International Conference on Renewable Energies and Power Quality (ICREPQ'18)
Salamanca (Spain), 21th to 23th March, 2018
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, No.16 April 2018

A low-cost IoT solution for power availability improvement in hospitals.

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Abstract. Power is a crucial element in hospitals whether it's within the intensive care units, surgical bays, or medical scanning rooms. Without reliable power, patients' lives are at risk. The power availability improvement is therefore a crucial point in healthcare. A supervising system superimposed to the main components of the power system as able to promptly signal anomalies or malfunctioning or outages can be very useful for this task. To this aim, an Internet of Things (IoT) based solution has been implemented that allows equip at low cost the various electrical components in the distribution MV/LV substations of the hospital's power system so as to be connected to a central supervising system. The solution implements a platform based on Rapsberry pi 3.

Key words

Power availability, Internet of Things, electrical distribution, supervising system.

1. Introduction

High quality care for patients is a typical hospital's priority. A key point of this lies in power availability and reliability since many medical technologies and modern communications are reliant upon power, whilst complex health care is increasingly being delivered in the community.

To date, the impact of power loss on health is a poorly studied area and literature is scarce [1]. However, understanding how health is affected by power loss, especially within the setting of extreme events, is vital to future planning so that the health impacts can be prevented and/or mitigated [2].

Meeting these demands requires good power monitoring technology together with effective design, operation, and maintenance of the electrical distribution. Hospitals require extraordinary reliability from their power systems. Life-support systems, as well as critical ancillary infrastructure systems such as HVAC, communications, records management, and security must all remain online during a power disruption. When widespread power outages strike throughout the electricity grid, hospitals must be outage-proof. Moreover, it is also evident that healthcare is increasingly dependent on power [3].

Electricity was recognized by the UK Department of Health as the 'most vital of all infrastructure services' because 'without it most services will not function [4].

The IoT's industrial applications, or the Industrial Internet, is transforming many industries, including healthcare. Collectively, these account for nearly two-thirds of the world economy [5].

In electric industry systems IOT technology has been applied to the line/equipment condition monitoring, fault location and substation security protection and many other tasks with promising success [6]. IoT applications are indeed implemented with the purpose of acquiring the states of LV and MV apparatuses, thus increasing the availability of substation components so as to reduce fault times, monitor grid topology and use manpower more efficiently [7].

The paper proposes a low-cost open platform based on raspberry pi to supervise and monitor the health parameters of components of a MV/LV distribution system delivering electric energy to the various distribution substations of a large hospital.

The platform has the main aim of supporting the maintenance management activities in order to improve power quality indices through the increase of power system service continuity.

2. Moving Towards Predictive Maintenance

It is well known that poor maintenance strategies can reduce a plant's overall productive capacity between 5 and 20 percent. Recent studies also show that unplanned downtime costs industrial manufacturers an estimated $50 billion each year [8].

Collecting sensor information from customer equipment and devices, and effectively presenting the analysis results are key requirements for overcoming the challenges that customers face. Predictive maintenance (PM) provides that measurements that detect the onset of system degradation (lower functional state) to be eliminated or controlled prior to any significant deterioration in the component physical state. Basically, predictive maintenance differs from preventive maintenance by basing maintenance need on the actual condition of the machine rather than on some preset schedule [10].

The PM can be highly strengthen by IoT using smart, connected technologies that join digital and physical assets. Today, the high availability and low cost of digital technologies have made it possible for PM to diffuse across facilities and industries.

In PM, data gathered from connected, smart machines and equipment can predict when and where failures could occur, potentially maximizing parts' efficiency and minimizing unnecessary downtime. Other benefits include fewer unnecessary repairs, less need for spare parts inventory, and longer lifespan of equipment and parts—ultimately reducing costs.

PM solutions can be easily obtained by installing sensors on key components of the system to measure equipment health parameters. Sensors can provide real-time alerts for abnormal equipment conditions that help utility engineers plan preventative equipment maintenance, repair, and replacement [9].

