

Smart Metering System for Microgrids Using Wireless and Carrier Communication Technologies

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ABSTRACT

The paper describes the smart meter module for microgrid. In order to monitor and manage the micro-grid system, design of monitoring system and control capability, which contains hardware device. Hence real time implementation is adopted in software and hardware model. MPLAB and its program modules in software constitute with hardware device. It describes the probable methods of implementation for smart metering microgrid sources and load feeders. Smart meter measures real time parameters of a supply and process auxiliary to determine rms, peak and distortion in phase voltages and currents. Real power and reactive power is determined using measured voltages and currents and communicated using smart meters supported by GPRS. It also results in higher order harmonic which is not desirable to the loads. The microgrid smart metering system that is monitoring and control system have been implemented and experimentally validated in a real size microgrid which operate continuously.

KEYWORDS: Microgrid, Real Time, Monitoring System, PIC microcontroller, Smart Meter, Signal conditioning circuit.

INTRODUCTION

The objective to develop a smart metering module is to monitor all electric parameters of the generators and load lines of a microgrid. With addition, to provide the control system of these sources and load lines from main grid. To provide backup mechanism for data security in case of loss of both wireless and carrier based communication by means of memory storage (SD card). And later on retrieve this data. To develop algorithm in this smart meter to determine the harmonics and distortion and report to load dispatch centre of the main grid. To develop control strategy for auto-decision taking capability of these smart meters in case of abnormal conditions of either generators or loads. To generate the simulations for balanced and imbalance grid voltage and current with respect to harmonic and higher order harmonic.

INTRODUCTION

Smart meter is highly developed energy meter that measures the energy parameter and provides additional information to the utility compared to a regular energy meter. Smart meters can interpret real-time energy consumption data including the values of voltage, phase angle and the frequency and securely communicates the data. The capability of smart meters for bidirectional communication of data enables the ability to collect information regarding the electrical parameters feed from the microgrid to the required premises. A smart meter system includes a smart meter, 3-phase voltage measurement section, 3-phase current measurement section, PIC Controller PIC18F67K22 and its voltage regulator circuit including with GPRS module and its voltage regulator circuit, configured with SIM card and SD card for communication infrastructure, and important part control devices. Smart meters can communicate and execute control commands remotely as well as locally. And the smart meter is related with microgrid which explains the following electric power network and distributed network.

It is known that distribution networks are built as interconnected meshed networks, though in the procedure they are set into a radial tree structure. This means that distribution systems are separated into subsystems of radial feeders, which include a number of normally-closed switches and a number of normally opens witches. However, real distribution systems contain many nodes and branches (and switches), and the total number of trees is extremely large. The algorithm starts from a completely empty network, with all switches open and all loads detached. Load points are attached one by one by switching branches onto the current sub tree. It involves the term Distributed generation (DG) refers to electricity that is produced at or near the point where it is used. Distributed solar energy positioned on rooftops or ground-mounted, and is typically connected to the local utility distribution grid. Distributed Energy Resources (DER) is smaller power sources that can be aggregated to provide power necessary to meet up habitual request. The electrical energy grid continues to modernize, DER such as storage and advanced renewable technologies can assist the transition to a smarter grid. Microgrids are electricity distribution systems containing loads and distributed energy resources, (for example distributed generators, storage devices, or controllable loads) that can function in a controlled, coordinated way moreover while connected to the main power network or while islanded. In other words it can be defined as a small-scale power grid that can operate independently or in conjunction with the area's major electrical grid. Any small-scale local

station with its own power resources, generation and loads and definable boundaries qualifies as a microgrid. In fact, many microgrids will involve a combination of resources, sometimes a pretty complex one. Nor be any guidance give on the size of microgrids. Rather the spotlight of the definition is on two features:

- Is locally controlled system
- It can function both connected to the traditional grid (megagrid) or as an electrical island.

