Optimizing Design Of Heat Pump Using Fuzzy Logic And Genetic Algorithm

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ABSTRACT
Heat pumps offer economical alternatives of recovering heat from different sources for use in various industrial, commercial and residential applications. In this study, single-stage air-source vapor compression heat pump system has been optimized using a genetic algorithm (GA) and fuzzy logic (FL). The necessary thermodynamic properties for optimization were calculated by FL. Thermodynamic properties obtained with FL were compared with actual results. Then, the optimum working conditions of heat pump system were determined by the GA.

1 INTRODUCTION
The heat pump is basically an air conditioner with a valve that allows it to operate in reverse. A heat pump is an electric-powered device that extracts accessible heat from one area (the heat source) and transfers it to another (the heat sink) to either heat or cool an interior space or to extract heat energy from a fluid. In the case of a fridge, for example, heat is transferred from the interior of the fridge to the condenser coils at the back.

For climates with moderate heating and cooling needs, heat pumps offer an energy-efficient alternative to furnaces and air conditioners. Like a refrigerator, a heat pump uses electricity to move heat from a cool space into a warm one, making the cool space cooler and the warm space warmer. During the heating season, heat pumps move heat from the cool outdoors into your warm house; during the cooling season, heat pumps move heat from your cool house into the warm outdoors. Because they move heat rather than generate heat, heat pumps can provide up to 4 times the amount of energy they consume.

Several heat pump types exist; some require external mechanical work while others require external thermal energy. A commercial heat pumps based on the vapor compression cycle or the absorption cycle are operational in numerous applications in various industries. The most common type of heat pump is the air-source heat pump, which transfers heat between the interior of a building and the outside air. If you heat with electricity, a heat pump can trim the amount of electricity you use for heating by as much as 30–40%. High-efficiency heat pumps also dehumidify better than standard central air conditioners, resulting in less energy usage and More cooling comfort in summer months. However, the efficiency of most air-source heat pumps as a heat source drops dramatically at low temperatures, generally making them unsuitable for cold climates, although there are systems that can over-come that problem. One such system is the dual-fuel heat pump.

For homes without ducts, air-source heat pumps are also available in a ductless version called a mini-split heat pump. In addition, a special type of air-source heat pump called a ‘‘reverse cycle chiller’’ generates hot and cold water rather than air, allowing it to be used with radiant floor heating systems in heating mode.

Higher efficiencies are achieved with geothermal heat pumps (ground-source or water-source), which transfer heat between your house and the ground or a nearby water source. Although they are more costly to install, geothermal heat pumps have low operating costs because they take advantage of relatively constant ground or water temperatures. However, the installation depends on the size of your lot, the subsoil, and the landscape. Ground-source or water-source heat pumps can be used in more extreme climatic conditions than air-source heat pumps, and customer satisfaction with the systems is very high. A new type of heat pump for residential systems is the absorption heat pump, also called a gas-fired heat pump. Absorption heat pumps use heat as their energy source, and can be driven with a wide variety of heat sources [1, 2].

