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Optimization of Hybrid Renewable Energy Systems (HRES) Using PSO for Cost Reduction

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Abstract

This paper presents a method for the optimization of the power generated from a Hybrid Renewable Energy Systems (HRES) in order to achieve the load of typical house as example of load demand. Particle Swarm Optimization Technique (PSO) is used as optimization searching algorithm due to its advantages over the other techniques for reducing the Levelized Cost of Energy (LCE) with an acceptable range of the production taking in consideration the losses between production and demand sides; the problem is defined and objective function is introduced taking in consideration fitness values sensitivity in particle swarm process. The algorithm structure was built using MATLAB software.

Keywords- Hybrid Renewable Energy Systems (HRES); Particle Swarm Optimization Technique (PSO); Levelized Cost of Energy (LCE).

1. Introduction

Renewable power generation can help countries meet their sustainable development goals through provision of access to clean, secure, reliable and affordable energy. That is because of scarcity of conventional energy resources, rise in the fuel prices and harmful emissions from the burning of fossil fuels has made power generation from conventional energy sources unsustainable and unviable. An associated with the challenge of the world's increasing demand for energy is the electrification for approximately two billion people in developing countries that do not currently have access to electricity. Although the world's population is expected to reach nine billion people in 2050, Most of this expected population growth will take place in developing countries and emerging nations [1].

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The rapid industrialization over the past three decades due to globalization, inventions in new technologies and increased household energy consumption of the urban population has resulted in the unprecedented increase in the demand for energy and in particular electricity. This has led to a huge supply–demand gap in the power sector. It is envisaged that this supply–demand gap will continue to rise exponentially unless it is met by some other means of power generation. Inaccessibility of the grid power to the remote places and the lack of rural electrification have prompted for alternative sources of energy [2]. So, Renewable energy has gone mainstream, accounting for the majority of capacity additions in power generation today. Tens of gigawatts of wind, hydropower and solar photovoltaic capacity are installed worldwide every year in a renewable energy market that is worth more than a hundred billion Euros annually. It has become imperative for the power and energy engineers to look out for the renewable energy sources such as sun, wind, geothermal, ocean and biomass as sustainable, cost-effective and environment friendly alternatives to conventional energy sources. However, the non-availability of these renewable energy resources all the time throughout the year has led to research in the area of hybrid renewable energy systems. In the past few years, a lot of research has taken place in the design, optimization, operation and control of the renewable hybrid energy systems. It is indeed evident that this area is still emerging and vast in scope [2].

The Hybrid Renewable Energy Systems (HRES) are a combination between more than one renewable energy source or at least one renewable source to conventional source and it can be either grid connected or better to be in stand-alone mode due to its advances in renewable energy technologies and power electronics converters which are used to convert the unregulated power generated from renewable sources into useful power at the load end. The most important advantage of HRES is to make best use of the renewable power generation technologies operating characteristics and to obtain efficiencies higher than that could be obtained from if a single power source is used. It can also address limitations in terms of fuel flexibility, efficiency, reliability, emissions and economics. Various aspects must be taken into account when working with hybrid systems for the generation of electricity. Reliability and cost are two of these aspects; it is possible to confirm that hybrid generation systems are usually more reliable and less costly than systems that rely on a single source of energy [3-5]. In various research papers [6-9], it has been proven that hybrid renewable electrical systems in off-grid applications are economically viable, especially in remote locations. In addition, climate can make one type of hybrid system more profitable than another type. For example, photovoltaic hybrid systems (Photovoltaic–Diesel–Battery) are ideal in areas with warm climates [10].

On the other hand, various mathematical models of the elements that make up these systems have been used, as well as various design and simulation models. The complexity of the models of the components of the hybrid systems mainly depends on the type of application (simulation, design, etc.). A lot of authors have been writting their papers about the optimum economic designs for hybrid systems as PV and/or Wind and/or Diesel systems with energy storage in batteries. Usually, the optimum design is carried out minimizing the Net Present Cost (NPC) investment costs plus the discounted present values of all future costs during the lifetime of the system or by minimizing the Levelized Cost of Energy (LCE) total cost of the entire hybrid system divided by the energy supplied by the hybrid system.

