Chapter 2
Evolution of Electricity Meters

Abstract This chapter describes the evolution of electricity meters from electromechanical meters to modern smart meters. The operation principle of a typical electromechanical meter is well described with illustrations and calculations. The drawbacks of electromechanical meters are also highlighted. The operations of reactive energy meter and maximum demand meter are also discussed. The technological evolution from solid state electronic meters to smart meters is discussed. The importance of smart meters in modern energy measurement is highlighted. The basic hardware structure of a modern smart meter is illustrated. A broader discussion is done about the hardware components inside a smart meter including voltage and current sensors, power supplies, energy measurement, microcontroller, real time clock and communications. Importance of standardization of smart meters is described.

2.1 Introduction

In recent years, domestic and industrial users have shifted from traditional meters to smart meters. Electromechanical meters were a dominant part of electricity measurement before 1970 [1]. They could only measure the electrical energy. However it had been identified that the requirement of a meter which could communicate and measure the electrical energy along with other electrical parameters. Therefore solid state electronic meters were introduced to measure the overall electrical parameters.

Between 1970 and 2000, automatic meter reading was added to electronic meters and it was a great achievement since it could send the data in near time. However it could only provide the one-way communication. This limitation was overcome by the introduction of smart meters which can provide two-way communication. Smart meters can measure all the electrical parameters like electronic meters and communicate data in a meaningful way. The consumer is updated with

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electricity usage, cost, tariffs and other notifications sent by the utility. Smart meters have different functionality to manage the end user loads and run them in an optimal way to reduce the electricity bill as well as to conserve the energy. Smart meters have been used since a decade [1].

Nevertheless many researchers and developers are trying to add features to smart meters and try to come up with best solutions for energy efficiency, conservation and demand management. Smart meters are still evolving and many governments and organizations are trying to standardize them.

2.2 Operation Principles of an Electromechanical Energy Meter

Electromechanical energy meter is the most traditional and widely used energy meter over a century. It is capable of measuring only the active energy which is typically displayed on a mechanical counter in kWh. Figure 2.1 shows an example of a typical single phase electromechanical meter [2].

It is basically designed with four major systems which are driving system, moving system, breaking system, and registering system. The driving system consists of two electromagnets while the moving system consists of an aluminum disc. The permanent magnet acts as the breaking system while the gear train and counter act as the registering system. The electromagnetic force is produced by the

Fig. 2.1 A single phase electromechanical meter

arrangement of voltage and current coils. The voltage coil is connected across the supply while the current coil is connected in series with the load [3]. The voltage coil produces a magnetic flux in proportion to the voltage and the current coil produces a magnetic flux proportional to the current. The aluminum disc is mounted on a rigid axis. A mechanical force is exerted on the disc by the Eddy currents produced. The register mechanism integrates the speed of the disk over the time by counting the number of revolutions [4]. Figure 2.2 shows the basic arrangement of a single phase electromechanical energy meter.

Current coil or the series coil produces alternating flux which is proportional and in phase with the load current. Voltage coil or the shunt coil carries a current proportional to the supply voltage. The flux produced by the voltage coil is not in phase with the supply voltage. This flux is 90° lagging with the supply voltage. This is done by having properly adjusted copper rings in the flux path as shown in the Fig. 2.2. However some electromechanical meters use winding with the series connected lag adjusting resistor to perform this task [4].

The phasor diagram of the single phase energy meter is shown in Fig. 2.3 [5].

