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Automatic Meter Reading in Domestic Environment Using PLC

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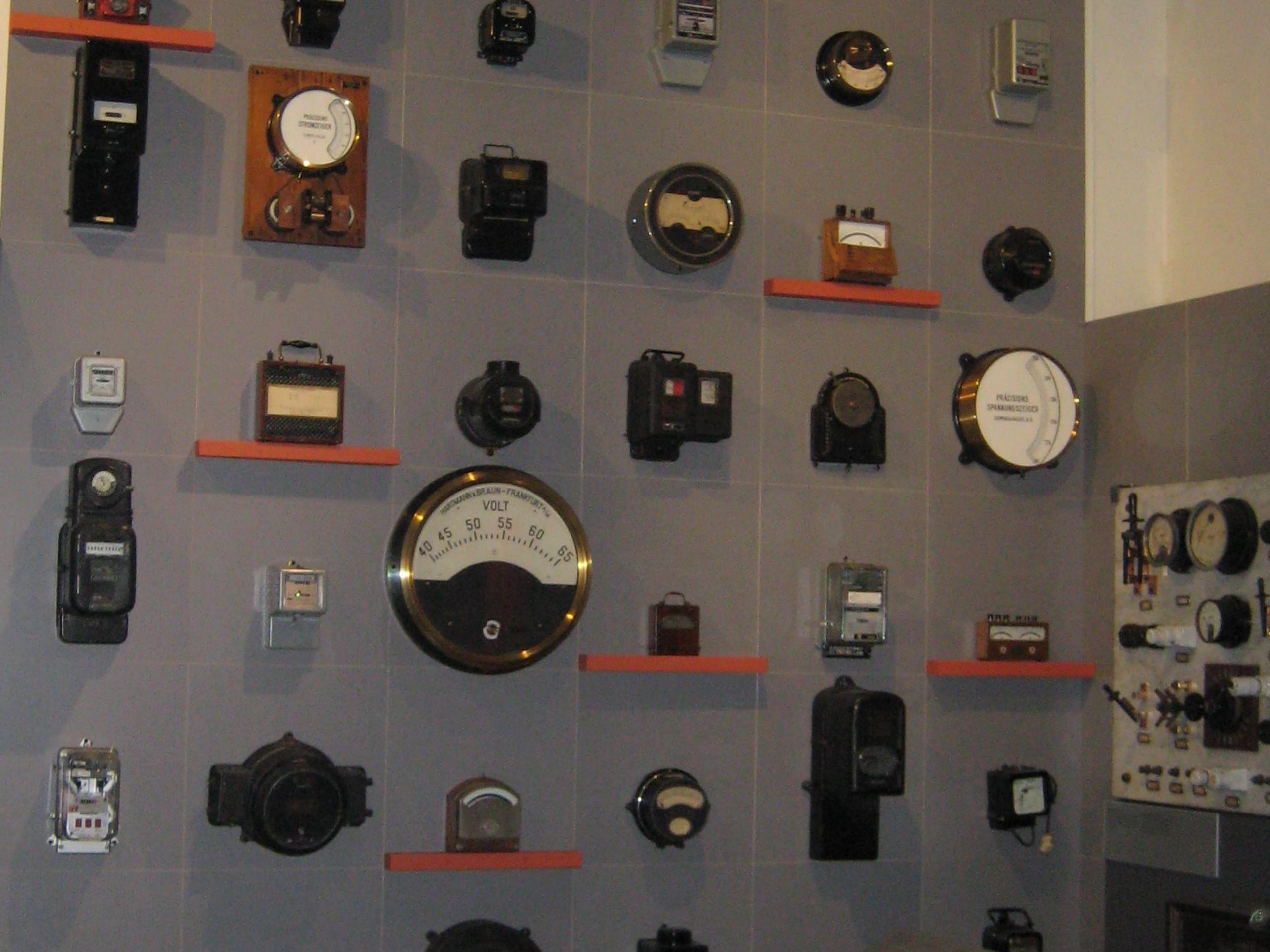
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68.
EDISON'S LIGHT BULB

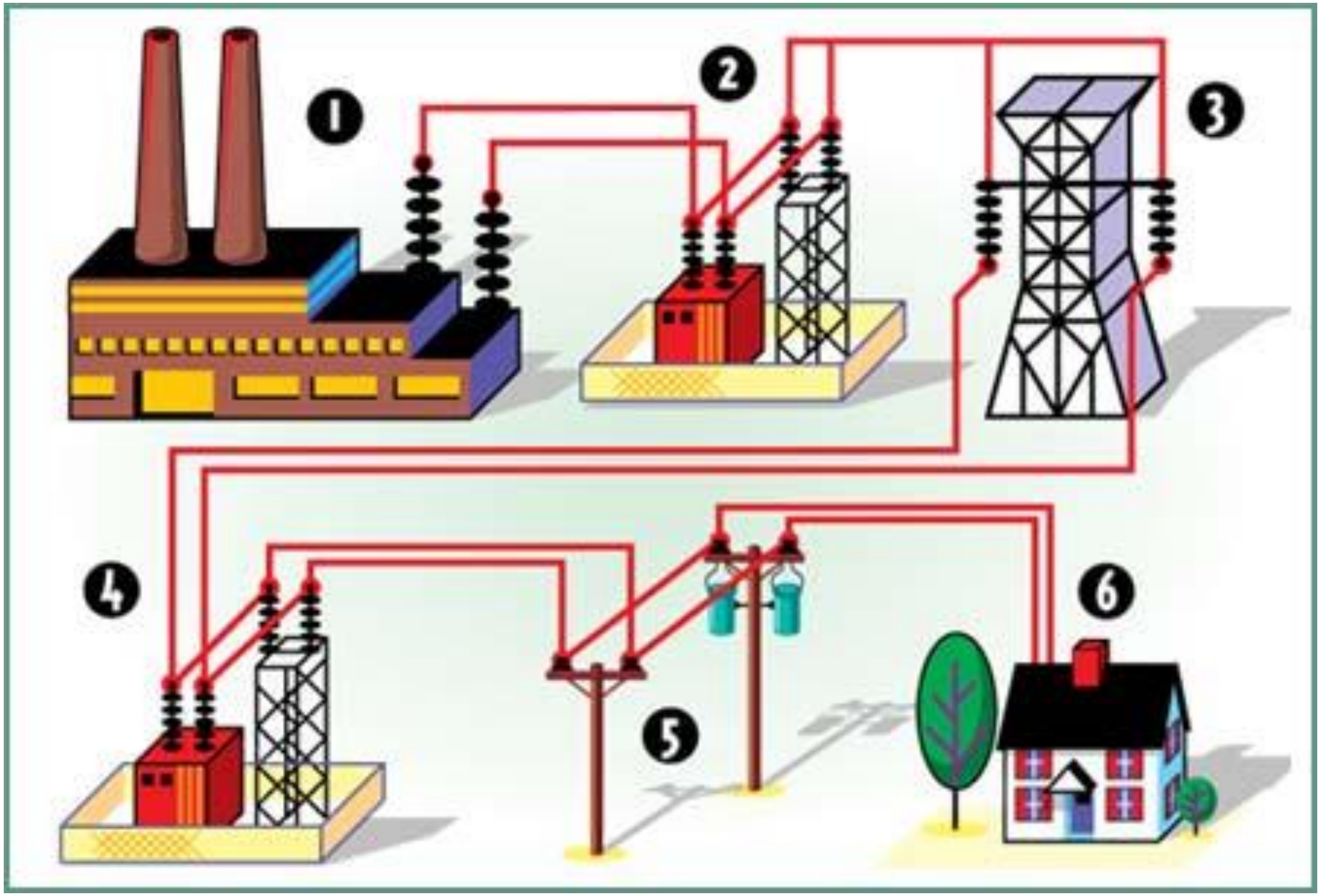
Content

- Background
- Challenges of the Future Network
- Power Meter Prototype
- The PLC Technology
- Conclusions

The Smart Team

Team	Task
Goos Tom & Serge De Pooter	PLC Network Programming
Pieter Boijen & Chris Menten	DataBase & applications
Sami Paavilainen	Residential Gateway
Marek Kwitek	HMI, user interface
Rachid Daerden, Cédric Devroye & Marek Krajewski	Power Meter
Yenthe Blockx & Sim Jacobs	Integrating the system components

Background: Power System



1: Power plant, 2: Step-up substation, 3 : Transmission. 4: Step Down Station, 5 Distribution.   6: Consumption

Figure Source: http://www.mnpower.com/about_electricity

Traditional Enegy System

Main functions: controls supply and demand process (Updpwn Direction)

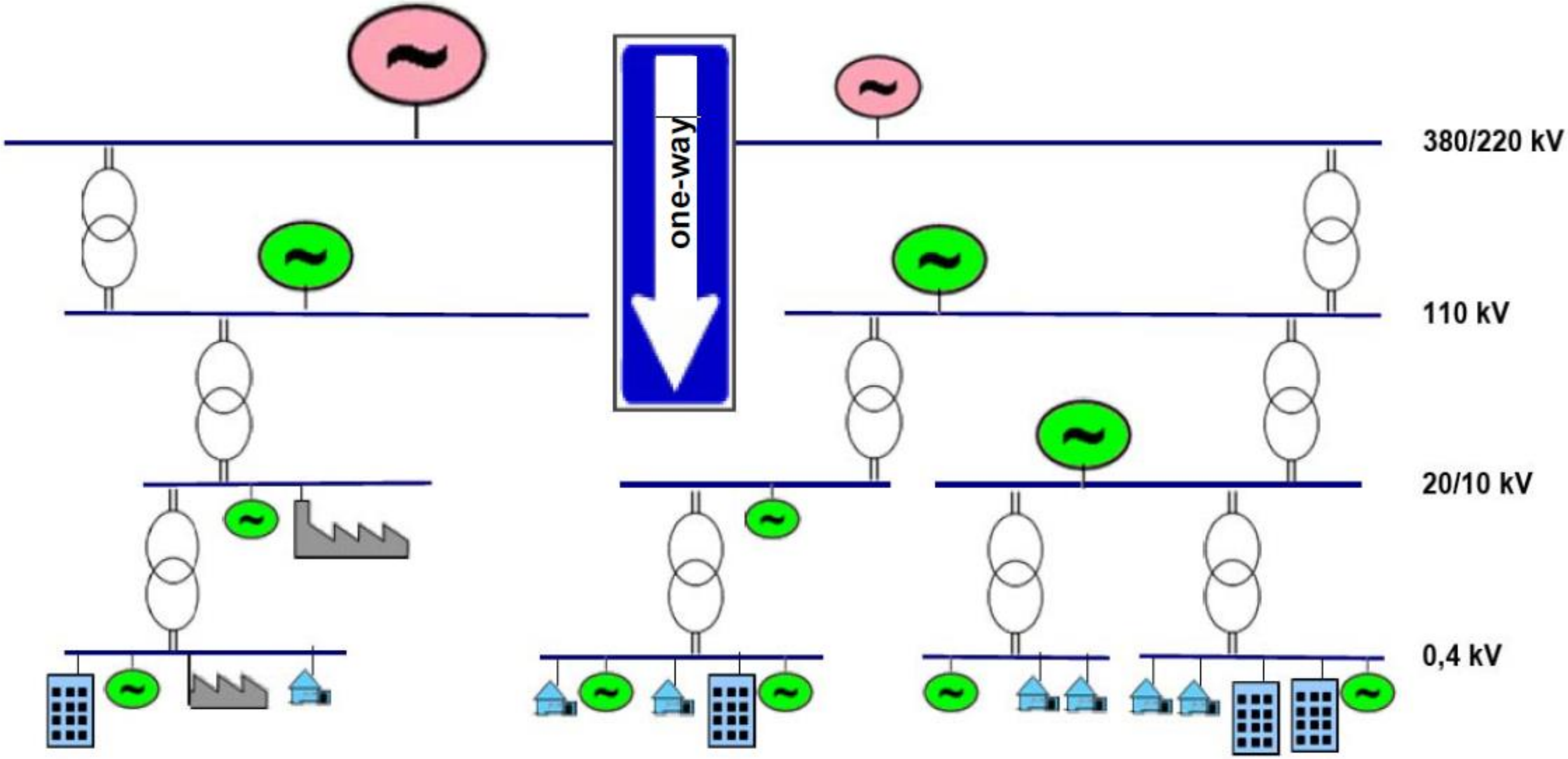


Figure source: Joachim Schyer, Remote Control for Smart Grid, 2010

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Energy System of the Future (Multi Direction)

