



ANN MODEL FOR PERFORMANCE ANALYSIS OF VCR SYSTEM WITH SUCTION PRESSURE, SUCTION TEMPERATURE, COMPRESSION RATIO AS INPUT PARAMETRE AND COP AS OUTPUT PARAMETER

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Abstract: Artificial neural network (ANN) network4 has been developed for performance analysis of simple vapour compression system for various values of suction pressure, suction temperature, compression ratio as input parameter and coefficient of performance as output parameter. 54 set of experimental data is used to train ANN, network4 and 06 set of experimental data is used to test ANN, network4. Value of experimental COP and that predicted by ANN network4 for the data used to test the network resemble close to each other with $R^2=0.999217$, $RMSE =0.163$, $COV=2.84\%$. In developed ANN model network4, network type feed forward back propagation, Adaptation learning function LEARNGDM, Training function TRAINLM, performance function MES, No of neurons 08, No of layers 01, and Transfer function LOGSIG, with other training parameter has been used to successfully train ANN network4. We accomplish ANN with developed network4 can be successfully applied for evaluating COP of simple vapour compression refrigeration (VCR) system for given value of suction pressure, suction temperature, and compression ratio as input parameter, & hence ANN may be very useful tool for performance analysis of refrigeration system.

Keywords: ANN, VCR system, COP, Compression ratio, Suction pressure, Suction temperature.

1. Introduction:

Refrigeration processes apply for removing heat from a low-temperature reservoir and transferring it to a high-temperature reservoir. The work of heat transfer is traditionally driven by mechanical means, but can also be driven by heat, magnetism, electricity, laser, or other

means. Many applications of Refrigeration have including, but not limited to: household refrigerators, industrial freezers, cryogenics, and air conditioning. Refrigeration has had a large impact on industry, lifestyle, agriculture, and settlement pattern. A simple vapour compression refrigeration system with unpretentious expansion device as capillary tube is used in numerous of small or medium refrigeration applications like domestic refrigerator, deep freezer, water cooler, room air conditioners, cooling cabinets and many more all over the world. The small scale refrigeration machines are produced in large numbers and have substantial contribution to energy consumption.

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Energy conservation in refrigeration, air conditioning and heat pump systems has a large potential.

The working environments for a refrigerating system in steady operation depend on several factors: boundary conditions (ambient temperature, cold room temperature, compressor speed, and control settings), refrigerant type and refrigerant charge, system architecture and size, thermal loads. The performance is influenced by matching of all these factors. Theoretical performance of the system deteriorates in real conditions due to internal and external irreversibility in the system, whereas experimental studies are more expensive and time consuming. Generally, to investigate the dynamic behavior of refrigeration systems, usually the heat exchangers are treated by transient models while the expansion valve as well as the compressor is considered in steady state. But need was felt to observe experimental values of refrigeration rate, power consumption, condenser duty, COP and overall heat transfer coefficient in condenser and evaporator and their variance with time and also to find the role of capillary tube length, compression ratio, while working of system under real transient conditions. Weather steady or transient condition ANN can be successfully applied for study in the design and balancing of components of a “vapour compression refrigeration system” for optimization of its performance. Artificial intelligence systems in refrigeration and air conditioning field are increasing gradually to solve the complicated problems. In this research work Experimentation has been conducted for different combination of capillary diameter & length, which in turn vary suction pressure. Refrigeration effect, power consumption, and COP has been experimentally evaluated for different value of suction pressure, suction temperature, compression ratio, delivery pressure & delivery temperature. Then Artificial neural networks (ANN) network4 has been developed and successfully trained to evaluate coefficient of performance of simple vapour compression system for various value suction pressure, suction temperature, and compression ratio as input parameter.

2. Review of Literature

A summary of ANN applications for vapour compression systems given by [1], are listed in Table 1

Table 1 -Applications of ANN for vapour compression systems

Authors [references]	Network architectures	Year	Equipment
Hosoz and Ertunc[2]	MLFFN	2006	Cascade refrigeration system
Yilmaz and Atik[3]	MLFFN	2007	Mechanical cooling system
Ertunc and Hosoz[4]	MLFFN	2006	Refrigeration system
Saidur <i>et al.</i> [5]	MLFFN	2006	Domestic refrigerators
Swider <i>et al.</i> [6]	GRNN	2001	Chillers
Navarro-Esbri <i>et al.</i> [7]	RBFNN	2007	Chillers
Chang [8]	MLFFN	2007	Chillers

Hosoz and Ertunc[2] studied the suitability of using MLFFN-Multi layer feed forward network to predict the performance of a cascade refrigeration system. The inputs to the network are water mass flow rate and evaporator load, while the outputs are evaporating temperature, compressor power in lower circuit, COP for lower circuit, compressor power in higher circuit and overall COP for cascade refrigeration system. ANN predicted results were reported to be closer with experimental values having correlation coefficients of 0.996, 0.994, 0.97, 0.985, 0.953 for evaporating temperature, compressor power in lower circuit, COP for lower circuit, compressor power in higher circuit and overall COP of a cascade refrigeration system, respectively with corresponding mean relative errors of 0.2%, 3.6%, 3.6%, 3.9% and 6%.

A MLFFN with one neural is occupied for input layer (condenser water flow rate) and four neurons in output layer (input power in cooling and heating mode, COP of the system in both cooling and heating modes) was developed for predicting the performance of a variable cooling capacity mechanical cooling system [3]. It was reported that ANN predicted results were closer to experimental results with average relative errors of 1.37%, 4.44%, 2.05%, 1.95% for input power, heating power, heating COP, and for cooling COP, respectively. The R^2 values for

predicting the input power, heating power, heating COP and cooling COP are 0.992, 0.972, 0.988 and 0.990, respectively.

Ertunc and Hosoz[4] established 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 consumption of energy in refrigerators was forecasted by using a MLFFN [5]. 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 R^2 of 0.9999 with RMS and COV values of 0.0001 and 0.0034, respectively.

The performance of two vapour compression chillers (chiller-A and chiller-B) was forecasted by using ANN [6]. They used GRNN (Generalized Regression Neural Network) model for forecasting the performance factors such as COP, compressor power input, chill water inlet and cooling outlet temperatures with reference to cooling capacity, chill water outlet and cooling water inlet temperatures. Their results presented that 94% of ANN predicted values for chiller-A and 87% for the chiller-B are within $\pm 5\%$ of the experimental values. The maximum COV of ANN predicted results for the chiller-A and chiller-B were reported as 1.7% and 3.9%, respectively.

