Time-Frequency Analysis Techniques for Detection of Power System Transient Disturbances

Aslam P. Memon, M. Aslam Uqaili, Zubair A. Memon, Asif A. Akhund

Abstract: The transients in power system cause serious disturbances in the reliability, safety and economy of the system. The transient signals are the transitory (short term duration) for which the frequencies as well as varying time information are compulsory for the analysis purposes. These disturbances occur for few cycles, which are difficult to be identified and classified by digital measuring and recording instrumentations.

In digital signal processing, fast Fourier transformation (FFT) is a powerful technique, utilized to measure the signals. This technique is more suitable for periodic analysis where time information of the signal is not necessary. Various types of transients indicate various behaviors and measuring characteristics but it is vital, first to detect and classify the type of fault and then to mitigate them.

This proposal suggests that transient signals can be detected and analyzed with the help of discrete wavelet transformation (time-frequency) with multiresolution analysis (MRA) algorithm and Daubechies as mother wavelet. This proposed methodology possesses the ability to de-noise and decompose the various types of transient using Matlab/Simulink and Wavelet toolbox and the simulation results prove their simplicity, accurateness and effectiveness for the detection of power system transient signals.

Keywords: Detection, discrete wavelet transform, power quality, transients.

I. INTRODUCTION

A. *Electrical Power Quality (EPQ)*

Power quality is defined as" any power problem manifested in voltage, current, or frequency deviations that result in failure or disoperation of customer equipment and system itself. In electrical energy systems, voltages and especially currents become very irregular due to the increasing popularity of power electronics and other non-linear loads. More in particular, the power supplies for IT (Information Technology) equipment and high efficiency lighting, inverters and adjustable frequency devices are main sources of disturbances [1].

Types of EPQ Disturbances (EPQDs): In an electrical power system, there are various kinds of power quality disturbances. IEEE and IEC have defined power quality disturbances into seven categories. Some disturbances come from the supply network, whereas others are produced by the load itself. These categories are: Transients, Short Duration Voltage Variations (SDVV), Long Duration Voltage Variations (LDVV), Voltage Imbalance, Waveform Distortion, Power Frequency Variations and Voltage Fluctuations [2-3]. Power system transients are the most common disturbances from power quality point of view.

Nowadays, the prime focus of industries is in the field of control engineering. It concerns mainly to monitor a system, detect the occurrence of fault in the system and identify the type of fault. This is mainly done to protect the system and avert any possible damages

B. *Power System Transient (PST)*

Transients in power system cause serious disturbances in the reliability, safety and economy of the system. The transients occur due to switching, lighting strikes, various types of faults and other intended or unintended causes. They become the harmful reasons of power system components which suffer from huge amount of currents and voltages. Transients are also known as voltage disturbances less than sag or swell and caused by sudden variations in electrical power system [1-3].

Types: Transients are classified as: oscillatory transient, the most common type caused due to the switching on secondary systems, radiated noise, lighting induced ringing and electronic equipment having impacts of high rate of oscillations with low voltage power supplies failure and short duration voltage disturbances. Impulse transient

Aslam P. Memon is working as Assistant Professor in Department of Electrical Engineering, Quaid-e-Awam U.E.S.T, Nawabshah, Sindh, Pakistan. Email: **aslam@quest.edu.pk**

Muhammad Aslam Uqaili is working as Meritorious Professor in Department of Electrical Engineering, and Pro. Vice Chancellor in Mehran U.E.T, Jamshoro, Sindh, Pakistan. Email: **aslam.uqaili@faculty.muet.edu.pk**

Zubair Ahmed Memon is working as Professor in Department of Electrical Engineering, Mehran U.E.T, Jamshoro, Sindh, Pakistan. Email: **zubair.memon.faculty@muet.edu.pk**

Asif A. Akhund is working as Lecturer in Department of Electrical Engineering, S.C.E.T, Rahim Yar Khan, Punjab, Pakistan. Email: **engr.asifakhund@gmail.com.**

caused due to capacitor switching and tripping of adjustable speed drives (ASDs) systems having main impacts of magnification of voltage at customer capacitors [1-3]. Detail of PST with spectral contents, duration and magnitude are shown in Table 01[1, 2, 4-5].