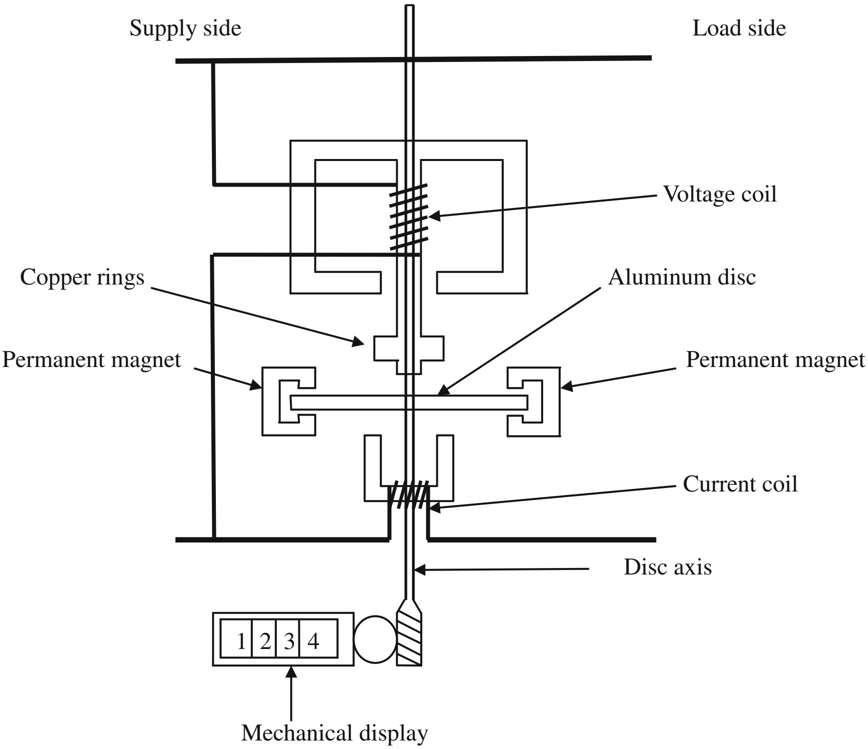
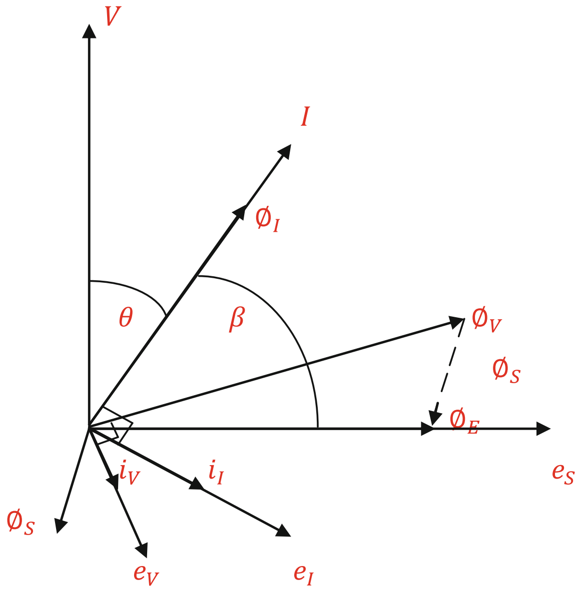


Fig. 2.2 Components of a single phase electromechanical energy meter

Fig. 2.3 The pahsor diagram of the single phase energy meter



where;

$\emptyset_I$ is the flux due to current coil
$\emptyset_S$ is the flux due to quadrature band
$\emptyset_V$ is the flux of the voltage coil
$\emptyset_E$ is the effective flux $(\emptyset_S + \emptyset_V)$
e_S is the induced e.m.f. due to $\emptyset_E$
e_I is the induced e.m.f. due to $\emptyset_I$
i_V is the current in the rotor due to e_V
i_I is the current in the rotor due to e_I (neglecting the rotor resistance)
I is the current through the series coil
V is the supply voltage
θ is the phase angle between the current and the voltage (load connected to meter)

The energy calculation inside an electromechanical energy meter is described as follows [6].

The average driving torque acting upon the disc can be written as

$$T_{d(av)} = k_d[\emptyset_E i_I \cos(\theta) - \emptyset_I i_V \cos(180 - \theta)] \tag{2.1}$$

where;

$T_{d(av)}$ is referred to average driving torque
k_d is a constant for the meter

Since

$$\emptyset_E \propto \frac{V}{\omega} \rightarrow \emptyset_E = k_1 \frac{V}{\omega} \tag{2.2}$$

$$\emptyset_I \propto I \rightarrow \emptyset_I = k_2 I \tag{2.3}$$

$$i_I = k_2 \frac{I}{Z} \omega \tag{2.4}$$

$$i_V = k_1 \frac{V}{Z} \tag{2.5}$$

where; Z is the eddy current path impedance (the phase angle is assumed to be zero), k_1 and k_2 are constants, ω is the angular frequency.

Substituting terms in (2.1), using (2.2)–(2.5)

$$T_{d(av)} = k_d \left[k_1 \frac{V}{\omega} k_2 \frac{I\omega}{Z} \cos(\theta) - k_2 I k_1 \frac{V}{Z} \cos(180 - \theta) \right] \tag{2.6}$$

$$\begin{aligned} T_{d(av)} &= \frac{k_d k_1 k_2}{Z} [VI \cos(\theta) + VI \cos(\theta)] \\ T_{d(av)} &= \frac{2k_d k_1 k_2}{Z} VI \cos(\theta) \\ T_{d(av)} &= k' P \end{aligned} \tag{2.7}$$

where; $k' = \frac{2k_d k_1 k_2}{Z}$ and P is the active power

Form (2.7), we can see that the driving torque is directly proportional to the active power.

The breaking torque is produced by two permanent magnets mounted in opposite directions.

$$T_{b(av)} = k_b \emptyset_b i_b \tag{2.8}$$

$$\begin{aligned} T_{b(av)} &= k_b \emptyset_b \frac{e_b}{R_e} \\ T_{b(av)} &= k_b \emptyset_b \frac{N\emptyset_b}{R_e} \\ T_{b(av)} &= \frac{k_b \emptyset_b^2}{R_e} N \end{aligned} \tag{2.9}$$

where;

$T_{b(av)}$ is referred to the average breaking torque
i_b is the eddy current due to $\emptyset_b$
e_b is the induced e.m.f. due $\emptyset_b$
k_b is a constant of proportionality,
$\emptyset_b$ is the flux produced by permanent magnets,
N is the rotational speed of the aluminum disc and
R_e is the resistant of the eddy current path.

