Journal Of Harmonized Research (JOHR)

Journal Of Harmonized Research in Engineering
5(2), 2017, 80-88

ISSN 2347 – 7393

Original Research Article

PERFORMANCE ANALYSIS OF SIMPLE VCR SYSTEM BY DEVELOPING ANN MODEL WITH SUCTION & DELIVERY, PRESSURE & TEMPERATURE AS INPUT AND COMPRESSOR WORK AS OUTPUT PARAMETER

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Abstract: In this study, artificial neural networks (ANNs) model has been developed to analyse effect on compressor work of the other variables like suction pressure, delivery pressure, suction temperature & delivery temperature. In developed ANN model network 2,network type feed forward back propagation with training function TRAINLM, adaptation learning function LEARNGDM and with other parameter network has been successfully trained to analyse performance analysis of simple vapor compression refrigeration system using refrigerant R134a, which does not damage ozone layer. Experimentation was conducted to investigate effect of suction pressure and other variables like suction temperature to compressor, delivery pressure, outlet temperature to compressor and compressor work per kg of refrigerant. As we know conventional analytical approach involves more complicated formula & assumptions ,whereas experimental studies are tedious ,so in this paper an attempt has been made to train (ANNs) for suction pressure range(156kPa-425kPa), delivery pressure range(1101kPa-1769kPa) suction temperature range(10 ^{0}C - 34 ^{0}C) ,outlet temperature from compressor range(68 ^{0}C - 88 ^{0}C)as input to artificial neural networks (ANNs) model network2and it has been successfully trained for output as compressor work. Experimental output and output predicted from network2 resembles close to each other with**R^2=0.9999858,RMSE = 0.128kJ/kg**, **COV=0.379%**& ANN with Network type -feed- forward back prop, training function- TRAINLM, adaptation learning function –LEARNGDM, with 8 No of neuron can be successfully applied in the field of performance analysis of simple vapor compression refrigeration (**VCR**) system.

Keywords-CVR System, Suction, Delivery, Pressure & Temperature

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Received on: April 2017
Accepted after revision: May 2017

Introduction: A refrigerator is a machine that removes heat from a low temperature region to high temperature region. The Second Law of Thermodynamics states that heat can't flow itself from body of lower temperature to body of higher temperature without aid of an "external work". Therefore, a refrigerator will require this "external work", or energy input, for its operation. In a vapor compression refrigeration (**VCR**) system a refrigerant is alternatively compressed and expanded and goes from the liquid to the vapor state.

Single-stage refrigeration cycle which is shown in Fig.1 (Bureau of Energy Efficiency, 2004). During process4-1, low pressure liquid refrigerant in the evaporator absorbs heat from space to be cooled. As heat is absorbed it changes its state from a liquid to a vapor, and at the evaporator exit it is slightly superheated. During process 1-2, work is done on the compressor and its pressure and temperature is raised. During 2-3, the high-pressure high temperature vapor passes from the compressor into the condenser to reject heat to environment. Entire process of heat rejection may consist of de-superheating (2-2a).The initial part of the cooling process, then condensation (2a-2b) followed by sub cooling (2b-3). Sub-cooled refrigerants enters the expansion device at state 3, during 3-4the high-pressure sub cooled liquid passes through the expansion device, which reduces its pressure as well as controls the flow into the evaporator

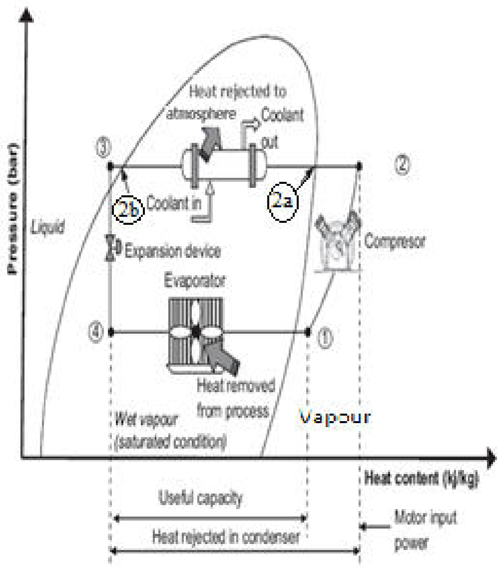

Fig. 1. Single-stage refrigeration cycle. (Bureau of Energy Efficiency, 2004)

Power consumption, for various suction pressure, suction temperature, and delivery pressure and delivery temperature is estimated experimentally. These data are used to train Artificial Neural Network (ANN) for performance analysis of refrigeration system.

