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An Artificial Intelligence Based Current Measurement Technique in High Voltage Power Transmission and Distribution Lines using Pyro-Sensors

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Abstract- **High voltage transmission lines are the fundamental element in order to transfer electricity from the power plant/grid to consumers. The frequency, current and voltage are the key figures to sustain the absolute quality of the power transmission, and maintaining such high performance requires smart solutions and equipment like Current Transformer (CT) & Potential Transformer (PT). This proposed work enlightens an inception to monitor current in the high voltage transmission lines by using pyro-sensors, machine learning (ML) techniques and artificial intelligence (AI). Using pyro-sensors around the transmission/distribution lines, data can be gathered in the form of heat waves (infrared waves) that are generated by the electric current in the transmission/distribution line. The proposed methodology uses this data to be processed by neural network based artificial intelligent algorithm to evaluate the amount of current in the transmission line. The claim about the authenticity of the proposed technique is tested and verified by MATLAB simulation neural network toolbox. The simulation results are the reminiscence of predicted current with actual, promulgating the potential of replacing existing current measuring technique of CT at the grid station.**

Index Terms**—**Pyro-sensors, Machine learning, Artificial Intelligence, Current transformer, Potential transformer

I. INTRODUCTION

The ever-growing demand of electric power supply for the community is demanding strenuous efforts to keep the grid stations running round the clock. The frequency, current, and phase of high-voltage power lines are important measures of the quality of the power transmission. So, it is highly significant to continuously produce and transmit these parameters through high power transmission lines. Also it is very important to gage the real time quality of transmitted power through high power transmission lines far away from power plants and substations. Currently there is no smart technology available to measure the power line quality on any remote location [1-2].

The conventional measuring method includes contact current transformer (CT) at the end of a transmission line [3], but CT cannot measure power quality or other parameters at a certain location in high voltage transmission lines. Moreover, contact measurement method have several problems regarding safety and electronic damage due to the electromagnetic fields induced on the conductors. In order to measure current, voltage and frequency of high power lines, noncontact measuring techniques are in practice and when there is a discussion of noncontact measurement phenomena, the temperature measurement techniques seems highly dependable as these methods are widely used in several applications nowadays (e.g., gas thermometry, diode thermometers, capacitance and noise thermometers, IR thermography) [4-6]. Several temperature measurement techniques are discussed as follows.

The most common and important physical measured entity is temperature. As a result, sensor utilization has a vast range of applications and covers a large amount of sensor market by volume [4]. Multiple physical entities which are being sensed and measured (e.g., humidity, pressure, motion, body temperature, flow, stress and gas concentration) revolves around temperature fluctuations therefore, temperature alterations required to be reimbursed [5]. Based on vibrant physical phenomenon, several temperature sensing techniques are in practice like thermal expansion [6], thermoelectricity [7], fluorescence [8], etc. The relative position of the sensor and the environment, distinguishes the temperature measurement techniques into three categories [6]: i) Invasive: When sensor is in direct contact with the medium of interest (e.g.: thermocouple in a gas stream), ii) Semi-Invasive: In some systems, the medium of interest behaves to produce remote outputs (e.g., surface coatings whose color changes with temperature), iii) Non-Invasive: The medium of interest is monitored remotely (e.g., IR thermography). Since a non-contact (non-invasive) temperature measurement method uses an IR sensor so it is important to discuss the remote monitoring IR technology before proceeding further.

Ever since the invisible spectrum was discovered, use of IR sensors has been sky rocketed. The invisible spectrum is not visible to human eye, but it still demonstrate its presence with the amount of heat released by the light. In order to visualize and articulate this invisible spectrum thermal sensors/IR thermometers are becoming a basic need nowadays. Radiation thermometers measure thermal radiation emitted from the surface of a material. The infrared ray is the electromagnetic wave having a longer wavelength. The infrared has a wavelength between 0.75μm~1μm [9]. Every matter emits thermal radiations or heat energy comparing to their absolute temperature ratings [10]. The known electromagnetic spectrum stretches from gamma rays towards microwaves having wavelengths from 10^{-12}m to hundreds of meters including x rays, UV rays, visible spectrum and IR waves in between two extremes. Such pivotal details are important in order to apprehend the driving force to replace existing voltage measuring technology PTs with the IR temperature sensor. But first let us look at some of the drawbacks of using PTs at grids stations.