In this paper a general method is used to optimize the power generated from a hybrid system of Wind and PV module to minimize the LCE uses the PSO as the optimization technique. The PSO technique is explained in the second section while the algorithm used to minimize the LCE will be discussed in the third section. The result of the application is shown in the fourth section and the conclusion in the final section.

2. Particle Swarm Optimization (PSO)

With the growth of more mainstream interest in computational intelligence algorithms applied to real-world engineering problems there is a need to build tools that can be used in a wide variety of environments, from classroom to the field. Particle Swarm Optimization (PSO) is one recent technique that has been used with great success in the Computational Intelligence arena. PSO applies the concept of social interaction to problem solving. It was developed in 1995 by James Kennedy (social-psychologist) and Russell Eberhart (electrical engineer) [11, 12].

Inspired initially by flocking birds or fishes, Particle Swarm Optimization (PSO) is another form of Evolutionary Computation and is stochastic in nature much like Genetic Algorithms. Instead of a constantly dying and mutating GA population it has a set number of particles that fly through the hyperspace of the problem. A minimization (or maximization) of the problem topology is found by a particle remembering its own past best position and the entire group's (or flock's, or swarm's) best overall position. This algorithm has been shown to have advantages as GA without the big computational hit. Unlike in genetic algorithms, evolutionary programming (EP) and evolutionary strategies, in PSO, there is no selection operation. All particles in PSO are kept as members of the population through the course of the run. PSO is the only algorithm that does not implement the survival of the fittest. No crossover operation in PSO while mutation in EP is resembles. A variant of PSO is that it can be used for:

- Discrete PSO which can handle discrete binary variables
- MINLP PSO can handle both discrete binary and continuous variables.
- Hybrid PSO utilizes basic mechanism of PSO and the natural selection mechanism, which is usually utilized by EC methods such as GAs.

The PSO algorithm is based on the concept that complex behaviour follows from a few simple rules [11].

- It uses a number of agents (particles) that constitute a swarm moving around in the search space looking for the best solution.
- Each particle is treated as a point in a N-dimensional space which adjusts its "flying" according to its own flying experience as well as the flying experience of other particles.
- Each particle keeps track of its coordinates in the solution space which are associated with the best solution (fitness) that has achieved so far by that particle. This value is called personal best (pbest).
- Another best value that is tracked by the PSO is the best value obtained so far by any particle in the neighbourhood of that particle. This value is called (gbest).
- The basic concept of PSO lies in accelerating each particle toward its pbest and the gbest locations, with a random weighted acceleration at each time step as shown in Figure 1.

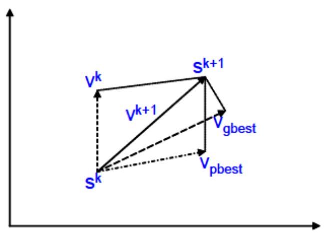

Figure 1 Concept of modification of a searching point by PSO.

Where:

S^k: current searching point.
S^{k+1}: modified searching point.
V^k: current velocity.
V^{k+1}: modified velocity.
$V_{pbest:}$ velocity based on pbest.
V_{gbest} : velocity based on gbest

- Each particle tries to modify its position using the following information:
  - The current positions,
  - The current velocities,
  - The distance between the current position and pbest,
  - The distance between the current position and the gbest.
- The modification of the particle's position can be mathematically modelled according to the following equation :

$$V_i^{k+1} = wV_i^k + C_1 rand_1(...) \times (pbest_i - S_i^k) + C_2 rand_2(...) \times (gbest - S_i^k)...... \quad \textbf{(1)}$$

Where,

V_i^k: velocity of agent i at iteration k,
w: weighting function,
Cj : weighting factor,
rand : uniformly distributed random number between 0 and 1,
S_i^k : current position of agent i at iteration k,
$pbest_i$: pbest of agent i,
gbest: gbest of the group.