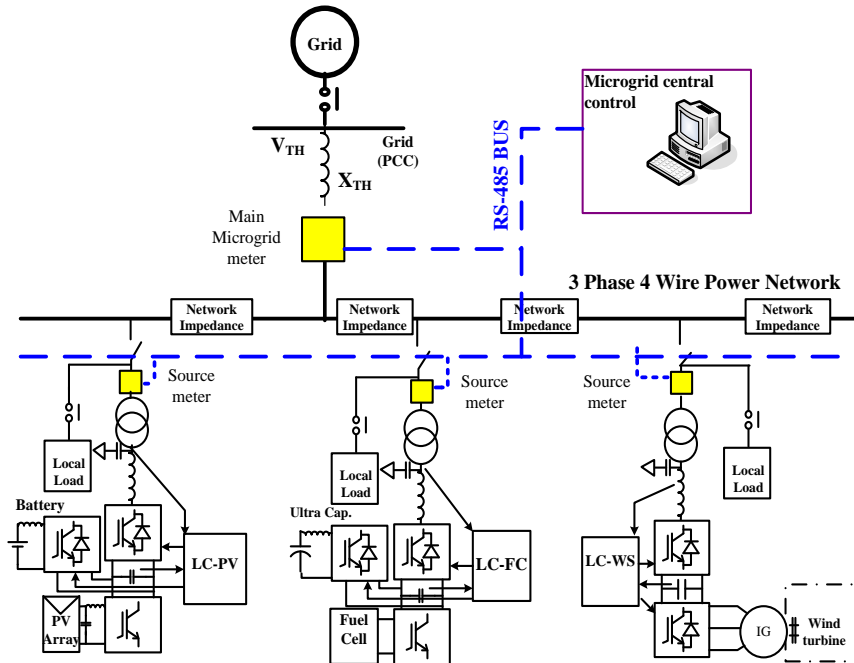


Fig.1. Typical structure of microgrid and conventional metering with RS- 485 communication.

SMART METER

Smart meters are the foundation in the new conception of the electrical network or Smart Grid (SG), providing detailed information about users’ energy consumption. Nevertheless, their features are not simply helpful for the energy suppliers, but they can also play a big role in the control of the Microgrid since the noted power and energy profiles integrated in energy management systems (EMS). In addition, basic power quality (PQ) conflict can be examine and reported by some advanced metering systems. The advanced Smart Meter systems reports information about energy consumption, also basic power quality (PQ) indices , with increasing importance due to the propagation of non-linear loads. These PQ measures can range from voltage profile measurement to harmonic distortion calculations. Thus, paper will represent an example of Smart Meter integration in a Microgrid scenario.

APPLICATION OF SMART METERING

1. Grid frequency management.
2. Event correlation (network and substation level)
3. Control center computers and terminal units (SCADA)
4. Lightning strike monitoring
5. Scheduled load shedding
6. Energy metering (time of use tariffs)
7. Traveling wave fault location
8. Synchrophasor measurement
9. Merging units/sample values
10. TDM communications networks
11. Quality of supply metering

HARDWARE DEVELOPMENT OF SMART METER

The important properties of smart meters are also simulated using MATLAB simulation software where problems of unbalance and harmonics are targeted their results are produced in previous paper. Below a detail description of smart meter development and associated hardware is produced.

These involves all elements and parts of the hardware are derived analytically and verified by simulation before them use in hardware. Choice of component values is based upon knowing the standard guide voltage, power

frequency, harmonic destruction and short time over voltages. As smart meters are basically used for distributed/renewable energy generations, the output of inverters may contain harmonics and voltage pulses under islanding condition of this inverter, the output may have voltage variation at faster rate. The smart meter must detect these voltage and current property and report to the utility as discussed in earlier chapters, smart meter used in microgrid measures voltages and currents in all three phases.

It also measures the active and reactive power in the circuit, unbalance properties can be easily detect from positive, negative and zero sequence component of voltage and current causes oscillations in power and results in laser in both loads and distribution and transmission line.

Another important properties of smart meter is to detect the harmonics, the inverter coupled renewable energy sciences may contain wide range of harmonics, as inverter operation is based on nonlinear PWM techniques. The output voltage and current generated by inverter may contain higher order harmonic components which results in interference with communication lines and sensitive loads. The lower order harmonics are specially need to attend as lower order harmonics causes detrimental effect on both loads and generators. The smart meter should be able to assure both higher and lower order harmonics and report to utility. Detail description of smart meter hardware is given in subsequent sections.

CONNECTION OF SMART METER

Smart meter are located at the output electric power generator or at load fades the electric power generators may be inverter fed renewable energy sources or it can be synchronous generator. The load terminals or feeder point may be industrial premises input commercial building etc. The smart meters can be installing after fuse or MCB protection circuits in three phase four wire network of RYB-N. As shown in fig.2. The smart meter current sensors which are hall effect based sensor (details are given in next sections) are directly beaded on lines or in other word, the lines are passed through hall effect current sensors to measure voltages the three phase points and neutral are tapped from one terminal of hall effect current sensors as shown in fig.2 the other signal conditioning circuit, microcontroller and interface circuits are within smart meter itself.