Multi-energy sources from both the suply and distribution side

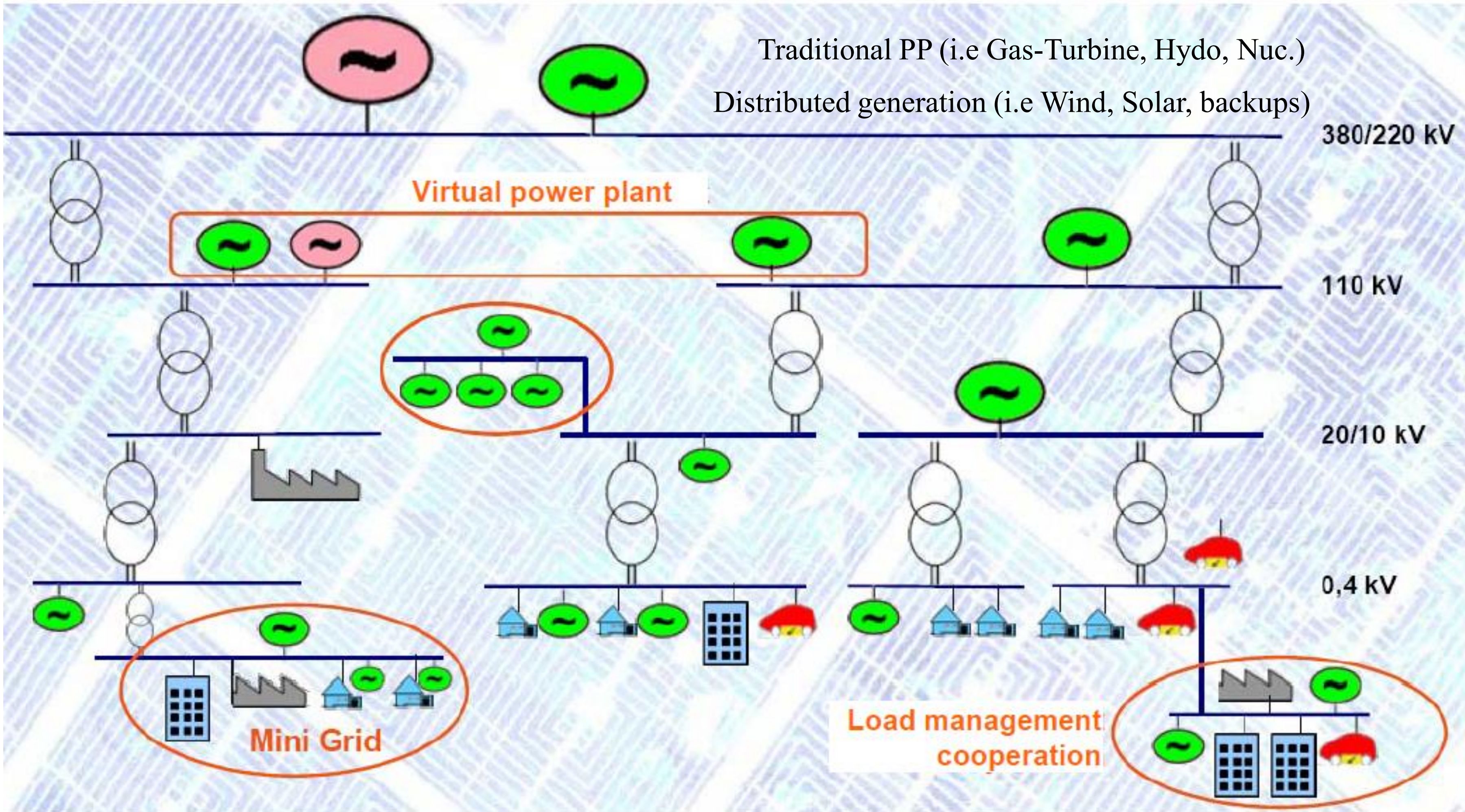

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Figure source: Joachim Schyer, Remote Control for Smart Grid, 2010

Challenges of the Future Network

- Efficient Transmission
- Faster Fault location
- Faster Reaction to peaks
- Better Balance
- Protection for distributed grids with decentralised power generation
- Faster Load manipulation
- Managing net flow back into the network (backups)
- Interfacing (SA/LV-MV)➔Communication
- Managing Carbon emissions
- ..etc

The needs and solutions

- Reliable Commication and IT systems
- Data acquisition and control:
  - MV source-Grid
  - MV Source-Load
  - MV to LV

Intelligent Substation

- **Monitoring low voltage stations**
- **Monitoring consumer appliances**
- **….**

Intelligent Metering

But must be implemented into the existing electrical network

Present Grid vs. Future

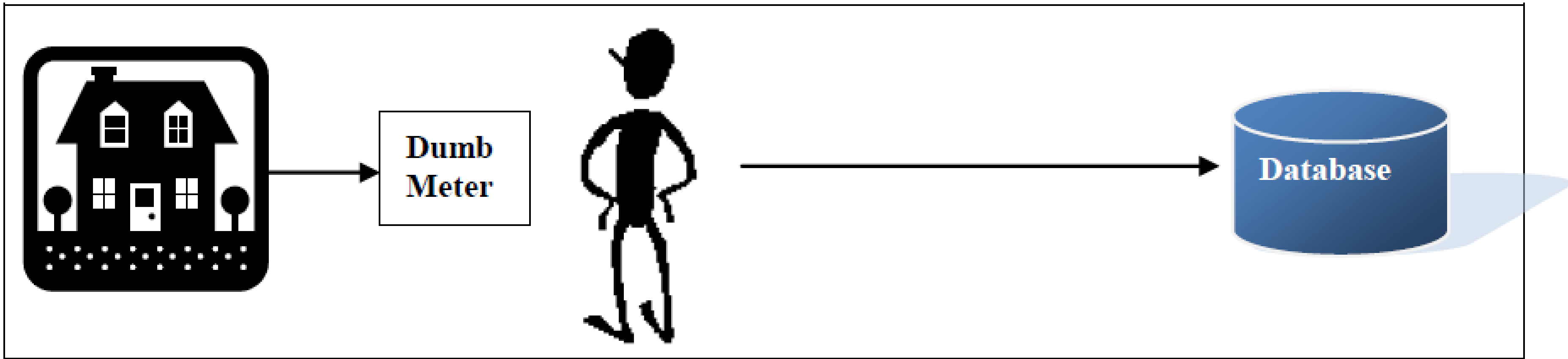
- ❑ Manual restoration of Customers
- ❑ One way Communication
- ❑ RTU
- ❑ Sensors for specific requirements
- ❑ System failure and outages
- ❑ Manual network components diagnostics
- ❑ Meter for billing

- ❑ Complete automated restoration
- ❑ Two way communication
- ❑ IED
- ❑ Sensors installed at strategic network point
- ❑ Adaptive restoration
- ❑ Fully automated and remote interrogation
- ❑ Smart Meter for complete contol

These are more true at the Distribution Network. Since DN are relatively passive.
Transmission Networks already employs high levels of system monitoring and Intelligent Control

The key in DN to be intelligent is the Smart Meter

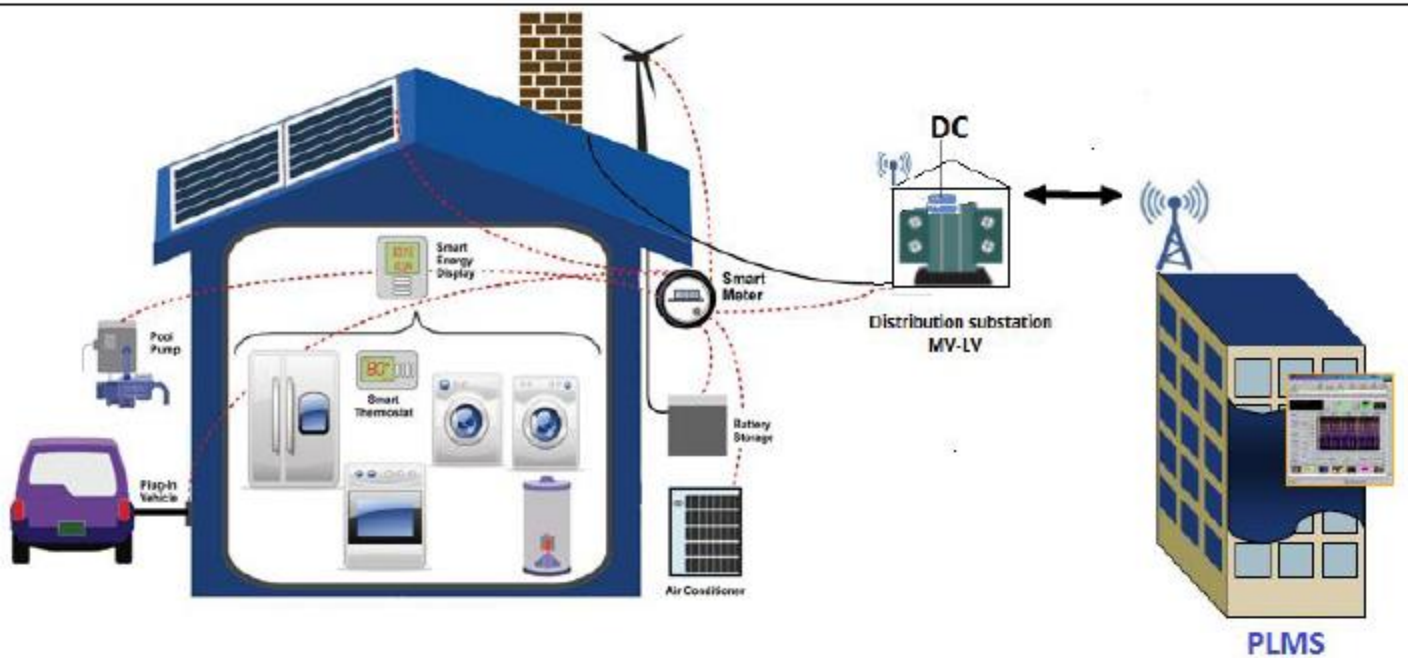
Automatic Meter: Where we are?