The following weighting function is usually utilized in (1)

$$w = wMax - [(wMax - wMin) \times iter] / \max Iter \quad \textbf{(2)}$$

Where

wMax= initial weight,
wMin = final weight,
maxIter = maximum iteration number,
iter = current iteration number.

$$S_i^{k+1} = S_i^k + V_i^{k+1} \quad \textbf{(3)}$$

A large inertia weight (w) facilitates a global search while a small inertia weight facilitates a local search. By linearly decreasing the inertia weight from a relatively large value to a small value through the course of the PSO run gives the best PSO performance comparisons with fixed inertia weight settings.

The PSO algorithm updates the velocity vector for each particle then adds that velocity to the particle position or values. Velocity updates are influenced by both the best global solution associated with the lowest cost ever found by a particle and the best local solution associated with the lowest cost in the present population. If the best local solution has a cost less than the cost of the current global solution, then the best local solution replaces the best global solution. The particle velocity is reminiscent of local minimizers that use derivative information, because velocity is the derivative of position.

PSO is easy to implement and have a few parameters to adjust. Also it is able to tackle tough cost functions with many local minima. Figure 2 shows the initial random swarm set loose on the cost surface. The particle swarming becomes evident as the generations pass (see Figure 3). The largest group of particles ends up in the vicinity of the global minimum and the next largest group is near the next lowest minimum. A few other particles are roaming the cost surface at some distance away from the two groups. Figure 4 shows plots of ***pbest*** local best and ***gbest*** global best as well as the population average as a function of generation. The particle ***gbest*** global best serves the same function as elite chromosome in the GA. The chaotic swarming process is best illustrated by following the path of one of the particles until it reaches the global minimum (Figure 5). In this implementation the particles frequently bounce off the boundaries [13].

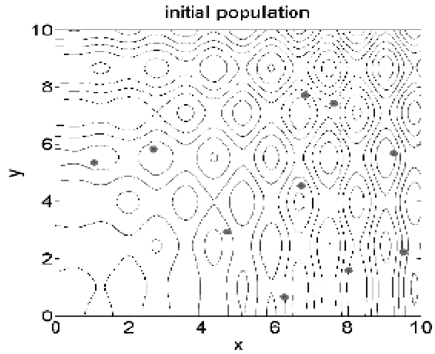

Figure 2: Initial random swarm of 10 particles.

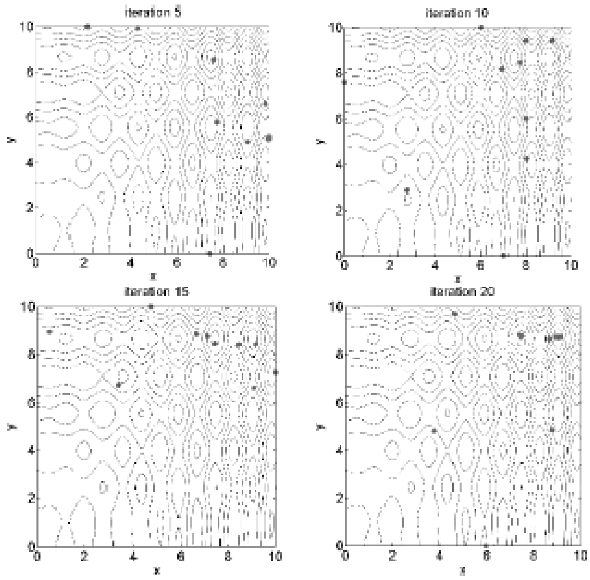

Fig.3: Swarm iterations.

