Signal processing of Power Line Carrier Communication (PLCC) based on wavelet packet analysis

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Abstract: Power Line Communication (PLC) happens to be a good option because of the availability of power outlets in every room of a building. However, the power conductors were installed solely for the purpose of distributing 50 Hz mains power. For data signals, they exhibit very high attenuation, variable impedance and there is radio frequency shielding. Previous research has shown that much of the noise is time synchronous with the 50 Hz mains frequency and that the majority of data errors occur during these periods of high noise. Current emphasis in power line communication is mainly focusing on two aspects, of which the first is aimed at implementing Local Area Networks (LAN's) over mains cabling, whereas the second and more ambitious one has to do with supplying telecommunication services through the Low Voltage Home Network. This work aims to suggest a novel home network power-line communication signal processing method, based on wavelet packet analysis. The major drawbacks for the PLC signal transmission include noise influence, signal attenuation, and multi-path and reflection.

Keywords: PLCC, Local Area Network, Wavelet packet Analysis.

1 INTRODUCTION

This is an age of information explosion were information content is the barometer of intelligence and prosperity to the nations. The communication traffic all across the world is ever increasing and demand to have better and faster mode of communication is as never before. In such circumstances if the power utilities could supply communication over the power-line to the costumers, it could make a tremendous breakthrough in the field of communication and power system simultaneously. With every household equipped with necessary infrastructure all people can be connected at all time and all places. Using the power-line as a communication medium could also be one of the most cost-effective ways as compared to other systems because it uses an existing infrastructure which exists to every household connected to the power-line network, unlike other mode of communication that require loads of infrastructure beforehand.

The deregulated market has forced the power utilities to explore new markets to find new business opportunities, which have increased the research in power-line communications in the last few decades. The research has initially been focused on providing services related to power distribution such as load control, meter reading, tariff control, and remote control etc; but now the commercialization of this technology is in progress and policies are being made to convergence power line, communication signal, phone, internet etc all with one socket.

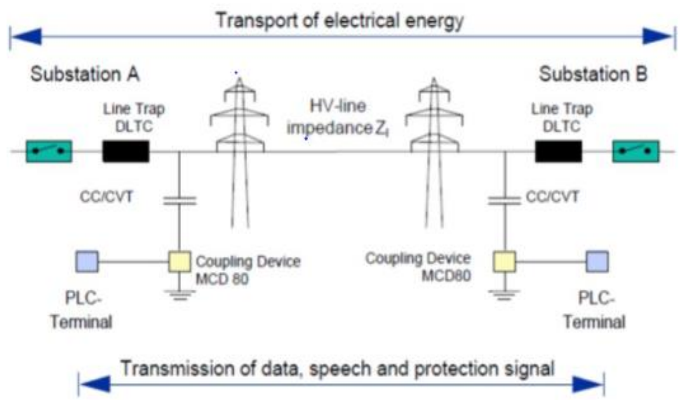


Figure 1 – Communication via power line

Since last few years the use of Internet has increased, and if it would be possible to supply this kind of network communication over the power-line in more competitive way, the utilities could also become communication providers and internet service providers which is a rapidly growing market. On the contrary to power related applications, network communications require very high bit rates and in some cases real-time responses are needed (such as video and TV). This complicates the design of a communication system yet it has been the focus of many researchers for last few years. Systems under trial exist today that claim a bit rate of 1 Mb/s, but most commercially available systems use low bit rates, about 10-100 kb/s, and provides low-demanding services such as meter reading.

2 POWER LINE CARRIER COMMUNICATIONS

Power line communication, also known as PLC, uses existing power distribution wires to communicate data. This, however, is not a new idea. In 1838 the first remote electricity supply metering appeared and in 1897 the first patent on power line signaling was issued in the United Kingdom. In the 1920's two patents were issued to the American Telephone and Telegraph Company in the field of "Carrier Transmission over Power Circuits". One would think that the long-ago conceived idea of power line Communications would be well developed by now. However, this is not the case because the power line is not well suited for data communication. There are two main applications for power line communication - one for broadband Internet access to the home and the other for home and office networking. This work focuses on using power lines for home and office networking.