TABLE I. CHARACTERISTICS OF PST AS FREQUENCY RANGE, TIME DURATION AND MAGNITUDE

Category		Typical spectral content	Typical duration	Typical voltage magnitude	
		Transients			
1.1		Impulsive			
	1.1.1	Nanosecond	5-ns rise	<50 ns	---
	1.1.2	Microsecond	1- s rise	50 ns–1 ms	---
	1.1.3	Millisecond	0.1-ms rise	>1 ms	---
1.2		Oscillatory			---
	1.2.1	Low frequency	<5 kHz	0.3–50 ms	0–4 pu
	1.2.2	Medium frequency	5–500 kHz	20μs	0–8 pu
	1.2.3	High frequency	0.5–5MHz	5μs	0–4 pu

C. Signal Processing Technique

In signal processing, it is well known that the fast Fourier transformation (FFT) is a powerful tool for the analysis of periodic signals. This technique does not contain the time information of the signal and shows only frequency domain information. Hence, the time information of transient signals is completely lost. As transients possess the nonstationary characteristics of not only time but also of frequency domain. Traditional FFT algorithm is not suitable for the detection and classification of transient signals which vary with time [1-3].

D. Suitability of Time Frequency Transformation (Wavelet Transform WT)

The wavelet transform (WT) also known as time frequency analysis provides a fast and effective way of analyzing nonstationary voltage/current waveform distortion. The WT decomposes a signal into its frequency components and unlike the FFT; the wavelet can tailor the frequency resolution, a useful property in the categorization of the source of a transient. The ability of wavelets to focus on short time intervals for high- frequency components and long intervals for low- frequency components improves the analysis of signals with localized impulses and oscillations. Most electrical power quality (EPQ) problems are transitory (short term duration). The disturbances occur in such signals for few cycles, which are difficult to be identified or classified by recording instruments. [4-9]. It is also difficult to analyze and classify transients on line because of huge amount of data storage from the recording instruments.

E. Suggestion/Proposal

Digital measuring instrumentations have been in focus to record the transient data for information. These recording instrumentations do not provide accurate classifications of transient events data [3]. Various types of transients indicate various behaviors and various measurements are taken to maintain the system. From above discussion, it is vital, first to identify and classify the type of fault and then to mitigate them. Hence such transient analysis demands for time-frequency techniques to detect and analyze them in an efficient and simple way. This proposal suggests that transient signals can be detected and analyzed applying discrete wavelet transformation (DWT) with multiresolution analysis (MRA) algorithm and Daubechies as mother wavelet.

II. WAVELET TRANSFORM (WT)

A. Introduction

Latest advances in electrical power quality mitigation techniques are based on extraction of disturbances data instead of traditional methods. Hence time-frequency analysis is more suitable to detect disturbances from data. PQ transient disturbances vary in a wide range of time and frequency, and WT has unique ability to examine the signal in time and frequency ranges at the same time which makes WT a best suited tool for power quality disturbances [13]. FFT permits mapping signals from time domain to frequency domain by decomposing the signals into several frequency components. This technique is criticized in that the time information of transients is totally lost, although the accuracy of frequency components is high. Fourier transform does not fit the analysis of transients owing to the non-stationary property of its signals in both time and frequency domains. Wavelet transform generally offers this facility [13-14].

The wavelet transform represents signal as a sum of wavelets at different locations (positions) and scales (duration). The wavelet coefficients work as weights of the wavelets to represent the signal at these locations and scales.

Types: The wavelet transform can be accomplished three different ways.

The Continuous Wavelet Transform (CWT) where one obtains the surface of the wavelet coefficients, for different values of scaling and translation factors. It maps a function of a continuous variable into a function of two continuous variables.

The second transform is known as the Wavelet Series (WS) which maps a function of continuous variables into a sequence of coefficients. The third type of wavelet transform is the Discrete Wavelet (DWT), which is used to decompose a discretised signal into different resolution levels. It maps a sequence of numbers into a different sequence of numbers [13-14].

