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"A comparative study for Controlling of Variable Refrigerant Flow (VRF) System using the intelligent optimizer techniques"

Mr. Ganesh Patidar[1], Mr. Nitin Jaiswal[2,]

[1] M. Tech Scholar in Thermal Engineering, LNCT, Indore (M.P), India. E-mail: (ganeshcpatidar@gmail.com)
[2]Assistant Professor in ME Dept., LNCT, Indore (M.P), India. (nitin.jess@gmail.com)

Abstract — With increment in population and advancement, a dramatic expansion in demand of energy has been seen in recent many years. This energy is utilized for different reason from domestic to modern area. Out of these areas, one regular zone that has a portion of around 25 % of energy utilization is by building area. Government lately to improve and decrease the energy utilized in building areas accordingly helping to lessen fossil fuel byproduct from generation station, which are fossil fuel based. To accomplish this a variable refrigerant flow (VRF) cooling system are been progressively executed in enormous structures. Such system has the upside of having high productivity on account of the way that each space of building is controlled independently as indicated by prerequisite with the assistance of controllable electronic valve opening.

The significance of variable refrigeration is felt in view of the way that energy conservation is one of the superb targets of ventures as well as each segment of society. Global warming has become a reality and decreasing fossil fuel byproduct has gotten basic in the present time. Presently in country like India where majority of power is as yet created utilizing fossil fuel based thermal power plant, saving energy assets is more indispensable.

In this work, a model has been set up to improve proficiency of VRF technology utilizing ANN algorithm. The purpose for utilizing this algorithm is because of its excellent capacity to extract information from a nonlinear information with incredible solidness which keeping pace of union immovably high.
Keywords: Variable Refrigerant Flow, Artificial neural Network, Levenberg and Marguetz algorithm, Backpropagation, Mean Square Error, energy saving techniques, MATLAB.

I. INTRODUCTION

Continuous increase in demand of energy all around the world has become one of the common trends. To fulfill this demand most of the sources used are fossil fuel based and are root cause of global warming. India is also facing same mismatch situation of demand and supply due to uneven demands and hence government has made policies for decrease in energy consumption in building sector. Building sector contribute to about one fourth of energy consumption, hence it requires proper planning. Another aspect that shows the importance of optimizing the energy consumption in building sector is continuous increase in cooling equipment installed in it to provide more comfortable environment to its users.

The world is facing an urgent need for systems, which are energy efficient and yet provide same comfort. VRF system developed with same objective just with additional saving of energy and used refrigerant. Refrigerant used in such systems can be either air-cooled or water-cooled. One the most important difference between VRF and the conventional system is its ability to operate with high efficiency during partial load condition of building by controlling each room of the building separately thus sharing heat among different sections.

The work proposes a control technology to help VRF operate at a certain point to optimize performance. The purpose of doing so is to create a combination of set points for all conditions of operation and later chose one of them to make most optimal operation of cooling. The first in this process is to use ANN model to predict those set of points where system should operate to give best possible result. Then the second step will be to test the system over those set points for better efficiency and power saving

II. LITERATURE REVIEW

Many works have been done in past in search for an algorithm or model which can solve the problem of optimizing VRF. Some of the latest work has been discussed in this section below:

Roba Saad, Mohamed I. Hassan Ali in [1] discussed that under different weather condition specially designed for hot and humid Middle East nations, EES can be a good way optimizing results of VRF. The operation is specially to first decide the parameters, which highly influence the efficiency of VRF, and then those parameters are used for regulating refrigerant. On testing Condenser pressure and evaporator pressure are two parameters found to be most significant. These two will finally help in reducing energy usages. On testing the model developed by author has delivered an output with an approximately 8% error.

Huaxia YAN, Shiming Deng in [2] depicted that MEAC technique can be beneficial for energy saving air conditioning techniques. Although according to author, most of these technique focuses only on temperature control only hence are unable to use its full potential in saving energy. In this work author has proposed the novel technique control both air temperature and humidity by modelling and designing such system for air conditioning. The result on evaluation were found out to be more efficient than previous one.

Liujia Dong, Yaoyu Li, Timothy I. Salsbury, John M. House in [3] proposed a ESC scheme for optimizing energy usage of any VRF system with actually having a prior knowledge of model under consideration. The proposed model has five different modes of operation which any user can set based on its requirement. The optimization is achieved by controlling speed of fans at indoor opening and at outdoor opening. The switching between different modes is achieved based on switching logic developed specially for this purpose.