A RBFNN (Radial Biased Function Network) model was developed for predicting the performance factors (such as cooling capacity, power consumption and chiller water outlet temperature) of a variable speed compression based refrigeration systems with reference to speed, chill water temperature inlet, condensing water temperature inlet and refrigerant evaporator temperature [7]. It was reported that the network forecasted cooling capacity, chill water outlet temperature and power consumption were closer to experimental values within $\pm 2\%$, ± 0.2 K and $\pm 5\%$ deviations, respectively with RMS errors of 0.084, 0.054 and 0.048.

Chang [8] testified the suitability of ANN model to determine the optimal sequencing of six chillers used in a semiconductor industry. In his work, MLFFN with four neurons in input layer (representing supply temperature of chill water, return temperature of chill water, supply temperature of cooling water and return temperature of cooling water), one neuron in the output layer (power consumption) was developed. Two hidden layers comprising of 20 and 40 neurons were used. It was stated that significant energy savings can be made by changing the chiller start-up sequences using ANN model.

3. Artificial Neural Network an Overview:

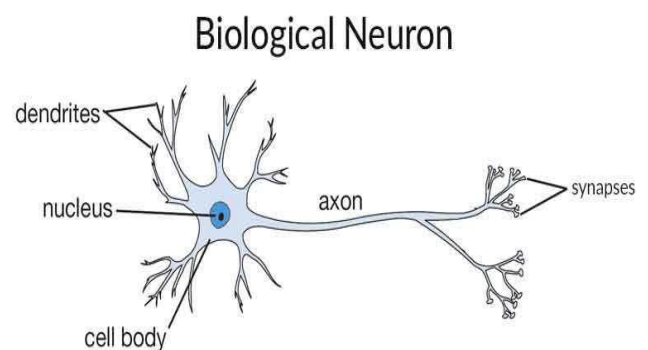


Fig. 1 Biological Neuron by [10]

ANN has a powerful ability in recognizing accurately the inherent relationship between any set of inputs and outputs without requiring a physical model, and the predicted results using ANN do account for all the physics relating the outputs to the inputs [9]. The term 'Neural' is derived [10] from the human (animal) nervous system's basic functional unit 'neuron' or nerve

cells which are present in the brain and other parts of the human (animal) body. The typical nerve cell of human brain shown in Fig.1 comprises of four parts –

Dendrite—It receives signals from other neurons.

Soma (cell body)—It sums all the incoming signals to generate input.

Axon—When the sum reaches a threshold value, neuron fires and the signal travels down the axon to the other neurons.

Synapses—The point of interconnection of one neuron with other neurons. The amount of signal transmitted depends upon the strength (synaptic weights) of the connections.

Artificial Neural Networks are the biologically inspired simulations performed on the computer to perform certain specific tasks like clustering, classification, pattern recognition etc. Artificial Neural Networks is broad applying in a biologically inspired network of artificial neurons configured to perform specific tasks. Neural networks resemble the human brain in the following two ways -

- A neural network acquires knowledge through learning.
- A neural network’s knowledge is stored within inter-neuron connection strengths known as synaptic weights.

A representative neural network contains a huge number of artificial neurons called units arranged in a series of layers shown in Fig.2.

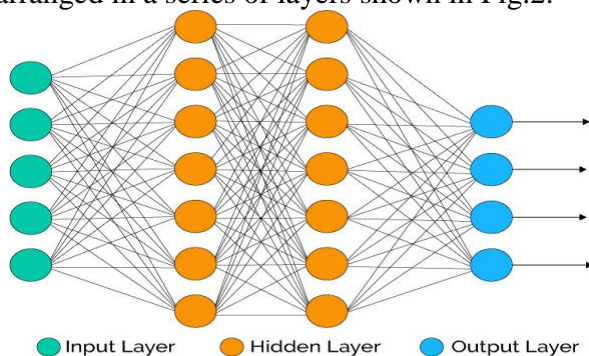


Fig.2 Artificial neural network, comprises different layers by [10]

- **Input layer**— Input layer contains those units (artificial neurons) which receive input from the outside world on which network will learn, recognize about or otherwise process.

- **Output layer**—It contains units that respond to the information about how it’s learned any task.
- **Hidden layer**—These units are in between input and output layers. The job of hidden layer is to convert the input into approximately that output unit can use in some way.

Most neural networks are fully connected that means to say each hidden neuron is fully connected to the every neuron in its previous layer (input) and to the next layer (output) layer. Most commonly used network architectures in the field of RACHP (Refrigeration, Air Conditioning & Heat Pump) are

01. Multi-layer feed forward,
02. Radial biased function network,
03. Generalized regression neural networks and
04. Adaptive neuro fuzzy system.

4. Methodology

Experimental Setup -Experimental setup of VCR system is shown in Fig.3



Fig. 3 Experimental setup of VCR system

In the above experimental setup R134a is used as refrigerant, suction and delivery pressure are measured by analog pressure gauge, temperatures are measured digitally using thermo-couples. Suction temperature is varied by using different combination of capillary length and diameter. In this research work Experiment is conducted on experimental setup as shown in Fig. 3, for different combination of capillary length & diameter, which in turn varies suction pressure. Auto expansion valve is also there to regulate the suction pressure.

Refrigeration effect, power consumption, and COP are experimentally evaluated for different values of suction pressure, suction temperature, delivery pressure delivery temperature, and for different compression ratio. Experiment is performed and data are collected with regular interval of time, out of huge collection of experimental data only few steady state data are used to train and test network4. Enthalpy values are calculated using peace software.

By this experimental setup we can collect following experimental data.

- p_1 , Suction pressure.
- p_2 , Delivery pressure.
- Mass flow rate of refrigerant.
- Current (Amp).
- Voltage (Volt).
- T_1 , Suction Temperature /Temperature at inlet to compressor.
- T_2 , Delivery Temperature at outlet to compressor.
- T_3 , Temperature at outlet to condenser.
- T_4 , Temperature at outlet of expansion valve.
- T_5 , Temperature at inlet to heat exchanger (suction line).
- T_6 , Temperature at outlet to heat exchanger (suction line).
- T_7 , Temperature at inlet to heat exchanger (delivery line).
- T_8 , Temperature at outlet to heat exchanger (delivery line).
- T_9 , Temperature of brine at inlet to evaporator.
- T_{10} , Temperature of brine at outlet to evaporator.
- T_{11} , Temperature of brine.

From experimental data enthalpy can be calculated using peace software [11],and then from enthalpy values performance parameters like heat absorbed per kg of refrigerant , compressor work per kg of refrigerant and COP of VCR system can be evaluated and after that ANN will be applied for further analysis and optimization of system.