Artificial intelligence systems covers areas such as ANN, expert systems, genetic algorithms, fuzzy logic and various hybrid systems, which combine two or more techniques [1,2]. ANN overcomes the limitations of theoretical approaches by extracting the required information using training data, which does not require any specific formula. ANN model can forecast the desired output of the system using limited training data. M. Mohanraj *et al.* [3] has reviewed the performance of refrigeration and air conditioning systems, and analyzed in terms of first law and second law of thermodynamics using analytical and experimental methods. Various simulation techniques for modeling and performance prediction of vapor compression refrigeration systems are summarized by Ding [4].Practically a refrigeration system has to work under transient conditions. Steady or transient condition for optimization of performance for study in the design and balancing of components of a "vapor compression refrigeration system "ANN can be successfully applied .The values calculated from the ANN were found to be in good agreement with the actual experimental values. This method will help engineers to obtain a very accurate and fast forecast of system performance.

Review of literature: A summary of ANN applications for vapor compression systems are listed in Table 1.

Table 1 -Applications of ANN for vapor compression systems

Authors [references]	**Network architectures**	**Year**	**Equipment**
Ertunc and Hosoz [5]	MLFFN	2006	Refrigeration system
Saidur *et al*. [6]	MLFFN	2006	Domestic refrigerators

Performance of refrigeration systems: Ertunc and Hosoz [5] developed a MLFFN model with five neurons in input layer (representing evaporator load, air mass flow rate, water mass flow rate, dry bulb temperature and wet bulb temperature of air at the condenser inlet) and five neurons in output layer (representing condenser load, mass flow rate of refrigerant, compressor power absorbed by the refrigerant, electric power consumed by the compressor motor and COP) for forecasting the performance of a refrigeration system using an evaporative condenser. The network with 5-4-4 arrangement yields correlation coefficient values of 1, 0.999, 0.998, 0.991 and 0.933 for condenser heat rejection rate, mass flow rate of refrigerant, compressor power, electric power input and COP, respectively with corresponding RMS errors of 4.12 W, 0.04 g/s, 2.41 W, 11.67 W and 0.18. The mean relative errors are in the range between 1.90% and 4.18%.

The energy consumption of refrigerators was forecasted by using a MLFFN [6]. In their learning, the energy consumption of 149 refrigerators was used for training. The energy performance of refrigerator was predicted with reference to eight parameters (such as capacity, door opening, loading, age, number of units, income, location and number of occupants). The network arrangement 8-15-1 with log-sigmoid transfer function using LM training algorithm yields a maximum R2 of 0.9999 with RMS and COV values of 0.0001 and 0.0034, respectively.

Artificial neural network an overview: Artificial neural networks (ANN) try to mirror the brain functions in a computerized way by reestablishing the learning mechanisms the basis of human behavior. ANN can operate like a black box model, which requires no exhaustive information about the system or equipment. ANN can study the relationship between input and output based on the training data. ANN is a nonlinear informational processing device, which is built from interconnected elementary processing devices called neurons. Each input is multiplied by a connection weight. The product and biases are summed and transformed through a transfer function (consists of algebraic equations) to generate a final output. The process of combining the signals and generating the output of each connection is represented as weight. Most commonly used network architectures in the field of RACHP (Refrigeration, Air Conditioning & Heat Pump) are

(i) Multi-layer feed forward,
(ii) Radial biased function network,
(iii) Generalized regression neural networks and
(iv) Adaptive neuro fuzzy system

An illustration of MLFFN is given in Fig. 2, which has an input layer, followed by one or more hidden layers and an output layer [3]. Several layers of neurons with nonlinear transfer function sallow the network to study linear and nonlinear relationships between input and output vectors. Back propagation learning algorithms extensively used to train the MLFFN. The network is trained with particular number of neurons in the hidden layer, momentum factor, learning rate and transfer function. MLFFN is more suitable for performance prediction of RACHP systems. The number of neurons in input layer is equal to the number of parameters that affects the performance of RACHP systems and the number of neurons in output layer corresponds to the number of parameters to be predicted.