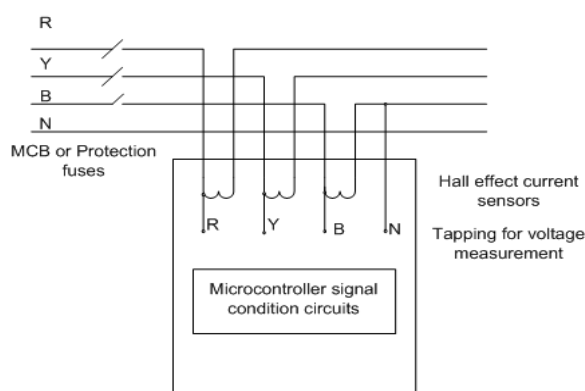


Fig.2. Connection of smart meter

PIC18F67K22 PIC Microcontroller, 64 pin IC, having features of NanoWatt XLP Technology, this 8-bit microcontroller is well suited for power-constrained and battery-power applications. Robust features such as wide operating voltage and temperature ranges and high endurance flash program and data EEPROM make this an excellent microcontroller for rugged automotive and industrial applications. Additional peripherals, such as a 12-bit A/D converter, 3 comparators RTCC and general purpose I/O, give this cost-effective microcontroller apparently unrestricted possibilities in a variety of applications where high performance with low cost is required.

MICROCONTROLLER INTERFACE

The proposed architecture of smart meter High speed microcontroller or DSP controller is proposed as a key computing and scheming aspect which synchronize with all sub-elements. The signal conditioning circuit converts voltage and current parameters into corresponding parameters which are within the array of microcontroller ADC (0 to 3.3V). The signal conditioning circuit details are given in next subsection. The digital input and output signal provision is provided for local control action. These digital input/output can be program for actions e.g. on / off, reset, transfer, fault conditions etc.

The system also has real time clock configured with IC DS1307 which keep the meters synchronized with real world time clock and provide time stamping for measured data. The smart meter module is proposed to provide with LCD display which shows all parameter like voltage, current, harmonics, and non-linearity percentage, active

and reactive power locally. These data are also transfer to the microgrid central control using GPRS connectivity. Hence the proposed smart meter module has GPRS module inserted with SIM card. The SIM900 GPRS module is proposed to use which can communicate with main microcontroller using SCI.

Digital microcontrollers are very popular for the development of embedded application because of lots of inbuilt resources, such as Input Output pins, Analog to digital converter, Pulse width modulation, serial communication ports, etc. They also provide easy software platform for firmware code development to implement the algorithms, logics, control strategies, etc. In this smart meter development following are the minimum resources required in microcontroller that can be used in smart meter.

Table.1. Resources required for smart meter hardware

Sr. No.	Description	Resources
1	Phase R Y B voltage measurement	2 ADC
2	Phase R Y B current measurement	3 ADC
3	Input pins for switches & Push buttons	4 IO pins
4	Input pins for external digital signal	2 IO pins
5	Output pins for LED indications	4 IO pins
6	Output pins for LCD display	7 IO pins
7	Output pins for relay activation	2 IO pins
8	Serial Peripheral interface for real time clock	4 communication pins

Microchip’s PIC microcontroller PIC18F67K22 used for implementation of smart meter and its algorithm. Its main resources are listed below:

Table.2. Resources presented in Microchip’s PIC18F67Kxx microcontroller

Sr.No.	Description	Resources
1	Program Memory Size(Kbytes)	128
2	RAM(bytes)	3862
3	EEPROM/HEF	1024
4	Pin count	64
5	Max. CPU Speed MHz	64
6	Internal Oscillator	16MHz, 32KHZ
7	No. of Comparators	3
8	No. of ADC channels	16
9	Max ADC Resolution (bits)	12
10	Max 8 Bit Digital Timers	6
11	Max 16 Bit Digital Timers	5
12	UART Serial communication	2
13	SPI Serial peripheral interface	2
14	I2C communication	2
15	Cap. Touch Channels	16
16	Temp Range Min.	-40
17	Temp. Range Max.	125
18	Operation voltage	3.3V

As resources available in PIC18F67K22 is more than desired requirement for smart meter development, so can concluded that the PIC18F67K22 is suitable for smart meter hardware.