Training of ANN

Experimentation has been performed for various suction pressure (p_1) for refrigerant R134a and value of other parameter like Delivery pressure (p_2), Temperature of refrigerant inlet to

compressor (T_1), Temperature of refrigerant outlet to compressor (T_2), Temperature of refrigerant entering the expansion valve/capillary tube (T_8), compression ratio (p_2/p_1) and other parameters are recorded till the steady state is reached with respect to time. Enthalpy values are calculated at different pressure and temperature using peace software [11], and with the help of other parameter compressor work per kg of refrigerant, heat absorbed per kg of refrigerant in the evaporator, and COP of VCR system is calculated. Out of huge experimental data few steady state data are selected for different p_1 . Out of which 54 set of input and target data is used to train ANN network4. The 06 set of sample data, which are excluded while training the ANN network4, are used to test trained network4.

The performance of the ANN is 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 [1].

The fraction of absolute variance is given by

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

The root mean square value is calculated by

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

Coefficient of variance is calculated by the following equation

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

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 [1]. Here in research work R^2 , RMSE , COV is calculated for data used to test the network.

Training of artificial neural network network4 is done by MATLAB software using neural network tool box. Input parameters to the network are p_1 , T_1 , and compression ratio. Output parameter is COP of VCR system.

For this in MATLAB software, in workspace three new worksheet is opened renamed it as **INPUT**, **TARGET** and **SAMPLE**. Input data (suction pressure, suction temperature and compression ratio) of 54 set of data is saved in INPUT sheet. Similarly experimental output (coefficient of performance) of 54 set of data is saved as TARGET sheet. 06 set of experimental

data are used to test the network. Input parameter of these 06 set of data (suction pressure, suction temperature and compression ratio) value is saved in worksheet named as **SAMPLE**, and workspace is as shown in Fig 4. Predicted output of ANN has been saved as **network4_outputsample**.

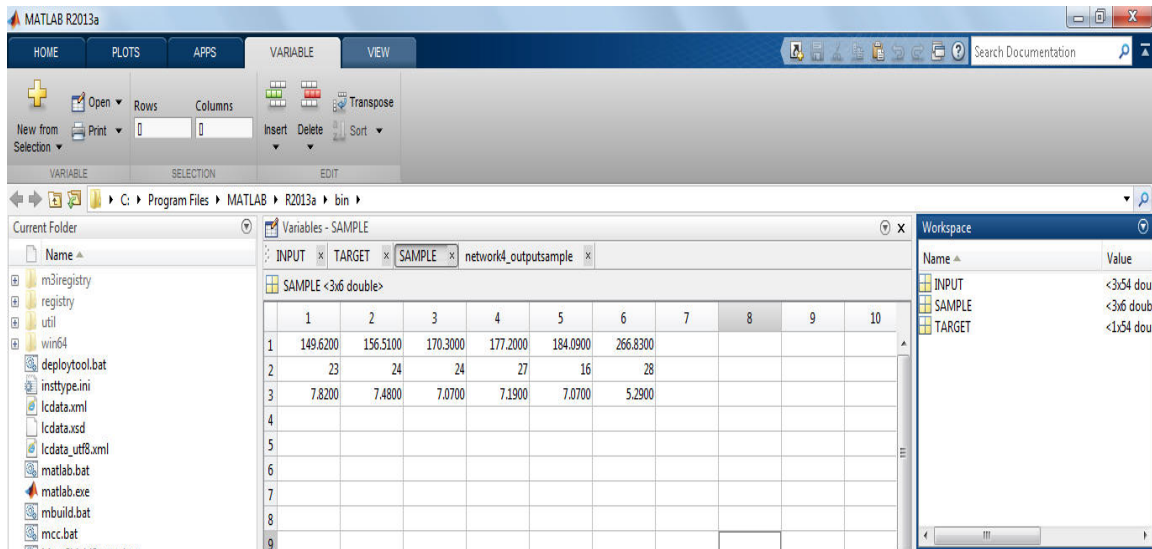


Fig. 4 Spread sheet of MATLAB for network4.

In command window of MATLAB software, under command prompt we run `nntool`. As a result “neural network /data manager (nntool)” window opened and in this window then by selecting import tab, “import to network /data manager” window opened and we import, input

data sheet from MATLAB as input data, target data sheet as target data, sample data sheet as input data as shown in Fig. 5, and then closed the “import to network/data manager” window and “neural network /data manager (nntool)” window shows imported data as shown in Fig.6.

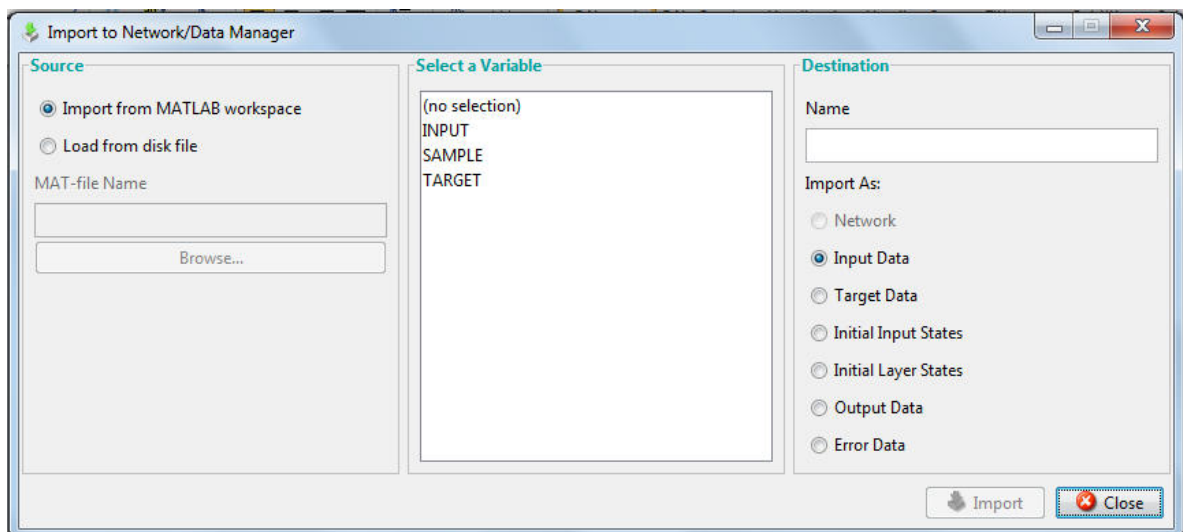


Fig. 5 Importing of data in MATLAB while training network4.

