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Neural Network Technology for a VRF System

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ABSTRACT

Energy is used for a variety of purposes, ranging from home to industrial [12]. The building industry, which accounts for roughly 25% of total energy use, is one of the most common. In recent decades, an exponential increase in energy demand has been witnessed due to population growth and development [30]. In recent years, the government has worked to optimize and minimize energy use in the building sector, thereby reducing carbon emissions from fossil-fuel-based power plants [13]. Variable refrigerant flow (VRF) cooling systems are increasingly being used in large buildings to achieve this. Because each section of the building is regulated separately according to necessity with the use of controllable electronic valve opening, such a system has the benefit of being very efficient. The need for variable refrigeration arises from the fact that energy conservation is a top priority for not only industries but all sectors of society. Global warming is now a fact, and limiting carbon emissions is a must in today's world. Saving energy resources is especially important in countries like India, where 70% of power is still provided by fossil fuel-based thermal power plants. However, in the HVAC industry, saving energy is crucial, but not at the expense of user comfort. In this paper, an ANN algorithm was used to create a model to improve the efficiency of VRF technology. The reason for utilizing this algorithm is that it has an amazing capacity to extract information from nonlinear data with considerable stability while maintaining an intractably high pace of convergence.

Keywords: Variable Refrigerant Flow, Artificial neural Network, Levenberg and Marguetz algorithm, Backpropagation, Mean Square Error, energy saving techniques, MATLAB.

I. INTRODUCTION

One of the most common trends is the steady increase in energy demand all across the world. Most of the sources used to meet this need are based on fossil fuels, which are the primary driver of global warming. India is also experiencing a demand-supply mismatch due to unequal demand, thus the government has enacted rules to reduce energy usage in the construction sector. Because the construction industry accounts for around one-fourth of total energy use, careful planning is required. Another factor demonstrating the necessity of reducing energy usage in the construction industry is the constant increase in cooling equipment installed to create a more comfortable atmosphere for its customers. The capacity of VRF to operate with great efficiency during partial load conditions of the building by managing each room separately and exchanging heat among different sections is one of the most significant differences between VRF and traditional systems. The globe is in desperate need of systems that are both energy efficient and comfortable. VRF systems were developed with the same goal in mind, but with the added benefit of energy savings and the usage of refrigerant. Air-cooled or water-cooled refrigerant can be employed in such systems.

The research presents a control technique to assist VRF in operating at a certain location in order to maximize performance. The goal is to build a set of set points for all operating scenarios and then choose one of them to ensure the most efficient cooling operation. The initial step in this procedure is to utilize an ANN model to anticipate which set of points the system should operate at in order to achieve the best potential outcome. The system will then be tested across those specified points for improved efficiency and electricity savings.

II. LITERATURE REVIEW

Many studies have been conducted in the past to find an algorithm or model that can tackle the challenge of VRF optimization. In this section, we'll look at some of the most recent work:

In [1,] Roba Saad and Mohamed I. Hassan Ali explained how EES can be a good technique to optimize VRF results under various weather conditions, specifically tailored for hot and humid Middle Eastern countries. The procedure is designed to first determine the parameters that have a significant impact on VRF efficiency, and then use those parameters to regulate refrigerant. Condenser pressure and evaporator pressure were discovered to be the most important parameters during testing. These two will eventually aid in the reduction of energy consumption. During testing, the author's model produced an output with an error rate of around 8%.

MEAC technique can be advantageous for energy saving air conditioning techniques, according to Huaxia YAN and Shiming Deng in [2]. Although, according to the author, most of these techniques focus solely on temperature management, limiting their ability to save energy to its full potential. In this paper, the author proposes a novel technique for controlling both air temperature and humidity by modeling and building an air conditioning system. The evaluation resulted in a more efficient solution than the prior one.

[3] suggested an ESC approach for optimizing energy utilization of any VRF system without really having prior knowledge of the model under consideration by Liujia Dong, Yaoyu Li, Timothy I. Salsbury, and John M. House. The proposed model features five different operating modes that any user can select based on their needs. The optimization is accomplished by adjusting the fan speed at both the inside and external openings. Switching between modes is accomplished using switching logic created specifically for this purpose.