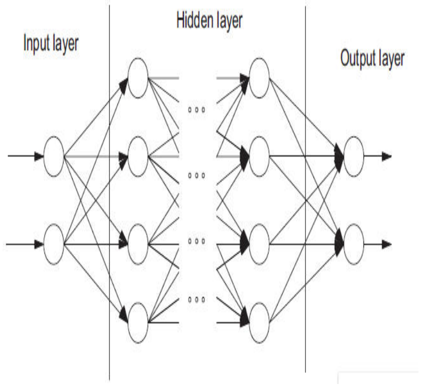

Fig 2. Multi-layer feed forward network [3]

Methodology

Fig.3. Experimental setup

By above mechanical model we can collect following experimental data

- P1Suction pressure.
- P2 Delivery pressure.
- Mass flow rate of refrigerant.
- Can expand refrigerant from different capillary length & diameter.
- Can use with/without internal heat exchanger.
- Current (Amp).
- Current (Voltage).
- T_1Suction Temperature /Temperature at inlet to compressor.
- T_2Delivery Temperature at outlet to compressor.
- T_3 Temperature at outlet to condenser.
- T_4 Temperature outlet of expansion valve.
- T_5 Temperature inlet to heat exchanger (suction line).
- T_6 Temperature outlet to heat exchanger (suction line).
- T_7 Temperature inlet to heat exchanger (delivery line).
- T_8Temperatureoutlet to heat exchanger (delivery line).
- T_9 Temperature of brine inlet to evaporator.
- T_{10}Temperatureof brine outlet to evaporator.
- T_{11}Temperature of brine.

And with suitable modification other necessary data can be collected .From experimental data performance parameter can be calculated using peace software [7] and then ANN will be applied for further analysis and optimization of system.

Training of ANN: Experimental data were collected for refrigerant R134a and for different suction pressure p_1 in kPa (kilo Pascal), value of suction temperature i.e temperature inlet to compressor T_1in ^{0}C, temperature outlet to compressor T_2in ^{0}C and delivery pressure p_2 in kPa was recorded and with the help of other parameter compressor work per kg of refrigerant was calculated. Enthalpy value are calculated using peace software[7].Out of huge experimental data few steady state data were selected for different suction pressure out of which 69 data was used to train network and after training it was tested with the 11 test data set which were excluded while training the ANN network2.The performance of the ANN was measured by absolute fraction of variation (R^2),Root mean square error (RMS) and coefficient of variance (COV), which can be calculated by using following equations (1),(2),(3)suggested by [3].

The fraction of absolute variance is given by

$$\mathbf{R^2} = \mathbf{1} - \frac{\sum_{m=1}^{n}(y_{pre,m}-t_{mea,m})^2}{\sum_{m=1}^{n}(t_{mea,m})^2} \quad (1)$$

The root mean square value is calculated by

$$RMS=\sqrt{\frac{\sum_{m=1}^{n}(y_{pre,m}-t_{mea,m})^2}{n}} \quad (2)$$

Coefficient of variance is calculated by the following equation

$$\mathbf{COV} = \frac{\mathbf{RMS}}{\sum_{m=1}^{n}(t_{mea,avg})} \times \mathbf{100} \quad (3)$$