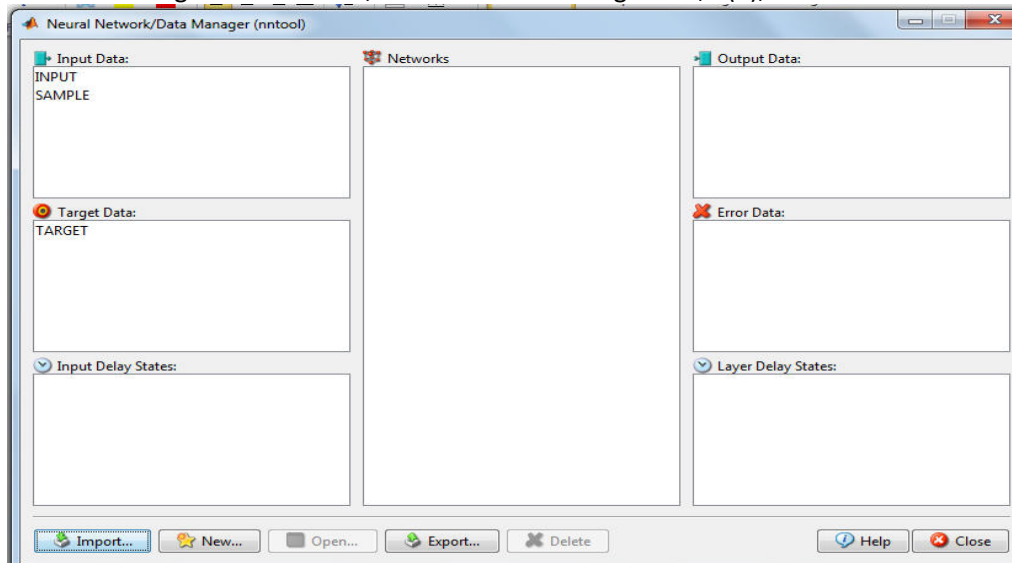


Fig. 6 Imported data in neural network while training network4.

New network is generated by selecting “New” tab, “in neural network /data manager (nntool)” window, by doing so “create network/data” window opened , here new network appeared and renamed it as network4,as shown in Fig. 7.

Input parameter for this network is suction pressure, suction temperature and compression ratio. Output parameter for this network is COP of VCR system.

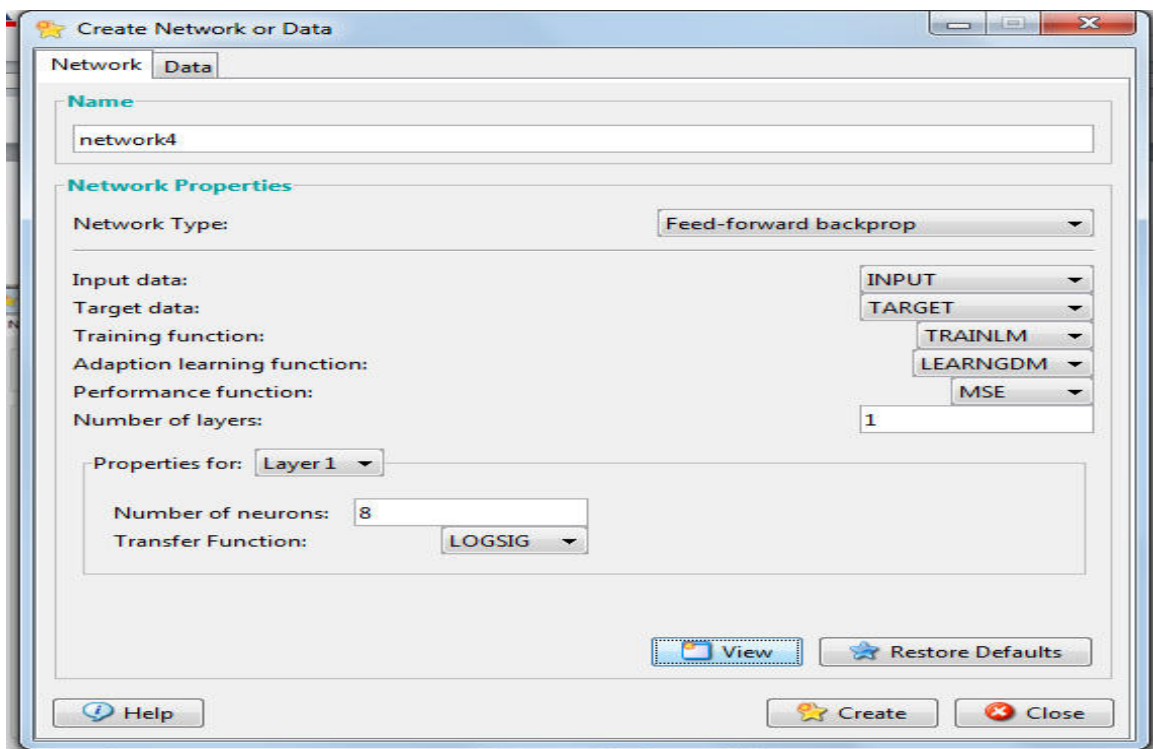


Fig. 7 Create network/data in MATLAB while training network4.

After so many trail finally selected Network property as shown in Fig. 7 as Network Type Feed forward back propagation, Input data as INPUT, Target data as TARGET , Training function as TRAINLM, Adaptation learning function as LEARNGDM, Performance

function as MES, Number of layers as 01, Number of neurons as 08 , Transfer function as LOGSIG. By pressing view tab, in “create network/data” window, network to be created can be viewed in “custom neural network (view)” window as in Fig. 8.

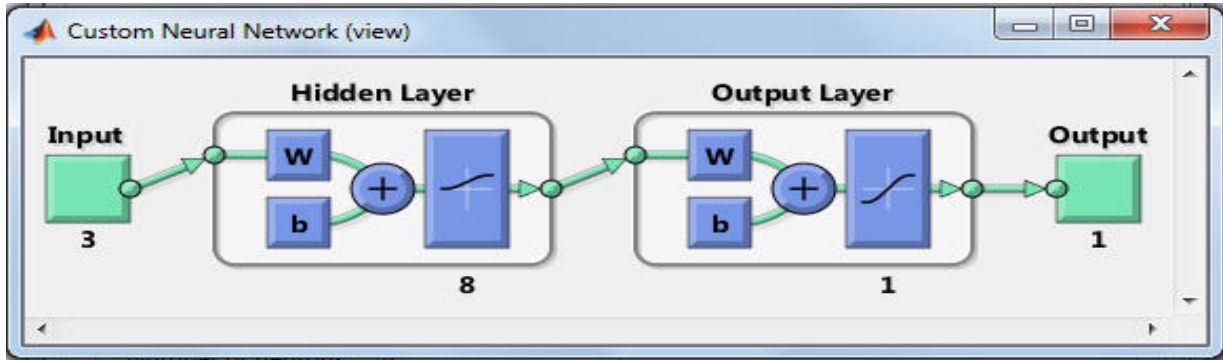


Fig. 8 Custom neural network (view) ANN while training network4.

