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IoT Based Remote Monitoring, Control, and Protection of Irrigation Water Pumping System

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Abstract- *The Internet of Things (IoT) is a multidisciplinary concept that includes a wide range of application domains and device capabilities. The IoT technology provides a platform that allows apparatus to be monitored by sensors, connected using a communication channel, and controlled remotely across a network infrastructure. This paper represents the IoT-based remote monitoring, control, and protection of irrigation water pumping systems. The sensors measure parameters; namely supply voltage and motor current to estimate operating conditions and provide protection. The measured parameters are sent to the user through the SIM900 GSM module for remote monitoring and control purposes. The android application has been developed to provide a better user interface, timer-based operation, status of pump and feedback notifications, etc. Protection to the pump (3-Φ Induction Motor) is provided through an ATmega 328P microcontroller embedded in the Arduino Uno board. Appropriate relay characteristics are programmed in the microcontroller for protection against various types of faults like thermal overload, single phasing, under/over voltage, voltage imbalance, reverse rotation. The system is tested in the lab and it is observed that all the protections are working satisfactorily. Single phasing is detected and the supply is tripped within 0.15 sec, undervoltage protection operated in 0.3 sec, and 5% unbalance in supply voltage is detected successfully and protection is operated within time.*

Keywords: Android app; microcontroller; GSM; IoT; induction motor protection.

1. INTRODUCTION

According to the CEA report [1], in India irrigation, i.e. water pumping load constitutes around 19% of the total load. There are two types of water pumping load, irrigation pumps used by farmers for irrigating their agricultural fields and water pumps used by Municipal authorities for water supply in cities. There are numerous issues involved with the irrigation load. The main issues are,

- poor quality of power supply leading to damage to water pump sets [2-3],
- irregularity in power supply timings [3-4] and
- agricultural fields are at a distant location away from the residential area of the farmers.

Automation is one of the best solutions with better quality and less human resources. There are many different control and automation systems that have been designed and implemented using electronic devices and relays. Some automation systems such as Supervisory Control and Data Acquisition (SCADA), Programmable logic controller (PLC), and Networked Control System have been employed for monitoring and control have gained tremendous acceptance in different applications [5-8]. Automatic operation control and protection of electrical equipment using PLC and SCADA systems are expensive and not a feasible solution for individual equipment [9]. Development in IoT technology has provided a low-cost solution for remote monitoring and control of electrical systems [10].

Monitoring and control of electrical equipment using IoT is a common approach [11-14] The remote operation of the pumps using IoT can solve the problem of irregularity in power supply timings and unattained locations. The data can be acquired and stored from a remote location and can be used for performance evaluation and process control [15]. The IoT platform can also be important in the condition monitoring of industrial motors [16-18]. Android operating system can be used for remote operation and control of electrical appliances. Android operating system is a mobile operating system (OS) developed by Google, based on the Linux kernel, and designed primarily for smartphones and tablets. Android studio is the official integrated development environment (IDE) for developing the android platform based on IntelliJ IDEA.

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The App has been designed to work with Jelly Beans and higher versions. Different monitoring and control technologies to manage irrigation are now available in agriculture [19-21]. The automated irrigation system using a microcontroller platform is presented in Ref. [22]. The complete system is divided into four units: i. acquisition, ii. Microcontroller; iii. Monitoring; and iv. Automatic function. Automation in the field of irrigation can considerably increase water-use efficiency. The protection of the pumping system is significantly important along with the automatic control. A remote-operated irrigation pump with robust protection for the pump sets at a cost similar to the existing system has been designed in this paper. The squirrel cage induction motors are widely used in water pumps due to their high robustness, reliability, low cost and maintenance, high efficiency, and long service life.

The Induction motor is the heart of any pump, the protection of the induction motor against various types of faults is a highly important issue especially in case of poor quality of power supply. Table 1 depicts the general faults that occur in an induction motor along with their impacts and general causes. Protections from the various faults, mentioned in Table 1, have been designed and tested. The proposed system provides remote operation, control, and protection of the irrigation water pumping systems. The proposed system has capability to work satisfactorily for three different rating of induction motor, i.e. 5 HP, 7.5 HP, and 10 HP.