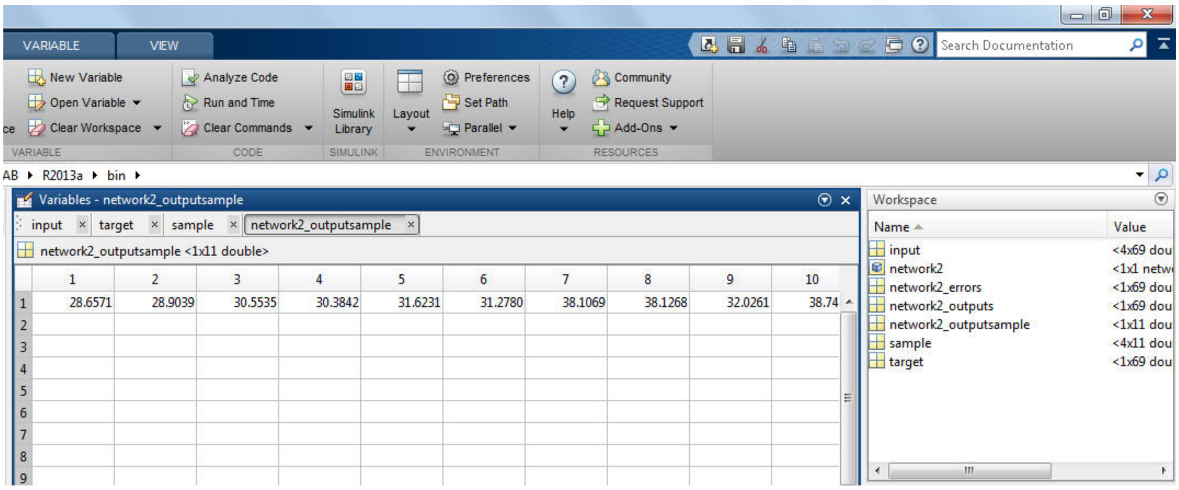

Fig 4: Spreadsheet of MATLAB as training is over.

Here, n is the number of data patterns in the independent data set, $Y_{pre,m}$ indicates the values predicted by ANN, $t_{mea,m}$ is the measured value of one data point m and $t_{mea,avg}$ is the mean value of all measured data points. Here in this paper R^2, RMSE, COV is calculated for data used to test the network.

Training the artificial neural network is done by MATLAB software using neural network tool box. Input parameter to the network are suction pressure p_1, suction temperature i.e. temperature inlet to compressor T_1 in ^{0}C, delivery pressure p_2 and temperature outlet to compressor T_2 .output parameter is compressor work kJ per kg of refrigerant. 69 set of data is used to train network. For this in MATLAB software new worksheet is opened renamed it as input and input data of 69 set is saved. Similarly another worksheet is opened and renamed it as target and experimental output of 69 data set is saved as target. 11 set of experimental data were used to test the network. Then opened a new work sheet and renamed it as sample. Input parameter of these 11 data set value are saved in worksheet named sample ,and after training is over complete workspace is as shown in fig 4. Predicted output of ANN has been saved as **network_2outputsample**.

In command we run nntool, as result new window appeared and we import input data sheet from MATLAB as input data sample data sheet as input data and target data sheet as target data then closed the window as shown in fig 5.

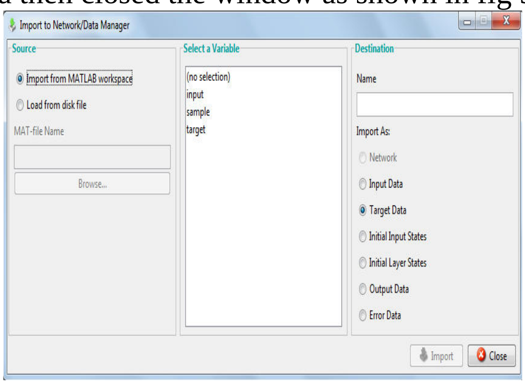

Fig 5: Importing of data in MATLAB

Then we generate new network by pressing new tab and renamed it as network_2 as output parameter for this network is compressor work here and after so many trail, finally selected Network property as shown in fig 6 as network type –feed forward back propagation target data as target, input data as input, ,adaptation learning function as LEARNGDM, training function as TRAINLM, performance function as MES number of layer 1, no of neuron as 8 ,transfer function LOGSIG, and viewed network shown in fig 7.

