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Integration Model for Cost-Effective Communication Infrastructure Development to Support ICT in Ethiopia (a Case Study)

SUBMITTED BY BEKELE G/MEDHIN

A Thesis IN Partial fulfillment
For The

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(MSC.I.S.)

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TOWARD INTEGRATION MODEL FOR COST-EFFECTIVE COMMUNICATION INFRASTRUCTURE DEVELOPMENT TO SUPPORT ICT IN ETHIOPIA (A CASE STUDY)

BY
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ABSTRACT

The key problems in providing communication services in developing countries like Ethiopia have been identified as using standard telecommunications network designed for high capacity and densely populated areas. The core network of this standard telecommunications is not a problem, the problem is in access network which contribute the 50% investment to the overall network, and this needs flexible technology. As a result of this the cost of telecommunication provision has tended to be at high cost compared to that of the actual income of the citizen.

In order to enhance the interconnectivity to our citizen, we need to integrate technologies and favor those which can reach end users directly. The power line network has been realized to have enough capacity and suitable for voice and data communication to support communications services in lowly populated areas where the electrical power line infrastructure already exists.

The objectives of the thesis, therefore, were to: I) explore a model(s) on how to integrate power line and telecommunications technology for a cost effective communication infrastructure; and II) assess integration model to end users that provide broadband services with affordable price. Accordingly, a cost model was built to provide residential data transmission over power line with the necessary and sufficient assumptions and cost elements inculcated in the model. The paper will discuss the trends in the provision of telecommunications services and also the use of power line network setup for communication and other services which has been identified to be provided to end users will be discussed.

Acknowledgments

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1 Introduction

1.1 General

Telecommunications services and networks form an increasingly large part of the infrastructure and the basis for economic development and social progress of any country. Digital technologies have now made it possible to distribute voice, data and video on the same communication channel therefore, enabling us to transmit more information per spectrum. The role of telecommunications has been evolving along this digitization process and the convergence of computing, broadcasting and communications. While many developing countries that made considerable progress in reforming their telecommunications infrastructure began building the foundations for building knowledge base society, a number of developing nations in sub-Saharan Africa remained far behind both on the regulatory and universal access to communications, information and knowledge fronts.

Notwithstanding its recent progress, Ethiopia is one of those countries whose historical, political and social progress and monopoly market structure led to the underdeveloped telecommunications sector **(Lishan, 2004)**.Even with improvements in recent years, the telecommunications network in Ethiopia is still among the least developed in the world until recently it was in 2003/2004 only 484,368 fixed lines in service, tele-density reached only 0.73 per cent, this is despite the 20 per cent growth realized in the last two years. With further improvements in 2004, Ethiopian Telecommunication Corporation (ETC) connected 160,000 new lines. However, there is a big gap between urban and rural areas, with about 60 per cent of telephones concentrated in the capital city Addis Ababa, accounting for less than the three percent of the total population[1].

On the other hand, the information revolution has not only changed the world, as we know it, but it has also altered its future potential. Central to all these are knowledge and information, their capacities, both inherent and catalytic to other capacities, and their extensive scope and versatility with the promise of quantum achievement.

The engine that drives the deployment of knowledge and information is what we collectively call Information and Communications Technologies (ICTs) **(UN, 2003)**. Thus, ICTs have become very important to virtually all aspects of life, activities and operations. These ranges from research and development to industrialization, from health services to entertainment, from education to systems of governance. In essence, it has become a utility that is fundamental to the basics of life. At least, these developments have affected the lives and lifestyles of people as well as the way institutions and organizations do business **(UN, 2003)**.

In the home front, Ethiopia has embarked on a process of economic transformation through modernizing key sectors of the economy including agriculture, services and the industrial sector. For the most part, these have to be Administrator and Guided by an ICT-driven competitive and market oriented development approach.

Hence, the crucial developmental potentials and opportunities of ICTs in facilitating and accelerating socio-economic development have been recognized in Ethiopia. Like other countries, Ethiopia is equally placed to take advantage of these technologies to accelerate its socio-economic development process. But, it has to be adequately equipped with infrastructure that can facilitate effective communication, dissemination and processing of information.

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[1] ***ETC Annual statistical bulletin 1996 EFY (2003/2004)***

However, one of the major problems identified in the developing countries scenario is the appropriateness of telecommunication technologies for different market segments. Most of the telecommunications systems, which have been used, are designed for use in densely populated areas. Deploying these technologies in low density areas would result in very high capital and operational expenditure per user, making services unaffordable to the vast majority of the people.

Furthermore, with the advent of ICTs the trend is toward data communications, which requires high bandwidth. This means it requires heavy investment for broadband services outlays but it is beyond the reach of the population, both rural and urban. Therefore, the cost of providing telecommunication as infrastructure is high given the low per capita income of the population and the poverty of the country. Therefore, for the development of information and communication technology in Ethiopia it is necessary to investigate a communication infrastructure that can reach the maximum number of population with affordable cost and with less investment for the country.

in order to raise tele-density in non-urban and low-density areas there is a growing need for integrating different technologies **(Anatory and Nerey, 2003)**.

Infect, the delivery of communication services is not new for the Ethiopian Electric Power Corporation (EEPCO), as the corporation has been using both transmission and distribution networks to transmit not only electricity but also data signals that are necessary to supervise its networks. Thus, the development of power distribution grid and deployment of Power line communication (PLC) technology in EEPCO and future plan have to be synchronized in such a way that technical and non-technical impediments would be minimized or removed altogether. As a consequence of this, there was a felt need to investigate the possible integration of power line communication and telecommunications technology to provide cost-effective broadband services than that of telecommunication or PLC technology alone can provide for rural communities. This thesis will investigate and propose the use of power line distribution network to be a solution to communications problems in sparsely populated areas. Hence, the Power line networks can be utilized where the telecommunications networks are not available. To this end, the research was undertaken with the following objectives in perspective.

1.2 Objective of the Thesis

The objective is to support the nation's development efforts using ICTs, and enhance interconnectivity to citizens. This thesis would attempt to find a model to integrate technologies (power line and telecommunication technology) for a cost effective communication infrastructure accessible and affordable to low income end users.

1.3 Scope of the thesis

The thesis is initiated by the researcher's desire to provide information access to citizens who are currently consumers of electricity. This means, among other things, the customers are the actual end-users of the broadband services to whom would be available the service through the existing electricity infrastructure.

Estimating of Infrastructure and service provision costs at the end user are beyond the scope of this study. The effort exclusively promotes the utilization of the electricity grid for data and voice delivery services.

From a technology point of view, therefore ,the scope of the thesis is to examine some of the pros and cons of power-line communication technology as well as non-technical issues relating to its deployment, including public policy and business development perspectives. From a service point of view, the scope of the thesis is limited to broadband data services for residential customers as well as telephony and data communication services for rural community.

1.4 Structure of the Thesis

This thesis is organized in the following format for the purpose of readability.

Materials and methods section provide broadband access technology and electricity infrastructure and how the power line communication (PLC) can be provided over it. It also discussed and provides background on the power line technologies and its architecture, advantage and disadvantage of this technology as materials for the thesis analysis. This research begins with the construction of an engineering cost model for power line communication. The spreadsheet-style models are based on capital cost data collected from the current information technology market and Ethiopian Electric Power Corporation is discussed in cost model for power line communication (PLC) and describes the specific implementations used in a certain type of network architecture the cost model. The quantitative results for power line communication and telecommunication is discussed in the **Result** section of the thesis shows the quantitative results of power line and compares the cost of the telecommunication broadband service and summarizes the cost. The **discussion** section based on the above cost analysis result, the integration model discusses and cost effective model especially for rural community will be recommended. Electric power for telecommunication services will be discussed where there is no telecommunication infrastructure in the area. The last part and the **conclusion** section will summarize the thesis and suggest issues for further research.

1.5 Own contribution

The techno-economic methodology and models for power line communication used in the thesis are largely based on the results of various researches which will be described in the material and method section of this thesis. In these research, the techno-economic aspects of power line communication have been extensively studied.

Author's own contribution to the thesis includes applying existing methodologies, tools, and models in developing a new integrated model (power line and telecommunication) of network technology to find cost effective data access network in the Ethiopian context.

2 Materials and Methods

This thesis investigates that the integration of power line communication and the telecommunication technology enables the citizen to have cost-effective broadband services than telecommunication only. Thorough, investigation will be done that PLC technology alone can enable rural communities to get telecommunication services with reasonable price.

To reinforce, this conclusion the thesis will do a separate cost-benefit analysis for each technology .For telecommunication broadband system, the thesis used a model of the existing telecommunication broadband services including customer premises equipment cost and monthly charge of different access technology to find out cost pre subscriber.

For Power line communication, the thesis used the model for an end-to-end power line system, covering low voltage and medium-voltage PLC communication to analyze a PLC system. it assumed that power companies would directly give telecommunication services to there customers. With reference to the cost issue, because, PLC technology is still in its early stages and there are few market available products, the thesis estimated the costs by assuming three scenarios: low, Medium and high cost.

In the following section, as part of materials and methods, the qualitative analysis of the existing telecommunication broadband access technology, power line communication technology, and power line cost analysis briefly introduces in relation to integration of technology. Each of the technologies has its own strengths and weaknesses both from the technological and economic perspectives.

2.1 Broadband access technology

Broadband network infrastructure consists of several segments. As new services that require broadband connectivity are introduced, access network is the segment that first becomes a bottleneck. Access network is also the most expensive segment to build and upgrade, this makes the choice of optimal technology extremely important. Cost, reliability and quality of service are important and interrelated issues in all options. For this reason, choosing a technology option depends on the cost-effectiveness and affordability of the customer.

From the technological and economic perspectives each of the broadband access technologies has its own strengths and weaknesses. The following briefly introduces the qualitative analysis of the existing telecommunication broadband access technology in relation to integration of technology.

2.1.1 **Digital Subscriber Line (xDSL)** digital Subscriber Line (DSL) is a dedicated high-speed option for delivering data over the twisted pair copper wires connecting every household to the telephone company[2]. The major difference between dial-up and DSL connections are (i) a split at the user's premises (except for DSL Lite) and (ii) an additional modem at the telephone company[3].

Starting from the customer premises, DSL modems split the connection between the customer's telephone and the customer premises equipment (CPE) that connects his or her personal computer. They send data over copper wires, encoding and compressing it at the same time that correcting, routing and monitoring performance of the connection.

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[2] **NRC (2002), pp. 10.**

[3] **There are different options for twisted pair copper wires according to the type of application and maximum data rate demanded (from CAT 1 to CAT 7) according to ANSI/EIA/TIA standard 568.**

Therefore, the wires reach a splitter that separate the plain old telephone service (POTS) from digital signals. The digital signals are received by asynchronous DSL modems (in the case of ADSL) a DSL access multiplexer (DSLAM) and, then, the connection from different DSL subscribers are sent into a single asynchronous transfer mode (ATM) line at rates of gigabits by a router or digital switch[4]. Although currently most available DSL services correspond to ADSL, there are at least the general options ADSL, DSL Lite, High-Bit-Rate DSL, Symmetric DSL, and Very-High-Bit-Rate DSL.
Among the most important DSL characteristics is that, while it can use existing telephone lines, the data rate decreases importantly as function of the customer's distance from the central offices, which also differs with the type of service. No service can be provided beyond a distance of 18,000 feet from the switching node (Newmann 2002).

For ADSL, for instance, the upstream and downstream data rates vary, respectively, from 640 Kbps and 7.1 Kbps at a top distance of 12,000 feet from the CO to 176 Kbps and 1.54 Mbps at no more than 18,000 far from it (Dodd 2002). Thus, this option is not very effective for providing services where distances tend to be long, such as in rural areas.

One solution, though expensive, for addressing this problem has been identified as investing in Digital Loop Carriers (DLC). In DLCs, the DSLAM is bundled to the capacity to convert digital signal (from T-1 or E-1 lines between customers and DLC) to optical signal (from fiber cable between the DSLAM and central office). Thus, telephone companies are connected with fiber between their

[4] **See Dodd (2002), NRC (2002)**

Central offices and the DSLAM-DLC bundle between there and DSL customers twisted pair used to increasing the availability of DSL beyond 18,000 feet.

2.1.2 **Wireless access (BFWA)** the options for wireless access to broadband Internet services are varied, among which one finds Multipoint Multi-channel Distribution Service (MMDS), Local Multipoint Distribution Service (LMDS), and Free Space Optics (FSO), unlicensed fixed wireless, wireless Mesh and satellite access. LMDS and Wireless Mesh are not covered here due to relative lower cost and advantages of other options such as MMDS and unlicensed fixed wireless (Also, LMDS presents a limited radius of transmission of 3-5 miles compared to about 30 miles of MMDS[5].

Mobility, however, has an inverse relation with available bandwidth over large geographical areas[6].This point-to-point technology uses lasers to provide high bandwidth optical connection, and is used for cost considerations mostly by businesses. For each customer premise costs can vary from $4,500 in low end to more than $25,000[7]. While it achieves rates comparable to fiber optics, its reliability strongly depends on weather, topography, foliage and signal might be interrupted by passing objects. Unlicensed wireless is a low-cost alternative that uses unlicensed portions of the spectrum (ISM 2.4 GHz or UNII 5.8 GHz)[8]. This option is a low cost alternative for last-mile for small Internet Service Providers (ISP), compared to cable modem and

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[5] **See http://www.wcai.com/mmds.htm and ttp://www2.conterra.com/images/inside/FixedBroadbandWirelessPrim.pdf**
[6] **NRC (2002) pp.284.**
[7] **www.FreeSpaceOptics.com**
[8] **ISM stands for industrial, scientific and medical radio bands as defined by the ITU, and UNII stands for Unlicensed National Information Infrastructure. See http://www.itic.org/policy/2003/fcc_030902.pdf for a detail on unlicensed spectrum**

ISP. While spectrum is unlicensed, locating antennas for obtaining continuous presents a challenge. In the case of 2.4 GHz, which has an available bandwidth of about 80 MHz, it also presents many source of interference from Bluetooth, radio broadcasting, and cordless telephones.

There are two major approaches: wireless local area network (Wireless LAN) and wireless wide area network (Wireless WAN). Wireless LAN allow connectivity at the local level within an indoors radius of about 300 ft (about 100 meters) using 802.11x (or WiFi).
It allows maximum data rates of 11Mbps or 54Mbps if using 2.4 or 5 GHz radio bands, respectively. As coverage is limited, organizations that would like to cover a wide area would have to, necessarily, place wireless access points (WAP) covering all the target area.