3. IoT in electrical distribution

In the fastly evolving context of electricity distribution the strong need of integrating renewable energy sources and distributed generation with the growing needs of the power demand from new end uses (such as Electric Vehicles), has required utilities to introduce more intelligence in the components fitting their MV and LV distribution networks [11].

Nowadays, various are proprietary solutions provided by main global manufacturers offering solution for intelligent transformer substations, compact medium-voltage switchgear with communication capability, regulated distribution transformers, as well as integrated remote control and automation solutions which monitor and control the medium- and low-voltage grid equipment [12].

IoT applications are implemented with the purpose of acquiring the states of LV and MV apparatuses, thus increasing the availability of substation components so as to reduce fault duration and use manpower more efficiently by [7].

The task of applying IoT solutions in an existing system looks like a very appealing option. Although the retrofit of existing equipment brings various difficulties due to: i) successive generations of equipment; ii) origin from different manufacturers; iii) different environmental conditions, leading to heterogeneous ageing states of equipment.

Integration of various equipment with even very different technology typically would require high-cost custom made solutions implementing closed architectures. The closed architecture, however, would make difficult to the customer to extend the supervisory system to other equipment, also critical, but not strictly making part of the electrical system (fire alarm systems, intrusion detection systems, etc.). So, it could be of interest an open solution that could be applied to equipment of most different type to make them smarter by building a network in which they can communicate.

4. Hospital's electricity distribution system

A typical distribution system layout for a hospital is reported in Fig. 1. A medium voltage distribution ring owned by MV customer, connecting several MV/LV distribution substations (L) is operated with a normally-open point (NOP), splitting the ring into two separate feeders connecting the different L with an in-out insertion scheme. The purpose of the NOP is to ensure selectivity for protection systems and reduce the impact of faults in the grid by limiting the number of distribution substations that are affected when protection trips.

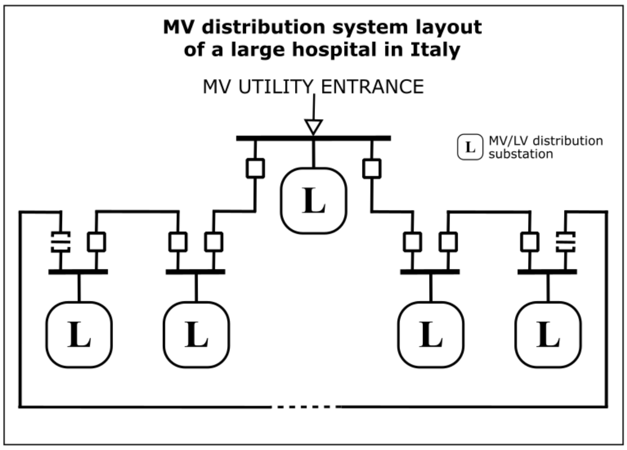

Figure 1: Hospital's typical electrical distribution layout.

A distribution substation provides a MV (20 kV) switchgear, MV/LV transformers (two or more, paralleled or not), a LV main switchboard structured in two separate but interconnected busbars (normal power, emergency power), where emergency power is originated from a motor-generator set. A further distribution busbar is also provided for supplying critical loads through an uninterruptible power supply (UPS). The typical electrical layout of a distribution substation is reported in Fig. 2.

5. The proposed supervisory system

The proposed supervisory system has the main task of monitoring the correct operation of the distribution substation and alarming when anomalies or faults occur. To this aim the following components of the substation are controlled by monitoring the relevant signals:

• minimum voltage monitoring relays at MV busbars (V1),

• alarm signal from dry type transformers' temperature control (A1),

• minimum voltage monitoring relays at normal LV busbars (V2),

• alarm signal from automatic power factor correction system (A2),

• alarm signal from motor-generator set control board (A3),

• minimum voltage monitoring relays at emergency busbars (V3),
• alarm signal from the UPS control board (A4),
• minimum voltage monitoring relays at busbars supplied by UPS (V4).