Zhu, Yang; Li, Yaoyu; Dong, Liujia; Salsbury, Timothy I. and House, John M., in [4] discussed that energy is used for various purpose from domestic to industrial sector. Out of these sectors, one common area that has a share of around 25 % of energy consumption is by building sector. Government in recent years to optimize and reduce the energy used in building sectors thus helping to reduce carbon emission from generation station, which are fossil fuel based. To achieve this a variable refrigerant flow (VRF) cooling system are been increasingly implemented in large buildings. Such system has the advantage of having high efficiency because of the fact that each space of building is controlled separately according to requirement with the help of controllable electronic valve opening.

Matthew S. Elliott, Carolyn Estrada, and Bryan P. Rasmussen in [5] proposed model has five different modes of operation which any user can set based on its requirement. The optimization is achieved by controlling speed of fans at indoor opening and at outdoor opening. The switching between different modes is achieved based on switching logic developed specially for this purpose. In this work author has proposed the novel technique control both air temperature and humidity by modelling and designing such system for air conditioning. The result on evaluation were found out to be more efficient than previous one.

Xuhui Wang, Jianjun Xia, Xiaoliang Zhang, Sumio Shiochi, Chen Peng, Yi Jiang in [6] developed a grey box model for VRF system to evaluating energy consumption of the system. The general process of operation of this technology is to provide customized modulated refrigerant to each unit such that each unit has its level of cooling, giving a more comfortable environment to users according to demand and also to form a system which is highly energy efficient. The energy efficiency is important because in most of the developing countries. Air condition contributes to about 35-50% of energy demand, which is a large amount of energy.

III. INTRODUCTION TO VRF

VRF's system basically donate a system which has the ability to regulate the flow of refrigerant in the various individual unit's based on their demand. The initial days of this technology were way back in 1980's initial years in japan where a company called "Daikin industries" first proposed and implemented in its works. The general process of operation of this technology is to provide customized modulated refrigerant to each unit such that each unit has its level of cooling, giving a more comfortable environment to users according to demand and also to form a system which is highly energy efficient. The energy efficiency is important because in most of the developing countries. Air condition contributes to about 35-50% of energy demand, which is a large amount of energy. Any reduction in this energy will help greatly in reducing carbon emission from fossil fuel-based power plants. The operation of controlling is done by two main devices one is a variable frequency drive, whose main work is to control the speed of fan of outdoor condensing unit, which help in flow of amount of refrigerant according to demand.

The second parts is electronic expansion valves at indoor evaporator whose work is to supply refrigerant flowing through refrigerant pass lies to various units of work place.

The VRF's technology comprises of many indoor fan coil units, which has the opening at each individual section/ unit and for this entire indoor fan coil has single output opening unit. Every indoor unit has its own separate mechanism to sense its environment, which help in deciding the required change to be done and for that, a demand is to be send to outdoor unit. His feedback of information to outdoor unit to vary refrigerant is very crucial in improving VRF's performance. During cooling Mode, Expansion is equivalent to indoor unit where liquid line has a condensed liquid, whereas at the time of heating mode, expansion is equivalent to outdoor unit and liquid line carry condensed liquid. Fig 4.1 describe an arrangement of typical VRF system.

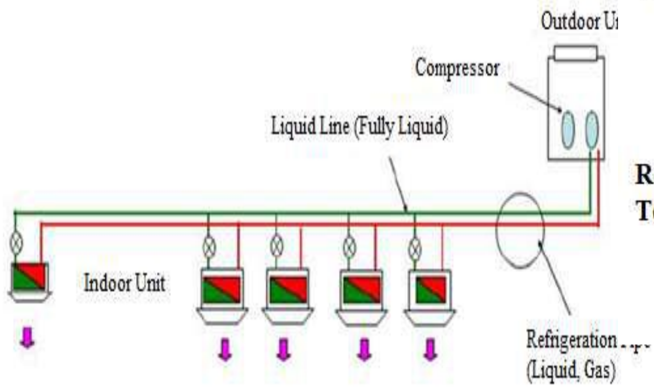

Fig 1 Typical VRF system

Few of VRF's advantages discussed in brief in following section:

- **Control to Comfort**

Unlike conventional cooling/heating system where a continuous fluctuation in room temperature is observed due compressor either starts or stops. It works only on these two modes based on requirement. No speed controlling is provided hence a dip and rise in temperature is observed. This problem is removed by VRF where a steady temperature is maintained without any significant variation by the continuous speed variation with the help of inverter frequency variation according to demand thus provides a great comfort to users.