Overhead transmission lines are needed to be monitored for constant power availability over long distances. Fault occurrence is a likely event in the overhead transmission lines which could cause abrupt variations in voltage and amplitude of the frequency [11]. Also some renewable energy source could cause power fluctuations and voltage disturbances [12]. In addition, sectional monitoring is imperative for these high power transmission lines because these lines covers a large geographical area and exposed to the variant environment. If an incident occur at a certain location, for example, corrective measures such as disconnection and reclosing should be taken timely in order to mitigate the cause. Large frequency bandwidth should also be addressed as it is a basic need of the newly deployed high-voltage DC (HVDC) transmission grids [13]. Furthermore, conventional potential transformers (PT) unfortunately cannot meet these measurement requirements [14] as magnetic core issues of PTs limits the frequency bandwidth in the range from tens of Hz to kHz. Considering about the expensive ferromagnetic material of PTs' and the necessary galvanical connection to the high-voltage live wires, PTs are highly unlikely to be deployable to cover large geographical areas for realizing sectional monitoring.

To find an economical and efficient solution, researchers are trying to find new avenues of current and voltage measurements such as:

- Several scholarly efforts are made to develop a smart solution to monitor the power for overhead transmission lines at any remote location [10].
- One research is shown in the literature [15] which highlights the functionality of microprocessors for data collection and processing based on hall sensing theory.
- In literature [16], CT voltage sensor and wireless transmission technology are adopted to design a non-contact measurement system.
- Another articulation discussed in [17] about the capacitive coupling and magnetic field sensing assisted techniques to measure non-contact voltages of overhead transmission lines which covers large terrestrial area.

II. PROPOSED SYSTEM METHODOLOGY

The blue-print of the proposed study comprises of a PIR (pyro-electric infrared) detection module, which is a back bone of the proposed system, attached with close proximity of high power transmission line above. This module contains a non-contact IR temperature sensor encapsulated within an insulating material, aluminium for example, for minimizing the external heat content due to harsh weather environment. This temperature sensor is used to measure heat waves from the overhead power lines. The ideal distance of IR sensor from the measuring object depends upon the specification of the IR temperature sensor used. This measured data will then be transmitted to an analog to digital converter in order to transmit digital output to an artificial intelligent network for the purpose of displaying measured current or voltage and to train the neural network for future voltage/current predictions on several remote locations as well as at several smart grids. The proposed heat wave measuring system is shown in the Fig. 1 and the detail of components is elaborated below.

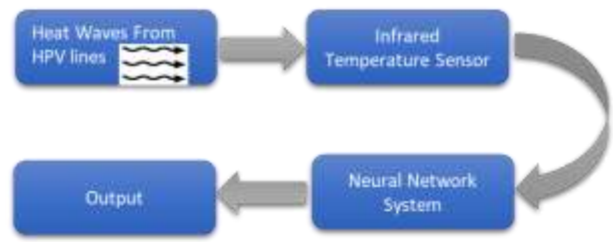


FIGURE 1: Main structure of the proposed heat wave measuring system.

A. Thermal Radiation or Heat Waves

It is a common phenomenon that all type of matter emit radiation at non-zero temperature out of which some are in visible spectrum and some are invisible spectrum like ultraviolet UV rays, infrared IR. Thermal radiation of heat waves emitted by all matter at zero temperature are in the wavelength range of 0.1 µm to 100 µm. Different regions of electromagnetic spectrum along with the ranges of each region are mentioned in below Fig. 2.

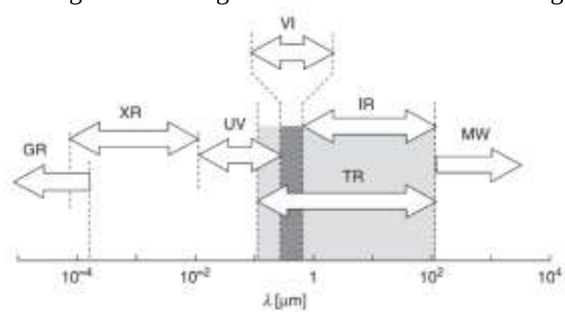


FIGURE 2: Electromagnetic Spectrum (GR gamma rays; XR X-rays; UV ultraviolet; VI visible; IR infrared; TR thermal radiation; MW microwaves), adopted from [16]

The phenomenon of emitting radiation from the matter lies in the fact of collisions of electrons of the matter, thus releasing energy. The propagation properties of electromagnetic waves can be applied on thermal radiations, since these radiations are also electromagnetic [18-20]. The relation for frequency and wavelength of thermal radiations can be related through $\lambda = c/v$, where c is he speed of light $c = 2.998 \times 10^{8}$ m/s.

