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MATLAB BASED SIMULATION AND COMPARATIVE ANALYSIS OF META-HEURISTIC OPTIMIZATION ALGORITHMS FOR TECHNICAL EFFICIENCY ENHANCEMENT OF A HYBRID RENEWABLE ENERGY SYSTEM

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ABSTRACT

Algorithms for calculating the maximum or minimum of mathematical functions are known as optimization algorithms. When optimising a system's architecture, different priorities may be considered. Greater operational productivity and decreasing manufacturing costs are two examples of such objectives. Approaches and processes for optimization can assist in the solving of challenging situations. When constructing an HRES, we must remember the efficiency of its elements. The main goal is to improve performance while lowering costs. These objectives can be met by optimising the system's modelling. The main objective of this dissertation is reviewing recent research activities conducted on modern META-HEURISTIC optimization techniques used in engineering design and products for the purpose of technical efficiency enhancement. Based on the advantages and disadvantages of existing techniques, a productive analysis to find the best among the existing techniques for energy production enhancement of a hybrid renewable energy system, Simulation and MATLAB coding of various meta-heuristic techniques for energy optimization and then based on research work, report writing and paper publication in a journal.

Keywords: *META-HEURISTIC optimization techniques, hybrid renewable energy system, MATLAB coding, energy optimization, MMMUT, Gorakhpur.*

INTRODUCTION

Mathematical optimization (sometimes written optimisation) or mathematical programming is the process of selecting the best component (based on any criterion) from a set of feasible alternatives. Optimization challenges exist in all quantitative domains, from computer science and engineering to operations research and economics. An optimization problem, in its most basic form, comprises methodically picking input values from within a specified range and computing the function's value in order to maximise or minimise a certain function. The application of optimization theory and techniques to different formulations is a large field of applied mathematics. The aim of this literature review is to present current information, including substantive results as well as theoretical and methodological implications by using optimization methods in software-based simulation and study of different meta-heuristic optimization strategies with the goal of reducing material and optimising performance in a **hybrid renewable energy system.**

HYBRID RENEWABLE ENERGY SYSTEM (HRES)

Electricity is one of the most important drivers in a country's economic growth. Countries are consciously reducing their dependence on fossil fuel oil and shifting their focus to renewable energies in order to satisfy long-term energy demands. Renewable energy contributes for just 7.4% of worldwide electrical generation, excluding hydropower. In India, for example, green energy accounts for just 69.02 GW of total capacity of 344 GW. The Indian government wants to increase clean power to 175 GW by 2022 to reduce dependency on fossil fuels. For scaling HRES, there are essentially two optimization methodologies that are guided by economic (e.g. net cost) and reliability requirements.

Few examples of typical metaheuristic algorithms are Swarm-Optimization Article [3]; Simulated metaheuristic algorithms[10]; Search algorithms for Cuckoo [11]; Genetic Algorithms (GA)[6]; PSO hybrid Metaheuristic Algorithm based on PSO simulations [9]; Simulated Annealing(SA)[11]; Simulated Annealing algorithm (AC) [12]; Firefly[16]; and Grey Wolf optional algorithms.

3.1) Study's motivation: Particle swarm optimization (PSO) and Ant Colony Optimization (ACO), two recently developed metaheuristic methods, can be useful in the construction of an optimised HRES architecture. Since it is simple to apply, it can be used in both experimental analysis and technical issues. It has a small number of parameters, and their influence on the solutions is minimal as opposed to other optimization strategies. PSO is less reliant on a number of initial points than other optimization approaches, and it has a rather clear computational framework.

Even though PSO algorithm has been successfully used to optimise HRES designs, due to its nuanced and conflicted existence, it needs many modifications [33].AC algorithms have a short time to convergence [40], but they need a lot of long-term memory space [43]. Other approaches have a lower rate of convergence to the desired outcome than metaheuristic algorithms (first ACO, then PSO).