Mathematics: In wavelet theory known as the mathematics tool, defining a model for non-stationary signals $x(t)$ are decomposed by a set of small wave components called wavelet. Every wavelet is created by scaling and translation operations in the functions called mother wavelet. Firstly this transformation is expressed by continues wavelet transform (CWT) as:

$$W_\psi(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} x(t)\psi^*\left(\frac{t-b}{a}\right)dt \tag{1}$$

Where a and b are scale and translation real numbers, $a \neq 0$ and ψ^* is complex conjugate of ψ and $W_\psi(a,b)$ are the wavelet coefficients. Secondly for computer implementations discrete wavelet transform (DWT) will be utilized as:

$$W_\psi(m,n) = \frac{1}{\sqrt{a_0{}^m}} \sum_{k=-\infty}^{+\infty} x(k)\left(\frac{k - a_0{}^m nb_0}{a_0{}^m}\right) \tag{2}$$

Where $a = a_0{}^m$, $b = a_0{}^m nb_0$, m and n are the integer numbers provided $a_0 \rangle 1$ and $b_0 \neq 0$ [3, 10-13]. Due to this process redundancy of continuous form must be eliminated hence a_0 and b_0 be selected as to from orthogonal basis by satisfying the condition as $a_0 = 2$ and $b_0 = 1$. This requirement invites us to use multiresolution analysis (MRA), which is also known as multiresolution wavelet method (MWM). In this method original signal $x(t)$ is decomposed into different scales resolutions and the mother wavelet function

$\psi(t) = 2\sum_{n=-\infty}^{+\infty} d_n \phi(2t-n)$ is chosen with function $\phi(t) = 2\sum_{n=-\infty}^{+\infty} c_n \phi(2t-n)$ known as scaling function, where d_n and c_n are squared sum able sequences [3].

Discrete Wavelet Transform (DWT) and Multiresolution Analysis (MRA): In Multiresolution analysis (MRA), wavelet functions and scaling of functions are used as building blocks to decompose and reconstruct the signal at different resolution levels. The wavelet functions will generate the detail version of the decomposed signal and the scaling function will generate the approximated version of the decomposed signal.

MRA refers to the procedures to obtain low-pass approximations and high-pass details from the original signal. An approximation contains the general trend of the original signal while a detail embodies the high-frequency contents of the original signal. Approximations and details are obtained through a succession of convolution processes. The original signal is divided into different scales of resolution, rather than different frequencies, as in the case of Fourier analysis. The maximum number of wavelet decomposition levels is determined by the length of the original signal and the level of detail required. Details and approximations of the original signal are obtained by passing it through a filter bank, which consists of low and high-pass filters. A low pass filter removes the high frequency components, while the high pass filter picks out the high-frequency contents in the signal being analyzed [11-13].

Mother Wavelet: Selecting a suitable mother wavelet for power system transient signal is an art, instead of developing algorithms of wavelets for different problems. At the lowest scale like scale 1, the mother wavelet is most localized in time and oscillates most rapidly within a very short period of time. As the wavelet goes to higher scales, the analyzing wavelets become less localized in time and oscillate less due to the dilation nature of the wavelet transform analysis. As a result of higher scale signal decomposition, fast and short transient disturbances will be detected at lower scales, whereas slow and long transient disturbances will be detected at higher scales [3, 11-15].

Choice of mother wavelets plays a significant role in detecting various types of power quality disturbances, especially when considering small scale signal decompositions. For fast and short transient disturbances, Daub4 (called as Daubechies 4) and Daub6 wavelets are better, while for slow and long transient disturbances, Daub8 and Daub10 are particularly good. At the lowest scale like scale 1, the mother wavelet is most localized in time and oscillates most rapidly within a very short period of time. As the wavelet goes to higher scales, the analyzing wavelets become less localized in time and oscillate less due to the dilation nature of the wavelet transform analysis [15-17].

III. APPLICATION SIMULATION AND RESULTS

The computational analysis using Matlab/Simulink and Wavelet Toolbox Ver 4.2 (R2008a), the application of DWT with MRA algorithm and Daubechies 4 as mother wavelet at 6th level decomposition is proposed as the most suitable and efficient methodology for detection of PST signals. This methodology is applied on original signals which are generated at 0.2 seconds (10 cycles), and the sampling arte of 10 KHz. All the major categories of power system transients like oscillatory, impulse, temporary interruptions, line current faults, and transient in linear circuits (Fig. 01-05) are developed and analyzed for applying proposed methodology for detection of PST disturbances.

Fig. 01 demonstrates oscillatory transient signal (0.2 seconds or 10 cycles) developed from switching capacitor bank circuit, with 6 levels of signal decomposition gives visualization of time-frequency version and accuracy of signal disturbances with time localization. The detail coefficients show higher frequencies from d1 to d6. These coefficients detect the power system oscillatory transients very quickly at first level.

