(IJAER) 2022, Vol. No. 23, Issue No. VI, June e-ISSN: 2231-5152, p-ISSN: 2454-1796

SMART FRAMEWORK FOR POWER DISTRIBUTION AND LOAD BALANCING

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ABSTRACT

Automated power system reduces time consumption and increases efficiency of the power system through proper monitoring and control of the system. The proposed model is based on reliability and accuracy in its monitoring various parameters including current, voltage and power factor. The system is able to provide the status of different feeders with respect to changes in different loads namely domestic, municipal, commercial, and industrial load. Various loads are assigned different priority for control purposes. A STM32 controller collects the data regarding capacity, voltage etc of the supply from the power house and controls it according to the demand of the user. In addition to this the model includes provision for active power calculation which enables the determination of power factor. Real time monitoring of various parameters is made possible through a web interface. The data can be sent to the control centre and to the consumer through wireless communications. Existing solutions for load balancing are based on Programmable Logic Controller (PLC) and Supervisory Control and Data Acquisition (SCADA), but STM32 provides a cost- effective alternative. The model is able to provide automatic operation of the distribution as well as load balancing of the power system.

Keywords: *load balancing; power factor measurement; STM32; real time monitoring; automation; smart distribution*

I. INTRODUCTION

Distributed energy resources have stolen the spotlight in the energy sector as the focus of today is on ensuring universal access to reliable, high quality electric power to meet the ever-increasing demand. As more microgrids and nano grids are implemented, there is a requirement for an economic power distribution and load balancing system. In the present utility grid those functions are handled using SCADA (Supervisory Control And Data Acquisition) and it is not economically viable to employ in smaller isolated power systems. Modern day smart grids necessitate a well-developed communication and control network at an affordable cost. A simple STM32 processor can effectively manage the power distribution for a system as compact as a nano grid, this aspect has been established with a prototype in this paper. Power quality has to be ensured in every power system for it to be deemed reliable and consumer friendly.

Power factor is the ratio of actual power to apparent power drawn by an electrical load. A constant power factor is an indicator of good power quality. Load with less power factor draws more current from the power line which is responsible for more losses. For better voltage regulation and power factor correction it is required to initially measure the power factors of loads. Power factor measurement can be done for the system using instantaneous voltage and current values, in this report the same STM32 module used for load balancing can cater to power factor calculation as well. Earlier communication strategies in power systems were mostly wired, they are being replaced by wireless communication techniques in all modern grids. Constant monitoring of electrical parameters in every feeder is necessary and the data needs to be logged for future analysis purposes. Real time data monitoring is being enabled in the proposed system using a node MCU (Micro Controller Unit), which makes the current, voltage, real power, apparent power and power factor values available online to any device that can access the internet.

II. SYSTEM DESIGN METHODOLOGY

The block diagram of the system designed is shown in Fig. 1. An STM32F411 Black pill processor is the central control unit for the implementation of both load balancing as well as power factor measurement. The prototype involves four feeders with different loads: industrial, domestic, commercial and municipal loads. Each of these four feeders is further subdivided for different set of loads depending on priority. Priority order is assigned to various loads and as the power demand for the higher priority loads increase load shedding is performed starting with the least priority loads, as mentioned in [1]. The industrial load is given maximum priority and least priority load is the 100 W municipal load. Power factor calculation is done separately for each feeder using the instantaneous values of current and voltage measured using the ACS712 current sensors in each feeder and the ZMPT101B voltage sensor respectively as discussed in [3]. Wireless communication using a ESP8266 Node MCU is done to facilitate real time monitoring of the electrical parameters like rms voltage, rms current, apparent power, real power and power factor on any device that has access to the internet.