Yang Zhu, Yaoyu Li, Liujia Dong, Timothy I. Salsbury, and John M. House studied how energy is used for diverse purposes ranging from home to industrial. The building industry, which accounts for roughly 25% of total energy use, is one of these common areas. In recent years, the government has worked to optimize and reduce the amount of energy used in the construction sector, thereby reducing carbon emissions from fossil-fuel-based power plants. Variable refrigerant flow (VRF) cooling systems are increasingly being used in large buildings to achieve this. Because each section of the building is regulated separately according to necessity with the use of controllable electronic valve opening, such a system has the benefit of being very efficient.

The proposed model by Matthew S. Elliott, Carolyn Estrada, and Bryan P. Rasmussen [5] features five alternative modes of operation that every user can set based on their needs. The optimization is accomplished by adjusting the fan speed at both the inside and external openings. Switching between modes is accomplished using switching logic created specifically for this purpose. In this paper, the author proposes a novel technique for controlling both air temperature and humidity by modeling and building an air conditioning system. The evaluation resulted in a more efficient solution than the prior one.

In [6,] Xuhui Wang, Jianjun Xia, Xiaoliang Zhang, Sumio Shiochi, Chen Peng, and Yi Jiang developed a grey box model for VRF system energy consumption evaluation. This technology's general operation procedure is to give tailored modulated refrigerant to each unit so that each unit has its own level of cooling, providing a more comfortable atmosphere for users based on demand while also forming a highly energy efficient system. Because most developing countries rely on imported energy, energy efficiency is critical. Air conditioning accounts for 35-50 percent of total energy demand, which is a significant amount of energy.

III. OBJECTIVE

The globe is in desperate need of systems that are both energy efficient and comfortable. Also, the terrible effects of global warming have begun to manifest themselves, causing catastrophic destruction due to the unpredictability of the environment. As a result, there is a higher need for cooling systems at a lower cost.

VRF systems were created with the sole purpose of saving energy and using refrigerant. The capacity of VRF to operate with great efficiency during partial load conditions of the building by managing each room separately and exchanging heat among different sections is one of the most significant differences between VRF and traditional systems [13].

In this paper, an attempt is made to construct a model utilizing an Artificial Neural Network-based algorithm to regulate various parameters in a VRF cooling system in order to:

- Reduce energy consumption by managing the input parameter
- Optimization results in a reduction in refrigerant usage.
- Creating a new system using the ANN testing and training technique.

Optimized input parameter values should be used to reduce energy and refrigerant usage. The optimization can be done using a variety of strategies, the most contemporary and accurate of which are Artificial Neural Network (ANN) based Artificial Intelligence (AI) and Machine Learning (ML) based techniques.

When the prediction error (predicted value – actual value) is low, the ANN is producing accurately optimized input parameter values. As a result, if the error is low, the refrigerant and electricity consumption will be minimal.

IV. INTRODUCTION TO VRF

VRF's technology essentially gives a system that can regulate the flow of refrigerant in various separate units based on their demand. The technology's origins can be traced back to the early 1980s in Japan, when a business called "Daikin industries" proposed and applied it in their works [35]. This technology's general operation procedure is to give tailored modulated refrigerant to each unit so that each unit has its own level of cooling, providing a more comfortable atmosphere for users based on demand while also forming a highly energy efficient system [34]. Because most developing countries rely on imported energy, energy efficiency is critical. Air conditioning accounts for 35-50 percent of total energy demand, which is a significant amount of energy. Any reduction in this energy will go a long way toward lowering carbon emissions from fossil-fuel power plants[18]. Two major gadgets are used to control the operation. One is a variable frequency drive, whose primary function is to regulate the speed of the outdoor condensing unit's fan, which aids in the flow of refrigerant in accordance with demand[19].

The second component is electronic expansion valves, which are located in the indoor evaporator and are responsible for supplying refrigerant flowing through refrigerant pass ways to various work units.