The rest of the paper is organized in the following sections. Section II presents the proposed system description. The design of remote operation and control is described in section III. Section IV represents testing and analysis of the proposed system. Finally, section V concludes the work done in this paper.

2. PROPOSED SYSTEM DESCRIPTION AND WORKING

The basic architecture of the proposed system is shown in Fig 1. This proposed system is divided into three major sections;

- Android application,
- GSM module and
- Protection of water pump i.e. 3-Φ induction motor.

The pump (3-Φ induction motor) is connected to the supply through a contactor to turn on or turn off. The trip coil of the contactor is controlled by relays and these relays are controlled by MOSFET. Finally, MOSFET is controlled by a signal given by the microcontroller. To protect the motor, current, and voltage sensors are used to monitor the operating conditions. The protection algorithm is programmed in the microcontroller (Arduino Uno board).

The Android app enables the user to communicate with the pump at a remote location. Basic Start and Stop operation of pump along with options like timer mode setting and machine rating are given in the App. According to the options selected by the user, a string will be generated and the same will be sent to the motor end by SMS. The SMS sent by App will be received by the GSM module at the motor end. The message will be extracted by the microcontroller and further actions will be initiated. If the pump is turned on successfully then the microcontroller will feedback this status to the app by generating SMS, which will be sent by GSM modem. The timer options selected by the user are implemented by the microcontroller and it will turn on and turn off the pump according to the timer settings. The currents and voltages are sensed by the sensors and the microcontroller reads their values. If the power supply is available then the microcontroller will send SMS through the GSM modem to inform the user. Protection against various types of faults is provided by a protection algorithm in the microcontroller. In case of any fault in the induction motor or problems in the power supply, the microcontroller will trip the pump and communicate the message back to the user through a GSM modem. Hence, the user will remain updated about the status of the motor.

Table 1. Types of Faults, their impacts, and general causes

Fault	Impact	General causes
Thermal overload	Damage to stator and rotor windings. Life of insulation decreases [23-24].	Under voltage, voltage imbalance, overloading, etc
Single phasing	The current in remaining phases increases significantly thus leading to excessive heating and thermal overload. Slip increases, power factor becomes poor, maximum loading capacity decreases [25-26], [31].	The fuse of one phase melts.
Faults (3 phase and blocked rotor)	Stator and rotor windings may be damaged permanently [24], [30].	Mechanical bearings failure.
Over voltage	It may result in excessive high flux that can create saturation and thermal damage of the steel core [27], [23].	Low loading on the distribution system.
Under voltage	Motor draws higher current which leads to overloading. Slip increases, ohmic losses increase, efficiency goes down, and life of motor reduces [27-28].	High loading on the distribution system.
Voltage Unbalance	Large negative sequence components are introduced. Excessive overheating of the motor, derating of motor [27], [29].	Open delta connection, unbalanced loading, and impedances.

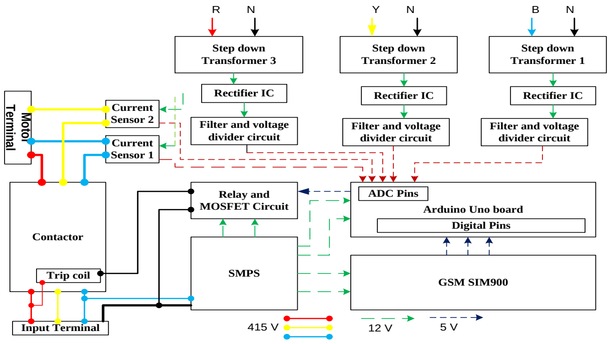

Fig. 1. Detailed block diagram of the proposed system at the pump end

Table 2. Generation of String in Mobile App

String	Values	Meaning
FinalMessage[0]	1/0	Start Motor/Stop Motor
FinalMessage[1]	1/0	Timer Mode YES/NO
FinalMessage[2]	0-2	Hour input 1
FinalMessage[3]	0-9	Hour input 2
FinalMessage[4]	0-6	Minute input 1
FinalMessage[5]	0-9	Minute input 2
FinalMessage[6]	1/2/3	Pump rating 1 - 5 HP, 2 - 7.5 HP, 3 – 10 HP