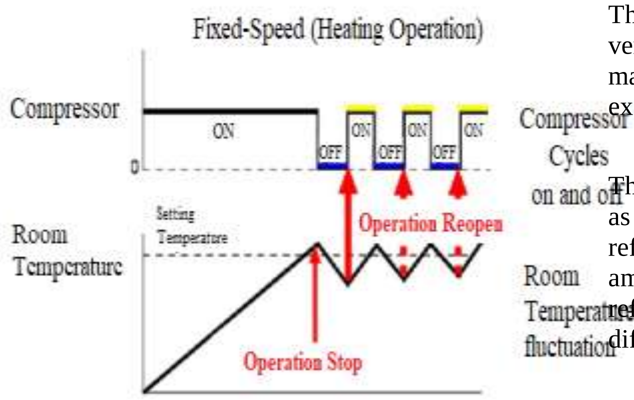

Fig 2 Conventional Fixed Speed Compressor Operation

A dip and rise are clearly seen in above figure for conventional system due switching of compressor. However, in below figure 3.3 for VRF this is very less significant due to continuous operation of compressor at different speed.

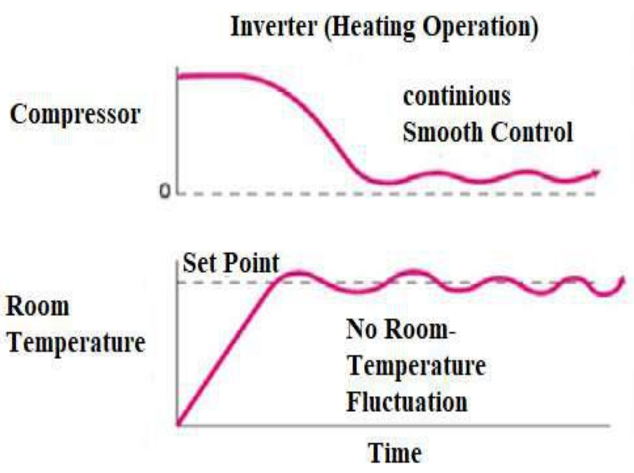

Fig 3 VRF System Compressor Operation

- **Flexible Design**

The VRF system has another great feature, which allow user to install indoor unit of any size based on requirement, these unit, may even have different sizes based on zoning. Area of zoning and work to be performed in it will decide the demand and hence required flow of refrigerant accordingly. Hence, while designing a VRF system one should consider the elevation of highest and lowest indoor units

- **High-Cost saving**

VRF are effective in cost saving by reducing use of energy by varying speed of compressor and by cost effective installation. The units required for VRF are far light weighted then conventional systems and compact in size too. The size of pipe required is also comparatively small again saving cost of installation.

The power required for operation in VRF system is very low as the speed control operation of compressor make sure to let flow of refrigerant to inlet pipe exactly according to demands from indoor coil units.

- **Less duct losses**

The required number of ducts are comparatively less as in this process instead of conditioned air some refrigerant is used for cooling. Hence, a very less amount of air is required as the movement of refrigerant mainly does heat exchange among different units.

- **Parallel cooling and heating**

Unlike conventional HVAC's, VRF's has an added benefit that they can perform both heating and cooling in different sections of building at the same time. They perform heat exchange among sections and hence less loss of energy happens. This is done with help of Heat Recovery Units (HRU) whose purpose is to exchange heat with in different zones.

- **Ease of installation**

Due small size of all parts of VRF's compare to

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conventional systems, they take less space along with fewer efforts in moving both indoor and outdoor unit because of this compact size. Both this unit produce comparative less noise while operation.