The above mentioned monitoring points are illustrated in detail in Fig. 2.

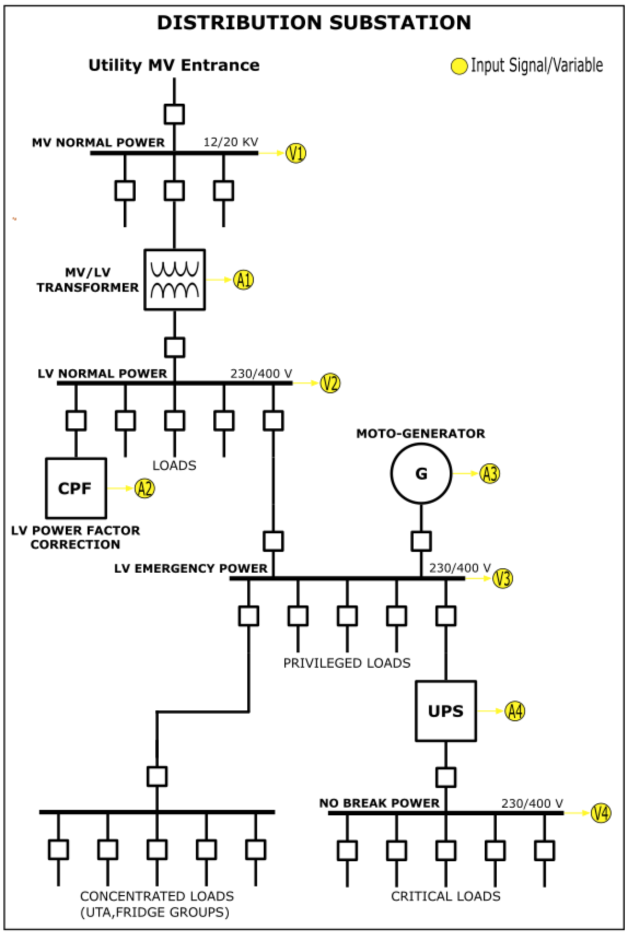

Figure 2: Typical lay-out of a MV/LV distribution substation supplying demand areas of a hospital

In Table I the different variables or alarm signals taken by supervising system at each monitoring point are reported in detail.

Regarding the location, a distribution substation can be hosted within the volume of a building or separate from it. The substation structure must meet the requirements of the standards (CEI 99-4, Sec. 5 and CEI 0-16, para. 8.5.9) as regards, for instance: a) access, b) walls, floors and ceilings, etc. in accordance with Standard CEI 61936-1, c) ventilation, d) infiltration of water or flooding, e) lighting. The substations must be fitted with lockable doors so as to prevent access by unauthorized persons. Therefore, the supervising system can be also easily assigned with the task of monitoring sensors relevant physical environment of the location.

So, the following signals deriving from local sensors are also monitored:
• room temperature,
• flooding sensor,
• magnetic contacts for doors and windows,
• smoke detector,
• occupancy sensor,
• lighting levels sensor.

TABLE I. Monitored components and variable/signal input

Alarm signal characteristics		
Component	***Sensor***	***Variable/ Signal***
MV busbars	Min Voltage relay	TVs' Voltage level
Transformer	Relay on existing temperature monitor	Treshold alarm
Normal LV busbars	Min Voltage relay	400 V Voltage level
Power factor correction system	Internal control unit (Interface RS485)	General error
Motor-generator	Internal control unit (relay contact)	Low fuel level, low oil pressure, high engine temperature, under/over voltage, overload, under/over battery voltage, battery charger failure, earth fault
Emergency LV busbars	Min Voltage relay	400 V Voltage level
UPS	Internal control unit (relay contact board, interface RS485)	Battery low, overload, general error
UPS LV busbars	Min Voltage relay	400 V Voltage level

The supervisory system enables the user to control and monitor the various main equipment of the distribution substations being part of the customer's power system. To accomplish the operations different algorithms, on the different platforms, have been used to communicate and exchange information between various devices. The user can access the supervisory system through a dedicated webpage.