3. DESIGN OF REMOTE OPERATION

The Android App will generate a message according to the options selected by the user and will send it to the pump terminal. The SMS received by SIM900 will be read by the microcontroller and it will generate the trip signal to turn the pump on or off. In case of any fault, the microcontroller will turn the pump off and send the feedback SMS to the App. ATtention (AT) commands are instructions used to control a modem. These are the following AT commands that are used in the Arduino program to send and receive SMS.

- AT+CMGF=1 – Set SMS mode to text.
- AT+CMGD=1,4–Deletes all SMS saved in SIM memory.
- AT+CNMI=2,2,0,0,0–Alert the GSM to receive SMS.
- AT+CMGS – Used for sending SMS.

All the callback functions for the components of Activity are written in the java file of the activity. All the resources for the App like strings, pictures, activity graphical details, etc are present in res files. The components of the app (like buttons, edit text, etc) are stored in a layout file in .xml format. Fig. 2 depicts a flow chart of the string generation in the App which will be sent to the SIM900 through SMS. This string will contain all the commands. The structure of the string is shown in Table 2.

The conception and functionality of the Android App are described below.

- First of all the graphics for the App is created in a layout file in xml format. It can be designed either by dragging and dropping off the components or by writing the code in the xml file.
- The background and other graphics can be set by various commands in the xml file. Then all the buttons and text boxes are assigned identity.
- All the components are imported in the java file from the xml file.
- An Activity class is created as an extension of the default Activity class defined in Android. The on Create function is called first when the Activity begins.
- In this function the callback functions for all the components are defined which overrides the default functions defined in the default Activity class.
- The events like a button press, text box-press, etc are captured by Android, and then the callback function is triggered.
- A string is being generated in the App which will be sent to the SIM900 and this string will contain all the commands.

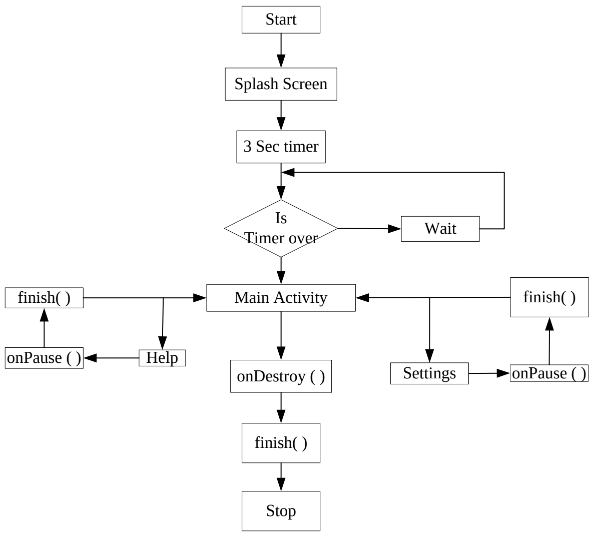

Fig. 2. Flow chart of String generation in App

Fig.3. (a) Splash Screen | Fig. 3. (b) Main Activity | Fig. 3. (c) Settings Activity

Fig. 3. Snapshots of App in Moblie

Table 3. Type of protection and threshold settings

Rating	5 HP	7.5 HP	10 HP
Full load current	7.3 A	11.7 A	13.4 A
Thermal overload protection	Pick up – 1.06 pu Characteristic equation $t=\frac{628}{I_{pu}^{10.1}}+25$	Pick up – 1.06 pu Characteristic equation $t=\frac{650}{I_{pu}^{9.13}}+20$	Pick up – 1.06 pu Characteristic equation $t=\frac{776}{I_{pu}^{10.6}}+20$
Instantaneous fault protection	Pick up - 2.5 pu	Pick up - 2.5 pu	Pick up - 2.5 pu
Under voltage	Limit – 360 V Timer – 5 min	Limit - 360 V Timer – 5 min	Limit - 360 V Timer – 5 min
Over voltage	Limit – 445 V Timer – 10 sec	Limit - 445 V Timer – 10 sec	Limit - 445 V Timer – 10 sec
Voltage unbalance	Limit – 5% Timer – 5 min	Limit - 5% Timer – 5 min	Limit - 5% Timer – 5 min

