Design of Three Phase Three Wire Power Monitoring System for Healthcare Units

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***Abstract*--Various power monitoring systems with high accuracy have been developed over the years. These systems are generally developed for three phase four wire systems. There is a need for development of a power monitoring system for a three-phase system without neutral i.e., three phase three wire system. The aim of the paper is to propose a monitoring system for high voltage three phase supply. The design of the system is regulated by healthcare regulatory at every stage. The effect of voltage imbalance in three phase system is catastrophic in sensitive healthcare loads. The power monitoring system uses a power monitoring IC and microcontroller interface to measure and log the data of the three-phase supply. The system is also expected to protect the sensitive load in case of any voltage unbalance by using interrupt generation.**

***Keywords*— Power monitoring system, New Product Introduction, Power quality**

I. INTRODUCTION

Healthcare units generally work on high power as it includes components that require high power like X-ray generator, ultrasound systems etc. A three-phase supply is preferred over single phase supply for this reason [3], which may be either a three phase three wire or three phase four wire system.

In general, a three phase three wire system is used in most of the healthcare organizations. These systems are generally prone to voltage variations which affect the performance of the healthcare units [4]. The components in the medical devices are degenerated or even damaged due to the supply variations. A power monitoring system is required to monitor and take necessary actions in order to avoid damage of sensitive components. Since all the available meters are for three phase four wire system and not suitable for the voltage ratings of the system, there is a need for customized monitoring system design.

The paper proposes a real time monitoring of the power and protection circuit. The power monitor proposed assess and logs the supply voltage and current level at specific intervals of time. The system also includes a phase loss detection circuit which generates an interrupt whenever one of the phases of the system is out of balance. The system consists of a microcontroller and a power monitoring IC, which together serves the purpose of providing information about all the three phases.

II.DEVELOPMENT OF POWER MONITOR

The development of the power monitoring solution undergoes the stages of new product introduction life cycle [1]. The steps followed are in the order of as shown in the fig. 1-

- Problem definition and requirement formulation: As the first stage of product developments, this phase acquires information regarding the requirements from the customer end. The requirements also consider the regulatory standards that any medical equipment manufacturer need to abide by.
- Conceptual design and benchmarking: This phase compares the developed concept to the available solutions in the market.
- Concept screening and scoring: This phase of product design is used to select the best concept by using techniques like pugh matrix and weighted matrix of design [1].
- Concept design: The best concept chosen is sent to the detailed design process.
- Prototyping and testing: The output from the schemes of conceptual design is a prototype, which is tested rigorously for reliability.
- Final design: The proven design is tested in clinical environment and changes are made if there is any mal-operation.
- Technical Design review: This phase is generally is marked by review of product by a panel of experts and government bodies.
- Manufacturing and servicing: Once the design is approved it is manufactured and company takes the responsibility of maintenance of the product.

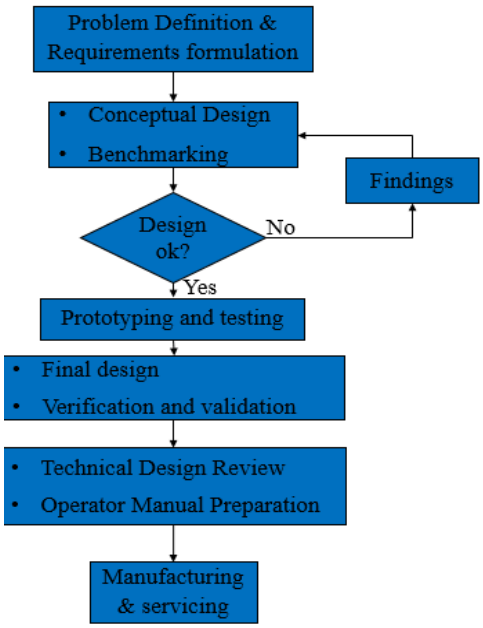

Figure 1. The process of new product introduction in healthcare domain

This new product introduction cycle is followed strictly in all healthcare organizations, along with the regulatory standards set. The fig 2. shows a block diagram representation of the three-phase three wire power monitoring system regulated by directives from RoHS[2], IEEE, IEC and so on.