In literature, there are some studies based on optimization of heat pump systems. Comely et al. Determined optimum working conditions R-22 and R-404a refrigerant mixtures in heat-pumps using Taguchi method. It was observed that the most effective parameters are found to be the condenser air inlet temperature for the coefficient of performance and exergetic efficiency [3]. Sago and Stamatelos investigated the effect of climatic conditions on the design optimization of heat pump systems for space heating and cooling. It is concluded that climatic conditions significantly affect the performance of heat pump systems, which should lead to markedly different strategies for domestic heating and cooling, if an optimization is sought on sustainability grounds [4]. Ceylon and actors made modeling of a hazelnut dryer assisted heat pump by using artificial neural networks. When the comparison was made between the predicted values and used experimental results in training artificial neural network, multiple determination coefficient estimated at 0.99 for 40 and 50LC drying air temperatures [5]. Essen et al. Used adaptive Neuro-fuzzy inference system for the modelling of ground-coupled heat pump system. In order to achieve the optimal result, several computer simulations have been carried out with different membership functions and various numbers of membership functions. This paper shows that the values predicted with the adaptive Neuro-fuzzy inference system, especially with the hybrid learning algorithm, can be used to predict the performance of the ground-coupled heat pump system quite accurately [6]. Thermodynamic and thermoeconomic optimization of a vertical ground source heat pump system has been studied by Saudi et al. An economic model of the system is developed according to the Total Revenue Requirement method. The objective functions based on the thermodynamic and thermoeco-Nomic analysis is developed. The proposed vertical ground source heat pump system including eight decision variables is considered for optimization. An artificial intelligence technique known as evolutionary algorithm has been utilized as an optimization method [7]. A model of the behavior of a two-stage semiconductor thermo-electric heat-pump with an external heat transfer is devised by Chen et al. The performance of the heat-pump, assuming Newton's heat-transfer law, is analyzed using the combination of finite-time thermodynamics and non-equilibrium thermodynamics. The analytical formula describing the heating load versus working electric-cur-rent, and the coefficient of performance versus working electric-current are derived. For the fixed total number of thermo-electric elements, the ratio of the number of thermo-electric elements of the top stage of the total number of thermo-electric elements is also optimized for maximizing the heating load and the coefficient of performance of the thermo-electric heat-pump [8]. Sozen et al. Have made performance prediction of a vapor-compression heat-pump by using fuzzy logic. Input data for the fuzzy logic are mixing ratio, evaporator-inlet temperature and con-denser pressure. In the comparison of performance, results obtained via analytic equations and by means of the fuzzy-logic controller, the coefficient of performance, and rational efficiency for all working situations differ by less than 1.5 and 1%, respectively. The statistical coefficient of multiple determinations equals to 0.9988 for both the coefficient of performance and the rational efficiency [9]. Sanaa and Niroomand presented the modeling and optimizing processes of a ground-coupled heat pump with closed vertical ground heat exchanger. Two Nelder–Mead and genetic algorithm optimization techniques were applied to guarantee the validity of the optimization results. For the given heating/cooling loads and various climatic conditions, the optimum values of heat pump design parameters (saturated temperature/pressure of con-denser and evaporator) as well as vertical ground heat exchanger design parameters (inlet and outlet temperatures of the ground water source, pipe diameter, depth and number of boreholes) were predicted. Furthermore, the sensitivity analysis of change in the total annual cost of the system and optimum design parameters with the climatic conditions, cooling/heating capacity, soil type, and number of boreholes were discussed. Finally, the sensitivity analysis of change in optimum design parameters to increase in the investment and electricity costs was performed [10]. Sanaa and Niroomand presented the modeling and optimizing a ground-coupled steam ejector heat pump with closed vertical ground heat exchanger. The system includes two main sections of the vertical ground heat exchanger and steam ejector heat pump, and was optimized by minimizing its total annual cost as the objective function. Two optimization techniques (NeldereMead and Genetic Algorithm) were applied to guarantee the validity of optimal results. For the given heating/cooling loads as well as for various climatic conditions, the optimum design parameters of ground-coupled steam ejector heat pump with closed vertical ground heat exchanger were predicted.

Furthermore, the changes in total annual cost and optimum design parameters with the climatic conditions, cooling/ heating capacity, soil type, and number of boreholes were discussed [11].

Thermodynamic properties of refrigerants are very important parameters affecting the performance of vapor compression heat pump systems. The engineering calculation and simulation of vapor compression heat pump systems require the availability of simple and efficient calculation for the determination of thermodynamic properties of refrigerants. Thermodynamic properties of R-404a refrigerant were presented in the literature as limited data in case of tables. In this study, in order to determine enthalpy values for any temperature and pressure of R-404a refrigerant FL method were used. Then, enthalpy values obtained from FL method have used in the optimization process of single-stage air-source vapor compression heat pump system with GA. Therefore, entropy values of R-404a refrigerant have easily calculated and optimization of single-stage air-source vapor compression heat pump system is fairly simplified.