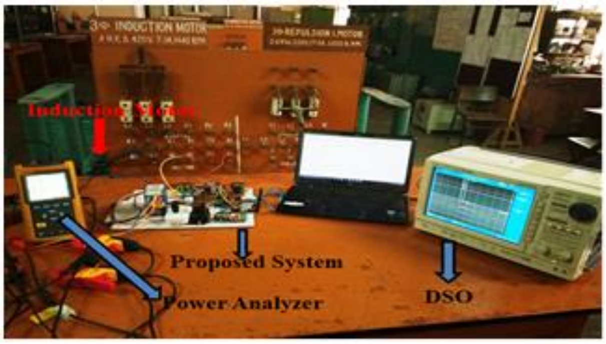

Fig. 4. Complete laboratory setup of the proposed system

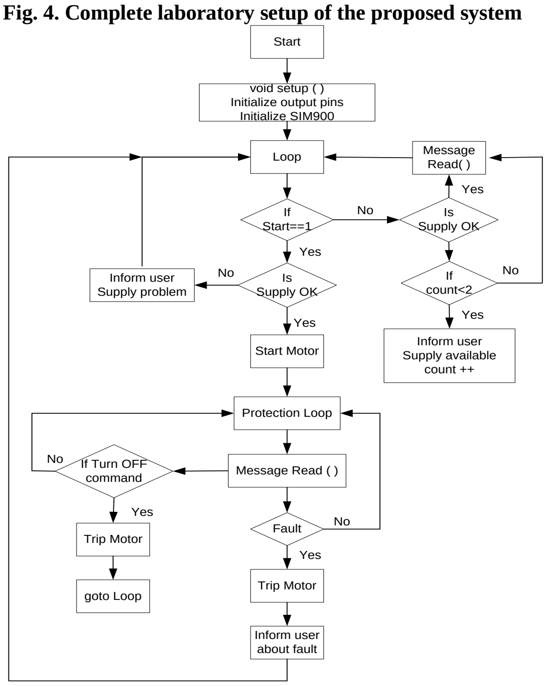

Fig. 5. Complete algorithm of the proposed scheme

Fig. 3 shows snapshots of the Android App on Mobile. Fig. 3 (a) and Fig. 3 (b) represent splash screen and main activity page respectively. Fig. 3 (c) shows the setting activity page which provides access to the user to change machine rating in the program from the App. SharedPreferance is used to store the receiver number and machine rating which removes the need for entering the number and rating whenever App starts. The notifications are updated in the App only if the number from which SMS is coming matches the saved receiver number. This feature provides security to the App, also a function check has been provided which acts as a backup in case the contactor does not operate when a trip signal is given. This function generates the trip signal again and again till the time contactor operates.

4. TESTING AND ANALYSIS OF THE PROPOSED MODULE

The proposed module is tested on a squirrel cage induction motor present in the laboratory as shown in Fig. 4. In the proposed module three different sizes (5 HP, 7.5 HP, and 10 HP) of induction motor are considered and their protections are programmed. The instantaneous fault and thermal overload protection are tested at lower values of current due to the safety of the laboratory induction motor. The induction motor protection schemes and their settings are given in Table 3. The complete working of the proposed system is shown in Fig. 5. When the start signal is received and is read by the microcontroller the pump is turned on, otherwise, the microcontroller checks the supply and waits for the message. In the beginning, a delay of 1 sec is given. During this period the microcontroller is in a halt state. Since the motor draws a very high current during starting time this delay prevents the microcontroller to issue a tripping signal. Then the voltages and currents given by the sensors are read by the microcontroller. The voltages of the three phases are checked first and if voltages are not within the limits or are unbalanced then a timer is started. If the voltages do not come back to a normal state and if this timer is over then the pump is turned off and this information will be sent to the user. Then single phasing condition is checked and if it is found then the pump is turned off without any delay. After this, the phase sequence of the supply is checked and if it is wrong then the pump is turned off.