The circuit with microcontroller interface is developed in ORCAD software.

INTERFACE OF SD CARD, LCD DISPLAY, GPRS

In smart meter apart from voltage measurement circuit, current measurement circuit, microcontroller interface, with SD card for data storage purposes with time and date which is build with RTC circuit and main part is GPRS module SIM 900 with its voltage regulator circuit, use of buffer IC done. LCD is integrated to see various parameters visually, which is interface microcontroller pins, couples of LED indications connection to inform the status. This GPRS module also issue commands from microgrid central control apart from monitoring data. Hence it is bi-directional connectivity with limited bandwidth. The detail circuit of GPRS module is shown in fig.3. It required 3.8V supply with 1Amp short time capacity instead of 3.3V supply.

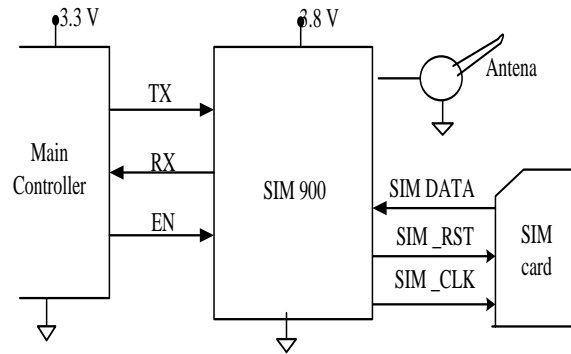


Fig.3. GPRS module circuit using SIM900.

Thus, it required special power supply arrangement which can be provided with adjustable regulator LM317 1Amp (not shown in fig.) The active status of GPRS and SIM card connectivity is provided with LED indication. The control instruction of this GPRS module is provided in SIM900 datasheet. It is communicating with PIC18F67K22 with SCI.

Though the GPRS connectivity is wireless but signal strength may not always reliable hence to provide backup system, SD card memory provision is provided which stores data as per selected time stamping (sampling rate). The SD card connected with PIC controller using SPI lines.

Below in PCB Board complete circuit for SD card interface, LCD display, LED indications, Push Buttons and switches, relay interface and real time clock IC DS1307.

SIGNAL CONDITIONING CIRCUIT FOR 3-PHASE VOLTAGE AND CURRENT MEASUREMENT

In voltage signal condition circuit which is design on left most corner side of PCB board consist of Isolation Opamp OPA1200 to measure phase voltage followed by differential amplifier OPA336. This also provides isolation from circuit to the PIC18F67K22 microcontroller. Complete voltage measurement circuit is shown in fig.4.

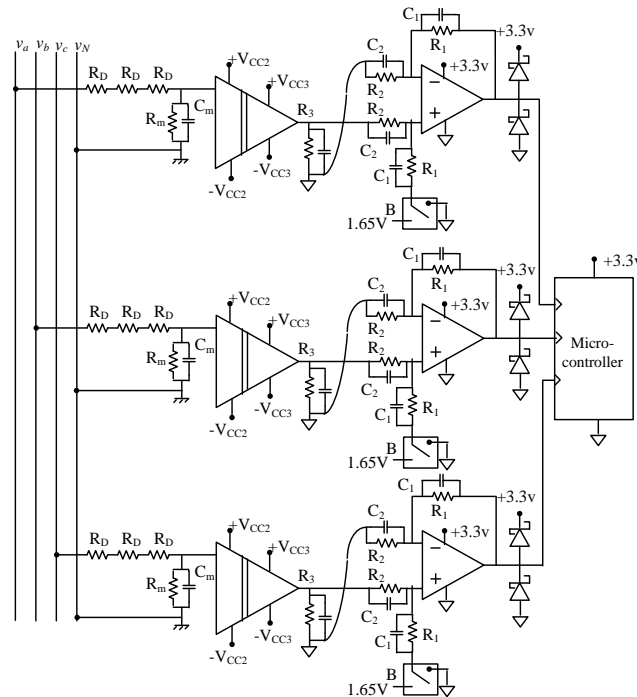


Fig.4. The signal conditioning circuit for three phase voltages

A Hall Effect current sensor IC ACS712 for line current measurement is used. Only one phase current

measurement is shown in circuit Fig.5. The circuit is similar for other two phase current measurement. The reference frame transformation technique is proposed to use which helps to measure active power, reactive power, harmonics detection, negative sequence components, etc.