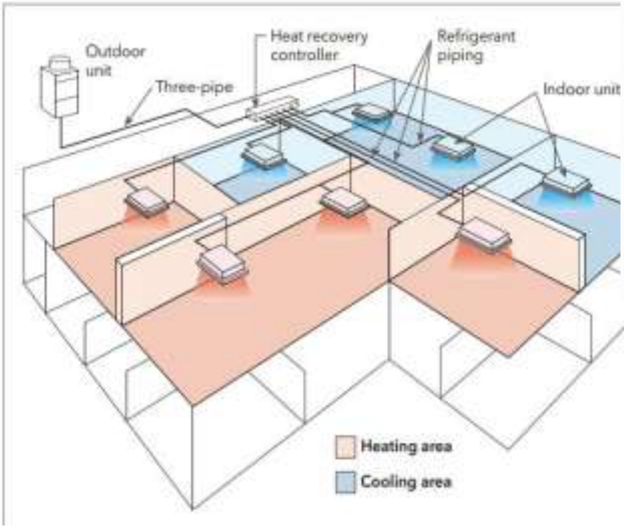

Fig 4 variable refrigerant flow controlling to each individual zones

IV. METHODOLOGY:

Following techniques are utilized in present work for the purpose of optimizing VRF:

Artificial Neural Networks (ANN):

The evolution of ANN has been dated back in 1980's with the evolutions of computers. From the very same process of evolution, the term artificial neural network is been derived. The word artificial is used to denote the capability of this model to replicate the working of human brain. Usually, machines possess a property work according to pre-defined instruction saved in it. However, this is not how human works. The brain of any human has the capacity to take decision based on its experience which we call training in computers language. Hence, it gives capability to brain to take decision that too right in cases which are new 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 consists of billions of neurons, which are interconnected with each other. These interconnections have a certain strength, which makes our memory storage. 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. These neurons continuously send signal according to sense organs response to brain in the form of electromagnetic pulses. 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.

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.

Levenberg–Marquardt (LM) Algorithm:

The algorithm used in this work is Levenberg–Marquardt (LM) Algorithm which a type of back propagation algorithm. The reason behind using this algorithm is due to its exceptional ability to extract information from a nonlinear data with great stability which keeping speed of convergence intractably high. The algorithm is a combination of two different algorithms proposed by two mathematicians Levenberg and Marquardt and hence the named over them. The drawback of prior one is removing by the advancement of second. The equation was 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. Levenberg develops following equation in his proposed algorithm:

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

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

In above equation g is guassian coefficient, E is error function x is priority function W is weight function. W_k is present weight, W_{k+1} is next iterations weight and α is step size.

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

Then further, the equation of gradient vector can be further evaluated as

$$g_i = \frac{\partial E}{\partial w_i} = \frac{\partial\left(\frac{1}{2}\sum_{p=1}^{P}\sum_{m=1}^{M} e_{p,m}^2\right)}{\partial w_i} = \sum_{P=1}^{P}\sum_{M=1}^{M}\left(\frac{\partial e_{p,m}}{\partial w_i} e_{p,m}\right)$$

Further the gradient vector can be evaluated as,

$$g = Je \qquad (4.6)$$

Where matrix is formed as,

$$e = \begin{bmatrix} e_{1,1} \\ e_{1,2} \\ \cdots \\ e_{1,M} \\ \cdots \\ e_{P,1} \\ e_{P,2} \\ e_{P,3} \\ \cdots \\ e_{P,M} \end{bmatrix}$$

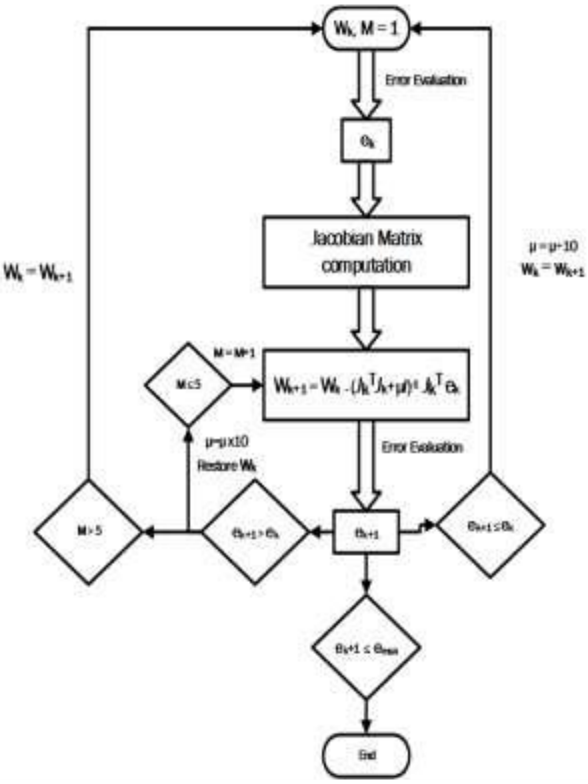

Fig 5: Block diagram for training using Levenberg–Marquardt algorithm.

