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Intelligent Substation Automatic Load Shedding System for Power Distribution

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Abstract— This paper is on an Intelligent Substation Automatic Load Shedding System for Power Distribution. This serves as a solution to the manual method of load shedding where the feeders are put off and on by pressing their control switches on the control board located in the control room currently being used in developing countries like Nigeria. The prototype developed comprises the power supply module, the sensing unit, the dynamic load controller, the generation and transmission stations, the fuse, the programmable control switch, the distribution feeders and the output display. The power supply supplies the 5V needed for the operation of the system. The sensing unit serves as input to the dynamic load controller. The available megawatt power is input to the system through the SU. The dynamic load controller contains the algorithm that implements the load shedding based on available megawatt power. The generation and transmission station (GTS) represents the available power in the transmission grid. The Fuse is a protective device. The load represents the customer load point. The programmable control switch (PCS) helps the DLC to transfer power automatically to the appropriate feeder(s). The system will help improve the load shedding schedules, and the accuracy, quality and fairness of, and adherence to, these schedules.

Index Terms— Load, Shedding, Feeders, Automatic, Intelligent, Distribution, Substation

1 Introduction

NIGERIA is a developing country with a fast growing economy. Unfortunately, a greater population of Nigeria lacks access to electricity notwithstanding the great economic potentials Nigeria is resonated with. Even the few that have access to electricity still battle with the predicament of availability and qualityThe country has experienced a continuous increase of load density over the whole power distribution system. The distribution feeders may become overloaded due to load growth and substation planning. Of recent, the country has been faced with serious decline in power generation and subsequent drop in the power distributed to the users due to the shortage in gas supply to power plants, activities of vandals and the security challenges it is currently facing. The resultant effect of this drop is that the distribution companies have resorted to load shedding as a means of ensuring that the users get a fair share of the available power. In power distribution, load shedding is inevitable whenever there is a drop in the quantum of energy made available to the distribution companies.

Load-shedding [1] is a process by which the electrical authority handles the dearth of the electrical power being consumed by the society. Shedding is done to minimize the load being consumed by the society through several substations which are connected to the main power station [2]. When the frequency of the power generator falls down, it fails to generate the required power. As a result, the authority lacks the scheduled amount of power & this leads the authority to perform a shedding. And the main station orders the sub-stations to cut some of the feeders for a certain period of time & thus the shedding procedure continues.

To ensure that the system is stable and available during disturbances, manufacturing facilities equipped with on-site generation, generally utilize some type of load shedding scheme [3]. In the shedding process, under a main power station there are several sub-stations who perform power-cut for a certain period of time to control the shortage of electrical energy used by the people of the locality [4]. Workers form the electrical authority are engaged in the substations who attend the calls and directions from the main power station & as per the upper levels direction, power system of some area are cut down by the workers for a period of time. And then after the completion of those areas' shedding some other areas are cut off. In this way the shortage of electrical energy is covered up by the electrical authority [5].

In recent years, conventional under frequency and PLC-based load shedding schemes have been integrated with computerized power management systems [6] to provide an automated load shedding system. It can provide faster and optimal load relief [7] by utilizing actual operating conditions and knowledge of past system disturbances. These types of system are expensive and are currently not being used in the country.

Nigeria currently uses the manual method of load shedding where the feeders are put off and on by pressing their control switches on the control board. This method has a lot of challenges. Feeders for some areas may be favored to the detriment of others by allocating more time to them. The frequent on and off operation can lead to wear and tear of the system components and the introduction of human errors in the calculation of the amount of load to be allowed on at a particular time interval can be quite challenging. The Intelligent Substation Automatic load shedding system proposed in this work will help mitigate this problem by eliminating human interaction with the system and ensuring fairness in load distribution.

2 Literature Review

Load shedding schemes work in such a way that when load increases in a system, unit governors will sense the speed change and increase the power input to the generator. Extra load will be handled by using the unused capacity of all generators operating in the system [1]. If all generators are operating at the maximum capacity, it is necessary to disconnect a portion of the load, equal or greater than the overload, intentionally and rapidly. As frequency is a reliable indicator of an overload situation, frequency sensitive relays can be used to disconnect a portion of the load automatically. This arrangement is referred to as Load-Shedding or Load-Saving scheme and is designed to protect system against frequency interruptions.