Dumb Meter: manual operations

Electronic Meter With Communication Channel: Automatic Meter Reading

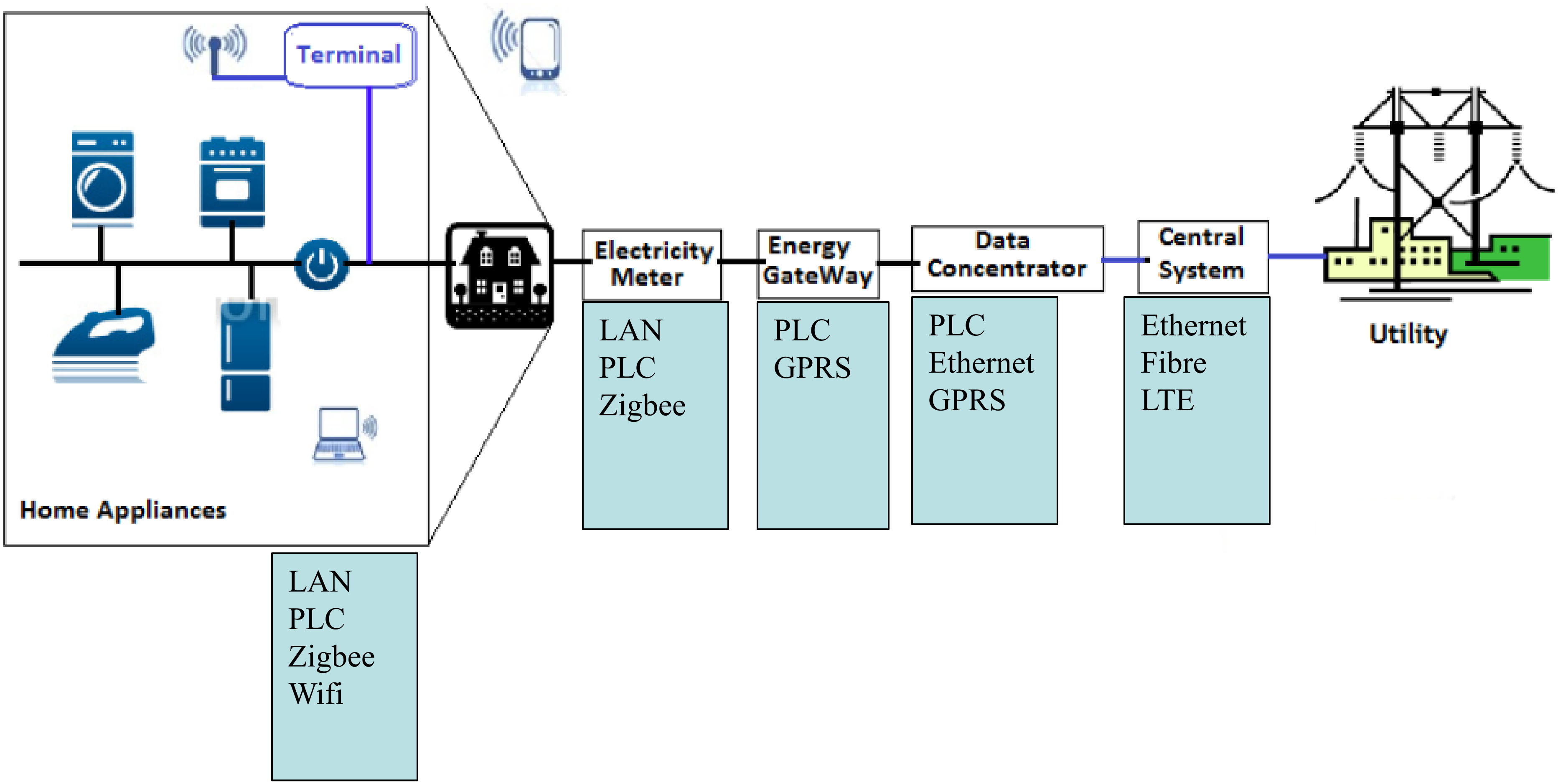
Power Meter: Where we want to go



PLMS: Power and Load Management System.   DC: Data Concentrator

Smart Meter

The Automatic Meter: System Architecture



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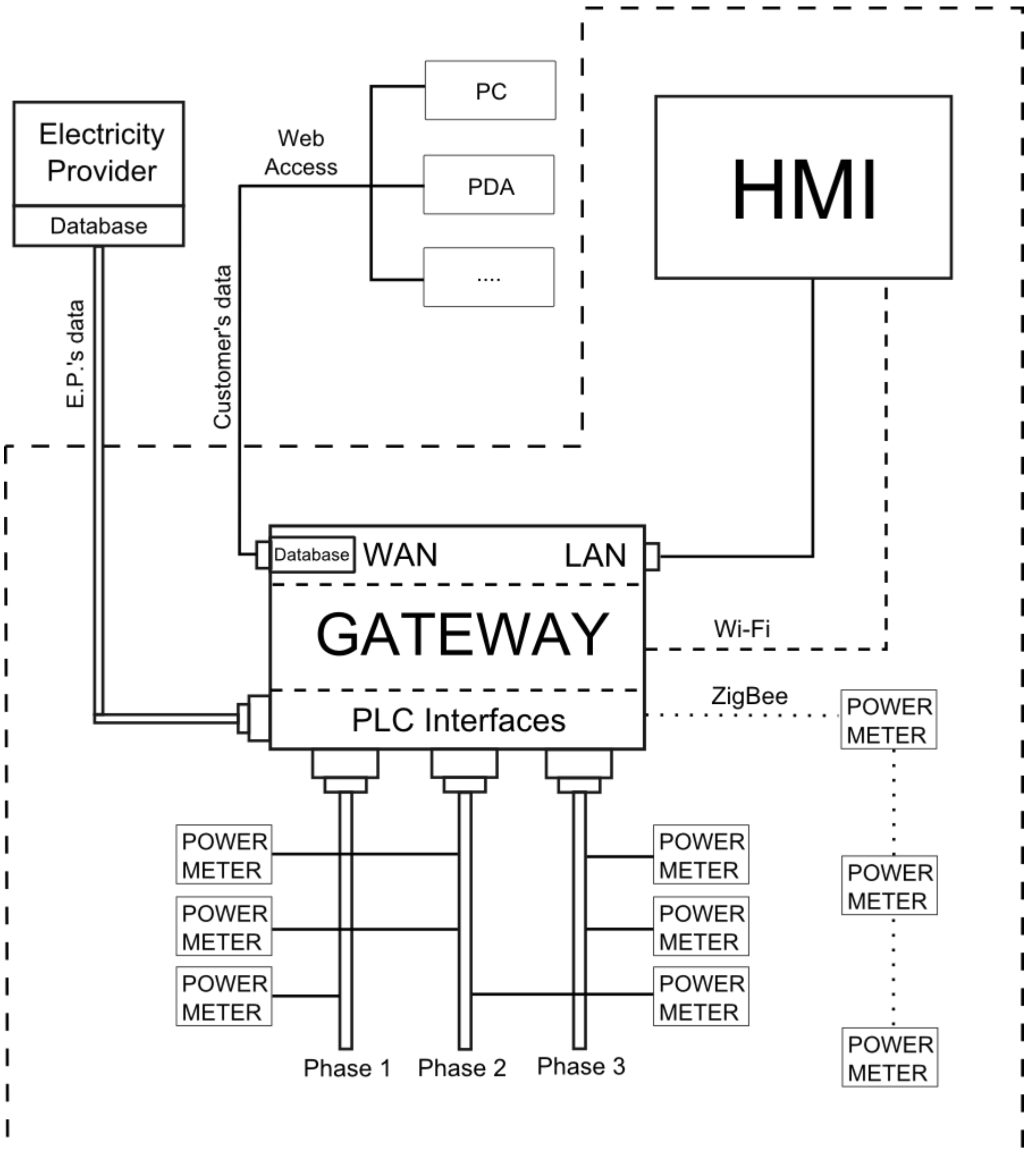
Automatic Meter: System Overview



The Power Meter: General Requirements:

Features			
Tariff Item			
Measurement	The active energy in kWh on # tariff items 1. Voltages and currents per phase 2. Power factor per phase 3. Power per phase 4. The maximum values (power, current) stamped 5. The reactive energy kVArh 6. The duration of any lack of power per phase		
Electrical Requirements			
	Three phase	Single phase	
Reference Voltage	3x230/400 V	230 V	
Base Current	10 A	5 A	
Maximum Current	60 A	60A	
Accuracy Class	1,0	1,0	
Own consumption	<2 W and 10 VA	<2W and 10VA	
Use from current circuit	2.5 VA	2.5VA	
Resistance to shock waves	6KV (Diff Mode)	1.5KV (Circuit Low)	
Resistance to lighting	8KV		
Dielectric Strength	4KV		
Resistance to RF EM field	80MHZ-1000 MHz		
Weather conditions:			
Nominal operating	range: -10 ˚ C to + 60 ˚ C;		
Operating range limit: -	25 ˚ C to +65 ˚ C;		
Storage temperature	-25 ˚ C to + 70 ˚ C;		
Relative humidity	40 ˚C : 90%		

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Power Meter: Structure of the Meter Prototype

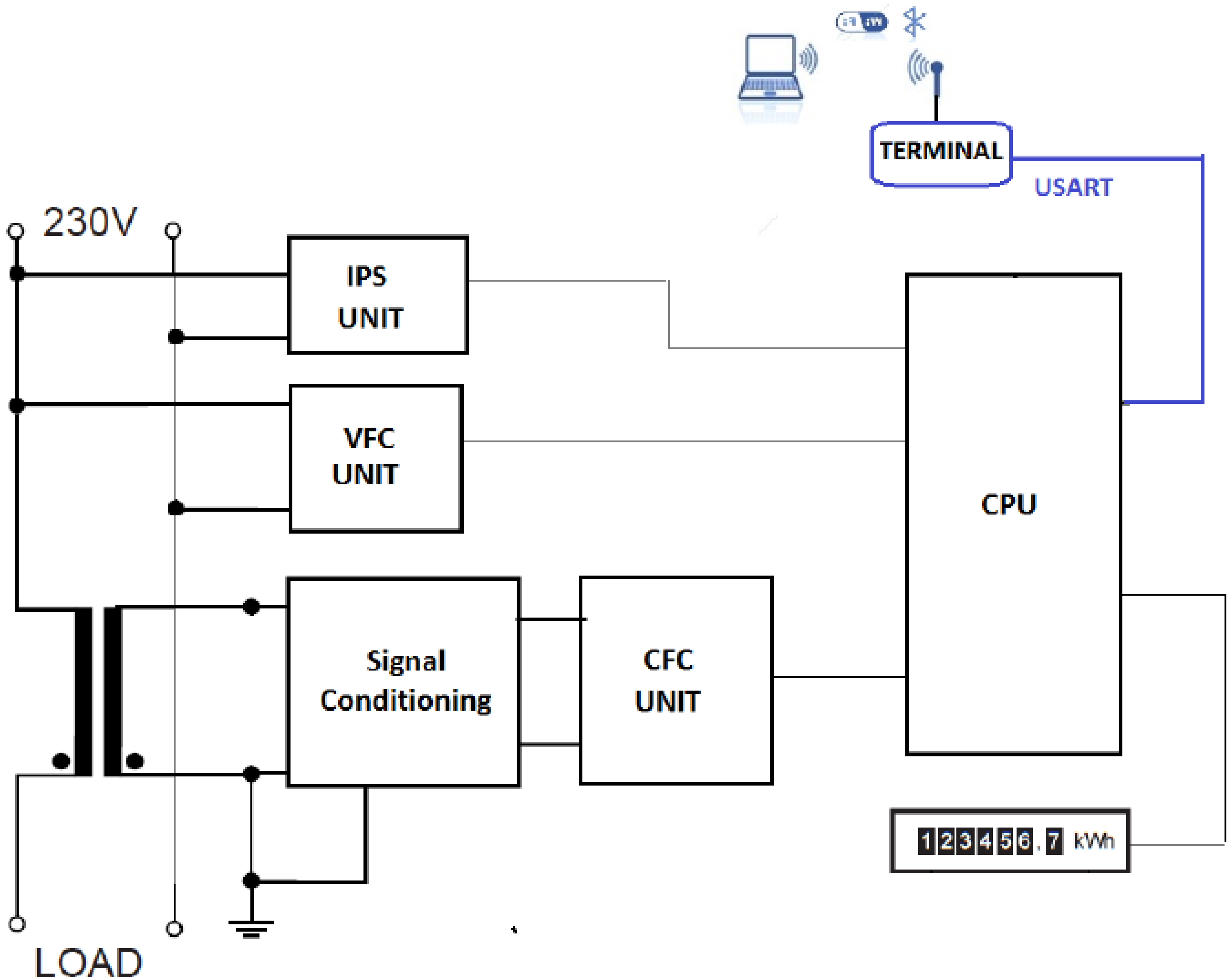
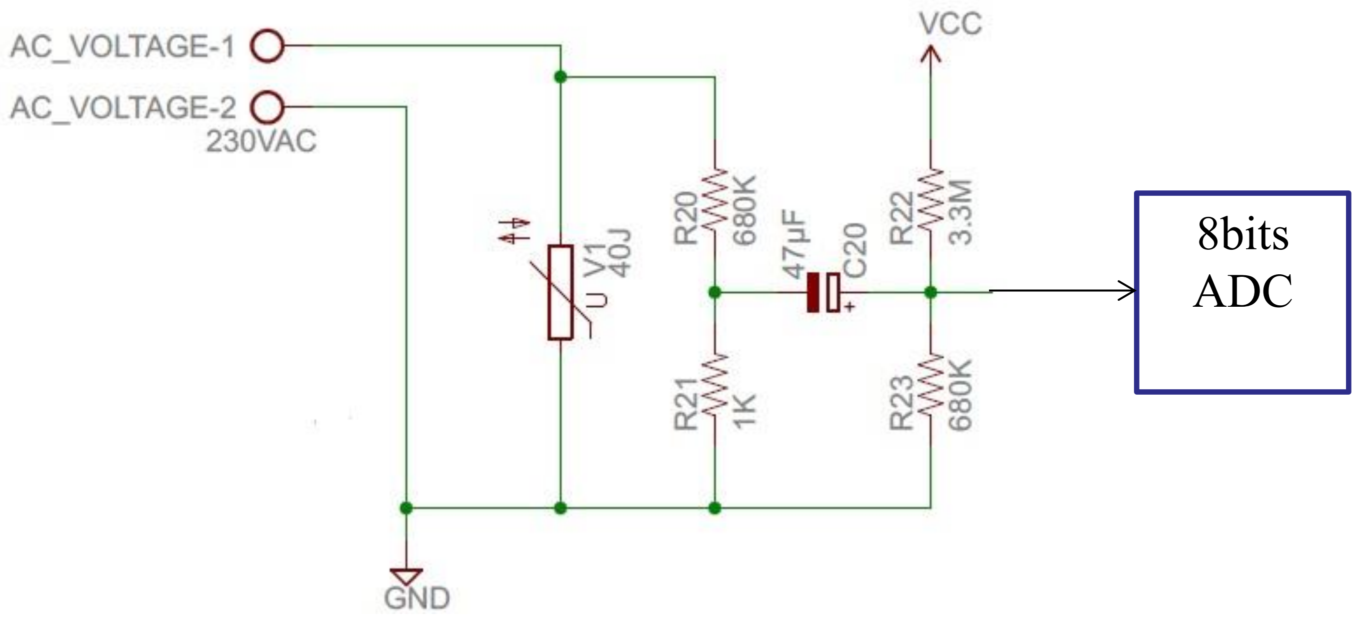