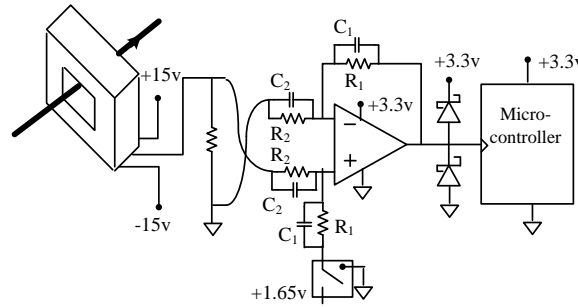


Fig.5. The signal conditioning circuit for three phase line current measurement.

Let the three phase instantaneous voltages are:

$$\begin{aligned}
 v_a(t) &= v_m \cos(\omega t + \delta) \\
 v_b(t) &= v_m \cos(\omega t + \delta - \frac{2\pi}{3}) \\
 v_c(t) &= v_m \cos(\omega t + \delta + \frac{2\pi}{3})
 \end{aligned}
 \tag{1}$$

Where δ is the initial phase displacement, ω is the angular frequency of the supply voltage and V_m is the peak of the sinusoidal voltage. Similarly the three phase line current is:

$$\begin{aligned}
 i_a(t) &= I_m \sin(\omega t + \delta - \theta) \\
 i_b(t) &= I_m \sin(\omega t + \delta - \theta - \frac{2\pi}{3}) \\
 i_c(t) &= I_m \sin(\omega t + \delta - \theta + \frac{2\pi}{3})
 \end{aligned}
 \tag{2}$$

The voltage space phasor for the AC system of (1) is given below:

$$\bar{V}(t) = \frac{2}{3} [v_a(t) + v_b(t)e^{+j\frac{2\pi}{3}} + v_c(t)e^{-j\frac{2\pi}{3}}]
 \tag{3}$$

The voltage space phasor rotates at the angular frequency, (ω). If we assume that the d-q plane is made to rotate in the direction of space phasors of AC quantities at the same angular frequency (ω) as that of the AC space phasor, then on this virtual d-q rotating reference frame, the space phasor appears stationary as both the space phasor and the reference frame are rotating at the same angular speed. The technique of transforming the AC space phasor into a synchronously rotating d-q reference frame is called the synchronously rotating reference frame transformation.

The space phasor voltage on a complex plane is given by:

$$V = V_m = e^{j(\omega t + \delta)}
 \tag{4}$$

The space phasor referred to the synchronously rotating d-q reference frame is given by:

$$\begin{aligned}
 V_{d-q} \cdot e^{j\omega t} &= V_m e^{j(\omega t + \delta)} \\
 V_{d-q} &= v_d + jv_q = V_m e^{j\delta} \\
 &= V_m \cos \delta + jV_m \sin \delta \\
 v_d &= V_m \cos \delta \text{ and } v_q = V_m \sin \delta
 \end{aligned}
 \tag{5}$$

Similarly, for the current space phasor, the d-q components in synchronously rotating reference frame are given by:

$$\begin{aligned} i_d &= I_m \cos(\delta - \theta) \\ i_q &= I_m \sin(\delta - \theta) \end{aligned} \tag{6}$$

The advantage of rotating reference frame transformation is evident. The 3- ϕ AC quantities are transformed into two dc quantities. These DC quantities can help to measure peak of AC waveform and hence RMS value of voltage and currents can be easily measure. In smart meters for microgrid this method is adopted. The same technique can be further elaborated to measure active and reactive power for the smart meter.

After all mathematical manipulation, the instantaneous active and reactive power in synchronously rotating reference frame with d-axis aligned to the voltage phasor is given by the following relation to measure using smart meter:

$$\begin{aligned} p &= \frac{3}{2} v_d \cdot i_d \\ q &= \frac{-3}{2} v_d \cdot i_q \end{aligned}$$

SOFTWARE DEVELOPMENT OF SMART METER

MATLAB simulation is used for verification of the results for the required results. Later it is implemented on hardware developed smart meter module kit as shown below in PCB design. MPLAB is used for programming purpose with PICKit3 debugger. Signals for sine wave are also viewed on DSO for timer counter of PIC controller. MPLAB is free software surroundings for the development of embedded application on PIC and dsPIC microcontrollers and it is developed by Microchip Technology. The latest version is MPLAB X. Here MPLAB XC8 — C compiler for PIC18F67K22 device.