Fig. 02 illustrates clearly the impulse transient signal response at d1 at once. d2 to d6 decompose this signal into lower frequency very slowly.

In fig 03, d1 points up temporary interruption of signal very accurately up to d3, but d4 to d6 only preserve the information of signal.

A line current fault with 20 cycles (0.4 seconds) is evident in figure 04 where d1 at 0.25 second and after 0.31 up to 0.36 exactly show the impacts of faults of line currents. Same fault current is shown at d3 and onward with lower frequency decomposition coefficients.

Fig 05 demonstrates the transient analysis signal of linear circuit which is observed at d1 level at 0.4 seconds and vanishes at o.12 seconds. This signal is shown more clearly at levels d2 to d6. .

The demonstrations of the examples with proposed technique, give an idea about magnitude, periods, and time confinement from start to finish of the transient disturbances (as suggested by IEEE 1159, 1995 [5]) together with time-frequency information simultaneously.

Due to these accurate time localizations of transient signals, it is easier to detect and classify the transient signal and its sources in an efficient way. After this information mitigation methods are easier to be suggested and implemented.

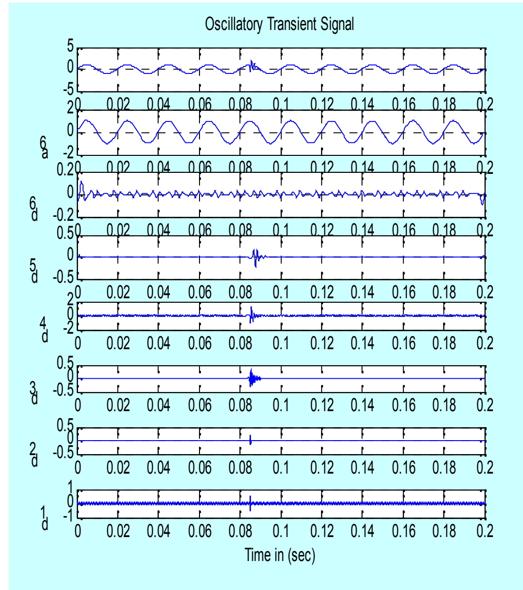

Fig. 1. Oscillatory transient signal with d1-d6 detail and 1 approximation a6 coefficients

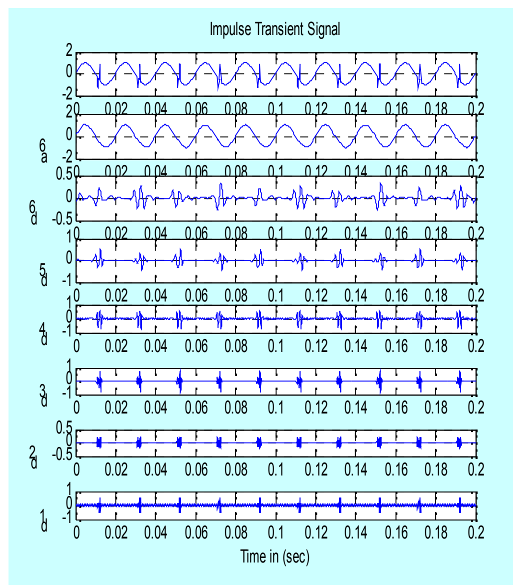

Fig. 2. Impulse transient signal with d1-d6 detail and 1 approximation a6 coefficients

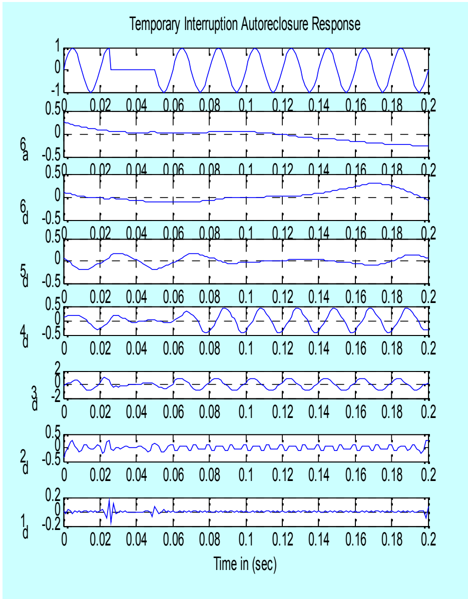

Fig. 3. Temporary interruption transient signal with d1-d6 detail and 1 approximation a6 coefficients

