residential load in a smart micro grid in paper [17]. In this work, inorder to achieve the objective of minimum cost of the total electricity price, the appliances of the consumers are scheduled as per the priority-which indirectly minimizes the peak power demand. The information related to a day ahead schedule with affordable delay and usage is recorded and load shifting strategy is implemented. With the proposed algorithm the objective of minimizing the electricity bill of consumers is achieved along with reduction in peak power.

Table- I:Total bill reduction WRT minimum price

Total Bill Reduction			
Initial Bill	Final Bill	Bill Saving	% of Saving
34581	30069	4512	13.05
34581	31435	3146	9.10

MATLAB software was used to carry out the simulation of the proposed model. An affordable delay of 8 hour is considered. Total price and peak power are considered in terms of minimum price criteria where savings of 13.05% and 17.44% was achieved respectively.(refer Table-I)

Table- II: Peak Power reduction WRT minimum power

Peak Power Reduction			
Initial Peak Load	Final Peak Load	Peak Reduction	% of Peak reduction
274.70	226.80	47.90	17.44
274.70	216.65	58.05	21.13

Similarly a 9.10% of total price and 21.13% of peak power was achieved in terms of minimum peak power criteria.(as in Table-II)In this paper [18], the author proposed a system for a microgrid which consists of combination of distributed generators of power and the loads. To meet the surplus or deficient power, battery energy storage system is being used. A Fuzzy Logic Controller (FLC) with an adaptable rule inference system has been considered in the proposed EMS model.GA has been proposed to increase the total profit by including the BESS as energy buffer.Battery stress index is taken as a constraint and the optimization results have been compared with the former FLC model. Simulation output indicate – the best operation is seen when there is balance between supply and demand. This proposed technique improves the microgrid profits without affecting the BESS.

The Energy Management System of this paper [19] includes a Fuzzy Logic Controller (FLC) which uses Multi-Objective Genetic Algorithm for optimization. It improves the net profit of the generating units and state of health of batteries. Two objective functions for increasing the profits in specified time and reduce the battery stress. The proposed controller meets the above two objectives by adopting monoobjective GA. The results are compared by implementing two more approaches-MO GA with only profits and genetic algorithm with a convex objective function. Themulti objective GA simulations give an extended set of optimal solutions on the Paretofront that allow to create predefined objectives depending on the user requirements.

Paper [20] proposes architecture for the EMS for minimizing the cost function. The modules considered in the microgrid are generation of diesel generator, solar PV, buying or providing energy, storage device. Rolling optimization method has been adopted to meet the design criteria. Here this optimal method makes use of multi-point radiation based parallel branch and bound (MPRP-BB) algorithm to enhance the computational efficiency. The experimental outputs evaluate pros and cons of global as well as rolling optimization methods. From the simulation, it is proved that the rolling optimal method can satisfy the energy requirement whereas the global optimal method cannot meet the same. Comparing the cost criteria, the former method is expensive than the latter method if the predicted generation from solar is met and it can satisfy the demand when the predictions are incorrect, which creates a more practical EMS model.

In this paper [21], a two-step algorithm has been proposed: the initial one takes and modifies the demand request and the intermittent prediction at any given period. An economical cost function of all the modules is defined. Later, power quality issues are taken care of, like the voltage profile at coupling point, pf correction. This proposes minimal reactive power reference signal for the given selected models.

In [22], the EMS model is considered for two communicative microgrids. Initially in offline minimization method, it indicates the communication between the two grids and incorporating storage devices avoids the problems due to unpredictable renewable generation and this in turn minimizes the overall cost of the energy.

Considering this offline strategy, two real time algorithms of less complication has been proposed for the communication of the proposed grids taking the supply and demand into consideration. The output indicates that the defined methods operate close to minimal offline method considering different constraints.In paper [27], author proposes an operating cost-minimization model to achieve optimal energy management in a residential microgrid. In considers costs of energy trading, penalty on adjustable load shedding, wearing of batteries in EVs.Three scenarios are considered to estimate the tradeoff between operational cost of MG and average SOC of battery in EVs.The limitation in this model is that role of plug and play feature of EVs on stability of MG is not considered.Author of [28] an adaptive intelligence model for EMS of grid connected MG. The main objective is to maximize the usage of RERs and reduce load fluctuations considering the stochastic nature of RERs and uncertain loads. The results(Table-III) show that the efficiency of hybrid ESS and the ratio of discharged energy to the energy available is more compared to PSO method alone.