3.2) Objective of the present study: The efficacy of two metaheuristic techniques, PSO and ACO, is investigated and compared to GA in this research in order to develop a techno-economically optimum configuration of a PV-BG-Battery-PHES dependent system for powering an Indian educational institution. GA is a metaheuristic baseline approach that has previously been used in HRES research. For off-grid power generation, HRES systems frequently combine PHES and battery systems engineering with solar PV & BG. As a result, utilising a metaheuristic technique to optimise such an HRES design is unusual.

The investigation is structured as follows: Section 1 goes over the hybrid system architecture used in the report, Section 2 goes over component modelling, Section 3 goes over the HRES evaluation parameters, Section 4 goes over the simulation approach, Section 5 goes over the case study and data needed for analysis, and Section 6 wraps up the report.

METHODOLOGY

4.1) proposed hybrid green energy system: An off-grid facility is one that is not connected to the main power grid. From wristwatches and calculators to remote buildings and satellites, stand-alone systems come in a broad range of sizes and applications. With the aid of a turbine, PHES converts the water energy into energy of electricity [53]. The battery is a widely used with high stability, economic feasibility, flexibility, and bulk storage capability [56, 57, 58, 59]. Various types of hybrid systems, such as PV-Fuel cell systems [61] and PV-Diesel systems [60], have been combined with battery storage systems. battery endurance [59], operating life [62] and methods for extending it [63][64], and reaction time [65] have also been studied in various articles.

Researchers have also looked at energy storage devices for use in the car industry [66] and for the electrification of a Hong Kong island [67]. As a result, several papers have looked and proposed battery storage for HRES integration. Chen et al. [68] offer an exhaustive analysis of various forms of electrical energy storage systems, revealing PHES as efficient and cost-effective systems. While PHES is one of the most cost-effective ways to store large amounts of power [69], its sluggish dynamics prevent it from reacting as quickly as possible to sudden shifts in load. As a result, batteries are combined with PHES to solve this problem.

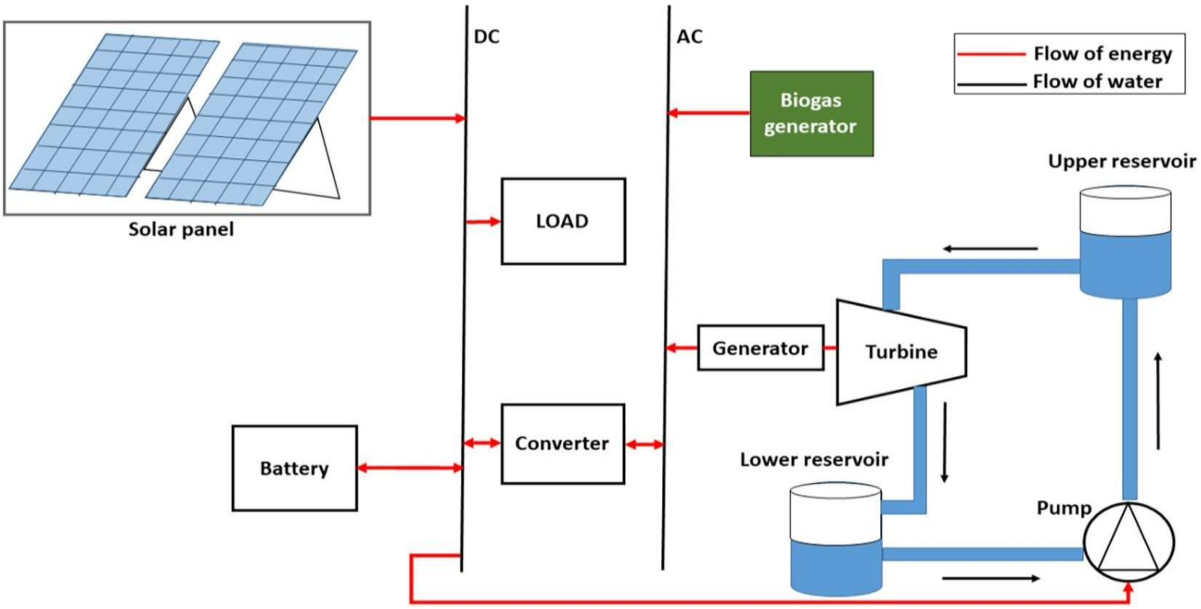


Figure 1: Proposed schematic diagram of proposed HRES

4.2) modelling of the hybrid renewable energy system: In this part, the hybrid system component mathematical formulations were discussed.