Figure 3: Simplified Circuit Diagram of a Power meter

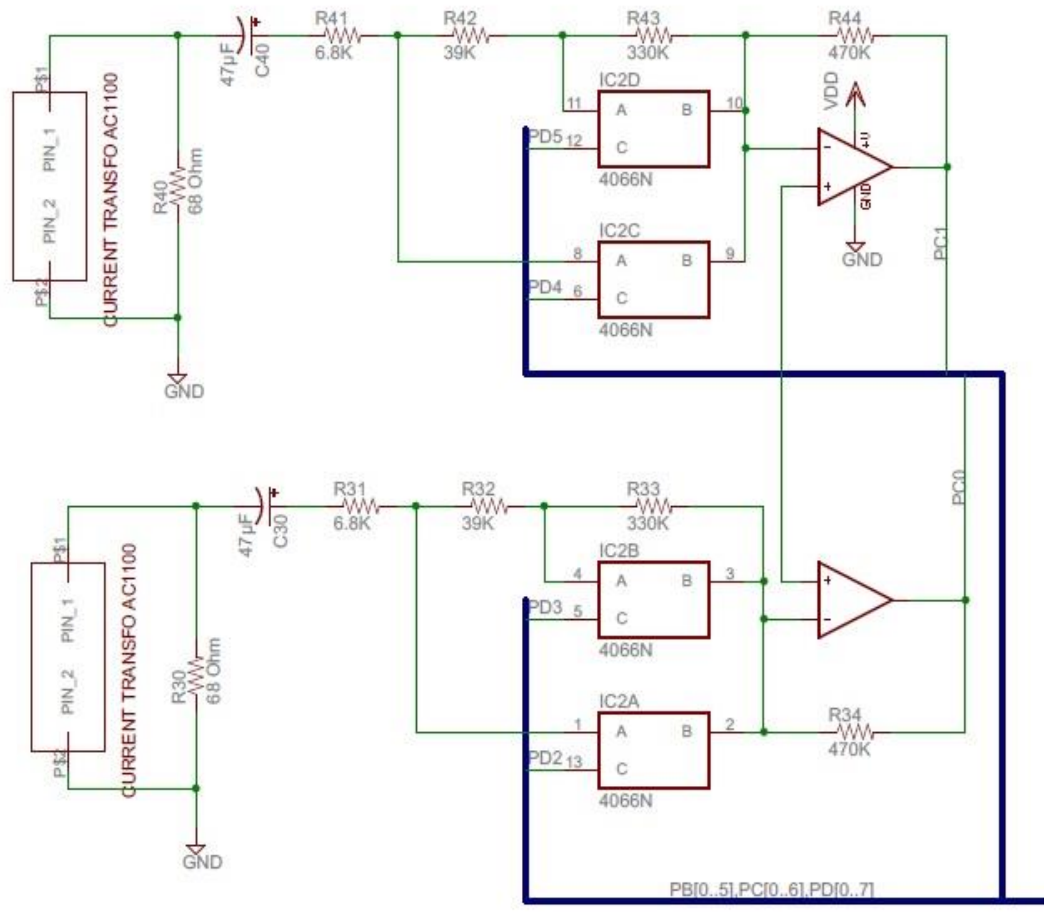
Meter: Voltage Front end Circuit (VFC)



1. Step down with voltage divider circuit to 1 Vpp
2. Apply the conditioned signal to the ADC channel of the microcontroller

Current Front-end Circuit (CFC).

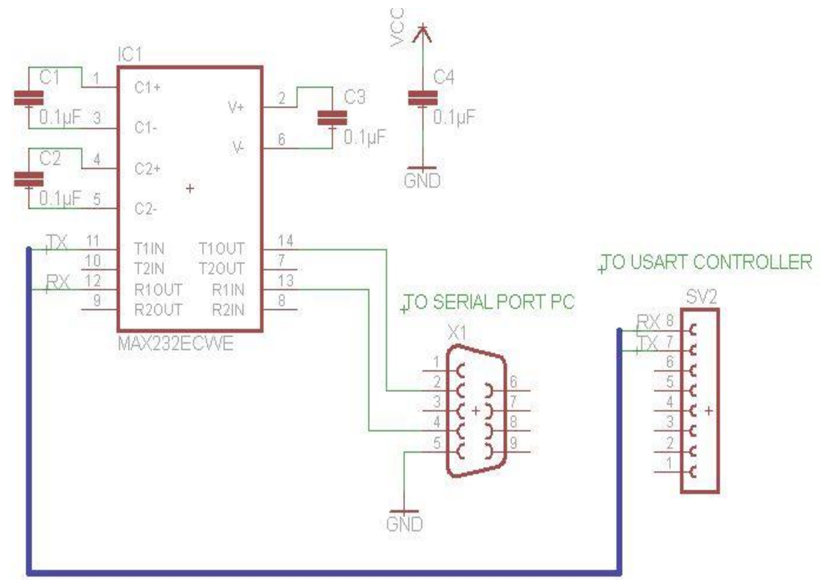
1. Use a **step down CT**: $Is = Ip.\frac{Np}{Ns}$
2. Use **resistors** to convert Current to Voltage (Because of the ADC): $R\ = \frac{U}{I}$
3. Use voltage amplifier with **variable gain** to be able to measure small range of currents (This allow higher resolution ADC)
4. Use the **CD4066BCN controlled switch** to allow automatic setting of the gain



Other Circuits: The RS232 interface

An RS232 channel is required to connect the Power Meter to other devices:

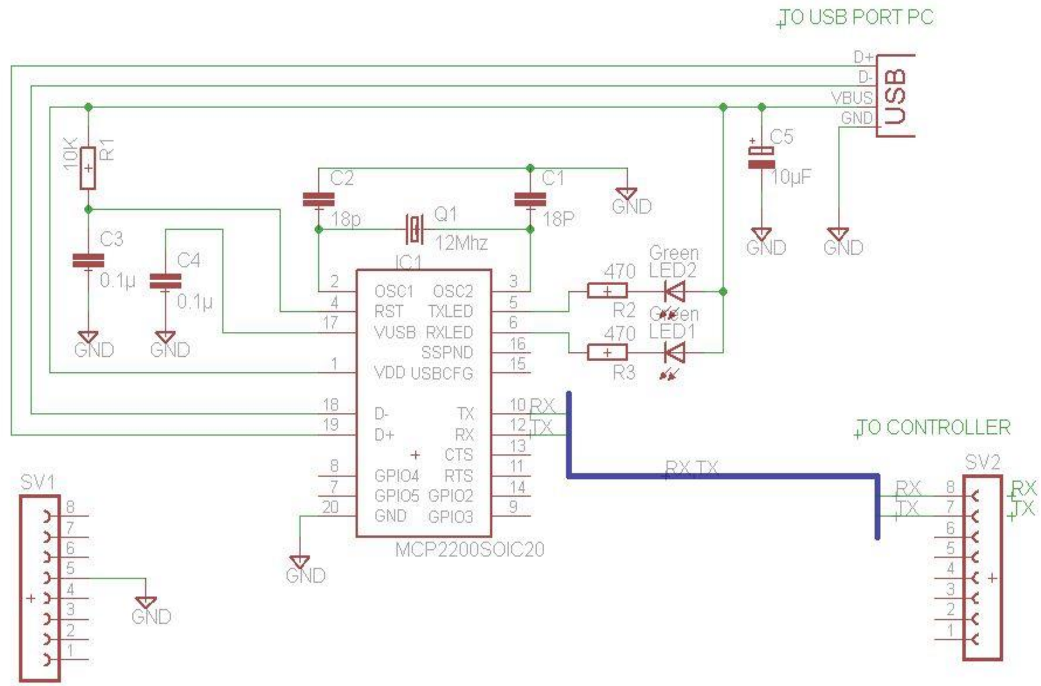
1. The **MAX232 chip** is used to build the HW interface between the USART of the microcontroller and the RS232 com port of a PC



Other Circuits: The USB interface

An USB channel is also required to connect the Meter to other devices that uses USB protocol:

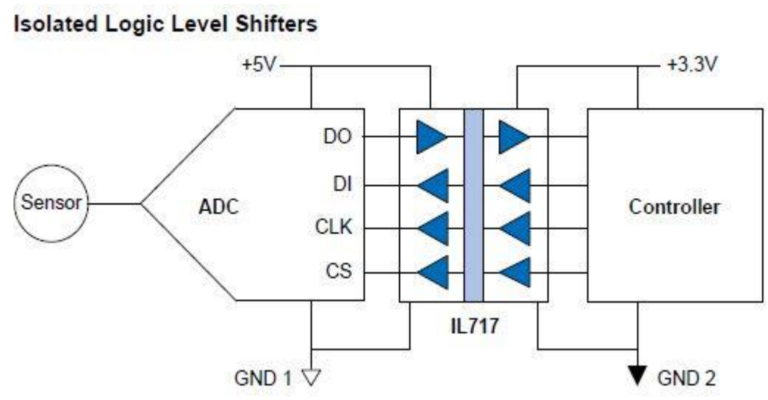
1. The **MCP2200 chip** is used to build the HW interface between the USART of the microcontroller and any device that uses a USB protocol