Home and office networks typically use Ethernet or wireless devices. Ethernet provides High speed networking, but requires dedicated category 5 cabling which would need to be installed in the home. Wireless devices are now becoming more popular and work quite well, but provide speeds that are excessive for simple applications. Performance of wireless networks is also affected by line of sight obstructions such as walls. One major attraction of power line communication is the high availability of power outlets. The average home has an average of three power outlets per room resulting in choice of location and mobility – "as long as there is a power socket, there is a connection to the network". The high node availability is why this technology has tremendous market potential.

3. TYPICAL MODEL OF PLCC

A power line carrier system includes three basic elements: a transmission line, presenting a channel for the transmission of carrier energy; tuning, blocking, and coupling equipment, providing a means of connection to the high-voltage transmission line; and transmitters, receivers and relays. The simplified diagram of a power line carrier system is shown in figure 2

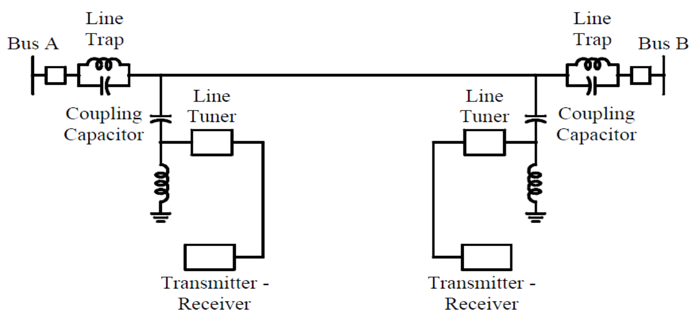


Figure 2 Typical Model of PLC

The power line carrier component library at its current stage of development includes the following components: line traps, line tuning units, coupling capacitors, balanced resistive and reactance hybrids, skewed hybrids, carrier transmitter, and dBm probes.

4. WAVELET TRANSFORM

A 'wavelet' is described as a 'little' wave, little in the sense of being of short duration with finite energy which integrates to zero Wavelet analysis represents the next logical step: a windowing technique with variable-sized regions. Wavelet analysis allows the use of long time intervals where we want more precise low-frequency information, and shorter regions where we want high-frequency information.

Figure 3 Wavelet transform of a given signal

The Figure 3 sows the Wavelet transform of a given signal. Here's what this looks like in contrast with the time-based, frequency-based, and STFT views of a signal. Wavelet analysis overcomes the limitations of the Fourier methods by employing analyzing functions that are local both in time and frequency. The WT is well suited to wideband signals that are not periodic and may contain both sinusoidal and impulse components as is typical of fast power system transients. In particular, the ability of wavelets to focus on short-time intervals for high-frequency components and long-time intervals for low frequency components improves the analysis of signals with localized impulses and oscillations, particularly in the presence of a fundamental and low-order harmonics. In a sense, wavelets have a window that automatically adapts to give the appropriate resolution.

5. SIMULINK MODEL OF PLCC COMMUNICATION SYSTEM

This SETUP illustrates a typical communication that takes place in Home network PLC environment. Here by multiplying a modulated complex signal with a complex sine wave we achieve to perform frequency up conversion. Quadrature Phase Shift Keying (QPSK) Modulator and Demodulator are used for communication. Non Linearity and Gaussian Noise is added in order to have a real time channel with many irregularities and noises which is generally every home PLC faces. The Up converter and Down converter are used as Amplifier at respective place as a signal conditioning block.

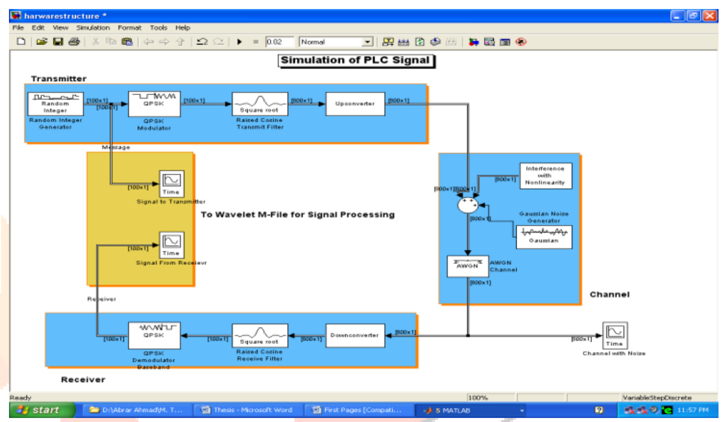


Figure 4 Simulink Model for Simulation of Signal

6 SIMULATION RESULTS

When the simulation runs, three scopes plot open. The first spectrum represents the Random signal at the sender side. The graph shows the magnitude of 3 and time range of 100Micro-second.

