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Automatic Control of Power Transfer System using PLC Techniques

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Abstract: In most of the developing countries, like Iraq, electrical power fails frequently which is a considerable problem facing these countries. The stand-alone generator sets have become in the forefront of the backup aid to maintain the availability of electricity for residential areas under the situation of sudden electrical power shutdown, fluctuation and failure. In Iraq, the stand-alone power generating sets (250-400 kVA) are known as Zone Generators (ZG) which supplies electricity to a limited area (Zone) of 40-60 houses in case of the National Establishment of Electricity (NEE) absence. Private Generator (PG) which is a small mobile generator (1-4 kW) is used to supply electricity to a single house in emergency cases (when both NEE and ZG are absent), this type of generators is operated manually by the owner. This study tries to establish a humble automated solution for supplying a load (residential) with electricity from three sources, the first one is the NEE, the second is the ZG in case of NEE absence and the third source is the PG when both NEE and ZG are absent. A Programmable Logic Controller (PLC) is used to control an Automatic Transfer System (ATS) to supply the load with the available source. This automated system protects the load from over voltage and under voltage hazards which may occur during the operation, it also monitors the availability of the three phases of the main source (NEE).

Key words: ATS, PLC, hall effect sensors, Zone Generators (ZG), Automatic Transfer System (ATS), NEE

INTRODUCTION

PLCs have taken precedence over other automated systems because they are robust, simple and have reliable hardware and software techniques (Hugh, 2010). Figure 1 describes the main electrical power circuit in this project, the NEE is fed into the ATS through a main transformer, ZG and PG are connected directly to the ATS. The residential loads normally contain two types of loads (Ashour, 2004):

Light loads: Such as lighting, fans and socket outlets. These loads are always supplied from the ATS, so, the electric power is always available to these loads.

Heavy loads: Such as air conditioning units and electric water heaters. These loads are supplied only from the NEE, so if the mains failed, these loads will be shutdown. The internal construction of the ATS is shown in Fig. 2. It consists of the following items the PLC, Siemens (2011) that is the heart the of the system, receives electrical voltages from the three sources, processes them

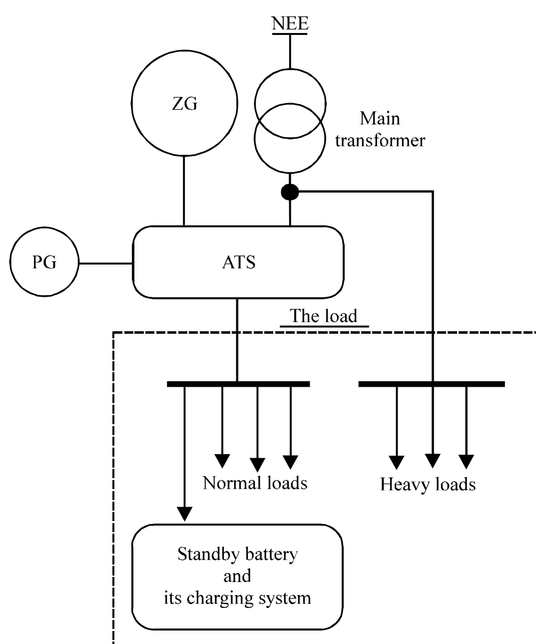

Fig. 1: General electrical power scheme

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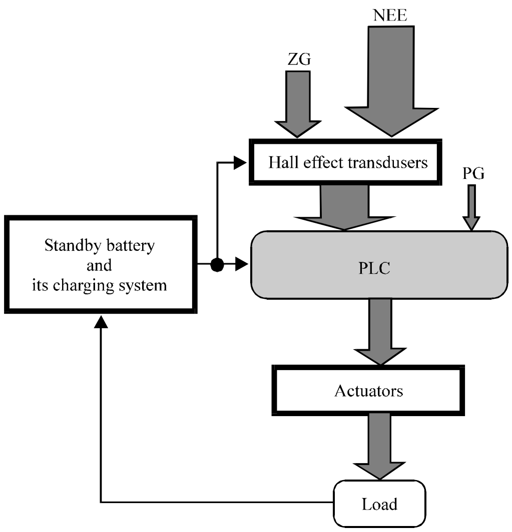