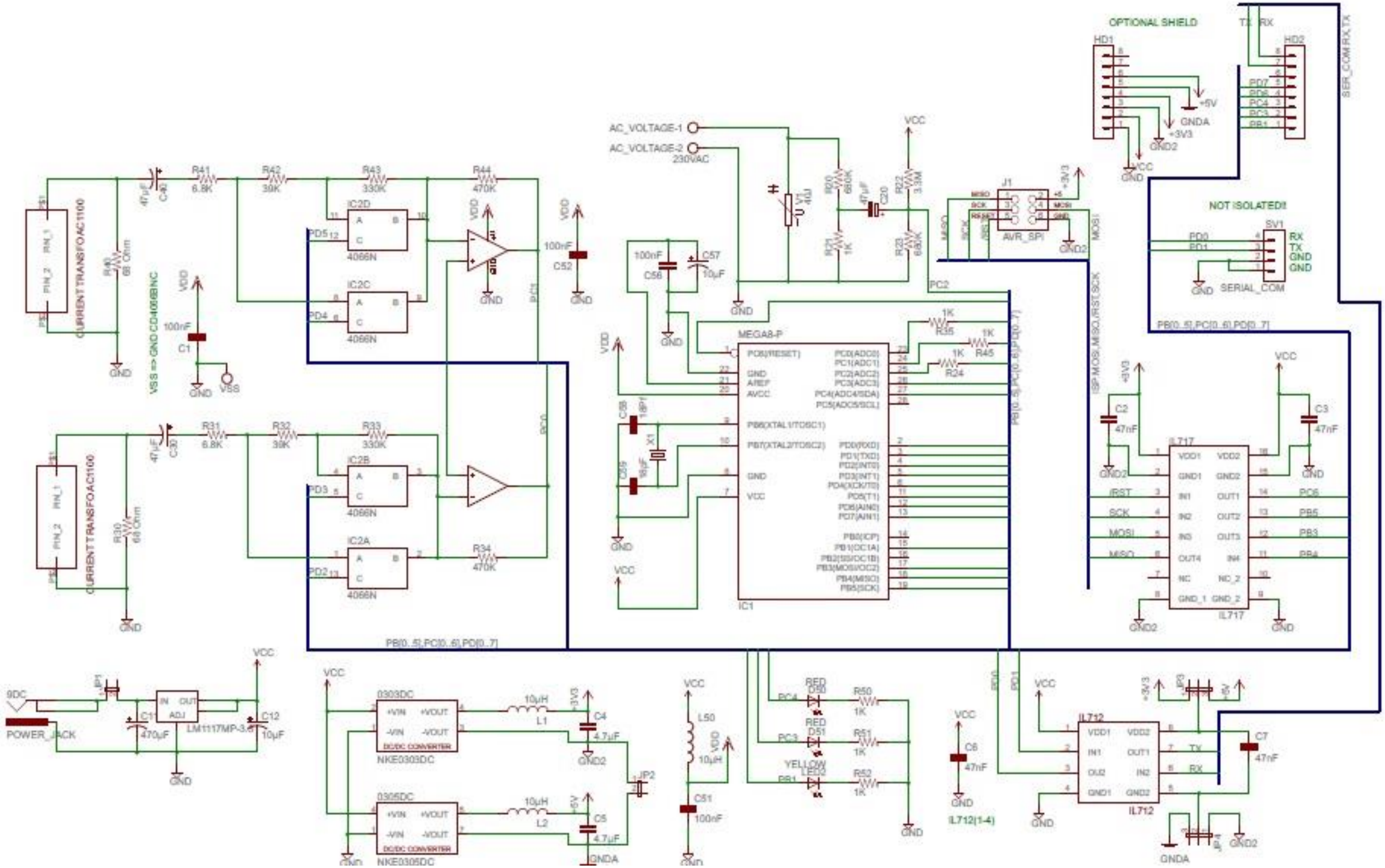
Other Circuits: The Galvanic Isolation

An USB channel is also required to connect the Meter to other devices that uses USB protocol:

1. The **IL712 and IL 717 chips** to isolate the Meter signals from the LV grid. These chips can isolate up to 3KV.



The Power meter Circuit diagram



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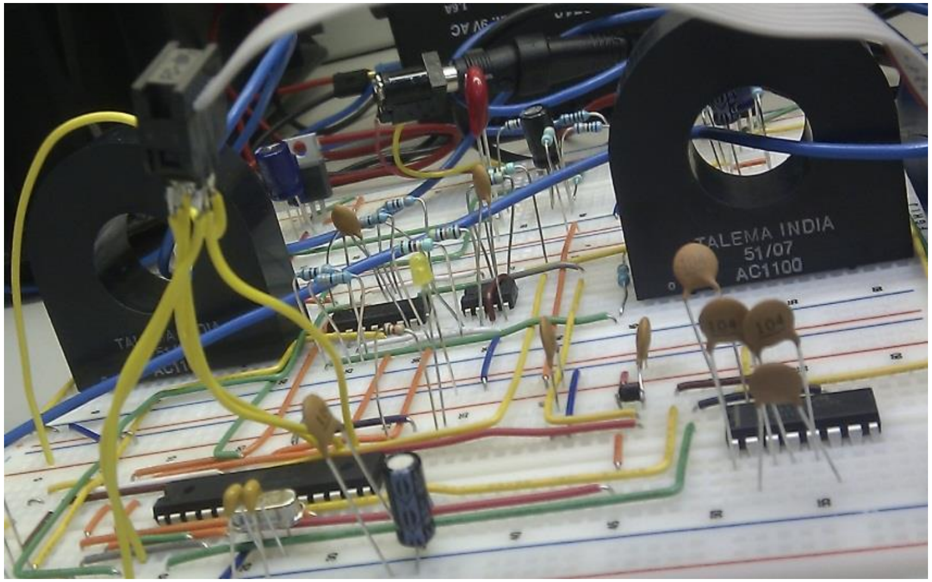
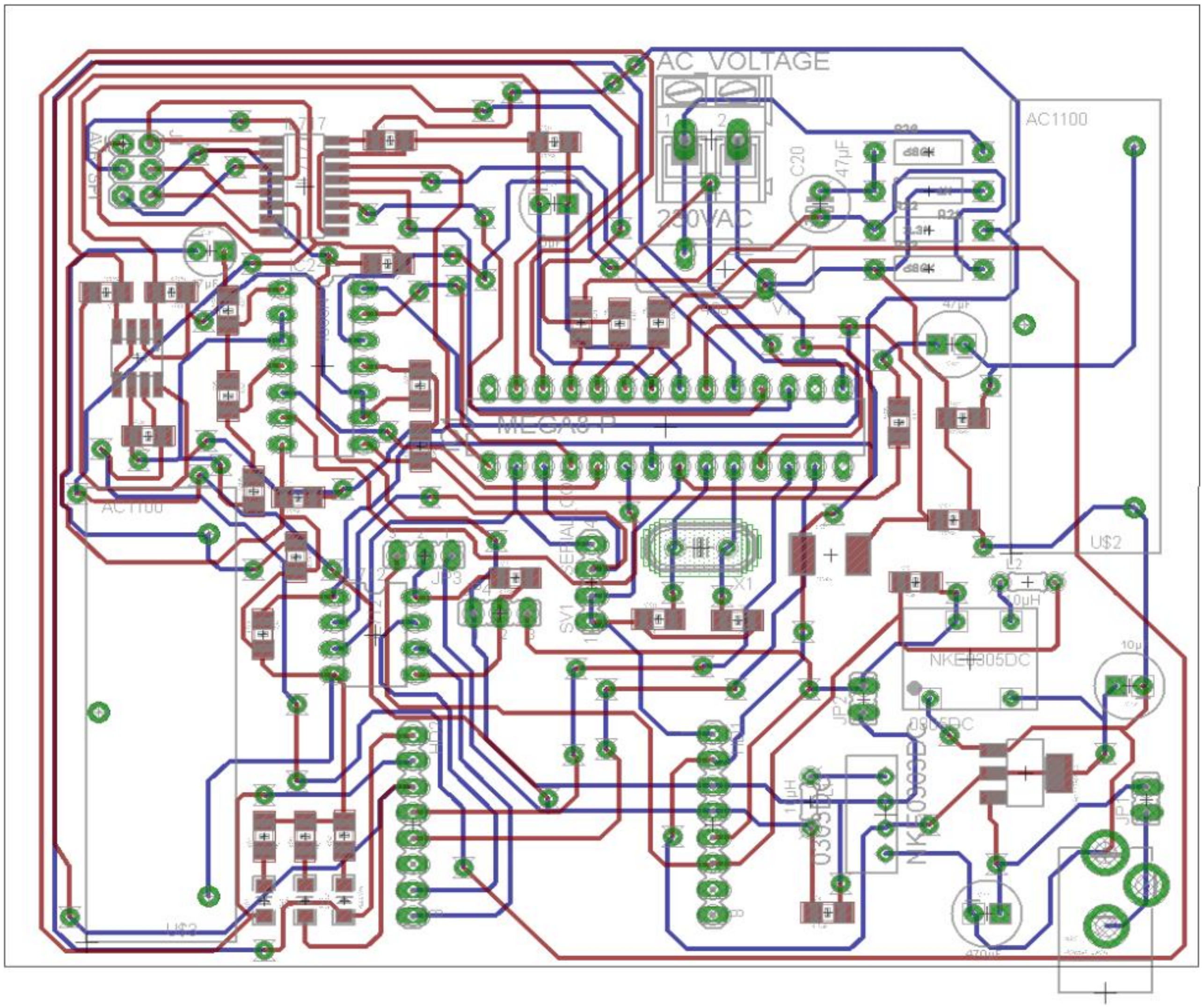
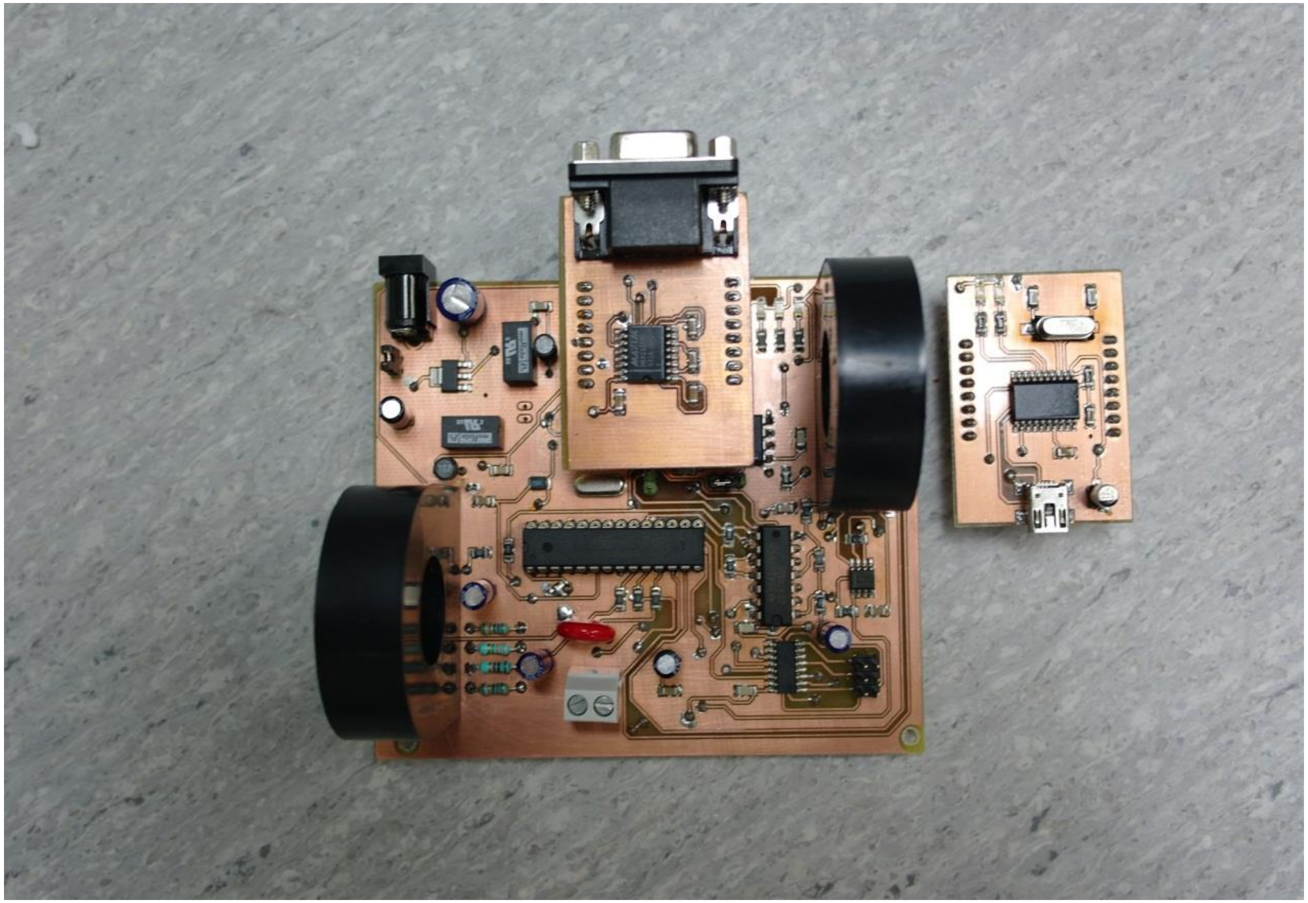
Power Meter: Bread Board Prototype