6. The platform

The supervising platform is composed of 3 elements: a raspberry pi3 b, a supervisory shield and a 230V AC/12V DC power supply.

It can detect the status of external devices and once detected, the software set on the server determines how the system will respond. All sensor data are stored in local SD card and will be available to remote computer via internet.

Raspberry Pi is a single-board computer running on Linux operating system, that can be directly used in electronics projects because it has GPIO pins right on the board [13]. CPU speed is 900 MHz and on board memory is 1 GB RAM. Micro-SDHC (Secure Digital High Capacity) card is used to store both operating system and program memory. The board is provided by 40 GPIO pins which support common protocols like I²C, SPI and UART. The card also incorporates Wi-Fi 802.11n (150 Mbit / s) and Ethernet port, therefore the device access to the LAN network is simplified.

The supervising shield is designed to plug on to the general purpose input/output (GPIO socket) of Raspberry Pi 3B. It includes:
• 16 Digital Inputs,
• 5 Changeover Relays,
• 1 Temperature Input,
• 4 Tactile Switches,

• 1 LCD screen,
• 1 RS485 Port,
• 1 Hardware clock.

The picture of the implemented board is shown in Figure 3.

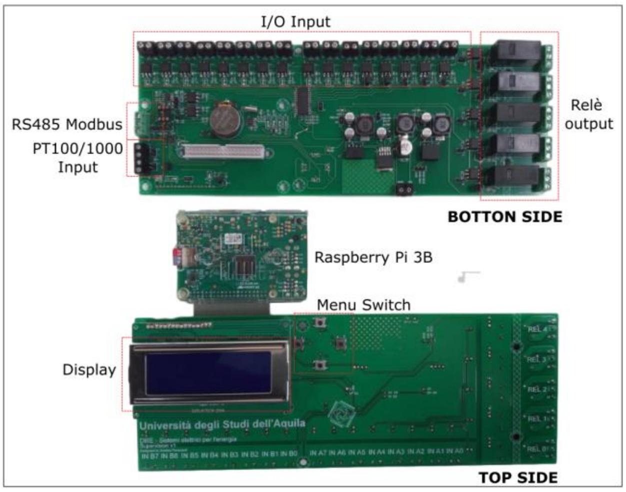

Fig. 3: The implemented board.

The digital input signals are captured by Raspberry Pi via the parallel I/O expansion for I2C bus. Each input is optically-isolated and LED indicators show the on/off state of it.

NO/NC Relays are used to control high current devices that cannot be controlled by Raspberry's Digital I/O pins due to current and voltage limits. The specific application requires the use of such relays to connect voltages up to 260V or currents up to 16A.

For temperature detection it has been chosen to use the Platinum RTD. With the correct configuration, 2-3 and 4 wires probes can be inserted on terminals. In addition, both pt100 and pt1000 can be inserted.

The board is equipped with 4 switches to access the menu, scroll through the options and change the settings.

The 20x4 LCD show common parameters such as operating status, temperature, the inputs condition, date and time. Additionally, it display the past events list and the menu.

The RS-485 module allows the board to interface with home automation applications. It allows up to 256 devices to communicate through the same data line. For this purpose, the Modbus protocol is available, it is a serial communications protocol, suitable for the rs485 interface and uses a master/slave or client-server architecture.

Raspberry Pi models have not a built-in real-time clock, so they are unable to keep track of the time of day independently. A real-time hardware clock with battery backup has been therefore added. The PI re-installs the time at boot through I2C interfaces and keeps track of it while it is on.

The complete design of the supervision system provides an individual supervisory device (SV) directly installed within each distribution substation, see Fig. 4. Each device is connected to each other through a local area network (LAN). A star connection is chosen where the devices are connected either via ethernet port or wi-fi.

