Powerline Telecommunication
-- Practical Results From Field Trials

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Abstract

This paper presents some practical results obtained from several field trials undertaken by Birka Energi AB concerning the implementation of Powerline Telecommunication (PLT) to provide broadband access to households. The results presented in this paper not only serve to provide deeper insight into the functioning of the communication system, but also its limitations and potentials. This paper should be of great interest to electric utilities contemplating to introduce PLT in their own networks.

Deregulation, rapid development in the Information and Communication Technology (ICT), and also the enormous growth of the Internet are driving electric utilities to operate in a totally new paradigm. In recognition of these changes, Birka Energi has in the year 1999 implemented several field trials on PLT with cooperation with Norweb and several other industry partners with the intention to introduce value-added services to its customers. During the implementation, a lot of measurement data have been taken both during and after the installation of the system. These data were analysed and the results presented in this paper.

Among some of the interesting results to be presented in this paper are, for example, the electromagnetic emission level (EMC compatibility) and its associated regulatory framework, the effect of PLT on power quality, and also the performance of the system. Based on the practical results and also in combination with communication theories, this paper also explores the limitations and potentials of PLT.

1. Introduction

1.1 Background

As of 1st of January 1996, the Swedish electricity market has been opened up to allow end-users to their change power suppliers. The new legislation that controls the electricity market states that the same companies, which produce and trade electricity, cannot offer electricity network supply. This enables the new Network companies to develop new services based on their core business such as to better utilise their existing assets such as the extensive power distribution networks to provide broadband power line services.

There are at least two possible business strategies that the new Network companies can take, i.e., passive or offensive. The passive business strategy focuses on core business and support activities; and the network company's activities are primarily aimed at minimising cost of existing activities, and being cautious with investments and development costs. A more offensive business strategy consists of two parts. The first part focuses on developing the activities so that the company can manage the core business and support activities in a very rational way, with a view to using this know-how if activities are expanded. Unlike the passive strategy, the "rational size" can be bigger enabling the company to operate more extensive activities in the future. The second part of the strategy consists of actively finding new connections, promote new costumer-oriented products that use more electricity, widening the areas of activities through new concessions and developing certain secondary services that create added value in terms of facilitating the competitiveness of the electricity.

The latest PowerLine Telecommunication (PLT) technology that enables the delivery of broadband services via power lines, could very well fit in both strategies if proven to be successful. Firstly, the network company can become a passive beneficial owner for the right of use. Secondly, if an offensive strategy is adopted, then it is possible to develop new value-added products to the electricity customer through, for example, partnership with telecommunication operators, etc.

Since the announcement of the breakthrough PLT technology in the end of 1997 by Norweb, many utilities worldwide have conducted field trials on this new technology. In Sweden, during summer 1998, Birka Energi AB (Stockholm Energi AB then) tried the broadband power line concept at three secondary substations in Stockholm. At the same time, parallel tests were done by Sydkraft and Vattenfall.

The tests were successful and Birka Energi AB decided that the technology should be tested in a much wider scale. A partnership was formed in the beginning of year 1999 with Nor.Web, Tele2 and Sydkraft for the next step with 200 customers connected to the Internet at 1 Mbit/s in Stockholm. The project was aimed at evaluating the technology on a larger scale, market expectations, pricing principles, possible value added services, regulatory aspects and the possible framework for a open network.

1.2 Purpose of the paper

The purpose of this paper is to share the experience and highlight some of the interesting findings from the implementation of PLT systems in Birka Energi AB. Despite the fact that the company that supplied this commercial PLT system in the market has been dissolved and stopped supplying such systems, the experience and also the findings presented in this paper could still be useful for utilities planning to implement similar systems in the future. This is in view of the fact that there is still a lot of development in the PLT technology currently. Many still see that the existing wires, especially those in the premises, have an important role to play in the increasingly connected homes.

It is the authors' belief that once the technology is perfected and a good business model established, PLT technology could very well become an alternative to other similar access technology such as ADSL, etc., as well as creating a transparent network in house. This will provide users a transparent access to the information highway, reaping the benefits from the various value-added services, and at the same time keep the industry competitive.

1.3 Research Methodology

The research design that resulted in the report and subsequently this paper is combination of an extensive literature review, field study, and interviews. Literature review provides an understanding of the various underlying technologies and requirements (data communication technology, requirements of EMC and Power Quality, etc.) and helps in interpreting and analysing the field data. Interviews with people involved in the project, test customers, as well as with the related regulatory authority are important in understanding the various impacts and potentials of the project. Thus, the main data sources are therefore measurement data from the field as well as interviews with the people concerned. All the results are documented in a report [1]. This paper represents an extraction from the report, presenting the most interesting results.

1.4 Outline of the paper

This paper is divided into 4 sections. Section 1 provides the background and purpose of the paper. Section 2 provides readers with a brief description of the electric distribution network used by the PLT system as well as a description of the PLT system itself. In section 3, results obtained from the study are presented and discussed. Finally, conclusions of the study are presented in section 4 together with a brief discussion on the possible future of PLT.

2. Test System Description

2.1 Electric Network Configuration

The Swedish power transmission and distribution system are divided into at least 4 categories:

1. The national systems for 400 kV and 220 kV are owned by the Swedish National Grid (Svenska Kraftnät).
2. The regional systems for 130-50 kV are owned by approximately 10 network operators.
3. The distribution systems for 33-11 kV are owned by a large number of network operators.
4. The distribution systems for 0.4 kV are owned by the same operators as above.