Figure 5 Input Signal to the Transmitter

The second spectrum scope shows the signal and the interference at the channel end on the receiver side. Because of the introduction of the noise in the channel the signal is distorted to a high degree and magnitude has also been affected.

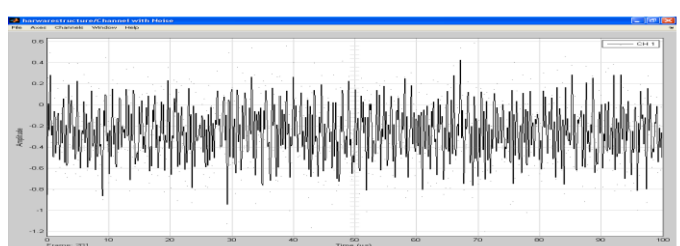


Figure 6 Signals with Channel Noise

The third scope illustrates the signal after it has been down converted back to base band at the receiver, prior to the root raised cosine filtering. Note that Here the slight change in the signal is witnessed as compared to the sending side signal. Now this is the signal required to be processed with the help of Wavelet Packet Analysis.

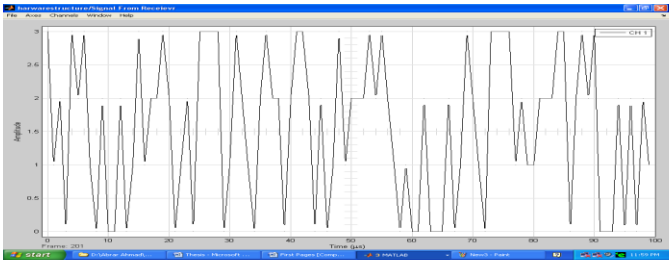


Figure 7 Signals from Receiver

6.1 SIGNAL PROCESSING ON WAVELET

Firstly we open the MATLAB Editor and write the program the prescribed MATLAB M-File format as shown bellow. There are four stages in which this MATLAB Programming is done.

1. Signal Generation
2. FFT Analysis
3. Wavelet Transform at Three Levels
4. Wavelet Packet Transform

Following is the MATLAB Editor block with M-File programming. In the Matlab, the editor is opened by navigating from the file. The Editor of Matlab supports simulation which can be viewed at any stage of the editing. After Editing the M-file program in Matlab Editor File, when this program is commanded to run which is under the Debug tag (or can directly be run by pressing function key F5), the results can be viewed and analyzed one by one at the press of Enter key.

6.1.1 Signal Generation

Here is a Signal of 50Hz is mixed with 50 Hz, 10 Hz, and 120 Hz signals in order to generate a signal that is closely polluted to the level of Home network plc signal. Following is the programming to generate the said signal.

```
T = 1/Fs;                 % Sample time
L = 1000;                 % Length of signal
t = (0:L-1)*T;            % Time vector
% Sum of a 50 Hz sinusoid, 10 Hz sinusoid and a 120 Hz
sinusoid taken as % noise
x = 0.7*sin(2*pi*50*t) + sin(2*pi*10*t) + sin(2*pi*120*t);
y = x + 2*randn(size(t));     % Sinusoids plus noise
plot(Fs*t(1:50),y(1:50))
title('Signal Corrupted with Zero-Mean Random Noise')
xlabel('time (milliseconds)')
```