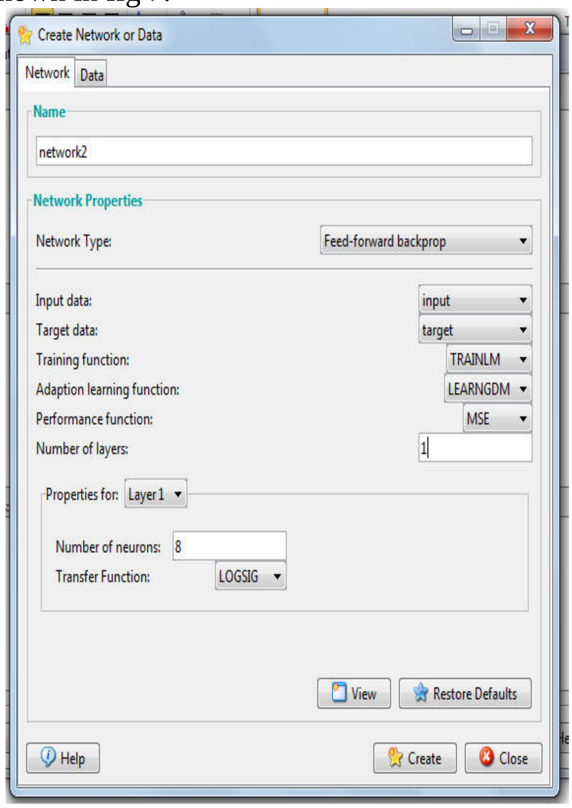

Fig 6: Property of network2 in MATLAB

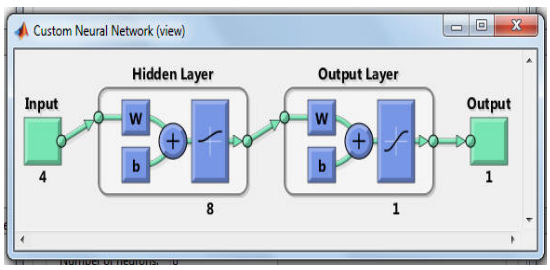

Fig 7: View network while training ANN.

Custom neural network window opened and it show trend of input and output data as trend is matched we created the artificial neural network called network2 and added it to network/data manager. Created network2 is selected and opened in neural network/data manager window and shown as fig 8.To trainnetwork2train tab is selected and then under training information, in training data, input is selected as input and target as target. Training result under in same window show predicted outputs of data used for training as **network2_output** and error as **network2_error** of the 69 sets of data used for training as shown in fig 9.

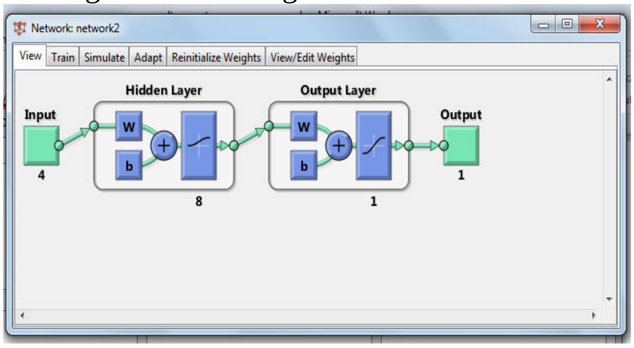

Fig 8: Creating network2in MATLAB

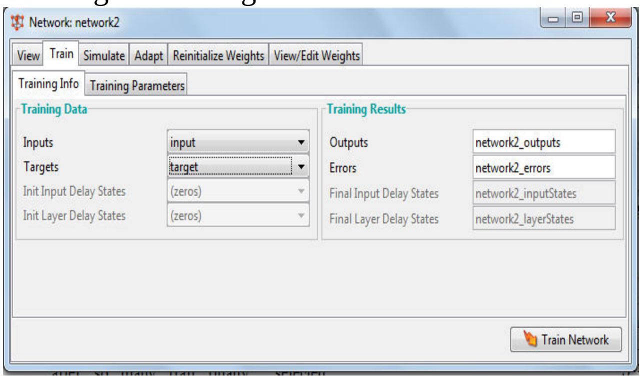

Fig 9: Training information of network2

Then selected the training parameter tab under same train tab and after so many trail finally selected training parameter as shown in fig 10, which gives training of ANN network2 in fig 11andcorrespondingregression analysis as shown fig 12.