The PLT-system uses the 0.4 kV distribution network to operate on. The high frequency signal is injected on the 0.4 kV side in a secondary substation and by several 0.4 kV feeders, cables and connection points, the signal is distributed to the customer site (see Figure 1).

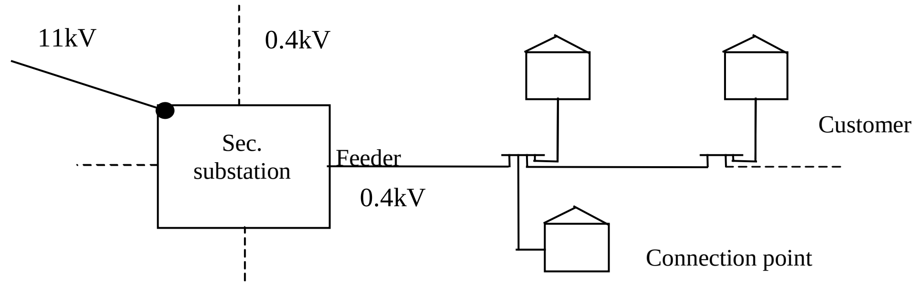

Figure 1. The electric network configuration for PLT implementation

2.2 PLT System

The PLT system studied in this report is a system that is supplied by NOR.WEB. Figure 2 below shows the different components in the system. These components are further described below.

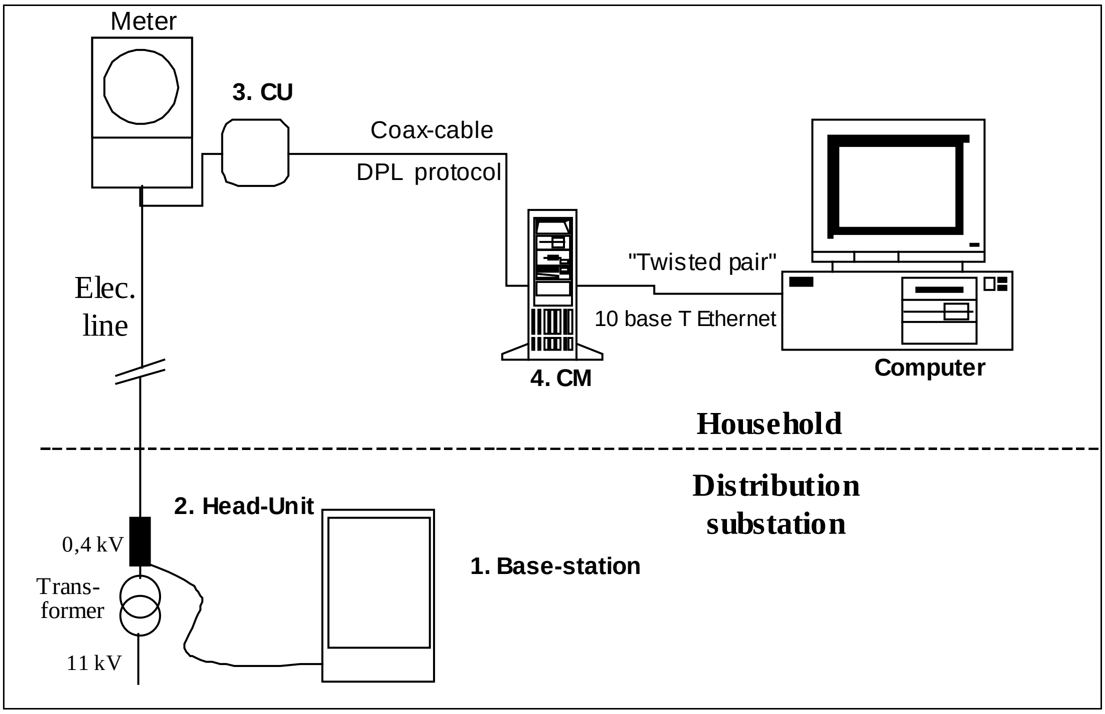

Figure 2. Components in NOR.WEB's PLT System

1. Base-station is placed in every distribution substation where PLT- system is deployed. The base-station manages the communication between the substation and the households that are connected to the substation and subscribed to the service. The communication between the base-station and the Internet Service Provider (ISP) is via a fibre-optic cable.
2. Head-unit is installed on each feeder cable to enable data signal to be injected to the feeder from the base-station. This head-unit also functions as a signal filter that separates the data signal from the AC voltage signal. Coaxial cable is used to connect between the head-unit and the base-station.
3. Coupling unit (CU) is a filter installed at every subscriber's house to separate the data signal from the AC voltage signal. It is installed before the energy meter so that the data signal is extracted before the meter. From this coupling unit, the data signal is transferred

to a PLT-modem located near the subscriber's PC. The connection between the CU and the modem is via coaxial cable.

4. PLT modem (CM) handles the communication between the modem and the Ethernet card that is installed in the computer. Specifically, the modem acts as a protocol converter that converts the proprietary protocol to the standard Ethernet protocol. The connection between the modem and the Ethernet card is via a common twisted-pair. The modem is also installed with transient protection against any potential transient on the electricity network.

Besides these four components, repeater unit is also used where the signal has attenuated too much before it reaches the customer's premise. A big disadvantage of using a repeater is that it reduces the communication speed by about 50%.