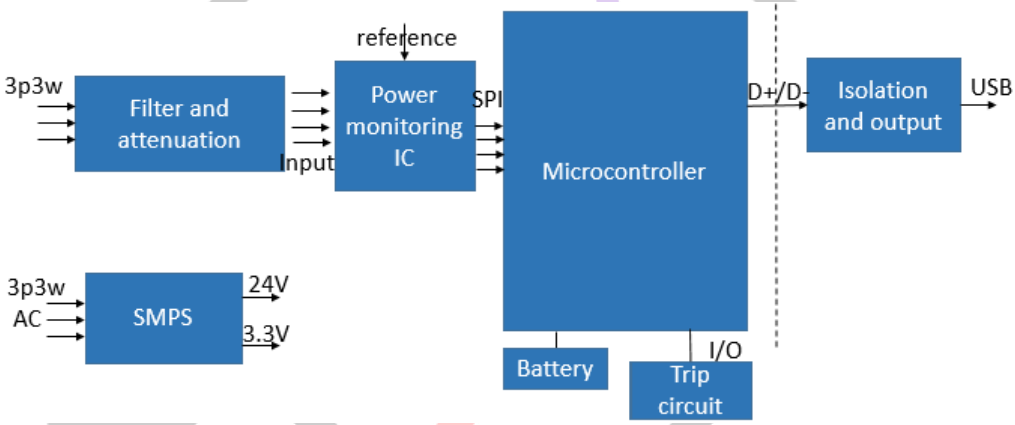

Figure2. The scheme for development of three-phase three wire Power monitor

The power monitoring system for a three phase three wire system consists of the following blocks:

- Filter and attenuation: The attenuation network consists of resistor divider circuit for each phase to convert the high input voltage to the microcontroller voltage levels. The attenuation network is reconfigured for three phase three wire network by taking one of the phases as reference and measuring the other two phases with respect to it. This referred phase can be considered as a virtual neutral. The filter requirements are taken care by RC networks, ferrite beards, voltage divider circuit. The sensing of current is done by selecting sensors like rogowski coils or current transformer at the inputs.
- Power monitoring IC: The power monitor IC takes analog inputs from three phases and a reference voltage as inputs. The IC used has the ability to compare the parameters and trigger interrupt for any power quality issue.
- Microcontroller: The microcontroller takes data from the Power monitoring IC through SPI/I2C and communicates the power quality issue to a relay driver circuit or stores data in the normal operating conditions.
- Isolation and output: The data from microcontroller is transported to the designated computer though USB port, which also supports data isolation according to the healthcare standards.
- Trip circuit: A trip circuit consists of a relay driver circuit based on the behavior of switching devices. The relay helps to isolate the supply from load by using circuit breaker switching.
- Power supply: The power supply to the components mentioned are provided by the same three phase supply to be measured. This circuit converts the three phase AC into a regulated DC voltage required for the ICs.

III.POWER SUPPLY:

The requirement of a power supply is present for any system with number of ICs in it. The power monitoring system requires power for the IC, controller and relay driver circuit. A supply voltage for IC levels is to be made available from the three phase supply. Fig 3 shows a power supply scheme which uses rectifiers, filters and regulators.