The VRF technology consists of multiple indoor fan coil units, each of which has an opening at each individual section/unit and a single output opening unit for the entire interior fan coil [12]. Every interior unit has its own system for sensing its surroundings, which aids in determining the desired adjustment and sending a request to the outdoor unit. His information to the external unit to change the refrigerant is critical in optimizing the functioning of the VRF. During cooling mode, expansion is equivalent to an indoor unit with a condensed liquid in the liquid line [7], but during heating mode, expansion is equivalent to an outdoor unit with a condensed liquid in the liquid line. Figure 1 depicts a typical VRF system configuration.

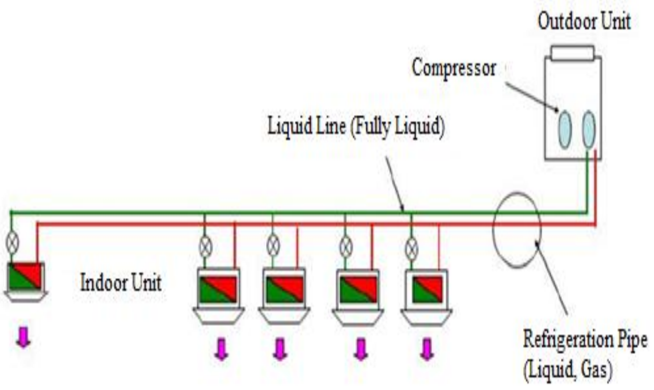

Figure 1 shows a typical VRF setup.

In the following part, we'll go over a few of VRF's benefits in more detail:

- **Control to Comfort**

Unlike traditional cooling/heating systems, where room temperature fluctuates continuously as the compressor begins and stops [14]. It only operates in these two modes, depending on the situation. Because there is no way to control the speed, the temperature drops and rises. This problem is solved by VRF, which maintains a constant temperature without substantial variation by continuous speed variation with the help of inverter frequency variation based on demand, providing a high level of comfort to users.

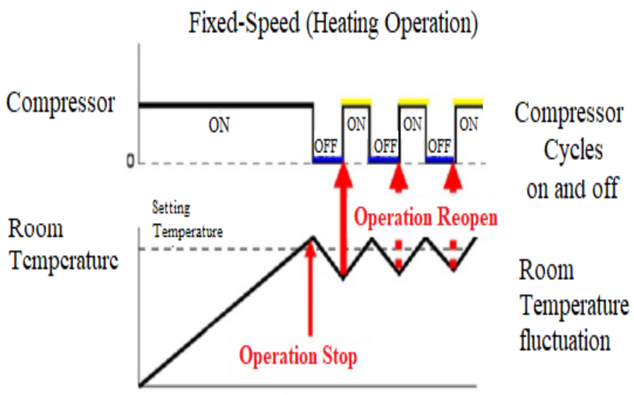

Figure 2: Operation of a Fixed-Speed Compressor

In the typical system, due to compressor switching, a dip and rise can be plainly seen in fig. 2. However, due to the continuous functioning of the compressor at varied speeds in fig.3, this is much less significant for VRF.

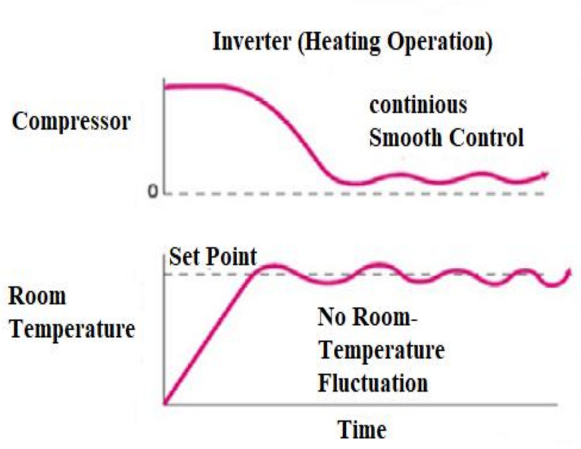

Fig 3 VRF System Compressor Operation

Flexible Design

Another amazing aspect of the VRF system is that it allows users to create indoor units of any size based on their needs; these units can even be of different sizes depending on zoning. The demand and, as a result, the required flow of refrigerant will be determined by the zoning area and the work to be done there. As a result, when building a VRF system, the highest and lowest interior units should be considered.