Under frequency relays are usually installed at distribution substations where selected loads can be disconnected which will balance load and generation. The first line of these relays is set just below normal operating frequency range. When the frequency drops below this level, these relays will drop a significant percentage of system loads. If the frequency stabilizes (or increase), it means the load drop was sufficient, but if the frequency continues dropping (with a slower rate) until it reaches the second line of relays, a second block of load is shed. This will continue until the overload is relieved or all the frequency relays have tripped.

Scheduled load shedding is controlled by way of sharing the available electricity among all its customers. By switching off parts of the network in a planned and controlled manner, the system remains stable throughout the day, and the impact is spread over a wider base of customers. Load shedding schedules are drawn up in advance to describe the plan for switching off parts of the network in sequence during the days that load shedding is necessary. On days when load shedding is required, the networks are switched off according to the predetermined plan, to ensure that, as far as possible, customers experience load shedding in accordance with the published load shedding schedules. In exceptional circumstances, if scheduled load shedding is not achieving the required load reduction and/or unexpected emergencies or failures occur, then System Control Centres will shed load outside the published schedules by using emergency switching in order to protect the network. Such events are rare, but if a state of emergency load shedding is declared, then all customers can expect to be affected at any time, and the planned schedules may not necessarily apply.

A lot of works have been done on load shedding. The most common method is the manual method. In the manual method an operator at the substation performs the power cut for certain period of time to control shortage of electrical energy used by locality. Power supplies to some area are manually cut down by the workers for a period of time.

[8], [5] worked on SMS based load shedding system. In this method the distribution point is monitored by one central location. A Relay is used to operate a circuit breaker to cut off the supply of the zone. User can send commands in the form of SMS messages to read the remote electrical parameters. This system can automatically send the real time electrical parameter periodically in the form of SMS. It can be designed to send SMS alerts when relay trips. In this system micro-controller are used to effectively communicate with the sensors. The controller is provided with internal memory to hold the code. This internal memory is used to dump some set of assembly instructions into the controller. The functioning of the micro-controller is dependent on these assembly instructions.

The main theme behind the system proposed in [9] is the development of a computerized procedure for controlling the load-shedding time period in a systematic way so that in the shedding management process, manual work may be minimized. This computerized shedding scheme will be easy to operate having fewer complexities with a proper user friendly interface provided with the system. This Project is a very good example of embedded system as all its operations are controlled by intelligent software inside the microcontroller.

The system proposed in [10] used PIC16F676 Microcontroller, since this controller has two ports which are more than enough for our project. The system uses it for the centralized operation and digital processing. The author developed a microcontroller based control system and a technique of load control for fixed load.

3 System Design

3.1 Hardware Design

Fig. 1 shows the detailed block diagram of prototype automatic load shedding control system. It is made up of Sensing Unit (SU), generation and transmission station (GTS), dynamic load controller (DLC), programmable control switch (PCS), output display, distribution Feeders (DF), fuse and load.