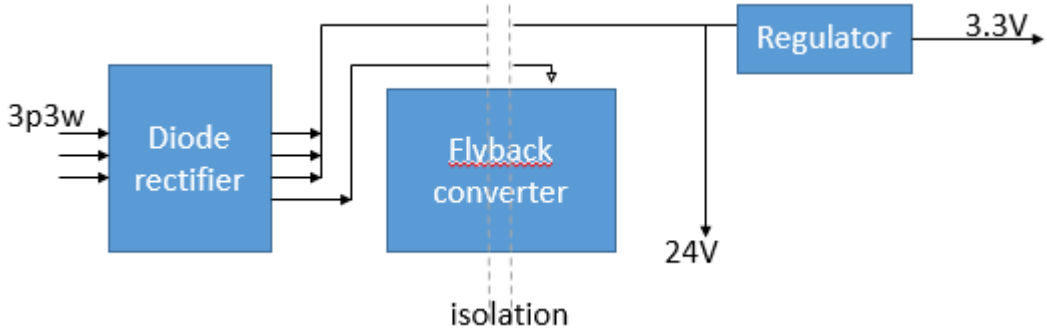

Figure 3. Scheme of the power supply

- Diode rectifier: The three-phase supply is given to the diode rectifier circuit made of six pulse diode bridge that converts ac voltage of high value from the supply to a DC voltage with ripple.
- Filter circuit: The DC output has ripple components that is filtered by using smoothing reactor and capacitor bank.
- Flyback converter: The flyback converter converts the DC output from the diode rectifier to a regulated 24V DC that is given to a relay driver circuit. The isolation from the supply to the Power monitor is taken care by the flyback converter transformers.
- Regulator: The regulator is a buck regulator IC that converts 24V DC to 3.3VDC regulated output supplied to the IC and microcontroller peripherals.

The power monitoring system is supposed to work as per the flow diagram shown in fig. 4-

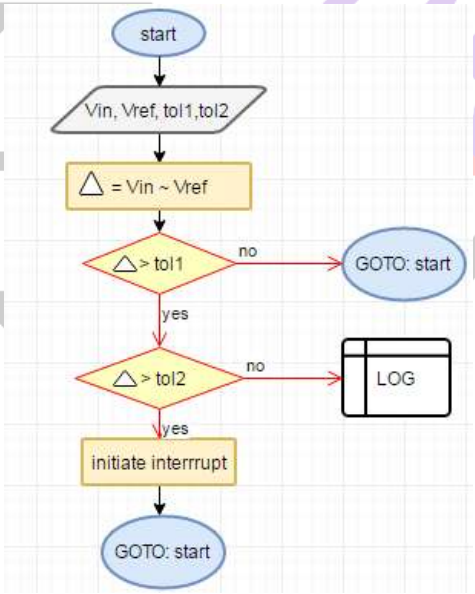

Figure 4. Flowchart of the power monitoring system

The flowchart for the power monitoring system is as in the fig. 4, which can be explained as follows:

- The input to the power monitoring IC will be three phase analog parameters of voltage, current and reference voltage as sensed from the three phase three wire supply.
- The IC converts the analog inputs to digital signal.
- The digital parameters are compared with the reference values to check for any imbalance in the supply.
- The imbalance is detected by comparing the tolerance value of allowable imbalance.
- An interrupt routine is setup by the interfaced controller if there is an imbalance, otherwise the measurement is logged in the EEPROM of the controller.

IV.REGULATORY STANDARDS:

The International Electrotechnical Commission (IEC) is an organization that publish the international standards and technical reports collaborated with the International Organization for Standardization (ISO) for the standardization of any electrical or electronic process or product.

The IEC 60601-1 in the first edition started with parent safety and essential performance standards for medical electrical equipment. The addition of adequate design process and risk management was done in further amendments.

IEC 60601-1-2 - Medical electrical equipment - Part 1,2: General requirements for basic safety. 60601-1 compliance is a requirement for medical electrical equipment commercialization.

The current system being of maximum 480Vrms, needs a minimum creepage. 2 MOPP is the declared isolation level for medical device power supply. MOPP can be abbreviated as Means of Patient Protection, which was introduced as a part of standard for medical electrical equipment IEC 60601-1.

RoHS: Restriction of Hazardous Substances

RoHSdirective restricts the use of few chemical substances in electronic circuits that pose risks to human health [2]. This also aims to provide sustainable and cost-effective methods to recycle electronic waste.

- RoHS formerly known as Directive 2002/95/EC, originated in European union in the year 2002, restricting use of 6 hazardous widely used materials found in electrical components.
- Mandate 2011/65/EU was distributed in 2011 by the EU, which is known as RoHS-Recast or RoHS 2 [5]. RoHS 2 incorporates a CE-stamping order, with RoHS consistence now being required for CE checking of items.
- Directive 2015/863, published in 2015 also known as RoHS 3, added four additional restricted substances.
- Few applications like fluorescent lamps, cathode ray tubes, piezoelectric devices etc., are exempted from the RoHS directive levels of safety. These applications follow different levels presence of hazardous materials in the electronic components.