Wireless WAN, by other hand, are designed to cover larger areas using cellular networks that, using the present systems, allow relative low speeds with a maximum of 50 kbps and 70 kbps for GPRS and CDMA2000 (or 3G), respectively[9]. Wireless WAN, however, present higher security features and allow higher mobility.

New developments, however, introduce changes to the landscape and add attractiveness to Wireless WAN with 802.16a, or WiMax. 802.16a works in both unlicensed and licensed spectrum options[10]. It is designed for metropolitan or areas up to about 31 miles (50 kilometers), and a maximum speed of 64 Mbps, assuming 14 MHz channel. In terms of security, 802.16a supports triple-DES (128-bit) and RSA (1024-bit) encryption systems, maintaining its security above

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[9] .**GPRS: General Packet Radio Services, CDMA-2000: Code Division Multiple Access, third generation solution based on IS-95, the standard for CDMA, also known as TIA-EIA-95.**

[10] **See http://www.wimaxforum.org/news/downloads/WiMAXWhitepaper.pdf**

Wireless LAN's. It is still in development while some wireless operators still focus on 802.11x and 3G. The original purpose of MMDS was delivering video, but currently it is also used to deliver Internet, mainly for households and small business. Each customer premises requires a moderately expensive CPE compared to its performance[11].

While reliability and service quality depends on the actual number of users by cell, line-of-sight and access to rooftop installation, current CPE could allow up to 2 Mbps down and 256 Kbps up, and a theoretical radius of 20-30 miles per cell. In terms of cost, (Wanichkorn and Sirbu, 2002)) suggest that while fixed wireless would be an economic Alternative in low-density areas, it hardly competes with DSL and cable modem when line density rises above 100 per squared mile. According to their results most of the decreasing costs per location for increasing density come from SONET ring and cell site, which are very low compared with CPE and base station network equipment.

2.1.3 **Broadband Satellite access** satellite systems can provide broadband connectivity to almost any place on the planet, regardless of whether rural or urban. They are, however, more limited in bandwidth than other media for economic solutions, and have a problem of latency because of the long paths that signals must traverse between the earth station, satellite and back again. Their distance limits the bandwidth that can be sent for a given power, with the result that GEO satellites need high power transmitters and elaborate, aligned antenna systems (satellite dishes). LEO satellites were aimed at global mobile telephony, where user terminals had

[11] **See http://www.tmcnet.com/bizwatch/articles/102401c.htm**

limited power and could not accommodate accurately aligned dish aerials. LEO Satellites[12] describes moving orbits relative to the earth; So that complete coverage requires large constellations of them (the Iridium system had 77). Complex management procedures switch terminals from channel to channel, depending on which satellite is in reach at the time. MEO satellite systems take a compromise position between the features of GEO and LEO. A small volume of rural broadband provision can be accomplished with existing satellites.

2.1.4 Fiber Optics

Fiber-to-the-Premises (FTTP) present important improvements to the previously mentioned options[13]. As presented by Dodd (2002), as data in fiber optics cables are transmitted by light pulses, they are not affected by electromagnetic interference and, thus, there is no noise. It presents higher bandwidth than twisted pair and coaxial cable, with capacities from 20 Mbps to 10Gbps. Currently; however, it also presents some major problems.

First, it is too expensive both in terms of the fiber and the CPE required at residences.

Second, labor to install fiber optics is more expensive than DSL options.

Third, in the case of active star architecture (requires local electrical power that, being controlled (the provider), decreases vulnerability to the system.

The central idea of FTTH is extending the reach of fiber until reaching the customer premises. The most common architectures are passive optical network (PON), active node star and hybrid of the two

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[12] There are also Middle Earth-Orbiting (MEO) satellites, orbiting between 6,000 and 13,000 miles. GPS services use MEO satellites.

[13] FTTP is used as general term to account for different architectures such as Fiber-to-the Home, Curb, or Business, FTTH, FTTC and FTTB respectively.

approaches.[14] Regardless of the architecture, the fiber option provides higher bandwidth and lower interference than DSL or cable modem options.

The central office or head end (CO/HE) send data over the fiber by an optical line termination (OLT) device that is connected to a powered active node. Depending of various factors, this node can be located as far as 70 km from the CO/HE. Then, the active node is linked to a series of optical splitters generating several back-ends PONs (that is why it is called hybrid) and providing service to residences as far as 10 km.

Depending mainly on distance, splitting loss, and wavelength, each split can vary from 4 to 64 customers. Besides the possibilities of FTTP for providing bundled telephone, data and video in areas with no DSL or HFC service, some options allow getting fiber optics closer to the customers in relatively dense areas and, thus, increasing data speed rates for DSL and HFC[15]. It can also reduce the loop length for the former, and the number of customers per node for the latter.

2.1.5 Backbone network

Delivery of a broadband service to customers depends not only on the broadband access network, the so-called "last mile", but also on a means of connection to the mainline or backbone networks that form part of national and international data transmission networks. This connection is known as backhaul and has been called the "middle mile".

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[14] **PON shares fiber strands for distribution and uses optical splitters to manage the signal (separate and aggregate). PON architecture only requires power at the end (PON is also called point-to-multipoint).**

[15] **The idea described here corresponds to Fiber-to-the-Curb**

Backhaul is a significant issue, since high-capacity networks are normally found in large towns, and obtaining connection to them is a substantial factor in the cost of broadband services. Backhaul to the nearest available main network node can be addressed by a variety of technologies like Optical fibre DSL-family technologies cover copper circuits Radio links and Satellite links. Therefore for this PLC model this thesis used optical fibre technology for Backhaul.

The following table indicate the summary of Broadband technology discussed above.

Table 1: Summary Broadband Technology Options

◆ Technology	Capacity per user (Mbps)	Advantages	Limitations	Target Customers
xDSL	6-8 downstream 1.5 upstream	◆ Uses the () Telephone network	◆ Addressability depends on distance and number of DLCs in the loop. ◆ Service not adequate for large business ◆ Highly sensitive to electric interference	◆ Residential and SMEs
Fiber-to-the - home	From a few hundreds to 1,000	◆ Highest speed ◆ Not affected by electrical interference ◆ Neap fewer amplifiers	◆ High cost of fiber, construction and CPE ◆ Reliability issues by need of local power for active nodes	◆ Large business ◆ High-tech SMEs with Proximity to fiber ◆ Residential customers
Wireless-MMDS	Comparable to DSL	◆ No need for cables on last mile ◆ Cell radius up to 30 miles	◆ Blocking of signal from third parties (buildings, trees, etc.) ◆ Reliability affected by geography and weather conditions	◆ Residential and SMEs not covered by DSL or cable modem
Wireless - Unlicensed Free	Maximum rate for 2.4 GHz of 11 Mbps	◆ Usage of unlicensed free spectrum ◆ Alternative last-mile technology to DSL and Cable Modem	◆ Problems/Cost for obtaining reliable coverage ◆ Interference ◆ Problems for site acquisition and antenna location	◆ Residential and SMEs(specially where no DSL or cable modem available)
Broadband over Power lines (PL)	Varies up to a maximum of 2 Mbps in best cases	◆ Use of installed power lines makes it potentially disruptive	◆ Radio frequency problems generated by PL ◆ Security and reliability problems by using shared networks ◆ Limited capacity compared to other wire line options	◆ Areas with high number of customers per substation ◆ Places with low cost-effective DSL or cable modem

Source: based on Dodd (2002), NRC(2002), Newmann(2003), and McKinsey(2002)

2.2 Power line communication Technology

2.2.1 Electrical power distribution networks

Electrical power networks are composed of several different parts: power plants, transmission networks, substations, distribution networks, and customers as shown in (Figure 2.1.1.).

Distribution networks are divided into two parts: Medium voltage (MV) networks and low voltage (LV) networks (Figure 2.1.2). Medium voltage lines start from a substation, connected with LV lines via a distribution transformer. Low-Voltage (LV) lines finally reach customers. Low voltage networks consist of LV feeder lines, drop lines, Watt-Hour Meters (WHMs), circuit breakers, and electrical outlets. As seen in Figure 2.1.2, a typical network topology of LV networks is a tree-and-branch topology. Therefore, the LV network is used as a shared Medium when it is used as communication media (Figure 2.1.3.).

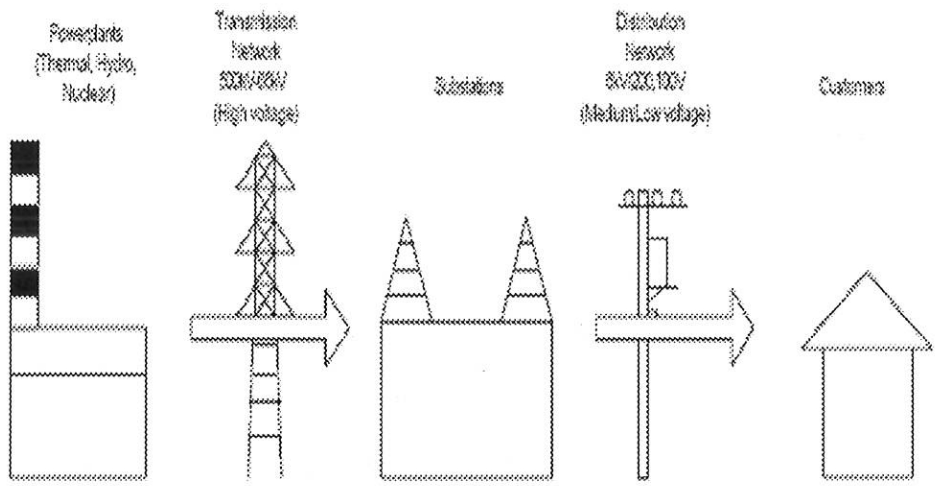

Figure. 2.1.1 Outline of electrical power network

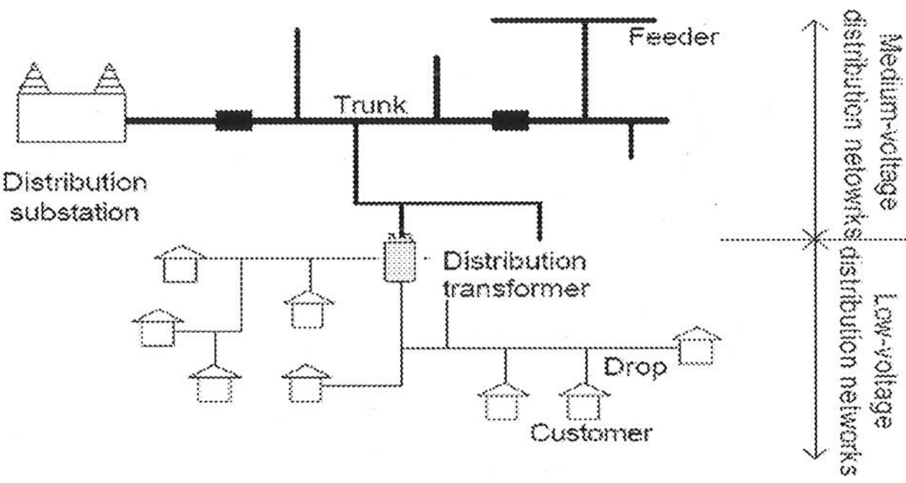

Figure. 2.1.2 Outline of distribution network (overhead)

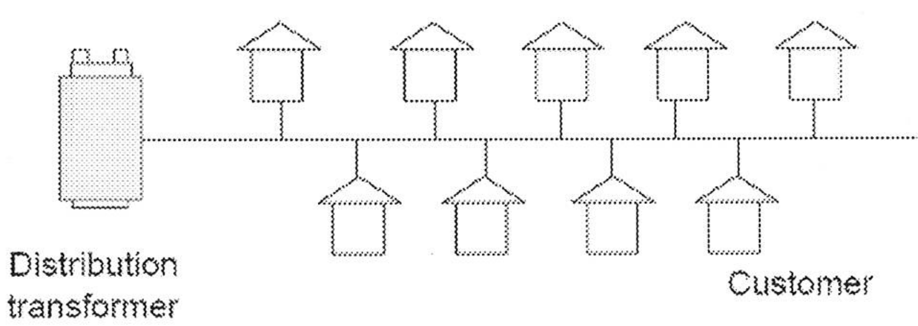

Figure. 2.1.3 Logical bus architecture of LV network

2.2.2 Electric Power supply system and Power Line Communication In recent years PLC it has also come to stand for Power Line Communication. The basic concept of PLC is to transmit information and electricity simultaneously along electricity lines as an alternative to constructing dedicated communications infrastructure.

Electrical power companies have used both transmission and distribution networks as media to transmit not only electricity but also data signals that are necessary to supervise networks. For the purpose of supervising electrical networks, the network itself is a suitable as well as economical medium to communicate these operational and maintenance data. This is because power companies don't have to use expensive leased lines and because the network connects to all nodes such as substations and relay switches, which are to be monitored (Figure. 2.2.1).

Power companies have achieved such transmission over power lines by using data signals with higher frequencies, 10 to 450 kHz, than that of ordinary electricity, 50 or 60 Hz (JEAC 314). The basic idea of PLC is similar to this practice. The difference is that PLC uses much higher frequencies than such operational use, typically varying from 1.7 MHz to 30 MHz (Gray, 2001); in order to achieve high speed transmission rates (Figure. 2.2.2). Due to such high frequencies, PLC signals hardly pass through a distribution transformer, which bridges a MV network and a LV network, according to (Dostert), signals with frequencies over 20 kHz rarely go through a distribution transformer.