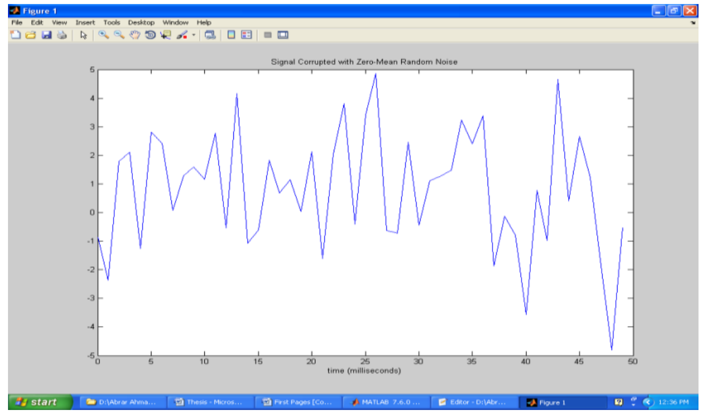


Figure 8 Signals with Noise

6.1.2 FFT Analysis of the Signal

Now the above generate signal is processed with Fast Fourier Transform (in short FFT), following is the MATLAB M-file programming to achieve the same.

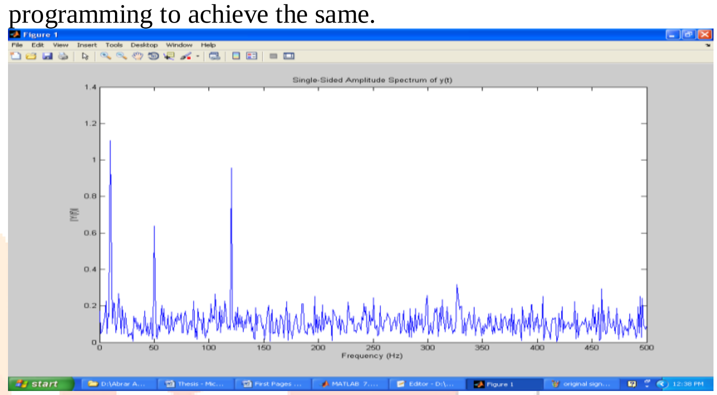


Figure 9 Fast Fourier Transform of the Received Signal

The Spectrum Shows the three peaks at 10Hz, 50Hz, and 120 Hz which is the same corresponding peaks introduced at the time of generation of signal.

4.6.3 Wavelet Analysis to the signal

After the FFT, the MATLAB Editor is caused to process the signal with help of Wavelet Analysis which takes the approximation of Signal and discard the detail (the second half) of the signal. Thus as much we raise the level; we are able to analyze the signal with closer monitoring.

For example if a signal has a frequency of 100 Hz, Wavelet at next level undertakes the fist half of the signal i.e. 0-50 Hz (approximation part), and at the next level it again divides the signal in two parts Approximation and Detail of 0-25, and 26-50 and considers only the fist half of approximation and discards the next half i.e. Detail as illustrated by the figure 4.8. Wavelet transforms carry out the processing in the same manner depending on the scale of level.

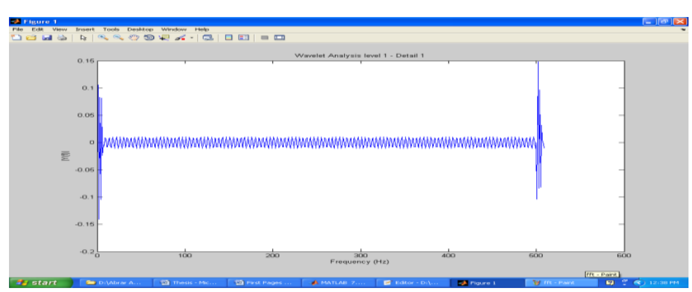


Figure 10 Wavelet Transform at Approximation level 1 (0-500Hz)

Level II

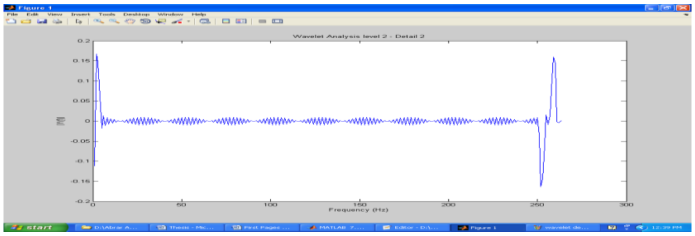


Figure 11 Wavelet Transform at Approximation level II (0-250Hz)

