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A DEVELOPMENT OF A 3-PHASE SMART METER CONFORMED TO DLMS-COSEM AND PRIME PROTOCOLS

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A Thesis Submitted in Partial Fulfillment of the Requirements

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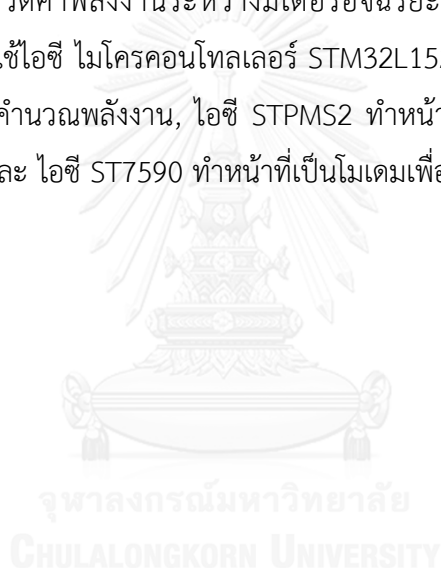
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KITTITACH PORNPRASITPOL: A DEVELOPMENT OF A 3-PHASE SMART METER CONFORMED TO DLMS-COSEM AND PRIME PROTOCOLS. ADVISOR: ASST. PROF. WANCHALERM PORA, Ph.D., pp.

This thesis proposes a development of a 3-phase 4-wire prototype smart meter operating at a nominal voltage of 220 volt and current of 10 A. The smart meter is aimed to evaluate application possibility of communication among metering equipment operating in the smart energy grid system based on DLMS-COSEM and PRIME protocols. The smart meter contains a hardware driver to control its energy measurement unit and a firmware developed with C and C++ languages. The firmware is responsible for metering data communication between the smart meter and its data concentrator unit. The smart meter is equipped with Microcontroller STM32L152VBT IC as its processor, STPMC1 as energy calculator, STPMS2 as energy sensors on each phrase the power lines and ST7590 as power line communication modem.

Department:	Electrical Engineering	Student's Signature	
Field of Study:	Electrical Engineering	Advisor's Signature	
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Chapter 1

Introduction

The objective of this thesis is to assess the performance of DLMS/COSEM and PRIME standards operating in a power line communication network using prototype smart meter specifically designed to comply with the two standards.

1.1   Statement of research topic

Energy has been a fundamental component of national economic growth, industrial expansion and household convenience that we considerably depend on its sustenance. Efficient energy management obviously has a direct impact on the country development as a whole. This can be achieved through smart energy network including smart energy meters.

The main limitation of the existing electricity distribution processes is that consumers are passive participants, with limited access to information on their energy usage and costs. The design of the conventional power distribution network is a one way flow of energy and information from service providers to the end users, and it is unlikely support the modern energy management where customers engaging in demand responses, and the range of emerging energy resources and renewable generation technologies can be incorporated in to the network.

In a power distribution network, smart meter is an important tool for energy utilities to operate in various types energy supplies and cope with the changing user requirements and communication technologies. The smart meter provides additional intelligent billings for energy planning, network authentications, two-way energy flows and bi-directional communication between consumers and energy distributers. Thus, the smart meter has been proposed as an enabling technology to integrate effective energy management in the future distribution systems.

However, there has been a variety of proprietary protocols for delivery and interpretation of metering data, which have posed difficulties for both Advanced Metering Infrastructure (AMI) system developers and utility distributors regarding non-

interoperability of metering devices from different manufacturers. DLMS/COSEM has recently been accepted as a standard-based language for meter communication. Its major objective is to support interoperability among metering equipment[1]. Although it is a well-defined protocol, integrating it into a smart meter poses certain challenges for smart metering system developer. These challenges include tasks on resources management and compatibility with existing hardware and software platforms[2].

With regards to cost-efficient implementation, existing power lines can be used as a medium for data communication between metering devices.

PRIME is a recent physical and data link layers specification for power line communication that needs practical assessments through field deployment as the standard has still been in its early phase.

1.2   Aims of the thesis

Aim of this thesis is to develop a three-phase smart meter complied with DLMS-COSEM and PRIME-PLC protocol communicating with data-concentrator through Power Line Communication, PLC.

1.3   Research framework

The prototype 3-phase smart meter holds the following features:

1. The smart meter can communicate and exchange metering information with a simulated data concentrator unit (DCU) based on DLMS-COSEM and PRIME protocols over the power line

2. The smart meter can with voltage input: 220/380 V (three-phase 4-wire) with basic current 10A at frequency 50 Hz

3. The smart meter shall be able to store and display the billing data namely active power (kW), active energy (kWh), reactive power (kVAR), reactive energy (kVARh), RMS voltage, RMS current, and Power factor.

4. The C++ library shall comply with DLMS-COSEM Application Protocol and be able to manage the communication between the smart meter and the simulated data concentrator unit to exchange energy data as specified in 3.

1.4   Research methodology

1. Study DLMS/COSEM standard. The DLMS/COSEM is explained in the Chapter 2 section 2.2

2. Study Basic encoding rule, BER, (IEC 8825-1). This is explained in the Chapter 2 section 2.3

3. Study A-XDR (IEC 61334-6). This is explained in the Chapter 2 section 2.3

4. Test abilities of the smart meter to store energy record and study the structure of protocol data unit (PDU)

5. Design and develop a C++ program library for services of the DLMS/COSEM command in the application layer, BER and A-XDR

6. Design and develop smart meter hardware and implement it with standard C program library.

7. Test electrical and electronic functionality of the smart meter

8. Study power line communication based on PRIME protocol

9. Test PRIME communication using the prototype smart meter and a simulated DCU implemented on a computer

10. Design and develop GUI for DCU using .NET Framework and revise DLMS/COSEM library

11. Test and gather testing results to analyze and summarize then write thesis

1.5   Structure of the thesis presentation

This thesis is categorized into 6 chapters including this Chapter. In Chapter 2, Smart meters and communication standards, i.e. power line communication, DLMS/COSEM and PRIME protocols will be explained. In Chapter 3,

hardware of the smart meter is described. In Chapter 4, the design of smart meter firmware will be demonstrate. In Chapter 5, experiment on the smart meter's functionalities and result of the experiment will be explained. In Chapter 6 the experiment result is concluded with discussion over the benefit of the thesis research and recommendation for future development.

Chapter 2

Smart meters and communication standards

This chapter explains the basic knowledge of smart meters and communication standards selected for this thesis research, DLMS /COSEM and PRIME protocols.

2.1   Smart meter [2]

Smart meters are an innovative energy device that can be programed and reprogramed to monitor the energy consumption at household premise and can remotely exchange energy data with the energy distributor in a timely manner and store this data within their electronic memory. The ability of smart meters for bidirectional data communication enables them to collect information regarding the electricity consumption trend necessary for the power grid operator to plan for energy generation to fit the aggregate demand of the whole system. A metering system consists of smart meters, a communication network, and a data concentrator unit and a command center. The information fetched by smart meters is a group of predetermined parameters such as a unique meter identifier, timestamp of the data, electricity consumption values, device status and communication status. They can also collect analytical information for maintenance of the power distribution network. Moreover, smart meters can restrict the maximum consumption, and can remotely terminate or re-connect electricity supply to any customers' loads. Collection of energy consumption data from all customers on a regular basis allows the energy utility to manage electricity generation more efficiently and suggest the customers to manage their load profiles for less unnecessary lost. In addition, smart meters help utility companies to detect unauthorized usages and notify the distributor of the tampering events.

Design for preferable electricity distribution networks is towards offering the energy users with sustainable, flexibly manageable and cost-efficient services. This is achievable through considering the adoption of energy production from both conventional centralized generators and renewable energy supplement devices own by private sectors. This synergy of various energy generators will require utility companies to manage a great amount of real-time energy data, which

necessitate effective metering data system with standardize communication protocols.

2.2   Smart Metering Communication over the power line

A conventional scheme represents the reading of the meter by the power utilities sending out personnel to manually record the power consumption on site. Recently, data communication for metering systems has been implemented using various solutions for a better and efficient way to collect information from the energy meters. Metering data transmission technologies have been adopted through various forms of solutions such as PLC, ZigBee, Wi-Fi, to yield the finest performances concerning data rates, and coverage areas or data reliability that match geographic, economic and regulation constrains[2]. Typically, metering schemes that deploy PLC trends to be towards the narrow frequency range. The use of these frequencies brings advantages as well as disadvantages, with the main benefits being: the feasibilities for the signal to propagate across the power transformers but with difficulty against long distance communication as it faces with great attenuation mostly in the low voltage part within the distribution grid [3]. An example of Power line communication for power distribution systems is illustrated in Figure 2-1
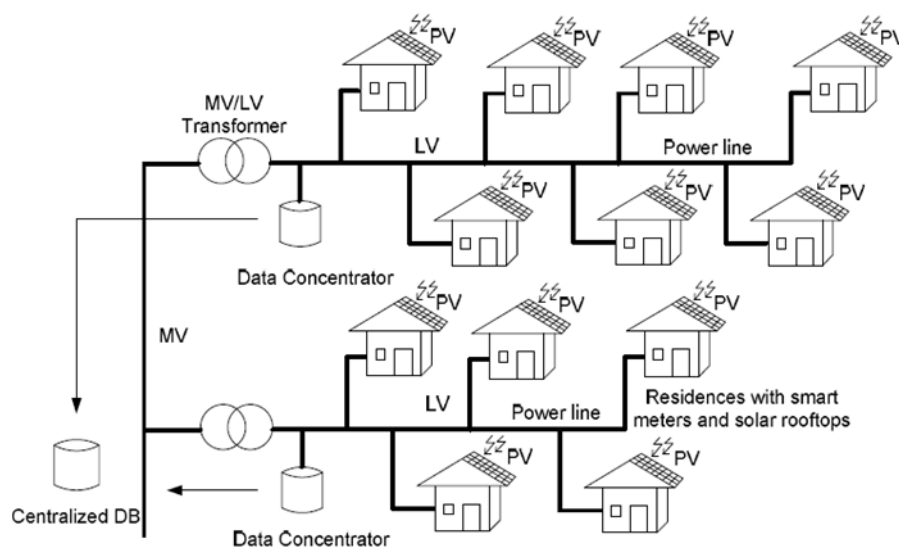
Figure 2-1: An example of Power line communication for power distribution systems

Power line communication or PLC can be categorized as narrowband and broadband. The narrowband deploys the frequency band of 3- 500 kHz. The

narrowband is suitable for Automatic Metering Infrastructure, while the broadband with 2–250 MHz is more adopted for in home network. Most problems affecting performance of PLC are found in the low voltage power lines. This problem is related to signal attenuation caused by noise. Every power distribution network contains with it a number of nodes represented by the medium and low voltage power transformers. The presence of them raises problems when the communications undergo from low voltage line to medium voltage line without bypassing components, because the PLC signal cannot tolerate attenuation when crossing the junction. However, communicating through the power transformer is possible with the use of OFDM and DBPSK techniques. PLC is expected to enable communication crossing through power transformers with less data loss when equipped with relevant improvement concerning the narrowband frequencies. CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance) offers the optimum performance regarding the medium access technique. PLC is considered to be a next generation metering communication solution, due to its effectiveness and low implementation cost and wide area coverage up to 5 Kilometers in theory as well as enhanced transfer rate. The structure of a PLC metering system depends on the location of the routers or concentrators and the number of them needed to be installed on part of the grid.

2.3   DLMS/COSEM [1, 3]

DLMS, which stands for "Device Language Message specification", and COSEM for "Companion Specification for Energy Metering", are combined together as a protocol suit for data communication among metering devices. DLMS/COSEM can be seen as an object oreiented model, representing the methods and attributes of smart meters seen at their interfaces. The protocol specifies a messaging procedure to encode the data into a series of bytes carrying the metering information. DLMS/COSEM contains characteristics described as follows.

2.3.1   Client/Server based protocol

Communication with electricity metering equipment using the COSEM interface object model is based on the client/server model where metering equipment performs the server role and the data center performs the client role. In this model, communication is established between application process on the client side and the server side. The client application process uses remote services of the

server application process. These services can be categorized as request-type and response-type services. These two types of the services are separately originated in the client application and the server application process. Moreover, the client and the server application processes are set up on the different types of the metering devices; message transmission is carried out as specified in the communication flow, as depicted in Figure 2-2
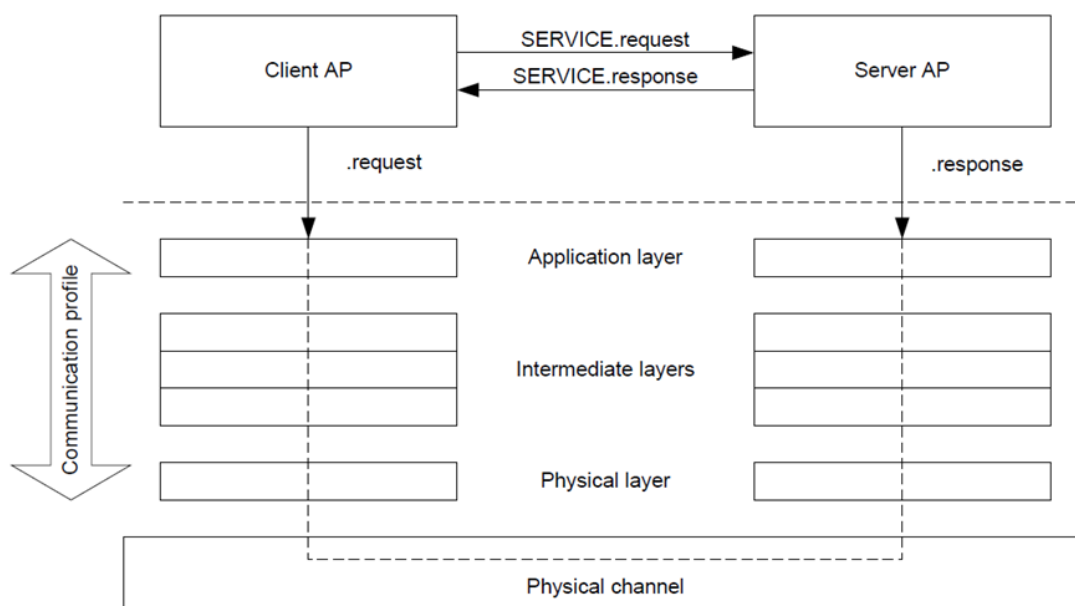
Figure 2-2: Client and Server Association in COSEM

In general, communication profiles are separated into proper protocol layers. The client and server COSEM applications call services of the highest protocol layer namely application layer which is the only protocol layer specified in the COSEM standard. COSEM Application layer contain a set of service elements called the xDLMS_ASE. All services concerning COSEM interface as specified in the xDLMS application protocol are offered by this xDLMS_ASE.

2.3.2 Connection-Oriented Protocol

The xDLMS application can be viewed as connection-oriented scheme. In other words, there have to be an association established between the client and server application processes before they are permitted to use xDLMS_ASE services. Thus, in this communication model, activities can be categorized into three phases,

Phase1: connection establishment, Phase 2: Data communication and Phase3: Connection release, as displayed in Figure 2-3.
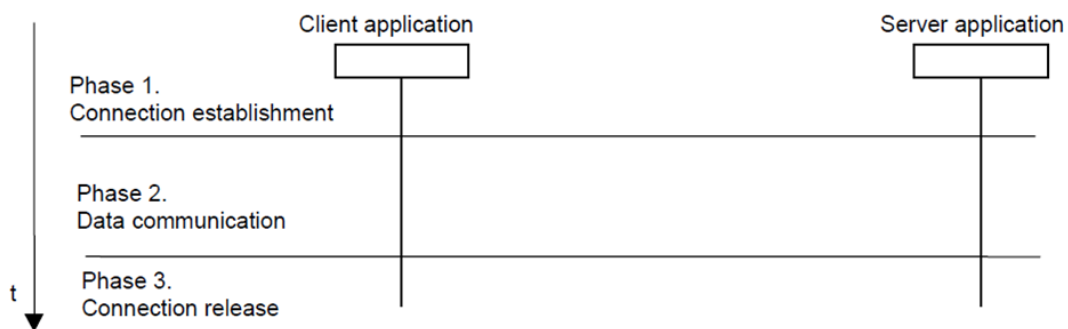
Figure 2-3: Connection-Oriented communication environment in DLMS/COSEM

2.3.3 COSEM application layer

The major element in the COSEM application layers is the COSEM ASO. This element offers services to the COSEM AP, and deploys services supported by layers underneath.