PCB DESIGN BOARD



TEST SCENARIO AND RESULT

As we have already seen above the software and hardware work. Three phase voltages and currents in the circuit can be applied to PCB board power connected provided for voltage and current measurement which is visible at left side of the board. The control power supply of 5V is used for

various circuit function of the board such as LCD display, switches, LED, relay, GPRS module, etc. Digital microcontroller PIC18F67K22 has been used for implementing all algorithms and to perform real time calculation for active power, reactive power, positive and negative sequence. It is 3.3V controller and fed through LM1117-3.3 linear regulator. 16pin JHD629-204A, M12 LCD display is plugged in right side corner. Two sliding switches are used for ON/OFF purpose of displaying voltage and current respectively on LCD. To generate the different situations for output result two push button switches are activated for increasing and decreasing the values of 3-phase voltage and current magnitude. For this operation the observation is calculated for balanced and unbalanced condition. LCD shows the peak value of phase voltage and currents. In general, this smart meter measure three voltages and currents from circuit and use them for further analysis, but for experimentation purpose, the peak voltage or peak current in one of the phase is increase or decrease manually to investigate the effect of unbalance to active power. The rated peak voltage is 325V and it can either increase or decrease using push button to introduce unbalance in three phase voltages by changing for example B-phase voltage. Similarly, rated peak current is 10A which can be increase or decrease to insert unbalance in current.

Experimental results for balance condition:

Three phase voltages are kept in balance condition with their default values of 325V peak and all phases are 120deg phase displaced. Currents are also kept balance to study the effect on active power. Below figure shows the three phase currents in case of balance condition. As shown in figure, the current amplitudes are almost same and hence balance condition is established as a result there is no oscillation in active power and active power is very smooth with perfect DC quantity.