The emitted thermal radiations are not directional and can be transmitted to all directions of the conductor. Here an infrared temperature sensor can be placed to record and analyze the emitted radiations from the high power transmission lines in order to measure current, voltage and frequency. The IR temperature sensor is discussed as below.

B. Design of Temperature Measurement System

Heat wave measurement system comprises of two main components, one is infrared thermometer and other is a non-

conducting shell in which this pyro-sensor is placed for achieving a non-contact system [19]. To choose the thermometer, three criteria were available including spot size, cost and most importantly the temperature range. The minimum distance should be around 1cm, considering the length of the insulators typically attached to the tower and the spot size at that distance should not be bigger than 3 cm considering the size of the attached sphere.
Minimum temperature for the transmission conductor depends upon the type of the conductor material used, but it is common to specify the temperature range of conductor from 50 ◦C or 70 ◦C as the maximum operating temperature so the required temperature range could vary from few degrees Celsius to nearly one hundred Celsius depending upon the weather conditions, hot or cold. Cost was also a considerable and critical aspect while designing and implementing this proposal in order to develop a realistic alternative to the existing contact temperature measurement systems, which are available in several hundred or thousand dollars. A brief block diagram of non-contact temperature measuring sensor is shown in Fig. 3.
Temperature of power line depends upon the amount of heat being released from that high power transmission line. At ambient temperature, there would be very less number of photons being emitted from the surface of transmission line and the emitted photos will remain less until the temperature of the surface reaches a certain threshold value. Once the surface of the conductor is hot enough to breach the threshold point, amount of photons would release in abundance from the conductor, providing a detectable amount of heat waves for the IR sensor.
Since heat is a form of energy (E) and suppose conductor current, resistance and the amount of time the current flowing through the conductor is known, then the amount of heat can be calculated using;

$$P = W/t \Rightarrow E/t \quad (1)$$

$$E = Pt \Rightarrow I^2Rt \quad (2)$$

$$H = I^2Rt \quad (3)$$

Now, for elaboration of proposed current measurement technique the important parts of the heat wave measuring system are presented in detailed as follows:

i). 81101 Thermopile Sensor

The infrared sensor chosen for this study is a non-contact temperature sensor 81101. It can not only be used to measure component temperatures but can also be used for measuring body temperature, surface temperature, heat ventilation and much more. The temperature range of this IR sensor is −40 ◦C and 125 ◦C with a spectral range of 8 µm to 14 µm and measurement resolution of 0.02°C.
This non-contact temperature measuring sensor works on thermocouple principle where heat waves are measured from the high power transmission lines and converted to electrical signals for further processing. The thermopile sensors are fabricated with different polysilicon technologies [20-22], Bi-Sb-Te [23] and AlGaAs-GaAs [24].

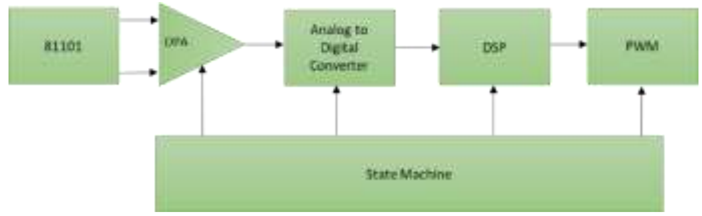


FIGURE 3: Block diagram of temperature sensor

ii). Amplifier

The purpose is to amplify the signal, received from the IR sensor that in actual could be very weak. As mentioned above, thermal radiation emitted by hot surfaces can be described by Plank's law, which shows that radiance increases exponentially with (absolute) temperature. In order to achieve maximum gain of the recorded heat wave signal, an amplifier with band-pass characteristic could be used that could provide a total gain of 1000. Furthermore, the amplifier must be fast (high bandwidth), low-noise, linear and able to perform over a high dynamic range [24, 25]. The amplified signal then fed to A/D converter.

iii). A/D Converter

Three basic steps for converting analog signal into a digital signal involves sampling, quantization and coding. The nature of the signal is changed after passing through A/D converter as our ultimate goal is further digital signal processing at neural networks end to have estimation of the current and voltage values of the high power transmission lines. A state machine controls the operation of the temperature sensor which controls the measurement and calculates the ambient temperature of the object. This post processing of the measure temperature is then output from PWM. A brief description of the temperature sensor components is as follows.