4.2.1 Solar photovoltaic power output

The PV power model is defined as:

$$E_{PV}(t) = A_{PV} + \left[1 - \alpha_P(T_C(t) - T_{C,STC})\right] \times I_T(t) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The (HDKR) model is expressed as [75]:

$$I_T(t) = \left[1 + \frac{H_{d,h}}{H_{o,h}}\right] H_{b,h}R_b + H_{d,h}\left[1 - \frac{H_{b,h}}{H_{o,h}}\right]\left(\frac{1+\cos\beta}{2}\right)\left(1+\sqrt{\frac{H_{b,h}}{H_h}}\right)\sin^3\frac{\beta}{2} + \rho_{gr}\left(\frac{1-\cos\beta}{2}\right) H_h \ldots (2)$$

4.2.2 Biogas generator power:

Sum of energy generated by the BG.

$$E_{BG}(t) = \eta_{BG} \times F_{BG}(t) \times LHV_{BG} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

4.2.3 Modelling of pumped system:

4.2.3.1 [22] specifies the turbine's nominal size. -

$$E_{TI} = \frac{[(1+SM_L)\times \text{Peakload}]}{\eta_{turbine}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

The turbine capacity is analysed when the hydraulic head is chosen for the proposed development, and the flow rate is computed as-

$$Q_{turbine}(t) = \frac{E_{turbine}(t)}{\rho g h} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

$$E_{TM} \leq E_{turbine}(t) \leq E_{TI} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

4.2.3.2 Pump modelling

The pump's flow rate in m^3/s is stated as [22]-

$$Q_{pump}(t) = \frac{\eta_{pump} \times E_{pump}(t)}{\rho g h} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

4.2.3.3 Upper reservoir modelling-

The number of autonomy days as well as the turbine’s average volumetric flow rate decides the UR's size.

[52] is the method for calculating the volume of the UR.

- UR= (1+SM UR)autonomy daysQ TM.. (8)

where SM UR denotes the UR volume protection margin, which is estimated to be 5%, and At maximum turbine power, Q TM stands for maximum volumetric flow rate in m^3 /s.

4.3) Formulation of single objective function: The TNPC parameters are used to guide a single-objective optimization strategy. The entire optimization problem is coded in the MATLAB platform.

In its most basic form, the objective function may be stated as follows:

$$\mathbf{Min\ TNPC} = \sum_{i=A_{PV},E_{BG},N_{Batt},UR} \frac{ACC_i}{CRF} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (17)$$

Subjected to the following constraints:

$0 \leq E_{BG} \leq E_{BG}^{max}$

$0 \leq UR \leq UR^{max}$

$0 \leq A_{PV} \leq A_{PV}^{max}$

$0 \leq N_{Batt} \leq N_{Batt}^{max}$

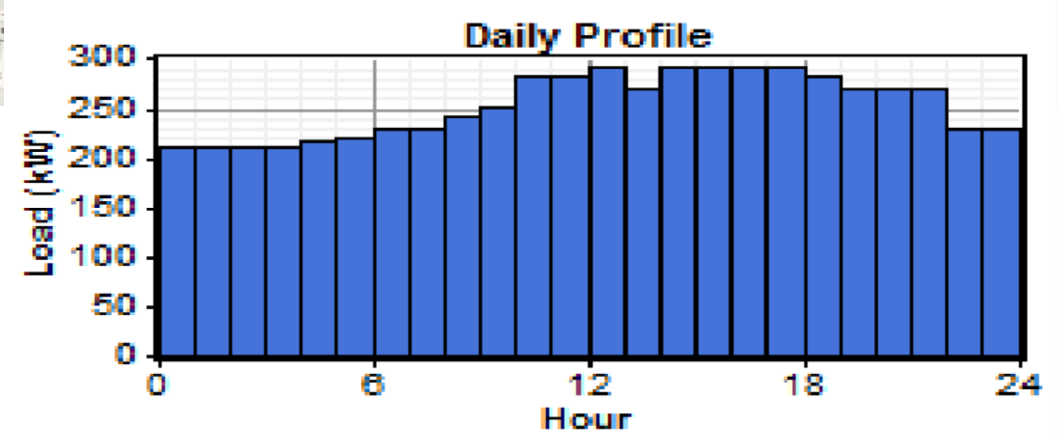
And the system reliability constraint

$0 \leq LPP \leq LPP^{max}$

4.4) The case study:

Madan Mohan Malaviya University of Technology in Gorakhpur, northern India, was chosen as the case study to test the applicability of the proposed HRES modelling. The institute's geographic coordinates are 26°43' north latitude and 83°26' east longitude. The site is 59 metres above sea level.

Figure2: Google Map of MMMUT, gorakhpur



4.4.1. Analysis of load data: When evaluating the university's load profiles, it's important to think about how much energy is used by the university's instruments and equipment. The electricity distribution board of the khorabar district, which is responsible for supplying electricity to the university, provided hourly data for a year. The daily average load is 260 kWh, with a peak load of 450 KWh.

Figure 3: Daily load profile

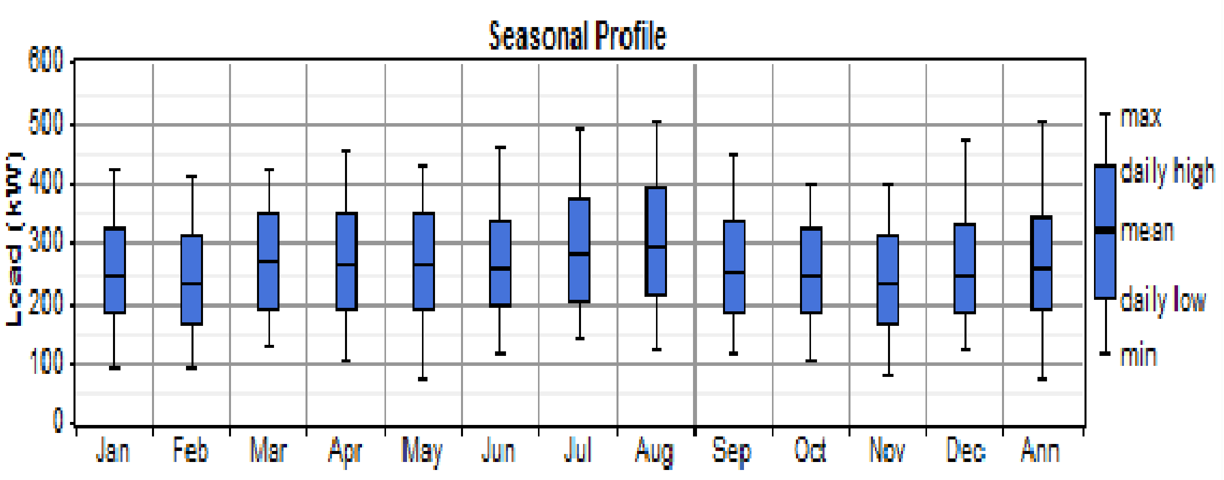


Figure4: Monthly load profile

4.4.2. Meteorological data:

In this part, the specifics of the meteorological data for the selected location for a year are presented, which directly govern hybrid performance of the system.

4.4.2.1. Solar radiation- A solar radiation sensor is used to measure the sun's energy. Solar radiation is the electromagnetic energy that the sun emits as a result of nuclear fusion. Solar radiation has a pattern similar to that of a black object with a warmth of roughly 5800 K.