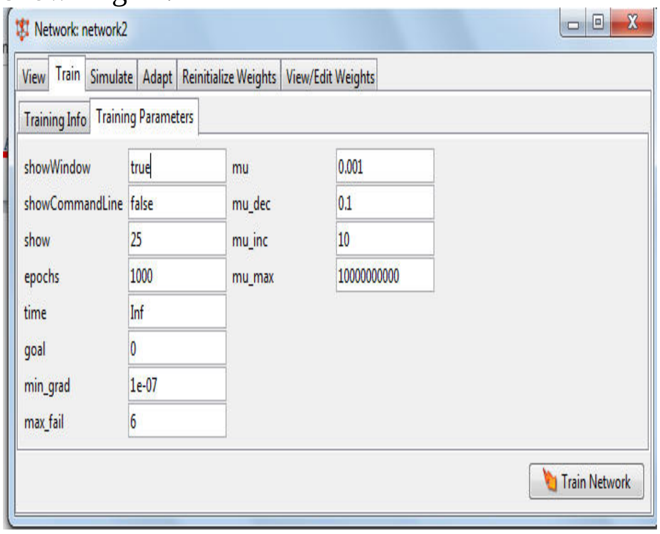

Fig 10: Training parameter of network2

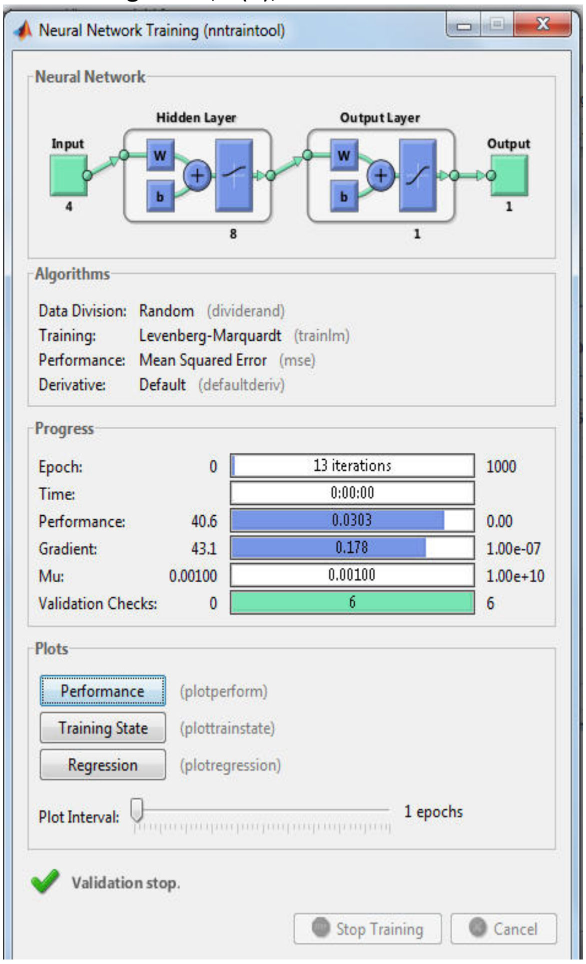

Fig 11: Training ofNetwork2

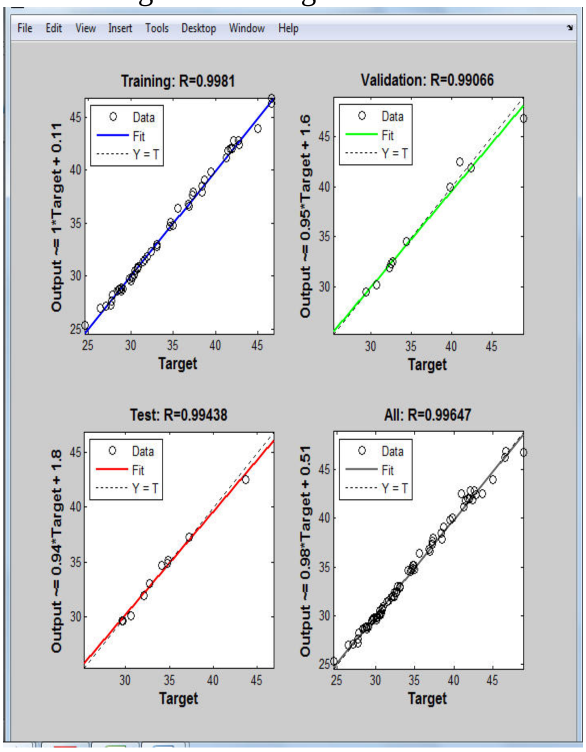

Fig 12: Regression analysis of network2

Then to simulate trained ANN network2we selected simulate TAB as shown in fig 13 with under simulation data selected input as sample and output as **network2_outputsample**.Then result i.e output /predicted data of 11 set of sample input data used to test networks stored in network /data manager as shown in fig 14. Fig 15shows predicted output value of network2 as**network2_outputsample** for given 11set of input data used as sample to test networ2. Predicted output network2_outputsample value which is exported to work sheet and compared with experimental output of 11sample data used to test ANN network2, which resembles to each other as shown in table 2.