At steady state

$$T_{d(av)} = T_{b(av)} \tag{2.10}$$

Therefore using (2.7) and (2.9);

$$k'P = \frac{k_b \emptyset_b^2}{R_e} N$$

$$P = \frac{k_b \emptyset_b^2}{k' R_e} N \tag{2.11}$$

From (2.11) we can clearly see that the active power is proportional to the rotational speed of the disc.

The disk axis will transmit the disc rotation to a mechanical counter. This system continuously accumulates the disc displacement with the time. Therefore

$$\alpha = \int N dt \tag{2.12}$$

$$E = \int P dt \tag{2.13}$$

where;

α is the disc displacement
E is the active energy and
t is the time

Using (2.11)–(2.13)

$$E = \int \frac{k_b \emptyset_b^2}{k' R_e} N dt \tag{2.14}$$

$$\begin{aligned} E &= \frac{k_b \emptyset_b^2}{k' R_e} \int N dt \\ E &= \frac{k_b \emptyset_b^2}{k' R_e} \alpha \end{aligned} \tag{2.15}$$

According to (2.15), the displacement is proportional to the active energy. Therefore the counting system can be calibrated accordingly with the active energy to display the energy consumed.

2.3 Drawbacks of the Electromechanical Energy Meters

Electromechanical meters react to the changes more slowly than digital meters. They have many susceptible errors due to environmental variations and regular operations [7]. The moving parts inside these meters are prone to wear over time, varying temperature, and conditions. On the other hand mechanical gears wear due to effects of dirt, dust and humidity. The gear ratios also change over time due to lack of lubricants. Nevertheless, vibration and shock affect the accuracy of the meter in the long run. Therefore periodic calibrations are required at regular intervals. Furthermore, due to the lack of linearity of iron core and the inertia of the spinning disk, errors can be caused at low and high loading [7].

Electromechanical meters require manual readings. In other words meter readers have to go and take the reading manually to issue the bill. Because of the man power requirement, there is always an additional cost to the bill apart from the energy consumed. Moreover the tampering of meter readings, human errors in readings, irregularities in billing time, and controversial billing are also possible with manual readings [8].

Power theft is a major problem caused with electromechanical meters. Illegal reconnection of power lines, bypassing of the energy meter, and very weak conditional access enforcement cannot be detected directly with these meters [9].

2.4 Reactive Energy Meters

The active energy doesn't represent the total energy delivered to a consumer. Therefore the measurement of reactive energy is also an interesting part to analyze the overall energy delivery. The reactive energy had been traditionally measured by reactive energy meters before the digital meters were introduced. Reactive energy meters are also known as sine meters because they measure the reactive component of the current which is 90° apart from the applied voltage. Even though the appearance is same as the typical electromechanical meter the construction of the sine meter is little bit different. The voltage coil is used to produce voltage flux which is in phase with the supply voltage. This is done by adding a high non-inductive resistor in series with the voltage coil. Meanwhile the current coil produces a flux in phase with the load current. The torque is proportional to the product of volts $\times$ amperes $\times$ $\sin\theta$, where θ is the phase angle between the voltage and current. This meter reads the reactive energy typically in kvarh. A register mechanism is used to count the units of reactive energy. The lagging currents cause forward count in registers while leading currents cause backward count. The accuracy of measurement is lower than electromechanical meters due to some limitations in design [5]. The phasor diagram of a single phase sine meter is shown in Fig. 2.4.

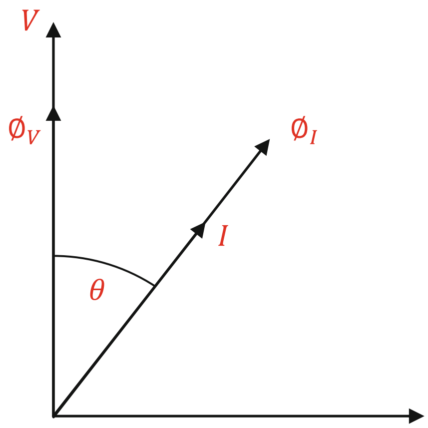


Fig. 2.4 The phasor diagram of a single phase sine meter

2.5 Maximum Demand Meters

Maximum demand is also taken into consideration for bulk consumers in electricity billing. Even though the real mechanical work is done due to the active energy delivered to the consumer, additional cost is paid for the maximum demand. This cost is designed to encourage the consumers to operate near to unity power factor. Maximum demand is measured with maximum demand meters. There are three main types of maximum demand meters [5]. They are

- Integrated instruments
- Thermal type indicators
- Electromagnetic type meters.