Hence further hessian matrix can be evaluated as,

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

Where,

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

$$H = J^T J \qquad (4.5)$$

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

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

Levenberg–Marquardt algorithm can be presented as

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

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

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. All five chosen input parameters are available for all time hence are used for evaluating output values. 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

Every network has a single input layer and a single output layer. The number of neurons in the input layer equals the number of input variables in the data being processed. The number of neurons in the output layer equals the number of outputs associated with each input. Hidden layer in an artificial neural network is a layer in between input layers and output layers, where artificial neurons take in a set of weighted inputs and produce an output through an activation function.

The connecting lines between any two neurons represent weight. Any input data presented at input neurons are passed to hidden layer neuron after multiplication with weight value. Similarly, after processing at hidden layer neuron the data is transferred to hidden layer neuron by multiplying again with weight values. The value at the output layer neuron will be required predicted output.

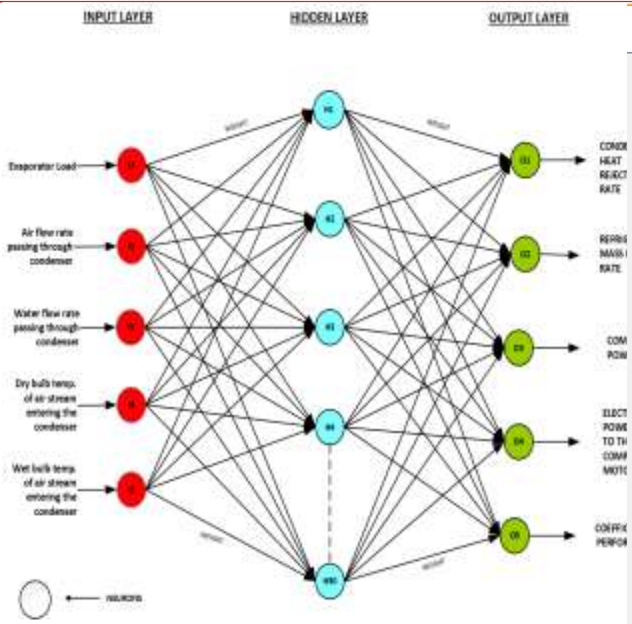

Fig 6: Model of an ANN used in Present study

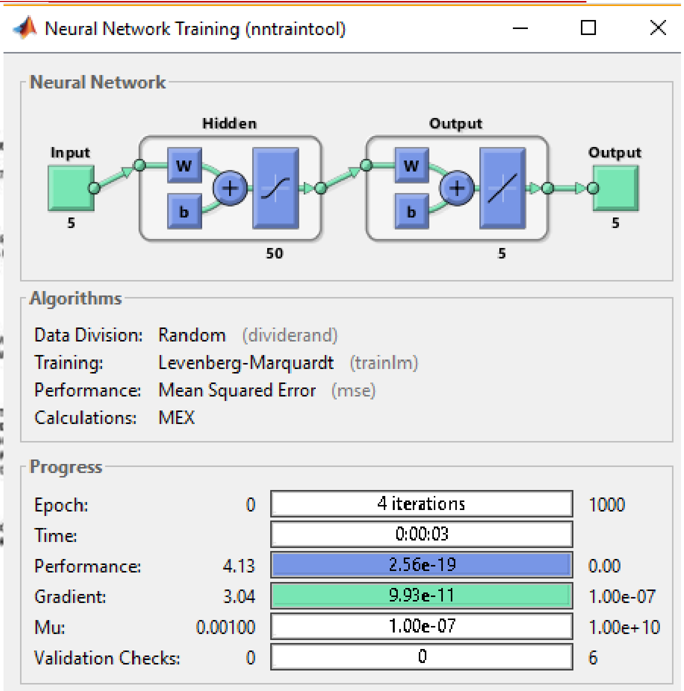

Fig 8 GUI of neural network training in present study

VI. RESULTS

The following study is done using MATLAB Environment. In MATLAB, the command used for training network using Levenberg-Marquardt backpropagation algorithm is "trainlm".