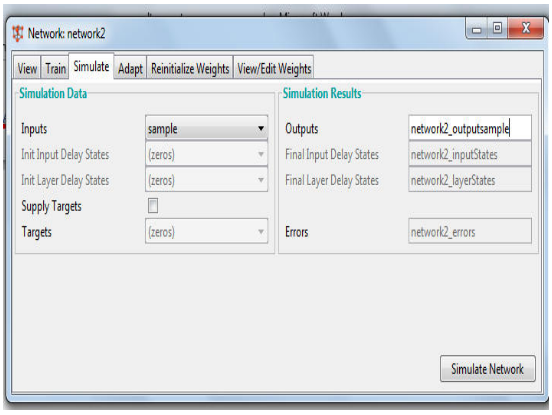

Fig 13: Simulation of network2 on ANN

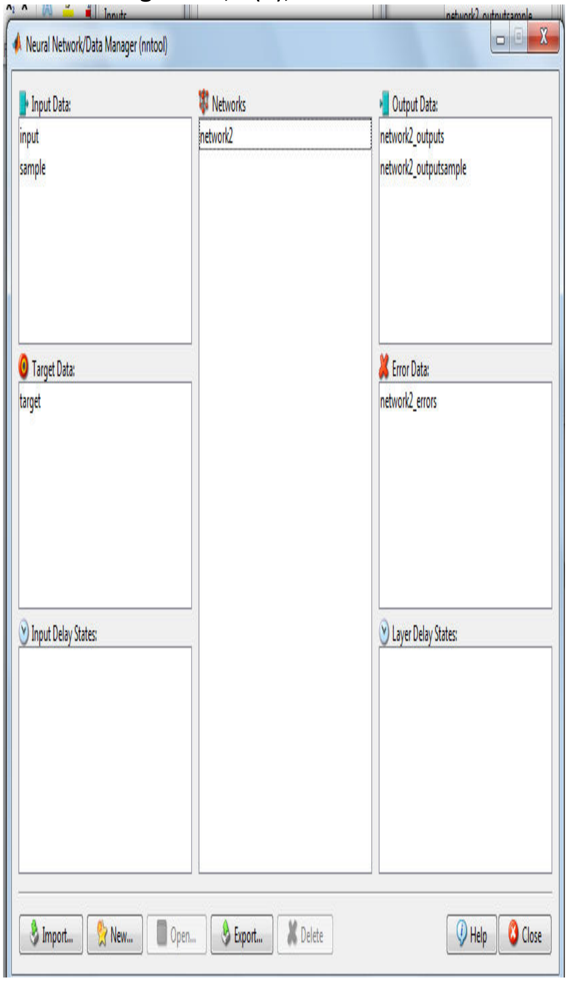

Fig 14: Network2_outputsample on ANN

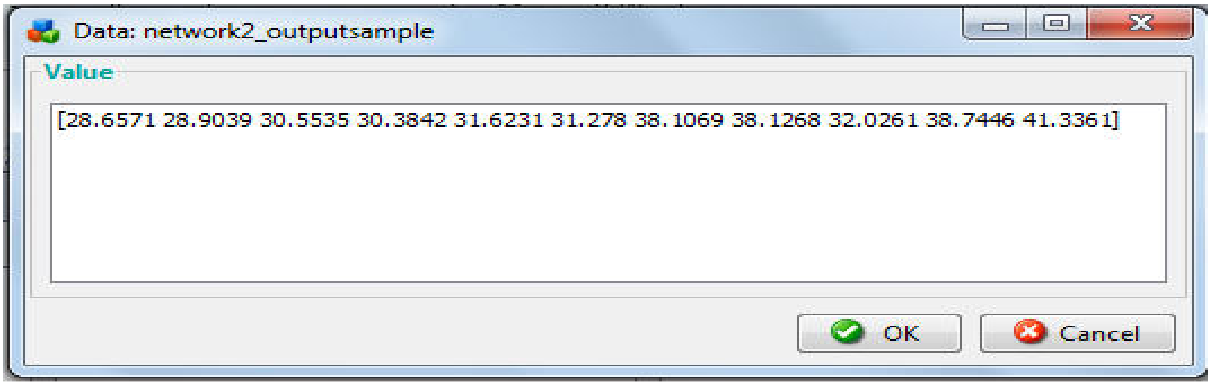

Fig 15: Result Predicted output of sample used to test network2 as network2_outputsample

Table 2 Response Data by ANN

S.NO	DATA TO TEST TRAINED NETWORK						Measured output –predicted output	R^2	RMSE	COV
	INPUT				OUT-PUT	ANN OUT PUT				
	p_1 kPa (kilo Pascal)	T_1 (°C) -Inlet to Compressor	p_2 kPa (kilo Pascal)	T_2 (°C) outlet to compressor	h_2-h_1 (Compressor work) kJ/kg	h_2-h_1 (Compressor work) kJ/kg				
1	156.51	23	1170.05	71	28.48	28.66	-0.18			
2	163.41	27	1211.42	75	28.81	28.90	-0.09			
3	170.30	25	1211.42	75	30.68	30.55	0.13			
4	170.30	26	1239.00	76	30.45	30.38	0.07			
5	177.20	26	1239.00	77	31.69	31.62	0.07			
6	177.20	27	1273.47	78	31.38	31.28	0.10	0.9999858	0.128 kJ/kg	0.379 %
7	204.78	26	1349.31	84	38.25	38.11	0.14			
8	211.67	27	1370.00	85	38.31	38.13	0.18			
9	211.67	29	1314.84	80	31.88	32.03	-0.15			
10	232.35	24	1411.37	83	38.58	38.74	-0.16			
11	259.93	27	1376.89	87	41.37	41.34	0.03			

Result: Result is shown in Table2 as experimental output and Output parameter predicted from ANN network2, resembles close to each otherwith**R^2=0.9999858, RMSE =0.128kJ/kg**,**COV=0.379%**& can arrive to conclusion that ANNs named network2 with network architect feed- forward back prop, adaptation learning function –LEARNGDM, training function- TRAINLM, with 08 no neurons, can be effectively applied in the field of performance analysis of simple vapor compression refrigeration system. Actual performance of network is evaluated using11 set of test data, since these were not used for training and table 2 shows that $R^2$is **0.9999858**which is very close to 1 for test data and RMS error is very small**0.128kJ/kg.