Different types of meters have different arrangements and operation mechanisms. However the maximum demand calculation is common to every meter. Maximum demand is the highest average demand recorded over specified time intervals. The average demand within a period of time can be written as

$$MD_i = \frac{1}{T}\int_0^T f(t)dt \tag{2.16}$$

where;

T is the demand interval or the demand integrating period
MD_i is the average demand over the time interval T
$f(t)$ is the demand function (in kW or kVA)

The demand interval(T) may vary power utility to other. Typical values for T are 10, 15, and 20 min. The maximum demand is the highest value among all the average demands recorded over the month. Therefore the maximum demand is

$$MD_{month} = Maximum(MD_i) \tag{2.17}$$

2.6 Electronic Meters

Electronic meters are capable of measuring electricity usage with digital technology. At the same time they can measure the other electrical parameters such as phase voltages, phase currents, frequency, power factor, active power, reactive power, apparent power, maximum demand, and power quality measurements. Therefore they perform all the tasks that are done by the other types of meters. They have also the capability of sending the measured data through a communication link.

A Typical electronic meter consists of a power supply, microcontroller, Real Time Clock (RTC), LCD display, and communication ports [4]. It has voltage

Fig. 2.5 A single phase electronic energy meter

inputs, current inputs and a reference voltage. Voltage and current signals are processed to measure and display the electrical parameters.

Electronic meters provide timely data, high accuracy in measurement in a wide range of loads, greater flexibility of design, and updating capacity. They are not influenced by external magnets or orientation of the meter itself. Therefore digital meters are more reliable and tamperproof than electromechanical meters [2]. A single phase electronic energy meter used by a utility company is shown in Fig. 2.5.

2.7 Smart Meters

Smart meters are different from electronic meters because of their additional functionalities and features. Apart from electricity measurements and automatic meter reading (AMR), they allow two-way communication between the meter and the base station. Load profiling, pre-payment, remote disconnection and reconnection, power outage notification, tamper detection, and multi-tariffing are also possible with smart meters [10]. A three phase smart meter is shown in Fig. 2.6.

The electronic meters have been used effectively for accurate billing. However more functions are needed such as remote readings, outage detection, tamper detection, load profiling for better customer service and reliable supply. Therefore

Fig. 2.6 A three phase smart meter

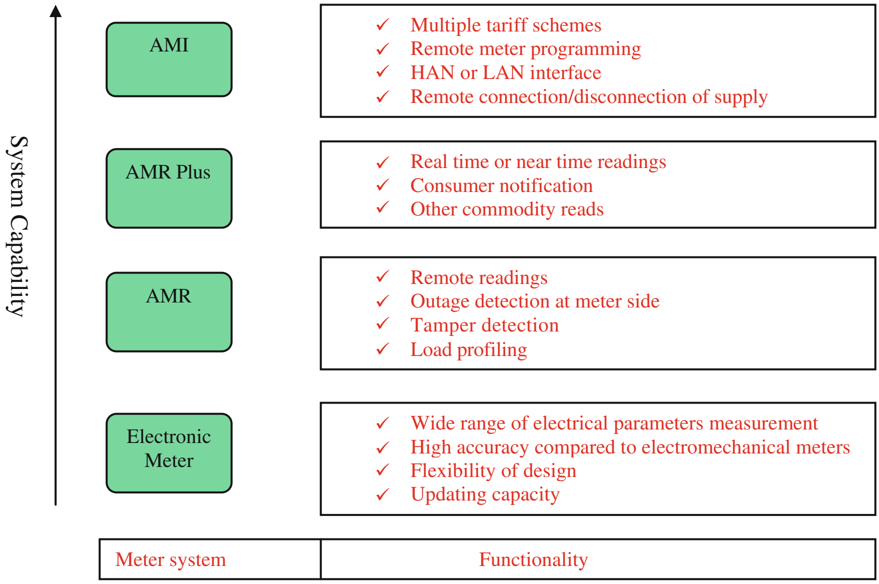


Fig. 2.7 Smart meter technology evolution

AMR system is introduced by combining the communication infrastructure to electronic meters. Meanwhile more features and functions are added to AMR system. Ultimately AMI (Advanced Metering Infrastructure) has been developed to today's technology with two-way communication and data management system. Figure 2.7 shows the evolution of smart meter technology from electronic meters to AMI [11].

2.8 The Hardware Structure of a Smart Meter

Figure 2.8 shows the functional bock diagram of a smart meter. It includes signal acquisition, signal conditioning, Analogue to Digital Conversation (ADC), computation and communication [1].

Smart meters use voltage and current sensors to get the input signals. Signal conditioning, ADC, and computations are done inside the micro controller unit (MCU). Additional hardware components are required for other operations like