Level III

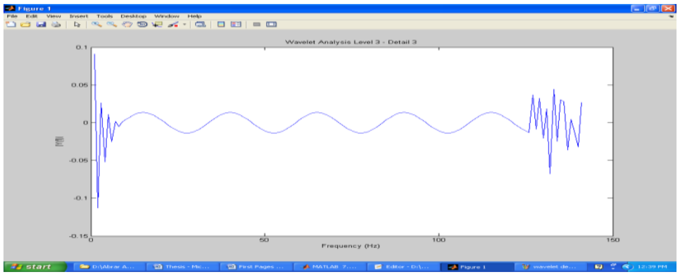


Figure 12 Wavelet Transform at Approximation level III (0-125Hz)

Here we can see that at Level 1 Signal as shown in figure 4.8, the frequency range is 500 Hz. At next kevel the signal is divided in 2 halves first 0-250 is approximation and from 251-500 as detail. As in Wavelet only Approximation is taken under consideration, 0-250 is taken for analysis at level II, at third level again the same is divided into two parts and first approximation that is 0-125 Hz is taken under consideration. In the same manner we can go to the deep down as per the requirement of the signal quality requirement.

Here we can analyze that as compare to Fast Fourier transform (FFT) which only gives the view of three peaks of 10, 50, and 120 Hz nothing more can be entertained. Because of this the signal quality is compromised. However on the other hand through Wavelet method the signal can be traced down to as mush levels required depending on the requirement of signal quality, yet we can't ignore that circuit complexity is going to increase corresponding to the level scaling. Hence it is proved here that in terms of signal processing quality Wavelet method scores well over the FFT.

4.6.4 Wavelet Packet Analysis

The wavelet packet was introduced by Coifman and Wickerhauser by generalizing the link between multi-resolution approximation and wavelets. Simply speaking, the wavelet packet transform is a generalization of the structure of the wavelet transform to a full decomposition. After FFT and Wavelet, the most comprehensive method available today for signal processing is Wavelet Packet Analysis.

The wavelet packet method is a generalization of wavelet decomposition that offers a richer range of possibilities for signal analysis. In wavelet analysis, a signal is split into an approximation and a detail. The approximation is then itself split into a second-level approximation and detail, and the process is repeated. For an n-level decomposition, there are n+1 possible ways to decompose or encode the signal. As shown in figure 12. Here we have taken the same course to process the signal. After FFT, and Wavelet method of analysis following is the MATLAB program for Wavelet Packet Method of Signal processing.

4.6.4.1 Decomposition Tree

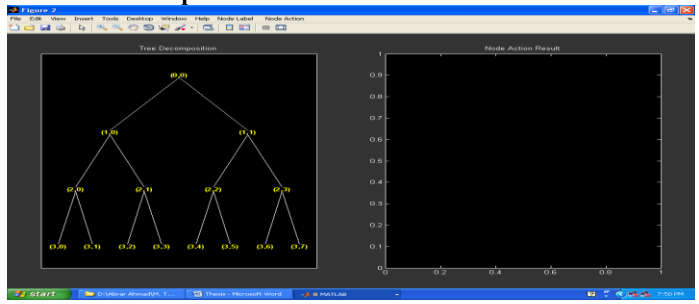


Figure 13 Wavelet Decomposition Tree

As shown in figure 13, the complete signal is divided in two parts at every level. In contrast of wavelet transform, here in wavelet packet transform both the Approximation and Detail is considered. Now as per the scaling of levels, approximations and details are being divided into two parts at every level resembling a tree. Here the whole of the signal can be viewed and no part of it is discarded as it has been done in wavelet method of analysis. In this decomposition tree the nomenclature of every node is done according to its position and frequency range. In the Matlab the signal can be highlight at any node just by clicking the respective node.

