Optimal System Designing for Hybrid Renewable Energy System with the Aid of Adaptive Genetic Algorithm Incorporates Cauchy Mutation (AGA-Cauchy)

Sandeep Segu Ramadas^{1,*} and Rudranna Nandihalli²

¹*Research scholar, Department of Electrical and Electronics Engineering, Visvesvaraya Technological University, Belagavi-590018, Karnataka, India*

²*Professor, Department of Electrical and Electronics Engineering, R V college of Engineering, Bengaluru-560059, Karnataka, India
E-mail: saandysegu@gmail.com; rudrannaa@gmail.com*

**Corresponding Author:*

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Abstract

Depletion and scarcity in conventional fossil fuels urge by utilizing renewable energy source for power generation. Hybrid renewable power generation having enormous pros in satisfying power demands over standalone renewable energy power generation. In recent decades, most of the researcher in this platform proved that the hybrid renewable power generation having consistency in satisfying power demand. These research outlets contemplate by incorporating photovoltaic power generation and wind for generating power to satisfy power demand. The intention is to design an optimal system in minimize cost for generating stable power supply to assure the demand. Here, three optimization techniques utilize to predict and design an optimal hybrid system configuration by choosing appropriate units for solar photovoltaic cells, wind power generation and number of battery backup. This objective solve by incorporating Genetic Algorithm (GA), Differential Evolution (DE)

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and Adaptive Genetic Algorithm with Cauchy mutation (AGA-Cauchy). It is quite evident that the proposed AGA-Cauchy reveals superior results as cost effective and by satisfying power demand over other comparative techniques.

Keywords: Hybrid renewable energy system, Genetic Algorithm (GA), Differential Evolution (DE) and Adaptive Genetic Algorithm with Cauchy mutation (AGA-Cauchy), solar photovoltaic cells, wind power and Battery.

1 Introduction

Wind and solar are two significant source of renewable energy derived from solar photovoltaic cells and wind turbines. These two sources of energies are rich and eco-friendly to environment over conventional fossil fuels [1]. This sort of power generation via renewable energies trim down the cost involve in power generation and distribution to remote places [2].

In recent decades various researcher put forth their research intention in finding optimal system design by utilizing hybrid photovoltaic (PV) and wind power generation [3–8]. It is hard to find the full dataset from the research article to carry out research by incorporating new techniques to enhance the performance of existing methodologies [9, 10]. By incorporating recent develop optimization techniques; the intention of testing optimal design of hybrid solar PV and wind energy system will be appropriate. This investigation leads predicting optimal number of units to be utilized to design a optimal system configuration.

This paper investigates predicting optimal system configuration for solar PV, wind power generation and numbers of batteries enrol. This optimal designing system configuration involves incorporating optimization techniques to predict optimal units for solar PV, wind power generation and batteries to satisfy the power demand in cost effective.

2 Literature Review

O. Nadjemia et al. [11] 2017, had foreseen the expansion in energy demand has made the renewable resources more alluring. Representing the largest sources of renewable energy, solar and wind systems are extending because of the rapid depletion of fossil fuel resources and the developing confirmation of the

global warming phenomena. That paper shows a refresh writing survey on optimization procedures utilized for the sizing and energy management of hybrid photovoltaic/wind/battery energy systems. Besides, another sizing approach based on cuckoo search (CS) algorithm was proposed for grid-connected hybrid energy systems. The sizing optimization was a multi-objective problem with financial, specialized and ecological limitations. The proposed strategy have better accuracy, faster convergence and less computation time contrasted with the particle swarm sizing optimization (PSO) procedure.

A.M. Abd-el-Motaleb et al. [12] 2016, had proposed the extent of that review was the optimal sizing of distributed generation in a hybrid power system with wind and energy storage units considering vulnerabilities. The commitment of the paper can be expressed as takes after: (1) an objective function based on self-adjusted transformative procedure in blend with Fischer–Burmeister algorithm is proposed to minimize the one-time venture and yearly operational expenses of the wind/energy storage sources; and (2) impact of the cycle proficiency and charging/releasing rate of various energy storage units on the framework cost is examined under various dependability and load moving levels. The computational execution of the proposed optimization solver is demonstrated keeping in mind the end goal to acquire the minimum possible investment cost. The introduced contextual investigations in that paper gave noteworthy bits of knowledge to the appropriate limit establishment at various estimations of dependability and load shifting levels.