** It is clear that ANN (network2) gives very accurate representation of statistical data over the full range of operating condition and indicates that trainednetwork2 predicted compressor work required for given inputs very accurately. Evaluation of these result suggest that compressor work are predicted within acceptable error.

Conclusion: The ANN model developed in this work is as network2isprepared to analyze performance analysis of vapor compression refrigeration system to find out effect of inputs to the output. Input parameters are suction pressure, suction temperature/inlet temperature to compressor, delivery pressure and outlet temperature to compressor which gives the effect on the output parameter compressor work required per kg of refrigerant.

An attempt to train (ANNs) named here network2 with network type feed- forward back propagation with suction pressure, inlet temperature to compressor, delivery pressure and temperature outlet to compressor as input parameter and compressor work required as output parameter. ANN is effectively trained as experimental output and output parameter predicted from network2,look like close to each other for11set of test data with **R^2=0.9999858, RMSE=0.128kJ/kg**, **COV=0.379%**.We can conclude ANNs network 2 is effectively trained with Network type -feed- forward back propagation Training function- TRAINLM, Adaptation learning function–LEARNGDM, No of neuron as 8 and transfer function LOGSIG as in network2, no of layer 1,can be successfully applied in the field of performance analysis of simple vapor compression refrigeration system, as for given set of input parameter compressor work as output parameter can be predicted by network2accurately.

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