Thermal overload condition is checked and if the pump is getting overloaded then a timer is started and if this condition persists and the timer is finished then the pump is turned off. Finally, the fault is checked in the pump by measuring the current and if it is found then the pump is turned off instantaneously. Then this loop is started again and the same cycle repeats. Performance of the proposed system with some abnormal operating conditions is as follows:

4.1 Instantaneous fault current protection

The instantaneous fault current protection was tested by setting the fault current limit at 5 A. The current (RMS) waveform is shown in Fig. 6. As seen from the waveform the protection has operated instantaneously as soon as the set pick-up limit is reached. As compared to the protection method in [33], the proposed technique of the fault detection and isolation is fast and economical.

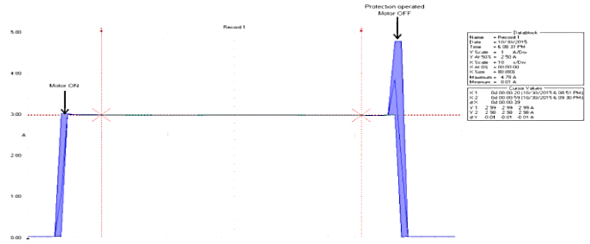

Fig. 6. Testing result of instantaneous protection

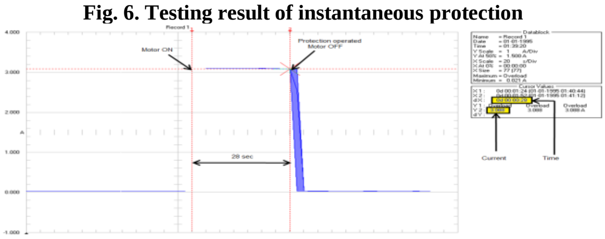

Fig. 7. Testing result of thermal overload protection

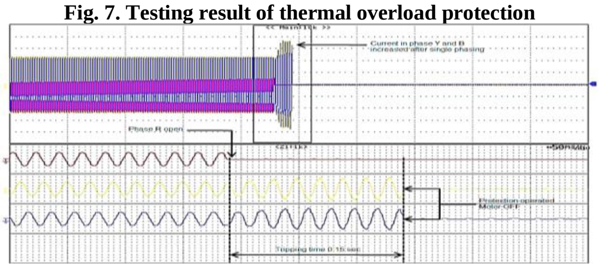

Fig. 8. Testing result of Single phasing protection

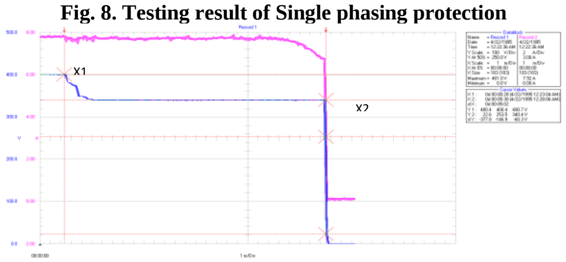

Fig. 9. Testing result of undervoltage protection

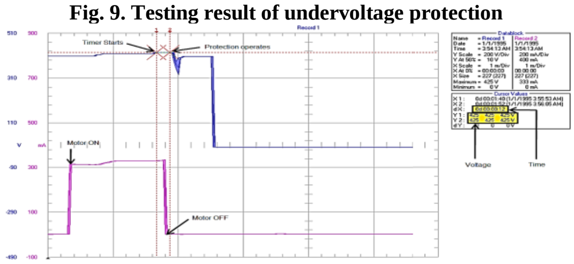

Fig. 10. Testing result of overvoltage protection

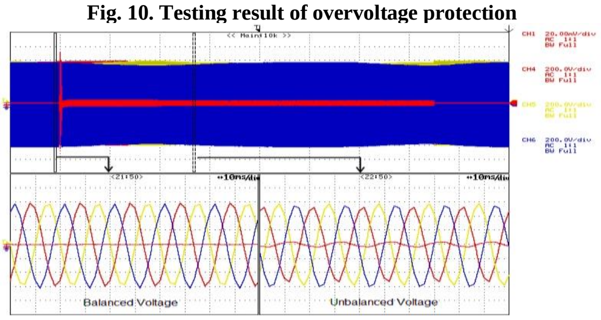

Fig. 11. Testing result of voltages unbalance protection

4.2 Thermal overload protection

The waveform of the motor current (RMS) is shown in Fig. 7. For the testing purpose, the thermal overload protection limit of the motor is set to lower value current as compared to the actual value of current. The base current is set at 1.8 A and the present value of motor current is 3.08 A so the per-unit value is 1.71 p.u. The relay characteristic for thermal overload protection is represented by Eq. (1). The equation is programmed in a microcontroller and the desired operating characteristic is verified. The tripping time for the current of 1.71 p.u. value is 27.76 sec calculated by Eq. (1). It is clear from Fig. 7 protection is working appropriately.

$$\text{Relay characteristics equation } \; t = \frac{628}{I_{pu}^{10.1}} + 25 \qquad (1)$$

In Ref. [33], overload protection is provided by sensing temperature but in this article the thermal overload protection is provided though monitoring current drawn by motor. Overload protection using current measurement is accurate and fast as compared to temperature measurement.

4.3 Single phasing protection