The PLT system studied uses two frequency bands. The choice of the frequency bands is made based on the characteristics of the power lines (e.g. damping, attenuation, etc.) and also to ensure as little disturbance on other radio communication equipment as possible. Each frequency band is further modulated in two different ways to adapt to the different conditions of the power lines (noise, etc.). As a result of the division in the frequency band and the different modulation used, there are a total of four possible communication speeds as shown in Table 1 below.

Table 1. Different configurations in the PLT system

Configuration	Frequency band	Communication speed [kbit/s]
PLT1L	2.2 - 3.5 MHz	250
PLT1H	2.2 - 3.5 MHz	350
PLT2L	4.2 - 5.8 MHz	410
PLT2H	4.2 - 5.8 MHz	820

Both the frequency bands used are connected to the power line. The selection of which frequency to used is determined by a pre-test done on the power line to establish the performance as well as the suitability of the particular frequency and the modulation method.

3. Practical Results from Field

3.1 On Power Quality – Harmonics issue

This section attempts to provide some insights to the question: "Could a wide introduction of PLT systems affect the power quality in the network?" Looking into the problem theoretically, no specific effect could occur, due to the fact that the PLT-system operates at very high frequencies, i.e., in the range of 2 to5 Mhz. In order to really make sure that the PLT-system does not affect power quality parameters, especially the harmonics, some measurements have been taken and analysed.

Two corresponding measurements have been initiated, one at a 0.4 kV feeder in a secondary substation with PLT-equipment mounted and the other at a customer installation (at the meter installation). In the first case, the total harmonic distortion (THD) in the three phase voltages and all three harmonic phase currents were measured. The measurement equipment, PQM (Power Quality Meter), measures all odd harmonics up to the 39th harmonic, i.e., up to 1950

Hz, both in voltage and current. At customer site, the total harmonic distortion in the single phase voltage and the single phase current, were measured.

Results from the measurements taken in the secondary substation and at the customer site are shown in Figure 3 and Figure 4 respectively.

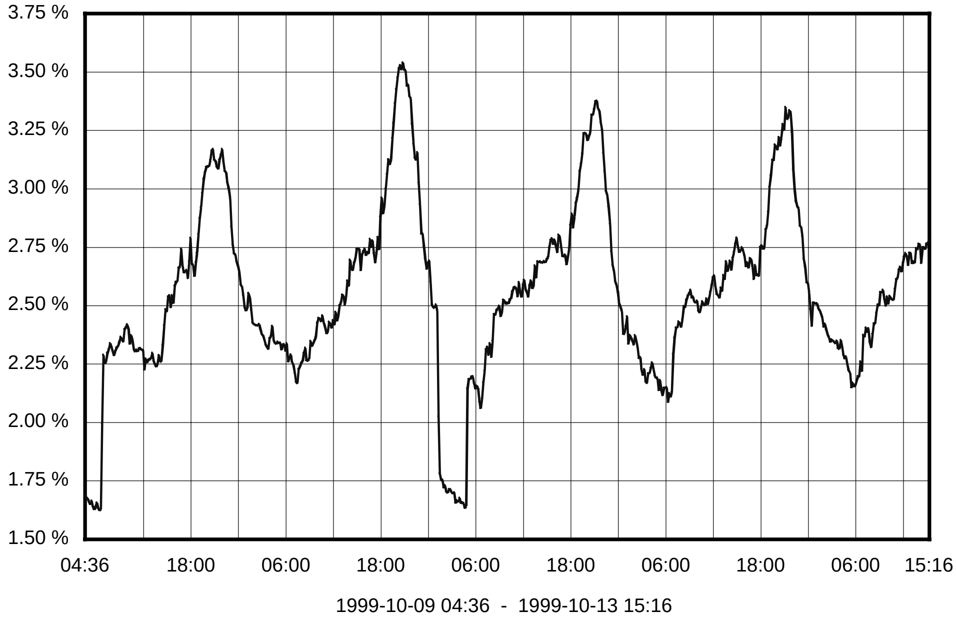

Figure 3. Total Harmonic Distortion (THD) at the secondary substation

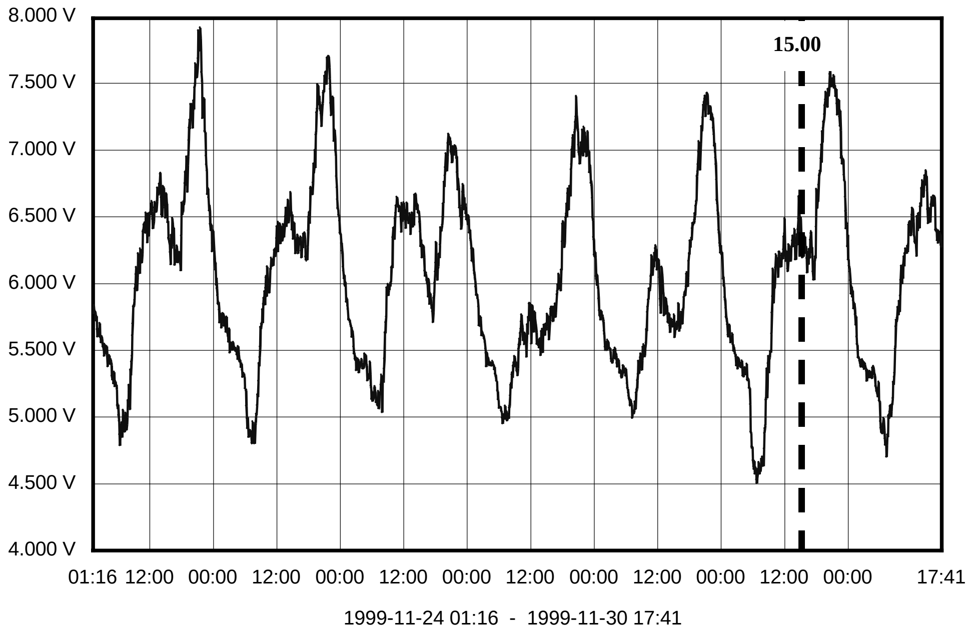

Figure 4. Total Harmonic Distortion (THD) at the customer site

From the measurements at the secondary substation, THD in voltage varied between 1.5 % and 3.5 % during a 24 hours period and the corresponding value at customer site varied between 2.0 % and 3.5 % during the same period. It should also be noted from the measurements taken at the customer site that the THD level was about the same even after the PLT system was shut off at 1500 hour.