4.6.4.2 Level 0 Results

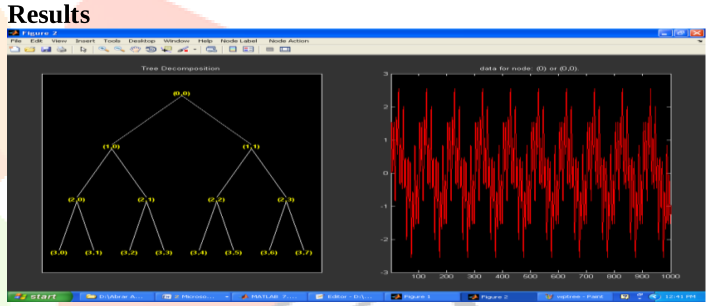


Figure 14 Wavelet Packet Transform at Node (0, 0), Level 0

At level 0, there is only one node named as node (0, 0). Here the original signal of frequency range 0-1000Hz is on display.

4.6.4.3 Level 1 Results

At level 1 the signal of 1000 Hz frequency is divided into two parts. First the approximation of 0-500 Hz and next detail of 500-1000 Hz by name of node (1, 0) and (1, 1) respectively. We can see the signal result is quite different with these two perspectives of approximation and details.

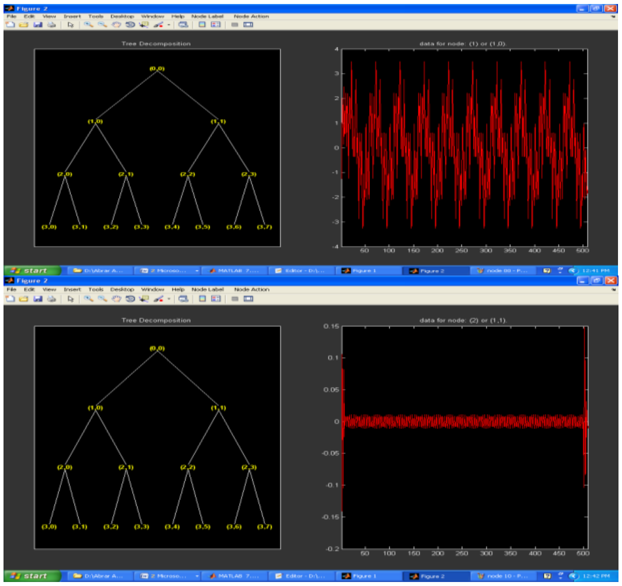
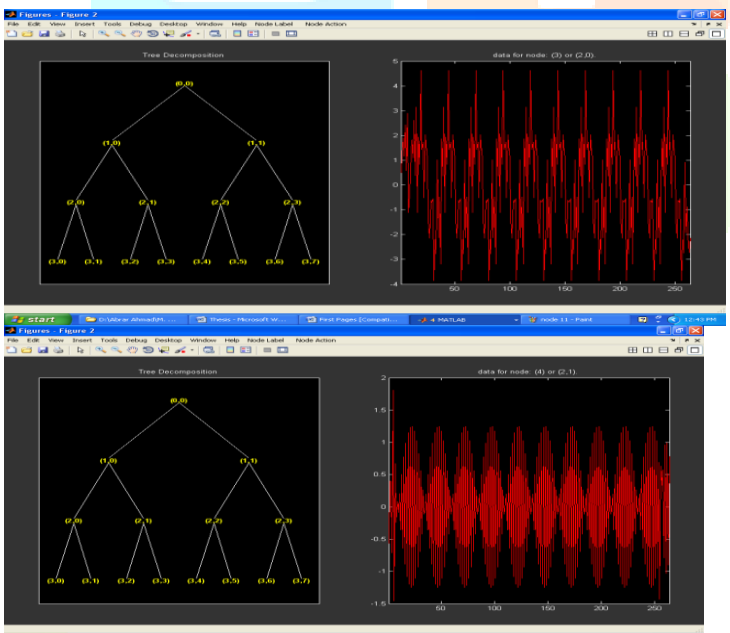


Figure 15 Wavelet Packet Transform, Level 1, Approximation at Node (1, 0) and Detail at Node (1, 1)

4.6.4.4 Level 2 Results

Here at level 2, 4 nodes are occurred: 2 from approximation part and two from detail part. Node (2, 0) and Node (2, 1) are approximation & detail of the approximation of Level 1. Similarly Node (2, 1) and Node (2, 2) are approximation and detail of the Detail of Level 1. The frequency range of 0-1000 Hz at this stage is divided into 4 parts of 250 Hz each.