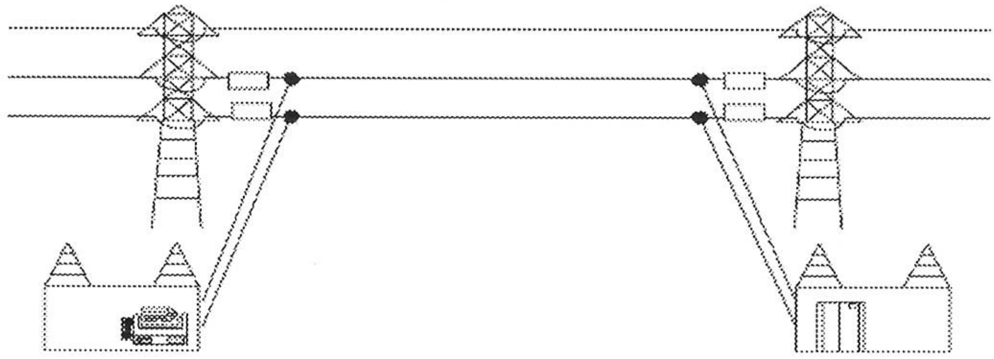

Figure 2.2.1 Communications over power lines

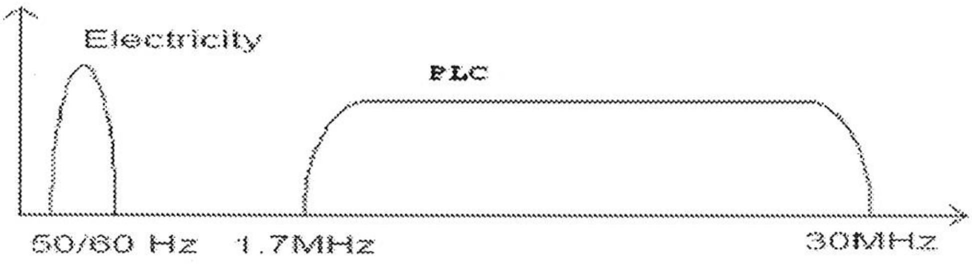

Figure 2.2.2 Sample PLC spectrum map on an electrical wire

Figure 2.2.3 illustrates, the data channel is mixed into and separated from electrical wires via a coupler inside of a PLC modem, featuring a high-band pass filter function. The extracted data signals at a substation enter an IP router and are transmitted to the Internet via the power company's based backbone networks. As for ordinary electrical appliances, according to Home Plug Alliance (HPA)[16], it is unnecessary for PLC users to add a blocking filter to each electrical outlet to protect the appliances from the data signals with high frequency through electrical wires (Mader). Although their technology is limited to the inside home application, similar things could be assumed for PLC access technology.

[16] **HPA HomePlug Powerline Alliance**, http://www.homeplug.org

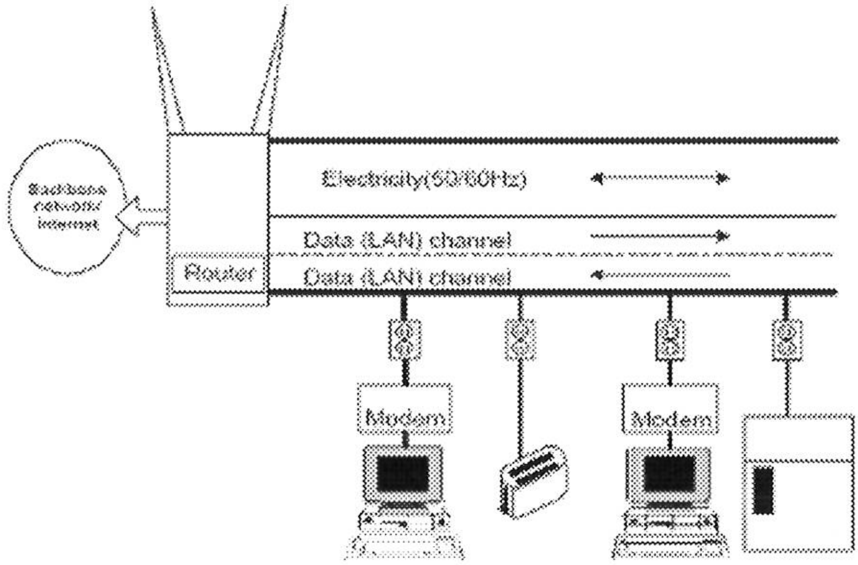

Figure. 2.2.3 Data over power lines

Power line communication uses several technologies depending on protocol layers. Popular technologies are Orthogonal Frequency Division Multiplexing (OFDM) and Spread Spectrum (SS) for the physical layer, carrier sense multi access collision avoidance (CSMA-CA) for the MAC sub-layer of data link layer (Table 2.1.1).

Table 2.1.1 Protocol layers of data access over power lines

Application layer		Same as any other technology	
Transport layer			
Network Layer			
Data link layer	LLC	LLC	
	MAC	CSMA-CA	
Physical layer		OFDM	SS

2.2.3 Network topology The general topology of a PLC network is illustrated in fig.2.2.4, where the three main parts of the network and the necessary PLC equipment are depicted.

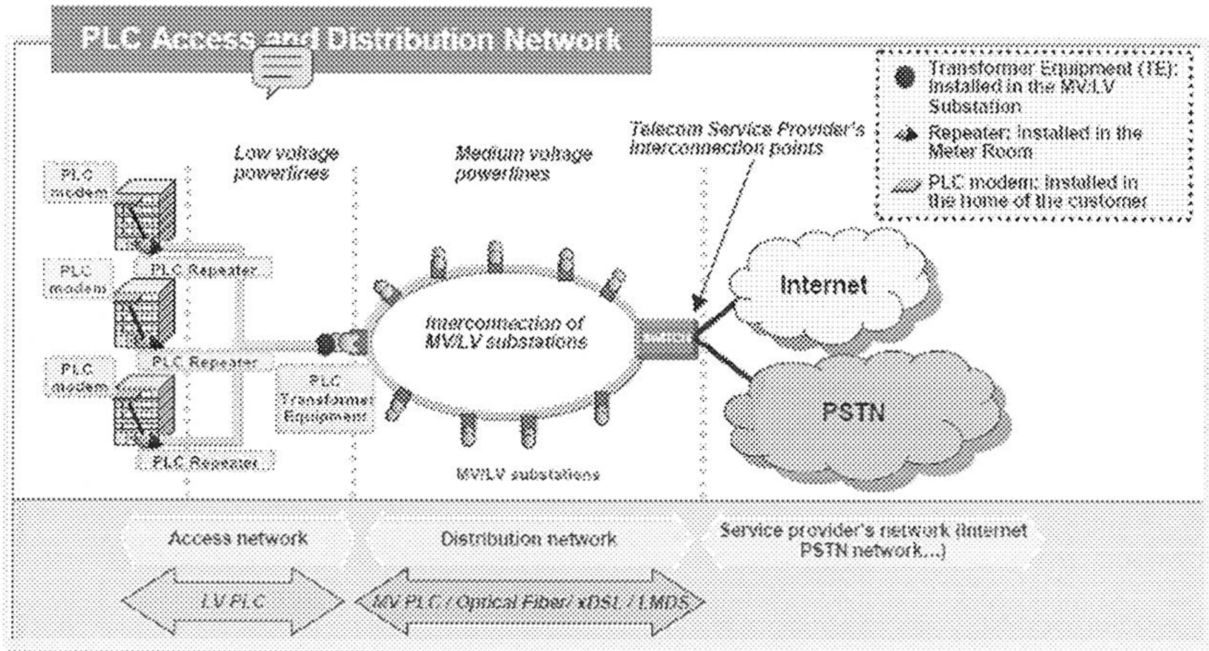

Figure 2.2.4: "PLC Access and Distribution Network". Source: Endesa Net Factory[17]

At this point, the three levels of the PLC network can be differentiated, as described below.

- **The PLC Access Network** The low voltage grid serves as the access part of the telecommunication network, where PLC technology is used. The access network interconnects the PLC modems or Customer Premises Equipment (CPE) through the low voltage power lines with the PLC Transformer Equipment (TE). The conventional electric socket becomes a connection point to telecom services. CPEs are located in the end user's home and TEs in the MV/LV substations,

[17] Endesa Net Factory PLC Access and Distribution Network www.endesanetfactory.com

which are part of the distribution network. Both aerial and underground low voltage grids are suitable for PLC technology.

The access network has two segments:

- the first one, from the CPE to the Repeater through the in-building power lines and in some cases through the low voltage grid; and
- the second section from the Repeater through the low voltage power lines to the TE in the MV/LV substation.

The power line modem could be linked to an existing LAN on the customer's premises, enabling several users to connect and share the high-speed connection; this is an option that is especially useful for Small Offices Home Offices (SOHO).

It is also straightforward to use the in-house electric network for setting up a home network, thus providing PLC signal in all rooms of the customer's house or office. The conventional socket could constitute a connection point to the PLC network.

• **The PLC Distribution Network** The distribution network interconnects the PLC transformer equipment (TE) installed in the MV/LV substations. This interconnection has a wide array of possible solutions, which can be combined as follows:

- The medium voltage power grid can connect different MV/LV substations using PLC medium voltage equipment, thus serving as a distribution network. As in the case of low voltage grids, both aerial and underground MV grids are suitable for PLC.

- Also, existing fiber optics connecting the MV/LV substations can be used in the distribution network.

- Besides fiber optics and medium voltage PLC, other technologies such as xDSL or LMDS can be used for a combined solution. Usually, the MV/LV substations are connected with one of the two typical references Ring configurations: One is using several rings in the same HV/MV substation. The other is having MV links connecting two HV/MV substations, allowing one MV/LV substation to be fed by two HV/MV substations. Both architectures have protection paths (redundancy) in case of failure.

The second architecture described above implies that fiber optic access has to exist in both HV/MV substations. The development of medium voltage PLC is of great importance.

It improves the economics and the speed of the rollout, allowing utilities to use their own existing power grids to connect the different low voltage substations, setting up a distribution network based on PLC or some PLC-fiber mixed solution.

- **The backbone Network (Interconnection to the Service provider's networks)** at some point on the PLC Distribution Network it is necessary to interconnect to the Service provider's networks in order to provide the Internet and telephony services. Other value added services, such as video streaming and multimedia services can also be set up in this segment of the network, and could be provided by the PLC operator directly. Depending on the services to be offered, there is a great deal of flexibility in the kind of telecom equipment needed for the interconnection. In general, switching equipment will be required for the selected solution.

2.2.4 **PLC Equipment** The three main types of PLC equipment are the CPE, the Repeater or Intermediate Equipment (IE) and the Transformer Equipment (TE) illustrated in Figure 2.2.5

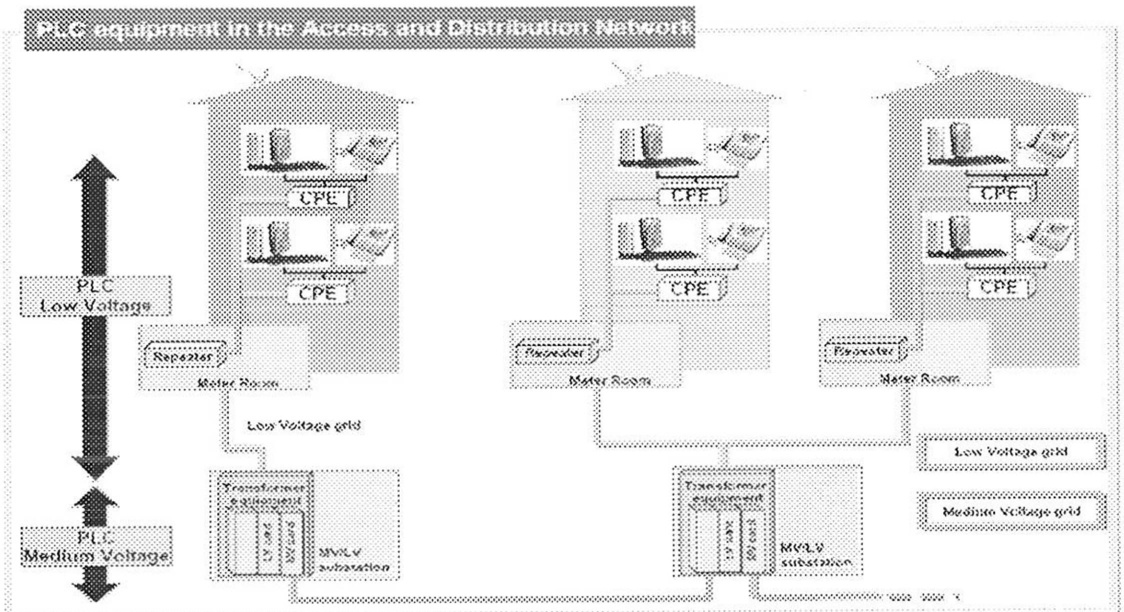

Figure 2.2.5 "PLC Equipment in the Access and Distribution Network". ***Source: PLC Utilities Alliance, PUA (2004)***[18]

• **Modem or Customer Premise Equipment (CPE)** The CPE is a PLC device (modem) located in customer's home as illustrated in Figure 2.2.6. By means of the electricity socket, the CPE receives both the telecom signal and the power supply. The CPE separates the voice and data traffic and delivers the traffic to specific customer appliances, such as personal computers and conventional telephones (via conventional Ethernet RJ45, USB, RJ-11 sockets).

There are several kinds of CPEs: CPE only for Internet (Ethernet and/or USB), CPE for Internet and Telephony (Ethernet and/or USB + RJ-11 sockets), and eventually CPEs for voice only (RJ-11). Additional

[18] Arthur D. Little
White Paper on Power Line Communications (PLC)
2004 http://www.electrosuisse.ch/es/041021_%20Whitepaper%20PLC%202004.pdf

functionalities, for the integrated Wi-Fi, have already been developed for PLC CPEs. Manufacturers are developing more competitive CPEs for voice only services and continue to improve the external design (shape, dimensions, weight, buttons, etc.) in order to make them more user-friendly.

It should be highlighted that the CPE with voice service functionalities has an integrated VoIP gateway that allows it to connect directly to a standard analog telephone.