By comparing the results above with the network operator's own recommended values for THD in voltage, which is set at a maximum of 6 %, conclusion could then be drawn that PLT-systems do not affect the distribution of harmonics in the network, when considering the "normal" range of harmonics.

3.2 On Communications – Performance issues

In order to establish the performance of the PLT system, results from the pre-test were analysed. On top of this, video conferencing was tested by using Microsoft's Netmeeting software to establish the suitability of the system for this demanding application.

The pre-test was conducted on a system where 13 customers were connected to the base-station. Altogether seven "DPL traffic-generating Robots" were connected at the customers' premises to simulate the Internet access traffic. Two applications were run to establish the performance in downloading a Megabyte file by means of FTP (File Transfer Protocol) and also the concurrent downloading of a 50 kbyte web page by HTTP (Hyper Text Transfer Protocol). These tests were carried out in the early hour of the morning for three days. Sample results from one of the test days are shown in Table 2 and Table 3 below.

It should be noted that all the values indicated in the tables are average values from four test-cycles. The tables also show a comparison between the results obtained here and the results obtained from other reference systems in Manchester, UK.

Table 2. Results from downloading file with FTP

One Megabyte Concurrent File Transfer by ‘n’ Robots;

all result values are in kbyte/s (k=1000):

DPR	**3am**	**4am**	**5:15am**	**1/2 H/L**		**Test Time**	**Number of Robots Competing**
10.9.1.37	61.90325	39.83306	27.52852	PLT2/H	averaged	3am	2
10.9.1.38	30.62728	20.62083	15.17703	PLT2/L	averaged	4am	4
10.9.1.39		29.99481	26.9703	PLT2/H	averaged	5:15am	7
10.9.1.40		30.00269	26.88896	PLT2/H	averaged		
10.9.1.42			38.79146	PLT2/H	averaged		
10.9.1.44			23.2885	PLT2/H	averaged		
10.9.1.45			23.49328	PLT2/H	averaged		
ISDN uncomp.	7.88403	7.88403	7.88403	n/a	**Manchester Reference System**		
Single DPR 1H	35.50489	35.50489	35.50489	PLT1H	**Manchester Reference System**		
Single DPR 2H	49.69	49.69	49.69	PLT2H	**Manchester Reference System**		

Table 3. Results from downloading a homepage by HTTP

Concurrent Web access for ≤ 50 kbyte Web pages; <u>all result values are in Seconds required to download one Web page:</u>

DPR	3am	4am	5:15am	1/2 H/L		Test Time	Number of Robots Competing
10.9.1.37	3.601231	3.836311	4.944793	PLT2/H	averaged	3am	2
10.9.1.38	5.76012	4.849668	6.80962	PLT2/L	averaged	4am	4
10.9.1.39		3.860155	3.326652	PLT2/H	averaged	5:15am	7
10.9.1.40		4.327579	4.111198	PLT2/H	averaged		
10.9.1.42			5.408851	PLT2/H	averaged		
10.9.1.44			4.37656	PLT2/H	averaged		
10.9.1.45			3.65927	PLT2/H	averaged		
ISDN uncomp.	11.96	11.96	11.96	n/a	**Manchester Reference System**		
Single DPR 1H	3.96	3.96	3.96	PLT1H	**Manchester Reference System**		
Single DPR 2H	2.88	2.88	2.88	PLT2H	**Manchester Reference System**		

In comparing the PLT system with an ISDN connection, the results from Table 2 showed that in the worst case, PLT system performed file transfer (FTP) at about 2 times the transmission rate of ISDN, i.e., at about 128 kbps. This happened when there were seven concurrent file transfers and when the PLT2L modulation was chosen. In the best case scenario, it was about 8 times that of ISDN, i.e, at about 512 kbps. The best case occurred when there were only two concurrent file transfers and when the PLT2H modulation was chosen.

Similarly, in the case of downloading a web page, PLT system was about 2 times faster than ISDN in the worst case scenario and about 4 times faster in the best case scenario. This is evident from the results shown in Table 3.

Besides the two common applications above, the performance of the PLT system was also tested with a more demanding application – Netmeeting – a video conferencing software by Microsoft. Video conferencing requires not only the necessary transmission speed, but also protocols that can transmit data streams in real-time and provide synchronisation for the audio and video data streams.

Video conferencing uses H.323 set of protocols, which is standardised by the International Telecommunications Union (ITU) to allow video and audio calls to be made over the Internet [2]. Among others, the H.323 set of standards defines how PCs can inter-operate to share audio and video streams over computer networks, including intranets and the Internet. By complying with H.323, multimedia products and applications from multiple vendors can inter-operate, allowing users to communicate without having to worry about hardware compatibility. The standards also specify Real Time Protocol (RTP) defined by the Internet Engineering Task Force (IETF) as the Transport Protocol. RTP is implemented on top of User Datagram Protocol (UDP) and Internet Protocol (IP). Each RTP packet contains a header that carries time-stamps, sequence numbers, a payload type, and a synchronisation source identifier [3].