C. Artificial Neural Network

The breakaway discovery of a neuron in a human brain during 19th century had opened new horizons for the scientists and researchers to study the phenomena. This biological discovery had also revolutionized the electronics industry and this study of artificial neural network (ANN) is a complete reminiscent of human neurons. It is to believe that a human brain has approximately 85 billion neurons [26] and ANN works in quite similar manner as a human brain does. In ANN network, different neurons are connected to each other through weights (a form of network coefficients). ANN networks have astounding abilities to predict or estimation values of the system and can learn and highlight the correspondence among system's parameters. Detailed working of ANN is promulgated in literature [27].
A typical ANN network architecture comprises of different layers and nodes. There can be a single layer or multilayer ANN systems depending upon the requirement of the operation. The nodes, that imitates biological neurons, are the element which can collect information and perform simple operations. This result is passed to different neurons/nodes. The output of each node is called activation value. A single layer ANN system with different nodes is shown in Fig. 4.

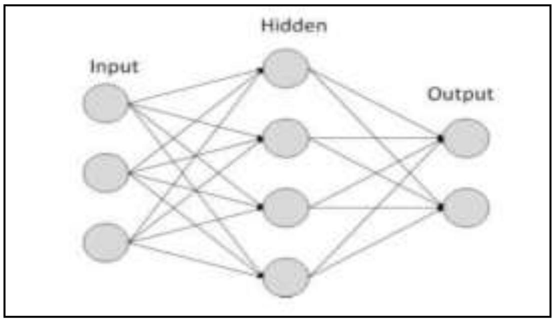


FIGURE 4: Single layer ANN network architecture

For single layer ANN network, having three inputs (x1, x2 & x3) and three weights (w1, w2 & w3) with a bias (b) that is associated with storage of information the equation to calculate output can be seen in Fig. 5.

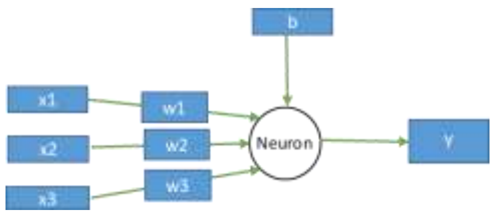


FIGURE 5: Single neural network node

$$v = (w1 * x1) + (w2 * x2) + (w3 * x3) + b \quad (4)$$

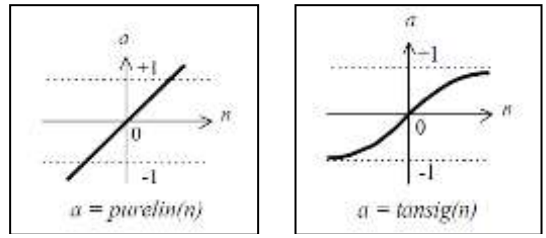
From (4), w = [w1 w2 w3] and x = [x1 x2 x3] and φ is an activation function so the output of a node of a neural network can be represent as:

$$y = \varphi(v) = \varphi(wx + b) \quad (5)$$

where v = (wx + b) and φ is a typical step or linear function, called activation function for ANN system which determines the behavior of a node. Based on input and output layers this transfer function also represents the expected output of the system. Whereas, bias (b) is an offset of threshold value for a neuron and often envisaged as a property of activation function.

Two types of activation functions are used one is linear and other is sigmoid. The linear activation function is easier to understand, but it can work for a single layer neural network only as θ (x) = x as shown in Fig. 6 (a) as all the hidden layers become ineffective for this function. The bias value is a reference point for the inputs to be compared with, so that output could be produced. If the input values are smaller than biased value, then by using sigmoid function. Whereas the sigmoid function is a smooth limiting function [29] in Fig. 6 (b) with mathematical representation as:

$$f(x) = 1/(1 - exp - x) \quad \textbf{(6)}$$



(a) **(b)**

FIGURE 6: Various Activation Function for a unit, adopted from [30]

In order to simulate the heat wave measuring network, a single layer ANN network is used to have efficient predictions. The neural network is trained by using four different set of data samples, including temperature, noise and voltage of overhead transmission lines and trained results are compared to have appropriate prediction results that are reminiscent to actual current values flowing through conductor. In order to train a neural network different types of algorithms are used, these algorithms are articulated in the paper [28].