Fig. 2: Schematic construction of the ATS

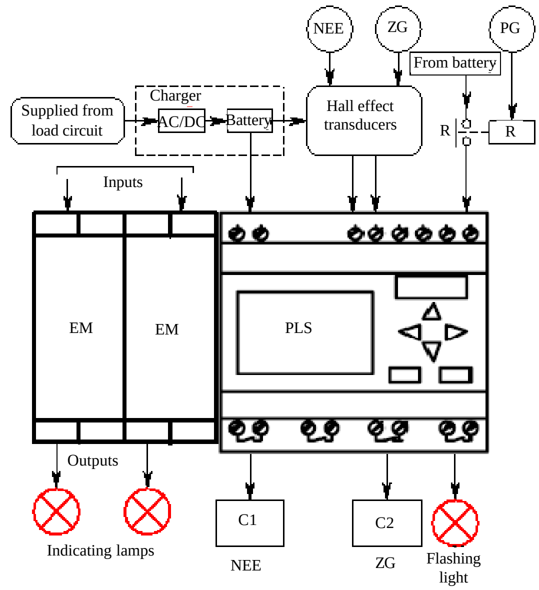

Fig. 3: External connections of the control circuit of ATS

according to its control program and then sends electrical signals to the actuators to supply electric power to the load.

- The hall effect transducers
- The actuators (contactors)
- The standby battery with its charging system

Hardware task: Automatic Transfer Systems (ATS) are used to supply continuous electrical energy to the load by automatic transferring of electric power between two or more sources when the NEE source is shutdown, decreased or increased between certain limits (Cousy, 1990; Ashour, 2004). The PLC which is used to control the ATS to achieve these requirements is the standard version of LOGO! 12/24RCE from SIEMENS with six digital inputs, two analog inputs and four relay outputs; Extension Modules (EM) are also connected to the PLC (Siemens, 2011). Connections between the PLC, EM, sensors and actuators are shown in Fig. 3. The hall effect transducers are used to convert the electrical AC signals (voltage or current) into a DC voltage (0-10 V) and transmit it to the analog input of the PLC in order to process it. The charging system is used to supply electric power to the PLC and the hall effect transducers because no interruption is accepted in their electric power supply, so, they are fed on-line from the charging system which is fed back from the load circuit.

As shown in Fig. 3, the charging system converts its input AC voltage coming from the NEE or from the ZG or the PG to DC voltage to charge the battery, feeding the hall effect transducers and the PLC without any power interruption. The electric power is fed to the load via. two power contactors (actuators) which are electrically and mechanically interlocked. When PG is operated; Relay (R) is energized and closes contact R to inform the PLC that PG is ON. Figure 4 describes the power connections of the ATS, it is important to note that phase (T) of the mains supply (NEE) is connected directly to the load because it feeds the heavy loads whereas the remaining two phases (R&S) feed the normal loads via NO power contacts of contactor C1, ZG feeds the normal loads via. NO power contacts of contactor C2. Two auxiliary NC contacts of contactor C1 and contactor C2 are connected in series to ensure the electrical interlock between PG and the other two sources.

Normal (light) loads are fed by electricity via two contactors (C1&C2), the design of these contactors is intended for 5 kW single phase load. The full load current of this load could be obtained from Eq. 1:

$$I = \frac{p}{v.\cos\theta} \quad (1)$$

Where:

P = The load Power (kW)
V = Supply Voltage (V)
$\cos(\theta)$ = 0.8 is the power factor (in general)

From Eq. 1, the full load current (I) is calculated as 28.4 A, so, according to IEC 947-4-1 regulations, contactors should be chosen within utilization categories AC3 and AC7b and their ratings must be 32 A with a coil voltage 220 V 50 Hz.