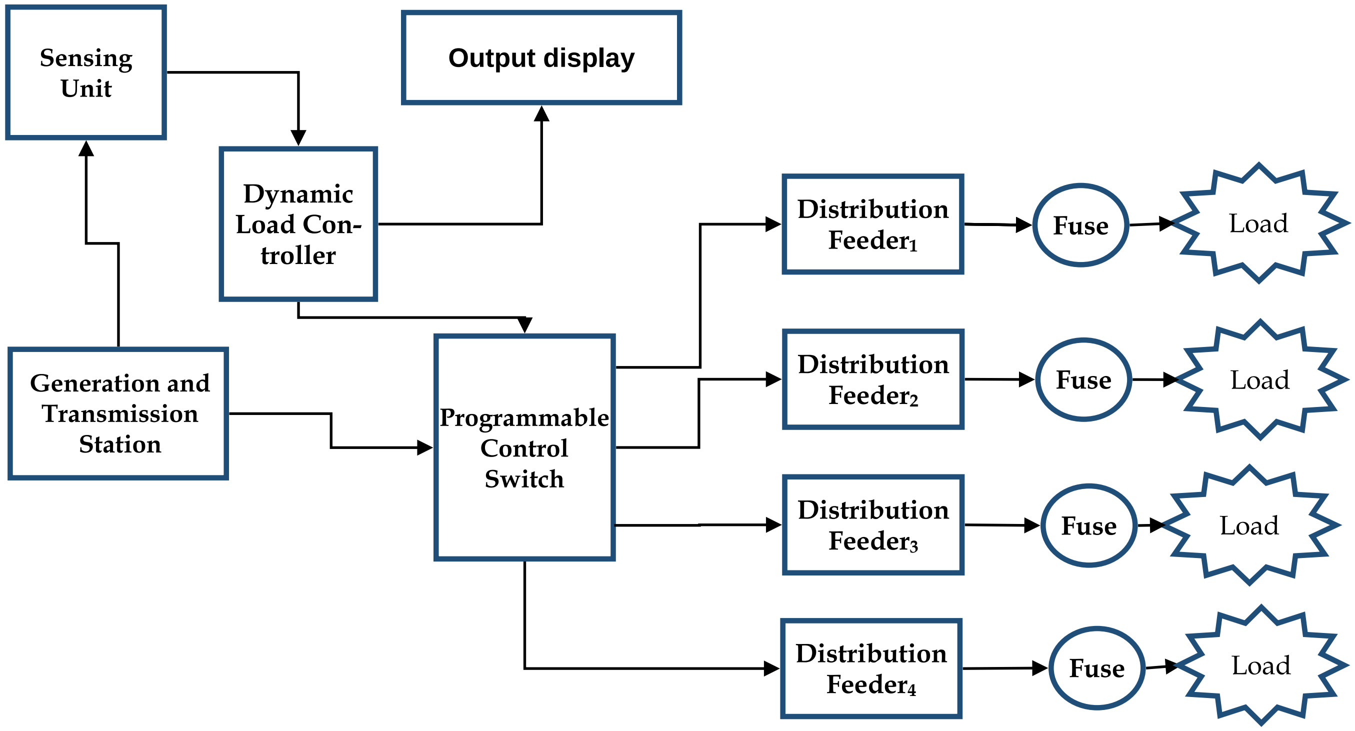

Fig.1: Block diagram of Intelligent Substation Automatic Load Shedding System

3.1.1 Sensing Unit

This serves as input to the dynamic load controller. The available megawatt power is input to the system through the system unit. The input interface will be implemented using a variable resistor and an analog to digital converter. The variable resistor is used to represent the available megawatt for distribution. The ADC digitizes the available MW power while the controller uses the digital value of the available MWP to perform automatic load shedding based on embedded control algorithm. The analog to digital converter used is ADC0804.

3.1.2 Dynamic Load Controller

This contains the algorithm that implements the load shedding based on available megawatt power. This coordinates the activities of the entire system and will be implemented using Atmel microcontroller.

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3.1.3 Generation and Transmission Station (GTS)

This represents the available power in the distribution substation. The 330KV or 132KV from the transmission company is represented by a phase voltage of 220V. The 33KV or 11KV is represented by 12V. Thus 132KV/11KV is represented by 220V/12V from It will be implemented using 220 phase voltage from mains line.

3.1.4 Fuse

This is a protective device and will be implemented/simulated using an off/on switch. A fuse is a type of low resistance resistor that acts as a sacrificial device to provide over current protection, of either the load or source circuit. Its essential component is a metal wire or strip that melts when too much current flows through it, interrupting the circuit that it connects. Short circuits, overloading, mismatched loads, or device failure are the prime reasons for excessive current. Fuses can be used as alternatives to circuit breakers.

3.1.5 Load

This represents the customer load point. It will be represented using an LED in series with a resistor.