III. SIMULATION RESULTS

For the training of a neural network for the incoming data to predict for an approximated output, a fast forward back propagation (FFBP) type is used. Training of neural network is based on dividing the data (voltage or current waves from PWM) into three sets: the training set, the validation set and the testing set which assess the performance of neural networks. Such dynamic artificial neural network can be turned to an open loop or closed loop network using *open loop* and *closed loop* functions in MATLAB Neural Network toolbox [29]. The block diagram of the system is shown in Fig. 7.

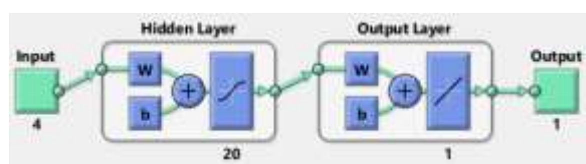


FIGURE 7: Open loop neural network

From MATLAB Neural Network Toolbox [29] Levenberg-Marquardt backpropagation algorithm was used to train the neural network. Although it uses more memory compared to other algorithms (e.g: Bayesian Regulation and

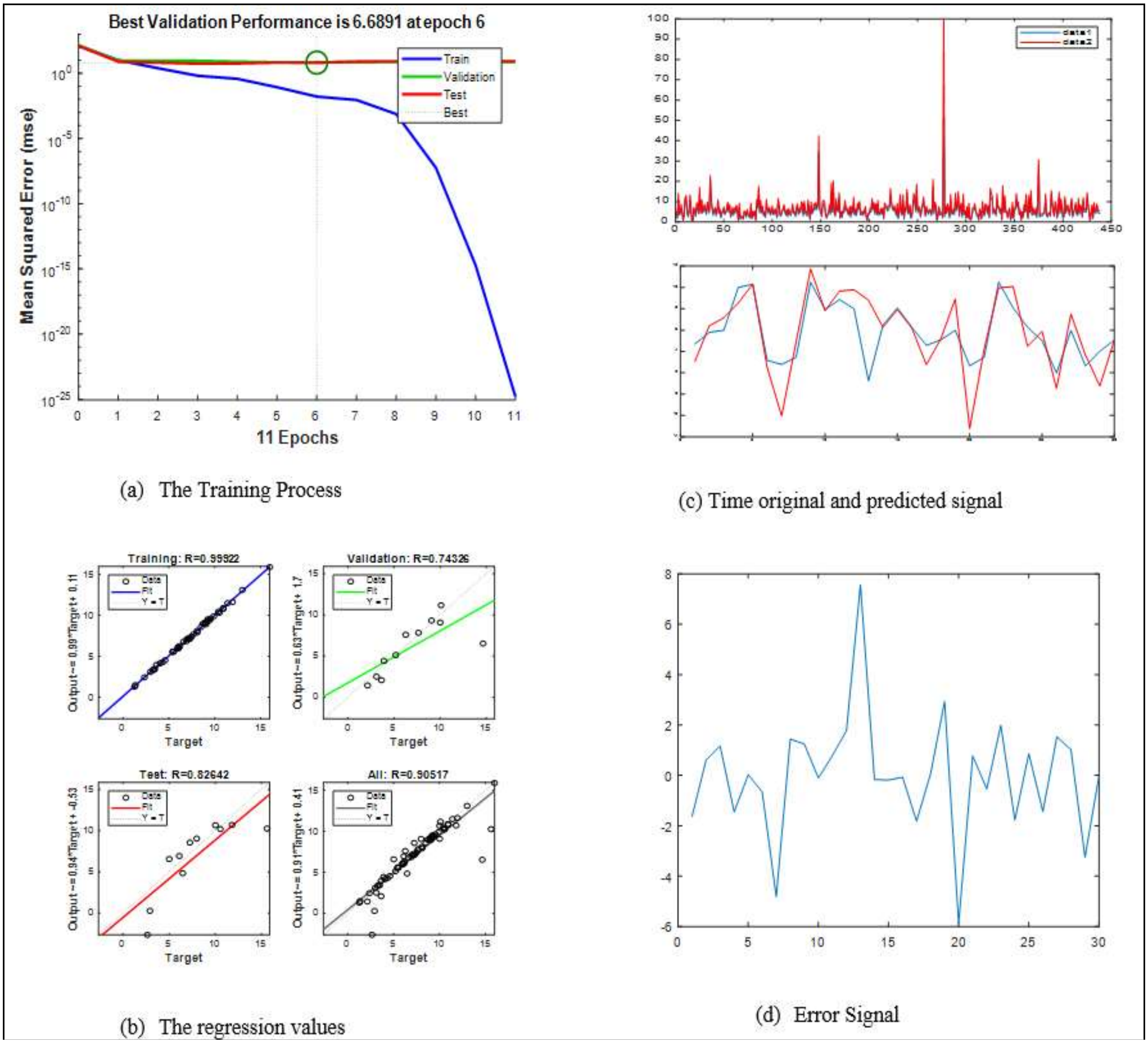


FIGURE 8: The results of training and prediction of ampacity of the power transmission line

Scaled Conjugate Radiant) this algorithm has good performance and is fast for training. The data samples are divided using *dividerand* parameter of training function. Therefore, 70% of the data samples are used for training, 15% are used for validation and remaining 15% are used for testing the output of the trained neural network with the actual output values. Results of the predictions are in close proximity with the original data acquired of the power lines.

Figure 8 shows the training performance and results of prediction of N=100 samples using MATLAB. Tab. I is the corroboration from where the data was predicted for N=100 samples having 20 neurons. Four input values are used of Max temperature of conductor, Min temperature of conductor, Noise or external atmospheric temperature and output voltage. Figure 8 (a) shows the best validation performance (6.689) is achieved after 6 epochs only, Fig. 8 (b) shows the regression values, showing how well the neural network is trained as Training R value is approximately equals to 1. Figure 8 (c) shows the overlapping signals of actual and predicted data, which corroborated through Fig. 8 (d) showing the error signal between the original and predicted data which is very low, advocating about the efficiency of the system to produce predicted output.