Power Meter: PCB



Power Meter: Final Prototype



Power Meter: The firmware

The main function of the firmware is to:

- Manage the measured data (Data Acquisition)
- Process the measured data
- Display and monitor the measured data

The most important function of the program is the **ISR** (Interrupt Service Routine):

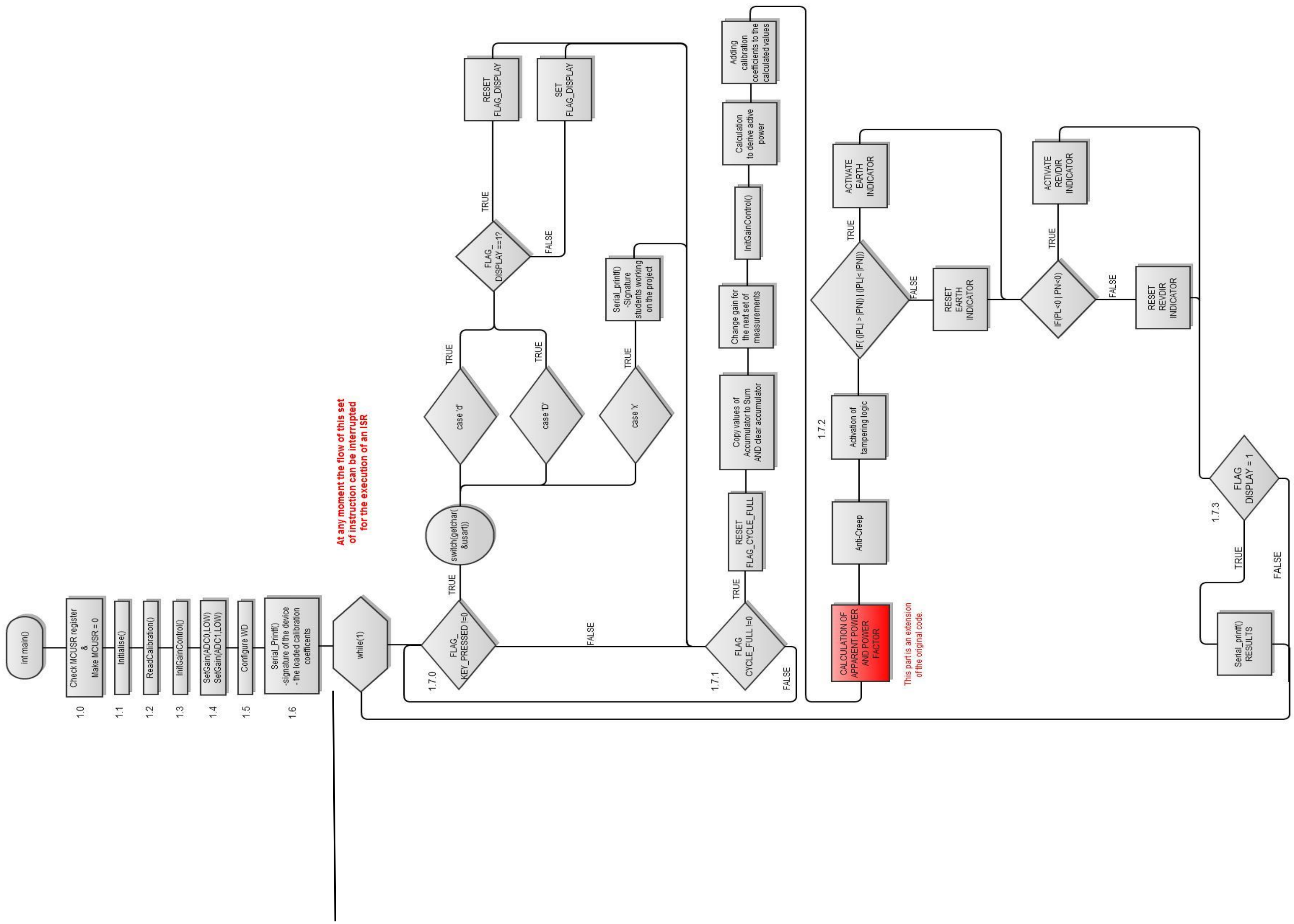
The ISR, reads, processes and cumulates sampled data and then returns the results to the main program.

The ISR is called every time the ADC is completed:

```
ISR(ADC_vect)
{
            signed int TempI;
            signed long TempL;
            PORTB=(PINB&DIRB)|DUTY;                // For duty cycle monitoring
            Sample[Index].Previous=Sample[Index].Fresh; // x[n+1] <- x[n]
   if (0==Index)                                   // x[n] <- DATA
      Sample[Index].Fresh=ADC;             // save voltage sample as it is
   else
      Sample[Index].Fresh=(0x03FF-ADC);    // save inverted to current sample
}
```

There other functions such as data filtering, gain control, ..etc.

Program overview: Flowchart



Program: Overview

Steps	Description	
1	Checking the MCUSR (Micro Controller Unit Status Register).	
2	initializing the registers: ACSR; CSR; BRR; TCCR; OCR; TIMSK; ADMUX; ADCSRA	
3	Calibration	
4	Determine the gain of the amplifiers	
6	Measurement and Data filtering	
7	Compute the power	
8	Display and Monitor	

PLC (Power Line Carrier): Principal

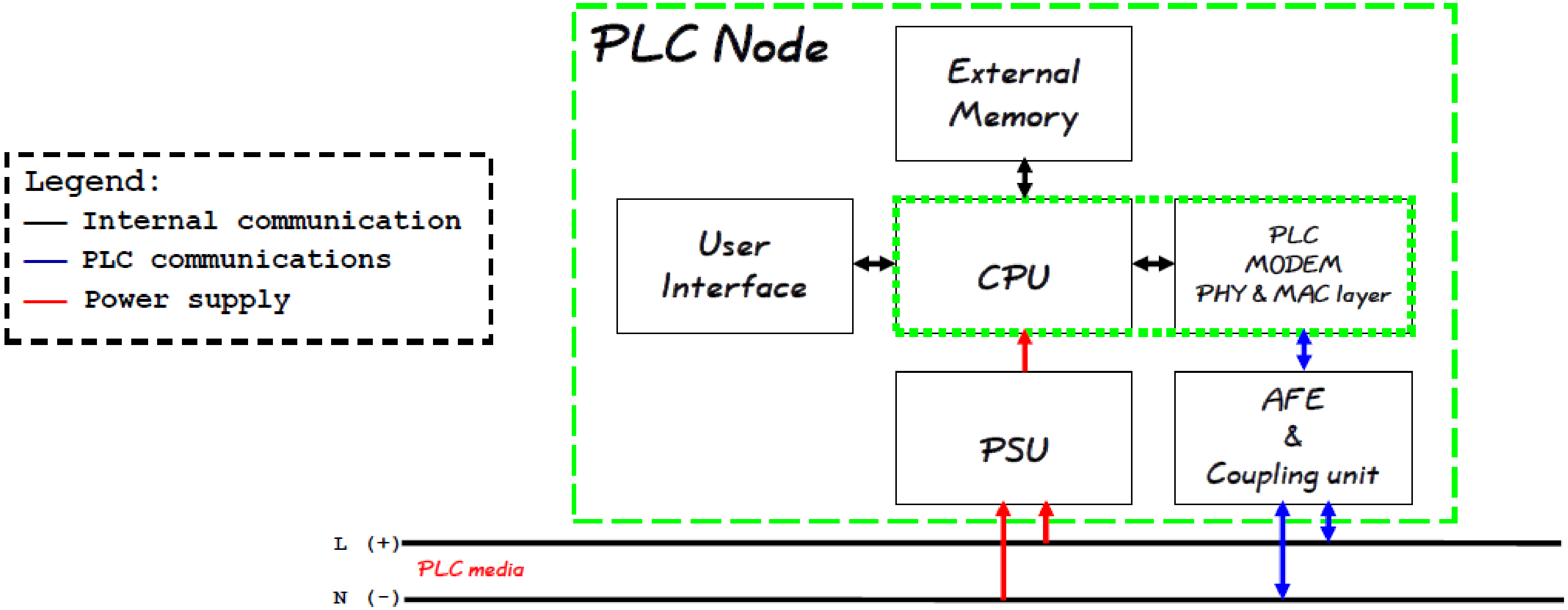
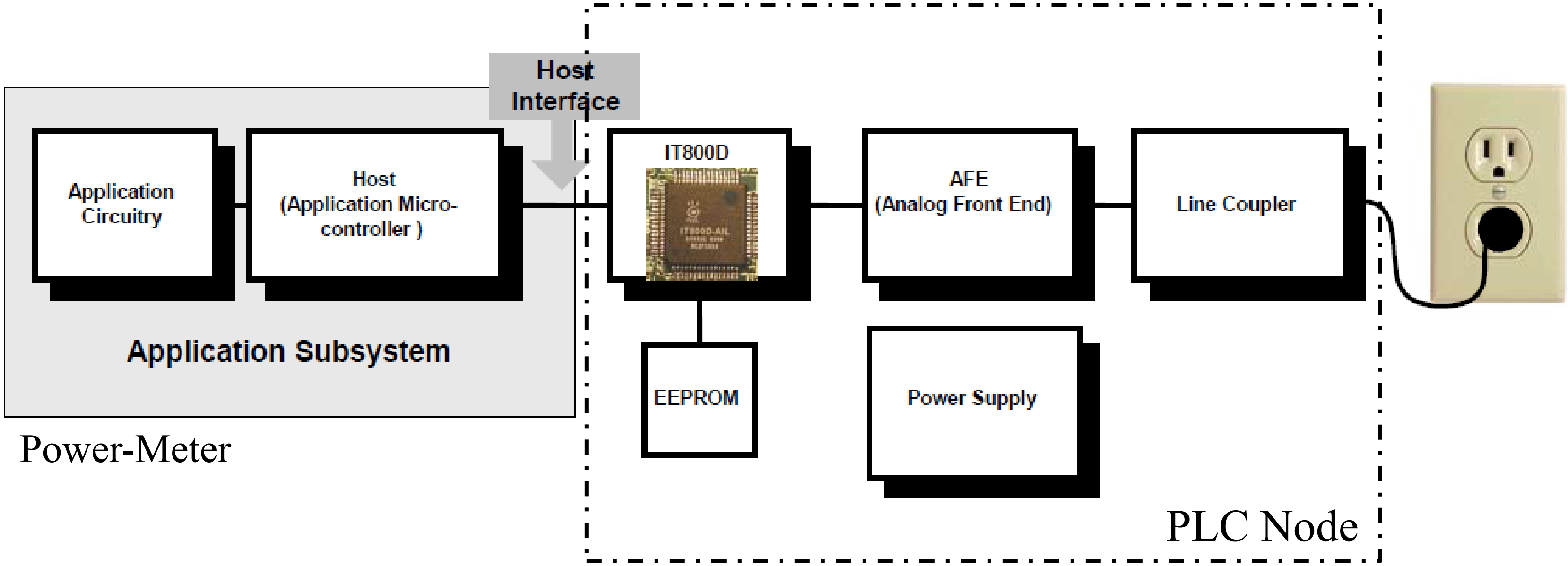