3.1.6 Programmable Control Switch (PCS)

This will help the DLC to transfer power automatically to the appropriate feeder(s). This will be implemented using bank of relays interfaced to a driver, the ULN2003. The ULN2003A is an array of seven NPN Darlington transistors capable of 500mA, 50V output. It features common-cathode flyback diodes for switching inductive loads.

3.1.7 Electromagnetic Relay

Relay is an electromagnetic device which is used to isolate two circuits electrically and connect them magnetically.

3.1.8 Distribution Feeders (DF)

These represent distribution transformers. It will be prototype using 220/12 V ac transformers. A feeder is the voltage power line transferring power from a distribution substation to the distribution transformers. To supply the power at load/consumer end, substation has transformer (usually step-down) to change the voltage level to a standard distribution level voltage. To connect the consumer/load end with the substation, we have feeders. There is no tapping taken out of them. They just connect the consumer area with the substation. A feeder differs from a transmission line in that a Transmission line is used in reference to a transmission system/substation and a feeder with respect to a distribution system/substation. The distribution feeders are represented using 220/12V transformers. Four distribution feeders ($XF_1 – XF_4$) were used.

3.1.9 Output Display

This will display available megawatt power, the state of the feeders and the on duration of the active feeder(s). Liquid Crystal Display will be used to implement the output display. HD 44780 based LCD was used in this work.

3.2 Design Analysis

3.2.1 The System Input/ Sensing Unit

The 330KV or 132KV from Transmission Company is represented by a phase voltage of 220V. The 33KV or 11KV is represented by 12V. Therefore, 330KV/11KV is represented by 220V/12V. The 12V is rectified and passed through a variable resistor (VR) and an ADC interfaced to a microcontroller. The VR is used to simulate the megawatt power available for distribution. The ADC digitizes the available MW power while the controller uses the digital value of the available MW power to perform automatic load shedding based on embedded control algorithm. According to the data sheet, the ADC0804 has a typical conversion time of 0.0001s

$$T = 1.1R_1C_2 \qquad (1)$$

If $R_1 = 10K\Omega$

$$C_2 = \frac{T}{1.1R_1} = \frac{0.0001}{1.1\ X\ 10000} = 1nf$$

To simulate the varying MW power, there is need to have a voltage reference. The 3.3V zener diode in series with R_3 is used to reference the voltage to 3.3V. The zener diode requires at least 5mA to function properly

$$V = IR_2 \qquad (2)$$

$$5 = 5\ X\ 10^{-3}\ X\ R_2$$

$$R_2 = 1K\Omega$$

R_3 is the variable resistor used to implement the Megawatt power simulation. It is advisable to choose value that will not shunt the system. $R_3 = 20K\Omega$ was selected for this work.

3.2.2 The Distribution Feeders and Consumer Loads

The distribution feeders are represented using four 220/12V transformers ($XF_1 – XF_4$). The microcontroller controls the feeders using relays driven by the ULN2003 as shown in the complete circuit diagram in figure. The consumer load is represented by light emitting diode in series with a resistor while the fuse is modeled with a switch. The inclusion of the consumer load is to get an indicator that will show the area that has power supply.

The resistor is a current limiting resistor. This helps in preventing excessive current flow into the diode that can damage it. The forward current of an LED is about 20-50mA. In this work a forward current of 30mA was used. The forward voltage is 1.6V for bright light. Therefore, the voltage across the resistor is

$$V = IR = 12 - 1.6 = 10.4V \qquad (3)$$

$$10.4 = 30\ x\ 10^{-3}\ x\ R$$

$$R = \frac{10.4\ X\ 10^3}{30} = 347\Omega$$

3.2.3 The Output Display

In most applications, the "R/W" line is grounded. This simplifies the application because when data is read back, the microcontroller I/O pins have to be alternated between input and output modes. In this case, "R/W" is connected to ground and just wait the maximum amount of time for each instruction (4.1 ms for clearing the display or moving the cursor/display to the "home position", 160 µs for all other commands) and also the application software is simpler. It also frees up a microcontroller pin for other uses. Before sending commands or data to the LCD module, the Module must be initialized. Once the initialization is complete, the LCD can be written to with data or instructions as required. Each character to display is written like the control bytes, except that the "RS" line is set. The LCD shows the state of the system at any point in time. Pin2 is the ground; pin1 is the V_{cc} while pin3 is the contrast. A is the anode of the backlight while k is the cathode of the backlight. From datasheet, the LCD requires at least 5mA to come on and $10K\Omega < R_{v2} < 40K\Omega$. Using a current of 25mA for a brighter screen,