4.6.4.5 Level 3 Results

At 3 level, the number nodes of rise up to eight, here all the four Approximations and Details received at the level 2 is further divided into Approximation and Detail similar to as done at the level 1 and level 2. Here the frequency range of 1000 Hz is now divided into 8 segments with all the details of nature of signal. Thus in this way we are now able to reach to finest details of the signal. With such a rich range of signal analysis, communication engineers are able to peep down to the deepest level of communication signal and the quality of signal can now be assured as compared to the wavelet method of analysis other methods of signal processing methods.

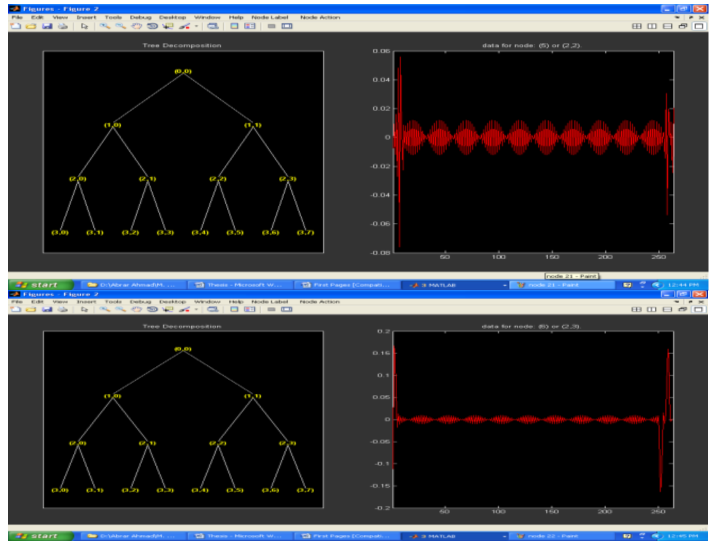
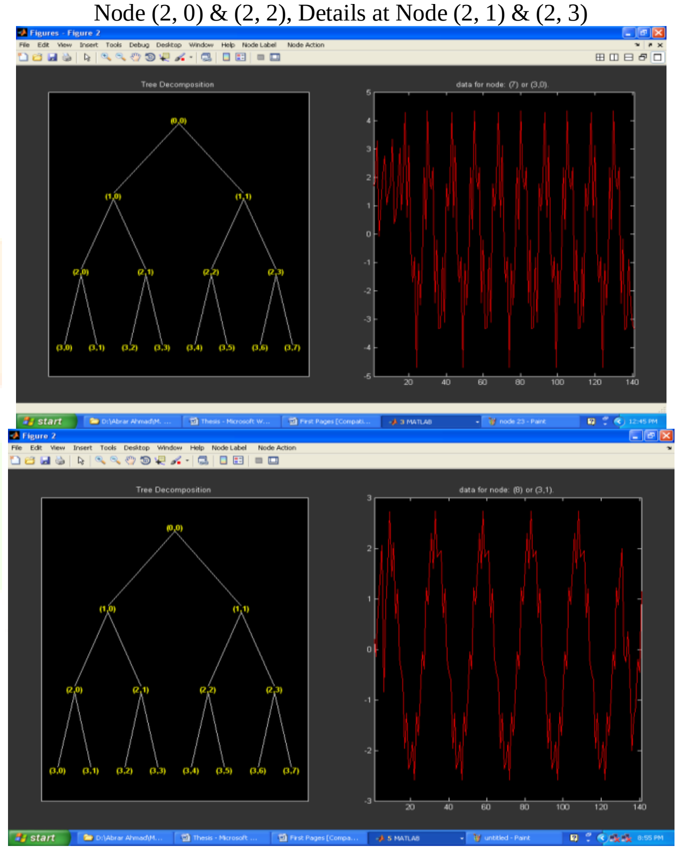


Figure 16 Wavelet Packet Transform at Level II, Approximations at Node (2, 0) & (2, 2), Details at Node (2, 1) & (2, 3)