COSEM ASO consists of three compulsory components:

1. The ACSE has a duty to initiate, manage, and terminate application associations.

2. The xDLMS_ASE arranges data communication services between COSEM APs.

3. The Control function manages the ASO services by initiating the relevant service primitives of the ACSE and the xDLMS ASE and the services of the layer below. The simplified COSEM AL structure is illustrated in Figure 2-4.
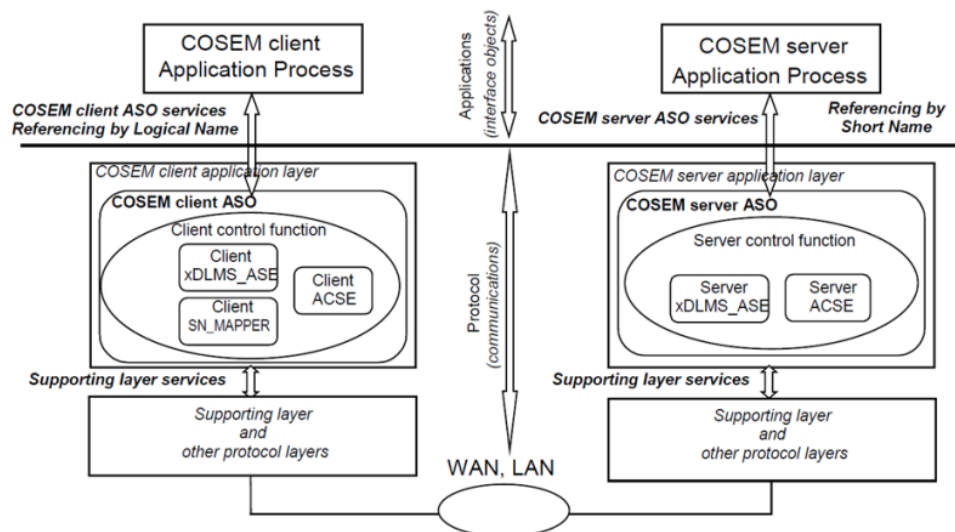
Figure 2-4: Structure of the COSEM application layers

2.3.4 COSEM Service specification

Services offered by the COSEM ASO can be separated into three components:

1. Application association establishment and release;

2. Data communication;

3. Layer management.

2.3.5 COSEM Application association establishment and release

Application association services depend on three service elements namely COSEM-OPEN, COSEM-RELEASE and COSEM-ABORT for the establishment and release of AAs.

The Client AP begins connection establishment with the Server AP by invoking COSEM-OPEN.request service. By invoking it means that the server generating a COSEM-OPEN.indication service primitive. In the case of confirmed association, when there is a request from the client, the server responses by invoking COSEM-OPEN.response service. This response will be transferred to the client as COSEM-OPEN.confirm.

The COSEM-RELEASE service is used to handle termination of an established application association. The request to terminate connection is prohibited for the COSEM server application processes. The COSEM-RELEASE.request service can be used only by the COSEM client.

The COSEM-OPEN service has the similar procedure to that of the COSEM-RELEASE service. The difference is that the OPEN service it is used for connection establishment whereas the RELEASE service is for the connection termination.

The ABORT service is deployed when physical disconnection is detected. This ABORT service is the same for both Client and Server.

2.3.6 COSEM Client and COSEM server type data communication services

Data communication services are carried out through xDLMS_ASE services. These services contain references to attributes or methods of COSEM interface objects. Services provided by the client side application layer during the data communications phase is depicted in Figure 2-5.
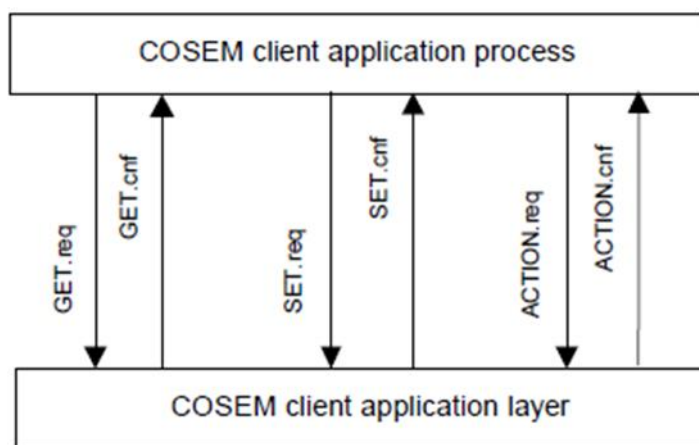
Figure 2-5: Client side data communication services

For data communication, the service group provided at the COSEM client side is:

2.3.6.1 COSEM interface object attribute related services: GET, SET (.request and .confirm);

1. GET.request is initiated by client AP to request the value(s) of one or all attributes of one or more COSEM interface objects from the remote server AP.
2. GET.confirm: It is initiated by the client application layer to indicate that a Get response APDU is received.
3. SET.request: It is initiated by the client AP to request the remote server AP to set the value in attributes of a COSEM interface object.
4. SET.confirm It is initiated by the client application layer to indicate that a SET.response from the COSEM server AP is received.

2.3.6.2 Services for COSEM interface objects: ACTION (.request and .confirm)

1. ACTION.request is originated by the client AP to invoke COSEM interface objects in the server AP.
2. ACTION.confirm is originated by the client application layer to notify when the ACTION.response from the COSEM server AP is received.

2.4 PRIME-PLC [4]

PRIME is the abbreviation for "PoweRline Intelligent Metering Evolution". It is an open communication protocol which is created to support interoperability among metering equipment and systems from different manufacturers. The protocol specifies Physical, Mac and Convergence layers for data transmission via a PLC narrowband over electricity grids. It utilizes OFDM multiplexing in CENELEC-A band and reaches up to 130 kbps raw data rate. This system aims at a low cost yet high performance transmission. The Figure 2-6 below illustrates PRIME structure consisting of convergence Sublayer, MAC and PHY layers. The proposed reference model is based on IEEE Std. 802.16 protocol layering.
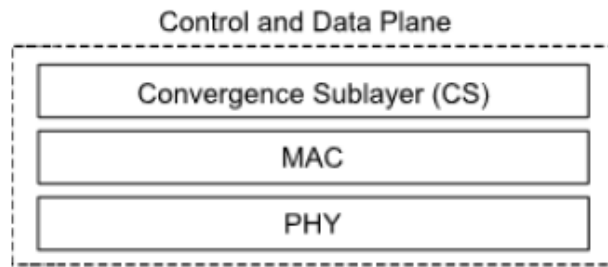
Figure 2-6: PRIME communication layers and the scope of PRIME specification

2.4.1 PRIME PHYSICAL LAYER

2.4.1.1 Overview

PRIME PHYSICAL layer defines the procedures to transmit and receive data on the power lines. It is designed for power distribution network with frequency of 50-60Hz AC. Communications over the power line with frequencies above this range poses some technical problems such as:

1. Distribution grids are typically installed over a mix of conductor types, and connected to loads with a variety of impedances. This mix network presents a variety of amplitude and phase response. Moreover, the channel condition may change when different loads are connected to the network.

2. Impulse noise generated from motors in electric appliances, switching power supplies and electric lamps also has unpleasant effect on power lines as well. It makes communication signals less reliable. Severity of this impulse noise varies with location corresponding with distance dependent attenuation.

To solve such problems, PRIME PHYSICAL layer uses a combination of methods based on adaptively modulated Orthogonal Frequency Division Multiplexing (OFDM), together with forward error correction and data interleaving. PHYSICAL layer transmitter is presented with diagram shown in Figure 2-7.
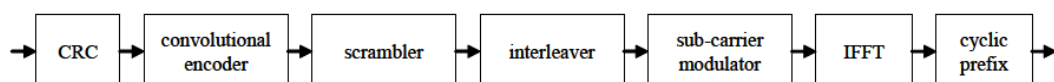
Figure 2-7: A block diagram representation of a PHYSICAL layer transmitter

The PHYSICAL layer receives its data unit from the Media Access Control layer. The data frame is then encoded using convolution, followed by scrambled and interleaved. Next, the output is differentially modulated using a DBPSK, DQPSK or D8PSK and multiplexed using OFDM.

2.4.1.2 Transmission technique

PRIME is suitable for narrowband power line communications because of its transmission technique that based OFDM approach instead of conventional single carrier transmission. OFDM is a digital modulation scheme, separating channel bandwidth into a large number of narrow-spaced orthogonal subcarriers to deliver data. These subcarriers typically overlap in frequency to obtain high spectral efficiency, orthogonally allows recovering each of the subcarriers separately at the receiver, so in practice subcarriers do not interfere with each other. Each subcarrier is modulated with a general modulation scheme at a low symbol speed, with data speeds similar to typical single-carrier modulation schemes using the same bandwidth. In practice, OFDM signals are efficiently generated and detected using the Fast Fourier Transform algorithm. OFDM is more attractive than single-carrier schemes because of its ability to operate under severe channel conditions, such as, attenuation of high frequencies in long power lines, narrowband interference and frequency fading. OFDM utilizes many narrowband signals instead of single rapidly-modulated wideband signal. As a result OFDM gives channel equalization. Additionally, low symbol rate allows a guard band between symbols, hence offering the ability to handle time-spreading and flush out inter symbol interference. As PRIME operates at low frequencies, multipath is operable. Therefore, cyclic prefixes affect only a small portion of OFDM symbols.

It is useful to note that PRIME OFDM signal presents these features:

1. The subcarrier spacing is exactly 488.28125 Hz.

2. Within the available bandwidth, it contains 97 subcarriers, with 96 of them will be used for data.

3. The IFFT interval length is 2,048 ms plus a cyclic prefix of 192 ms.

2.4.2 PRIME MAC LAYER

2.4.2.1 PRIME MAC topology

MAC Layer defines how network topology should be formed. This protocol layer provides the synchronization of all the nodes in the network, and controls the access to the medium by reducing or avoiding collisions in data transmission. In other words, MAC Layer specifies a mechanism to transmit data between two nodes with a routing mechanism.

In PRIME MAC LAYER, a sub network is created based on the tree topology with two types of nodes; the Base Node and Services Nodes. The Base Node, representing the root of the tree, functions as the master of the network managing the sub network connectivity. It controls the sub network resources and connections. Each sub network contains only one Base Node. This Base Node is originally the master of the sub network and other nodes register themselves on the sub network. Any other sub network node is a Service Node. Service Nodes are either leaves or branch points of the tree. Each of these nodes is one point of the sub network. These nodes perform two functions: registering themselves to the sub network; and helping their peer nodes to switch data in order to propagate connectivity.

Devices that exhibit Base Node functionality maintain their functions as long as they are not explicitly recon d by mechanisms. Service Nodes, on the other hand, change their behavior dynamically from "Terminal" functions to "Switch" functions. The changing of functional states occurs on the basis of certain pre-defined events on the network as illustrated in the Figure 2-8.
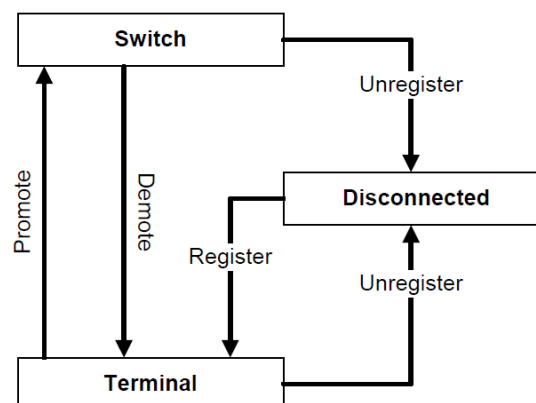
Figure 2-8 : The transition diagram of a Service Node

The three functional states of a Service Node as defined in this specification are:

Disconnected: Service Nodes typically initiates in a disconnected state. In this state a node cannot communicate or switch the data packets of another node.

The major task of a Service Node in a disconnected state is to try to register itself on an operational network within its reach.

Terminal: In this state a Service Node is allowed to communicate its PDUs by establishing connections, but it is not allowed to switch data for any other node.

Switch: In this state a Service Node can perform all Terminal functions. Additionally, it can forward from one device to another on the sub network. It represents the root of the tree.

The events and associated processes that trigger changes from one functional state to another are:

1. Register: a Service Node registers itself to the Base Node to confirm that this Service Node is member of a sub network. Thus, it is the transformation from the disconnected state to the Terminal state.

2. Unregister: The procedure that a Service Node releases itself from the Base Node. Unregister may be carried out for the purpose of changing the point of connectivity or for other reasons. Following this process, a Node is no longer a member of any sub network, resulting in transition to a disconnected state.

3. Promote: The procedure that a Service Node is qualified to switch traffic from other devices and serve as a branch point on the overall sub network tree. This process results in a change from a Terminal state to a Switch state.

4. Demote: The process in which a node stops serving as a branch point on a sub network tree. After a demotion, a node transits from a Switch state to a Terminal state. With these processes, the topology is resolved to build a tree. The root of the tree is the Base Node; the branches represent Service

Nodes in a Switch state and the leaves represent Service Nodes in Terminal states.

2.4.2.2 MAC Addressing

Each node has a universal MAC address 48 bits conformed to the EUI-48 as specified in IEEE Standard 802-2001. Each manufacturer generates this address in a production step and this can be used globally as the node identity when registering to the network. Every PRIME network

2.4.2.3 MAC functional description

A Service Node will start in a disconnected state. In a disconnected state, reception of any beacons on the channel is allowed. The service node stores the switch information that is obtained when a beacon is received from any new Switch Node. The Service Node chooses switch node from the switch information and register with that Switch Node.

2.4.2.4 MAC sub networks

In MAC sub networks, Base Nodes have a duty to create and maintain a sub network. In order to maintain the network, the Base Node needs to perform the following tasks:

1. Beacon transmission.

2. Promotion and demotion of terminals and switches.

3. Device registration management.

4. Connection setup and management.

5. Channel access arbitration.

6. Distribution of random sequence for deriving encryption keys

7. Multicast group management.

2.4.3   PRIME CONVERGENCE LAYER

The Convergence Layer (CL) specifies rolls of senders and receivers in the MAC network. In other words, this layer handles the traffic mapping which will be encapsulated into MAC SDUs. It controls system access, bandwidth allocation, and connection management and mesh topology resolution.
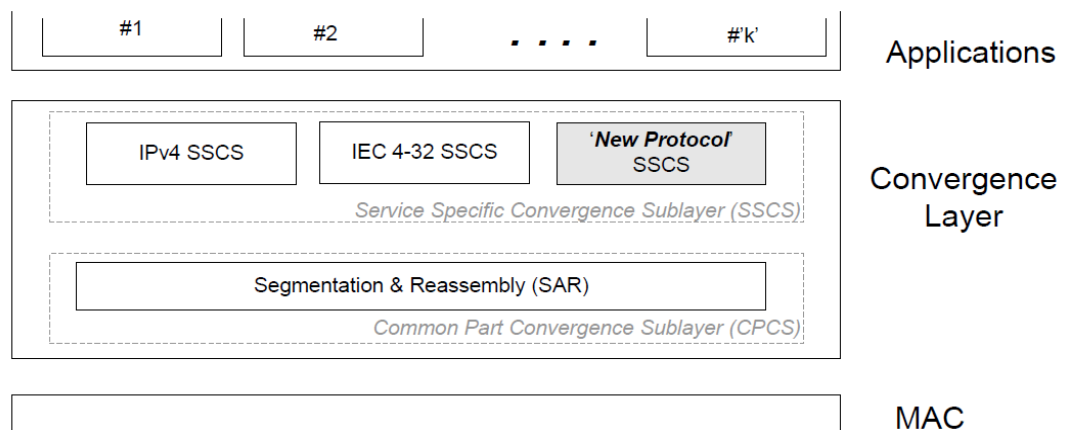
Figure 2-9 : Structure of the Convergence Layer

The convergence layer is separated into two sub layers:

2.4.3.1 The Common Part Convergence Sublayer

This section manages segmentation and reassembly service (SAR). The SAR divides a convergence layer data unit of the size bigger than specified into a number of smaller sized data units. The segmented unit will be assembled again at the receiving end SAR. Then the completed data unit will be send though to the application layer. PRIME defines a size for the segmented data unit all of convergence Sublayer to ease implementations.

2.4.3.2 The Service Specific Convergence Sublayer (SSCS)

The convergence sub layer allows a service node to communicate data only with the base node. The service node is prohibited to send data directly to other Service Nodes. Initially, service node uses IEC 61334-4-32 SSCS to create a PRIME MAC connection with the base to communicate unicast data. The base node is not allowed to generate connection with a service node. Once the connection has

been established, the base node will initiate sending all command and data request to the service node.