$$V_A = IR_{v2} \qquad (4)$$

$$5 = 0.00025\ X\ R_{v2}$$

$$R_{v2} = 20K\Omega$$

3.2.4 Power Supply Unit

It consists of a step-down transformer, bridge diode, a filter capacitor and a voltage regulator. The power supply supplies the power that can drive the motor as well as other the electronics components in the system. The power supply provides 5V dc for the microcontroller and its electronics components. The supply transformer is a 220V/12v, 1000mA step-down transformer. This step down the 220V AC input voltage to 12V AC. A bridge rectifier rectifies the already stepped down AC voltage to DC voltage. A filter capacitor filters the rectified DC voltage to remove unwanted ripples existing in the rectified DC voltage. This capacitor was chosen by careful calculation and experiments. A 7805 voltage regulator generates +5Volts voltage level required for the microcontroller and its electronics. The value of the smoothening capacitor is derived as follows:

$$C = \frac{0.8\ X\ I}{2\Delta V f} = \frac{0.8\ X\ 1}{2.5\ X\ 50\ X\ 2} = 320\mu F \qquad (5)$$

Where the power factor is 0.8

The ripple voltage = ΔV = 2.5V
The frequency = f = 50Hz
Load current = I = 1A

3.3 Software Design

The software design involves the design of the flowchart for the AT89C51 control program. Software has become the most critical

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element in the design and implementation of a computer based system of whatever size. Because of the critical nature of software, structured programming and top-down software development methodologies are usually used by many microprocessor system application designers. In structured programming, each software component is first described in terms of a few fairly abstract statements, and then they are iteratively refined until they could be expressed in the algorithm. The application program, that is, the set of instructions directing the microprocessor's execution of a specific task must first be developed and then loaded into the memory unit. The algorithms for the software program are presented in the figure 2.

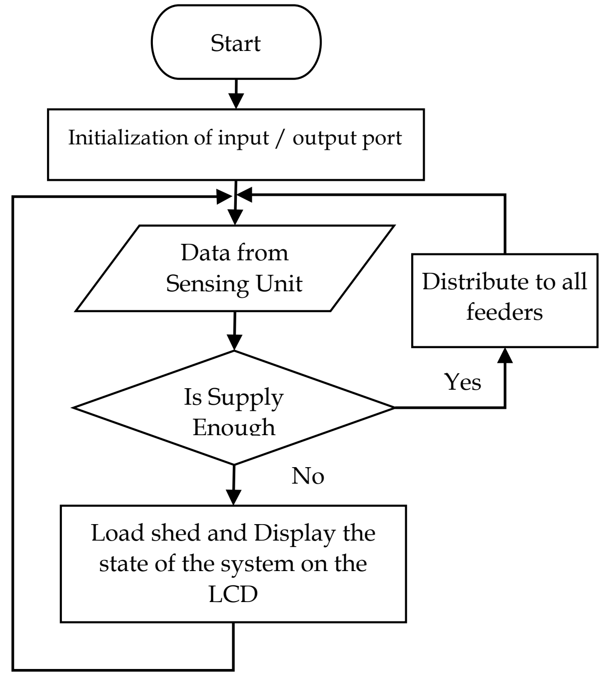

Figure 2: Flowchart for the system

4 RESULTS AND DISCUSSION

The different components of the system were integrated to have a complete working device. The complete circuit diagram was tested on a bread board, patterned and etched on a printed circuit board. The components were mounted following the design as shown in figure 3.