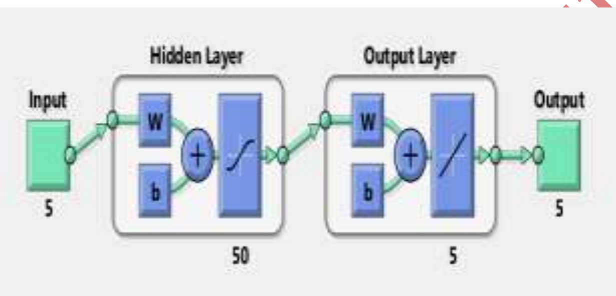

Fig. 7 Structure of ANN in present study

Fig. 7 shows the structure of developed neural network in present work. The structure comprises of three layers with each having a certain number of neurons.

Evaporator load: 10 - 80
Airflow rate passing through condenser: 1: 50
Water flow rate passing through condenser: 0.5: 20
Dry bulb temp. of air stream entering the condenser: 0:100 ^{o}**c**
Wet bulb temp. of air stream entering the condenser: 0:100 ^{o}**c**

Fig 8 shows a graphical user interface of neural network toolbox in MATLAB software. The figure shows the value of various performance parameters. The figure also shows the epochs and time spend in performing the operation. The image shows the Neural Network model diagram with LM based learning. It clearly shows the relationship connection between various layers. W denotes connection branch weights values and b denotes bias values. Here weights are of two types, Input weights (IW) which are weights between input layer and hidden layer neurons and Layer weights (LW) which weights between hidden layer and output layer neurons. Bias are additional neurons for the purpose of activation functions controlling.

An epoch is a measure of the number of times all of the training vectors are used once to update the weights. In this training, all of the weights are updated after each training vector is sequentially passed through the training algorithm. Mu stands for Momentum update. Mu is the training gain. Mu is the control parameter for the algorithm used to train the neural network. Gradient indicates how much variance occurs in the error rate. the performance indicating how much minimized errors occur during the training.

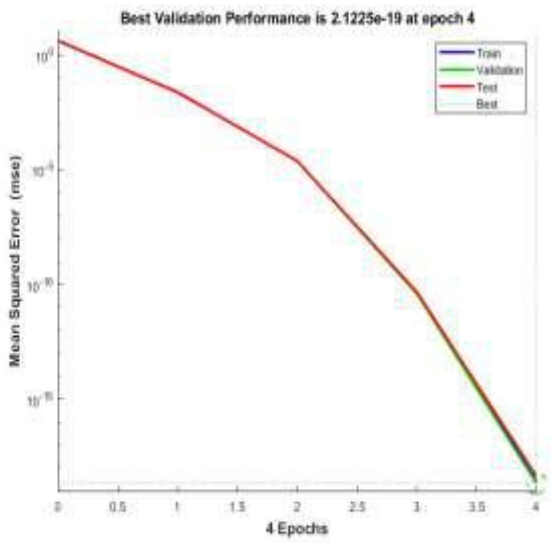

Fig 9 performance plot of developed model

Figure 9 shows a plot of error versus iteration for training, validation and testing stages. The plot shows the slope with which the error is reduced in each iteration. The graph shows that the minimum error is achieved at 4th iteration with a value of 2.122. Figure shows the performance plot between the performance function and the number of iterations. Once validation proves that no further improvement is possible in present model, training is stopped and results are presented for comparison.

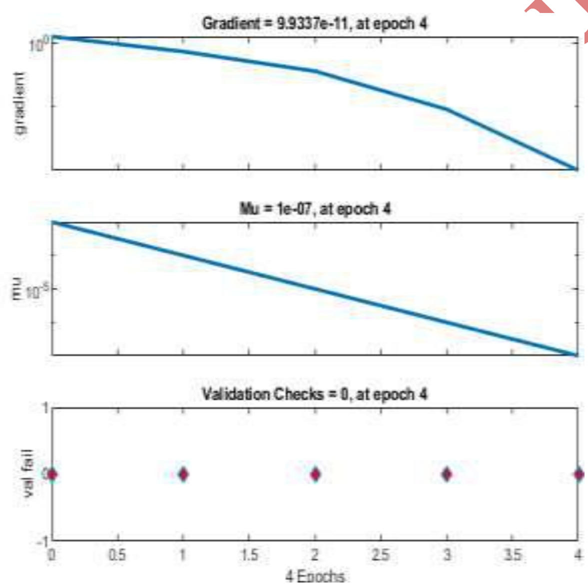

Fig 10 training states of present model

Fig. 10 shows training states of various training variable such as gradient magnitude, Mu and validation checks at each epoch for LM trained neural network.