2.5 Current calculation method

The current signal is obtained from current transformer (CT) with a burden resistor *(Rb)* across. The current is obtained using voltage signal multiplied with the GAIN; Ai. The input voltage signal will be transform into digital one using Analog-to-Digital Converter, ADC, A/D with sigma-delta modulator. After that the digital signal is undergone digital filters with multiplication of such parameters as Kdif, Kint, Kut and Ki as shown in the Figure 2-10.
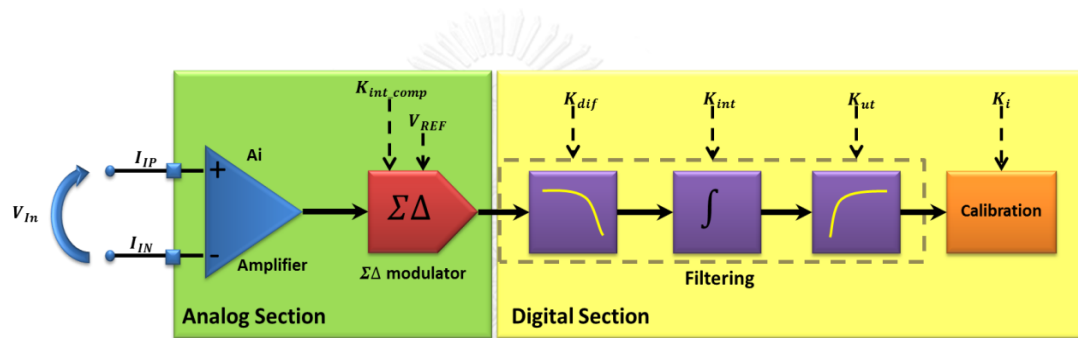
Figure 2-10: current calculation path

Given that u(t) voltage and current i(t) are obtained through:

$$u(t) = U_{max}.\sin(\omega t)$$

$$i(t) = I_{max}.\sin(\omega t + \varphi)$$

Since V_s is the current signal obtain through A/D with tuning

$$V_s = C.\sin(\omega t + \varphi)$$

C is obtained by:

$$C = I_{max}.R_b.(A_i/V_{ref}).K_i$$

Thus V_{si} is obtained by the integral of V_s

$$V_{si} = -\left(\frac{C}{\omega}\right).\cos(\omega t + \varphi).K_{int}$$

Thus:

$$i_{rms}K_sK_{int} = \sqrt{\frac{1}{T}\int_0^T V_{si}^2\, dt}$$

2.6   Voltage calculation method

Voltage signal obtained from voltage divider circuit is multiplied with GAIN A_U. Then the analog voltage signal undergone ADC with sigma-delta modulator will be converted into digital value after it is multiplied with the filter constant K_{dif}, K_{int} and K_{ut} as in in order to minimize the inaccuracy of the digital signal. Because the voltage obtained from the ADC can be inaccurate, there is also a calibration module implemented as shown in the Figure 2-11
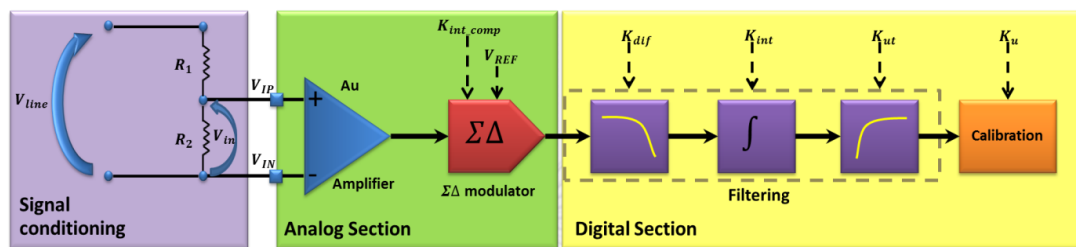
Figure 2-11: Process to find voltage value

Since V_d is the voltage signal obtain through ADC with tuning

$$V_d = A.\omega.cos(\omega t).K_{dif}$$

Given that, "A" equal to:

$$A = U_{max}.\left(\frac{R2}{(R1+R2)}\right).\left(\frac{A_U}{V_{ref}}\right).K_U$$

Thus V_{di} is obtained from the integral of V_d

$$V_{di} = A.\sin(\omega t).K_{dif}.K_{int}$$

Thus:

$$u_{rms}k_D = \sqrt{\frac{1}{T}\int_0^T V_{di}^2\, dt}$$

Given that

$$k_D = \frac{A}{U_{max}} = \left(\frac{R2}{(R1+R2)}\right).\left(\frac{A_U}{V_{ref}}\right).K_U$$

A_i is the current channel gain which is equal to 8

A_u is the voltage channel gain which is equal to 4

K_{int} is the gain the integrator circuit at 50 Hz which is equal to 0.815

K_{dif} is the gain of differentiator at 50 Hz which is equal to 0.6135

K_s is the Current sensor sensitivity which is equal to 0.88

V_{ref} is the internal voltage reference which is equal to 1.23

2.7   Power calculation method

$$P_1 = V_d.V_{si}$$
$$P_2 = V_{di}.V_s$$

Thus the power is equal to:

$$Power = (\frac{P_2 - P_1}{2})$$

Chapter 3

Hardware of the smart meter

3.1   Components of the Smart meter hardware

The smart meter hardware developed in this thesis has two major tasks which are firstly to perform energy measurement and secondly to communicate with the data concentrator unit as demonstrated in the Figure 3-1 . The smart meter hardware consists of four major modules; a microcontroller, a display, an energy measurement and a power line communication module as depicted in the Figure 3-2.
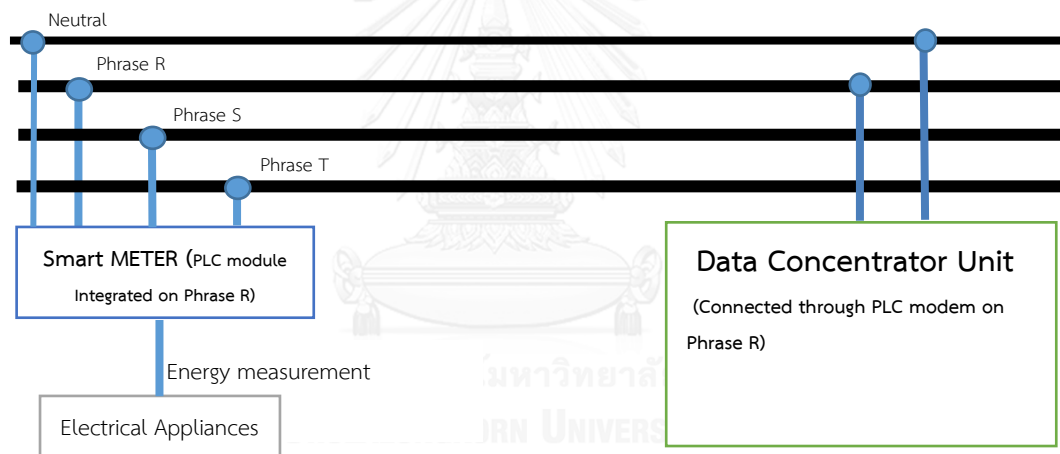
Figure 3-1: Hardware setup for the smart meter

The smart meter operates in the 3 phrase 4 wire system with nominal voltage of 220 volts, frequency of 50 Hz, and maximum current rating of 100 A.

Hardware operation begins with the measurement task where analog signals of voltage and current are measured through a voltage divider circuit and current transformer (CT) across a burden resistor (Rb), respectively. The analog signals are translated into digital data using ADC, STPMS2 IC and further calculated to obtain energy data using a hardware-based energy calculator STPMC1 IC. A selected group of the energy data is then displayed on a low power glass LCD. The

microcontroller STM32L152VBT then records energy data on MCU flash memory by every 15 minutes for further consumption behavior analysis and planning.

Secondly, the smart establishes PLC connection with the data concentrator through an operation of the power line modem, ST7590 IC. In this operation, the microcontroller exchanges commands and necessary data though serial connection with the power line modem. When connection between the smart meter and the DCU is created, the smart meter can response to the DCU request for energy data.
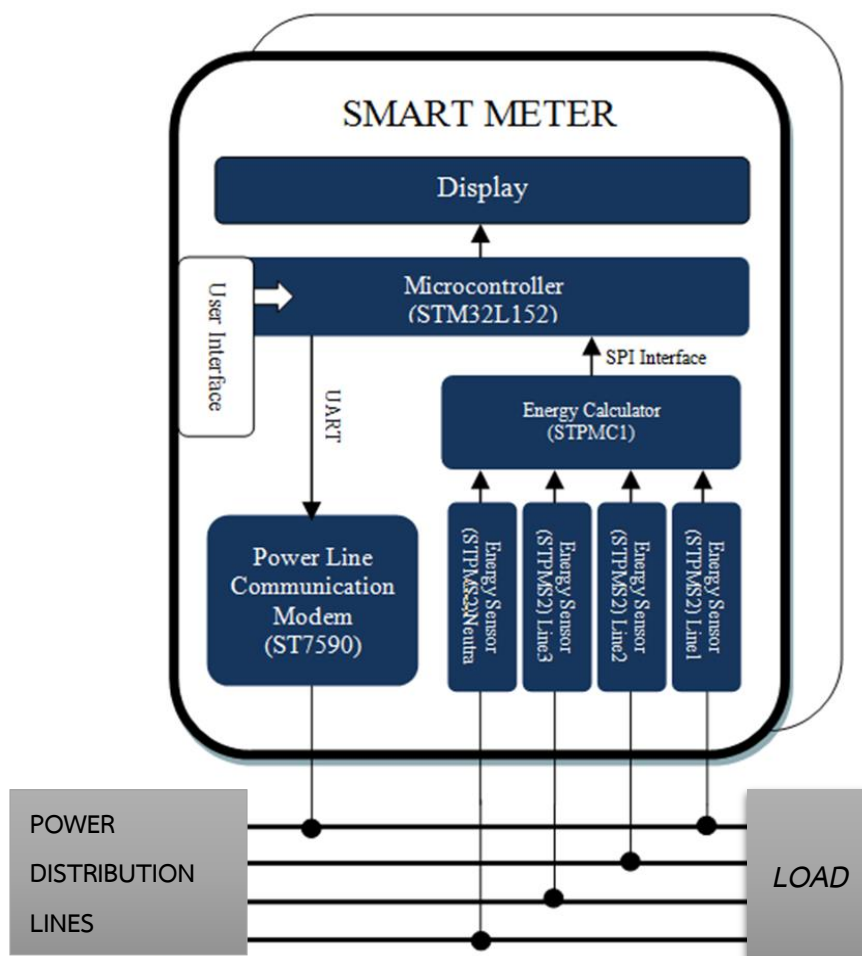
Figure 3-2: Hardware block diagram of the smart meter

The smart meter consists of the following major components;

3.1.1   Microcontroller unit: STM32L152VBT6 [5, 6]

The STM32L152VBT6 IC is a 32-bit low power microcontroller, typically operating around 1.8 to 3.6 V with maximum operating frequency at 32 MHz. It is manufactured by STMicroelectronics. The STM32L152VBT IC is responsible for processing energy data such as real power, RMS current and voltage, power factor, and for allocating tasks to communication module. The STM32L152VBT IC also contains:

1.   128 KB flash memory which is used to store temporally metering data;

2.   SPI interfaces which are used to control the energy calculator IC, STPMC1 and an external flash memory;

3.   USART interfaces to control the power line modem ST7590 and to connect with an RS232 module for debugging purpose.

GPIO ports which are used to drive a 15-digit glass LCD, two control buttons, an energy blinking LED, a debugging LED, three 6 relay-controlling transistors, a backup-battery manager and two external oscillators for system clock generation. Hardware peripheral and interconnections of Microcontroller unit is shown in the Figure 3-3.
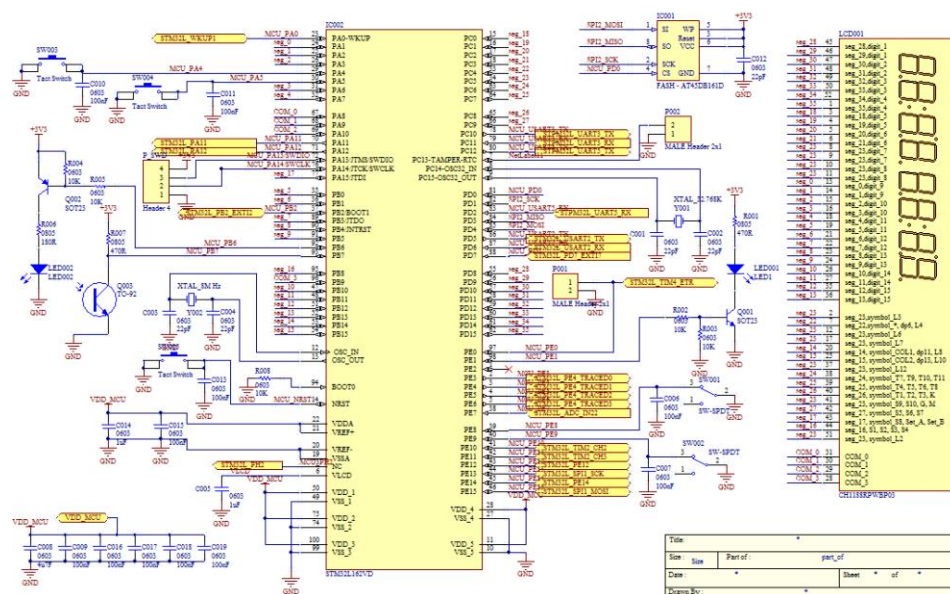
Figure 3-3: Microcontroller and display unit

3.1.2   Electrical Measurement Unit [7, 8]

The measurement unit consists of two major devices; an energy calculator (STPMC1) and energy sensor (A/D convertor: STPMS2) There circuit and inter connection are shown in the Figure 3-4 and Figure 3-5.
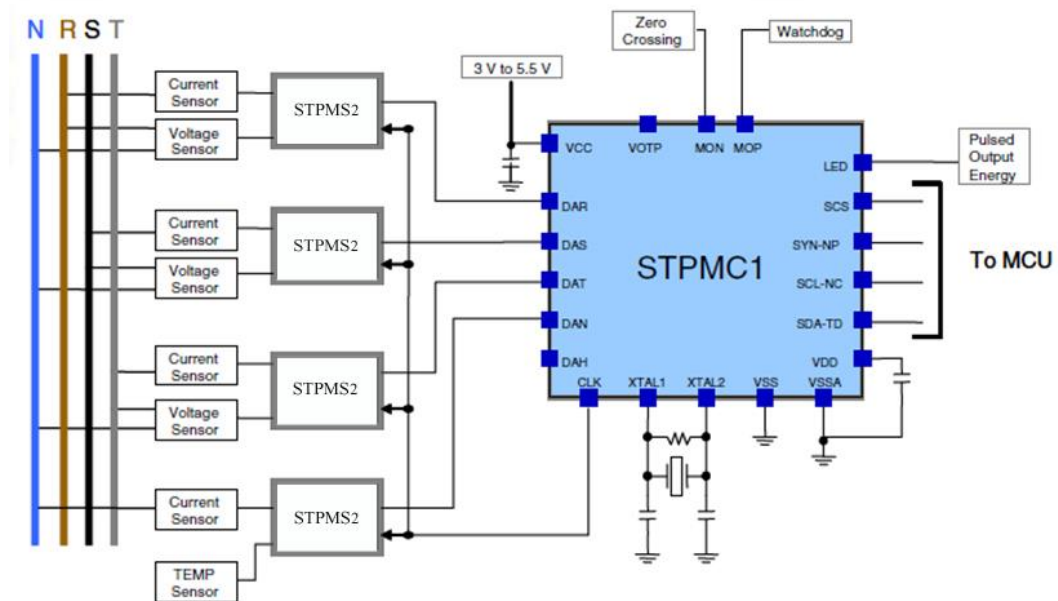
Figure 3-4: block diagram of the energy measurement unit

3.1.3   Analog to digital convertor: STPMS2 [8]

STPMS2 is a 16 bit analog-to-digital convertor with maximum input voltage of ±1.23 volts and maximum voltage-to-current sensing input 0.15 volts. The IC operates with reference voltage of 1.23 volts. There are four STPMS2 ICs used in the design for voltage and current measurement. STPMS2 measures analog signals from voltage sensors via a current divider circuit and detect current form through a current transformer or shunt resistors.