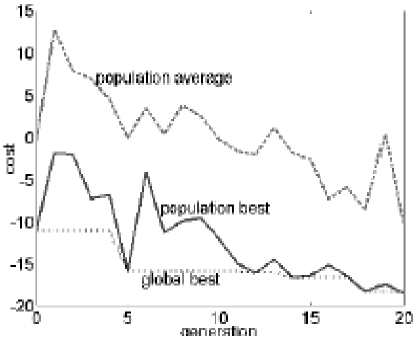

Figure 4: Convergence of the PSO algorithm.

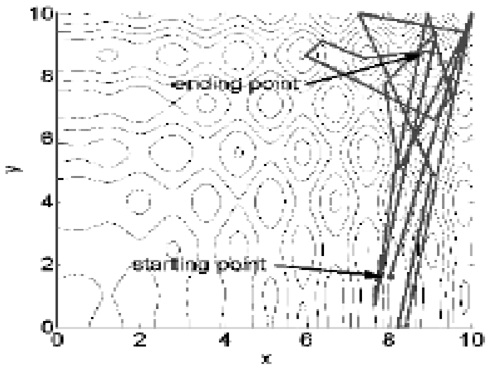

Figure 5: Path taken by a single PSO particle.

3. Proposed Algorithm

The most important objective of any renewable energy production project in the current deregulating environment is maximizing the quality of services by reducing the costs for customers, the investments, operation and maintenance. The problem is to determine how much power will be generated from multi hybrid renewable sources in order to cover all the demand loads including the losses and the storage power with the minimum life cycle cost of HRES power generation.

In this paper a simple general optimization approach is used to optimize the HRES using the PSO technique, to minimize the Levelized Cost of Energy (LCE). LCE can be explained as the price that energy has to be sold to break even over the lifetime of the technology. It yields a net present value in terms of, Euros per kilowatt. This is an assessment of the economic lifetime energy cost and lifetime energy production shown in Equations 4 and 5 and can be applied to essentially any energy technology. For computing the financial costs the equations can be embellished to take into account not only system costs, but also factors such as financing, insurance, maintenance, and different types of depreciation schedules [14].

Life Cycle Cost Life Time Energy Production

$$LCE = \frac{\text{Life Cycle Cost}}{\text{Life Time Energy Production}} \quad \textbf{(4)}$$

$$LCE = \frac{(CRF \times ICC) + (AOE)}{AEP_{net}} \quad \textbf{(5)}$$

Where:

LCE: Levelized Cost of Energy (€/kW)
CRF: Capital Recovery Factor (%)
ICC: Installed Capital Cost (€/kW)
AOE: Annual Operating Expenses (€/kW/yr)
AEP$_{net}$: Net Annual Energy Production (kW)

For more details for the economic and financial factors the formula can be written as in Equation 6.

$$LCE = \frac{\left(\left[\frac{d(1+d)^n}{(1+d)^n - 1}\right] \times ICC\right) + \left(ANN + \left[O \,\&\, M \times n\right]\right)}{8760 \times CF_{net}} \quad \textbf{(6)}$$

Where

d: interest rate (%)
n: operational life (years)
ANN: the annualized costs (insurance, other expenses)
O&M: Operation & Maintenance Cost (€/kW)
$\mathbf{CF_{net}}$: net capacity factor
8760: hours per year

The main goal of the proposed algorithm is to determine the suitable power generated from any number of sources for minimizing the cost fitness function. The following objective is determined to be used:

3.1 Cost Reduction

The ease of installation, declining cost of technology and supportive government policies has been catalysts for the fast growth of renewable energy generation in the world. As a reason, the management and planning engineers began to have a lot of research to reduce the cost using a lot of formula that explained that. Although, it can be measured in a number of different ways, and each way of accounting for the cost of power generation brings its own insights. The costs that can be examined include equipment costs (e.g. PV modules), financing costs, total installed cost, fixed and variable operating and maintenance costs (O&M), fuel costs and the levelised cost of energy (LCE). The analysis of costs can be very detailed, but for comparison purposes and transparency, the approach used here is a simplified one. This allows greater scrutiny of the underlying data and assumptions, improving transparency and confidence in the analysis, as well as facilitating the comparison of costs by country or region for the same technologies in order to identify what are the key drivers in any differences. The three indicators that have been selected are [15]:

- Equipment Costs
- Total installed project cost, including fixed financing costs.
- The levelized cost of energy.