Custom neural network (view) window opened and it show trend of input and output data, as trend is matched, we created the artificial neural network called network4, by pressing create tab

in “create network or data” window and added it to “neural network / data manager” as shown in Fig.9.

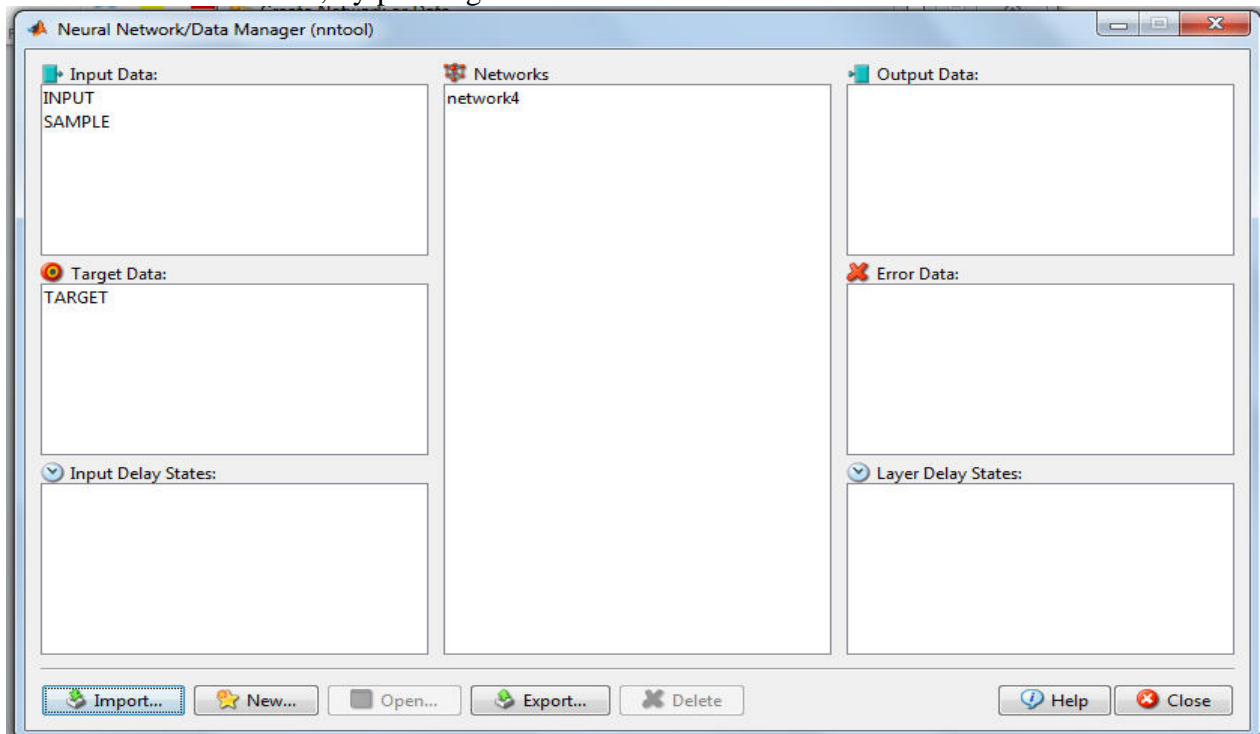


Fig. 9 Creating network4 in MATLAB.

Created network4 is selected in “neural network/data manager (nntool)” window and

“Network:network4” window opened as shown as Fig.10.

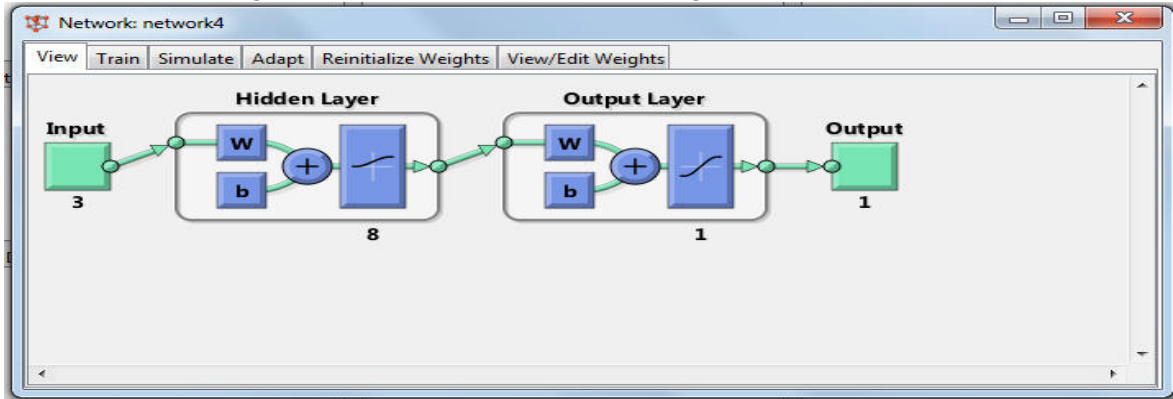


Fig. 10 Created neural network4 in MATLAB.

For training of network4 “Train” tab is selected and then under “training information”, in “training data”, input is selected as input and target as target to train network4. Training result

under in same window show predicted outputs of data used for training as **network4_output** and error as **network4_error** of the 54sets of data used for training as shown in Fig. 11.

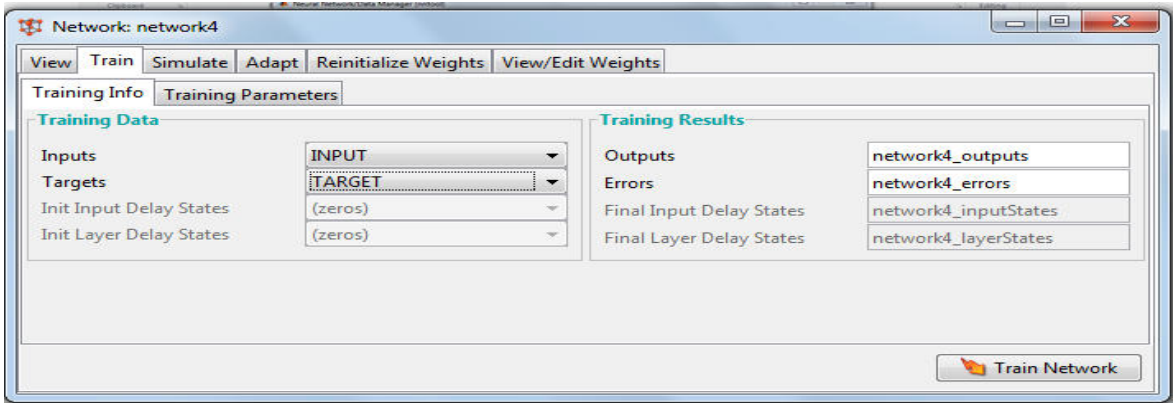


Fig. 11 Training information of network4.