Ali M. Eltamaly et al. [13] 2016, had proposed though smart grid takes care of a significant number of the contemporary issues, it offers ascend to new control and optimization problems particularly with the growing role of renewable energy sources. Load shifting technique had connected in this paper by partitioning the load into two classifications, high priority load (HPL) and low priority load (LPL). In that literature, another proposed design and optimization program for techno-economic sizing of standalone hybrid PV/wind/diesel/battery energy systems under smart grid hypothesis for the most reduced cost of generated energy at most elevated unwavering quality. The new proposed program was execute in adaptable design, which was not accessible in many market accessible projects. Numerous important outcomes can be extricated from the proposed program that could help analysts and decision makers.

Mohammed Alsayed et al. [14] 2013, had recommended power generation systems (PGSs) in light of hybrid renewable energy are one of the promising answers for future dispersed generation systems. Among various designs,

hybrid photovoltaic-wind turbine (PV-WT) grid associated PGSs are the most embraced for their great execution. That paper manages the optimal sizing of PV-WT by embracing diverse multi-criteria decision analysis (MCDA) optimization approaches. Sensitivity of MCDA algorithms has been investigated, by considering diverse weighting criteria procedures with various vacillation situations of wind speed and solar radiation profiles, in that manner highlighting points of interest and downsides of the proposed optimal sizing approaches.

Zong Woo Geem [15] 2012, had arranged photovoltaic (PV) and wind energies are renewable and free from greenhouse gas; they caught contrasting options to fossil fuels. Yet, numerous specialists had cost-optimally designed hybrid PV-wind systems. Nevertheless, they have from time to time given entire datasets to different analysts to complete comprehend their methodologies and to handle a similar issue with their novel strategies. Subsequently, this review indicates one case of the optimal design of a hybrid PV-wind system by providing, regular optimization formulation, full dataset and computing results with various design constraints. Ideally, numerous scientists will apply different optimization techniques to the problem in the future.

3 Proposed Methodology

The significance intention of this proposed technique is to predict the optimal size for hybrid wind and photovoltaic (PV) power generation in minimize cost. Renewable energy resources have come into prominence as a solution for increased energy demand worldwide. Since the nature of some renewable energy resources (RES) such as solar and wind energy is intermittent, the reliability of the system supplied from those sources are low. A hybrid energy system combining the several RES is one of the viable solutions to increase the reliability of the system. This method develops an optimal sizing for hybrid system configuration by predicting photovoltaic (PV) and wind power generating units. For predicting optimal sizing several techniques involves in the process are Differential Evolution (DE), Generalized Reduced Gradient (GRG), Genetic Algorithm (GA) and Adaptive genetic algorithm with Cauchy Mutation (AGA-Cauchy) are used. Amid, AGA-Cauchy produce superior results over comparative techniques in minimize cost by satisfying power demands. The entire flow of this proposed work detail in following Figure 1.

Figure 1 Overall flow diagram.

3.1 Adaptive Genetic Algorithm with Cauchy Mutation (AGA-Cauchy)

Genetic algorithms with adaptive parameters (adaptive genetic algorithms, AGAs) is a significant and promising variant of genetic algorithms. The probabilities of crossover and mutation greatly determine the degree of solution accuracy and the convergence speed that genetic algorithms can obtain. Instead of using fixed values of probabilities of crossover and mutation, AGAs utilize the population information in each generation and adaptively adjust the probabilities of crossover and mutation in order to maintain the population diversity as well as to sustain the convergence capacity. The following diagram details the flow of AGA-Cauchy in Figure 2.

Figure 2 Flowchart for AGA-Cauchy.

3.1.1 Initial solution

Adaptive based population is generated from randomly generated initial population, this form of generating population will covers certain region with couple of boundaries and try to find the optimal solution with in that region. Adaptive based population generation manipulate as follows.

$$Y_o = V_{\min} + V_{\max}^{-Y} \quad (1)$$

Y_o Denotes adaptive based population generation $V_{\min}$ and $V_{\max}$ refers opposite vector boundaries and Y indicates the population in the random generation.