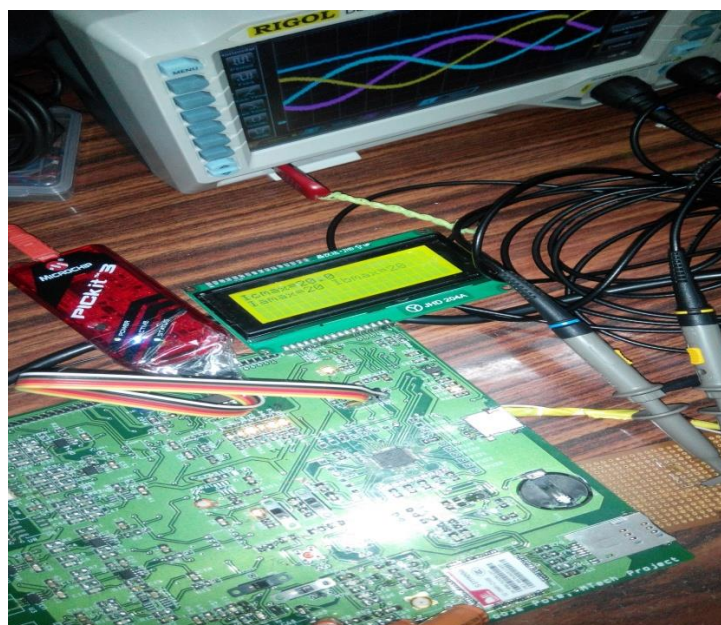


Fig.6. (a) Experimental setup with balance condition for current and voltages

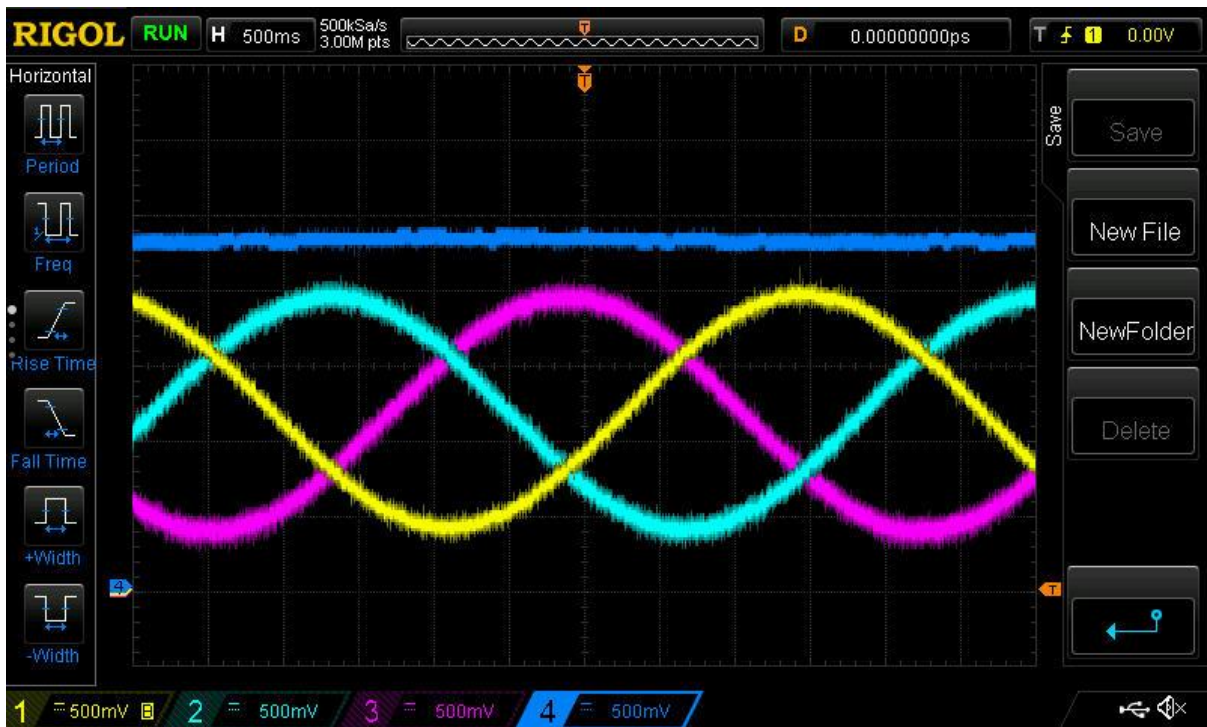


Fig.6.(b) Experimental result for three phase balance currents and active power (three phase voltages are not shown).

Experimental results for unbalance condition:

Three phase voltages are kept in balance condition with their default values of 325V peak and all phases are 120deg phase displaced. The C –phase current amplitude is increased to induce unbalance condition and study the effect on active power. Below figure shows the three phase currents in case of unbalance condition. As shown in figure, the C-phase current amplitude is higher than other phases and hence unbalance condition is established as a result there is severe oscillation in active power and active power has oscillation of 3 times the fundamental frequency.