3.1.4   Energy Calculator: STPM C1 [7]

The STPMC1 device is an energy calculator. It is used in combination with STPMS2 ICs, it implements all the functions needed in a 3-phase energy meter. It can be combined with a microprocessor to provide multi-function energy meters. The calculator has five input data pins. The first three receive the voltage and current information of the phases. Each data input processes delta-sigma signals,

multiplexed in time and generated by the STPMS2 device. All the data recorded by the STPMC1 are accessible through an SPI port, which is also used to control and calibrate the device. The configuration and calibration data can be saved in a 112-bit OTP block, or dynamically set in microprocessor-based meters.
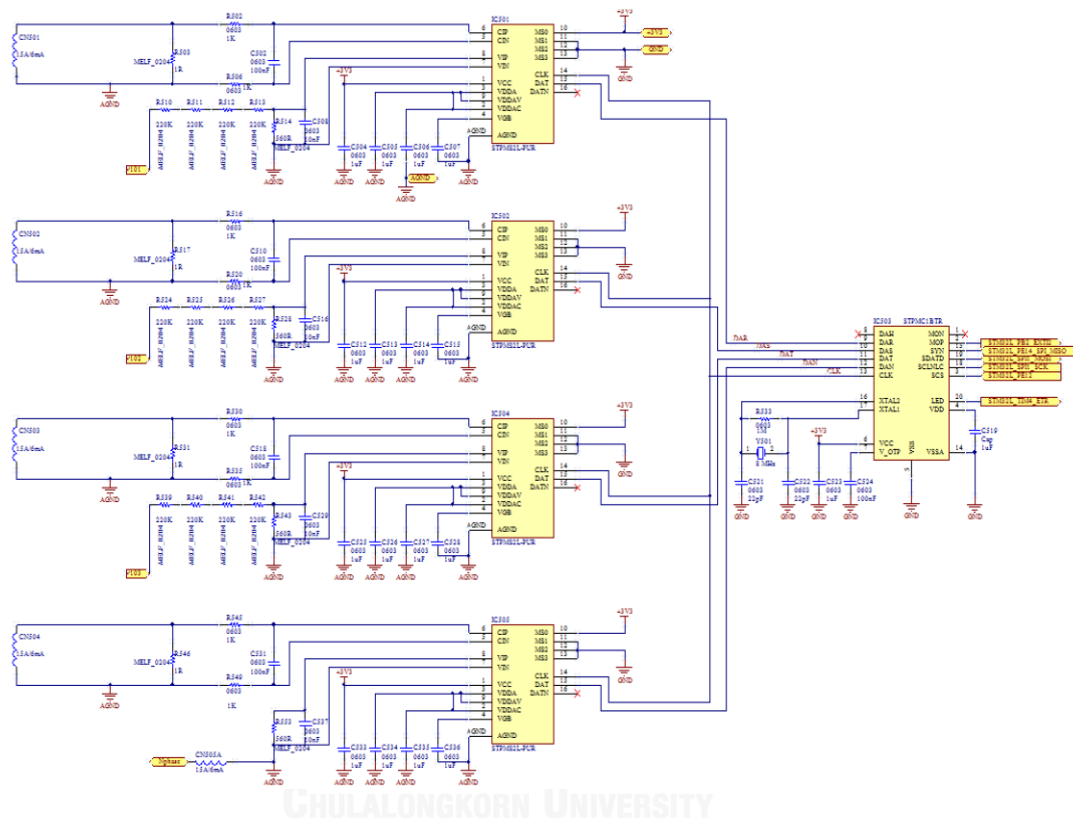
Figure 3-5: Schematic of the energy measurement module

3.1.5 Power line communication Module [9]

Functions of ST7590 IC are to manage PRIME-PLC communication. It is developed for smart metering and smart grid applications with a 128-bit AES encryption hardware. The IC provides firmware incorporating PRIME compliant PHYSICAL and MAC layers as well as IEC 61334-4-32 data link layer. The ST7590 IC's analog front end provides analog-to-digital and digital-to-analog conversion, automatic gain control and embedding a power line driver delivering output current up to 1 A rms. The block diagram of PLC communication with ST7590 acting as the communication manager is illustrated in Figure 3-6.
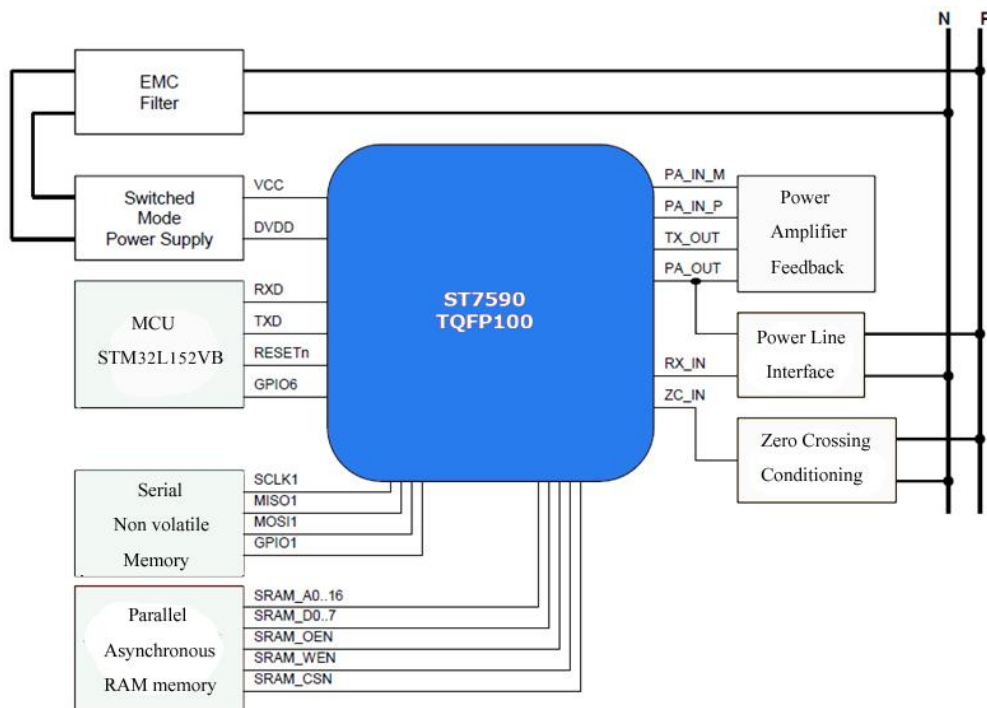
Figure 3-6: PLC communication module with external memories attached

3.1.6 Power supply module [10]

Functions of the power supply module are to generate three sets of DC voltage supplies out of the 220 Vac power lines. The voltage is regulated using PWM switching regulator ALTAIRR04-900TR of STMicroelectronics for low consumption and. The first voltage supply is for the microcontroller circuit and other device ICs operating with 3.3 VDC. The second supply is a 12 VDC which is required by ST7590 PLC modem and relay circuits. The last supply is a 3.3 volt isolated supply which is required by analog part of ADC STPMS2 module. The schematic of the power supply is illustrated in the Figure 3-7.
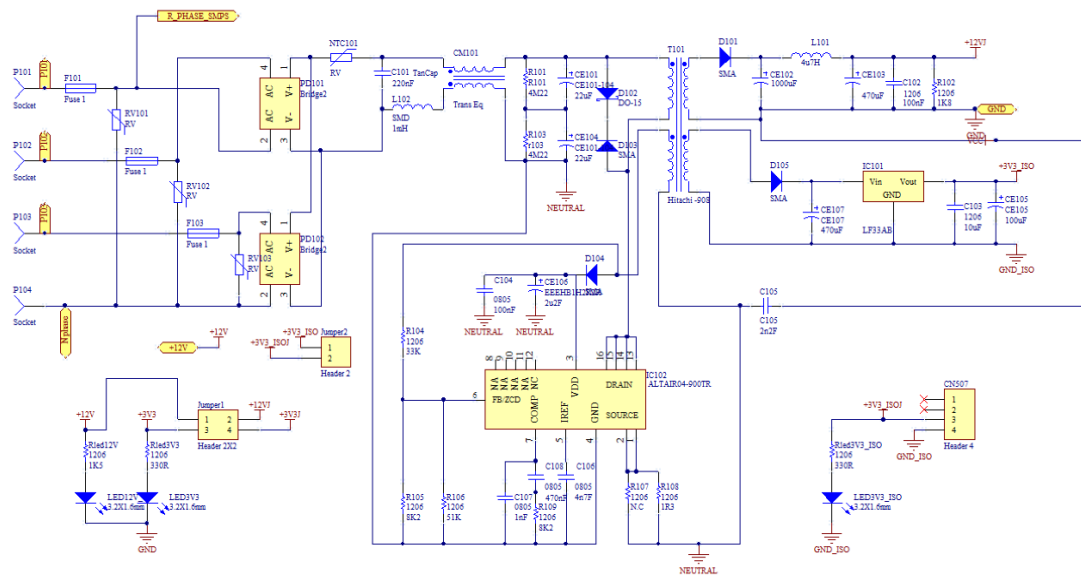
Figure 3-7: Circuit diagram of the power supply module

3.2   PCB design [11]

The prototype PCB is designed using Altium Designer software which is widely used PCB design software. The software allows user to use auto routing and create multi-layer PCB and can generate 3D result of the PCB. It also provides standard library for device dimensions and pin sizes of various electronic components. User can also specify PCB design rules to be compatible with the technology that the PCB manufacturer provides.

3.3   Smart meter hardware prototype

The smart meter prototype consists of two PCBs located on top and bottom with pin header interconnection between the two boards.

On the top board, there are microcontroller and external flash memory, LCD display, Energy count LED, push buttons for user interfaces, a serial wire debug port and USART debugging port with an opto-isolator circuit to isolate reference grounds of the smart meter and computer connected to it.

On the bottom board, there are energy measurement module (STPMC1), power supply module, PLC communication module (ST7590), and relay module, with input terminals connected to a 220V, 3 phrase 4 wire transmission lines.

Figure 3-8: Microcontroller and display PCB layout

Figure 3-9: the bottom PCB with PLC module, power supply, relays, and energy measurement module.
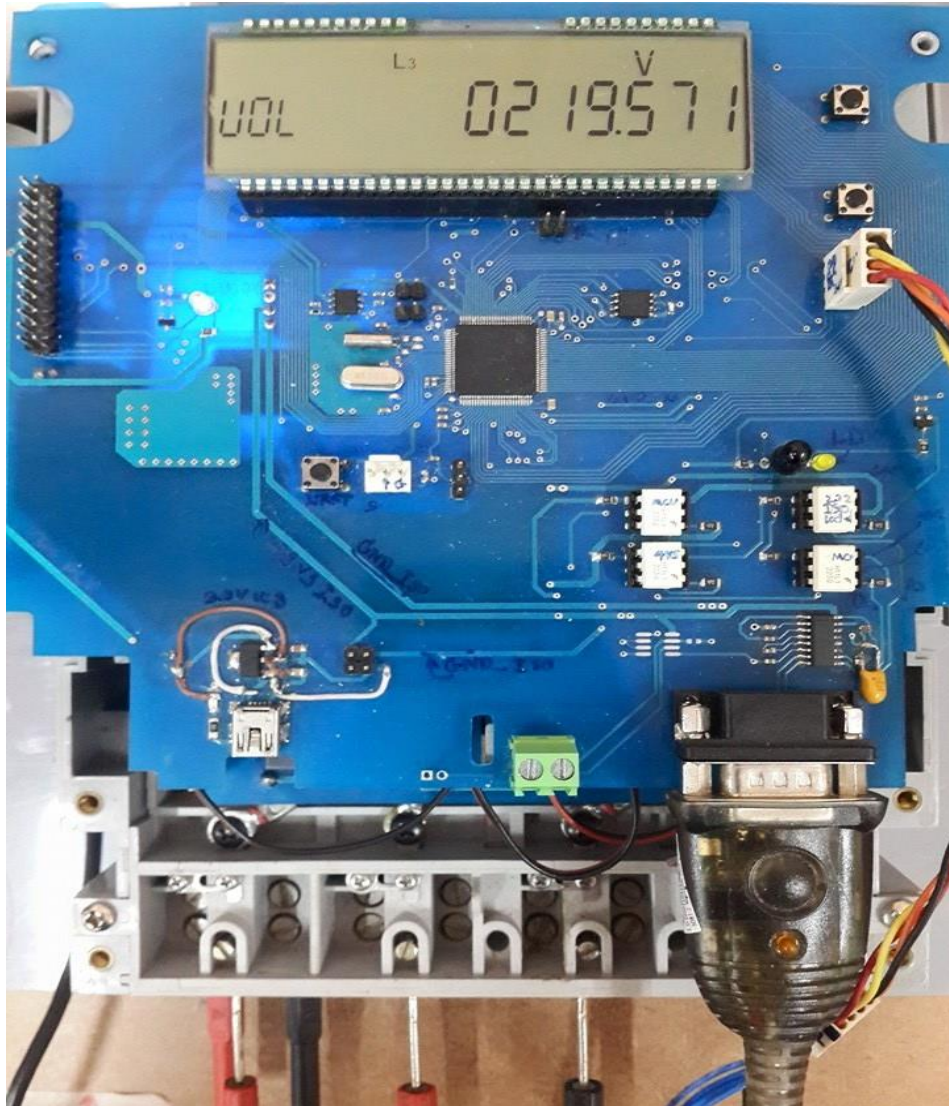
Figure 3-10: Smart meter hardware prototype (top board)
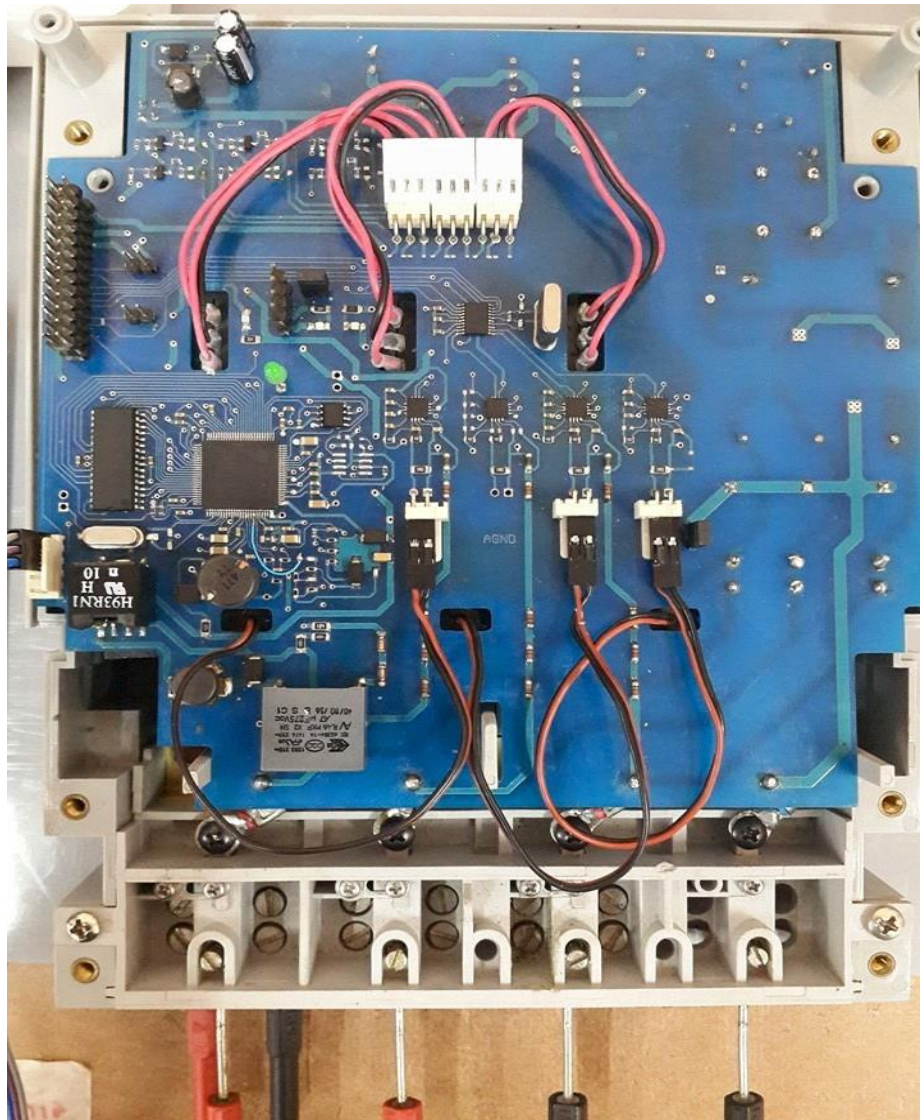
Figure 3-11: Smart meter hardware prototype (bottom board)