Table-III:Comparision with PSO and with Adaptive Intelligent Technique(AIT)

Week	New Load Demand with PSO	New Load Demand with AIT	HESS efficiency with PSO	HESS efficiency with AIT
1	9.88	3.34	26.02%	78.56%
2	8.16	0.84	25.46%	95.03%
3	10.68	8.12	42.68%	82.70%
4	10.72	12.00	64.76%	64.14%
5	12.29	11.20	38.11%	55.48%
6	9.06	2.70	26.38%	78.12%
7	9.65	3.19	37.63%	94.19%
8	1.31	1.11	25.80%	59.00%

The Table-IV summarizes some of the findings of optimization techniques in MG for EMS by earlier researchers

Table- IV: Analysis of MG EMSs based on various optimization techniques

Reference	Objective Function	Optimization Technique	Findings
[14]	$min \sum_{t=1}^{24}(a_1 \sum_{a=1}^{A}(E_a(t) * C_a(t))) + a_2(\varphi_a(t))$ where, Ca is the cost of electricity which is to be minimized in each time slot	ACO	Energy management controller with and without ACO has been compared. The results show that controller with ACO works more efficiently than without ACO in terms of minimizing cost of electricity bill, peak to average ratio and maximizing comfort level of users.
[23]	Min Obj(.) = $\sum_{t=1}^{H}\{\sum_{i=1}^{N} Fi(P_i(t))u_i(t) + P_{tie}(t) * price(t)\}$	Enhanced Bee Colony Optimization	Authorconsiders an MG system consisting of a three MicroTurbines, a PV, a wind turbine and battery storage. Of the total generation being supplied,44.74% is from DG units and 55.26% from the utility and the loss is 3.06%.If all the power is from utility, the cost is NT$8305.235.With PV and WT the cost is cut down to NT$5521.03.With battery and MTs the cost has come down to NT$5037.031.
[24]	For upper level EMS, $Y1 = \sum_{t=1}^{T}[C_F(t) + C_0(t) + C_M(t)]$ Where T is the schedule period of proposed EMS and t is the time period.For lower level EMS, $Y_2^j = \sum_{t=1}^{T} C_F^j(t) + C_0^j(t) + C_M^j(t)]$	Two level hierarchical optimization method	Nonlinearity is eliminated by considering approximate linearization and the nonconvexity by taking implicit logic constraints. Different cases are discussed to gain profits in interconnected mode and for stable operation in disconnected mode.
[25]	$minimize \sum_{h=1}^{H} C_h(\sum_{n=1}^{N}\sum_{a=1}^{A}(z_{n,a}^h))$	Energy consumption scheduling algorithm	A smart grid system with 10 users is considered where each user is provided with Energy Consumption Controller (ECC).Shiftable and non shiftable appliances are identified. The simulation results show that the energy consumption reduces to 24%,energy cost reduces by 21%.
[26]	$Min\ (F) = \sum_{i=1}^{NG} F_i P_i$	Reduced Gradient Method	Cost curves of various profiles like change in wind, battery profiles are drawn and hence show that O&M cost is optimized

IV. RESULTS AND DISCUSSIONS

After reviewing the papers it is observed that there is scope for using evolutionary algorithms and computational intelligence techniques (PSO, ACO, HBO, Firefly, elephant herding, gray wolf etc.) for energy management optimization. Microgrid management is a big issue in the present day research and tackling the issues such as seamless transfer of mode of operation from grid connected to the island and vice versa is very crucial.

The control scheme such as droop control, communication techniques using multiagents, prediction algorithms can be used for energy optimization in HRES. Multiobjective optimization function or fitness function can be developed considering various constraints.

VI. CONCLUSION

The energy management strategy of hybrid energy sources is a complex mathematical problem. It requires intelligent computational algorithms to resolve the objective problems. This paper presents a comprehensive exploration of various optimization techniques to solve cost minimization problems with constraints of hybrid energy systems in a microgrid system. The future work may be to develop a computational intelligent algorithm to provide better solution for cost minimization, enhance reliability, efficiency, sustainability of a given system.

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