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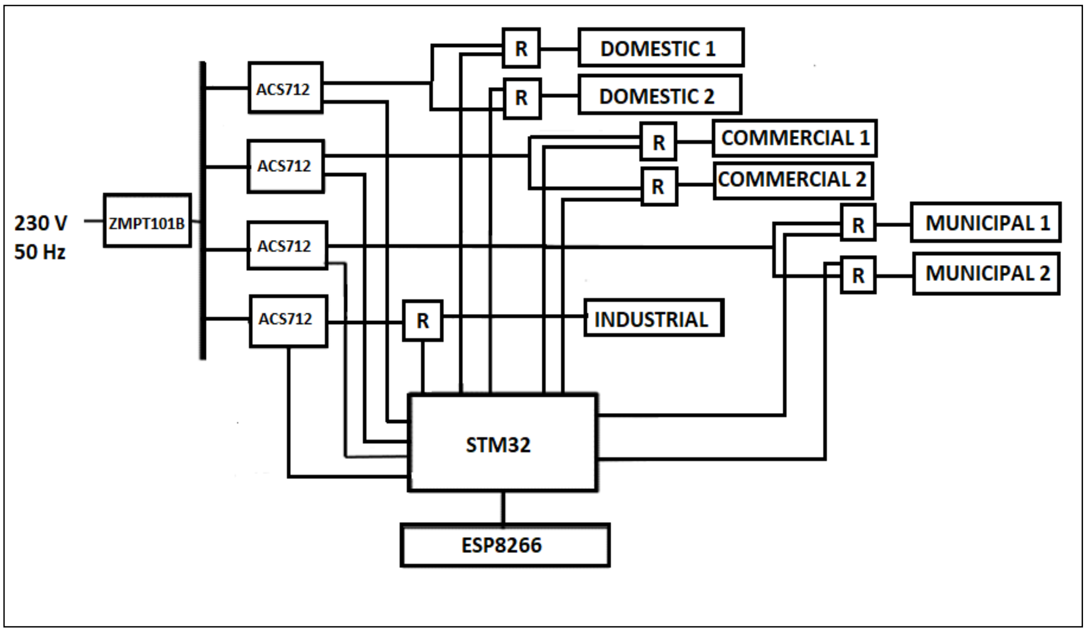

Figure 1. Block Diagram of load balancing framework.

The load balancing system consists of normally closed type relays connected to each individual load provided in each of the four different feeders set up. Each feeder except for the industrial feeder has two different loads in parallel each of which are of different power ratings. The priority of different loads within the same feeder differ as among the loads in a feeder some are critical importance compared to others. Load balancing is required for avoiding overload, in case of overload the system automatically adjusts the power distribution by shutting down some of the least priority loads in the system to prevent a total blackout situation. The current flowing into each of the feeders is an indirect measure of power drawn. Here a 230 V, 50 Hz ac source is taken as the supply source. It may be fed from various sources like solar photovoltaic, wind, biomass or micro-hydro power generators in case of a nano grid system. The load balancing sequence is based on the priority assigned to the loads, as mentioned previously initially the loads with least priority are shed followed by the higher priority ones. In reference to the block diagram in Fig. 1 the highest priority is given to the industrial load followed by the 100 Watt commercial load 1, 100 Watt domestic load 1, 100 Watt municipal load 1, 100 Watt commercial load 2, 60 Watt domestic load 2 respectively and the least priority load is the 60 Watt municipal load 2.

The Node MCU present in the circuit is an essential component for displaying the values. It facilitates real time monitoring of the electrical parameters on a specially developed web interface for viewing the values of voltage, current, power factor etc. The ESP8266 Node MCU-12E has General Purpose Input Output (GPIO) pins out of which two serve as to take in the input from the transmitter and receiver pins of the black pill board to facilitate Inter- Integrated Circuit (I2C) communication, which is a bus interface connection protocol for serial communication.

III. SYSTEM IMPLEMENTATION

A. *Software Implementation*

All the programming for the STM32 Black pill board is written in the Arduino Integrated Development Environment (IDE) platform in C programming language. For priority determination, the currents in each of the different feeders have to be measured in a sequence initially and then they have to be compared before a decision is to be made on whether the power drawn is a value that can be met by the source. None of the existing load shedding algorithms are being followed, rather we have developed a load shedding strategy taking into consideration all the requirements for a reliable power distribution system. If the power drawn by the industrial load increases above a certain level then the loads have to be shed in accordance to the priority order. But in certain cases when lesser number of loads can be shed even though they are not of the least priority to compensate for the excess power drawn by the highest priority load, which is the industrial load in this case, such an option is made.

Power factor metering is the next step involved in the software implementation. Program is written to compute the system power factor by taking data from ACS712-30A current sensor and ZMPT101B voltage sensor. Presently the power factor measurement is done by taking the instantaneous values of voltage and current values from the sensors using them to compute rms values of voltage (2) and current (1) in reference to equations derived from [2], [3]. An open source energy monitoring library was put to use during the software part development, which compares the phase difference of the voltage and current waveforms required to aid power factor measurement.

$$Irms = \sqrt{\left(\frac{\sum_{i=1}^{N} I(i)^2}{N}\right)} \quad (1)$$

$$Vrms = \sqrt{\left(\frac{\sum_{i=1}^{N} V(i)^2}{N}\right)} \quad (2)$$

The apparent power (3) is the product of the rms values of voltage and current. As shown in the above equation we can observe that the rms values of current and voltage are obtained by squaring the instantaneous values, finding mean of N samples of these squared values and then taking square root of the result of the prior operation. Actual power (4) is the mean of the sum of product of instantaneous value of voltage and current. This is also done by measuring the instantaneous values, taking product of current and voltage at ith instant and adding N such samples together. Power factor thus is calculated as the ratio of real power to apparent power obtained from equation (5).