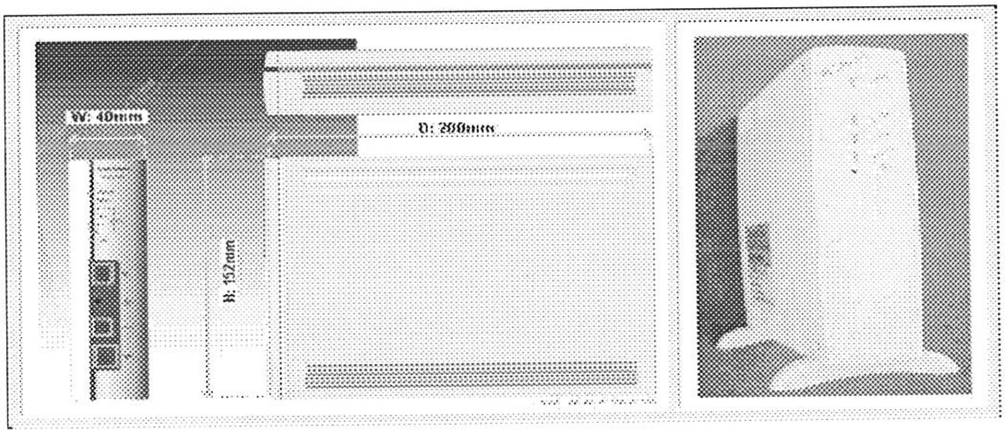

Figure 2.2.6: "Examples of commercial PLC modems (CPEs)" ***Source: PLC Utilities Alliance, PUA (2004)***

- **Repeater or Intermediate Equipment (IE)** Repeater or Intermediate Equipment (IE) Illustrated in Figure 2.2.7it recovers and re-injects the PLC signal coming from the TE into the in-house LV power lines of the end users (up to a distance of about 300 meters). It is normally installed in the meter rooms of each building or in some intermediate place in the low voltage power lines between the MV/LV substation and customer's home.

Sometimes it is used just as an intermediate node to expand coverage or improve bandwidth in difficult branches of the network (i.e. due to high channel attenuation between TE and CPE, long distances, etc.), not serving end users directly. In some cases, depending on the electrical topology, the repeater is not required, since the TE establishes a high-quality connection with the CPE.

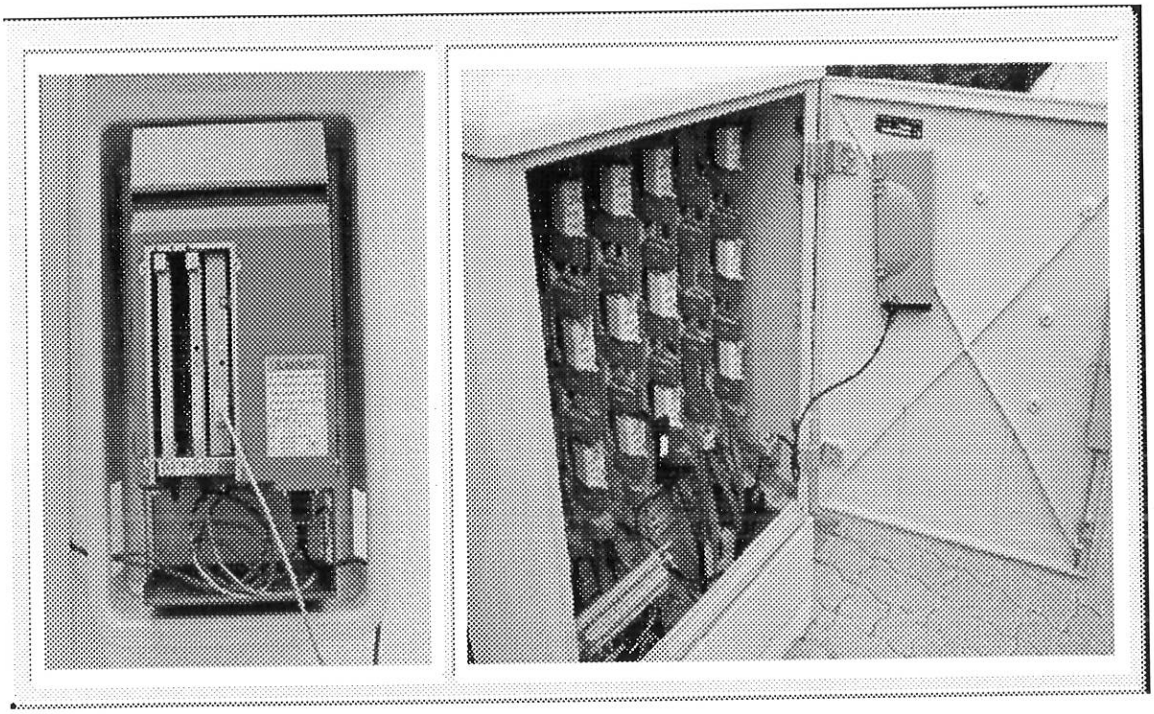

Figure 2.2.7: "Examples of two commercial repeaters in meter room and street cabinet" Source: PLC Utilities Alliance, PUA (2004) and PLCforum (2004)

- **Transformer Equipment (TE)** The TE is the PLC device installed at the MV/LV transformer substations. It injects the signal coming from the PLC distribution network (medium voltage electric cables, fiber optics, etc.) over the access network (low voltage electric cables).Downstream data are transmitted from the TE to the CPEs or to the Repeaters in a full duplex point to multipoint configuration.

Modern PLC TEs have a flexible modular configuration with several cards (figure. 2.2.8):

- LV cards, which inject the PLC signal coming from the PLC distribution network over the low voltage electric cables. MV cards, which allow the interconnection of MV/LV substations through the medium voltage grid, and Fast Ethernet or Gigabit Ethernet cards: for interconnection of MV/LV substations through conventional RJ-45 or GbE interfaces, which allows the use of existing fiber optic or other technologies for the PLC distribution network (xDSL, LMDS, etc.). The cards installed in the TE will be different depending on the role of the specific equipment in the network.

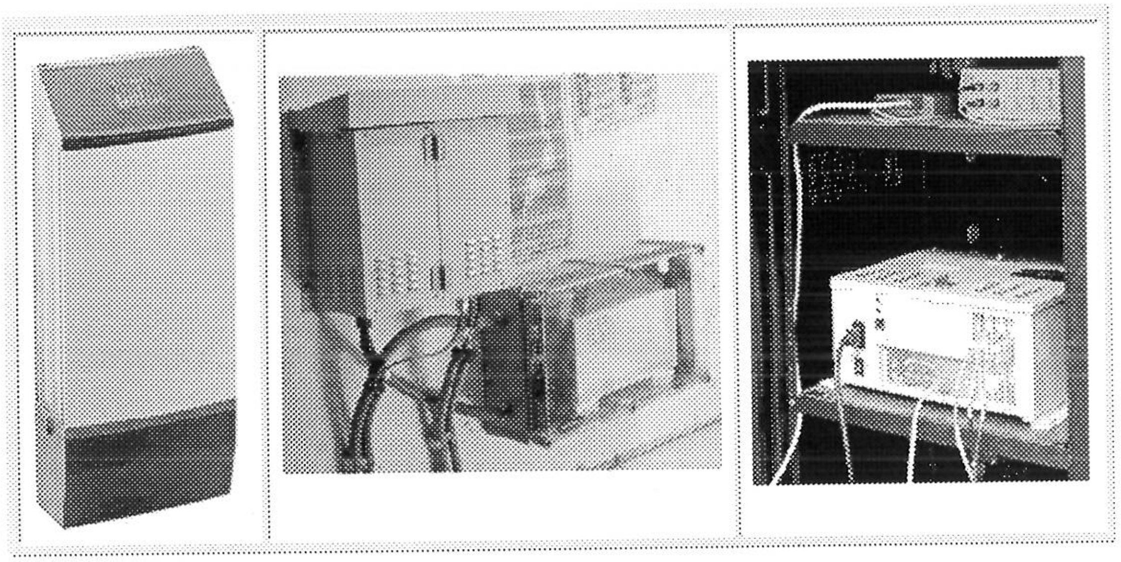

Figure 2.2.6: "Examples of TEs and installations on Transformer stations"
Source: PLC Utilities Alliance, PUA (2004)

- **Accessory Equipment: Coupling Units** coupling units are accessories needed to inject and adapt the telecommunication signal from the PLC equipment to the power lines (MV and LV).

There are two types of coupling units (figure. 2.2.9):
- Capacitive couplings inject the signal by direct contact with the power lines (for example: direct and piercing coupling); and Inductive couplings inject the signal by induction (for example: ferrite coupling).
The coupling solution to be implemented is chosen based on the quality of signal and ease of installation for the specific characteristic of the power grid of each utility and particularities of each network

node. Coupling solutions have evolved, significantly improving installation times, procedures performance, and security.

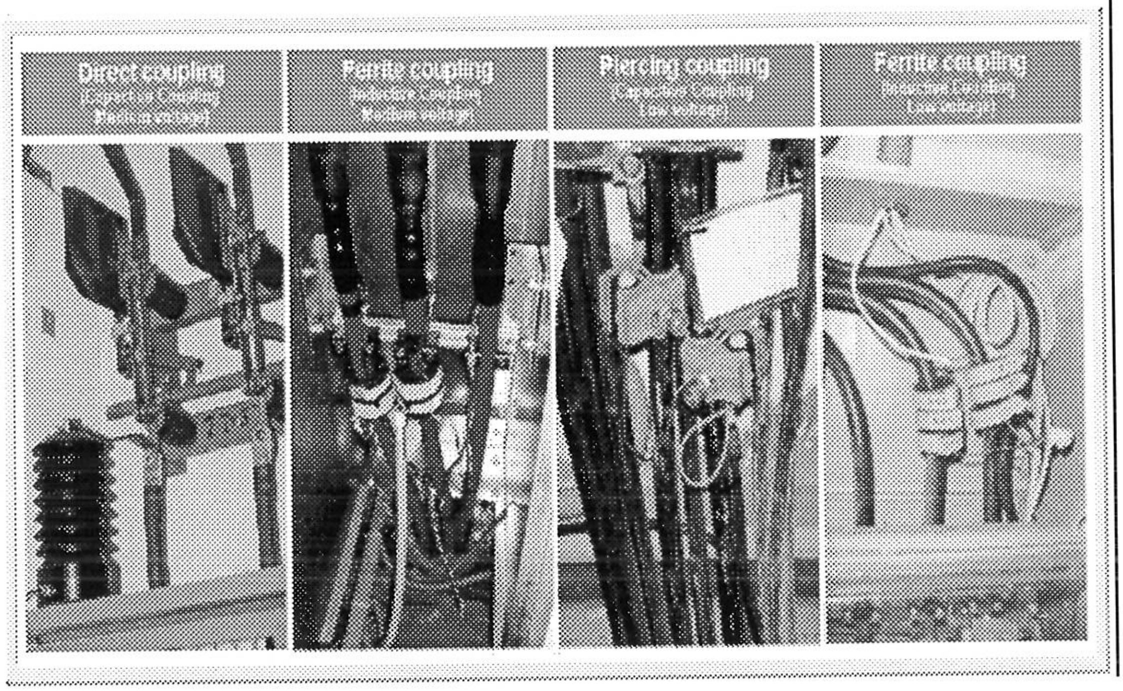

Figure 2.2.9: "Examples of Coupling Units" Source: PLC Utilities Alliance, PUA (2004)

2.2.5 **Information and communication technologies in power distribution** this section presents the convergence between telecommunications and power distribution and its effect for the involvement of electric utilities in delivering advanced telecommunications services.

As in every industry, electric utilities increasingly use information and communication technologies. While most electric utilities enjoy the benefits of monopolies, they face several problems likely to be addressed by an adequate use of information and communication technologies (ICT): monitoring variations in demand and load usage, electric power theft and reliability and security of their grid, which have gained in importance.

There are two solutions for addressing these issues: Automatic Meter Reading (AMR) and Supervisory Control and Data Acquisition (SCADA).

- **Automatic Meter Reading(AMR)** The technology behind AMR is available since the early sixties, when AT&T carried out trials in partnership with Westinghouse and some utilities (Tamarkin 1992). AMR are used for many purposes, including theft detection, outage management, customer energy management, load management, on/off services, distributed automation, in that order according to (Johnston, 2003).

In general, AMR systems have three major components: the meter interface unit (MIU), communication system, and central office system. The meter interface unit (MIU) collects data from the meter, controls electronics and manages communications. The communication interface allows two-way data transfer. If needed, the MIU might share capacity among different types of demand reading (electricity, gas, or water). The MIU takes the readings from meter dials and transform them into digital format.

The communication system is responsible for data transmission between central office and MIU. The options for data transmission are telephone networks, HFC, fiber, wireless and power line. Unfortunately, there is no best option for setting up the communication system.

The third component is the equipment required for the central office systems (COS). COS requires modems, receivers and data concentrators, controllers, host upload links, and hosts (servers, routers and personal computers). Their function is to assist the central billing computer and other data or connectivity “clients” in providing the data they need from the installed user base. Here one is to understand “client” as any other application or service that requires users’ information or connectivity. The first gain in efficiency by implementing AMR, however, is reduction of errors, elimination of estimated-based billing, and elimination of manual meter reading (Black and Ilic 2001).

• **Supervisory Control and Data Acquisition** As its name indicates, Supervisory Control and Data Acquisition (SCADA) focus on supervisory functions of an electric utility information system. As a result of the terrorist attacks of September 2001 and the August 2003 blackout, SCADA has gained increasing importance to guarantee the reliability of critical infrastructure (Gunnerson, 2003 and Symantec, 2003).
They work as a remote control process for monitoring, operation and maintenance of energy infrastructure by collecting data from the grid and substations. They are usually implemented in the high-voltage transmission and distribution levels (Cardell, Ilic and Tabors, 1998). There is a Central Monitoring System (CMS) in the central office and, in some cases, remote substations. The objective of CMS is controlling the server and routing communications of the SCADA network.

The substations are equipped with Remote Terminal Units (RTU), a host and modem for managing communications. The RTU works as an input/output device responding to the commands from the CMS, and can also perform programmed control functions allowing local decision-making without the need for checking with CMS. Each RTU is connected to meters, Load Tap Changers (LTC), equipment monitoring, and relays. All these devices are nodes in a local area network (LAN) managed by an IP router or a digital circuit access.

Connection to Load Tap Changers (LTC) is critical. The LTC is a mechanical switch in power transformers responsible for regulating the voltage ratio without interrupting load current. As LTCs are the most expensive and vulnerable device in transformers and substations, causing more failures than any other component on a transformer, there is need to closely supervise and control their behavior and performance.