The Web camera used was an Intel PC camera with USB (Universal Serial Bus) support. It has a frame rate of up to 30 frames per second and a picture resolution of 640x480 pixels (VGA) for capturing and 320x240 (VGA) for display.

The test was conducted between a PLT connected PC and another PC with a permanent 10 Mbps connection with the Internet. Both PCs were equipped with a Pentium II processor. This set-up was used to ensure that the limitations on the PLT connected system would show up. Several properties were investigated during this test and they were:

- How good is the quality of the video?
- How good is the quality of the audio?
- How good is the synchronisation of audio and sound?

One problem that cropped up during the test was that it was only possible to have “one-way” video conferencing. The PLT connected system could send out data stream but could not receive data from the opposite party. The problem was later traced to the fact that the PC connected with the PLT system was allocated with a non-standard internal IP address by the ISP (Internet Service Provider). While this internal IP address did not pose any problem to common applications such as file transfer, web page access, e-mail, etc., it did pose a problem to more demanding real-time application such as video conferencing that required a “virtual permanent connection” to be established between the two communicating parties. This problem, however, could be resolved if the PLT connected PC was given a standard IP address.

Nevertheless, based on audio and video received by the PC with a permanent 10 Mbps connection, the followings can be concluded:

1. The quality of the picture was good in general except in situation where the subject moved quickly, during which the picture became blur. This however, was not simply bandwidth related but could also due to the fact that the web camera was unable to process the rapid changes of the picture quickly enough. Besides the video capture device, other factors that could affect the quality of the picture include processor speed, Internet traffic, local ISP traffic, and concurrently running applications [4].
2. In terms of audio quality, it was very much like normal telephone conversation. Other factors that could affect the audio quality include, for example, the sound card, microphone, speakers, etc.
3. Synchronisation of the audio and video data stream was to a large extent rather good. Although there was a little delay but it did not border the conduct of the video conferencing so much.

3.3 On EMC issues

One of the main concerns on the use of PLT system is its electromagnetic emission due to the use of very high frequency spectrum as its data carrier. If not properly checked and controlled, this emission can cause disturbances to other electronic equipment that are sensitive to the emission, for example, radio, hi-fi equipment, etc. In order to minimise the emission, PLT system is not recommended to be deployed on overhead lines that are not shielded or screened.

In this section, measurements taken on the electromagnetic emission will be presented and discussed. From the measurements, we attempt to seek some insights to the following questions:

1. How much electromagnetic emission in the environment has been increased due to PLT system?
2. How far from the substation can the emission from the PLT system be detected?
3. Is there any major difference in the emission between a substation in the suburb supplying mainly single houses and a substation in the city supplying apartments?
4. Is there any significant impact of the distribution system configuration on the emission? The substation in the city has a capacity of 2x2000 kVA and has more outgoing feeders than the one in the suburb that has a capacity of only 800 kVA.

However, before the discussion, it is important to describe the equipment used and the method in which the measurements were taken. This is because we experienced that the configuration and set up of the equipment could have an effect on the measurements taken and therefore rendered meaningful comparison of data impossible if precautions were not taken. For example, it is important that the spectrum analyser used in the measurement be driven by battery and not from the AC source. This is to avoid signal and noises from the distribution network from entering the analyser, thus interfering with the actual measurement.

The equipment used in the measurement included an active antenna and a spectrum analyser. Table 4 below shows the configuration or set up used for the measurement.

Table 4. Configuration for measurement

Measurement	Maximum value of emission in one minute with & without PLT
Measuring range	1-11 MHz
Measuring bandwidth	9 kHz and 100 kHz
Measuring unit	dBm
Measuring location	Maximum radius of 75 meter around substations

Measurements were around the two substations that were installed with the PLT systems. One substation was in the suburb whereas the other was located in the city. These substations have 13 and 20 customers connected respectively.

Figure 5 below shows the various points where measurements were taken.

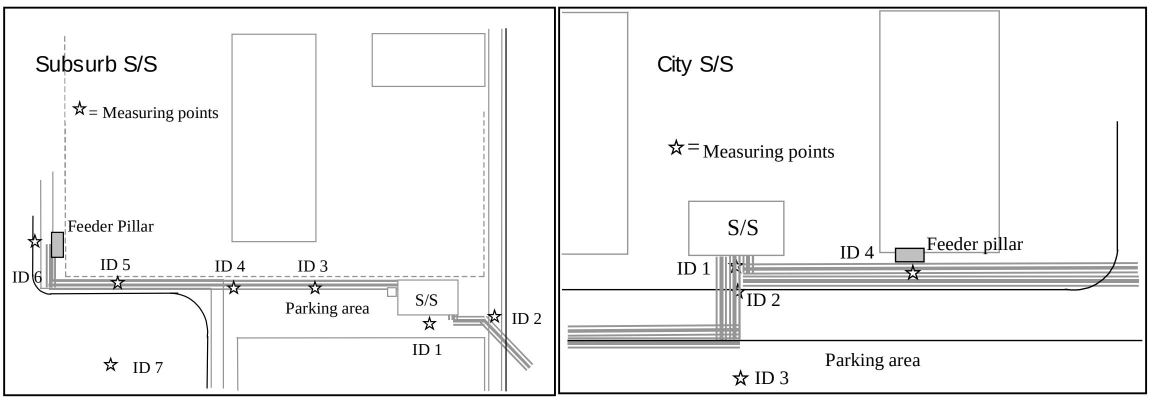

Figure 5. Measurement points around the substations at the suburb & city respectively

3.3.1 Results from measurements

Figure 6 shows the result of the measurements taken at location ID1 of the city substation. The full and dotted line curves indicate the measured noise levels with the PLT system switched on and off respectively. Location ID1 is approximately 1.5 meter from the substation.