2 MODELING AND OPTIMIZATION METHOD

2. 1 FUZZY LOGIC

Fuzzy logic has two different meanings. In a narrow sense, fuzzy logic is a logical system, which is an extension of multivalued logic. However, in a wider sense fuzzy logic is almost synonymous with the theory of fuzzy sets, a theory which relates to classes of objects with unsharp boundaries in which membership is a matter of degree. In this perspective, fuzzy logic in its narrow sense is a branch of fuzzy logic. Even in its narrowest definition, fuzzy logic differs both in concept and substance from traditional multivalued logical systems [12]. Fuzzy logic has become an important tool for a number of different applications ranging from the control of engineering systems to business. Fuzzy Algorithm relies on a systematic use of linguistic expressions to characterize the values of variables and relations between them [13].

Even though the broad sense of fuzzy logic covers a wide range of theories and techniques, its main technique is based on four basic concepts [13].

- Fuzzy if–then rules: a knowledge representation scheme for describing a functional mapping or a logic formula that generalized an implication in two valued logic.
- Possibility distributions: constraints on the value of a linguistic variable imposed using fuzzy set.
- Fuzzy sets: sets with smooth boundaries.
- Linguistic variables: variables whose values are both qualitatively and quantitatively described by a fuzzy set.

A fuzzy logic model with its fundamental input–output relationship consists of four components namely; the falsifier, the inference engine, the defuzzifier, and a fuzzy rule base (Fig. 1).

In the falsifier, crisp inputs are fuzzified into linguistic values to be associated with the input linguistic variables. After falsification, the inference engine refers to the fuzzy rule base containing fuzzy IF–THEN rules to derive the linguistic values for the intermediate and output linguistic variables. Once the output linguistic values are available, the defuzzifier produces the final crisp values of the output linguistic values [14]. More details on the fuzzy logic theory and applications are outlined in Refs. [12– 16].

2.2 GENETIC ALGORITHMS

The genetic algorithm is a method for solving both con-strained and unconstrained optimization problems that are based on natural selection, the process that drives biological evolution. The genetic algorithm has repeatedly modified a population of individual solutions. At each step, the genetic algorithm selects individuals at random from the current population to be parents and uses them to produce the children for the next generation. Over successive generations, the population ''evolves'' toward an optimal solution [17].

Genetic algorithms are a part of evolutionary computing, which is a rapidly growing area of artificial intelligence. The algorithm starts with a set of solutions (represented by chromosomes) called a population. Solutions from one population are taken and used to form a new population. This is motivated by a hope, that the new population will be better than the old one. Solutions which are selected to form new solutions (offspring) are selected according to their fit-ness's, the more suitable they are the more chances they have to reproduce. This is repeated until some condition