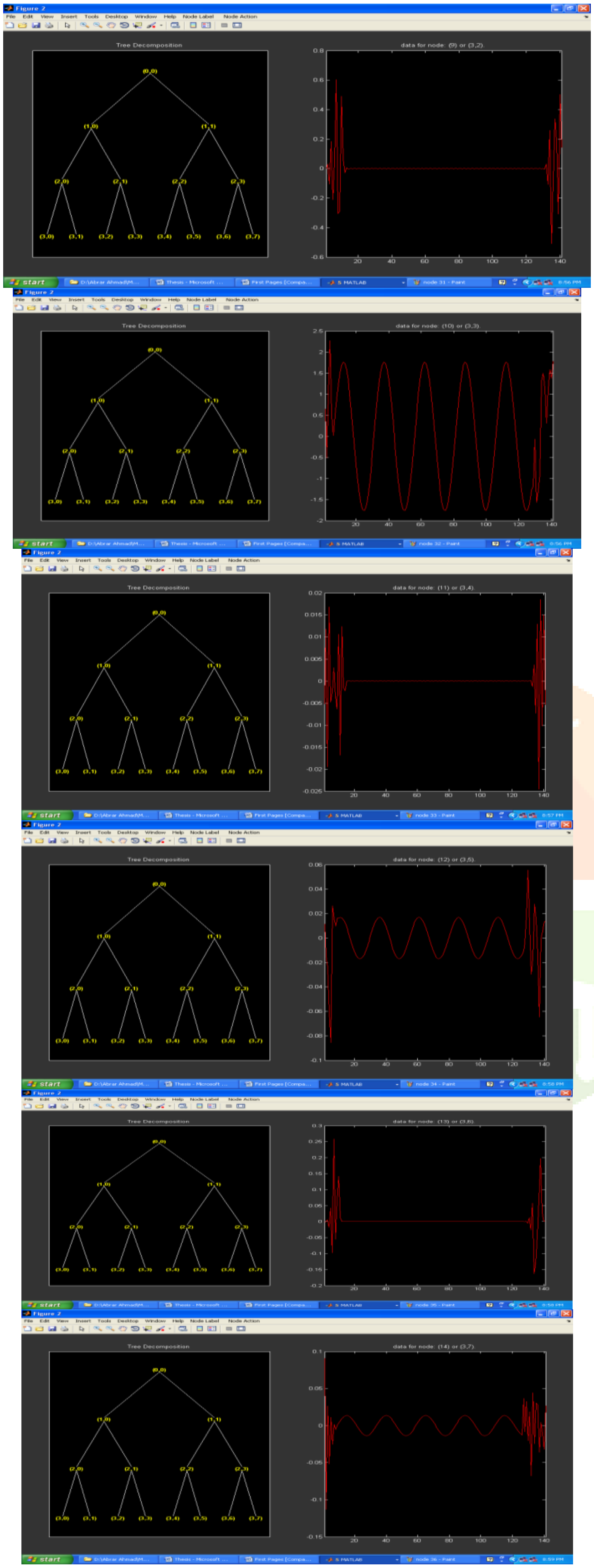


Figure 17 Wavelet Packet Transform at Level III, Approximation at Nodes (3,0), (3,2), (3,4), (3,6), and Details at Nodes (3,1), (3,3), (3,5), (3,7).

CONCLUSION AND FUTURE SCOPE

Due to the inherent characteristics of the low-voltage power line, the transmitted signal is seriously polluted for the influence of noise, attenuation, and multi-path phenomena. This thesis has proposed a wavelet packet analysis method for PLC signal processing. The reason for proposing this kind of analysis method is that the wavelet packet decomposition provides more precise frequency resolution than the wavelet decomposition. Comparison research between the wavelet transform and the wavelet packet transform based on actual sampled PLC signals presents the effectiveness of the proposed method. So far, the carry frequency in the experiments is limited to several hundreds of kilohertz. For a higher frequency, such as 10 MHz, the performance of the proposed method may depend on the frequency. Motivated by our initial research results in this work, we believe that the wavelet packet transform offers great potential as a new tool for the highly polluted PLC signal processing, and proposes a new angle to the researchers in this field.

This proposed method is primarily aimed at Home Network power line communication, which is more complex and polluting than broadband medium or high voltage plc. So it is expected that this proposed method will provide better results for medium and high voltage plc. Thus it can be considered a scope to future research.

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