Table 1 list of hazardous materials and safe levels of usage

Materials	Safe Levels
Lead (Pb)	< 1000 ppm
Mercury (Hg)	< 100 ppm
Cadmium (Cd)	< 100 ppm
Hexavalent Chromium(Cr VI)	< 1000 ppm
Polybrominated Biphenyls (PBB)	< 1000 ppm
Polybrominated Diphenyl Ethers (PBDE)	< 1000 ppm
Bis(2-Ethylhexyl) phthalate (DEHP)	< 1000 ppm
Benzyl butyl phthalate (BBP)	< 1000 ppm
Dibutyl phthalate (DBP)	< 1000 ppm
Diisobutyl phthalate (DIBP)	< 1000 ppm
Benzyl butyl phthalate (BBP)	< 1000 ppm
Dibutyl phthalate (DBP)	< 1000 ppm
Diisobutyl phthalate (DIBP)	< 1000 ppm

Table 1 lists the hazardous substances as per the RoHS 3, with the safe limits as per the directives in parts per million. The limits are strictly followed to pass the acceptance test of the components with RoHS certification.

V. RESULTS:

The reliability of the power meter is tested measuring the supply voltage. The trend analysis of the supply voltage and the expected output is compared by using a graphical representation as shown in the fig. 5.

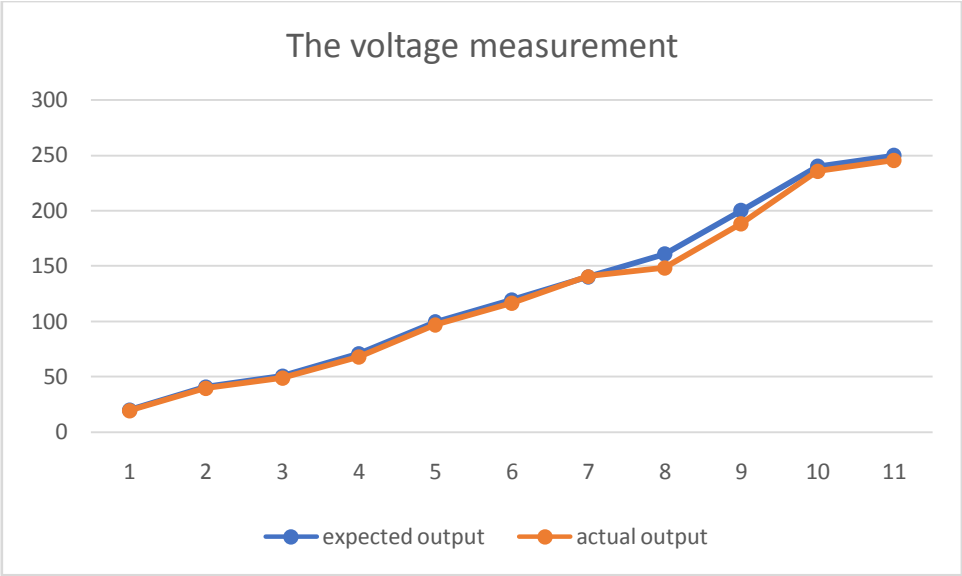

Figure 5. Trend of result versus the expected output of the monitoring system

VI. CONCLUSION:

The power monitoring system developed measures the voltage and current parameters of a three phase system. The trend analysis of results shows the accuracy of the system. This proves the concept of the design and can be taken to the next stages of design finalization. The unbalance of the supply was simulated and the accuracy of providing an interrupt within expected time was also tested. The Power monitoring system serves the purpose of measurement and preventive measures taken in the case of unbalance or power quality issues. The protection of the sensitive load is done by the interrupts generated by the controller to trip the circuit using a relay driver circuit.

VII. ACKNOWLEDGMENT

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