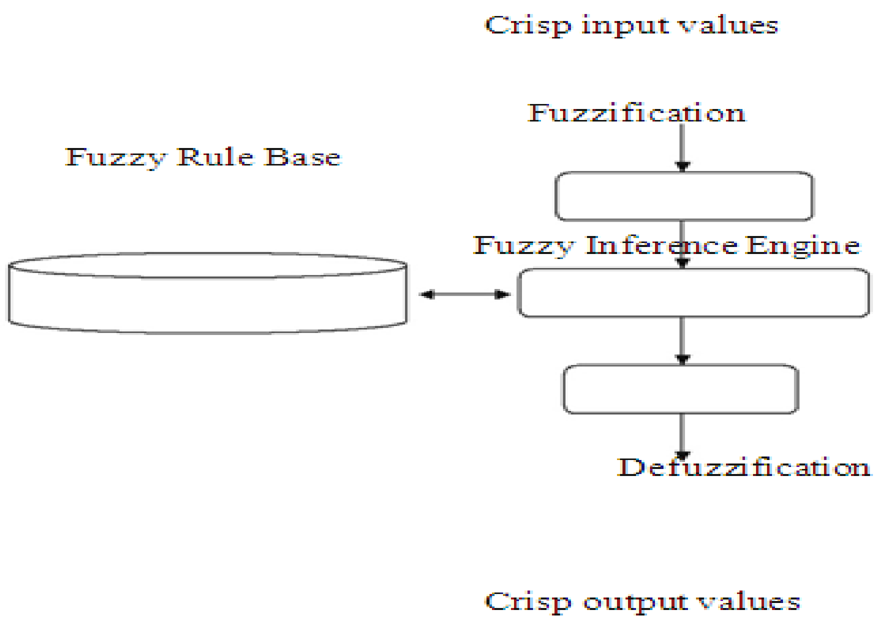

FIG. 1 BASIC FLOW CHART OF FUZZY LOGIC

(For example number of generation or improvement of the best solution) is satisfied [18].
The procedure of GA for the problem is described as follows:
Step 1. Read system data and GA parameters Step 2. Generate an initial population of an individual
Step 3. Calculate the fitness F_i of each chromosome in the population

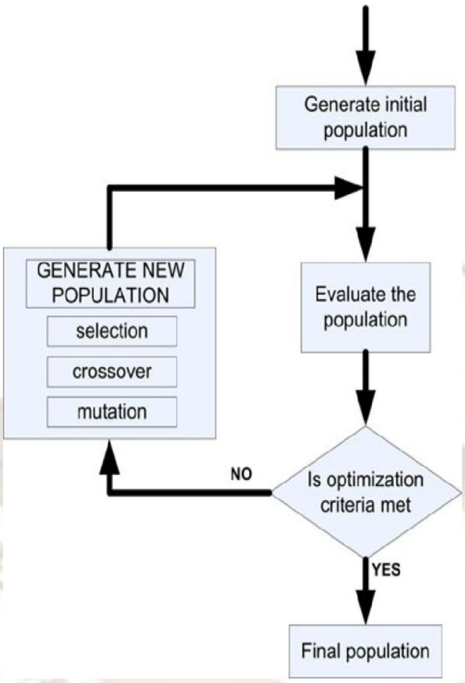

FIG. 2 BASIC FLOW CHART OF GA [19]