Figure Source = Ulrich Bjere. The PLC Technology

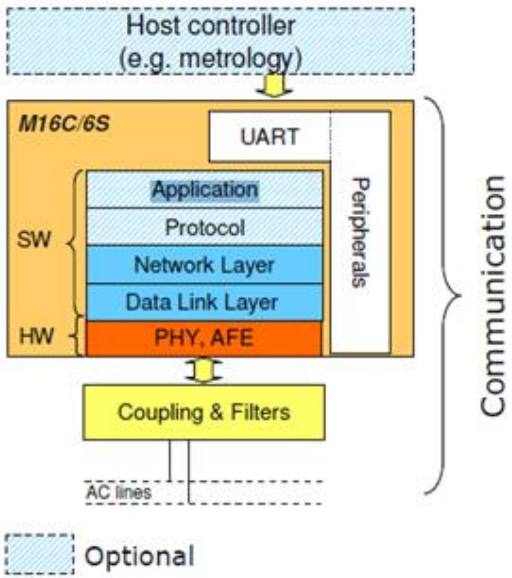
- AFE (Analog Front End)➔ Filtering and coupling to the power grid
- Physical & MAC Layer➔
    - ➔Communication to the PLC media
    - ➔ Modulation:
        - FSk: Frequency Shift Keying
        - DCSK: Differential Code Shift Keying (Renesas: Ytran Pantent)
        - BPSK: Binary Phase Shift Keying (Echelon)
        - ....
- Communication between external CPU

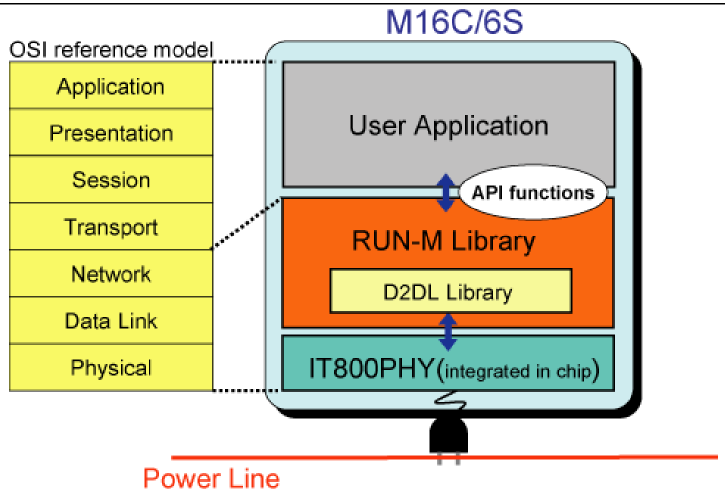
PLC: principle



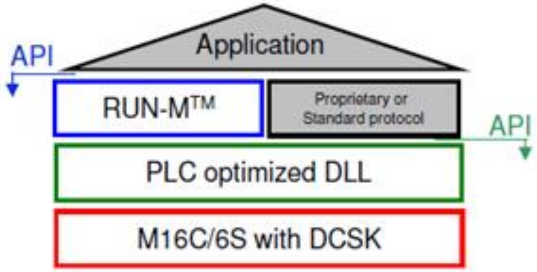
The **IT800D** is a Power Line Communication modem used in the **Renesas Run M modules**. The IT800D chips are responsible for the data link layer as well as for the physical layer.

PLC (Power Line Carrier)





Single chip MCU with integrated PLC modem



DCSK: **Differential Code Shift Keying Modulation** (Robust against powerline noise)

RUN-M: R*ENESAS* ***U****biquitous* ***N****etwork Layer for* ***M****etering Applications.*

- *Intelligent join procedure and self healing.*
- *Dynamic reconfiguration*
- *Intelligent Repeating mechanism*

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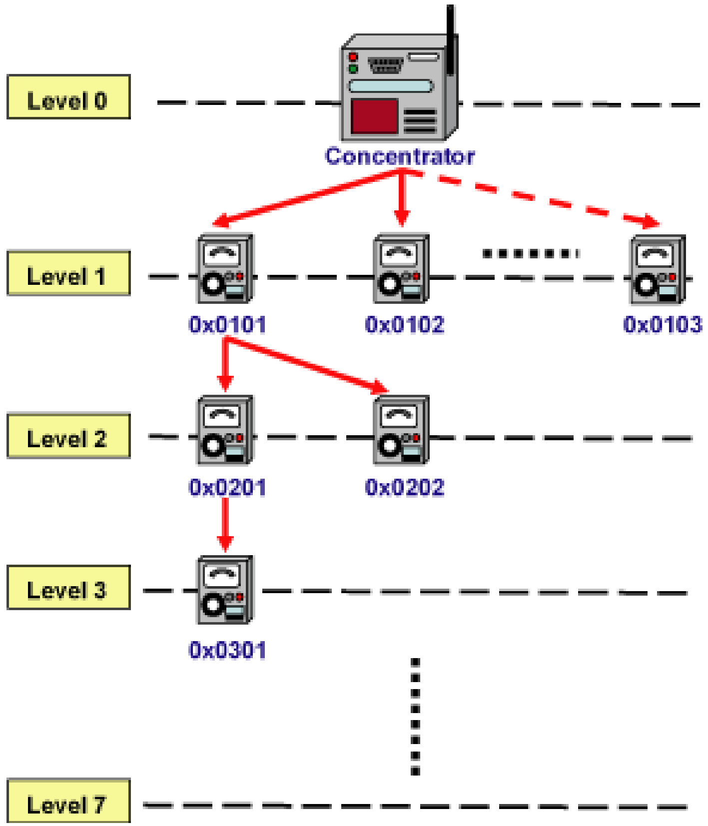
RUN-M Network Structure



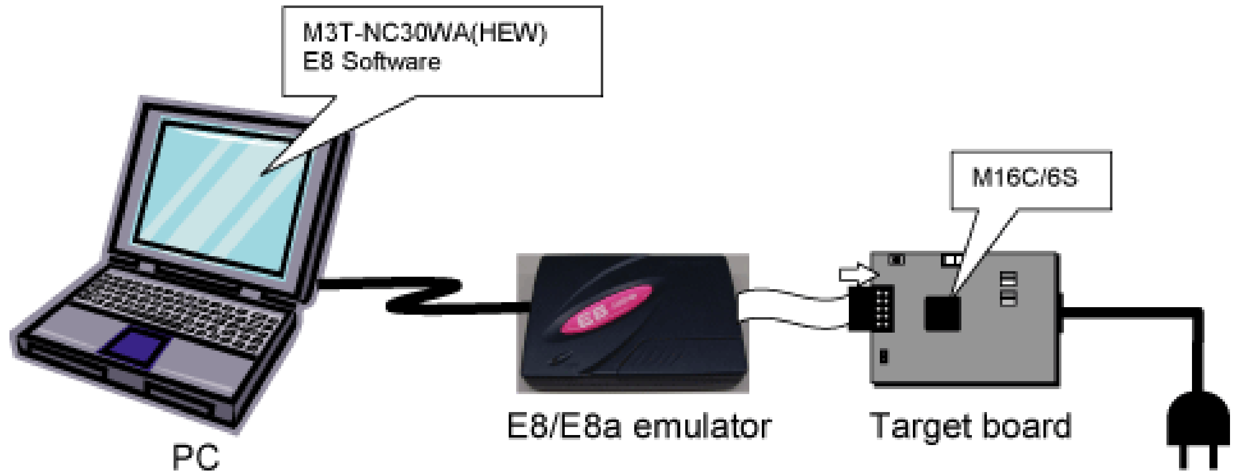
The features of the RUN-M network are described as follows:

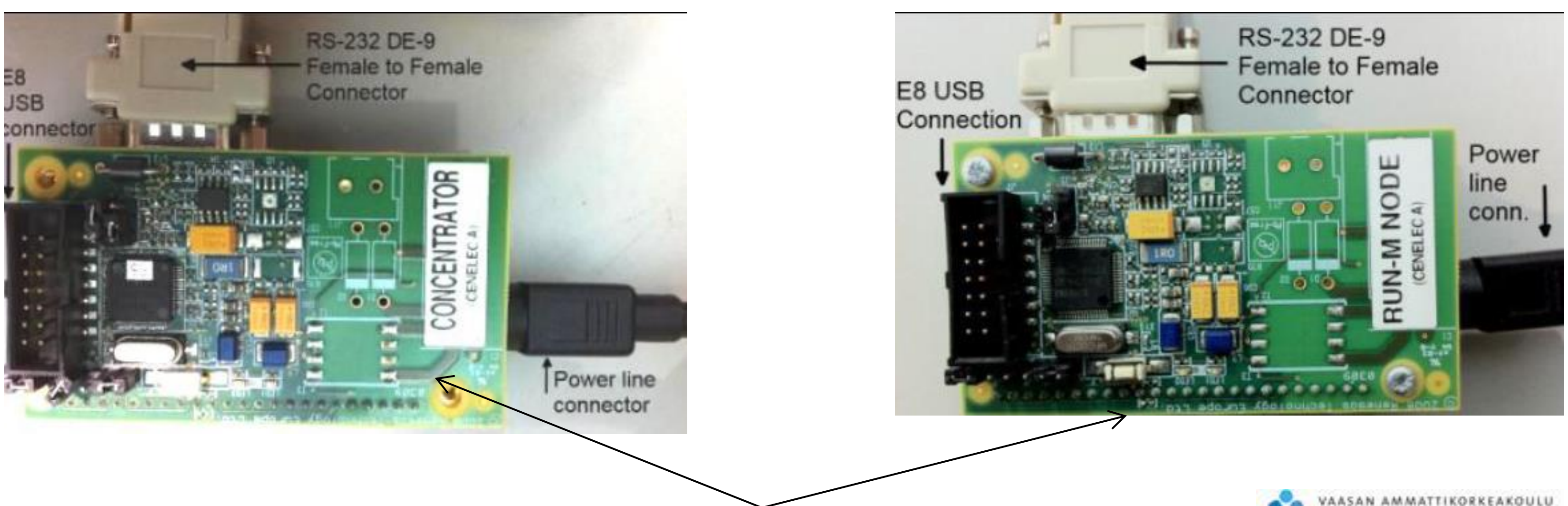
- ✓ Tree network structure
- ✓ Up to 7 levels tree depth
- ✓ Up to 255 nodes in each level
- ✓ Allows 1785 network participants
- ✓ Network is controlled by a main device (Concentrator)
- ✓ Concentrator is the only device located on level 0