Additionally to substations, the CMS can gather data from field RTUs, re-closers, and meters and switch controllers at different places on the grid. This can be done directly to the CMS, or indirectly using a substation as a hub. In order to gather data, all device and controller must be equipped with an Intelligent Electronic Device (IED) which is any device that included one or more processors that can control and communicate data with a third party. In total, a SCADA system might have between 30,000 and 50,000 data collection points, according to Symantec (2003). This system is so important, that most companies have deployed its network separately from other systems. As in the case of AMR, the communication network can be deployed on a combination of power lines, wireless, twisted pair or fiber.

With these considerations and given the above preliminary background, of broadband access technology and power line technology the thesis next analyzes the integration of electricity infrastructure and telecommunication for a cost-effective communication services. To do this it need to do cost analysis for power lien communication. It uses the engineering cost model and methodology, which was used in (Reed, 1993), (Gillett, 1995), (Sakai, 2003) and (Tongia, 2004). The first one deal with the question of integration: are there economies of scope or scale for either cable or telephone companies to provide multiple services over a single 'Integrated Broadband Network?'(Reed, 1992) The second answers the specific question as to which is more cost-effective, the Internet over telephone networks or the Internet over cable networks (Gillett, 1995). The third answers the question as to which is a cost-effective the Internet Service over power lines or other existing technology (Sakai,2003)and the last one uses techno economic analysis for broadband over power line network (Tongia, 2004). For this analysis accordingly:

The cost analysis a data have been collected from (EEPCO) by interviewing relevant employee which have relevance for the thesis on existing Ethiopian electricity infrastructure, topology number of customer and power line communication uses and future plan of expansion in EEPCO are considered.

With reference to the power line communication cost issue, because, PLC technology is still in its early stages and there is little market available products, the costs are estimated by assuming three scenarios: low, medium, high. With spreadsheet-style models based on cost data collected from the current information technology market and from power line communication vendors.

Using the software tools called decisionPRO version 4 for low, medium, high scenario for power line communication cost has been calculated in the following section.

2.3 Cost Model for power line communication (PLC)

The purpose of this section is to provide a brief and simple cost-benefit model for applying power line communication solutions to provide services for various communities, and then comparing their costs. This, it must be stressed, follows a very simple approach and so generates only "ball-park" costs, for comparative purposes only. Though these figures will give a good idea of which solutions are worth considering in a given context.Fully fledged business plans will require much more detailed modelling in the future.

2.3.1 Basic idea of the model

This model is used to find the cost necessary to provide residential data transmission over power lines. This chapter explains the assumptions and the cost elements in the model. The model looks only at the marginal cost of providing broadband services.

The model does not include the costs of providing traditional electricity service. Also, the model does not include power line infrastructure cost investments that are used for power service. Only the portions of the infrastructure that are specifically required to support PLC model and service are concderd.

It is difficult if not impossible to specify and obtain exact cost data of PLC as the technology is still in its early stages. Therefore, this thesis sets a price range as the substitute for the actual cost. Prices are collected from price lists available from vendors' websites. Since the market for networking equipment is extremely competitive and digital technology continues to advance rapidly, cheaper and more capable products are constantly appearing. This chapter details the model's inputs and variables, after first discussing the assumptions of this model.

2.3.2 Assumptions

To build a cost model for PLC, there are several assumptions:

- It is possible or likely that in practice some of the values used are incomplete, due to the simplicity of both the model and its input data.
- This model assumes that the practical equipment required is installed. This means that the low-voltage transformer equipment is reachable with power line system behind a particular transformer.
- This thesis assumes that Ethiopian Electric Power Corporation utilizes Ethiopian Telecommunications Corporation's fiber to connect the powerline distribution substation to the distribution transformer network.
- Electric power line will be installed in each household regardless of ICTs access
- It also assumes the customer, substation and distribution transformer in Addis Ababa of Ethiopian Electric Power Corporation for this model.

2.3.3 **Business model** There could be three possible types of business models that may enter the market. The characteristics of each type of PLC service provider are discussed below.

- **The Service Provider model** In this model, a PLC solution is installed on the power company's network. The power companies act as a service provider to provide broadband service to its customers. The power companies also operate the infrastructure. The power company is now in a position to offer the same kind of services that are offered by the telecommunication service provider whereby end users purchase delivered Internet and other telecommunication services from the power company which, in turn, purchases backbone/Internet service from the Service provider.

- **The Retail model** In this model, a PLC solution is installed on a power company's network. Here, the power company in turn leases its network to another party that will be responsible for providing and managing the PLC service to the end users.

- **The Wholesale model** This model is almost similar to the Retail model whereby a PLC solution is installed on a power company's network, the power company in turn leases its network to another party e.g., Company A. However, unlike the Retail model, Company A wholesales the bandwidth to other communications service providers, ISPs etc. As such, Company A does not directly provide any type of services to the end users; it leaves the communications service providers and ISPs to interact with the end users. In this model, the end users purchased delivered Internet services from the Communications service providers/ISPs.

2.3.4 **Network architecture and facilities** There are four kind of network architecture in the power line communication (Sakai, 2003) with there own advantage and disadvantages. For this thesis the following are used based on their advantage to build the cost model in Ethiopian context .

- **Medium-voltage (MV) & LV line network architecture (pure PLC network)** this architecture utilizes whole distribution networks including MV and LV networks (Fig. 2.2.10.). A signal will be transmitted from a customer to a distribution substation via a LV network, a bypass-transformer device, and a MV network. At the station, the signal would be separated from the power lines and would be transmitted to Internet through power companies' backbone network.

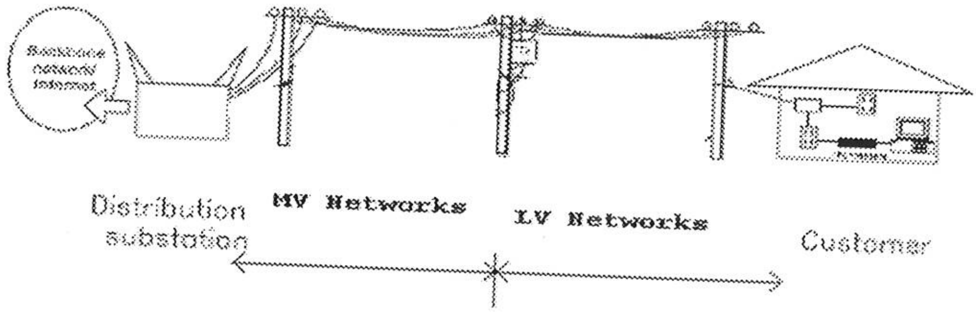

Figure 2.2.10 Network architecture of MV and LV Line
Source:

- **Fiber & low-voltage (LV) line network architecture** the image is shown in Fig. 2.2.11. The LV lines are connected with a fiber cable via an optical-electrical converter (O/E converter), which would be installed at the same pole where a distribution transformer is set.

The main Cost of this architecture is the rental fiber to the poles. Electrical power companies do not own fibers stretching from substations to poles for their utility operation. Therefore, this thesis assumes that they will rent fiber from telecommunication. Such fibers are called Fiber to the Poles (FTTP).

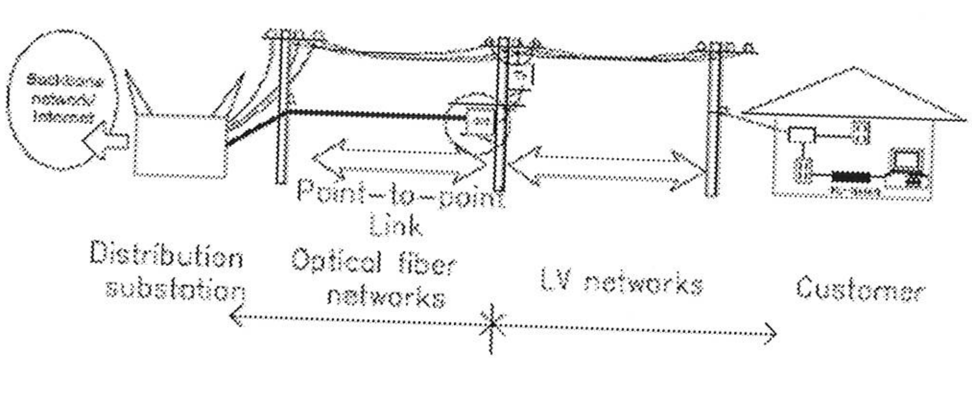

Fig. 2.2.11 Fiber and LV line Network architecture

2.3.5 **LAN size**

This thesis defines LAN as number of customer behind the distribution sub-station network per distribution transformer and total customer per distribution substation.

The LAN for this network can be calculated as follows: There are 19 sub-station and different capacities distribution transformers (50Kva to 1250Kva) give services for 350,000 residential customers in Addis Ababa. The residential voltage is 220 volt and the ampere is between 10-30 amps .For this thesis 20 AMP for average usage will be considered. The model assumes two related figures, as shown in Table 2.3.1.

Table 2.3.1 the number of customers per substation and per LAN

Customer/Per substation	18421
Per LAN	106
Number LAN	174

Therefore, the number of customers covered by a per substation in Addis Ababa is 18421 which is 350,000/19

Second, the capacity of a distribution transformer varies from 50Kva-1250Kva. This thesis uses transformers with average capacity 468Kva for residential units with 220 volt and 20 amperage averages. Therefore, the number of customers covered distribution transformer is 106 which is 468K/ (220v*20).

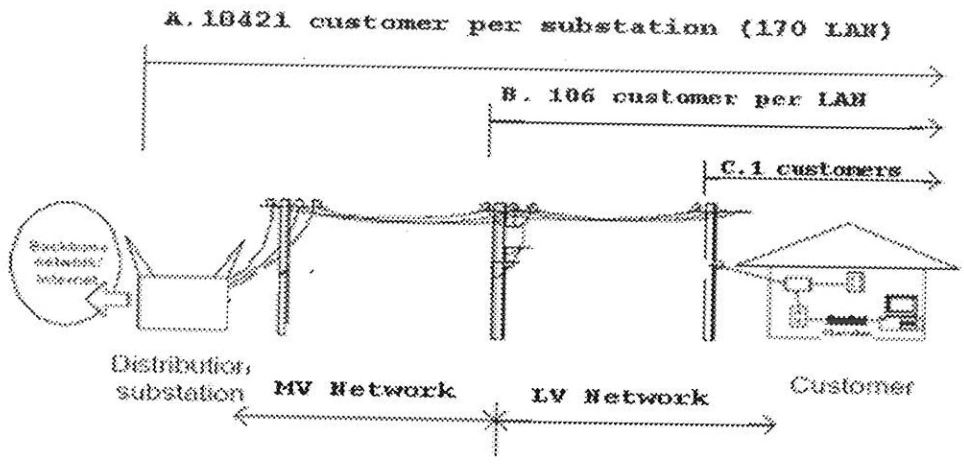

Figure 2.2.12 Network architecture of MV&LV lines

2.3.6 **Input cost elements** The input cost element shown below are the equipment cost for both PLC architectures to calculate the cost per subscribers. In the case of Medium-voltage (MV) & LV line network architecture (pure PLC network) has two parts cost one at substation level the other is at low voltage level.

- **Input cost elements at substation Level** Most facilities in a substation are shared by customers under one substation. Such facilities include optical transmission equipment, optical fiber, routers, and network management servers.

The shared infrastructure begins at the substation where an up-linking router and other hardware as well as a medium voltage coupler/modem are required. Depending on the number of feeders emanating from the substation, different MV couplers are needed.

At every distribution transformer, a concentrator-cum transformer by pass is required. This device interacts with customer premises equipment (CPE) on the low voltage side multiplexes the signal and then transfers the signal to the medium voltage line, by passing the transformer. In addition, depending on the distance involved, repeaters might be needed to extend the signal. The costs of the facilities at the substation are fixed here regardless of scenarios Table 2.3.2 below.

Table 2.3.2 the cost shared by customers per substation

Substation level shared cost	Unit	Low	Median	High
MV Coupler	$	600	800	1000
MV concentrator	$	600	800	1000
Up linking Router	$	5000	5250	5500
Repeater (MV)	$	1222	1340	1460
Number of repeaters (avg).		0.5	1	1.5

- **Input cost elements at low-voltage (LV) Level (Transformer)** at every distribution transformer, a concentrator-cum transformer bypass is required. This device interacts with the CPE on the low-voltage side, multiplexes the signals, and then transfers the signals to the medium-voltage line, bypassing the transformer. In addition, depending on the distances involved, repeaters might be needed to extend the signal. These are assumed to be on the medium voltage line. In summary, Table 2.3.3 shows the onetime cost.

Table 2.3.3.cost shard by customer per LAN one time cost

Low-voltage node	unit	low	median	high
LV coupler	$	600	800	1000
LV concentrator	$	1200	1300	1400
MV Coupler	$	600	800	1000

• **Fiber & low-voltage (LV) line network architecture** A LAN in this context is the group of residences served by a single fiber and it's attached to LV network. Therefore, many LANs converge in a distribution substation. The only cost which PLC will incur is the costs of low voltage equipment and additional LAN cards, which would integrate PLC into FTTH networks.

The cost elements are the cost of an O/E device and the labor cost of installing the device. The price of an O/E converter ranges between 400 and 600 USD. As for the labor cost of installing an O/E device, installing an O/E device has several elements: to attach an O/E device to a pole, connect the O/E device with a fiber cable and electrical wires respectively, and test the communication. In summary, the cost of installing an O/E device varies between 200 and 400 USD Table 2.3.4 show the onetime cost.

Table 2.3.4 show the onetime cost

Element	unit	Low	Median	high
LV-card	$	1000	1250	1500
O/E converter	$	400	500	600
O/E labor (installation)	$	200	300	400

• **Input cost elements at customer Level** the only cost element here is the cost of customer premise equipment (CPE). The cost of PLC modem is almost as low as the price of a power line carrier (PLC) modem. There are also other onetime costs such as line-conditioning and activation. Table 2.3.5 shows the onetime cost paid by one customer.