Chapter 4

Firmware of the smart meter
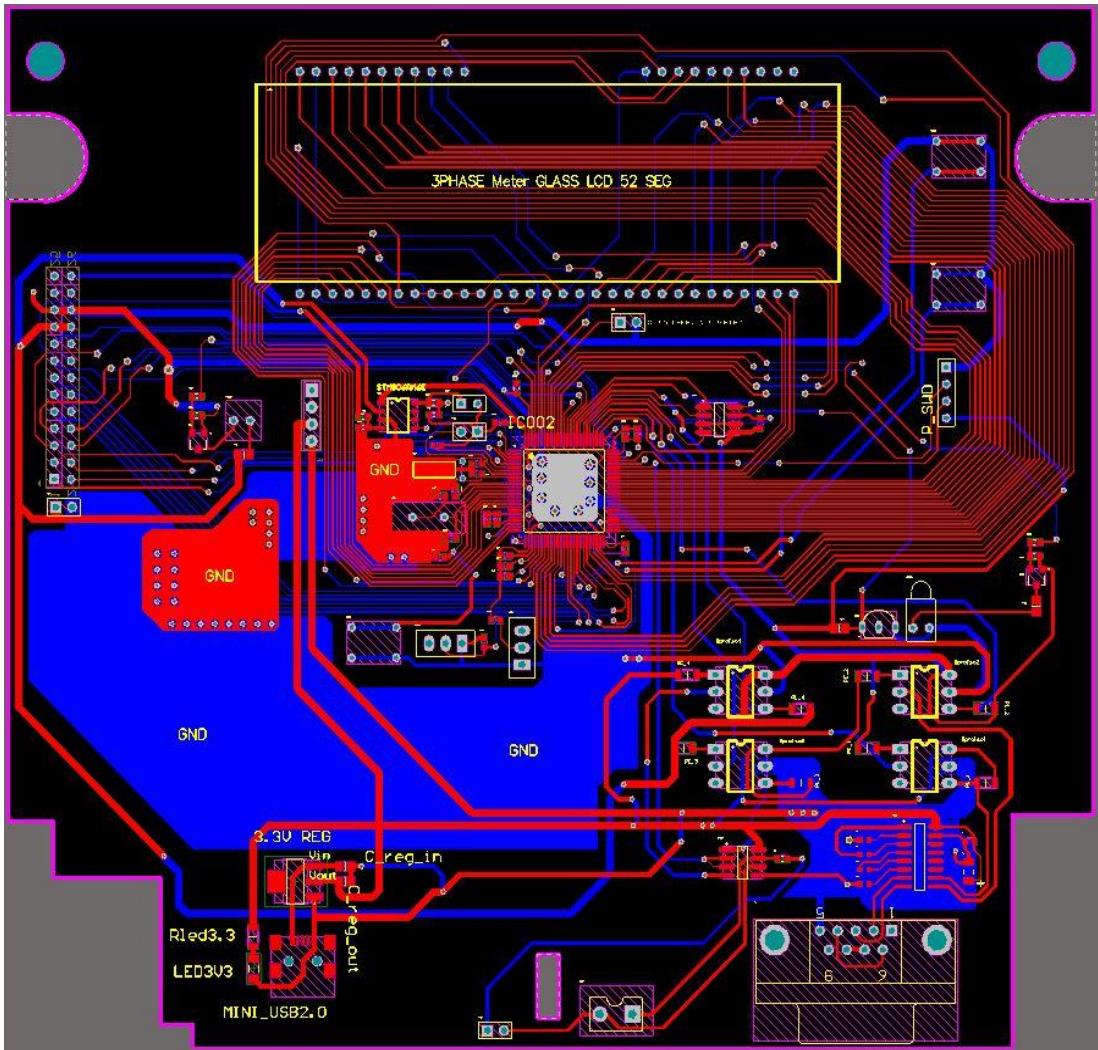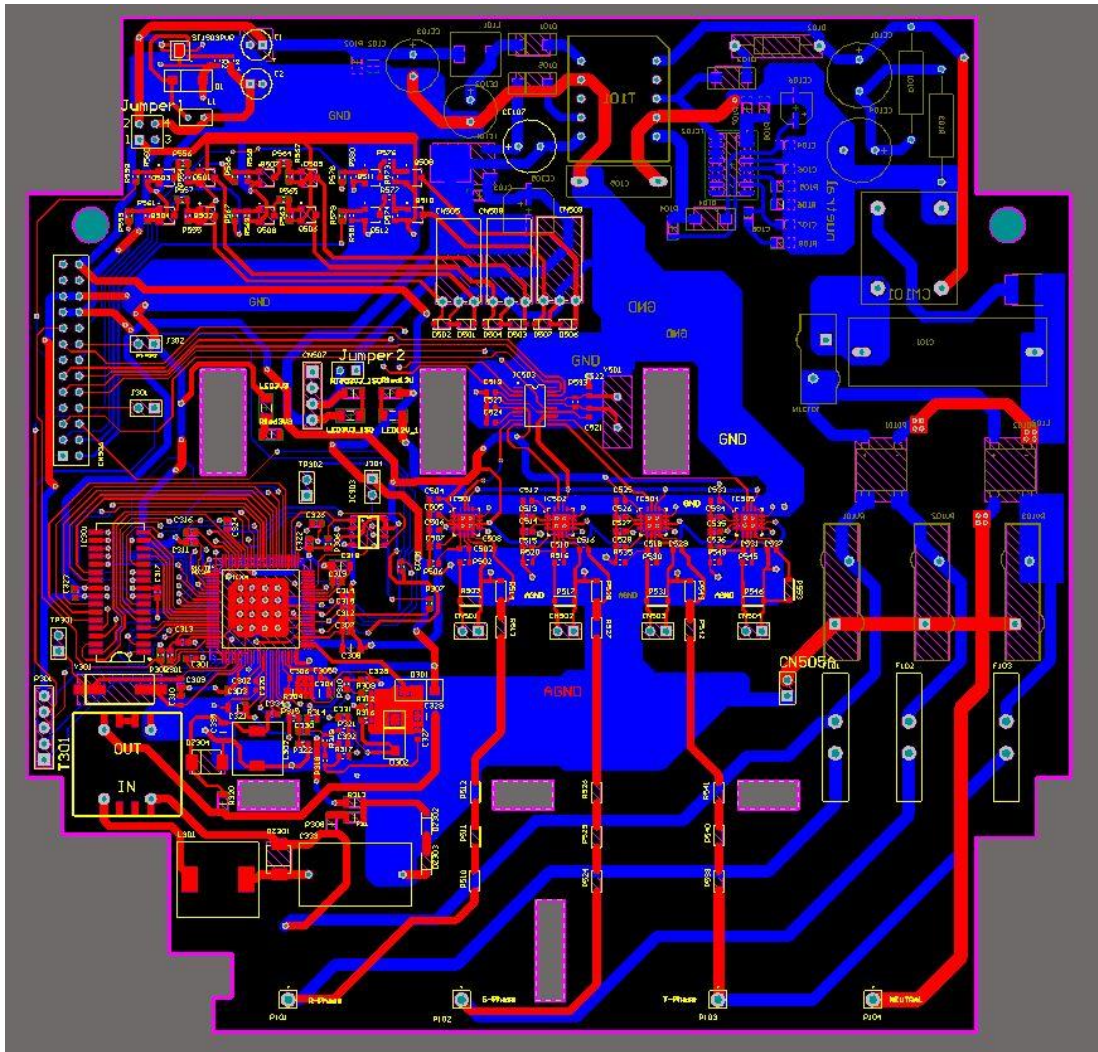
This chapter discusses the firmware design for the smart meter to perform energy measurement and communicate with a data concentrator unit. The firmware of the smart meter can be categorized into 2 groups as follows;

1. **The smart metering driver**: its function is to make the smart meter perform energy measurement properly;

2. **The communication firmware:** its functions are to establish and release connection between the smart meter and the data concentrator unit (DCU), and to manage data transfer services, as specified in the DLMS/COSEM and PRIME protocols.

4.1 The smart metering driver

The smart metering driver is a C language program developed for the microcontroller and hardware peripherals of the smart meter. Its function involves routine energy measurement and controls of physical interfaces to the user.

4.1.1 Structure of the hardware driver

The driver is developed to control microcontroller internal modules, and to:

1. Control the glass LCD display, the energy LED and the status LED;

2. Control automatic meter reading STPMC1 module through SPI interfaces;

3. Calculate arithmetically electrical power and other involving properties;

4. Control energy data recording process on the external flash memory;

5. Initialize PLC ST7590 module through USART interface;

6. Control user interfaces connected to GPIO ports.

The components of the smart meter hardware driver are shown in the Figure 4-1.
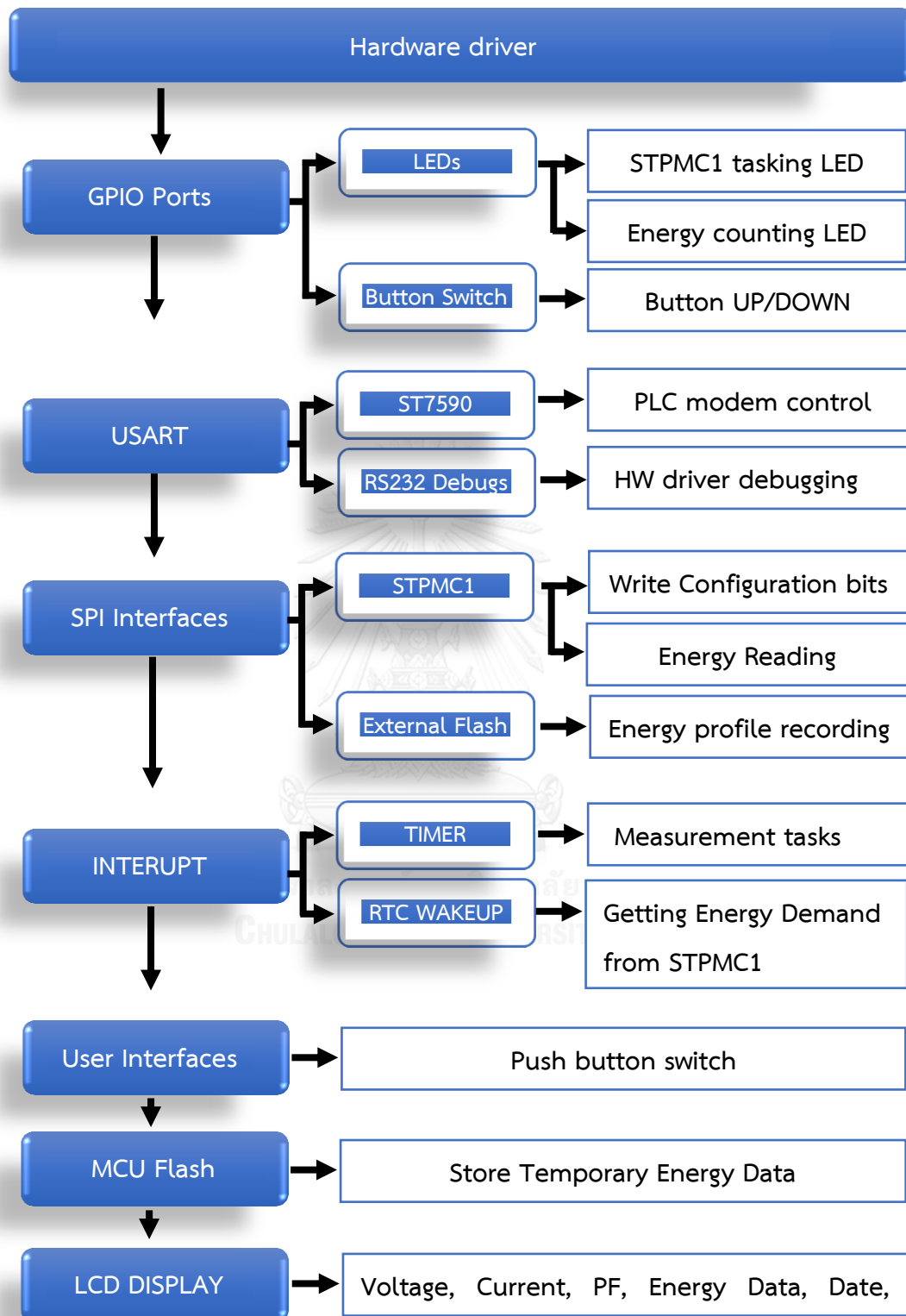
Figure 4-1: Structure of Smart meter's hardware driver

4.1.2 Smart meter driver's operations

The Smart meter driver is developed to deal with hardware control. The driver begins its operation by initialing shared data registers, then setting MCU configuration to activate connection with STPMC1, ST7590 module, and other external devices including buttons, LEDs, an LCD and an external flash memory. Next, the driver creates real-time-operating-system (RTOS) based threads for different functional modules so that the MCU can simultaneously handle various threads to perform their functions according to their priorities and delays. Finally, the Real time Scheduler is called to begin the threads and they will run routinely unless the hardware driver is interrupted or restarted. The hardware driver flow is in Figure 4-2.
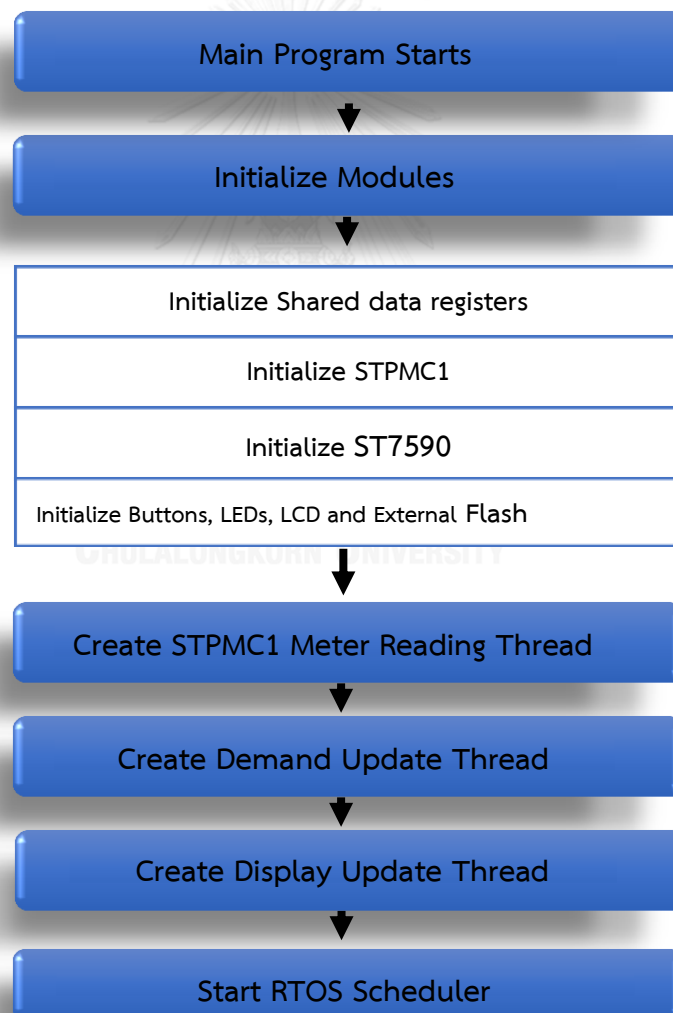
Figure 4-2: Smart meter driver flow

4.1.2.1 STPMC1 Meter Reading Thread

In general the thread consists of 15 subtasks as depicted in Figure 4-3 separated by a timer delay of 0.00625 seconds. Therefore STPMC1 completes its energy reading every 0.09376 seconds. The meter reading thread has the procedure as follows:

1. Setup reading process of the STPMC1;

2. Read internal data registers of the STPMC1;

3. Calibrate voltage and current;

4. Check the parity bits to verify that the received data is correct;

5. Check status of the last data received;

6. Check whether the Reactive Energy register of STPMC1 is full;

7. Check whether the Active Wideband Energy register of STPMC1 is full;

8. Check whether the Active Fundamental register of STPMC1 is full;

9. Add up value of the last measured voltage;

10. Add up value of the last measured current;

11. Compare accumulated energy with the energy limit. If the accumulated energy exceeds the limit then add up an integer number by a value of one. Each integer number represents one unit of energy consumption. In order to obtain the overall demand, the integer number is multiplied by the value of the energy limit.