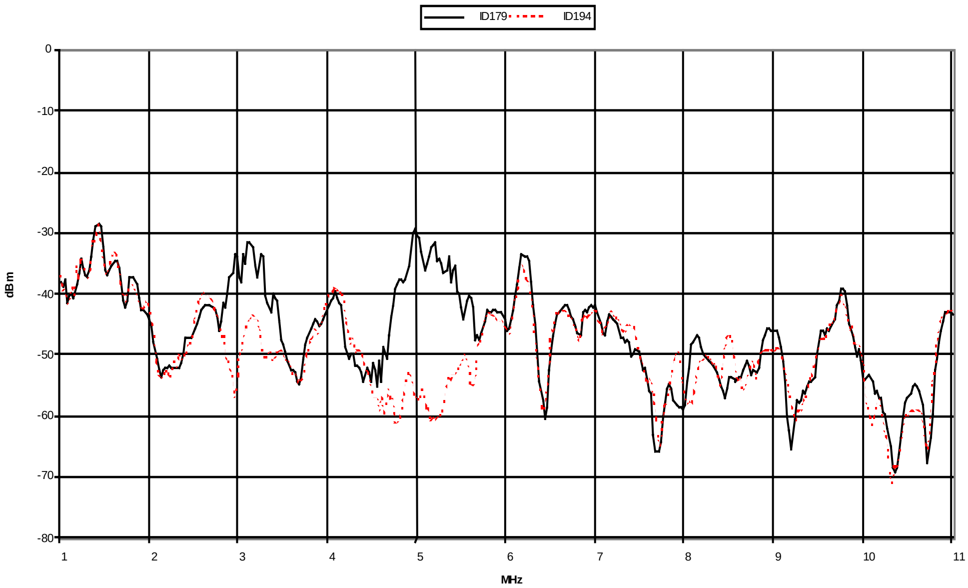

Figure 6. Noise level at ID1 (approx. 1.5 meter from substation)

By comparing the two graphs above, the emission from the PLT system (frequency centred around 3 and 5 MHz) is clearly visible. PLT system increases the background noise level by about 15 to 25 dBm. The maximum noise level at the frequency concerned is about –30 dBm, which is comparable to the noise levels at 1.5 and 6.2 MHz frequency bands. The frequency band between 5.9 to 6.2 MHz is allocated for broadcast radio in Sweden.

Figure 7 shows the result of the measurements taken at location ID 3, which is about 10 meter from the city substation. At this distance, the emission from the PLT is hardly noticeable. The noise levels with and without the PLT system on are almost the same at the frequency bands used by the PLT.

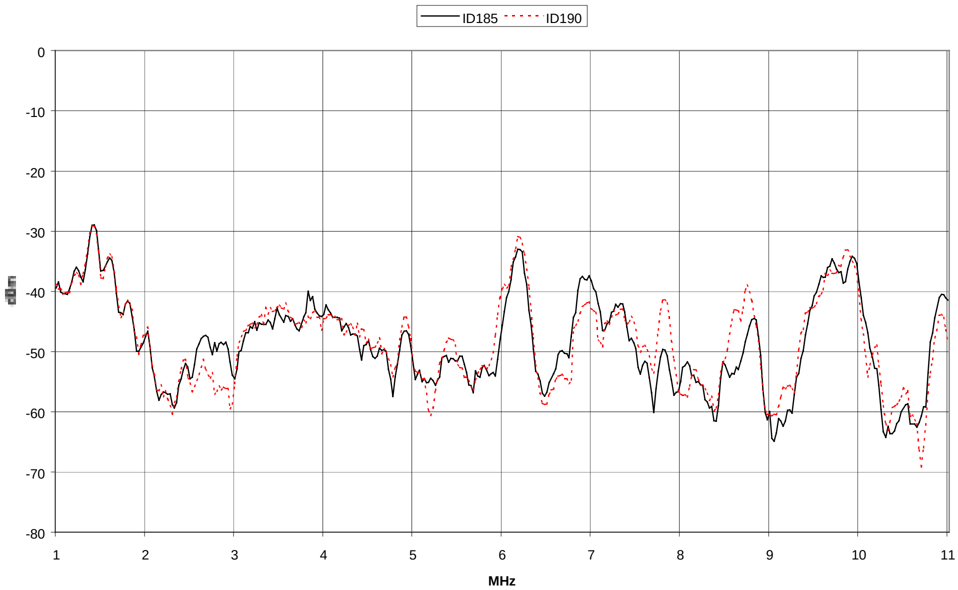

Figure 7. Noise level at ID3 (approx. 10 meter from substation)

Figure 8 shows the result of the measurements taken at location ID 4, which is about 1.5 meter from a feeder pillar having its incoming supply from the city substation. Here, the emission from the PLT system is again visible, although to a lesser extent than that at ID1. The background noise level increases by about 10 dBm at this location with the PLT system on.