Then selected the “training parameter” tab, under same “train” tab and after so many trail

finally selected training parameter as shown in Fig 12.

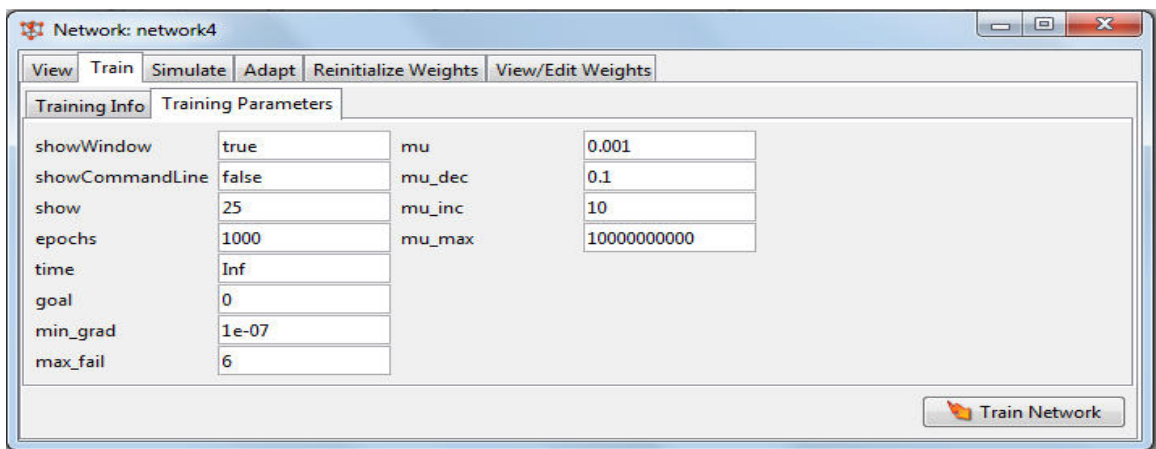


Fig. 12 Training parameter of network4.

After so many training of network4, best training of ANN network4 is shown Fig. 13 and corresponding regression analysis as shown Fig 14.

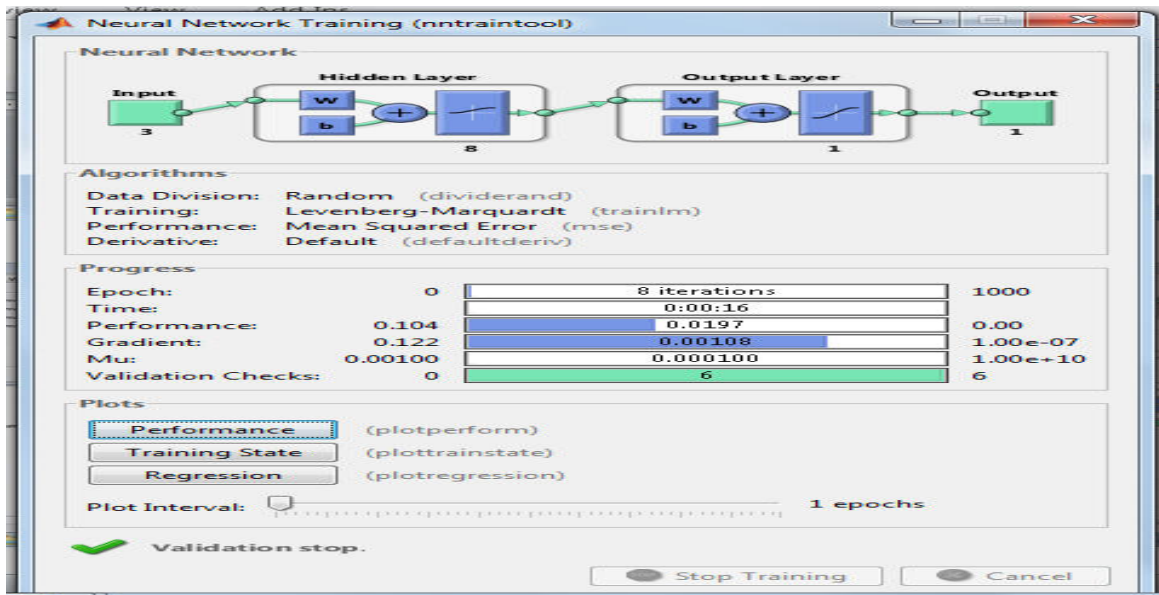


Fig.13 Training of network4.