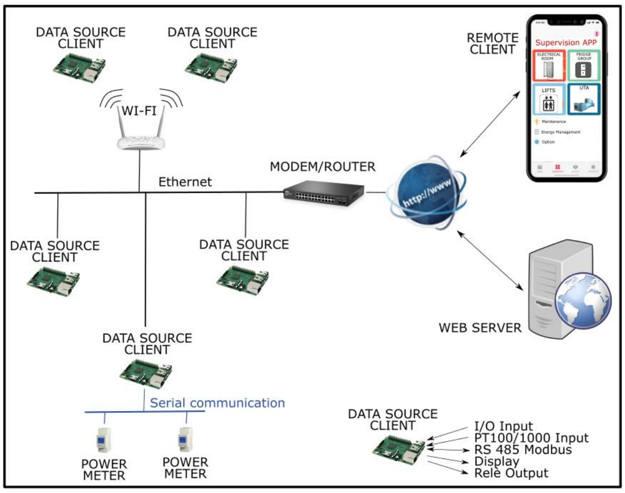

Fig. 4: The proposed supervising system layout

7. Software architecture

The software architecture is based on a relational SQL database associated with a REST service written in Python accessible from both a mobile application and a Javascript web appliance.

The main idea is based on a complete configurability of the system and on the absence of constraints.

User can configure the entire universe of his sensors by organizing them by area, service and device, moreover he can provide each of these objects with an intelligent specific reaction mechanism to its current state. That is, User can create for every object in the system a micro code written in Python as a description about its status. This code has the task of calibrating the alarm level subsequent to certain values provided by the sensor in terms of state severity (to this aim a colour code based on Red, Yellow and Green has been implemented). The code written in Python makes easily available external references such as the day of the week, the season, outside temperature or the status of another sensor.

The relational database manages information about: Areas (Zones), Equipment, Sensors along with concepts such as Users and Log (i.e. a sensor status).

The service is based on REST. REST defines a set of architectural principles by which it is possible to design a Web service. In the current system REST service is based on HTTP(s) protocol and provides an API (a Program Interface) based on the standard HTTP methods such as GET and POST. As an example a partial list of API methods implemented in the whole system is shown in Figure 5.

The overall architecture is structured in the following sections:

• the hardware platform, based on custom devices for digital and analogic acquisition and commercial devices such as Raspberry pi 3 for data collection

• the back-end structure, developed in Python using REST technology for external interface and based on a SQL database

• the front-end interface, represented by mobile devices and web interfaces.

Finally, the back end is provided as hosted by a cloud service such as Amazon or Azure to ensure continuity of

service and scalability. It provides the following functions:
• allows the final nodes to communicate and interact with the whole system through a REST interface,
• implements the system operating logic and the various entities (like sensors, users or user actions),
• implements the monitoring activities by adaptive programming.