Multiple Message Types

- Unicast: Message to a particular node
- Levelcast: Message to all nodes on a particular level
- Multicast: Message to entire network

Development Environment for Automatic Meter



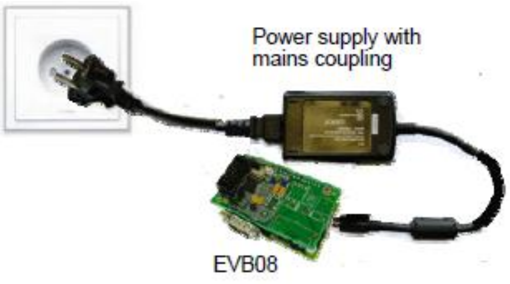


EVB08 modules

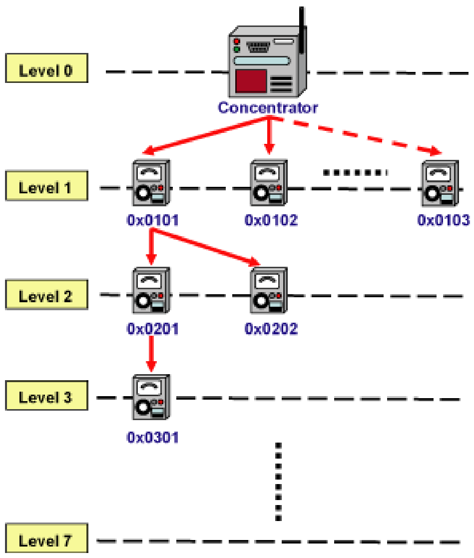
Developement Environment for AM

Concentrator set up

Node setup



Node setup



Functions added to the AM System

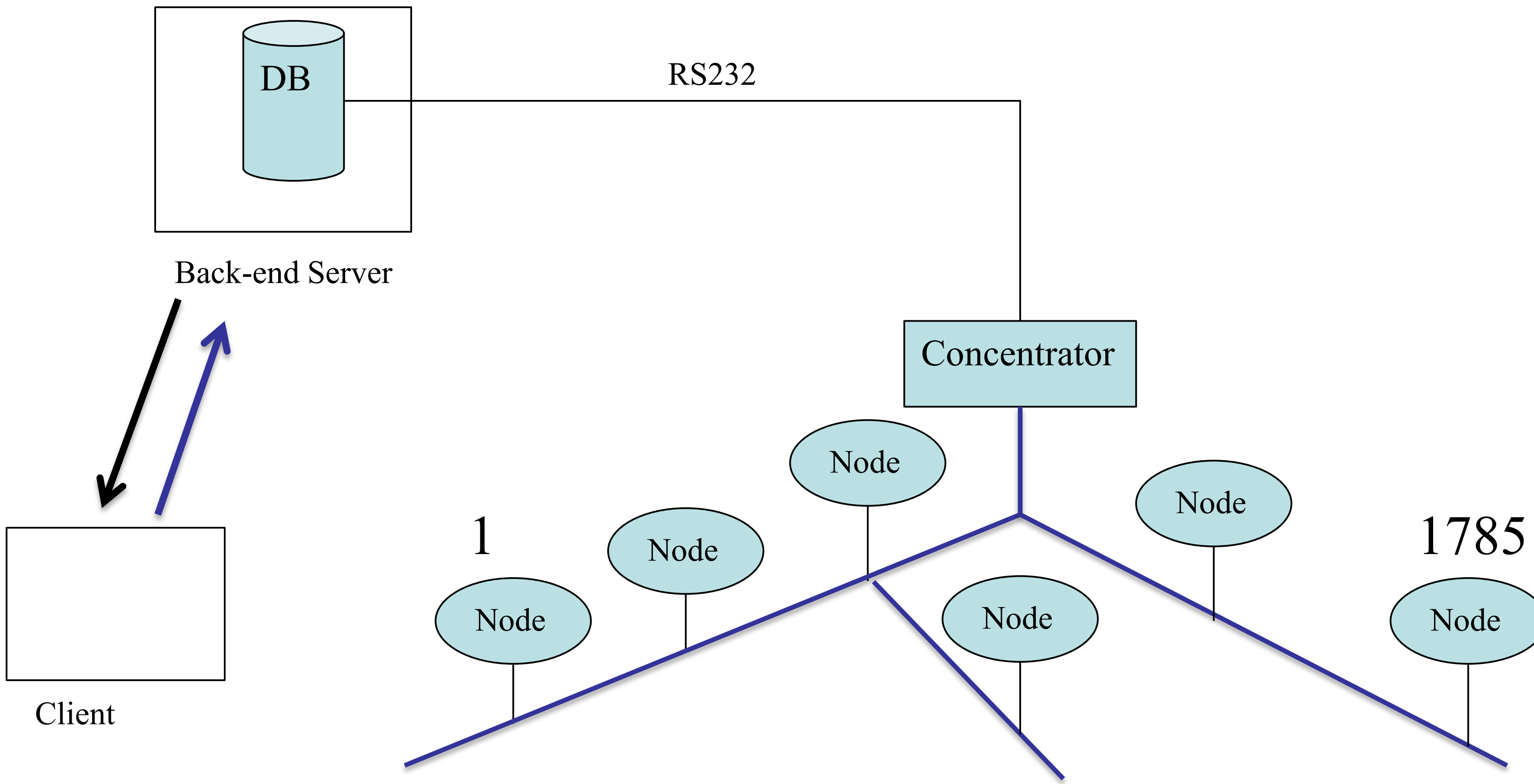
- RTC (Real Time Clock): To be used in every application that require date
- Send auto-request: Use RTC to request data from each node at regular period of the day/week/month/year
- Send auto-response: Similar to the request function, but with options to select which data will be sent.
- Tariff: Set the price per kWh
- Send messages: Send messages to selected node
- High usage Alarm: When customers uses more energy than predicted, the data concentrator sends a warning
- Store data of a node: The concentrator stores data temporary before sending to database
- Ping a node: To describes the status of the nodes
- **UMI**

```
DSN: 0x00000000    Network Id: 0x0142

 1 - Basic device set up
 2 - Send data to a node
 3 - Send a leave request to a node
 4 - Send a force leave
 5 - Send a line quality request to a node
 6 - Print child table
 7 - Warm start
 8 - Cold start
 9 - Cold start and reset of all parameters
 10 - Set the number of max. accepted children
 11 - Get management table value
 12 - Set management table value
 13 - Remote get management table value
 14 - Remote set management table value
 15 - Send new tariff
 16 - Send CNC message
 17 - View time
 18 - Set time
 19 - Send message
```

In Red: not implemented yet

NES (Network Energy Service)



Back-end applications

Priority	Description	Dependencies
1	Data export & import.	Communications (TCP/IP, USB...)
2	Instant kWh view. A live view of energy usage expressed in kWh.	Current power reading Memory access (for storing readings)
3	Daily/Weekly/Monthly/Yearly view. A historic view of average energy usage.	Memory access (retrieval of readings)
4	User input screen for settings regarding cost of energy (what prices at what times) and usage alarm threshold.	Input (buttons) Memory access (saving/retrieval settings)
5	High use warning alarm	Current power reading Access to settings Communications (optional)
6	Instant Cents/hr. view	Instant kWh view Input Access to settings
7	Usage graph.	Daily/Weekly... view Access to memory
8	Remote interfaces	TCP/IP Communications

Conclusion

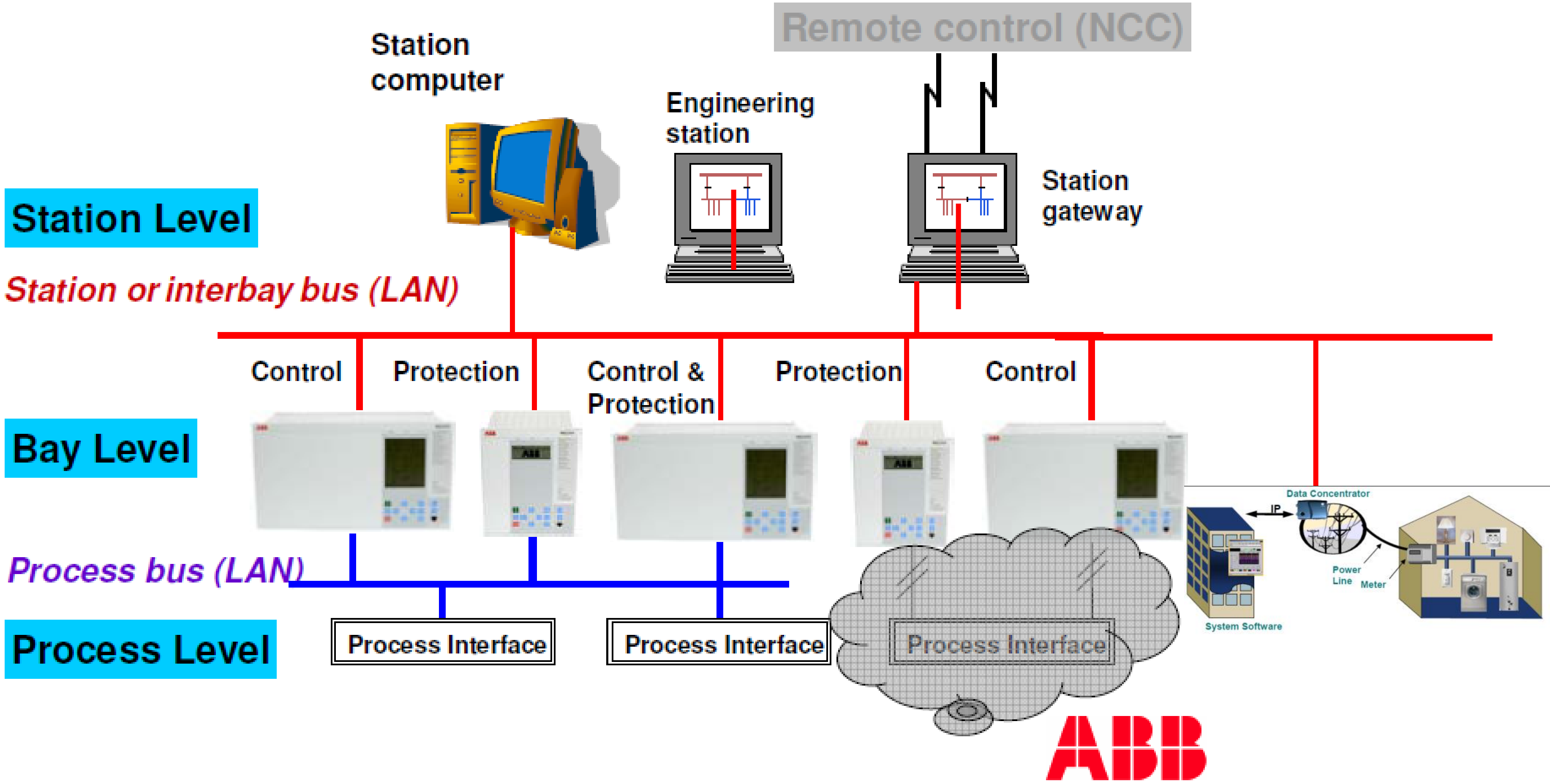


Figure source: Zoran Kajic, ABB Power Technologies AB