This generated population are verified under objective constrain for refining whether the particular generated population in random generation as well as in opposition based generation is well enough to carried out for fitness computation, the population which doesn't satisfy the objective constrain will set as penalty cost of 10^{20} as fitness function. The objective constrain for generated population in both cases is as follows.

$$\sum_{t=1}^{24} (Po_{solar}^t * \Delta t) + \sum_{t=1}^{24} (Po_{wind}^t * \Delta t) \geq \sum_{t=1}^{24} (Po_{demand}^t * \Delta t) \quad (2)$$

3.1.2 Fitness computation

The population get satisfied under Equation (2), taken for fitness computation process. Fitness computation utilizes to predict optimal sizing design of Wind-PV in minimizes cost. The following equations utilized to find the optimal sizing of Wind-PV under minimized cost and the significant objective functions for fitness computations as follows.

$$Co_{total} = Co_{capital} + Co_{maintenance}. \quad (3)$$

This objective function present in Equation (3) comprised of total capital cost mentioned as $Co_{capital}$ and $Co_{maintenance}$ is total maintenance cost.

$$Co_{capital} = \frac{ACo_{capital}}{ICo_{capital}} \left[\begin{array}{l} No_{solar} * Co_{solar} + No_{wind} * Co_{wind} + No_{batt} * \\ Co_{batt} + Co_{backup} \end{array} \right] \quad (4)$$

Where, $ACo_{capital}/ICo_{capital}$ is said to be capital recovery factor, then the capital recovery factor is calculated by using formula

$$\frac{ACo_{capital}}{ICo_{capital}} = \frac{i(1+I)^{\%}}{(1+I)^{\%} - 1} \quad (5)$$

$$No_{battery} (No_{solar}.No_{wind}) = roundup \left[\frac{So_{req}}{\delta - So_{battery}} \right] \quad (6)$$

$$So_{req} (No_{solar}, No_{wind}) = \sum_{t=1}^{\max t} (Po_{solar}^t + Po_{wind}^t - Po_{demand}^t) \Delta t - \sum_{t=1}^{\min t} (Po_{solar}^t + Po_{wind}^t - Po_{demand}^t) \Delta t \quad (7)$$

Where, No_{solar} Indicate number of solar, Co_{solar} indicate unit cost of solar, No_{wind} indicate number of wind turbines, Co_{wind} indicate unit cost of wind turbines, No_{batt} indicates number of battery, Co_{batt} indicates unit cost of battery, and Co_{backup} indicate cost of backup generator.

$$Co_{maintenance} = \left[Co_m^{solar} \sum_{t=1}^{24} (Po_{solar}^t * \Delta t) + Co_m^{wind} * \sum_{t=1}^{24} (Po_{wind}^t * \Delta t) \right] \quad (8)$$

$$Po_{solar}^t = No_{solar} * Po_{solar_each}^t \quad (9)$$

$$Po_{wind}^t = No_{wind} * Po_{wind_each}^t \quad (10)$$

Where, Co_m^{solar} solar indicates unit maintenance cost for PV array, Co_m^{wind} indicates unit maintenance cost for wind turbine, P_{solar}^t is calculated by Equation (9), P_{wind}^t is calculated by Equation (10). Separate fitness value is computed for randomly generated population and adaptive based generation computation process will retrieve group of fitness solution amid, half of the solution is utilized for further process.

3.1.3 Population updating

New population generation done by means of crossover and proposed Cauchy mutation are detail further.

Figure 3 Single point crossover process.

3.1.3.1 Crossover

Crossover is the process of switching two different individual genes from the parent chromosomes for the generation of two new offspring chromosomes. The crossover carried out according to the crossover probability and there are different types of crossover amid; single point crossover utilize in this process shown below.

Single point crossover as shown in Figure 3, is the most popular crossover and it is widely utilized. A crossover site is aimlessly selected along the length of the mated strings and bits next to the cross sites are exchanged. If suitable site chosen, better children can be obtain by combining good quality parents else it harshly hamper string quality. In single point, crossover the head and tail of one chromosome break up and if both head and tail have good genetic material then none of the offspring will get the both good features directly.

$$Po_M = Po_M^0 \left(1 + \delta \frac{(fo_{\max} - fo_{\min})^{\eta_C} - fo_{avg}^{\eta_C}}{\psi(fo_{\max} - fo_{\min})^{\eta_C} - fo_{avg}^{\eta_C}} \right) \quad (11)$$

Whereas $\psi = (fo_{\max} - fo_{\min} / fo_{avg})^{\eta_C} Po_M^0$, Po_M represent initial mutation probability and adaptive mutation probability respectively, δ and η_C are coefficient factors and fo_{avg} , $fo_{\max}$, $fo_{\min}$ represent the average fitness, maximal fitness and minimal fitness of the individual of each generation respectively. By using this equation, the rate has found and that rate utilized for crossover and mutation process. The population of the next generation made up of the new individuals created by the process of crossover and mutation in this way.