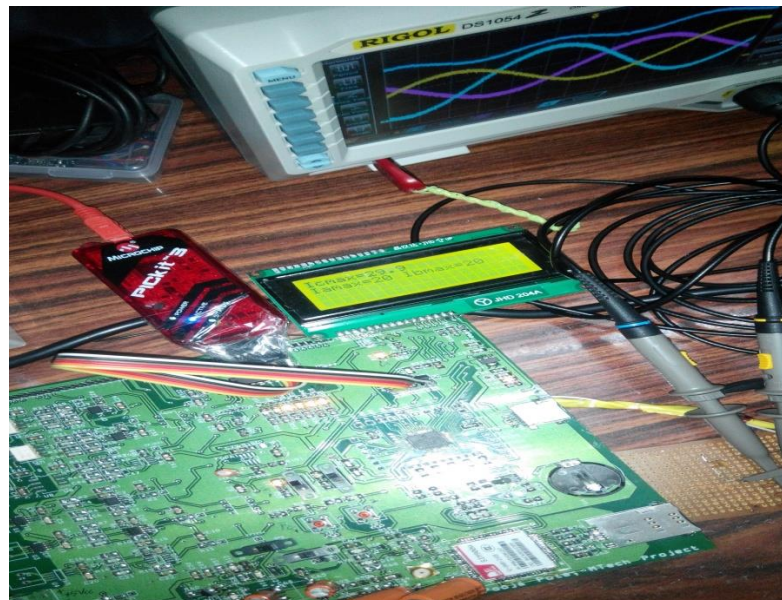


Fig.7.(a) Experimental setup with unbalance condition for current and voltages

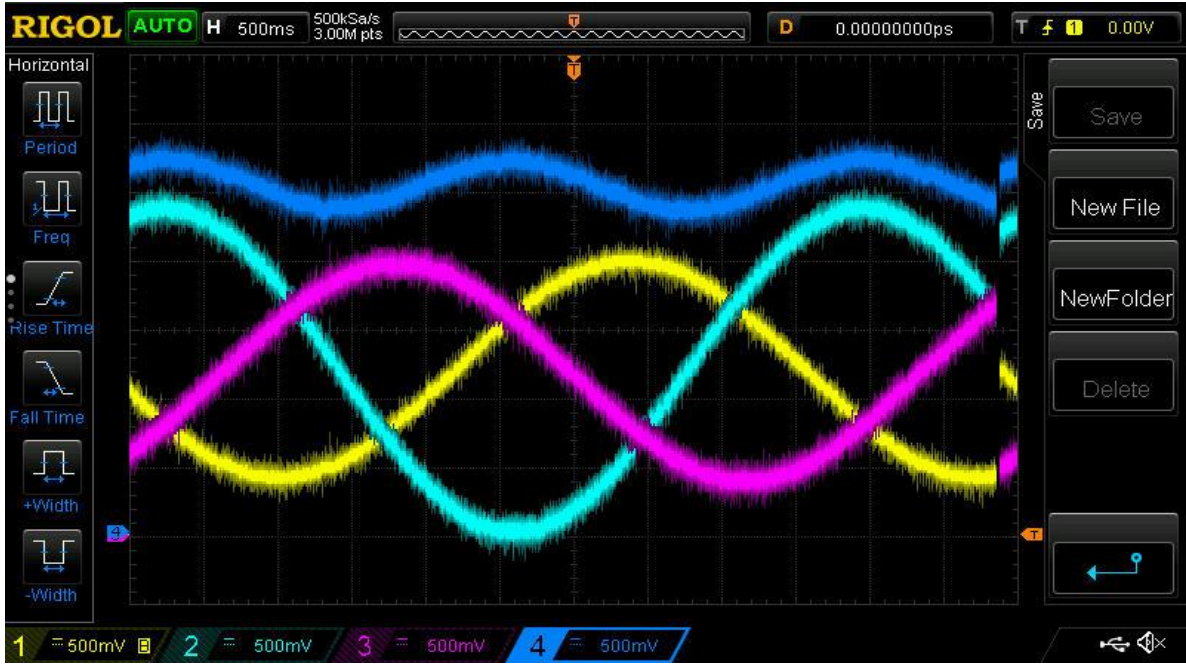


Fig.7.(b) Experimental result for three phase unbalance currents and oscillation in active power (three phase voltages are not shown).

APPLICATION DEVELOPED

As smart meter system provides numerous benefits such as efficient power system management and monitoring, working decisions those are taken timely to minimize outages and losses. Principally in microgrids, smart meters can execute energy fault analysis, insisted control and power feature study. Smart meters can schedule protective maintenance. Most importantly, smart meters can sense the existence of unnecessary harmonic element in current supplied from the centralized sources, which helps in recognition and modification of the source of the problem. Increased energy security as well as communication technology for data management, the installation is adopted for smart meters by configuring GPRS module supported by SIM card, SD card. Hence smart meters will provide consumers to preserve the power quantity and monitoring its energy continuously. Generally, unbalanced loads cause fluctuations in the voltage report of a sharing feeder positioned far-off from the substation. Smart meters can evaluate and control these fluctuations in low voltage grid.

CONCLUSION

It is originated that smart metering is important element to monitor the performance of microgrid sources. It defines the probable methods of implementing smart metering for microgrid sources and load feeders The smart meter architecture is presented which monitor the real time parameters such as phase voltages, line currents, their peak, rms and harmonic distortion, etc. The real and reactive power are also determined and communicated. The control quality is analyzed and detected through smart meter system. GPRS based system has been used for transferring data to central data logging system. Detailing of the signal conditioning circuit for converting high voltages and currents into appropriate form suitable for ADC channels of the microcontroller with advantage of GPRS module with facility of SD card for storage of data information are also produced in this project. The smart meter is designed to provide LCD display which shows all parameters of voltage, current, harmonic distortion, non-linearity, active and reactive power etc. It gives good power quality. Reliability increases. In the process of actual operation, control of microgrid becomes more accurate.

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