Fig. 2.8 Functional block diagram of a smart meter

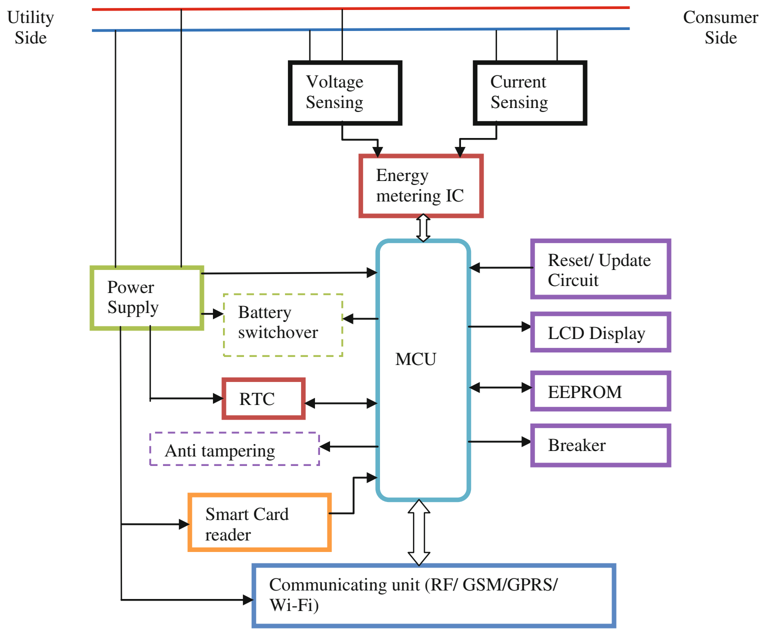


Fig. 2.9 Hardware structure of a modern smart meter

communication, time and date measurements, and data backup and storage. A smart meter is typically composed of following hardware components:

- Voltage and current sensing unit
- Power supply
- Energy measurement unit (metering IC)
- Microcontroller
- Real time cock
- Communicating system.

Figure 2.9 shows the hardware structure of a modern smart meter.

2.8.1 The Voltage Sensing Unit

Simple resistor dividers are widely used as voltage sensors in digital meters due to low cost. Figure 2.10 shows the configuration of a resistor divider type voltage sensor.

The values of R1 and R2 should be chosen such that the AC mains voltage is divided down to fit the input range of the ADC of the energy measurement chip. According to the Fig. 2.10 the AC voltage is applied to R1 and output is taken from the middle point of the divider. R2 should be grounded. The output voltage from the divider (to ADC) is given by (2.18).

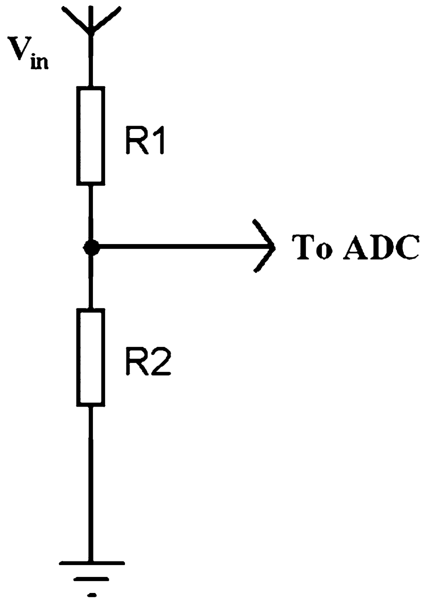


Fig. 2.10 Resistor divider configuration

$$V_o = \frac{R2}{R1 + R2} V_{in} \tag{2.18}$$

where

V_o is the output voltage
V_{in} is the input voltage

Normally R1 and R2 are in kΩ scale. R1 is much greater than R2 (R1 $\geq$ 500R2). Higher values of resisters are chosen because of the lesser power dissipation.

2.8.2 The Current Sensing Unit

The current sensing unit typically consists with current sensors and anti aliasing filters. Four types of current sensors are widely used in smart meters. They are:

- Hall effect-based linear current sensors
- Current transformers
- Shunt Resistor
- Rogowski coils.

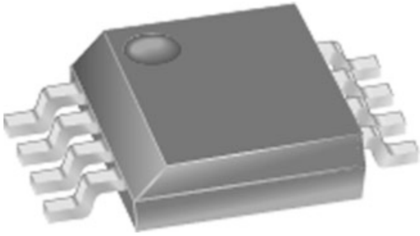


Fig. 2.11 ACS 712 Hall IC (Courtesy of Allegro MicroSystems, Inc.)

(A) Hall effect-based linear current sensors

These sensors consist of a chip and a copper conduction path located near the surface of the die. The current flowing through the copper conduction path generates a magnetic field. This magnetic field is sensed by the Hall IC and converted into a proportional voltage [12]. Figure 2.11 shows an example of ACS 712 Hall IC which is available in the market.

(B) Current transformers

Current transformers (CTs) produce a secondary current which is proportional to the primary current. Magnetic properties of CTs are highly linear over wide range of primary current, and temperature. The primary is connected in series with the device [13]. The isolation is provided from primary to secondary side thus ensuring high reliability for metering devices. However the linearity depends on the magnitude of the primary current and the impedance of the secondary. Every CT is classified according to its performance. Normally class 0.1, 0.2, 0.5 and 1 are used for metering purposes. Although CTs are expensive than shunt resistors, they consume lesser power. However CTs have nonlinear phase response at low currents and large power factors [1]. Figure 2.12 shows the typical through-hole type current transformers which are widely used in metering applications [14].