High Cost saving

VRF saves money by minimizing energy use, adjusting compressor speed, and having a low-cost installation. The units required for VRF are significantly lighter and smaller than those required for conventional systems. The pipe size required is also relatively modest, which reduces installation costs.

The power required for operation in a VRF system is very low since the compressor's speed regulation ensures that refrigerant flows to the input pipe precisely according to the demands from the indoor coil units.

Less duct losses

Because this procedure uses refrigerant instead of conditioned air, the number of ducts required is significantly reduced. As a result, just a little amount of air is necessary because the movement of refrigerant is mostly used for heat exchange between separate units.

Parallel cooling and heating

Unlike traditional HVAC systems, VRFs have the unique benefit of being able to heat and cool multiple parts of a building at the same time. They perform heat exchange between portions, resulting in minimal energy loss. Heat Recovery Units (HRU) are used to do this, and their aim is to exchange heat between different zones.

Ease of installation

Because of the tiny size of all sections of VRFs compared to conventional systems, they take up less room and need less work to move both the interior and outdoor units. During operation, both of these units make significantly less noise. The VRF that controls each individual zone is depicted in Figure 4.

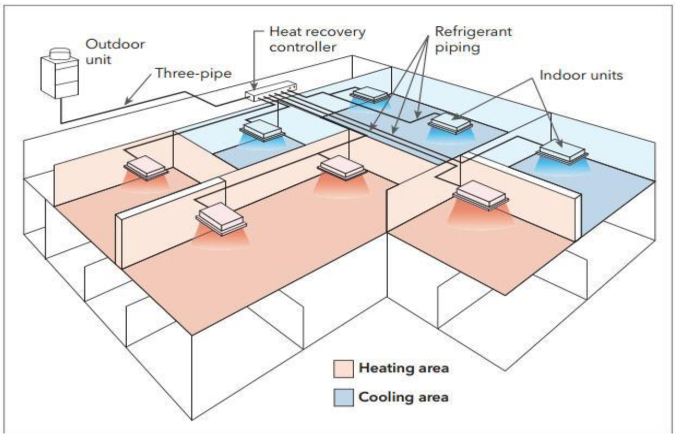

Figure 4 shows the variable refrigerant flow that controls the separate zones.

V METHODOLOGY:

In order to optimize VRF, the following strategies are used in this study:

Artificial Neural Networks (ANN)

The origins of ANN may be traced back to the 1980s, when computers began to evolve. The phrase artificial neural network is derived from the same evolutionary process. The term "artificial" refers to this model's ability to mimic the functioning of the human brain. Typically, machines have the ability to work according to pre-programmed instructions [8]. This, however, is not how humans work. Any human brain has the ability to make decisions based on their experiences, which we refer to as training in computer terms. As a result, it equips the brain with the ability to make correct decisions in situations that are unfamiliar to it. Therefore, machine learning is a method by which we inherit this specialty of human biological thinking system and try to replicate same in computer/machine.

Now let’s understand how human brain works to form exact algorithm which can give similar outputs. Brain consist of billions of neurons, which are interconnected with each other. These interconnections have a certain strength, which makes our memory storage [26]. Based on these memories we take decision over everything in real time. The strength of these connections depends mainly on signal from various cells/neurons situated in each part of our body [27]. These neurons continuously send signal according to sense organs response to brain in the form of electromagnetic pulses [28]. These pulses are passed to brain through a series of chain of cells linking brain with sense organs. These chains of cells have two responsibility to transfer signal from one part of body to other and second to modify the signal in such a manner that brain will take the decision instantaneously [9].

Now the objective of formation of neural network is to reproduce the same scenario in computer based upon programming, algorithms, processor and memory, which is discussed in detail in next section of this chapter [10].