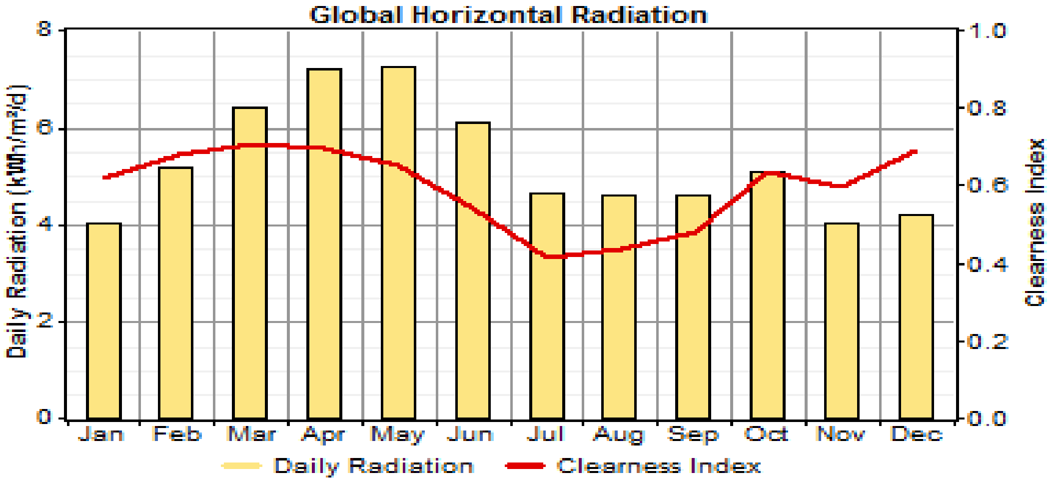


Figure 5: Yearly solar radiation data

The instrument is most typically used to calculate evapo-transportation in agricultural applications. The evaporation of moisture from the soil is a function of solar power, wind, and heat (or the reverse of rainfall). Solar data for Gorakhpur comes from the Solar Radiation Resource Assessment station (SRRA) installed on the rooftop of the electrical department of MMMUT in Gorakhpur, India, and accredited by the Centre of Wind Energy Technology of the Indian government. India's Ministry of New and Renewable Energy officially opened the SRRA station in 2013. (MNRE). The SRRA station's data logging system collects solar radiation data on an hourly basis for this research, which includes direct, diffuse, and global solar radiation. With an annual solar radiation of 4.97 KW/m^2/day and a clearness index of 0.586, the area is perfect for photovoltaic system installation.

4.4.2.2. Temperature profile: The temperature data was obtained from the "climate-data.org" website. The monthly average ambient temperature variation of almost a year is taken into account because the PV panel's power is depending on ambient temperature. Figure 5 depicts the temperature gradient throughout the course of the year, with the greatest value of atmospheric temperature occurring in the month of "May."

4.4.2.3 Biomass data: Due to the vast population, daily garbage creation has reached a gigantic level in northern India, particularly Uttar Pradesh. The biomass data was collected from the Gorakhpur municipality council, and the food waste share was calculated to be 5 tonne per day at a cost of Rs. 800 per tonne. Kitchen garbage has a greater calorific content and a moderate biodegradability quality, according to a paper [53]. Biomass contains the largest amount of methane gas, roughly 50–70%, and a larger concentration of methane indicates more thermal energy. The conversion ratio is 0.3 [56], which indicates that biomass is generated per unit mass of feedstock.

RESULT

In comparison to PSO, the findings suggest that ACO has a slightly superior architecture approach. The TNPC coalesces swiftly using the ACO approach, and the optimal design has a value of TNPC of $ 718564 and an cost of $ 0.5478/kWh. Figure 6 shows the convergence graph as well as a comparison graph for the GA method. The ACO method computes quicker than the PSO method, and both methods dominate the GA method, as seen in Figure 6. Figure 7 depicts the relationship between TNPC, BG, and PV panel area. The optimal configuration includes a PV panel with a surface area of 438.6 m^2, a BG with a capacity of 15 kW, a battery bank of 22 modules, a 20 kW transformer, and a UR volume of 2181.5 m^3.

In one set of issues, one performs mildly higher than the other, while performing worse than in another. Statistical analysis can be utilized to assess the output of both the meta-heuristic algorithms under examination. The output of the meta-heuristic algorithms under investigation may be evaluated using statistical analysis. 30 simulation runs were done for the ACO and PSO algorithms, as well as the GA, which was utilized as a reference, for statistical analysis. Each run has 200 iterations to reach the lowest TNPC, which is $823320, $834865, and $856867, respectively, for ACO, PSO, and GA.