3.1.3.2 Cauchy mutation

Cauchy mutation is the process of finding the probability that some new features might emerge due to change in the chromosome. Mutation performed

based on predetermined mutating probability by utilizing to mutate the individuals according to following Equations (12) and (13).

The one-dimensional Cauchy density function centered at the origin characterized by

$$fo(y) = \frac{1}{\pi} \frac{t}{k^2 + y^2}, \quad -\infty < y < \infty \quad (12)$$

Where, $k > 0$ is a scale parameter, y indicates population in the random generation. The Cauchy distributed function is

$$Fot(y) = \frac{1}{2} + \frac{1}{\pi} \arctan \left(\frac{y}{k} \right) \quad (13)$$

The Cauchy distribution operator utilized as a part of AGA is as follows.

$$We(i) = \left(\sum_{j=1}^{pop\ size} Vo[j][i] \right) / pop\ size \quad (14)$$

where $PopSize$ is the population size, $Vo[j][i]$ is the i^{th} velocity vector of the j^{th} particle in the population and $we(i)$ is a weight vector within $[-W_{max}, W_{max}]$.

$$g_{solution'}(i) = g_{solution}(i) + we(i) * Cadf(Y_{min}, Y_{max}) \quad (15)$$

Where, $Cadf$ is a Cauchy distributed function with the scale parameter $k = 1$, and $Cadf(Y_{min}, Y_{max})$ is a random number within $[Y_{min}, Y_{max}]$, which is a characterized domain of a test function.

The aforementioned Crossover and Cauchy mutation operators are utilize to update the previous generated random solutions. The following Table 1 illustrate the design parameters of PV, wind and battery n detail.

4 Result and Discussion

This section comprise of following analysis in sizing optimal numbers for solar, wind and battery with respect to economic cost. This investigation includes AGA-Cauchy distribution system, GA, GRG (Generalized Reduced Gradient) and DE to make the system design optimal. From different analysis, it is quite evident that the AGA-Cauchy reveals optimal result over other comparative technique. The entire implementation done in the working platform

Table 1 Design variables used for a PV-wind system

Variable	Value
Annual interest rate (i)	6%
Life span of the system (n)	20 years
Solar panel price (53W)	\$350/panel
Solar panel installation fee	50% of the price
Wind turbine price (1–20 kW)	\$20,000/turbine
Wind turbine installation fee	25% of the price
Unit cost of battery (C_{Batt})	\$170
Usage% of battery's rated capacity (η)	80%
Battery's rated capacity (S_{Batt})	2.1 kW h
Battery's life span	1500 cycles (4 years)
Unit time (Δt)	1h
Maintenance cost for PV array (C_{Mnt}^{Sol})	0.5 cent/kW h
Maintenance cost for wind turbine (C_{Mnt}^{Wind})	2 cents/kW h

MATLAB with system configuration 7th Generation Intel® Core™ i5-7200U Processor having 8 GB RAM (3.10 GHz) speed.

From Table 2, it is evident that change in sizing has influence the cost effective; this leads towards optimal sizing over conventional methodology (GRG). Difference in Solar PV, wind and battery units influence significance change in economic, which depict following analysis. Change in solar and battery unit from proposed methodology impact nearly 0.51% cost minimization over conventional methodology. Whereas, the contest technique GA having 0.10% lesser cost effective over conventional methodology and DE lags 2.92% lesser impact over proposed methodology this superior achievement from AGA-Cauchy possible because of its upgrading crossover and mutation section. Finally, the proposed technique comes up by designing the system configuration as 36 solar units, couple of wind power generation and 10-battery unit with cost effectively.