Table I: Actual vs. Predicted current ratings for overhead transmission lines

Temp. of Conductor C (Max)	Temp. of Conductor C (Min)	Noise (db)	Voltage from heat waves (V)	Current (I) (Actual)	Current (I) (Predicted)
28.9	14	2.13	0.43	4.69	3.06
28.1	13	4.23	0.69	5.79	6.40
25.6	12	4.41	0.67	5.99	7.16
25	11	4.45	0.99	10	8.55
26.7	8	4.38	1.11	10.29	10.32
30.9	18.4	1.46	0.29	3.17	2.51
29.5	9	1.78	0.17	2.78	-2.04
34.6	21.3	1.8	0.43	3.46	4.90
34	20.4	1.67	0.99	10.5	11.75
33.5	23.9	2.7	0.78	7.92	7.82
26.4	9.8	2.69	0.92	8.87	9.66
29.1	8.7	3.4	0.87	8.01	9.78
25.7	10.7	1.11	0.01	1.24	8.80
26.8	12.3	1.23	0.61	6.44	6.27
31.9	20.1	3.21	0.81	8.09	7.91
34.2	23.5	2.31	0.66	6.27	6.20
32	21	4.41	0.44	4.57	2.76
27.3	13.8	4.45	0.57	5.09	5.17
28.1	8.3	4.38	0.76	5.98	8.92
29.5	10.4	1.46	0.24	2.64	-3.24
30.4	17.6	1.78	0.43	3.46	4.23
30.9	19.4	1.23	0.99	10.5	9.96
25.3	14	1.43	0.81	8.09	10.08
26.7	8	1.78	0.66	6.27	4.50
25.4	10	3.52	0.49	5.01	5.87
29.2	11	3.47	0.12	1.97	0.54
33.2	22.1	2.7	0.76	5.98	7.51
32.3	23	2.69	0.24	2.64	3.66
34.9	21.9	3.4	0.37	4.01	0.76
31.6	18.5	1.11	0.58	5.09	5.08

IV. CONCLUSION

In this study a methodology for current estimation in the high voltage transmission lines by using pyro-sensors, machine learning (ML) techniques and artificial intelligence (AI) is proposed. Simulations using MATLAB software are conducted on the retrieved data from high voltage power transmission lines and estimation of current is being calculated using an artificial intelligent network algorithm. The efficacy of proposed methodology is verified by MATLAB simulation neural network toolbox. By tracing down existing power quality parameters of high voltage power lines, current estimation can be done in any remote location by using pyro sensors and ANN network.

The encouraging results regarding estimated current values are promisingly close to actual current values, thus making the system reliable to use in future that can be a replacement of using CTs & PTs and can be used at any remote location on high power transmission lines for measuring current.

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