Table 2.3.5 the cost paid by one customer

Per User (Unshared)	unit	low	median	high
Acquisition and Marketing	$	50	100	150
Line conditioning and activation	$	75	100	125
CPE (data + voice)	$	30	40	50

For a subscriber to connect to the PLC LAN, the PLC modem equipment is needed to perform the following functions:

- Provide a physical interface to the subscriber's computer
- Provide a physical interface to the electrical wire, including PLC modem functionality
- Support the PLC LAN's media access protocol.
- Separate data signal and electricity

- **Other necessary costs for both models** In addition to the one-time costs, which are amortized over specific periods; there are also explicit calculations of monthly operating costs. These include customer relations/billing, maintenance, and up-linking. Up-linking costs are the fees paid to the upstream (sometimes backbone) provider, and depend on a number of assumptions including the statistical multiplexing (oversubscription) ratio and the rated bandwidth per consumer. The end result is an estimate of the monthly costs, special cost as shown in table 2.3.6

Table 2.3.6 operational cost of the system

Element	Cost	Low	Median	High
Customer support	$/month	5	6	7
maintenance	$/month	3	4	5
Uplink cost/Mbps	$/Mbps/month	3500	4000	4500

The discount rate is assumed to be 6-12%. The amortization period is 3-7 year. Table 2.3.7

Table 2.3.7 special cost of the system

Elements	Units	Low	Median	High
Discount rate	%	6	9	12
Amortization Period	year	3	5	7

3 RESULTS

3.1 Result Cost per home passed

Output cost elements consist of cost per home passed. The results is performed using decision-Pro software tools to better understand PLC economics and was performed through a Monte Carlo, or stochastic, simulation. This kind of simulation model was used by **(Tongia, 2004)**.

3.1.1 Medium-voltage (MV) & LV line network architecture (pure PLC network)

the service provider model is where the outputs of the model consists of the cost per home passed. This is average cost divided by all homes reachable with PLC system. Each element consists of two sub-elements: onetime cost and ongoing cost:-

·Onetime cost (CAPEX): expenditure needed to invest onetime, usually up front;

·Ongoing cost (OPEX): expenditure needed continuously, usually monthly cost.

Three cost outcomes, which are defined as cost shared per substation, per LAN, and per customer, are composed of the above two sub-elements (CAPEX and OPEX).

The analysis begins with an examination of the cost per home passed resulting from the original parameter settings. The cost per home passed of PLC **(Cph)** is calculated in the following manner: first, calculate Capital Cost (CAPX) and then Operational Cost (OPEX) separately. Since the PLC is a shard technology then

CAPEX=subcost/ (PerLAN*NumberofLAN) + (LVcost/PerLAN) +CPEC.

OPEX= uplinkC +MaintenanceC +customerC + fiberR/Per LAN

Where

subcost is the cost at substation,

LVCost is Low-voltage cost,

fiberR is the monthly rent cost of the fiber,

CPEX is customer premises equipment cost,

uplinkC is the up link cost from the service provider,

MaintenanceC is the maintenances cost

customerC is customer support cost,

PerLAN the number of homes per LAN = 106 and

Number of LAN is the number of LAN in the substation = 174

Second, amortize CAPX at 6 % for the discount rate and 3 years for the period. The reason for this is that these numbers are usual with telecommunications business model. Finally, obtain **Cph** by adding CAPX to OPEX. Repeat these steps for each scenario (low, median, high).

- **Low cost scenario**

Cost_Per_Home*:=((Capex)+(Opex))/ 12*

Capex*:=(Substation_cost+LV_cost+Per_user_cost)*((1+Discount_rate)^(amortization))*

Opex*:=((Maintenance+UP_linking_cost+Customer_support+Fiber_cost)/ (Per_LAN*Num_LAN))*

Substation_cost*:=(MV_coupler_cost+MV_concentrator_cost+Repeater_cost+Up_Link_Router)/ (Per_LAN*Num_LAN)*

LV_cost*:=(LV_coupler_cost+LV_concentrator)/ Per_LAN*

Per_user_cost*:=CPE_cost+LineTesting_cost+Acquisition_markating_cost*

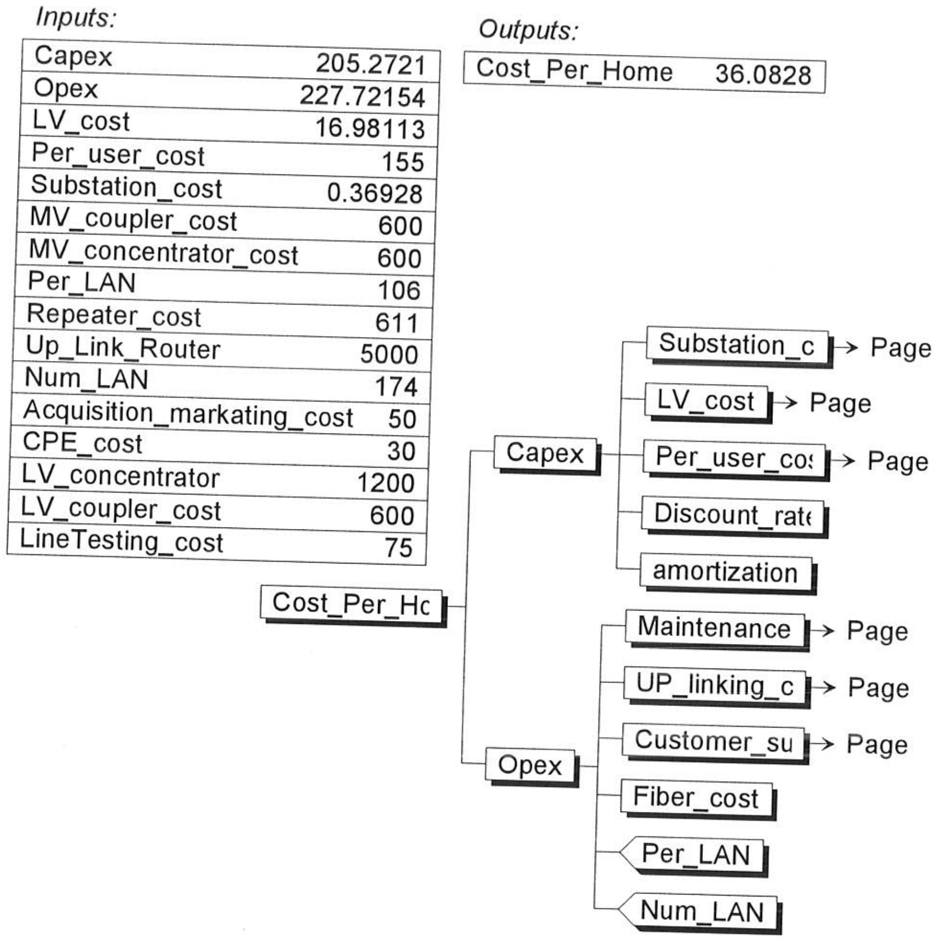

Figure 3.1.1 low cost scenario output

- **Median cost scenario**

Cost_Per_Home:=((Capex)+(Opex))/ 12

Capex:=(Substation_cost+LV_cost+Per_user_cost)*((1+Discount_rate)^(amortization))

Opex:=((Maintenance+UP_linking_cost+Customer_support+Fiber_cost)/ (Per_LAN*Num_LAN))

Substation_cost:=(MV_coupler_cost+MV_concentrator_cost+Repeater_cost+Up_Link_Router)/ (Per_LAN*Num_LAN)

LV_cost:=(LV_coupler_cost+LV_concentrator)/ Per_LAN

Per_user_cost:=CPE_cost+LineTesting_cost+Acquisition_markating_cost

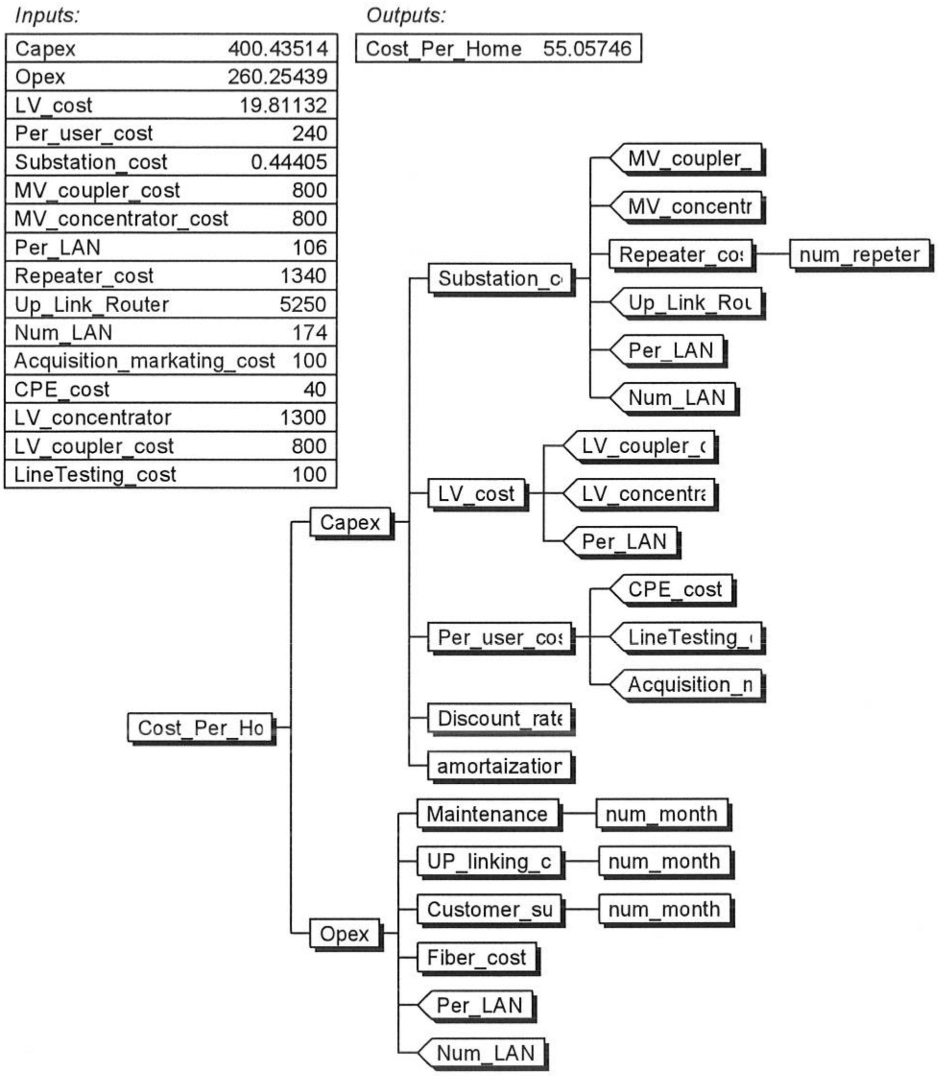

Figure 3.1.2 median cost scenario output

- ## High cost scenario

Cost_Per_Home:=((Capex)+(Opex))/ 12

Capex:=(Substation_cost+LV_cost+Per_user_cost)*((1+Discount_rate)^(amortization))

Opex:=((Maintenance+UP_linking_cost+Customer_support+Fiber_cost)/ (Per_LAN*Num_LAN))

Substation_cost:=(MV_coupler_cost+MV_concentrator_cost+Repeater_cost+Up_Link_Router)/ (Per_LAN*Num_LAN)

LV_cost:=(LV_coupler_cost+LV_concentrator)/ Per_LAN

Per_user_cost:=CPE_cost+LineTesting_cost+Acquisition_markating_cost

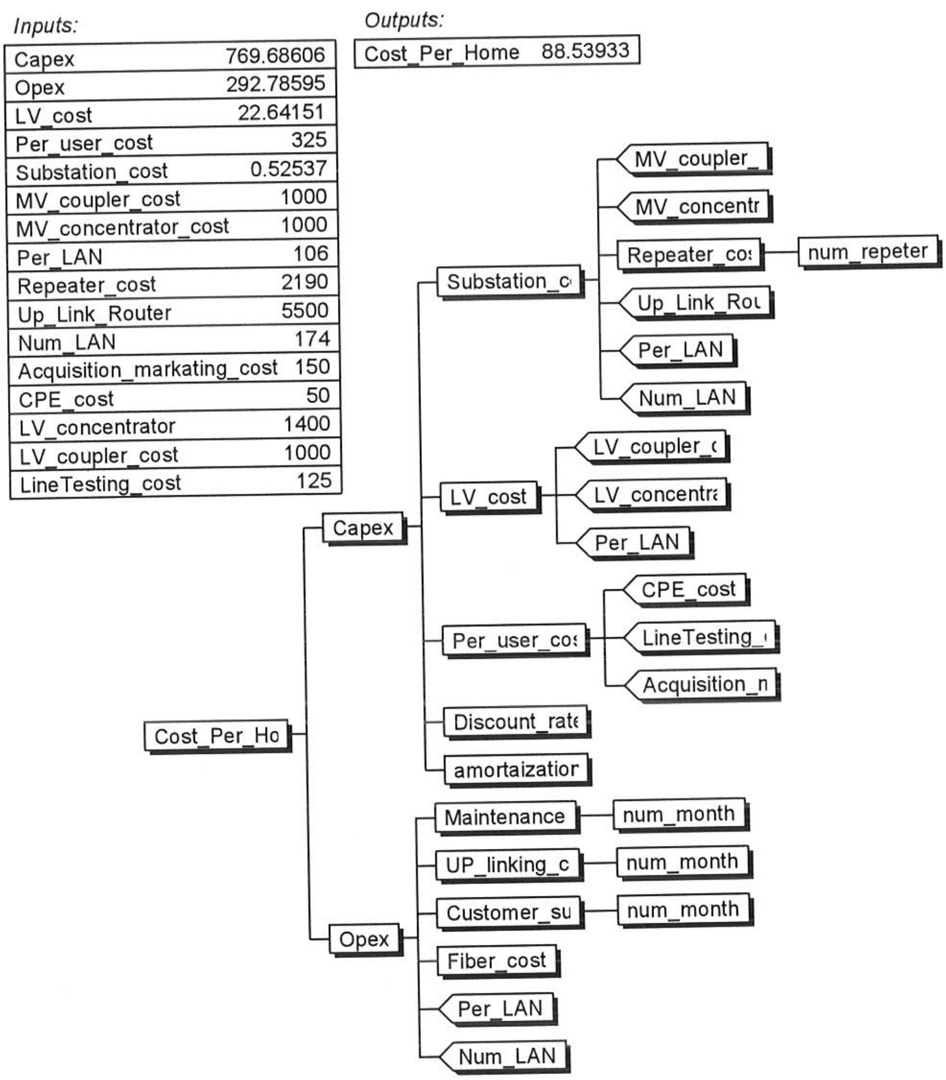

Figure 3.1.3 high cost scenario output

This result for PLC is shown as table 3.1.1 assumes that power companies provide PLC modems. The key finding here is that as the customer premises equipment (CPE) price increase the cost passed per home increase .