Table 2 Optimal sizing and its cost from different techniques

Technique	Number of Solar Panel	Number of Wind Power Generation Unit	Number of Battery	Cost in \$
AGA-Cauchy	36	2	10	7151.653
GA	83	1	13	7159.362
GRG [15]	37	2	9	7188.798
DE	87	1	13	7367.225

Figure 4 Hybrid power generation from different methodology throughout the day.

Figure 4, illustrates hybrid renewable energy Wind-PV power generation throughout the day from different methodologies optimal design configuration. This show the results obtain from AGA-Cauchy configuration reveals power generation as 62.4324 kW in 24hours. The total power generation from AGA-Cauchy take a lead over comparative system design. This system design not only satisfies power demand but also solve the cost effectively. This is clear that AGA-Cauchy methodology establish an optimal system design having power generation to satisfy the demand in low cost.

Figure 5, the difference in generating power units from hybrid renewable energy source to power demand is represent as delta. The scale range from (−3 to 5), this min max value denotes scarcity and surplus of power from the individual system design methodology. The proposed methodology attains almost positive result over other methodology, which expose optimal allocation of system size for each generating units. With solar photovoltaic system having 36 units of power generating, couple of units in wind power generation and 10 batteries backup leads the proposed methodology cost effectively and enhance the performance of overall system efficiency.

Figure 6, expose actual technical behaviour of AGA-Cauchy methodology; this shows the best and worst performance attain in individual iteration. This performance analysis exhibit, how the solution evolve in updating process, lesser length in every iteration range reveals effective performance in improved conventional genetic algorithm. When iteration moves on, the best fitness get converge in certain intervals and worst fitness lies non-linear in its nature, but lesser in the min-max range shows good sign in generating solution.

Figure 5 Change in power generation through the day.

Figure 6 Best-worst fitness in cost optimization.

The saturate point achieves once the iteration cross 150th level afterwards it moves constant throughout 200th iteration. At the point of saturation, the proposed methodology reveals effective cost as \$7151.653.

The Figure 7, exhibits the converging behaviour of implement methodologies. Amid, three implement methodologies the AGA-Cauchy reveal least cost over other implemented GA and DE. The AGA-Cauchy method exhibit linear convergence up to 80th iteration then slight narrow down in 85th iteration and then pickup with slight linear up to 150th iteration and make it saturate throughout the remaining section. The cost achieve from the proposed method is \$7151.653 which is \$7.709 lesser than GA, \$37.145 lesser than GRG and

Figure 7 Convergence graph.

finally \$215.572 lesser than DE. From the figure itself, the distance shows the superiority over other comparative methodologies.

5 Conclusion

Implementation executed successfully via MATLAB with the aid of optimization techniques. It is quite evident that the techniques perform well in this contest for designing an optimal system (number of solar photovoltaic cell, number of wind power generation and Battery backup). Sizing an optimal units in real time is quite challenging task influencing optimization techniques in this context really make the work bit easier. AGA-Cauchy reveals minimized cost for designing an optimal sizing generation system. In future, the upcoming researchers in this platform try to incorporate their own technique to improve/reduce the computational time involve in this manipulation process.

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Biographies

Sandeep Segu Ramadas obtained his Bachelor's degree in Electrical and Electronics Engineering from Visveswaraya Technological University, Belagavi in 2005, Then he obtained his Master's degree in Power Systems Engineering in 2007 from Visveswaraya Technological University, Belagavi and persuing his PhD in Electrical Engineering (Powe Systems – Renewable Energy Domain) from Visveswaraya Technological University, Belagavi. Currently, he is a Asst. Prof. at SJB Institute of Technology, Bengaluru. His specializations include Power Systems Renewable Energy and Artificial Intelligence. His current research interests are Renewable energy control using AI Techniques and controlling of hybrid renewable energy for standalone Systems.

Rudranna Nandihalli obtained his Bachelor's degree in Electrical Engineering from Karnataka University, Dharwad in 1984, Then he obtained his Master's degree in Power System Engineering in 1987 from Bangalore University and Ph.D Degree in 2011 from Visveswaraya Technological university, Belagavi. Currently, he is a Professor at R V College of Engineering, Bengaluru. His specializations include Transformer Insulation, Copper corrosion in Transformer. He serves as Technical member in various conferences. He is a Life Member of ISTE and indian society for contuing Engineering.