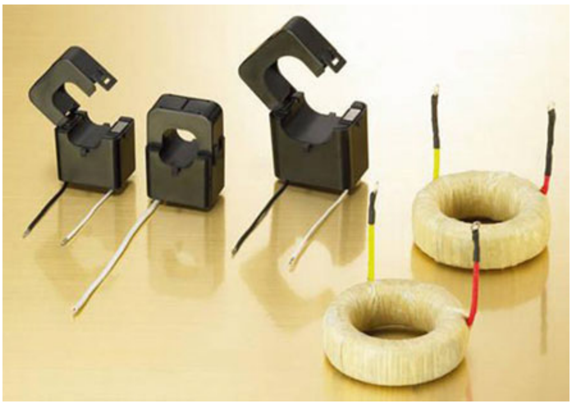


Fig. 2.12 Through-hole type current transformers (Courtesy of Taehwatrans Co. Ltd.)

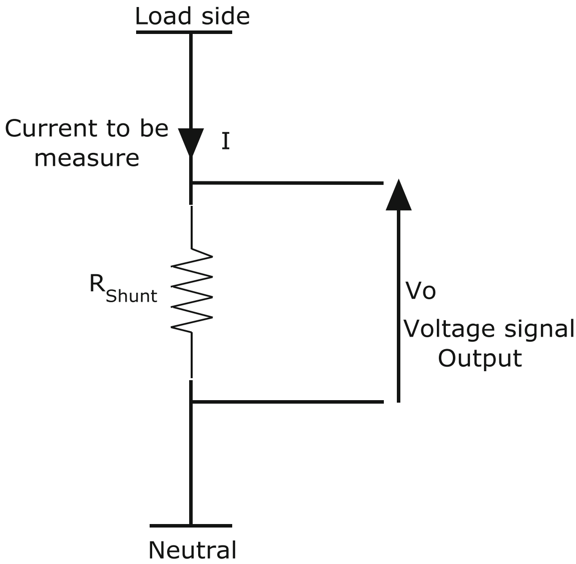


Fig. 2.13 Circuit diagram of a shunt resistor

(C) Shunt resistors

Shunt resistors are widely used in metering applications because of their lower cost than other types of current sensors. These sensors are simply placed in series with the load current path. Their resistances are typically in the range of 100 μΩ–500 mΩ. The power dissipated is proportional to the square of the current. Therefore a very small resistance should be selected to minimize the heat dissipation [1, 15]. Shunt resistors are highly stable resistors designed with low resisting materials so that the resistance doesn't change with the current, temperature or age. The voltage across the shunt resistor is proportional to the current that flows through it. This voltage signal is fed to an energy measuring chip or to a MCU. Therefore, when the resistance is known, the current can be calculated according to Ohm's law. The circuit diagram of a shunt resistor is shown in Fig. 2.13. Although resistive shunts are inexpensive, highly linear, and immune to magnetic influences, they do not have the inherent electrical isolation.

(D) Rogowski coil sensors

Rogowsli coils were introduced to the electrical industry as far back as in 1912, to measure the magnetic fields, but these could not be used for current measurements, since the power produced was not sufficient to drive electromechanical equipments. With the development of solid state electronics and microprocessor based systems, Rogowski coils have provided wide range of opportunities. These sensors are coils with non-magnetic core for which the name air cored is used. They give an output voltage which is proportional to the rate of change of current. They linearly convert the primary current up to all short circuit levels. Due to the absence of iron, they are saturation free. They have many advantages over conventional CTs, which include [16]

- High measurement accuracy
- Wide measurement range
- Wide frequency range
- Can withstand unlimited short circuit currents
- Small in size and weight
- Low production cost.

However Rogowski coils cannot produce a voltage signal which is directly proportional to the current flow. The relationship between the output voltage and the current flow is given by (2.19).

$$V = k\frac{dI}{dt} \tag{2.19}$$

where;

V is the output voltage
I is the current to be measured
t is the time and
k is a constant

Current signal should be recovered from dI/dt signal. Rearranging the terms in (2.19)

$$\begin{aligned} Vdt &= kdI \\ \int Vdt &= \int kdI \\ I &= \frac{1}{k}\int Vdt \end{aligned} \tag{2.20}$$

Fig. 2.14 Commercially available Rogowski coils (Courtesy of Taehwatrans Co. Ltd.)

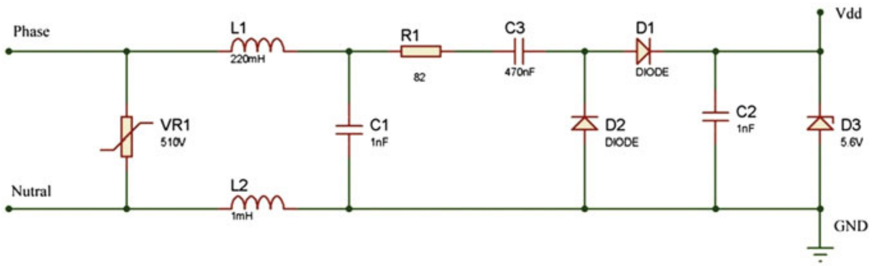


Fig. 2.15 Power supply schematic in STPM10 reference design (Courtesy of STMicroelectronics, Inc.)

