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A Study of Bio-Inspired Meta-heuristic Algorithms for Energy Optimization

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ABSTRACT

Colossal scale industrial and technological developments have been witnessed during the past century. These developments have however been accompanied with phenomenal rise in energy demands. In the absence of suitable replenishment of earth's limited energy resources, the world is today experiencing an acute energy crisis. Researchers today are thus focusing their attention on finding methods to develop technically efficient systems that utilize minimal energy resources. Various algorithms have been used by the researchers to solve this highly complex and computationally intensive energy optimization problem. Recently, the use of bio-inspired meta-heuristic algorithms has proved their efficacy in solving such energy optimization complex problems. This paper studies the use of bio-inspired meta-heuristic algorithms in various phases of manufacturing of the energy systems for minimizing their energy consumption while maximizing their efficiency in terms of performance. Future scope and directions of research in this area have also been discussed.

1. Introduction

Over the years, there has been a steep rise in energy demand across the world. And this demand curve is expected to continue depict an upward trend in the coming years also. Global concerns about global warming, depleting ozone layer, increasing carbon emission levels and deep apprehensions about climate change has motivated the researchers towards developing energy efficient systems. The development of such systems induces the need for strategic planning to save energy, developing efficient energy production systems and inventing renewable energy sources (Lund, 2005). The building of energy efficient systems involves complex design and optimization issues. Conventional optimization techniques have been used in the past by the researchers to solve them. These include non-linear and linear programming, quadratic programming simple integer programming as well as mixed integer programming, constrained and unconstrained programming. Apart from these, dynamic programming has also been used in different optimization problems.

The optimization problems in developing new, highly energy efficient systems involves complex optimization problems characterized by occurrences of compound local optima, non-linearity and non- convexity (Garey and Johnson, 1979). The use of conventional methods to solve such types of highly complex optimization problems would result in colossal computations resulting in slow processing, thus providing impracticable solutions for the real world applications (Banos et al, 2011). The last decade has witnessed development of Bio-Inspired Meta-Heuristic Algorithms which have been successfully used by the researchers to solve complex optimization problems. This paper reviews the use of Bio-Inspired Meta-Heuristic Algorithms for building energy efficient systems.

2. Bio-Inspired Meta-Heuristic Algorithms

Bio-Inspired Meta-Heuristic algorithms are inspired by the naturally occurring phenomena. They can be broadly classified as Evolutionary Algorithms and Swarm Intelligence Algorithms.

2.1 Evolutionary Algorithms

These Bio-Inspired Meta-Heuristic Algorithms are based on the natural evolution processes. These have been applied by researchers to find solutions to multi objective complex problems which are discontinuous as well as non-differentiable. Examples of Evolutionary algorithms include the Genetic Algorithms, Differential Evolution Algorithms; Biogeography based Optimization Algorithms, Evolutionary Programming Algorithms

2.1.1 Genetic Algorithms Genetic Algorithms are built on the Darwinian principle of survival of the fittest (Holland, 1975). These have been used to design efficient wind energy based systems. Liu et al (2000) used the Genetic algorithms to find the optimal count of actuators and their configuration for designing wind energy systems. Grady et al (2005) in his work on finding the best positions of the wind turbines so that their capacity of production is maximized with the constraints of limited count of installed turbines and the land area occupied by every wind farm, also used this algorithm. In order to maximize the thermal efficiency of flat solar plate panels, Varun and Siddhartha (2010) used the Genetic algorithms for optimization of the parameters of the solar system. These algorithms have also been used to improve efficiency of PV solar cell by Zagrouba et al (2010); geothermal systems by Tselpidou and Katsifarakis (2010); hybrid PV systems by Hefnawi (1998), Koutroulis et al (2006), Dufo-Lopez et al (2007) and Senjyu et al (2007).

2.1.2 Differential Evolution Algorithms: These work by generating a random initial population using mutation, crossover and selection operators to find optimal solutions. Chakraborty et al (2009) made use of this algorithm to integrate a Fuzzy unit commitment strategy in a solar energy system. Silmani and Bouktir (2012) applied these algorithms to optimize power flow in wind energy systems while Coelho et al (2008) improved the working of thermal generators by optimizing the economic dispatch flow systems. Lee et al (2011) used these algorithms for decreasing consumption of energy while Suzuki et al (2010) proposed an optimized operational plan for the energy plants based on this algorithm.

2.1.3 Multi Objective Evolutionary Algorithms: These algorithms have acquired enormous recognition amongst the researchers for their ability to solve complex optimization problems. Instances of these algorithms are Non Dominated Sorting Genetic Algorithm –NSGA and NSGA-II, Strength Pareto Evolutionary Algorithm –SPEA and SPEA-II etc. Benini and Toffolo (2002) used these algorithms for efficient designing of wind turbines. Kusaik et al (2010) proposed a multi objective optimization algorithm for optimizing the performance of wind turbines. Kusiak and Song (2010) maximized the capture of wind energy through optimal design of layouts for wind farms. Bilal et al (2010) applied these algorithms for designing energy efficient hybrid solar wind battery systems while Montoya et al (2010) used the Paerto optimization algorithms for minimizing power losses and voltage fluctuations in power networks. Yu et al (2015), in their endeavor to optimize energy consumption in green building designs, used multi objective genetic algorithm.

2.2 Swarm Intelligence Algorithms

These algorithms are galvanized by the collective societal conduct of insect groups. Ant Colony Optimization (ACO), Particle Swarm Optimization (PSO) and Artificial Immune System (AIS) are amongst the popular Swarm Intelligence Algorithms that have been researched in the recent years and applied successfully to optimization problems.