Table 3.1.1 end to end PLC result

PLC architectures	scenario		
	low	median	high
Medium voltage + Low-Voltage (End TO END PLC)	36.08	55.05	88.54

3.1.2 Fiber & low-voltage (LV) line network architecture

A LAN in this context is the group of residences served by a single fiber and its attached LV network. To distinguish the aggregated LANs from a LAN, this thesis considers calls them a cell. However, most facilities in a substation are shared by customers under one substation. Such facilities include optical transmission equipment, routers, switches, labor for the installation of optical fiber converter and network management servers. This thesis assumes that it uses fiber to the pole as rental from ETC.

- **Low cost scenario**

Cost_Per_Home:=((Capex)+(Opex))

Capex:=((LV_cost)*((1+Discount_rate)^(amortaization)))/12

Opex:=(Maintenance+UP_linking_cost+Customer_support+Fiber_cost)/per_LAN

LV_cost:=(OE_convertor+Labor_cost+CPE_Cost+LV_card)/Per_LAN

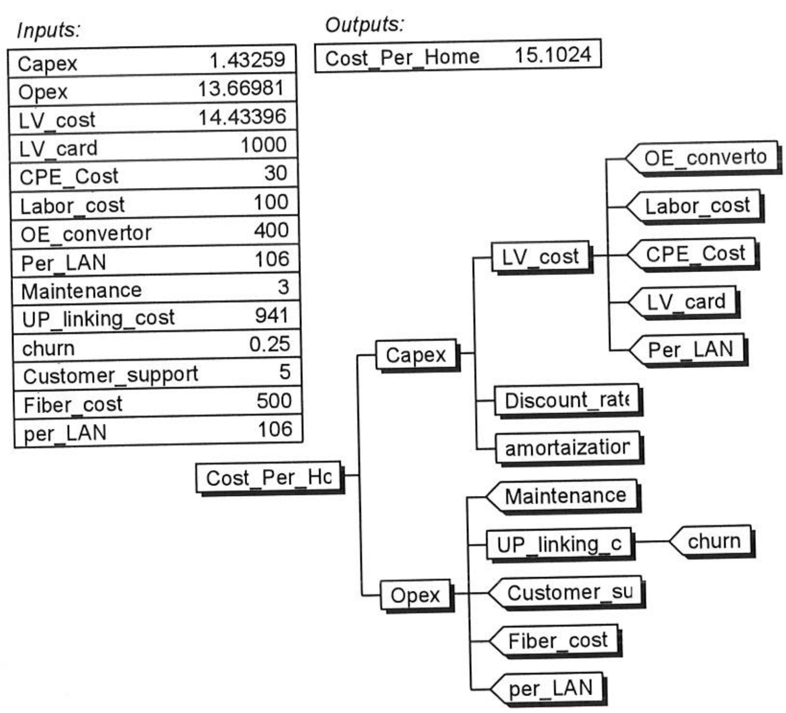

Figure 3.1.4 low cost scenario output

- **Median cost scenario**

Cost_Per_Home:=((Capex)+(Opex))

Capex:=((LV_cost)*((1+Discount_rate)^(amortaization)))/12

Opex:=(Maintenance+UP_linking_cost+Customer_support+Fiber_cost)/per_LAN

LV_cost:=(OE_convertor+Labor_cost+CPE_Cost+LV_card)/Per_LAN

Inputs:

Capex	2.40712
Opex	14.63208
LV_cost	18.77358
LV_card	1250
CPE_Cost	40
Labor_cost	200
OE_convertor	500
Per_LAN	106
Maintenance	4
UP_linking_cost	941
churn	0.25
Customer_support	6
Fiber_cost	600
per_LAN	106

Outputs:

Cost_Per_Home	17.0392

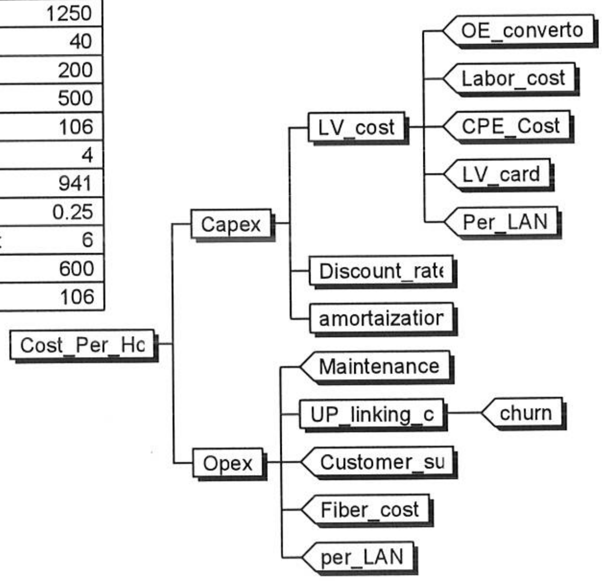

Figure 3.1.5 median cost scenario output

- **high cost scenario**

Cost_Per_Home:=((Capex)+(Opex))

Capex:=((LV_cost)*((1+Discount_rate)^(amortaization)))/12

Opex:=(Maintenance+UP_linking_cost+Customer_support+Fiber_cost)/per_LAN

LV_cost:=(OE_convertor+Labor_cost+CPE_Cost+LV_card)/Per_LAN

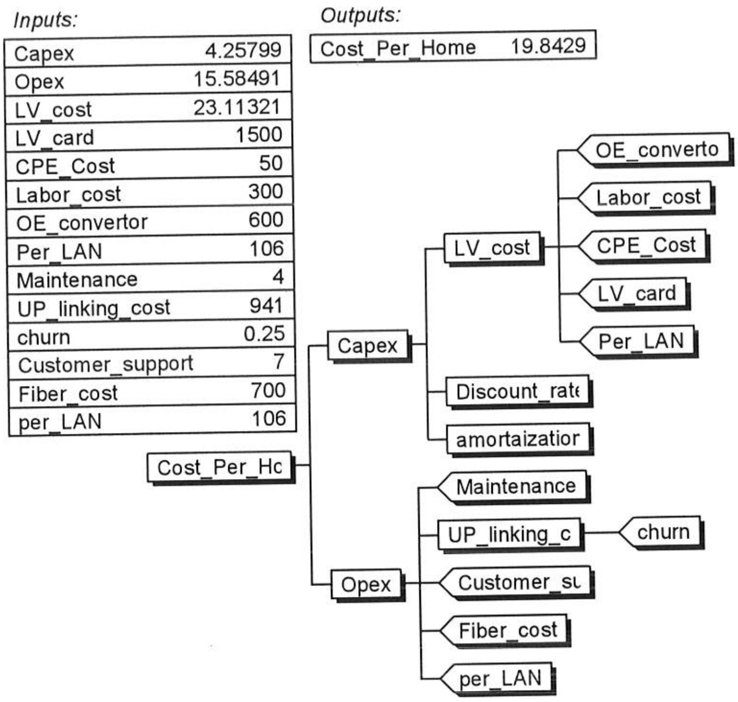

Figure 3.1.6 high cost scenario output

Table 3.1.2 fiber+ LV output result

PLC architectures	scenario		
	low	median	high
Fiber + Low-Voltage	15.10	17.04	19.84

- **summery of the power line communication result** In summery the power line communication cost for both kind of architecture has been calculated with all the assumption and as the assumption of this thesis the business model has been for The Service Provider model that means Ethiopian electric power line as service provider

Table 3.1.3 summery result for PLC

PLC architectures	scenario		
	low	median	high
Medium voltage + Low-Voltage (End TO END PLC)	36.08	55.05	88.54
Fiber + Low-voltage	15.10	17.04	19.84

3.1.3 **Telecommunication cost per subscriber** this part of the thesis uses the A data which was collected from ETC by interviewing and discussing with the employee relevant to the subject including a model of the existing telecommunication broadband services, customer premises equipment cost and monthly charge of different access technology and the power line cost analysis for comparison of the two technology have been done and the following final result has been achieved. A model of the existing telecommunication broadband services including customer premises equipment cost and monthly charge of different access technology, shown table 3.1.4 and 3.1.5 respectively[19].

Table 3.1.4 Customer premises equipment (CPE) and initial cost per customer

Rental of Customer premises equipment(CPE)and initial cost per customer			
xDSL	BFWA Voice + data	OPTICAL FIBER	
Installation	Installation	Initial	Monthly
394.51	3483.88		3035

Table 3.1.5 initial cost per customer per month

solution	Bandwidth	Monthly/ customer	CPE cost	Cost/customer
xDSL	64Kbps	39	40	79
BFWA	64Kbps	39	355	394

[19] **See appendices -1**

3.2 Summary of the result of cost analysis of both technology

From the quantitative analysis as sows in Table 3.1.6 power line communication Using End to end power line communication architecture cost per customer is cheaper compare to telecommunication broadband services. Therefore, it is very important to use power line communication for rural telecommunication where there is no telecommunication infrastructure available.

Table 3.1.6 power line and telecommunication cost per customer

Technology	Initial cost/ customer	Customer premises equipment cost/Month	Monthly cost /customer	Total monthly cost
ADSL	394.50	40	78	118
BFWA	3824.25	355	78	433
MV+LV PLC(Average)	none	none	none	59.89
Fiber +Low-voltage (Average)	none	none	none	17.34

4 Discussions of the analysis

4.1 Ethiopian Electric Power Corporation (EEPCO)

The Ethiopian Electric Power Corporation (EEPCO) is a statutory corporation owned by the Government of Ethiopia, It was set up by regulation on 7th of July 1997 for the purpose of generation, transmission and sale of electricity nationwide. EEPCO operates using two power supply systems, namely the main interconnected system (ICS) and the self-Contained system (SCS).

The main ICS, which serves the major towns and industrial centers, has a total installed capacity of 779.3MW. This installed capacity is generated by hydropower installations having a total installed capacity of 671 MW and thermal stations of about 101.4 MW. EEPCO currently provides electricity to a total of about 800,000 customers in approximately 632 towns and communities in Ethiopia, which is only a small proportion of the country from the total 72 million inhabitants. According to current figures only about 15% of the population is estimated to have access to electricity and the per capita energy consumption is 28kWh, which is one of the lowest in the world[20].
To support the Agricultural Development Led Industrialization Strategy (ADLI) by providing consumers access to electricity and thereby enhancing overall development efforts EEPCO has The Rural Electrification project which is designed to address the aforementioned constraints that impeded the development of Ethiopia.

The project is targeted to electrify 164 woreda towns to provide customers access to electricity. Successful completion of this project

[20] **See appendices -2**

4.3.1 **Fixed wireless access (BFWA) and Power line communication (PLC)** this solution could be one candidate for the integration. But, the installation cost customer premises equipment and monthly service charge will make it less cost effective for the integration model. The advent of improved wireless LAN technology, where the WiMax (IEEE 802.16) standard, still in the course of development and standardization, is a potential disrupter. It offers shared bandwidths of up to 70 Mbps extending as much as 50 km without requiring line of sight paths. Apart from this, other medium reach radio technologies which the Ethiopian telecommunications uses are expensive. Therefore, the integration of BFWA and PLC will not be cost effective integration.

4.3.2 **Satellite in the backbone network and PLC from distribution substation:** Because both the outdoor antenna and customer premises equipment are expensive the satellite connectivity is expensive. Therefore, it is not a good choice. Nevertheless, it could be useful to reach isolated areas where transmission costs to the area are high. This is especially true for the rural telecommunication where there is no any other Backhaul technology available to connect to the network point of presence. There will always be some locations in Ethiopia that can probably be served in no other way. Nonetheless, satellite solutions are expensive and limited in their performance and evolution potential, while their costs rise very steeply if richer services are required.

4.3.3 **Fiber and PLC (end to end PLC):** power line and fiber to connect the customer using end to end power line network to provide broadband services is the first candidate for the integration. Fiber has both technological and economical advantage as the backhaul connecting the distribution substation to the service provider or backbone of the telecommunication network. The cost for digging, ducting and installation is not that expensive in the Ethiopian context because the labor cost is inexpensive. Therefore, the fiber and PLC integration where there is no telecommunication infrastructure deployed is the best cost effective model.

2. In areas where telecommunication access infrastructure and electric power infrastructure are deployed

4.3.4 **ADSL + PLC in-home and apartments.** It is clear that the telecommunication broadband service is expensive and it is very difficult to provide services to the citizen. According to this study, integrating of ADSL and power line is definitely cheaper for the customer because the telecommunication doesn't have access network cost as it uses the existing power line network in side the customer premises. It is also cost effective especially for small apartment building to give broadband services because the customer premises equipment and initial cost of ADSL will be a shared cost. Therefore, this integration model is essential and useful for the Ethiopian telecommunication to get more customer and ganerate additional revenues.

4.3.5 **Fiber to the pole and PLC as access network** As a natural result of the way in which businesses deploy services responding to increased demand by minimizing costs, most high-investment broadband technologies are available in Addis Ababa. The Investment in fiber optics and deployment of other broadband networks has been mainly done in these areas, which also would have more competition. The fiber and the power line communication access network will make it even cheaper. The high rise buildings are the first customer to get high band width broadband services using the electric power network for there LAN infrastructure because it is cheaper than setting up LAN using cat 5 cable for the building. This kind of integration model is also cheaper to give services where copper wire line is not good for the ADSL network and expensive to upgrade it. Therefore this integration model not only is cost effective but it can also generate income for telecommunication

5 Conclusion and recommendations

Power Line Communication (PLC) is a recent and rapidly evolving technology, aiming at utilizing the electricity power lines for the transmission of data. The study has reviewed the technical state of the art of PLC technology and it has shown it to be very promising. It offers a permanent on-line connection as well as symmetric, two-way communication; it has good performance, very good geographical coverage, and is relatively cheap since most of the infrastructure is already in place. The PLC technology is highly attractive compared to other local access technologies in terms of capital expenditure and implementation requirements. Hence, PLC is definitely a significant last-mile local access technology.

Therefore, it has been concluded that PLC technology will play a significant role as a provider of necessary information communication infrastructure, as well as a platform for a wide range of new applications and services. It has been demonstrated that the integration of power line communication and telecommunication technology is cost effective especially for rural telecommunication.