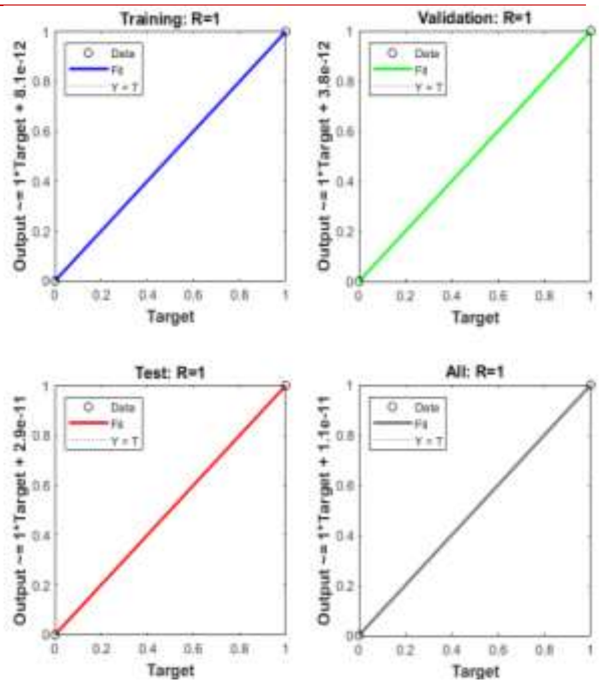

Fig 11 Regression plot

Fig 11 Regression plot is a plot to show correlation between output and targets. If the value of 'R' is 1, it means there exists a close relationship, and if it is 0, it signifies a random relationship.

Fig 12 shows the histogram plot between testing error and the number of instances it has occurred. The bar graph shows the frequency of times a particular error value has repeated. Histogram by definition means "a diagram consisting of rectangles whose area is proportional to the frequency of a variable and whose width is equal to the class interval."

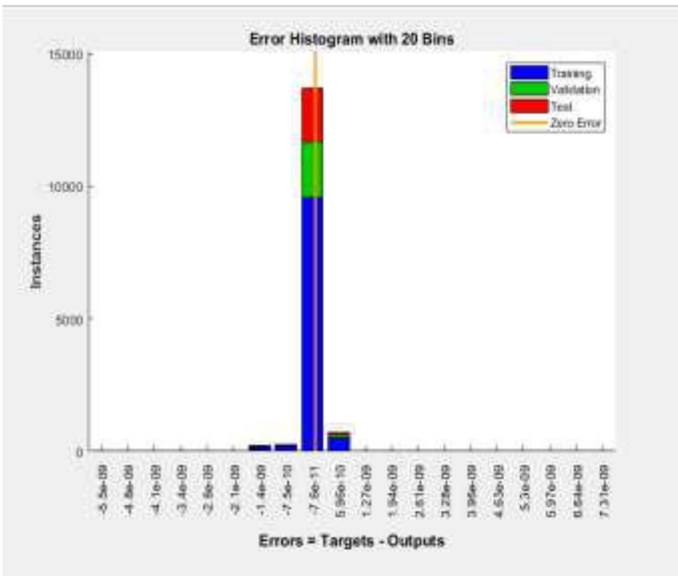

Fig 12 Histogram plot of testing results

A histogram is a display of statistical information that uses rectangles to show the frequency of data items in successive numerical intervals of equal size. In the most common form of histogram, the independent variable is plotted along the horizontal axis and the dependent variable is plotted along the vertical axis. The data appears as colored or shaded rectangles of variable area.

VII. CONCLUSION

In the present work capacity of artificial neural network in refrigeration system controlling is been checked. The system is been trained and tested using backpropagation algorithm of neural network. A total of five different parameters are selected whose value is known at every point of time and which influence the variable refrigeration flow by a significant amount. Based on these inputs value of five different parameters is been predicted which will help in deciding the performance of the refrigeration system. The output parameters include condenser heat rejection rate, compressor power etc. On simulating data over neural network toolbox in MATLAB software and calculating performance parameters which are correlation coefficient and mean square error it is found out that the model was very robust to a certain level such that a great efficiency is achievable. The amount of improvement in performance calculated as correlation coefficient lies at a point almost near to "1" and with an error of about 4%.
Hence the study has proved that the complex part designing any variable refrigeration flow system accurately using Artificial neural network. The network will help in reducing the cost of operation and power consumption of any HVAC system along with reduction in usage of refrigerant.

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