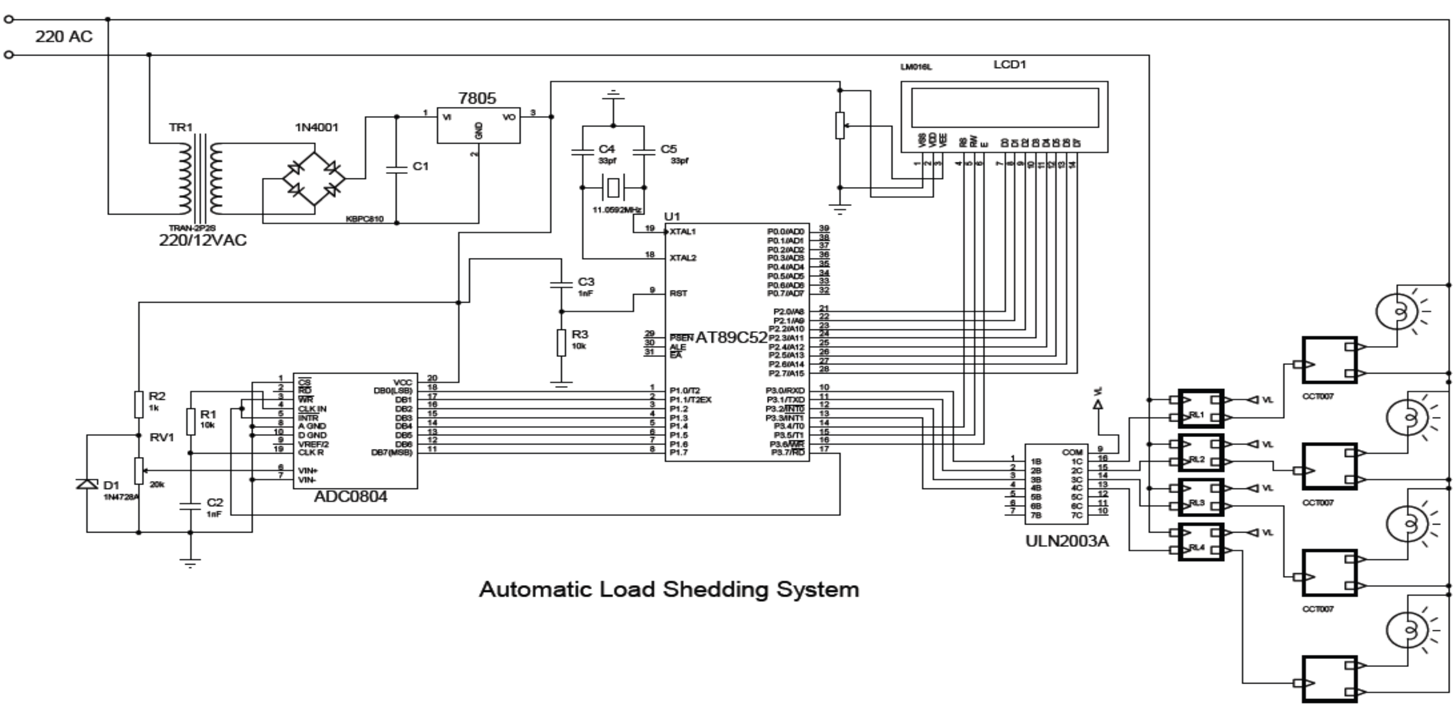

Figure 3: Complete Circuit Diagram of Intelligent Substation Automatic Load Shedding System

5 Conclusion

This project is on the design and construction of an Intelligent Substation Automatic Load Shedding System. This work presented an enhanced solution to the challenges of poor scheduling of load shedding. The system integrated Light Emitting Diode, Microprocessor, Analog to Digital Converter and electromechanical drives to automate the load shedding system thereby enhancing the scheduling of load shedding in power distribution stations. The proposed system provides information on the available megawatt from the national grid and the feeders that are on at any particular point in time depending on the supply.

The automation of the load shedding system will help in ensuring fairness, accuracy and efficiency in scheduling as human errors are eliminated. Operational cost is also reduced as the life spans of control components are elongated.

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