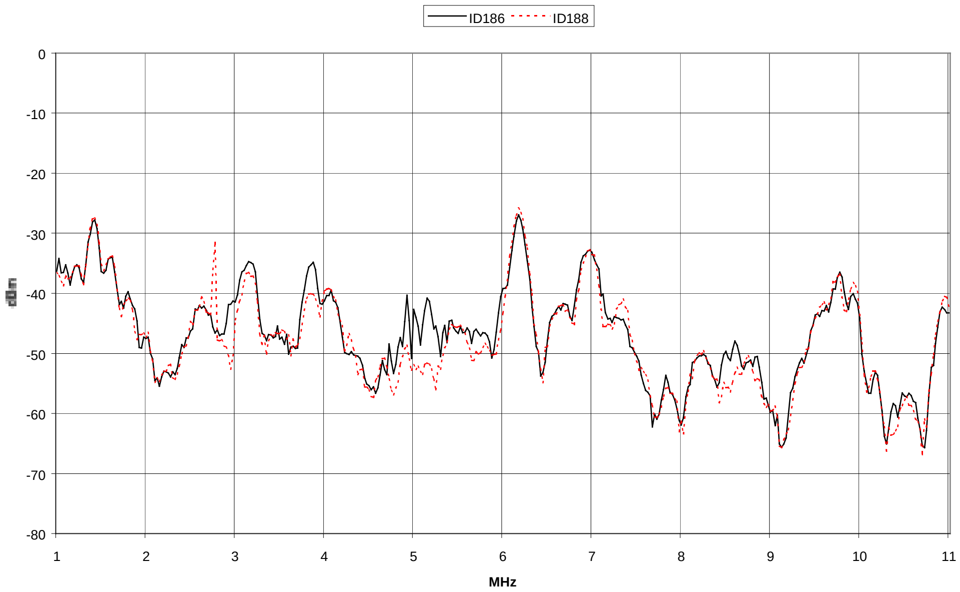

Figure 8. Noise level at ID4 (approx. 1.5 meter from feeder pillar)

Measurements taken from the substation in the suburb area also show rather similar characteristics as those described above. Thus, by combining and comparing the measurements taken at both the substations, the following conclusions can be drawn about the electromagnetic emission of the PLT system:

1. The electromagnetic emission caused by PLT system was in the region between 15 to 25 dBm. The maximum noise level at the two frequency bands used by the PLT system was about –30 dBm, which was comparable to other noise levels at frequency bands, for example, between 5.9 to 6.2 MHz used by broadcast radio.
2. This emission could be detected near the substation. However, the emission attenuated rapidly as the distance from the substation increased. At a distance of about 10 meters away from the substation, the emission could hardly be differentiated from the existing background noise anymore. But when it was near to the feeder pillar, the emission level tended to increase again by about 10 dBm.
3. When comparing the measurements from the substation in the city with that from the suburb, there was no significant difference in terms of the emission strength of the PLT system. However, the background noise level in the city tended to be higher than that in the suburb, making it more difficult to differentiate the PLT emission from other signals.
4. Concerning the configuration of the distribution system, it was observed that the larger feeder pillar that was located in the suburb tended to emit a slightly higher level of emission than the smaller one in the city. Possibly, this was due to the larger dimension of the busbar contained in the larger feeder pillar.

3.3.2 Regulatory issues on Electromagnetic Compatibility (EMC)

Regulatory issues concerning EMC are being co-ordinated in the European Communities by a directive issued by the council of the European Communities. The directive 89/336/EEC dated May 3, 1989, applies to all apparatus liable to cause electromagnetic disturbance or the performance of which is liable to be affected by such disturbance. Exception is given to radio equipment used by radio amateurs as defined in the radio regulations in the International Telecommunication Convention, unless such equipment is available commercially [5].

The purpose of the directive is primarily to promote free flow of goods within the European Communities by achieving compatible products. The directive states the actions various countries need to take as well as the process towards achieving conformity. The notion of EMC as described in the directive covers two main areas: electromagnetic disturbance and immunity.

In the directive, "electromagnetic disturbance" means any electromagnetic phenomenon that may degrade the performance of a device, unit of equipment or system. An electromagnetic disturbance may be electromagnetic noise, an unwanted signal or a change in the propagation medium itself.

"Immunity" means the ability of a device, unit of equipment or system to function satisfactory in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment.

Finally, "electromagnetic compatibility" means the ability of a device, unit of equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment.

With regard to the use of frequency band on the power distribution system and its compatibility, There exists today a standard issued by CENELEC[1]. The standard, EN 50065-1, specifies the general requirements, frequency bands and electromagnetic disturbances on the use of frequency range 3 kHz - 148.5 kHz for signalling on low voltage electrical installation.

Since the PLT system is using frequency bands in the megahertz range, it does not come under the purview of the CENELEC standard mentioned above. Instead, it comes under the purview of the regulatory body for radio communication in each country. In Sweden, it is the PTS (Post- och Telestyrelsen) that is given this task.

According to PTS, the frequency bands that are used by the PLT system are not currently regulated. However, several measurements have been taken to investigate the disturbance that could be caused by the use of PLT. The results show that the emission caused by PLT is not likely to be stronger than other similar equipment.

The comment by PTS is also supported by the results shown in the measurements taken in this study, where the emission caused by broadcast radio at frequency band between 5.9 to 6.2 MHz is shown to be at a similar level as that caused by the PLT system.