The waveform of the motor currents is shown in Fig. 8. During the normal operation current in all phases are equal. Single phasing was created by opening line R with a knife switch. It is clear from Fig. 8 that after single phasing the current in other phases is increased and the motor is turned off after 0.15 sec. Therefore protection can detect single phasing precisely. In [35], single phasing protection is provided using relay which will add extra cost of the relay in total cost of the system. In the proposed technique relay characteristic is programmed in the microcontroller so additional relay unit is not required.

4.4. Under voltage protection

The under voltage protection is set at 340 V (line to line) and the timer was set at 5 minutes. The voltage is reduced below the set limit at 28 sec as shown in Fig. 9. It is clear from Fig. 9 that protection is operated at 5.30 minutes. Therefore undervoltage protection is operating accurately. As compared to the undervoltage protection technique given in Ref. [34] the proposed technique is low-cost with same accuracy.

4.5. Over voltage protection

Over voltage limit was set at 425 V (line to line) and a timer was set at 10 seconds. The line voltage and line current waveform of the motor is shown in Fig. 10. As visible in the waveform, the motor is turned off after 12 sec if the voltage has crossed the limit. Therefore the over voltage protection is working accurately.

4.6. Voltage unbalance protection

The voltage unbalance limit was set at 5% and a rheostat was inserted in line R to create voltage unbalance. The timer was set to 10 sec. The voltage and current waveforms are shown in Fig. 11. The action of rheostat in line R-Y is visible from the reduction of current in line R. As visible from the waveform the protection operates after 10.6 sec and turns the motor off.

5. CONCLUSION

In this paper, a system for operating water pumps at a remote location from Android App has been developed and microcontroller-based protection has been provided to the pump (three-phase induction motor). The protections provided through the microcontroller have shown accurate results. Protection against thermal overload, fault, single phasing, under/over voltage and voltage unbalance has been provided. Phase sequence reversal is also identified with current samples and the motor is turned off in case of phase sequence reversal. The timers involved in these protections do not halt the microcontroller and are updated in every iteration. The timers were found to be accurate as visible from the results. The Android App developed for this project is working satisfactorily. Timer mode, feedback notifications, SMS sending and receiving functions of the App show expected results. All kinds of possible situations are defined in the java file. As a result, the App does not crash in any situation. This App provides a simple and effective interface and feedback status to the user. The approximate cost of the whole setup is around Rs. 3000 (40 $). Therefore the system provides a cost-effective solution for the operation and protection of remotely located water pumps.

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