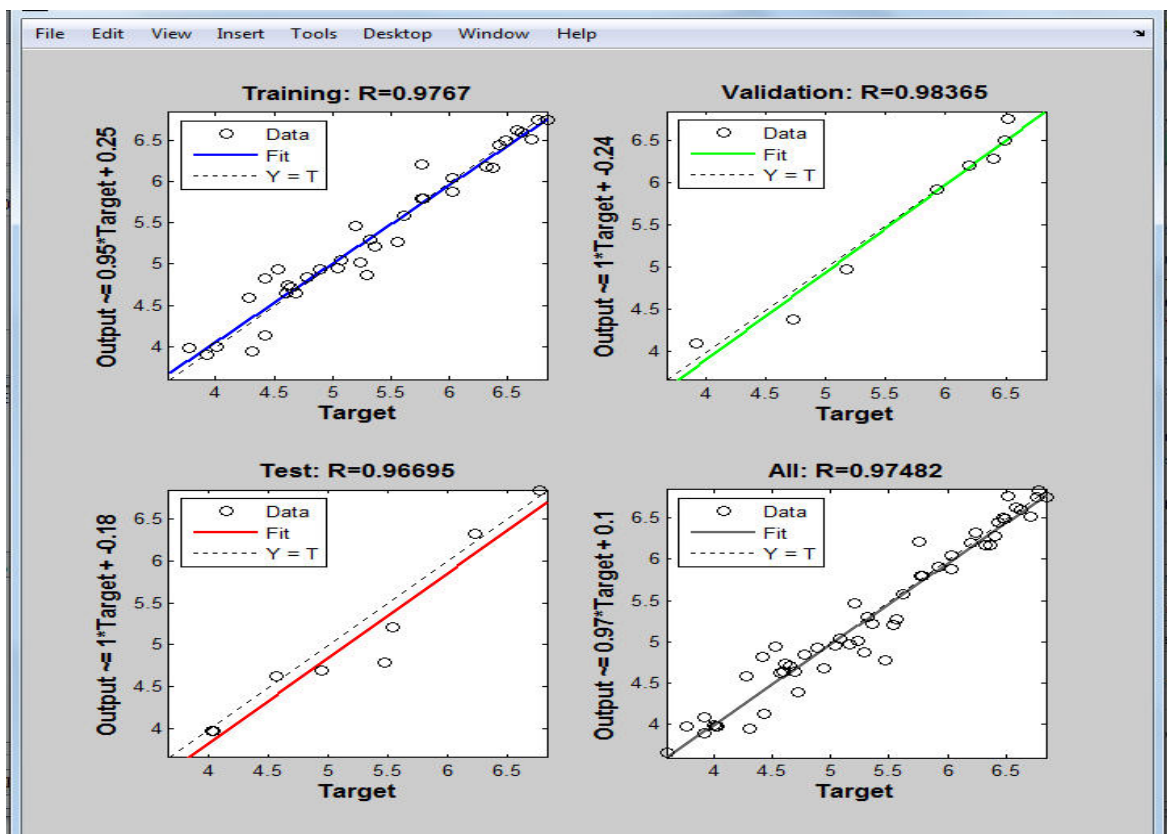


Fig.14 Regression analysis of network4.

Then to simulate trained ANN network4 we selected “simulate” TAB as shown in Fig. 15 with under “simulation data” we selected inputs

as **SAMPLE** and outputs as **network4_outputsample**.

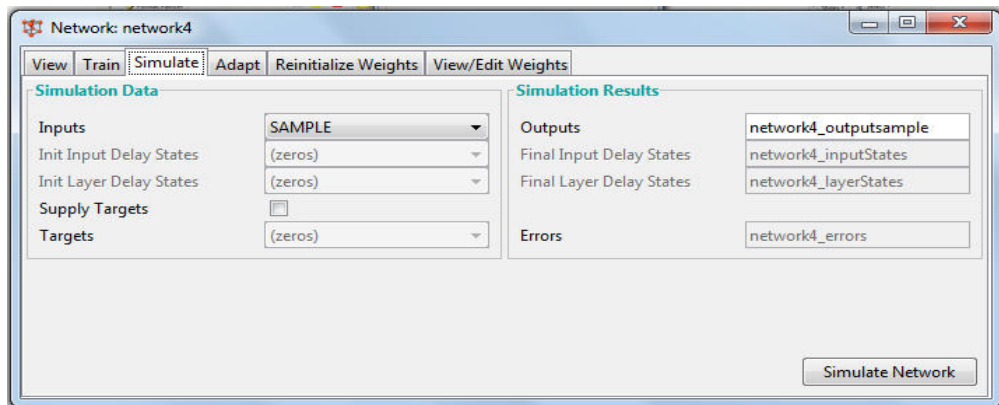


Fig. 15 Simulation of network4 on ANN.

Then by pressing “simulate network” tab result i.e output /predicted data of 06 set of sample input data used to test network is stored in

“neural network /data manager (nntool)”as **network4_outputsample** shown in Fig. 16.

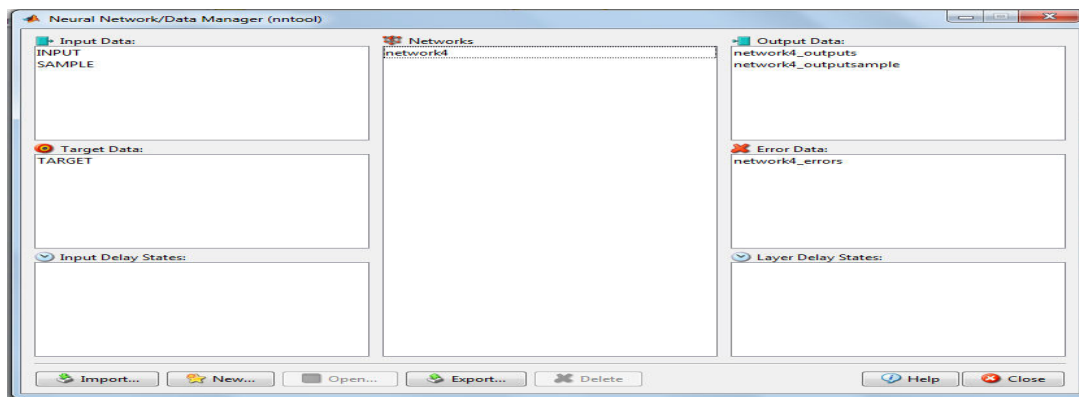


Fig. 16 Neural network window showing **Network4_outputsample** on ANN.

Predicted output value of network4 as “**network4_outputsample**” for given 06 set of

input data used as sample to test network4 is shown by Fig 17.

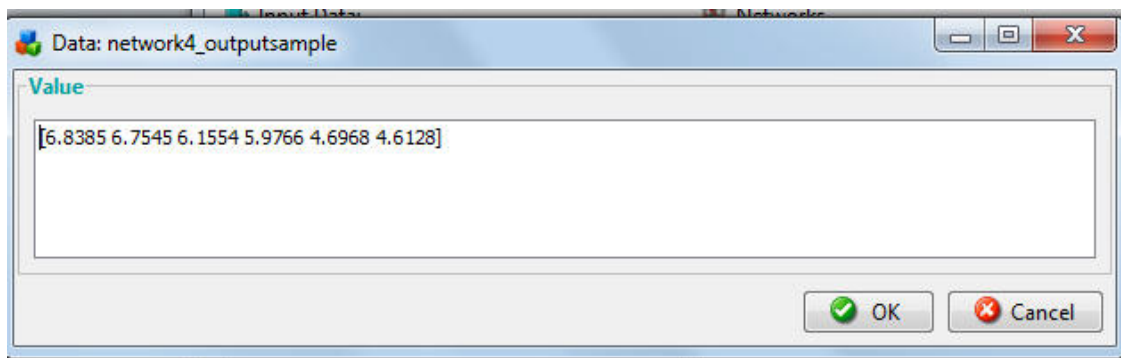


Fig. 17 Predicted output of network1 as network4_outputsample.

Then Predicted output, **network4_outputsample**, **network4_output** and **network4_error** all are

exported to workspace as shown in Fig. 18, and entire workspace is saved to suitable location for further use.