$$S = Vrms \times Irms \quad (3)$$

$$P = \frac{1}{N}\sum_{i=1}^{N} V(i) \times I(i) \quad (4)$$

$$PF = \cos\theta = \frac{Real\ power(W)}{Apparent\ power(VA)} = \frac{P}{S} \quad (5)$$

The last step in the software implementation pertains to the display of power factor and the measured voltage and current values et cetera. A web interface is designed using HTML (Hyper Text Markup Language) for real time monitoring of the electrical parameters online. The Node MCU is capable of acting as a WiFi module thus facilitating the access to internet. Any smart device which has access to internet can be used to monitor the values in the webpage. Thus, it is integrated to Internet of Things (IoT) and this is a necessary step if we consider addition of the system into a smart grid.

B. Hardware Implementation

The hardware set up that has been developed comprises of two separate parts the control circuit and the power circuit. The control circuit consists of all the electronic components that are used for control purposes, starting from the STM32F411 Black pill, current sensors, voltage sensor and the relay modules used for switching, Fig. 3. The power circuit refers to the load side with the lamp loads and the industrial load which comprise of two 50 Ohm, 5 Ampere rated rheostats in series with a capacitor bank. The hardware setup in Fig. 2. below shows the arrangement of all these components. As the industrial load is increased in steps we observe that the other loads are switched off in the order from least to most priority. Highest priority is given to the industrial load. The first load to be shed on priority basis is the municipal load 2 of 60 Watt, followed by the commercial load 2 of 100 Watt, domestic load 2 of 60 Watt, municipal load 1 of 100 Watt, commercial load 1 of 100 Watt and lastly domestic load 1 of 100 Watt.

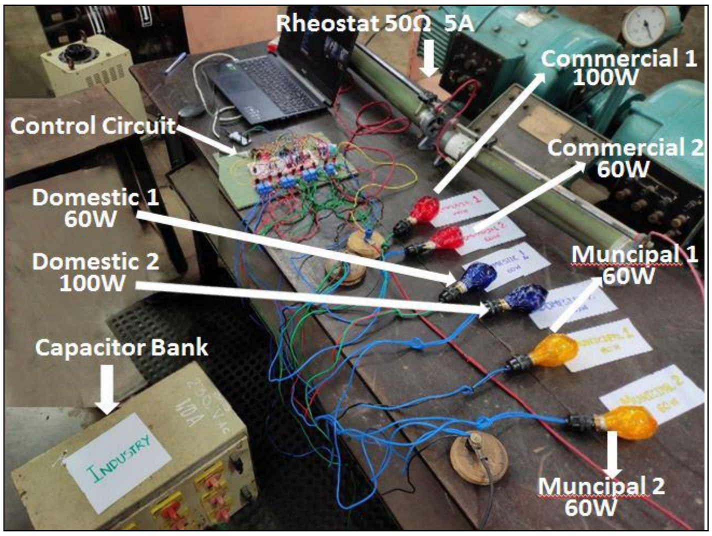

Figure 2. Hardware Setup

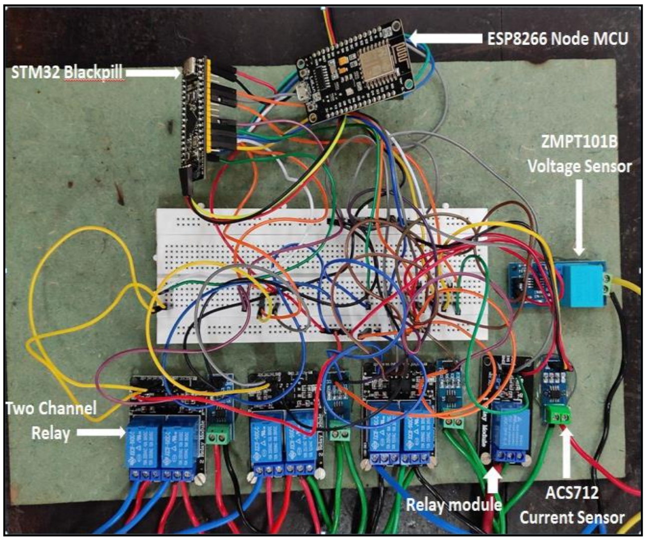

Figure 3. Control Circuit.