Levenberg–Marquardt (LM) Algorithm:

The algorithm used in this work is Levenberg–Marquardt (LM) Algorithm which a type of back propagation algorithm. The reason for utilizing this algorithm is that it has an amazing capacity to extract information from nonlinear data with considerable stability while maintaining an intractably high pace of convergence. The algorithm is a combination of two different algorithms proposed by two mathematicians Levenberg and Marquardt and hence the named over them [19]. The drawback of prior one is remove by the advancement of second. The equation were derived back in mid-20th century for the sake of 1st order error reduction purpose. However, with the invention of computers and high-level computation problem this algorithm is evolved in to a great tool for time series forecasting. In his suggested algorithm, Levenberg produces the following equation:

$$g = \frac{\partial E(x,w)}{\partial x} = \left[\frac{\partial E}{\partial w_1} \quad \frac{\partial E}{\partial w_2} \quad \cdots \quad \frac{\partial E}{\partial w_N}\right]^T$$

$$w_{k+1} = w_k - \alpha g_k$$

g is the Gaussian coefficient, E is the error function, and x is the priority function in the preceding equation. W stands for weight function. Wk is the current weight, Wk+1 is the weight of the next iteration, and is the step size.

$$J = \begin{bmatrix} \frac{\partial e_{1,1}}{\partial w_1} & \frac{\partial e_{1,1}}{\partial w_2} & & \frac{\partial e_{1,1}}{\partial w_N} \\ \frac{\partial e_{1,2}}{\partial w_1} & \frac{\partial e_{1,2}}{\partial w_2} & \cdots & \frac{\partial e_{1,2}}{\partial w_N} \\ \cdots & \cdots & & \cdots \\ \frac{\partial e_{1,M}}{\partial w_1} & \frac{\partial e_{1,M}}{\partial w_2} & & \frac{\partial e_{1,M}}{\partial w_N} \\ \cdots & \cdots & & \cdots \\ \frac{\partial e_{P,1}}{\partial w_1} & \frac{\partial e_{P,1}}{\partial w_2} & & \frac{\partial e_{P,1}}{\partial w_N} \\ \frac{\partial e_{P,2}}{\partial w_1} & \frac{\partial e_{P,2}}{\partial w_2} & \cdots & \frac{\partial e_{P,2}}{\partial w_N} \\ \cdots & \cdots & & \cdots \\ \frac{\partial e_{P,M}}{\partial w_1} & \frac{\partial e_{P,M}}{\partial w_2} & & \frac{\partial e_{P,2}}{\partial w_N} \end{bmatrix}$$

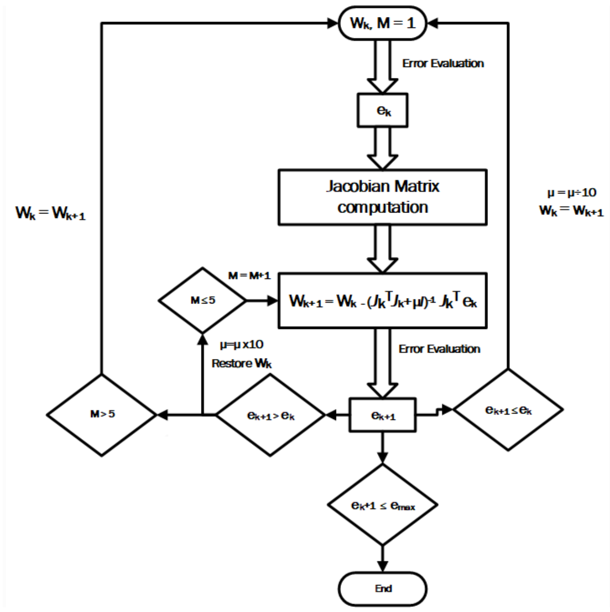

Fig. 5: Block diagram for Levenberg–Marquardt algorithm training.