According to (2.20), the output voltage should be integrated with respect to time to get the original current signal. Some energy measurement chips have built-in integrator to recover the current signal from Rogowski coils.

Rogowski coils are commercially available in a variety of configurations, including the popular flexible type. Figure 2.14 shows some of commercially available Rogowski coils [17].

2.8.3 Power Supply

Power supply unit may vary from smart meter designer to designer. However this unit typically consists of step-down transformers, rectifiers, AC-DC converters, DC–DC converters and regulators. Energy measurement chip designers provide their own reference power supply schematics. Figure 2.15 shows the power supply schematic which is used in STPM10 energy meter reference design [18].

However the power output from these circuits may not be sufficient to drive other hardware components in the smart meter. Therefore the required power to drive the energy chip, MCU, LCD, battery charger and communication unit should be taken into consideration before designing a power supply. Figure 2.16 shows the block diagram of a typical power supply used in smart meters. First the AC line voltage is rectified through a diode bridge. Sometimes the AC voltage is stepped down before the rectification. Then the unregulated voltage output is fed to a DC–DC converter or a regulator IC. DC–DC convertor consist of an inductor, a

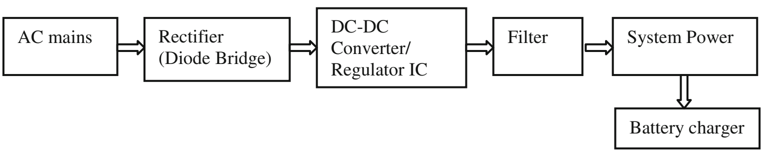


Fig. 2.16 A typical power supply used in smart meters

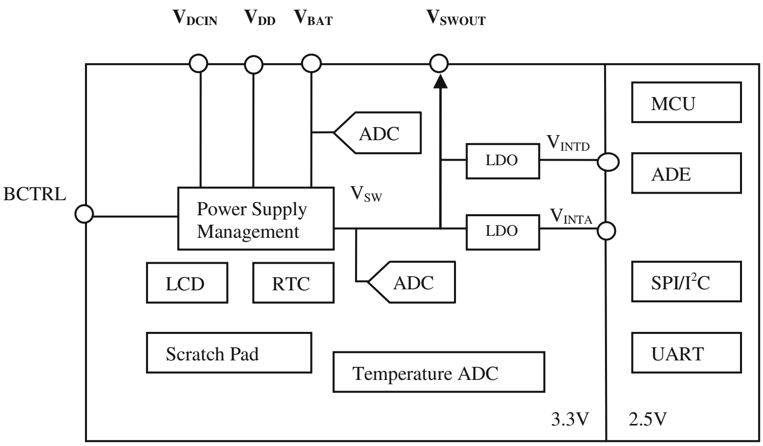


Fig. 2.17 Power supply architecture of ADE 5166 (Courtesy of Analog Devices, Inc.)

capacitor, and an electronic switch. The electronic switch in this converter can be a MOSFET, power transistor or IGBT. Else, a regulator IC is used instead of a DC–DC converter. The output is more filtered and fed as the system power. The battery charging unit controls a rechargeable battery.

Some energy measurement chips have inbuilt power management systems. For an example ADE 5166/ADE5169/ADE5566/ADE5569 chips have inbuilt power management circuitry that manages the regular power supply for battery switchover and power supply failures. Figure 2.17 shows the power supply architecture of the above chips. They are driven by two supply voltages which are V_{DD} and V_{BAT}. V_{DD} is the input voltage from an external supply and V_{BAT} is the battery input. These chips provide automatic battery switchover between V_{DD} and V_{BAT} based on the voltage level detected at V_{DD} or V_{DCIN}. More details on power management system can be obtained referring to the datasheets from Analog Devices website [19].

2.8.4 Energy Measurement Unit

Signal conditioning, ADC, and computation are done inside the energy measurement unit. Energy measurement unit could be a standard energy measurement chip or the system MCU itself. Modern energy measurement chips have digital signal processor (DSP) to perform signal conditioning, ADC and energy calculations. These chips can be found as single phase energy measurement chips or multi phase energy measurement chips. They provide active, reactive, and apparent energy information as data or frequency (pulse) output. RMS voltage measurement, RMS current measurement, frequency, temperature measurement, tampering detection, power management, THD, line SAG detection and communication are also possible in some of them. Some chips operate in single quadrant while others operate in two or four quadrants. They are designed according to IEC and ANSI accuracy standards. Well-known energy measurement chips manufactures are Analog Devices, Microchip, Teridian, STMicroelectronics and NXP.

2.8.5 Microcontroller

All functions inside the smart meter are performed by the MCU. It is considered as the core of the meter. It controls the following functions

- Communication with the energy measurement chip
- Calculations based on the data received
- Display electrical parameters, tariff and cost of electricity
- Smartcard reading
- Tamper detection
- Data management with EEPROM
- Communication with other communication devices
- Power management.