12. Perform similar process as subtask 11 for the Active energy, and Active Fundamental energy, Voltage and Current for the task 13 to 15.
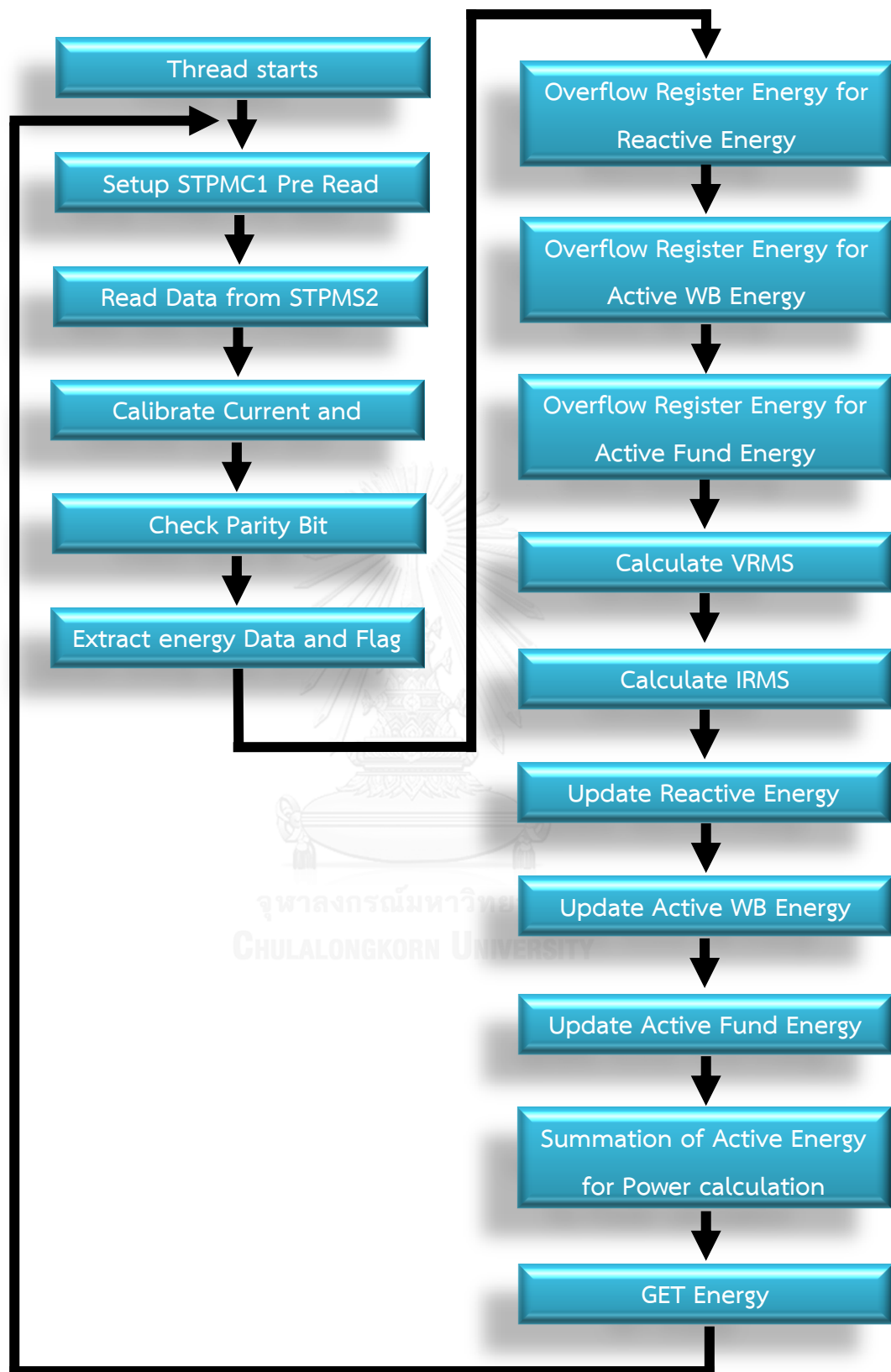
Figure 4-3: STPMC1 Meter Reading Thread

4.1.2.2 Demand Update Thread

This thread is responsible for updating demand record to the external flash. Once the thread starts, it gets the demand data from the MCU register together with the date and time from the RTC module to create time stamp for the recorded demand. Every 15 minutes, the demand is transferred to store in the external flash memory via SPI interface. The flowchart of the demand update thread is shown in the Figure 4-4.
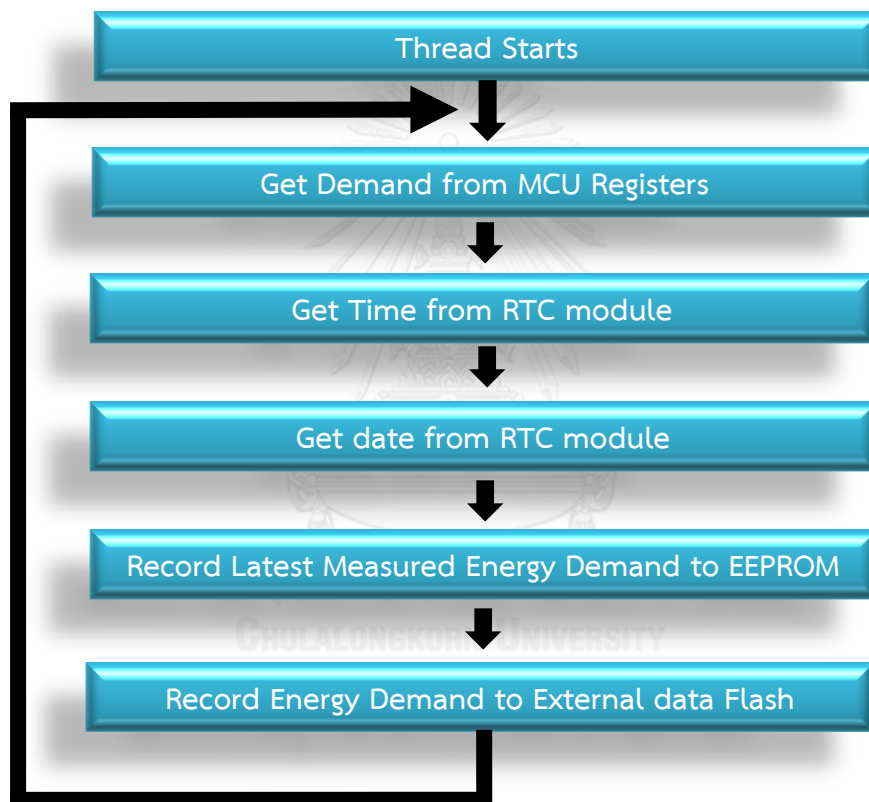
Figure 4-4: Demand Update thread

4.1.2.3 Display Update Thread

The display update thread is responsible for controlling the LCD module that is connected to MCU GPIOs and fetching energy data from MCU's EEPROM to present on the LCD. The energy data is presented in routine one type at

a time of 5 seconds. The routine begins with displaying time and date and follow the order as illustrated in the Figure 4-5.
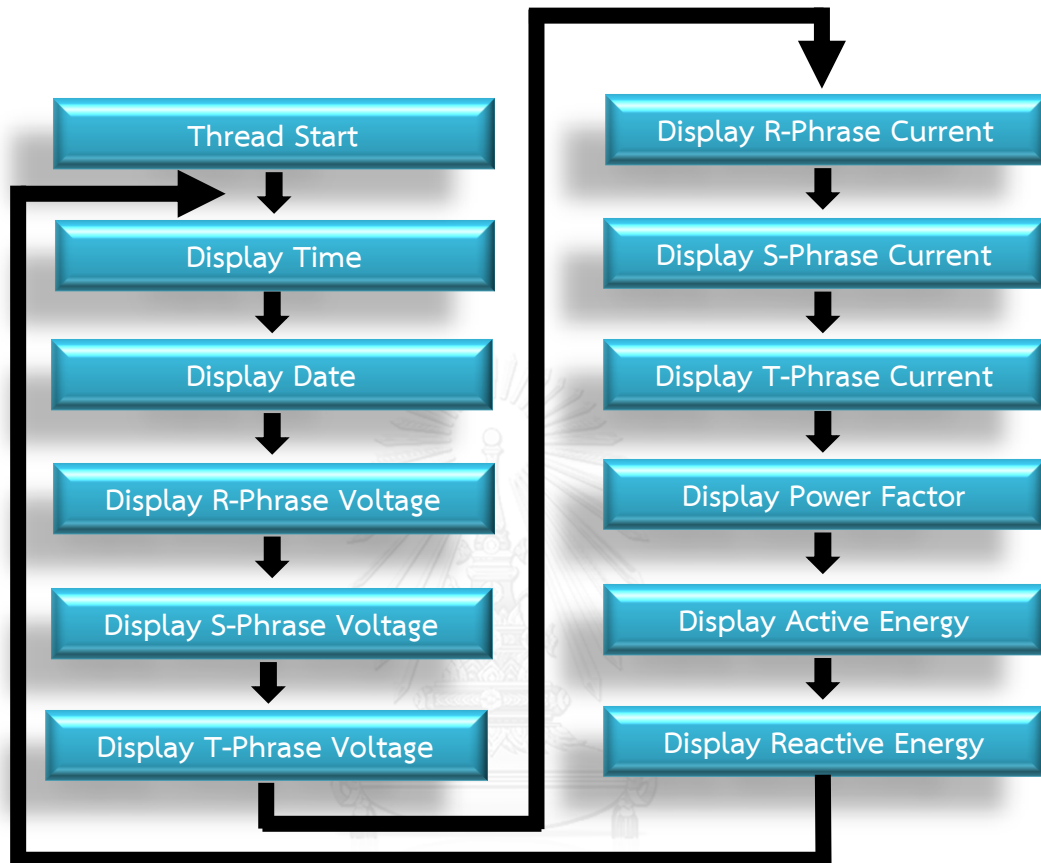
Figure 4-5: the display update thread

4.2   The communication firmware

Communication between any two devices according to DLMS/COSEM has to be based on client-server model. In this model the smart meter acts as a server providing services to the data concentrator whose role is a client.

4.2.1   Smart meter's communication profile based on DLMS/COSEM and PRIME

The communication profile used in the smart meter is based on DLMS/COSEM and PRIME-PLC protocols as presented in the Figure 4-6. The profile can be categorized into 5 sections as follows:

1. Application process: It contains the main thread. It defines functionalities and tasks of the smart meter and provides interface to the user.

2. Application layer: It contains the COSEM application layer thread. It also interprets commands received from the Application Process and follow specific procedures to call services of the lower layers as specified in the DLMS/COSEM protocol.

3. Convergence layer: This part is responsible for the initiation of low layer connection establishment;

4. Datalink layer: This layer contains functions to control the data transmission;

5. Physical layer: Its function is to find synchronization, monitor authentication of data packet and also assembly and disassembly the protocol data units.

Figure 4-6: Smart meter's communication profile based on DLMS/COSEM and PRIME-PLC protocols

The communication firmware is designed using the concept of threads to allow execution of multiple tasks simultaneously. There are three communication tasks responsible for different functionalities. These tasks are:

4.2.2 The main thread (COSEM_AP);

The main thread actually is the application process and responsible for managing and corporate with COSEM application layer thread and power line communication (PLC) thread. Flow chart of the main thread is presented in the
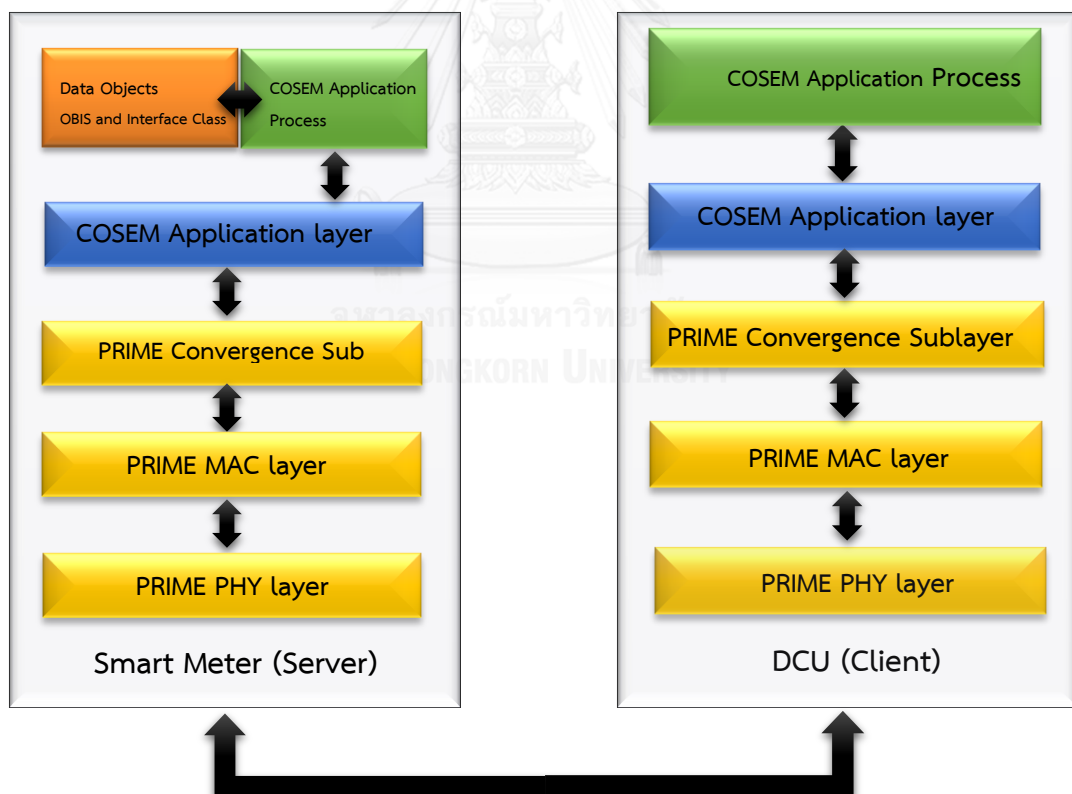
Figure 4-7. When there is incoming protocol data unit (PDU) detected at the PLC modem of the smart meter, the PLC thread has to request the PLC modem to obtain the arriving PDU. The process by which the PLC thread uses for obtaining data frame from the PLC modem is presented in Figure 4-9.

When an application protocol data unit (APDU) received via PLC thread is decoded, and the application layer its identifier is set by the PLC thread, the COSEM application layer thread will call relevant service to prepare the APDU for the COSEM Application process of the main thread to further process the APDU. When the COSEM_AL thread already prepare the APDU for the COSEM application process, it will set the service identifier and acknowledge the COSEM application process or main thread that the APDU is ready to process. When the main thread detects request via the service identifier, it will find out the relevant service and response accordingly.

In the case the GET-Ind is set, the main thread will collect Logical Name, Class Id, and Attribute Id from the data structure so that it can use for searching value of the object in the database. After that when the request data id is found, the main thread will put the data into a data structure of a response service namely GET-Res and then invokes service of such a data type in the COSEM application layer to set service identifier to inform the COSEM_AP thread that the response PDU needs to be send out to the DCU.

In the case that SET-Ind is set, the COSEM application process will collect Logical Name Class Id and Method Id from Data structure to search for the requested object in the data base. However instead of obtaining a data unit, this is the call for access to the service and then informing result of the access to the DCU using ACTION-Res. Then the main thread call for service in the application layer to

set service identifier to inform COSEM application process of the outgoing APDU needed to be transmitted to the DCU.
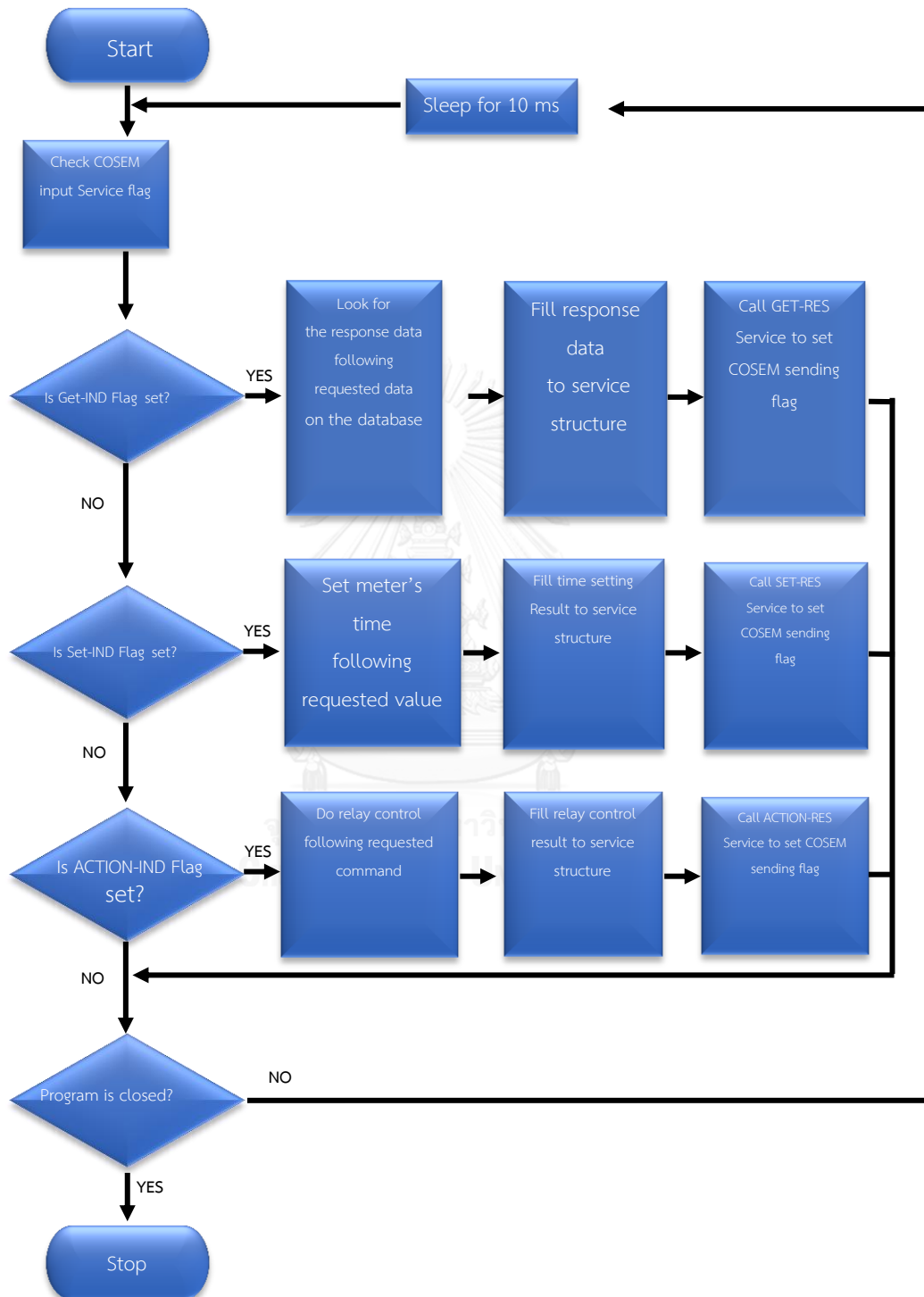
Figure 4-7: flow chart of the main thread (COSEM_AP)