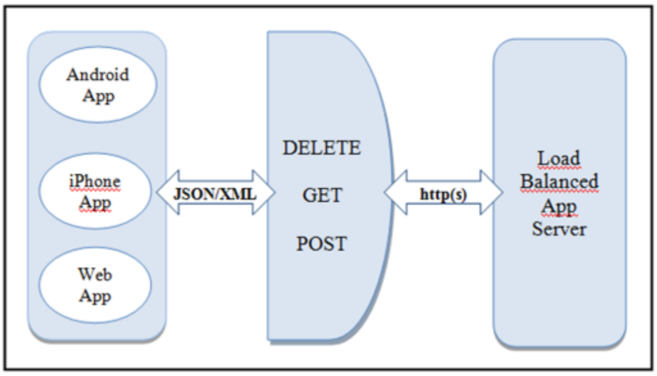

Figure 5: REST API Architecture

The monitor receives PUT methods from final devices (RPi) in terms of sensor identifier and relevant observed values, then it executes the associated sensor's code, which will provide a status output (e.g. [R]ed, [Y]ellow, [G]reen). These states are inserted in the log table. Moreover, if the response status is Red, a cloud message is delivered to all the users associated to the specific equipment.
The monitor service receives, via PUT methods from final devices (RPi), data in terms of sensor identifier and relevant monitored values that are associated to a specific colour code. The information is stored in the log table. An alarm is also generated for all the users if a Red status is associated.
In this framework, the adaptive programming mechanism allows users to create their own data structures in JSON or XML and to pass them to the reaction code who will have to take care of unpacking the data recorded, executing the relative code, and providing the status string to the Log Service.
The front-end interface is organized in the following sections:
• monitoring,
• administration.
The monitoring section is based on Android and IOS mobile application and provides the following services, see Fig. 6:
• a user interface, that allows access the system via authentication, and trace the devices of interest for knowing their actual status,
• a continuous monitoring of the status of the devices associated to the user through REST GET calls,
• the use of push notifications, based on cloud messaging platforms, for alerting an associated mobile device when an alarm is produced.
For security reasons, the monitoring interface can access only GET resources (read only).
Finally, the administration section is based on a web application that allows administrators to add, edit and delete users, equipment, sensors, link sensors to equipment and equipment to users and areas. In Figure 7 an example of the web App used to insert a new sensor in the database is reported in detail. In the example the text box reports the Python code used for associating to the different levels of temperature the relevant colour code.

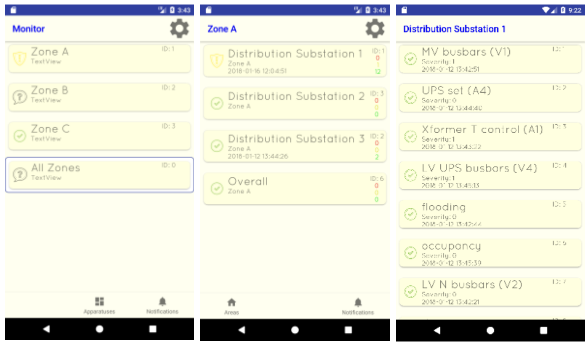

Figure 6: Snapshots of the Android version of the App.

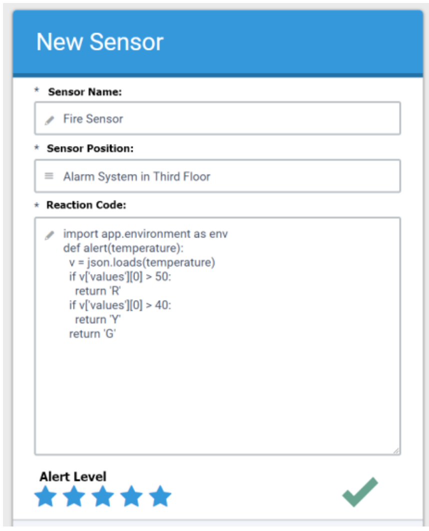

Figure 7 – Web App for administration tasks.

8. Conclusions

The paper proposes a low-cost open platform based on Raspberry pi 3 to supervise and monitor the operating states of components of a MV/LV distribution system delivering electric energy to the various processes of a large Italian hospital.
The system provides the selected electrical components of the customer's power system to be connected to a central supervising system in order to promptly signal anomalies or malfunctioning or outages. To this aim, the system provides centralized monitoring and management on a central server where it collects all events and provides simultaneous real-time remote access to several operators.
The system is based on Raspberry pi 3 platform that communicates over the internet with a customized app installed on Android mobile. Every supervised equipment is equipped with sensors or relays that allow the equipment to be monitored by the mobile app. So, the user can access the supervisory system through a dedicated webpage, where he can send a command through a Wi-Fi router/Internet.
The platform can be considered a cheaper but significant support to the maintenance management activities aimed

at improving power availability and reliability of large hospitals' power system.

For testing purposes the platform is being implemented in the distribution system of the S. Filippo Neri general hospital in Rome, Italy.

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