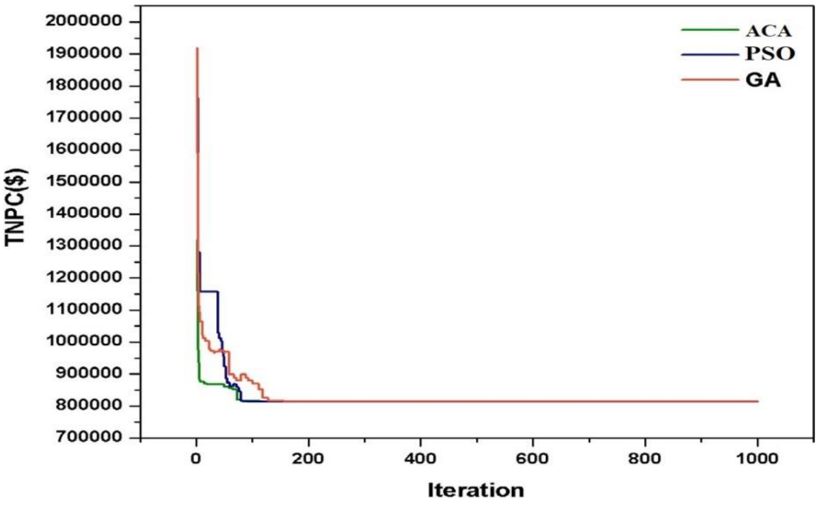


Figure 6: In comparison to GA, the convergence graph of TNPC by using PSO and ACO algorithms.

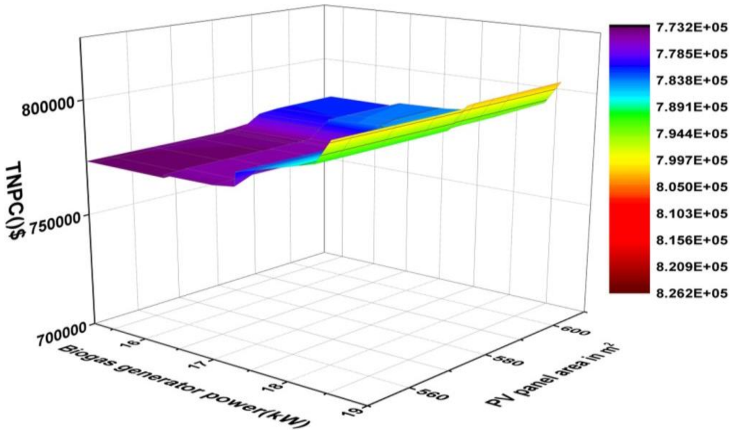


Figure 7: TNPC variation as a function of PV panel area and BG capacity

CONCLUSIONS

The performance of two meta-heuristic optimization strategies, the PSO and ACO algorithms, is analyzed and compared to GA in this work. in order to obtain a techno-economically optimised configuration of a PV dependent HRES for powering a suburban state deemed university in India. The following is based on the research findings: In terms of efficiency, the meta-heuristic ACO and PSO algorithms were compared to the baseline GA method. The study employs the convergence rate (for TNPC) as well as statistical comparison. The ACO algorithm, which is led by the GA algorithm, conforms earlier than the PSO method.

In regards of HRES techno-economic architecture, the ACO algorithm beats the PSO algorithm, according to the findings. The most appropriate designs are a battery bank with 21 modules, PV panel with a surface area of 438.6 m2 (size 69.2 kW), a converter with a capacity of 35 kW, a BG with a capacity of 15 kW, and a UR with either a volume of 2181.5 m3. The total TNPC collected is $718564, with an cost of $ 0.5478 per kWh. The present methods exceed some of the previous heuristic and metaheuristic techniques employed in hybrid system construction when the efficiency of the most efficient configuration is compared to published designs. **As a consequence of our study, PV-hybrid - dependent HRES appears to be a possible solution for supporting a considered institution in a stand-alone mode, particularly in faraway locations.**

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