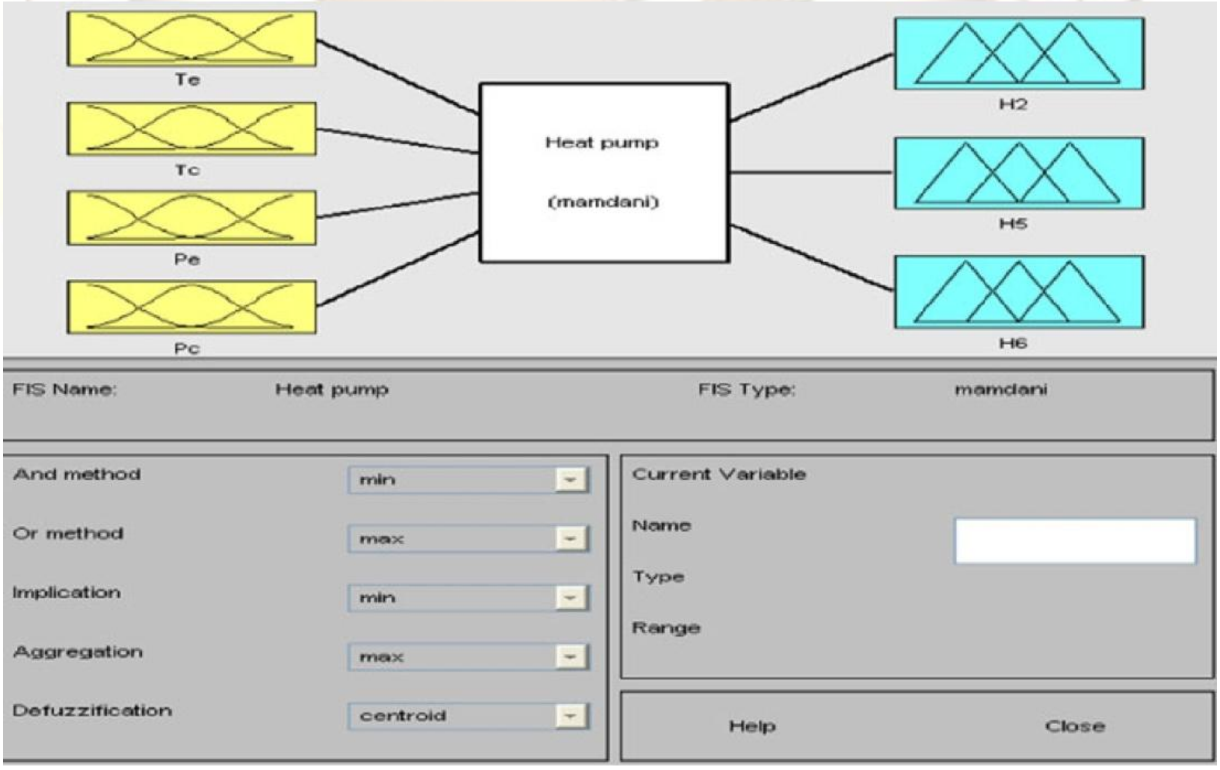

FIG. 3 INPUT-OUTPUT VALUES FOR HEAT PUMP IN FUZZY LOGIC

Step 4. Create a new population by repeating the following steps until the new population is complete
Step 5. Select two parents by tournament selection Step
6. With stochastic uniform, cross over the parent chromosomes to form a new offspring (children)
Step 7. With a mutation probability mutate new offspring
Step 8. Calculate the fitness F_i of each new offspring Step
9. Place new offspring in a new population
Step 10. Sort the all individuals from minimum to maximum
Step 11. Use new generated population (population size is a) for a further run of the algorithm
Step 12. If the end condition is satisfied, stop, and return the best solution in current population else go to Step 4 Flow chart of GA is shown in Fig. 2.

These and other variations of the basic algorithm have been discussed extensively by various authors [17– 23].

3 RESULT AND DISCUSSION

In this study, optimization of single-stage air-source vapor compression heat pump system using GA was carried out. R-404a as refrigerant in the system was used. In addition, thermodynamic properties of this refrigerant were obtained using FL.

Enthalpies of different points of refrigerant used in vapor compression heat pump systems are predicted using FL approach. The temperature and pressure are the input data and enthalpy of the refrigerant is the actual output. The training data for the thermophysical properties of refrigerants were provided from Solkane (2010) [24]. In Fig. 3, input- output parameter used in the analysis is shown. Models are run in MATLAB Fuzzy Logic Toolbox. In this study, Mamdani type fuzzy inference system (FIS) was employed. Type of membership function is a triumph. 55 rules in the designed fuzzy logic model were used.

4 CONCLUSION

GA method was presented to obtain the various optimum design parameters of single-stage air-source vapor compression heat pump system. R-404a as refrigerant in the system was used. Thermodynamic properties of this refrigerant were obtained successfully using FL. The values obtained from FL were found to be in good agreement with actual values. Then, the optimum working conditions of heat pump systems were determined by the genetic algorithm. The optimum working temperature of the condenser and evaporator is found to be 20.07 and -0.14LC. Optimum working pressure for the condenser and evaporator is found to be 10.87 and 5.98 bar by using GA. So, maximum COP for heating and cooling is found to be 10.23 and 9.23 by using GA. The results of this work show that GA can use for determining optimum working conditions. Genetic algorithm provides more flexibility to the designer.

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