3.2 The Objective function is ***"Min. LCE{P_{gen}(number of sources, P_{demand})}"***

That item should be composed with constraints to obtain the proper objective function. The main constraints in the optimization process in the proposed methodology are detailed in the coming subtitles.

3.2.1 Power Generated Constrain

The power generated from each source $P_{gen(i)}$ must be less than or equal to the maximum capacity of the source as:

$$P_{gen(i)} \leq P_{genmaw(i)} \quad \textbf{(7)}$$

Where

i = Number of sources

3.2.2 Power Balance Constraint

The total power generation of the HRES sources must cover the total load demand (P_{demand}) , the total power losses (P_{Losses}) and storage power ($P_{Storage}$) if used.

$$\sum_{S=1}^{N_S} P_{gen/source} = P_{demand} + P_{Losses} + P_{Storage} \qquad \textbf{(8)}$$

However, the PSO is applied to this optimization problem, with the constructed objective function to be used in choosing how many powers will be generated in HRES in this research. PSO got a good solution - with high probability to be the best one – by finite steps of updating particles positions and velocities. The flow chart of the applied optimization algorithm is shown in Figure 6. PSO appears in the core of it, searching to find the optimum power generated. This routine is programmed under MATLAB software.

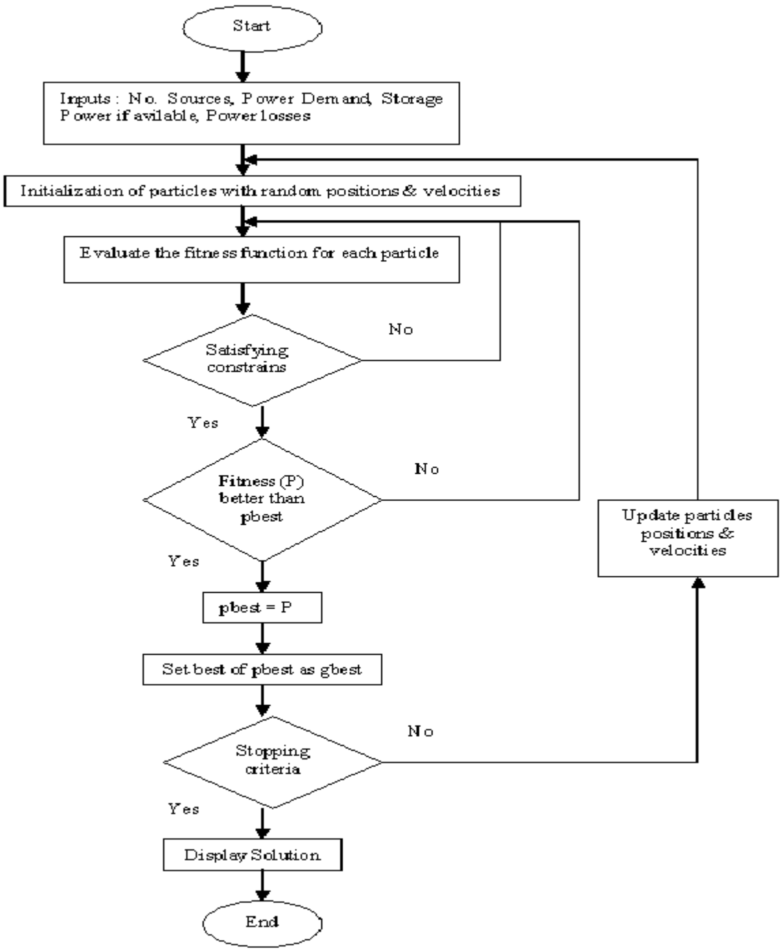

Figure 6: Flow chart

4. Application Result

The algorithm is applied in this paper for calculation of the average power generation from the HRES contains only a wind turbine/ PV module and a load of typical house has been used as the load demand of the hybrid system. The configuration of the hybrid Wind/PV is shown in Figure 7. The hybrid system include the Berggey BWC 1500 type wind turbine of rated power 1.5kW and the rated power of the PV module used is 0.53 kWpeak [16]. While Figure 8 shows the load profile of the typical house used. All the economic parameters that have been used in order to calculate the LCE are taken from table 1 [17].