IV. RESULT

A set of values obtained during the hardware testing is listed for each of the four feeders in the Table 1. The results are found to vary slightly from the values obtained theoretically due to the fact that the heating effect in the incandescent bulbs as well as the rheostats used as load result in losses. For each feeder at different loading conditions we observe the real power, the power factor and the load status of each relay.

Table I. Observations at different instants during loading

Feeder	***Real Power (Watt)***	***Power Factor***	***Load Status***
Industrial	***192***	***0.92***	***ON***
Commercial	***113***	***0.82***	***C1: ON,C2: ON***
Domestic	***102***	***0.74***	***D1: ON,D2: ON***
Municipal	***42***	***0.70***	***M1:ON,M2:OFF***
Industrial	***235***	***0.90***	***ON***
Commercial	***114***	***0.84***	***C1: ON,C2: ON***
Domestic	***45***	***0.70***	***D1: ON,D2: OFF***
Municipal	***56***	***0.81***	***M1:ON,M2:OFF***
Industrial	***235***	***0.97***	***ON***
Commercial	***77***	***0.82***	***C1: ON,C2: OFF***
Domestic	***35***	***0.69***	***D1: ON,D2: OFF***
Municipal	***34***	***0.70***	***M1:ON,M2:OFF***
Industrial	***292***	***0.95***	***ON***
Commercial	***55***	***0.79***	***C1: ON,C2: OFF***
Domestic	***39***	***0.68***	***D1: ON,D2: OFF***
Municipal	***6***	***0.10***	***M1:OFF,M2:OFF***

(C1:Commercial 1, C2:Commercial 2, D1:Domestic 1, D2:Domestic 2, M1:Municipal 1, M2:Municipal 2)

The real time monitoring of power factor, real power, rms voltage and current in each separate feeder is made possible on a web page as shown below in the figure. The web page is accessed using a browser and is made available to any smart device with WiFi access. This is made possible with the help of the Node MCU interfaced to the black pill board and using the I2C serial communication protocol. Along with the mentioned parameters the load status based on the status of the operating status of relays, whether energized or not, is displayed. Fig. 4 shows a screenshot of the web interface displaying the above-mentioned details. This information lets the consumer and the system operator know which of the loads are connected and which remain disconnected at a particular point of time.

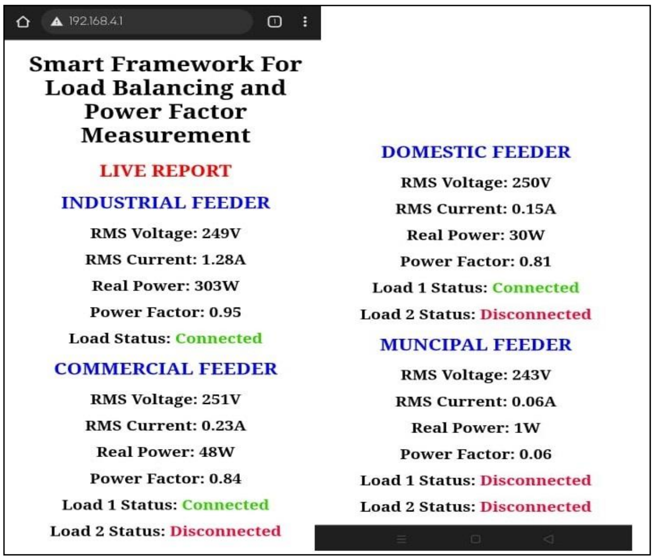

Figure 4. Web interface for real time monitoring

V. CONCLUSION

In this paper, the proposed model for load balancing and power factor measurement is based on its monitored electrical parameters including current, voltage and power factor. The proposed system is able to provide the electrical parameters of different feeders with respect to changes in different loads namely domestic, municipal, commercial, and industrial loads. Various loads are assigned different priority, based on how much critical importance they are of, for control purposes. The proposed model is built on STM32 processor which controls the switching and control processes. In small scale distribution systems and nano grid networks the STM32 based load balancing scheme provides a cost-effective alternative to Programmable Logic Controller (PLC) and Supervisory Control and Data Acquisition (SCADA). Poor power factor in an industrial plant can lead to low energy efficiency, unacceptable voltage regulation, larger equipment size, and potential damage to plant equipment when not corrected properly. Continuous monitoring of power factor in each feeder is done in this model. The STM32 Black pill module used for load balancing can cater to power factor calculation as well. The results of power factor measurement and connection status of each load is observed on a web interface designed solely for this purpose.

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