It is noteworthy that currently there is not an accepted standard limiting emission from Powerline communications systems in the frequency bands used by the studied PLT system

[1] European Committee for Electrotechnical Standardization

[6]. Proposals are being made in several countries to establish such a standard, for example, in the U.K. and Germany. Like many other countries in the European Communities, Sweden has not implemented any mandatory provisions that define in particular the permissible electromagnetic levels that equipment is liable to cause and its degree of immunity to such signals [5].

3.4 On Customers Response

A survey was conducted among those customers connected to the trial service in order to gauge the feedback of the customers. From the survey, it was found that most customers were using the Internet service for email and information search. The average usage time was about 11 hours per week.

Most customers were of the opinion that the Internet service via PLT has given them great value. First of all, the telephone line was no longer occupied while they were surfing on the Internet and the speed and performance were very much better than an analogue dial-up modem connection. Furthermore, the service was always on. Many of them have become dependent on the fast Internet service and have expressed their willingness to subscribe to the service even after the trial period with a reasonable and competitive flat rate.

The only negative view expressed by the customers was about the support services provided when they encountered problem. The primary reason for this was that sometimes, the Internet Service Provider (ISP) partner in this project was having problem in troubleshooting due to the fact that this was a new technology and very often information was needed from the supplier of the equipment.

4. Conclusions and Discussion

Deregulation, rapid development in the Information and Communication Technology (ICT), and also the enormous growth of the Internet are driving electric utilities to operate in a totally new paradigm. From a distribution network company's perspective, the possibility of utilising its existing network asset to generate more revenue by providing value-added services such as Internet access is not such a bad idea especially when there is an increasing pressure from the regulatory regime to decrease the network tariff.

In this paper, we have presented practical results obtained from several field trials on the use of Powerline Telecommunication (PLT) to provide broadband access to households. Several pertinent issues surrounding the use of PLT such as its possible impact on Power Quality, EMC, etc., are investigated. Overall, the results obtained are encouraging. In summary, it can be concluded that:

1. In terms of its effect on power quality, especially on harmonics, the measurements taken did not provide any evidence that PLT system would deteriorate the level of existing power quality. This was evidence when comparing the total harmonic distortion (THD) measured with and without the PLT system connected.
2. In terms of performance, it varied depending on the type of modulation scheme chosen as well as the number of concurrent access by the customers. The speed varied from a low of about 128 kbps to a high of about 512 kbps. The best case occurred when there were only two concurrent file transfers and when the PLT2H modulation was chosen. The connection rate was found to be adequate for performing simple video conferencing

except that a real IP address instead of an internal one was needed for 2-way conferencing.

3. On issues concerning EMC, the results revealed that PLT system tended to increase the background noise level by about 15 to 25 dBm at a distance very close to the source (about 1.5 meter). However, the emission attenuated rapidly as the distance from the substation increased. At a distance of about 10 meters away from the substation, the emission caused by PLT could hardly be differentiated from the existing background noise anymore. When it was near to the feeder pillar, the emission tended to increase again by about 10 dBm. Despite the increased in the background noise close to the source, the maximum noise level at the two frequency bands used by the PLT system was about – 30 dBm, which was comparable to other noise levels at frequency bands, for example, between 5.9 to 6.2 MHz used by broadcast radio. This finding was in concurrent with the investigation done by the PTS (the regulatory authority for telecommunication in Sweden) that showed that the emission caused by PLT was not likely to be stronger than other similar equipment.
4. On issues concerning the regulation of EMC, it is noteworthy that currently there is not an accepted standard limiting emission from Powerline communications systems in the frequency bands used by the studied PLT system. Proposals are being made in several countries to establish such a standard, for example, in the U.K. and Germany. Like many other countries in the European Communities, Sweden has not implemented any mandatory provisions that define in particular the permissible electromagnetic levels that equipment is liable to cause and its degree of immunity to such signals.
5. Finally, on customers' response, it was found that most customers were satisfied with the performance of the system. They were willing to pay a reasonable and competitive flat rate for the service should it be commercially introduced.

From the results obtained, it is quite clear that PLT does have the potential of being one of the few access technologies providing Internet access to household customers. If not for the closing down of sole company supplying the equipment, Birka Energi would have introduced the service more widely as planned.

It is noteworthy that the closing down of Nor.Web is primarily due to the uncertainty of the market for the technology and not so much in the ability of the technology to deliver the services intended. The uncertainty is caused by several reasons, one of them is the different (and often unclear) regulation imposed on EMC in different countries. Another is the rapid emergence of other competing access technologies such as ADSL, thus diminishing the window of opportunity for PLT.

Despite the set back suffered by PLT caused by the closing down of its pioneer company, it is the authors' opinion that the potential of PLT still remains. Many research and development works are still going on to further refine the technology and customers in the mass market are often looking for alternatives. The coming generation of PLT will be of higher transmission rate (possibly up to 10 Mbps) and will be more reliable. Theoretically, according to Shannon and Nyquist theorem [7], this can be achieved by using a combination of higher bandwidth, advanced digital signal processing and modulation technique.

There are several critical success factors for the next generation of PLT. Assuming that the uncertainty on EMC regulation could be resolved, future generation of PLT must be able to deliver integrated services transparently to the customers. For example, by integrating Internet access with home automation. Furthermore, PLT vendors must learn from their counterparts in the telecommunication industry to quickly co-operate with their competitors and reach a consensus so that some kind of "standards" could be established to promote and speed up product development and availability. This must happen fast before the market is being captured by a particular technology. Finally, the market conditions, for example, the costs for accessing the backhaul network and PLT hardware and software must decrease to make the business opportunity related to PLT more attractive.

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