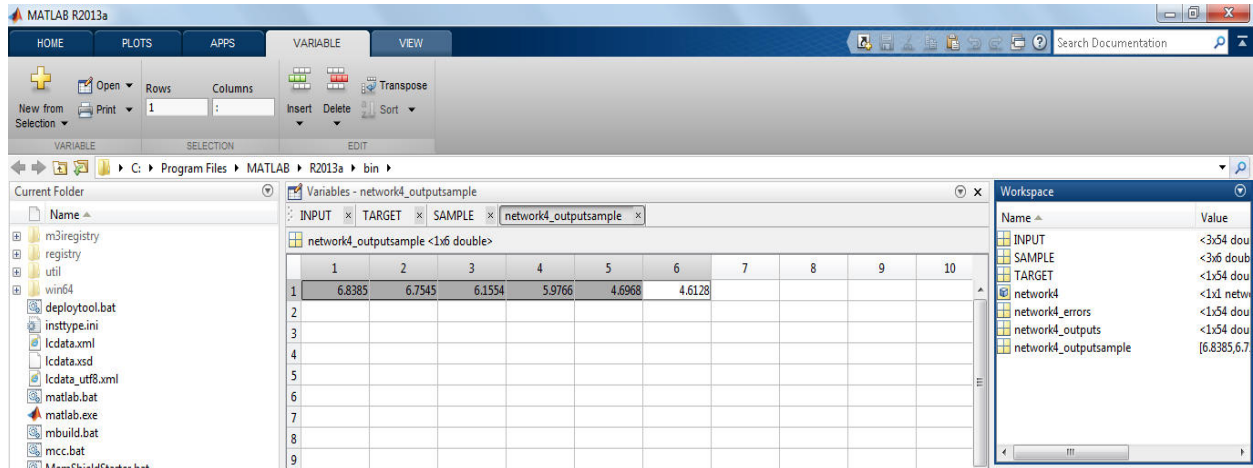


Fig.18 Exporting of simulated network network4 to work space of MATLAB.

Then Predicted output, **network4_outsample**, value which is exported to work sheet and compared with experimental output of 06 sample data

used to test ANN network4, which resembles to each other as shown in Table2.

Table 2 Response Data by ANN

DATA USED TO TEST TRAINED NETWORK						ANN OUT-PUT	Measured output –predicted output	R ²	RMSE	COV (%)
S.No.	INPUT			OUT-PUT	ANN OUT-PUT					
S.No.	p ₁ kPa (kilo Pascal) Suction Pressure	T ₁ (°C) Temperature at Inlet to Compressor	Compression Ratio	COP of VCR System	COP of VCR System	Measured output –predicted output	R ²	RMSE	COV (%)	
1	149.62	23	7.82	6.86	6.84	0.02	0.999217	0.163	2.84%	
2	156.51	24	7.48	6.74	6.75	-0.01				
3	170.30	24	7.07	6.06	6.16	-0.10				
4	177.20	27	7.19	6.01	5.98	0.03				
5	184.09	16	7.07	4.52	4.70	-0.18				
6	266.83	28	5.29	4.27	4.61	-0.34				

Result: Result is shown in Table2 as experimental output and Output parameter predicted from ANN network4 resembles close to each other with **R² = 0.999217**, **RMSE = 0.163**, **COV = 2.84%** & we can reach to conclusion that ANN named network4 with network architect feed forward back propagation, Training function as TRAINLM, Adaptation learning function as LEARNGDM,

Performance function as MES, number of layers as 01, Number of neurons as 08, transfer function LOGSIG, can be effectively applied in the field of performance analysis of simple vapour compression refrigeration system. Actual performance of network is evaluated using 06 set of test data, since these were not used for training and Table 2 shows that R² is **0.999217** which is very close to 1 for

test data and RMS error is very small **0.163**. It is clear that ANN (network4) gives very accurate representation of statistical data over the full range of operating condition and indicates that trained network4 predicted coefficient of performance of VCR system for given inputs (suction pressure, suction temperature and compression ratio) very accurately. Evaluation of these result suggest that COP of VCR system are predicted within acceptable error.

Conclusion: The ANN model developed in this research work, network4 is ready to analyze performance analysis of vapour compression refrigeration system to find out effect of inputs (suction pressure, suction temperature and compression ratio) to the output as COP of VCR system. Input parameter are suction pressure(p_1), suction temperature/inlet temperature to compressor(T_1) and compression ratio which gives the effect on the output parameter COP of VCR system.

Effort has been made to train (ANN) named here network4 with network type feed- forward back propagation with suction pressure, suction temperature and compression ratio as input parameter and COP of VCR system as output parameter .ANN has been commendably trained as experimental output, output parameter predicted from network4 very close to each other for 06set of test data with **$R^2=0.999217$, $RMSE = 0.163$, $COV= 2.84\%$**

These way we can conclude ANN network4 successfully trained with Network type - feed forward back propagation, Training function- TRAINLM, Adaptation learning function – LEARNNGDM, Performance function as MES, number of neuron as 08, number of layers as 01 and transfer function LOGSIG. Developed ANN, model network4, can be successfully applied in the field of performance analysis of simple vapour compression refrigeration system and for given set of input parameters (suction pressure, suction temperature and compression ratio), output parameter as COP of VCR system, can be predicted very accurately.

References

- [1]. Mohanraj M., Jayaraj S., Muraleedharan C., Applications of artificial neural networks for refrigeration, air-conditioning and heat pump systems—A review, *Renewable and Sustainable Energy Reviews*, 2012, 16(2), 1340–1358.
- [2]. Hosoz M, Ertunc H M., Modeling of a cascade refrigeration system using artificial neural networks, *International Journal of Energy Research* 2006, 30(14), 1200–1215.
- [3]. Yilmaz S, Atik K., Modeling of a mechanical cooling system with variable cooling capacity by using artificial neural network, *Applied Thermal Engineering* 2007, 27(13), 2308–2313.
- [4]. Ertunc HM, Hosoz M., Artificial neural network analysis of a refrigeration system with an evaporative condenser, *Applied Thermal Engineering* 2006, 26(5-6), 627–635.
- [5]. Saidur R, Masjuki H, Jamiluddin Y., A new approach to investigate the energy performance of a household refrigerator-freezer, *International Energy Journal* 2006, 7(1), 9–15.
- [6]. Swider D J, Browne M W, Bansal P K, Kecman V. Modeling of vapour compression liquid chillers with neural networks, *Applied Thermal Engineering* 2001, 21(3), 311–329.
- [7]. Navarro-Esbri J, Berbegallb V, Verdub G, Cabelloa R, Llopis R. A low data requirement model of a variable-speed vapour compression refrigeration system based on neural networks, *International Journal of Refrigeration*, 2007, 30(8), 1452–1459.
- [8]. Chang Y-C. Sequencing of chillers by estimating chiller power consumption using artificial neural networks, *Building and Environment* 2007, 42(1), 180–188.
- [9]. N. Li, L. Xia, D. Shiming, X. Xu, M. Chan. Dynamic modeling and control of a direct expansion air conditioning system using artificial neural network, *Applied Energy* 2012, 91(1), 290–300.
- [10]. <https://hackernoon.com/overview-of-artificial-neural-networks-and-its-applications-2525c1adff7> .
- [11]. http://www.peacesoftware.de/einigewerte/r134a_e.htm .