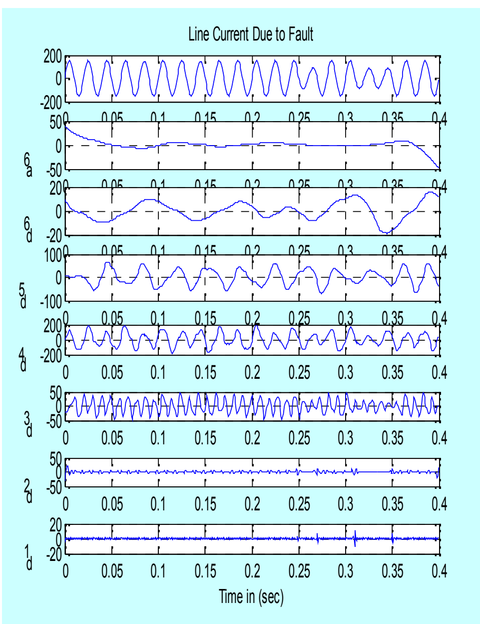

Fig. 4. Line current fault transient signal with d1-d6 detail and 1 approximation a6 coefficients

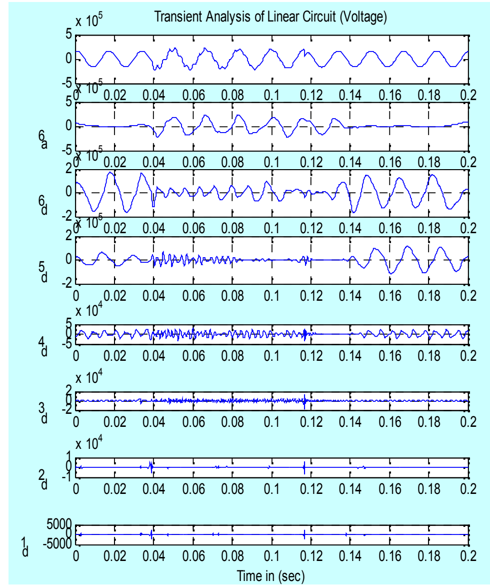

Fig. 5. Linear circuit transient signal with d1-d6 detail and 1 approximation a6 coefficients

IV. CONCLUSIONS

Simple and successfully all the major categories of PST are analyzed and detected with MRA algorithm of DWT and Daubechies 4 (db4) as mother wavelet at 6 level decompositions of signals using Matlab Version 7.12.0.635 (R2011a), Simulink Version 7.7, and Wavelet toolbox Version 4.7

The resolutions from Fig 01-05, at different ranges of scale levels, the prototype of all the types of power system transients are entirely dissimilar from each other. They can simply be discriminated from their detail/approximation coefficients and decomposition levels.

This technique from simulation results has demonstrated and established the appropriateness, potentiality and simplicity for the detection of power system transient disturbances. The method presented in this paper should be also adopted to identify harmonic loads in distribution systems.

Many algorithms have been proposed for detection and classification of PQDs. Pattern recognitions schemes are very popular solution for detection of power quality problems. The combinations of signal processing and classification tools will be the future work as an extension of this methodology.

ACKNOWLEDGMENT

The authors would like to offer their sincere thanks to higher authorities of Mehran U.E.T Jamshoro and Quaid-e-Awam U.E.S.T Nawabshah, for continuous encouragement and time to time facilities when required during this research work, which is an attempt for PhD project.