Smart meters are normally designed with a LCD. Therefore the consumer is updated with tariff and power outages. Sometimes alarm signals are generated to warn the consumer of higher tariffs and higher demands. Some meters use stepper motor counters rather than a LCD to display the energy consumptions. Those functions are also handled by the external MCU. Some smart meters consist with a single MCU which does all tasks including the energy measurement and routine arithmetic operations. In this case multi-tasking or high degree of parallelism is needed. In other words several operations must be performed simultaneously to the same data sets [1].

2.8.6 Real Time Clock

Real time clock is an essential hardware component in all smart meters which keeps track of the current time. It provides time and date information and alarm signals. Some energy measurement chips have a built-in real time clock device. For an example ADE5166 has a built-in real time clock (RTC) which communicates with the internal MCU [19]. Most smart meters have a separately driven RTC unit which can be accessed by the meter MCU. Most of them use reasonable accurate RTCs. The drift has been found as 60 min per year [20]. Smart meters connected to a smart network are periodically synchronized with actual time to avoid time drifts. Meters which are not connected to such network should have a high accurate RTC or should be corrected for the time at regular intervals.

2.8.7 Communicating Systems

The system that consists of smart meters, communication gateway, intelligent control, and data management is known as AMI. Several communication protocols are used in AMI [21]. AMI can consist with a HAN, a Neighborhood Area Network (NAN) and a WAN. Smart meters are the key elements in AMI which need to communicate with domestic appliances, other type of meters (typically water and gas meters), neighboring smart meters, and the energy supplier.

HAN is used to establish a communication link between the smart meter and the smart appliances, other meters, in-home display, and the micro generation unit. HAN provides centralized energy management, services, and facilities. The communication protocol can be a wired or wireless media [1]. Zig-bee, Z-wave, Wi-Fi, and power line communication (PLC) are widely used protocols in HANs. PLC might be a cost effective approach for a HAN but it has many drawbacks due to its robustness. Zig-Bee communication has been recognized as a cost effective, less complexity, low power, and reliable media to handle a HAN [22].

A NAN is used to transfer the data between neighboring smart meters. It facilitates diagnostic messages, firmware upgrades, and real-time messages. Zig-bee communication protocol is widely used in NAN due to high speed of data transferring and low cost [1].

Some smart meters are connected to a remote server through a WAN. They might not be connected to a NAN and data are directly transferred to the server using the wireless media. The communication is established between the meter and the server through a data concentrator for billing purposes, indication of power outages, remote disablement and enablement of supply, security tamper detections, and remote configurations [23]. GSM, GPRS, 3G, and WiMax communication technologies can be used to connect the meter to the WAN. GSM provides wider coverage than other media. However, it will be costly in the long run.

2.9 Smart Meter Standards

There are a lot of standards to measure the accuracy of the metrology of the smart meters. IEC and ANSI standards are commonly used for accuracy measurement of smart meters. Meanwhile standards for other functionalities of the meter like communication are still emerging [24].

Smart meter hardware components and functions should be certified according to the standards. These standards can be internationally or locally developed standards for accuracy, compliance, and functionality criterion. Smart meters are still evolving and many governments, organizations and utility industries are trying to set different standards and guidelines to improve the safety, operability and accuracy of meters and metering devices [11]. For an example the *NEMA SG-AMI* "Requirements for Smart Meter Upgradeability" is being developed by AEIC with NIST and Smart Grid Interoperability Panel (SGIP) in USA. Following are some of standards designed for smart meters in USA.

- Intentional and unintentional radio emissions, and safety related to RF exposure (FCC standards*, parts 1 and 2 of the FCC's Rules and Regulations [47 C.F.R. 1.1307(b), 1.1310, 2.1091, 2.1093*.
- Meter accuracy and performance (*ANSI C12.1, 12.10, and 12.20* specifications)
- Local technical codes and requirements
- Functional tests to satisfy the utilities technical and business requirements
- Utility specifications designed for special area requirements (surge protection for areas vulnerable to lightning, stainless steel enclosures for seaside areas).

Manufactures and utilities do a complete performance test on smart meter hardware and firmware. After the test, the smart meter system components are certified and ready for production and purchase. When it comes to the meter installation several regulations and standards should also be considered. The installation procedure should be done with minimum errors, installation delays and customer issues. Following are some of the regulations for smart meter installation used in USA.

- The National Electric Safety Code (NESC) for utility wiring
- The National Electric Code (NEC) for home wiring
- ASNI C12.1—Code for Electricity Metering
- Local building codes.

After the installation of smart meters, service testing is an essential requirement to maintain the accuracy and performance. Periodic and sample methods are used as in-service testing by utilities. In the periodic method, all the meters are tested on a periodic schedule. Yearly samples of meters are selected in sample method using the manufacturer and purchase date. After the tests, meters should be recalibrated if required [11].

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