Figure 9 shows the block diagram of the whole system including optimization, control and production that will be built totally in the Matlab Simulink and after it will be applied practically. The optimization system will have two main inputs the load demand quantity and the number of sources. If the any of the inputs change, the system will automatically update its situation to the new situation giving the new optimum power generation with minimizing the LCE.

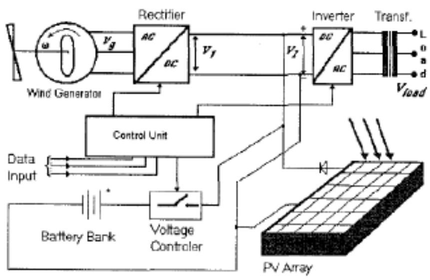

Figure 7: Wind/PV Stand Alone System

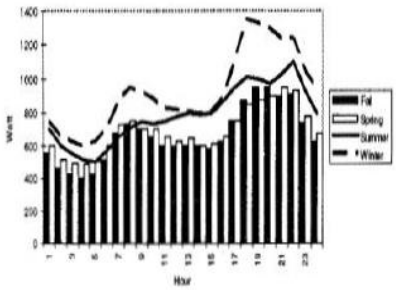

Figure 8: Load Profile of Typical House

Table.1: Economic Parameters

Technology	Unit	Photovoltaic	Wind turbine	Diesel generator	Lead-acid battery
Investment cost	€/kW (€/kWh for battery)	2,835.00	5,832.00	596.00	148.00
Lifespan	years	20	20	20	5
Interest rate	%	10	10	10	10
CRF	-	0.1175	0.1175	0.1175	0.2638
Annualised Investment cost	€/kW (€/kWh for battery)	333.00	685.02	70.01	39.04
Maintenance and operation cost	% of investment cost	2	2	6.4	2
Maintenance and operation cost	€/kW (€/kWh for battery)	56.70	116.64	38.08	2.96
STMGC	€/kWh$_{electr}$	0	0	0.25 (India), 0.18 (Colombia)	0

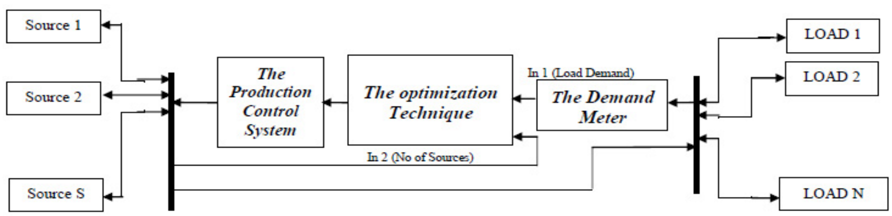

Figure 9: General Block Diagram of the system

The result of using all these data and applying it in the proposed algorithm using the PSO optimization technique was that the minimum LCE is found to be 0.0030277 €/kW and the power generated from the wind turbine is 1.0185 kW, while the power generated from the PV module is 0.23153 kW taking into consideration that the load demand as an average was about 1 kW and the losses and the storage was taken as a percentage from the load.

5. Conclusion

This paper discusses a simple general approach for the optimal power generated from multi sources in HRES to minimize the levelized cost of energy (LCE) using the Particle Swarm optimization technique. At which the PSO proved its high intensity and sensitivity in solving such optimization problems. Beside the availability of the approach to control the production of the power generated using the load demand as the main input with both the total power losses of the whole system and the availability of the power stored in the both cases stand alone with battery storage or stand alone with grid storage.

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