REFERENCES

[1] Dugan Roger. C., McGranaghan M.F., Santoso S. and Beaty H.W., (2003), Electrical Power System Quality, 2nd Edition, McGraw Hill Book Company, New York.
[2] M. H. J. Bollen, IEEE Industry Applications Society, IEEE Power Electronics Society, and IEEE Power Engineering Society, "Understanding Power Quality Problems": Voltage Sags and Interruptions. New York: IEEE Press, 2000. s
[3] Aslam P. Memon., M. Aslam Uqaili, and Zubair Memon "Combined Approach of Probabilistic Neural Network and Time-Frequency as the classifier for Power System Transient Problems", Mehran University Research Journal of Engineering and Technology, Vol 32, No. 4, pp. 612-622, October 2013.
[4] Math, H. J.; Bollen, Irene.; Yu-Hua, Gu. (2006), Signal Processing Of Power Quality Disturbances, 2nd Edition, IEEE Press Series On Power Engineering Mohamed E. El-Hawary, Series Editor, A John Wiley & Sons, Inc., Publication, 2006.
[5] IEEE Recommended Practice For Monitoring Electric Power Quality, IEEE Std. 159-1995.
[6] O.N. Gerek, D.G. Ece, "2-D Analysis And Compression of Power-Quality Event Data," IEEE Trans. Power Delivery, vol. 19, pp. 791-798, Apr. 2004.
[7] C. Venkatesh, D. V. S. S. Siva Sarma, "Techniques Used for Detection of Power Qulaity Events – A Comparative Stuydy", 6th National Power Systems conference, 15th-17th December, 2010.
[8] G.T.Heydt, P. S. Fjeil, "Application of Windowed FFT to Electric Power Quality Assessment", IEEE Trans on power delivery 14 (4) vol 4, pp.1411-1416, 1999.
[9] A.M. Gaouda, M. M.A. Salama, M. R. Sultan, A.Y.C. Hittani, "Power Quality Detection And Classification Using Wavelet Multi Resolution Signal Decomposition", IEEE Transaction on Power Delivery 14(4), pp.1469-1476, 1999.
[10] S. Nath, "Power Quality Assessment By Wavelet Transform Analysis", TIG, Research Journal, Vol. 01, No. 02, pp.96-101, Sept. 2008.
[11] Surya Santoso, Edward J. Powers, W. Mack Grady, Peter Hofmann, "Power Quality Assessment via Wavelet Transform Analysis", IEEE transactions on Power Delivery, Vol. 11, No.2, April 1996.
[12] S. Santoso, J. P. Edward, W. M. Grady, and A. C. Parsons, "Power Quality Disturbance Waveform Recognition Using Wavelet-Based Neural Classifier—Part 1: Theoretical foundation," IEEE Trans. Power Delivery, Vol.15, pp. 222–228, Feb. 2000.
[13] T. Lachman, Aslam P. M, T.R. Mohad and Zubair A. M, "Detection of Power Quality Disturbances Using Wavelet Transform Technique", International Journal for the Advancement of Science & Arts, Vol. 1, No. 1, 2010.
[14] John Williams and Kevin Amaratunga "Introduction To Wavelets in Engineering", International Journal for Numerical Methods in Engineering, Vo1.37. pp. 2365-2388, 1994.
[15] I. Daubechies, "The wavelet transforms, time-frequency localization and signal analysis", IEEE Transactions Information Theory 36(5): 961-1005. 1990.
[16] Rioul, O.; Vetterli, M. (1991). "Wavelet and Signal Processing", IEEE Signal Processing Magazine, Vol. 8, No. 4, (October 1991), pp. 14 – 38.
[17] Saxena, D.; Verma, K. S.; and Singh, S. N. (2010), "Power quality event classification: an overview and key issues," International Journal of Engineering, Science and Technology (www.ijest-ng.com), V. 2, No. 3, 2010, pp. 186-199.

First author

Aslam Pervez Memon was born in Hala, Hyderabad, Sindh Pakistan, on February 11, 1968. He did his B.E. and Master of Philosophy Degree with honors in Electrical Engineering (Electrical Power Engineering) from Mehran University of Engineering and Technology (M.U.E.T) Jamshoro, Sindh, Pakistan.

He is pursuing Ph.D in Electrical Engineering from (M.U.E.T) Jamshoro, Sindh, Pakistan. Currently he is Assistant Professor in Department of Electrical Engineering in Quaid-e-Awam University of Engineering, Science & Technology, (Q.U.E.S.T) Nawabshah, Sindh, Pakistan. His field of interest includes electrical power quality, power electronics, electric drives, power system, artificial neural networks and mathematical modeling and simulation techniques in Matlab, Pspice, and PSCAD. He has approximately 17 years of experience in the research and teaching. He is a member of the PEC, IEEE societies, the National Society of Professional Engineers (NSPE) and an associate member of the International Association of Engineers (IAENG).

He is the currently supervisor and co-supervisor of more than o6 students of master of engineering in Q.U.E.S.T, Nawabshah. He has been the author of more than 15 papers in different journals and conferences in the area of interest.