As a result, the hessian matrix can be evaluated as follows:

$$h_{i,j} = \frac{\partial^2 E}{\partial w_i \partial w_j} = \frac{\partial^2 \left(\frac{1}{2}\sum_{p=1}^{P} \sum_{m=1}^{M} e_{p,m}^2\right)}{\partial w_i \partial w_j} = \sum_{p=1}^{P}\sum_{m=1}^{M} \frac{\partial e_{p,m}}{\partial w_i} \frac{\partial e_{p,m}}{\partial w_j} + S_{i,j}$$

Where,

$$S_{i,j} = \sum_{p=1}^{P}\sum_{m=1}^{M} \frac{\partial^2 e_{p,m}}{\partial w_i \partial w_j} \, e_{p,m}$$

$$H = J^T J$$

$$w_{k+1} = w_k - (J_K^T J_k)^{-1} J_K \, e_k$$

$$H = J^T J + \mu I$$

The Levenberg–Marquardt algorithm can be described as follows:

$$W_{k+1} = W_k - \left[J_K{}^T J_k + \mu I\right]^{-1} J_K{}^T e_k$$

The figure 5 shows a block diagram of LM algorithm for predicting output value [22].

Fig 6 is a structural model of ANN used in present work. It consists of 5 input neurons 5 output neurons and a randomly chosen 50 neurons [23]. All five chosen input parameters are available for all time hence are used for evaluating output values [24]. The output parameters chosen are

- Condenser heat rejection rate
- Refrigerant mass flow rate
- Compressor power
- Electric power input to the compressor motor
- Coefficient of performance

Similarly the input values chosen are

- Evaporator load
- Airflow rate passing through condenser
- Water flow rate passing through condenser
- Dry bulb temp. of air stream entering the condenser
- Wet bulb temp. of air stream entering the condenser

A single input layer and a single output layer exist in every network [11]. The number of input variables in the data being processed is equal to the number of neurons in the input layer. The output layer has the same number of neurons as the number of outputs associated with each input. A hidden layer in an artificial neural network is a layer that sits between the input and output layers, where artificial neurons take in a set of weighted inputs and use an activation function to produce an output [21].

Weight is represented by the connecting lines between any two neurons [25]. After multiplication with weight value [29], any input data supplied at input neurons is sent to hidden layer neuron. Similarly, following processing at the hidden layer neuron, the data is multiplied by weight values and sent to the hidden layer neuron. The required anticipated output will be the value at the output layer neuron.

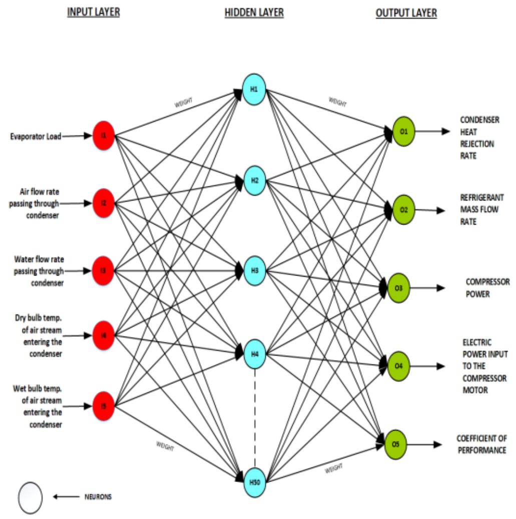

Figure 6: Ann Model Used In This Study

VI. CONCLUSION

The neural network backpropagation technique was used to train and test the system. The capacity of an artificial neural network in refrigeration system control is being tested in this work. A total of five different factors are chosen, each of whose value is known at all times and has a substantial influence on the variable refrigeration flow. Five separate parameters' values are projected based on these inputs, which will aid in determining the refrigeration system's performance. Condenser heat rejection rate, compressor power, and other output data are included. Simulating data using the neural network toolbox in MATLAB software and measuring performance parameters such as correlation coefficient and mean square error revealed that the model was very robust up to a point, allowing for high efficiency. The degree of improvement in performance determined as a correlation coefficient is almost as close to "1" as possible, with a margin of error of roughly 4%.

As a result, the study has demonstrated that artificial neural networks can accurately design any variable refrigeration flow system. The network will assist in lowering the cost of operation and power consumption of any HVAC system, as well as lowering refrigerant usage.

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