2.2.1 Ant Colony Optimization Algorithm: This optimization algorithm imitates the societal conduct of ants who in order to solve complex tasks like finding the shortest route to the food sources from their nests, use pheromones in order to communicate with each other (Colorni et al, 1991). This algorithm was applied by Li et al (2005) for designing solar energy driven power systems for space stations. Foong et al (2008) suggested an enhanced maintenance schedule for power plants using this algorithm. Warner and Vogel (2008) used this algorithm for optimizing the networks of energy supply systems while See et al (2012) optimized control systems of ocean wave energy converters and Toksari (2009) used it to estimate the demand and supply of electricity generation. Demand of transport energy systems was estimated by Baskan et al (2012) using the Ant Colony Algorithm.

2.2.2 Particle Swarm Optimization Algorithm: This algorithm, with its characteristics of quick convergence rate, much faster than the other algorithms of the same category, is popular among the researchers to solve a varied array of real world optimization problems. It makes use of individual solutions, also termed as particles to move through an n dimensional space to find an optimal solution. Each of these particles are associated with a velocity vector and a position vector. These are adjusted through successive iterations to find an optimal solution using the local best of discrete particles along with the global best found by the entire swarm. This algorithm has been used for long period forecasting of electricity load by Rashidi and El-Naggar (2010), distribution state estimation by Niknam and Firouzi (2009), scheduling of short period hydroelectric power systems equipped with wind turbine run generators by Lee (2008); finding solutions to unit commitment problems by Khan Mohammadi et al (2010).Besides these, it has also been used for optimal design of biomass fuelled systems by Lopez et al (2008); capacity coordination of wind photovoltaic systems by Lee and Chen (2009); optimal design of a dependable stand-alone hydrogen based PV/wind engendering system by Kavianai et al (2009). Konelakis and Koutroulis (2009) made use of Particle Swarm Optimization algorithm for designing an economic analysis methodology for photovoltaic systems connected through grid. Further, optimal sizing of these systems was done by Kornelakis and Marinakis (2010) while optimal sizing of hybridized power systems using this algorithm was studied by Hakimi and Moghaddas-Tafreshi (2009). Solutions to optimization problems related to economic dispatch using the Particle Swarm Optimization Algorithm were put forward by Mahor et al (2009), Jeyakumar et al (2006) and Wang and Singh (2009). Mandal et al (2008) optimized scheduling of short term hydro thermal systems. Abido (2007) used a multi-objective Particle Swarm algorithm to compute optimized solutions for environmental/economic dispatch problems while influence of loading conditions on the emission economic dispatch was studied by Alrashidi and Hawart (2008). Mohamed et al (2016) developed a Particle Swarm based smart grid application for a hybrid renewable energy system with least cost and maximum dependability. Delgram et al (2016) studied the building energy performance using multi objective Particle Swarm Optimization algorithm.

2.2.3 Artificial Immune Systems: These algorithms are based on the immune systems of living creatures and are used for discovering solutions to complex optimization problems. This algorithm has been successfully applied to power systems for resolving their economic dispatch problem by Rahman et al (2004). Coelho and Mariani (2009) applied chaotic artificial immune algorithm for finding optimized solutions to economic dispatch problem of thermal energy units using electric energy. Arsalani and Seddighizadeh (2012) applied the artificial immune algorithm along with the fuzzy logic to minimize the energy loss in transmission systems, thus improving their efficiency.

3. Use of Hybrid Algorithms

Researchers have developed hybrid models of various Bio-Inspired Meta-Heuristic algorithms to build improved energy systems in order to exploit the various benefits of these algorithms. Li et al (2009) developed a hybrid model of artificial immune system algorithm plus particle swarm optimization algorithm to optimize distribution of load in cascade hydropower stations. Yang et al (2011) developed an efficient hybrid of artificial bee colony and the genetic algorithm to study the optimization of energy consumption in central air conditioning systems. Energy demand forecasting system for turkey was successfully developed by Kiran et al (2012) using a hybrid of Ant Colony Optimization and Particle Swarm Optimization Algorithm. Anand and Kar (2015) developed an efficient hybrid PSO algorithm for emission controlled load dispatch with an objective to fulfill the power demand while controlling the emission within the environment limits

4. Conclusion

Bio-Inspired Meta-Heuristic algorithms have been successfully applied to build various types of energy efficient systems. They have been used in the spheres of planning, designing, scheduling and controlling of such systems. These have also been used for forecasting of demand and supply of several types of energies and problems of economic dispatch associated with the energy systems. Such systems are hitherto applied for building energy efficient systems. These tasks involve complexity of high multitude and multi objective optimization. Bio-Inspired Meta-Heuristic algorithms have been found to tackle these more efficiently as compared to the conventional techniques. This accounts for the high popularity of these algorithms for various real world applications. Each of these algorithms has its own advantages and disadvantages. Hybrids of two or more Bio-Inspired Meta-Heuristic algorithms have been developed to exploit the benefits of the individual algorithms. This has resulted in improved efficiency to solve highly complex multi-dimensional and multi modal optimization problems. Future research scope in this area call for further exploration and emphasis on development of hybrids models that can help develop modernized energy efficient systems. With the growing need to develop energy systems that are highly accurate, efficient and reliable, there is an increasing need for further research in the area to develop Bio-Inspired Meta-Heuristic algorithm that can provide best solutions in the design and building of such highly complex systems.

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