4.2.3 The COSEM application layer (COSEM_AL) thread;

This thread is responsible for managing transmission of the data whose length is exceeds the buffer size acceptable by the smart meter. The COSEM_AL thread separates a long length APDU into a group of smaller size PDU blocks before encoding them and transmitting block by block. Similarly, when there are incoming PDU blocks, the COSEM_AL receives the data block by block and decode the PDU and assembly these blocks into the original full-length PDU. If the PDU size is smaller than the buffer size negotiated with the client DCU, the COSEM_AL thread only pass the PDU to the other layers. Flowchart of the COSEM application thread is shown in the Figure 4-8.
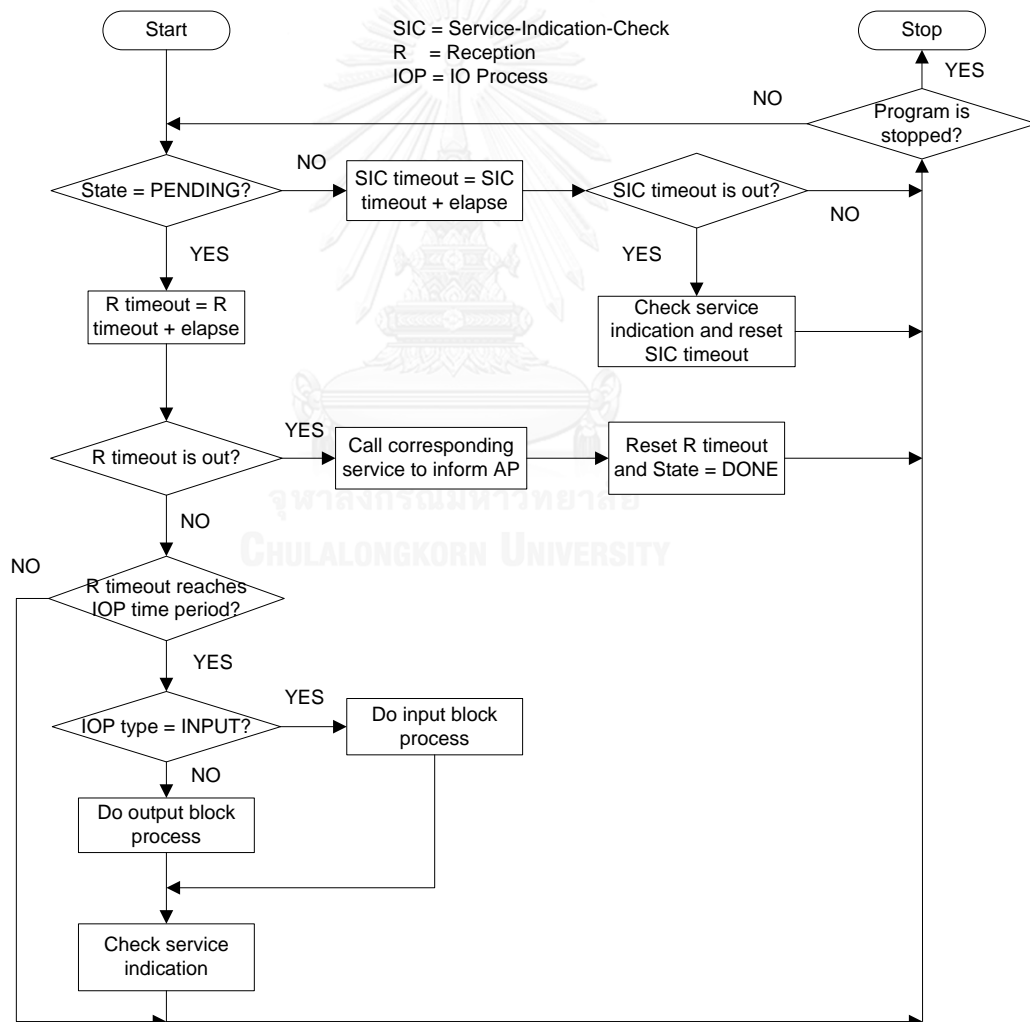
Figure 4-8: Flowchart of the COSEM application thread

In the, when the COSEM_AL thread enter into the status "operation done" and set timeout for the next service indication check, and set the timeout to await the next incoming data sent from the DCU equal to zero. When the thread is operating, it will check whether its operation status is "operation done" or "operation pending". When the thread completes its operation it will increase service-indication-check timeout to be equal to the elapse time received from the function input. This elapse time will be used as the time that the COSEM_AL thread goes to sleep and wait for the next operation.

The thread then check SIC timeout if it reaches the predefine timeout. When the time is reached the thread will check if there is any incoming PDU and set SIC timeout to zero and end the process. While the thread is running, it will increase R timeout by the time elapse. Then the thread will check if the R timeout reach the predefine value. When the timeout is due, the thread will call involving function to inform the application process thread that there is failure at the DCU transmission end because there is no incoming PDU within the timeout. If the timeout is not yet due, and the R timeout does not reach the IO Process Time Period, the thread will finish operation in this round. If the R timeout reach IO process Time Period within timeout, the thread will operate in input-output mode. In this mode the thread will verify IO process type whether the thread has to send PDU out or receive an input PDU or to manage the decoded PDU. After that, the thread will check if there is an incoming PDU as the last operation in this round.

4.2.4   The power line communication (PLC) thread

This thread is created for communication over the power line as defined in PRIME standard. The PLC thread is implemented on the microcontroller to control the PLC modem (ST7590 IC) via USART interface. The PLC thread is responsible for monitoring and gathering incoming PDUs from the PLC modem. The PLC thread is automatically invoked by the predefined time and sleep for a specific delay time. When the PDU is received completely, the PLC thread will pass the PDU up to the COSEM_AP thread for further processing.

As can be seen in Figure 4-9 the, the PLC thread begin its operation in the status "done" and set time to wait for the MCU to send PRIME-GetState request command to the PLC modem to inquire the Modem-state-check timeout and set the Reception timeout to await the responding PDU from DCU equal to zero.

When the thread is in running phase, it will check the operational status whether in the "done", "pending" or "state management. In the case that PLC thread is in "done" status it will increase MSC Timeout by the value of Elapse Time which is the input argument of the function and this is equal to the thread's sleep time before it will be awake again when the timeout is due. After that, when the MSC Timeout reaches the predefined period, the thread will send data frame request-type PRIME-GetState to the PLC modem to inquire the modem indication parameter. Then the thread enters the pending status awaiting the report-type PRIME-GetState data frame from the PLC modem. At the same time the PLC thread sets MSC Timeout to zero and end operation in this round.

In the case that the PLC thread is in the pending status, it will increase R timeout by the value the elapse time. After that, the thread will check whether the R Timeout reach the limit. If the R timeout is due, the thread will assume that there is a failure at the DCU transmission end because there is no received PDU detected in time. If the R timeout is not yet due, and the thread has not yet enter the Buffer-Collecting-Check time period received, the thread will end its operation in this round. However, if the R Timeout is not due in that period, the thread will automatically detect the received buffer from the USART interface. The data frame typically will not arrive all at the same time. Therefore, the PLC thread has to verify data frame in the buffer. If the data frame is not complete, the PLC thread will wait for the incoming data to arrive in the next operation round and verify it again. If the data frame is complete, the thread will verify CRC of the data frame. If CRC is incorrect, the thread will reset R timeout equal to zero and enters "done" status. If the CRC is correct, the thread will reset R timeout to zero and enter "Management State".

In the "Management State", the PLC thread will determine type of data frame that passes CRC verification within the Buffer-Collecting-Check time period. The PLC thread will then call service relevant to the type of data frame. After that, the PLC thread will check if there is any failure occurring in the communication through CRC verification. In the case that report-type PRIME-Getstate is detected or other report-type data frame is detected and the data frame is verified as correct, and there is an identifier is set, the PLC thread will call service as requested and determined by the identifier to create data frame of request-type and send it to the PLC modem so that the modem will send the data frame as requested. The thread then enters "Pending" status awaiting a report-type data frame from the modem. If

the verification result is other than this, thread will enter "done" status to start new operation round.

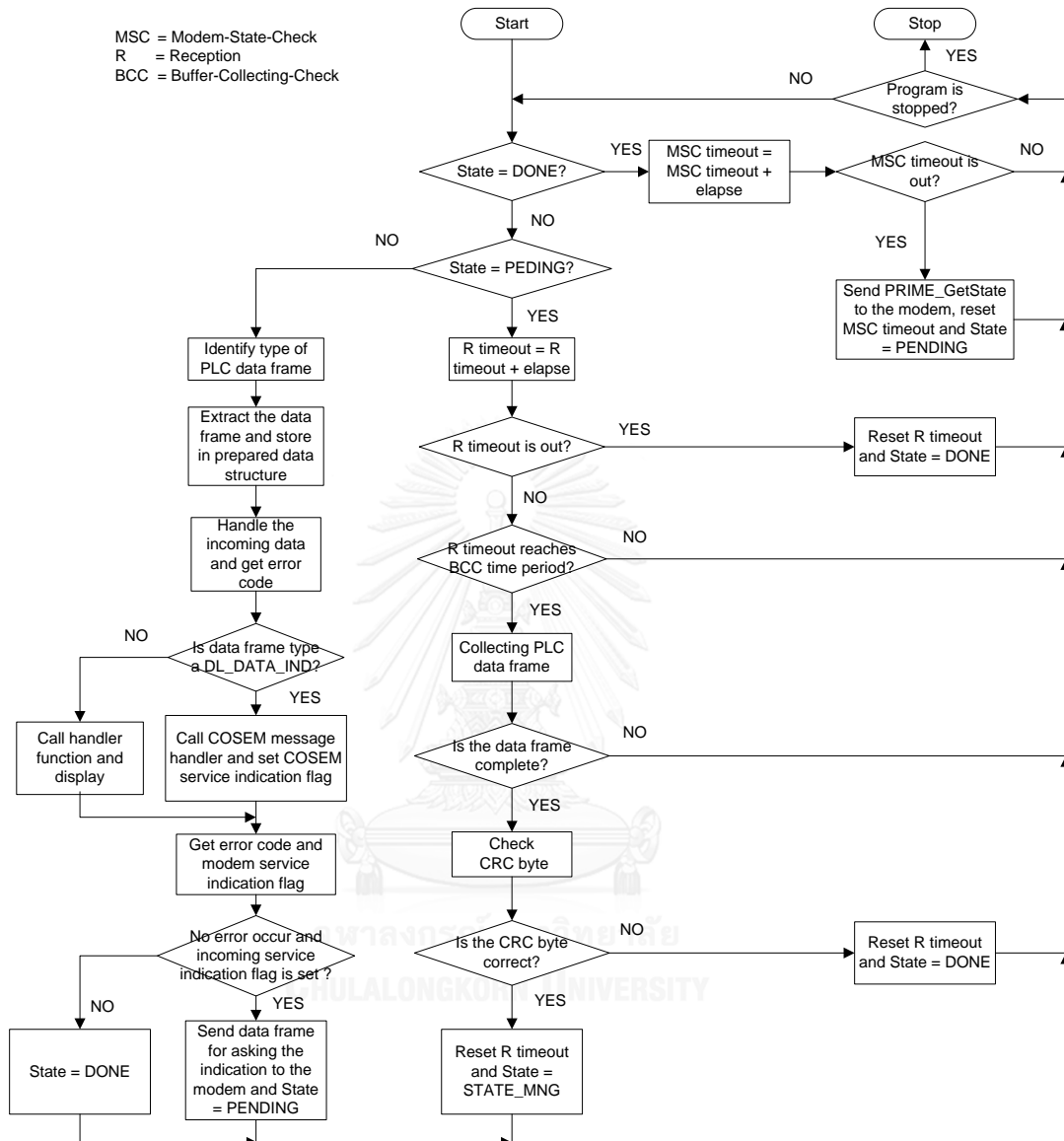Figure 4-9: flowchart of the power line communication thread

Flow diagram of the power line communication between Smart meter acting as a server and Data concentrator acting as and client is shown in Figure 4-10. These 3 communication threads are initiated and run in cooperation in this scheme.
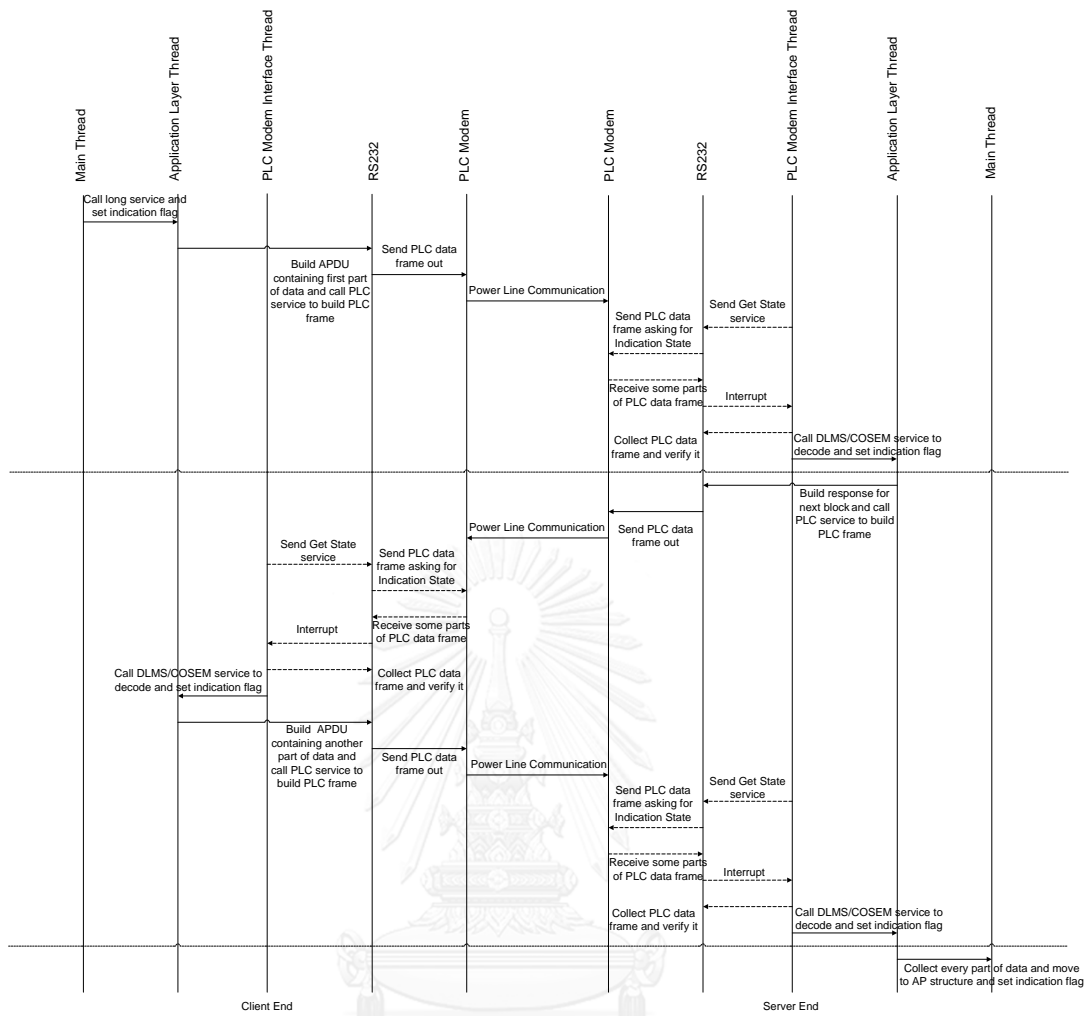
Figure 4-10: the procedure of the threads working on the power line communication
between the smart meter and the DCU

Chapter 5

Experiment

This chapter discusses the experiment on the smart meter functionalities. The experiment is conducted on the smart meter's accuracy and metering data communication with the data concentrator unit.

5.1 Smart meter's accuracy measurement

5.1.1 Preparation for accuracy test

The smart meter accuracy is tested with 2 specific devices as described in the section 5.1.1.1 and 5.1.1.2

5.1.1.1 MTE CALSOURCE 200:

MTE-CALSOURCE-200 is a programmable 3 phase power supply with configurable phase shift angle at maximum current rating of 120 amps.