5.1 Relevance of power Line communication for Ethiopian Electric Power Corporation (EEPCO)

The convergence between telecommunications and power distribution network, and its effect for the involvement of electric utilities in delivering advanced telecommunication services has been discussed. As in any industry, electric utilities increasingly use information and communication technologies. While most electric companies enjoy the benefits of natural monopolies, they face several problems likely to be addressed by an adequate use of information and communication technologies (ICT): monitoring variations in demand and load usage, electric power theft and reliability and security of their grid, which have gained in importance. Therefore, this technology is useful for the EEPCO lode dispatch center program with the Ethiopian telecommunication fiber infrastructure.

5.2 The significance of the power line in communication for telecommunication

The power line supplies electricity is self-evident but, it is worth pointing out that almost all functions and equipment of the telecommunication increasingly and fundamentally depend on an extremely reliable and cost-effective supply of electricity. Through PLC, the power line offers what is sometimes called the last mile connectivity to the individual customer. This means that the telecommunication can give broadband service with the affordable price for urban community.

The power grid is already in place in most of rural towns and it can offer last-mile connectivity. It is potentially cheaper than other forms of local telecommunications access, as these will generally require tremendous investment in achieving comparable scale and size.

Therefore, Ethiopian Telecommunication can use this infrastructure to give telecommunication services for rural community without investing in the infrastructure and access network, thus enhancing cost-effectiveness. At present, internet access is limited to slow speed and poor quality systems, utilizing the bottleneck of telephone wires not designed for such uses. Using the PLC it is possible to have broadband services.

In conclusion the Ethiopian electric power corporation has a plan to electrify 75 percent of the country in the coming five years. In contrast, the Ethiopian Telecommunications also has planned to give telecom service for 300 rural towns with an infrastructure which is very expensive. Therefore, if it uses the existing electric power distribution infrastructure, it can give service to 15 percent of the population and the telecommunication density will be very high compared to other developing countries.

Therefore, power line communication technology when integrated with the telecommunication technology is cost effective for the development of information communication technology in Ethiopia. However, there are policy issues that have to be addressed.

All the factors discussed, therefore, are compelling for the telecommunication as well as the Ethiopian electric power sectors, to invest in power line communication technology and deployment.

5.3 Issues for future study and Recommendation

A number of important issues arise for the development of cost effective information communication technology infrastructure and implementation of PLC in Ethiopia.

- In addition to the technical issues, it is very important to address policy consideration on how the Ethiopian Electric Power Corporation and the Ethiopian Telecommunication Corporation would be coordinated for the deployment of PLC.
- Another challenge in promoting PLC development and implementation is the structure and regulatory arrangements. PLC relies on the cooperation of access providers and backbone network provider (electricity distributors, backbone operators), content providers (broadcasters, ISP's, etc). Each of the parties must be coordinated and facilitated. Examples are where electricity distributors to obtain access to the distribution network, as asset ownership, maintenance and other commercial issues may prove difficult. Therefore a very strong regulatory institution is required.

- Industry guidelines and standards for the development of a PLC platform, which specifically addresses Ethiopia's requirements.
- There is need to ensure that regulation which apply to electricity businesses do not inappropriately inhibit electricity utilities investment in telecommunications and such that any uncertainty in this regard is addressed.
- Other potential regulatory barriers to the commercial deployment of PLC include performance requirements for the standard telephone service and the application, frequency management and licensing issues. This has to be resolved subsequent to systematic study.
- The Ethiopian Electric Power Corporation, Ethiopian Telecommunication Corporations and Ethiopian Telecommunication Agency which is a telecommunication regulatory agency as government entities have to devise mechanisms for the Development of power line communication in Ethiopia.

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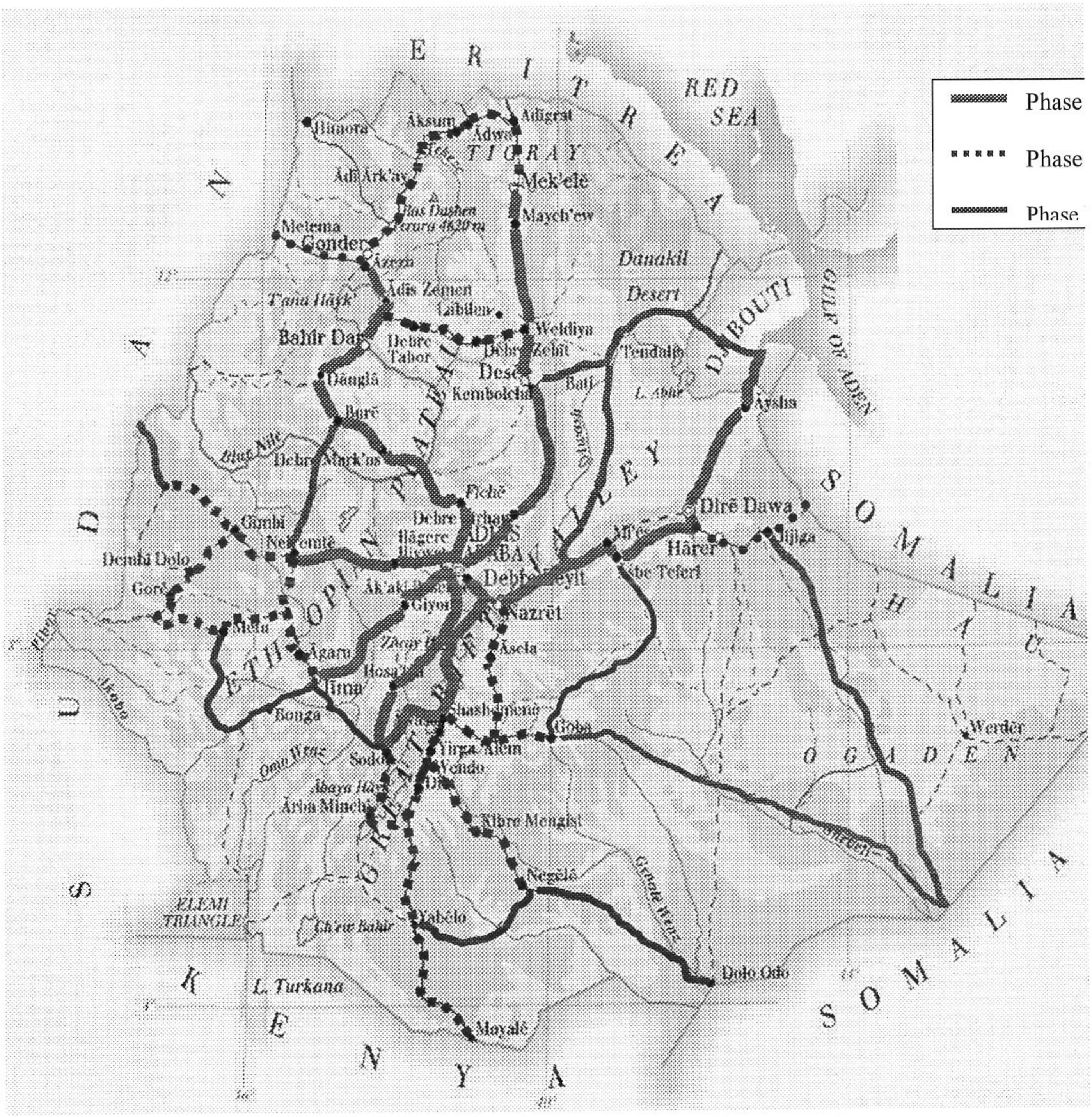
APPENDICES 1

IP VPN Tariff is composed of two compinents; Bandwidth Per Class of Service (CoS) and Customer Premise Equipment (CPE) (

dwidth	Charge for Bandwidth Per Classes of Service (CoS)						CPE Charge by Type				
	Silver CoS		Gold CoS		Platinum CoS		xDSL		BFWA Data Only		BFV (Data+
	Monthly Payment	Initial Payment	Monthly Payment	Initial Payment	Monthly Payment	Initial Payment	Initial Payment	Monthly Payment	Initial Payment	Monthly Payment	Initial Payment
'kbps	337.31	1,589.59	505.96	2,384.38	590.29	2,781.78					
kbps	674.61	3,179.18	1,011.92	4,768.76	1,180.57	5,563.56					
3kbps	1,349.22	6,358.35	2,023.84	9,537.53	2,361.14	11,127.12					
5kbps	2,698.45	12,716.71	4,047.67	19,075.06	4,722.28	22,254.23					
4kbps	4,047.67	19,075.06	6,071.51	28,612.59	7,083.42	33,381.35					
2kbps	5,396.89	25,433.41	8,095.34	38,150.12	9,444.56	44,508.47	**3,471.75**	**348.13**	**12,336.88**	**1,237.07**	**30,658.22**
3kbps	8,095.34	38,150.12	12,143.01	57,225.17	14,166.85	66,762.70					
/lbps	**10,793.79**	**50,866.82**	**16,190.68**	**76,300.23**	**18,889.13**	**89,016.94**					
/lbps	19,428.82	91,560.28	29,143.23	137,340.42	34,000.43	160,230.49					
/lbps	29,143.23	137,340.42	43,714.84	206,010.63	51,000.65	240,345.73					
/lbps	32,381.36	152,600.46	48,572.05	228,900.69	56,667.39	267,050.81					

Appendices 1A

Bandwidth	Silver CoS Monthly payment USD	CPE cost USD				Total/month	
		xDSL		Fiber		Monthly +xDSL	Monthly +BFWA
32 Kbps	38.99538	40.24624	355.1699			79.24162	394.1653
64 Kbps	77.9896	40.24624	355.1699			118.2358	433.1595
128 Kbps	155.9792	40.24624	355.1699			196.2254	511.1491
256 Kbps	311.9595	40.24624	355.1699			352.2057	667.1294
384 Kbps	467.9387	40.24624	355.1699			508.1849	823.1086
512 Kbps	623.9179	40.24624	355.1699			664.1641	979.0878
768 Kbps	935.8775	40.24624	355.1699			976.1237	1291.047
1 Mbps	1247.837	40.24624	355.1699			1288.083	1603.007
2 Mbps	2246.106	40.24624	355.1699			2286.352	2601.276
3 Mbps	3369.16	40.24624	355.1699			3409.406	3724.33
4 Mbps	3743.51	40.24624	355.1699			3783.756	4098.68


Phase
Phase
Phase
ERITREA
RED SEA
SUDAN
TIGRAY
Mek'elē
Gonder
Bahir Dar
Dese
Danakil Desert
DJIBOUTI
GULF OF ADEN
SOMALIA
Dirē Dawa
Hārer
ADDIS ABABA
Debre Zeyit
Nazrēt
ETHIOPIAN PLATEAU
GREAT RIFT VALLEY
OGADEN
HAUD
KENYA
L. Turkana
ELEMI TRIANGLE
Negēlē
Yabēlo
Moyalē
Dolo Odo
Jīma
Gonder
Gambi
Nekemtē
Āsela
Goba
Sodo
Ārba Minch'
Werdēr
Jījiga
Weldiya
Aksum
Ādwa
Ādīgrat
Metema
Gorē
Bonga
Ginir

ppendices 2 Existing Generation Facilities

- ICS & SCS Generation Installed Capacity

(ICS - Inter Connected System)

em No.	Power Plahts	Status	Inservice Date	Installed Capacity (MW)	Depe Capac
xisting ICS					
. Hydro					
1	Koka	Existing	1960	43.2	3
2	T.Abay-I	Existing	1964 (1998*)	11.4	1
3	Awash II	Existing	1966	32	:
4	Awash III	Existing	1971	32	:
5	Finchaa	Existing	1973	100	1
6	Melka Wakena	Existing	1988	153	1
7	T.Abay II	Existing	1994	73	(
8	Fincha IVth Unit	Existing	1994	34	:
9	Gilgel Gibe-I	U.Completion	1996	192	1
	Total Hydro			670.6	64
. Geothermal-Existing					
10	Aluto Langano	Existing	1991	7.30	7
	Total Geothermal			7.30	7
. ICS-Diesel					
11	**Stand by Diesel (Synchronizable)**	Existing	-	22.2	1
12	**Awash 7 Killo Diese (Containerized)**	Existing	1995	28.0	2
13	**Kaliti I Diesel (Containerized)**	Existing	1995	11.2	11
14	**Dire Dawa Diesel**	U. Construction	-	40.0	3
	Total			101.4	9
	Grand Total Existing ICS Hydro and Thermal			779.3	7

Appendices 3 Generation and Transmission Expansion Plan

Power Plants

	Generation Projects	No of Units MW	Existing total Istalled capacity up to the year indicated (MW)	Total System Installed capacity (MW)	Major related Transmission Projects	N Ci ar
- Under Construction						
.	Tekeze	4 x 75	300	1091.8	Tekeze - Mekele (new)	2 :
					Mekele - Alamata (reinforcement)	1
2	Gilge Gibe II	4 x 105	420	1511.8	Gilge Gibe II - Sebeta II (new)	1 :
					Gilge Gibe II - Gilge Gibe I new S/SI (new)	1 :
					Sebeta II - Sebeta I(new)	2 :
					Sebeta I - Welkite (reinforcement)	1 :
					Welkite - Gilgel Gibe I new S/S (reinforcement)	1 :
					Gilgel Gibe I new S/S - Gilge Gibe I power plant (reinforcement)	1 :
					Gilgel Gibe old S/S - Gilge Gibe I power plant (reinforcement)	1 :
					Finchaa - Ghedo (reinforcement)	1 :
					Ghedo - Gefersa (reinforcement)	1 :
- Committed and Under Study* (Feasibility)						
.	Amerti Neshe*	2 x 21.5	43	1554.8	Amerti Neshe - Finchaa	2
2	Awash 4*	2 x 17	34	1588.8	Awash IV - Awash III	1 :
3	Yayu Coal* Fired Thermal Plant	3x30/2x45	90	1678.8	Yayu Colal fierd Thermal Plant - Bedele	2 :
4	Gojeb	3 x 50	150	1828.8	Gojeb - Welayta Soddo	1 :
					Gojeb - Gilgel Gibe I new S/S	1 :
					Gojeb - Aba	1 :
					Gojeb - Jimma	1 :
- Committed and Under Rehabilitation						
.	Aba Samuel	1 x 9	9	1837.8	Aba Samuel - Kaliti	1 :

Appendices 5