Figure 5-1: MTE-CALSOURCE-200, programmable 3phase power supply

5.1.1.2 MTE PRS 1.3:

MTE PRS 1.3 is a reference multi-meter with 0.05% accuracy. This device will be used for energy comparison with the energy measure by STPMC1 energy calculator IC implemented in the smart meter.
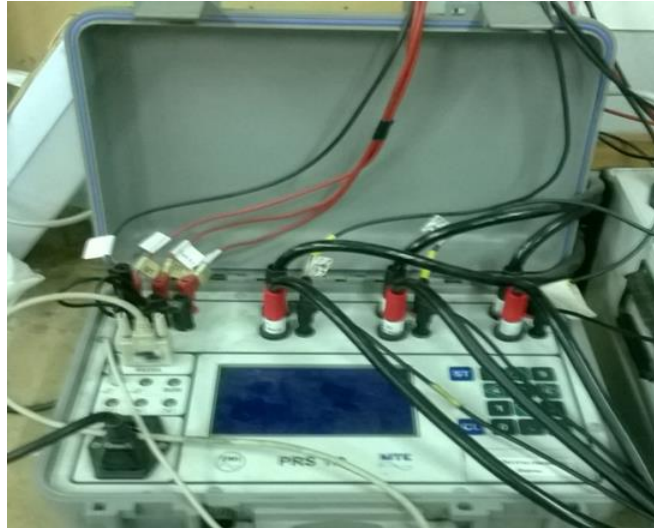

Figure 5-2 : MTE PRS 1.3, reference meter

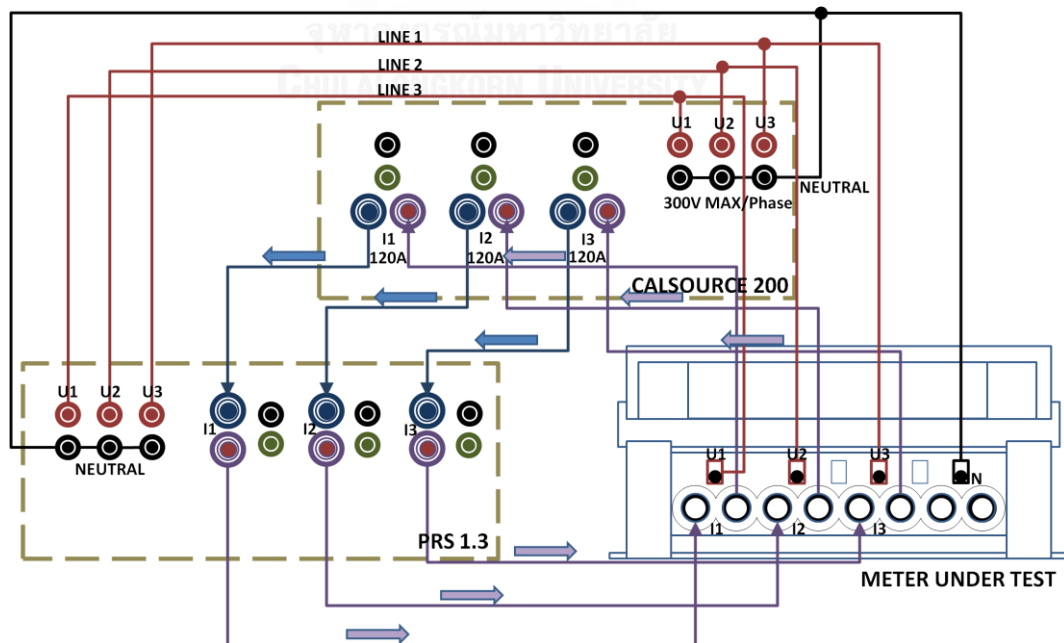To test the smart meter on its accuracy the devices are set up as shown in the Figure 5-3.

Figure 5-3: the testing setup to measure accuracy of the 3-phase smart meter

5.1.2 Measurement procedure

1. The accuracy measurement begins with the MTE CALSOURCE 200 supplies current through the MTE PRS 1.3 Reference Meter to the smart meter under test. The output current from the smart meter then flows back to the MTE CALSOURCE 200 as a loop shown in the Figure 5-3.

2. The voltage to current ratio of the current transformer, Ks is calculated as $K_S = \left(\frac{R_b}{Turn\ ratio}\right).1000 = \frac{0.25}{2500} = 0.1$ mV/A.

3. STPMC1 energy calculator' configuration bits are to be set to match the system hardware as in the Table 5-1.

Configuration bits	value	Definition
TCS	1	Current transformer is used
FRS	0	Operating frequency is 50 Hz
KMOT	1, 2 and 3	LED blink is set for phase R, S and T
LVS	0	LED blink represents the Active Power
PM	1	Meter accuracy is set for Class 0.1

Table 5-1: Important setting of configuration bits on STPMC1 IC

Energy LED blinks of STPMC1 is measured and compared with value read from the reference meter (MTE PRS 1.3). The currents and voltages at phase R, S and T are measured and recorded in STPMC1 registers. There can be some inaccuracy caused by phase shifts or current transformer defects. Therefore, the data in the STPMC1's registers are calculated and initially used for a tune to compensate such hardware inaccuracy. Accuracy of the smart meter is to be tuned to meet accuracy specification as in IEC 62052-11 standard as described in the Table 5-2.

| Value of current | | Power factor | Percentage error limits for meters of class | |
For direct connected meters	For transformer operation meters		class 1	class 2
$0.05I_b \leq I < 0.1I_b$	$0.02I_b \leq I < 0.05I_b$	1	± 1.5	± 2.5
$0.1I_b \leq I \leq I_{max}$	$0.05I_b \leq I \leq I_{max}$	1	± 1.0	± 2.0
$0.1I_b \leq I < 0.2I_b$	$0.05I_b \leq I < 0.1I_b$	0.5 inductive	± 1.5	± 2.5
		0.8 capacitive	± 1.5	$-$
$0.2I_b \leq I \leq I_{max}$	$0.1I_b \leq I \leq I_{max}$	0.5 inductive	± 1.0	± 2.0
		0.8 capacitive	± 1.0	$-$

Table 5-2: standard accuracy of metering device

5.1.3 Result of the experiment

At the power factor of 1, the R-phase current contains error of value between 0.461 to 0.554 %. The S-phase contains error of value between 0.247 to 0.445%. The T-phase contains error of value between 0.227 to 0.384 %. The measurement results at PF equal to 1 is presented in the Figure **5-4**.

At the power factor of 0.5, the T-phase current contains error of value between -0.394 to -0.271 %. The R-phase contains error of value between -0.506 to -0.471%. The S-phase contains error of value between -0.96 to -0.85 %. The measurement results at PF equal to 1 is depicted in the Figure 5-5.

Result of the experiment shows that the smart meter has the error less than the standard error limit of 2.5% with testing current varying from 1 to 10 amp and PF set to 1 and 0.5. The summary of experiment result is illustrated in the Table 5-3.
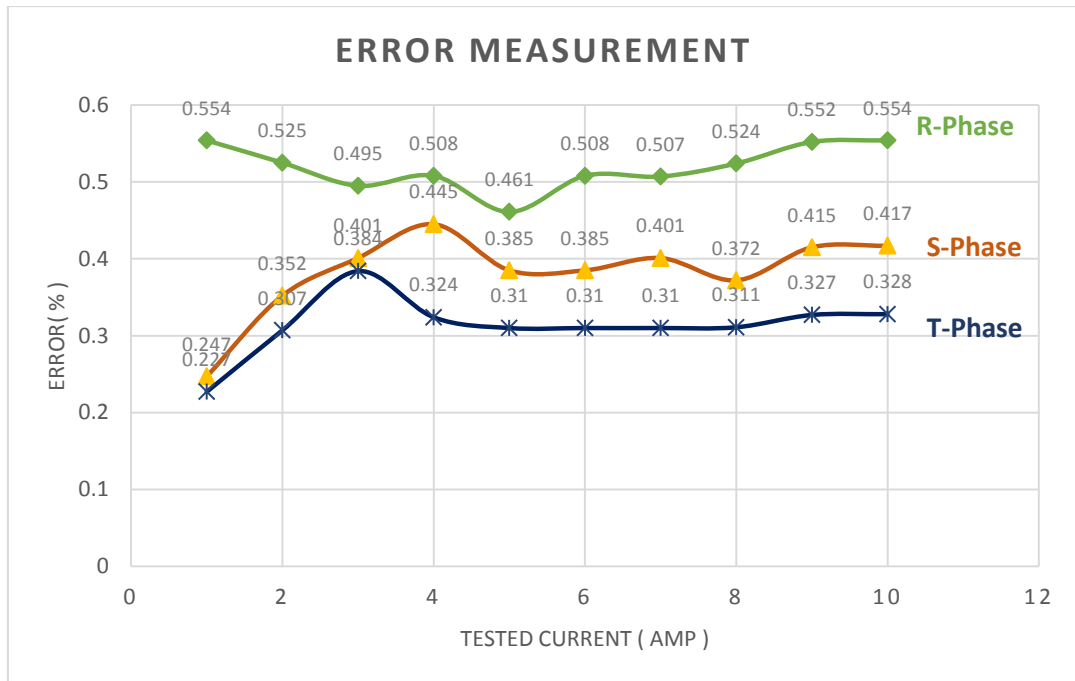
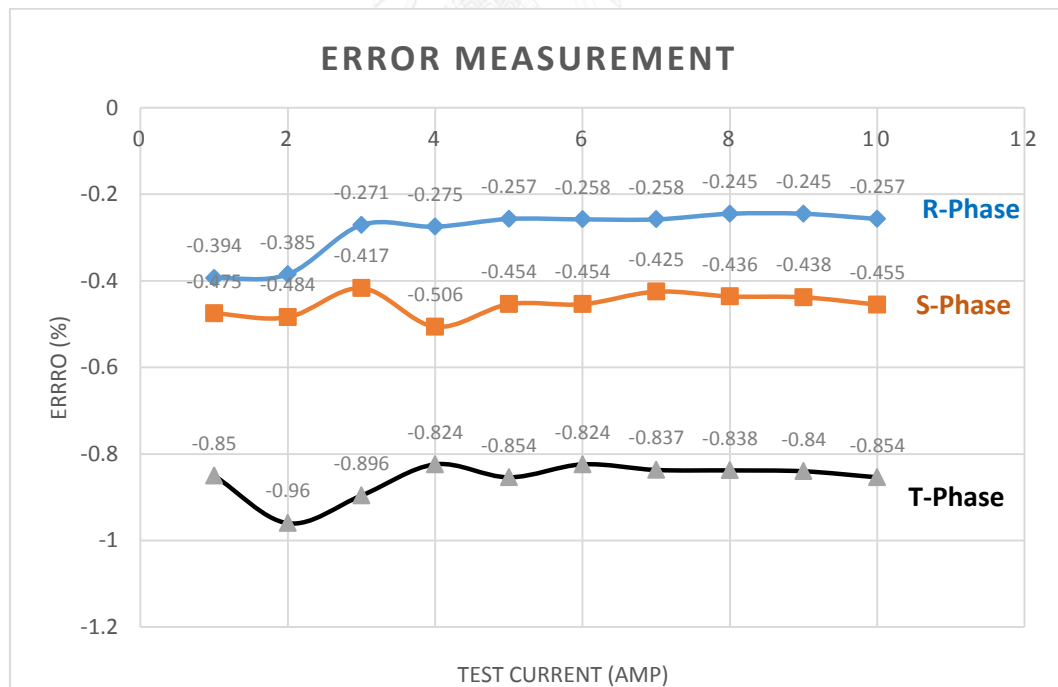Figure 5-4: Chart of error in the active energy tested at current between 1 ≤ i ≤ 10, PF.=1

Figure 5-5: Chart of error in the active energy tested at current between 1 ≤ i ≤ 10, PF.=1

Measurement condition	Power Factor (PF)	Error (%) (Class1)	Maximum measured error		
			R	S	T
$1 \leq I \leq 10$	1	± 1	0.554	0.445	0.384
$1 \leq I < 10$	0.5 inductive	± 1.5	-0.394	-0.506	-0.960

Table 5-3: summary of error measurement result

5.2   Smart meter communication experiment and result

The DLMS/COSEM power line communication experiment is set up as in the Figure 5-6. This experiment is conducted using normal GET service of DLMS/COSEM application. The procedure begins with the simulated data concentrator unit (DCU) sending GET-Normal-Request to the smart meter asking for voltage and current value of phase R, S and T. Initially, the smart meter will call GET-Normal-response service to send a PDU of a size smaller than the buffer size negotiated by the Smart meter and the DCU. When the DCU receive the first PDU block the DCU will use GET-Request-Next send request asking for the next data block to the smart meter. The Smart meter then response with GET-Response-With Data block. The process continues in this manner until the DCU received all of the data blocks. The experiment result is shown in the Figure 5-7.
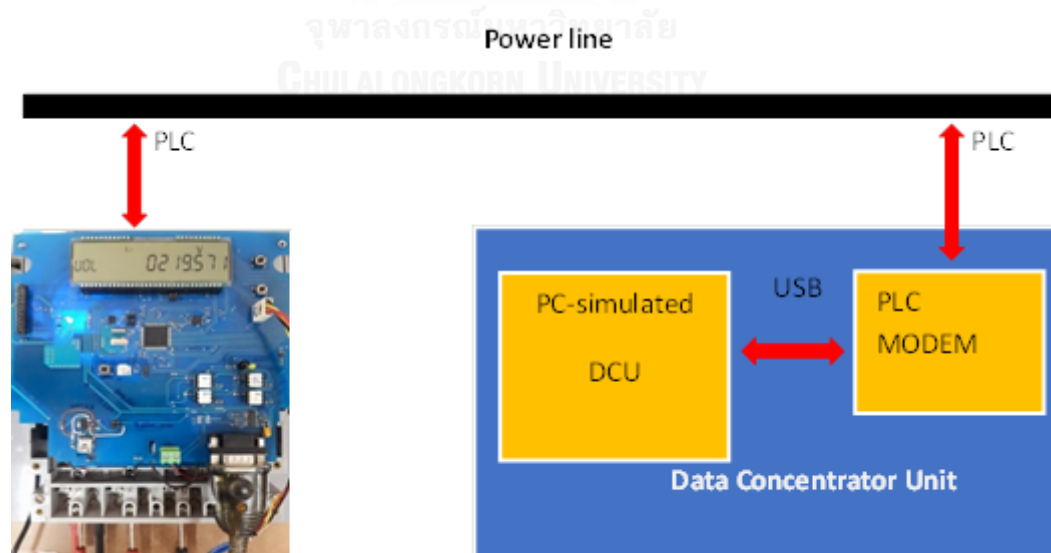

Figure 5-6: setup for the PLC communication experiment using COSEM GET services

Figure 5-7: communication experiment result using COSEM GET command

Chapter 6

Conclusion and suggestion

6.1   Conclusion

This thesis presents the development of a smart meter operating with a three-phase four-wire system, 220/380 volt 50Hz. The meter is implemented with a communication firmware consisting of DLMS/COSEM application layer and PRIME lower protocol layer for data communication with the data concentrator unit (DCU). The firmware is developed using C and C++ language equipped with RTOS. The firmware contains two set of software libraries one of them is DLMS/COSEM application services written in C++ and the other contains PRIME commands and a C-language library to control the smart meter hardware and PLC modem. RTOS is used for multi-threading abilities as the smart meter should be able to perform measurement while simultaneously communicate and response to DCU request. The smart meter creates load profile collected from the energy consumption demand updated every 15 minutes. The prototype smart meter is also developed to simulate the basic function for devices operating in the advanced metering infrastructure environment. The smart meter hardware consists of STM32L152VBT low power microcontroller and STPMC1 energy calculator and STPMS2 ADC to perform energy measurement. The smart meter is also equipped with PRIME-PLC modem IC ST7590 for its communication capability over the power line. The experiment on its measurement accuracy is done in comparison with a standard reference meter (MTE PRS1.3) with the result showing the error percentages is within the standard limit specified by the IEC 62052-11. The communication experiment is conducted using GET services as specified in the DLMS/COSEM protocol. The experiment setup consists of the smart meter and a computer-simulated DCU connected to the power line. The result for communication experiment shows that the smart meter and the DCU can communicate metering data with accurate block transfers. Form the result of the two experiments, it can be concluded that the smart meter can perform measurement with adequate accuracy and can communicate efficiently over the power line and can provide application services as specified in the DLMS/COSEM standard.

6.2   Suggestion

1. The communication firmware library based on DLMS/COSEM and PRIME consists of a large number of command sets and functions which in turn requires considerably hardware resources. It can be beneficial if the firmware is customized the number of services down to the size that can perform adequate functions while not requiring over hardware resource.

2. The smart meter contains a number of devices that requires quality power supply for a variety of voltage levels. The space for the circuit is also confined to such a small size that the power-electronic devices have to be laid aside low voltage semiconductor devices. The digital part and analog part of the circuit should also be well isolated to protect against noise interfering the analog sensors which may result in inaccuracy. Therefore good consideration is necessary when designing PCB layout.

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