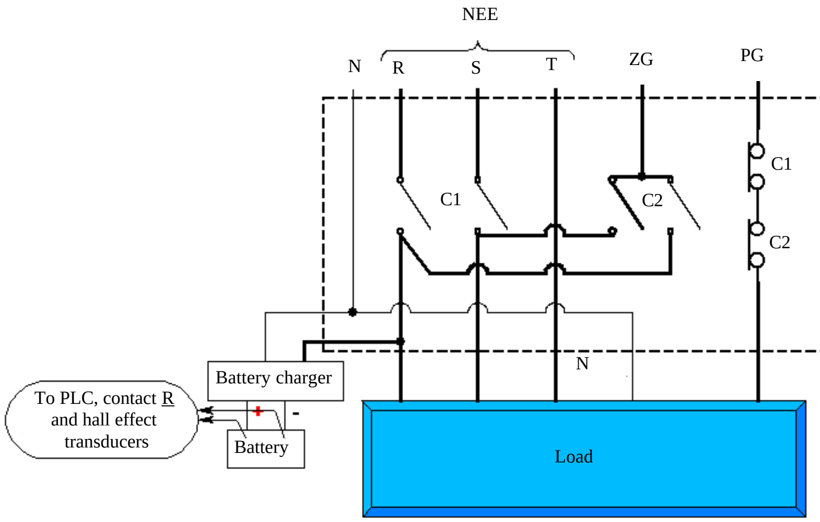

Fig. 4: Power circuit of the ATS

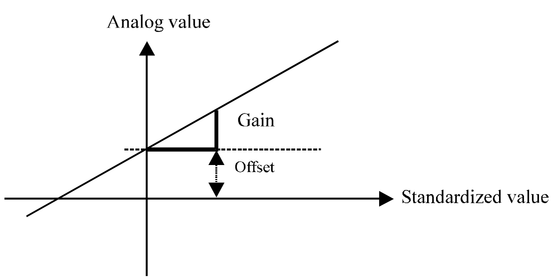

Fig. 5: Relationship between the actual analog values and the standardized values

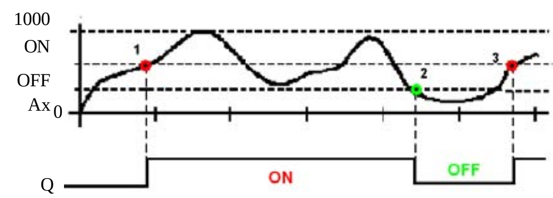

Fig. 6: Timing diagram of the analog threshold trigger function

MATERIALS AND METHODS

Software design: The PLC used in this research reads input voltages from 0-10 V or electric currents from 0-20 mA by an analog input (Hugh, 2010; Siemens, 2011). It reads the electric voltage or current and converts it with some processing into a standardized value of the range 0-1000 which means that this type of PLC has a resolution of 2^{10} (Siemens, 2011). This value is then saved in the RAM of the PLC and used in the software. Figure 5 shows the relation (which must be linear) between the actual analog values (0-10 V) and the standardized values (0-1000). The straight line shown in Fig. 5 describes how a standardized value is converted into its analog value and vice versa. Gain means the slope of this line and offset means the point at which the line intersects with the Y-axis (Siemens, 2011):

$$\text{Analog value} = (\text{Standarized value} \times \text{Gain}) + \text{Offset} \quad (2)$$

Equation 2 which is an equation of a straight line, describes the relations between all the parameters. Two analog functions (Siemens, 2011) where used in this study in order to protect the load from under voltage and over voltage hazards:

Analog threshold trigger function: This function is available in the software of LOGO! PLC (Siemens, 2011). It measures the value of the electrical signal at the analog input Ax, this value is substituted in Eq. 2 and then the output is ON or OFF according to the set threshold values as shown by the timing diagram of this function in Fig. 6. The output is set (ON) at the red points 1 and 3 and rest (OFF) at the green point 2.

Analog differential trigger function: This function is also available in LOGO! Software. It fetches the analog signal at input Ax and substitutes it in Eq. 2 and then the output is (ON) or (OFF) according to the set (ON) threshold value and the differential value (Δ). The OFF parameter is automatically calculated by the function where:

$$\text{OFF} = \text{ON} \pm \Delta \quad (3)$$

where by, Δ may be positive or negative. When Delta is set as a negative differential value, the ON threshold is greater or equal to the OFF threshold and the output is ON if $A_x > ON$ and it is OFF if $A_x \le OFF$ as shown in Fig. 7. When Δ is set as a positive differential value, the

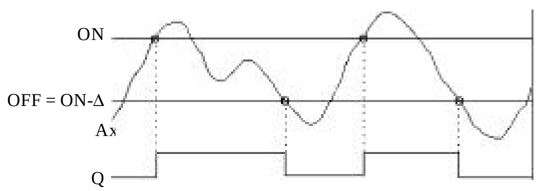

Fig. 7: Timing diagram of the function with negative difference delta

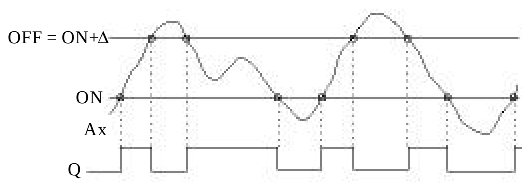

Fig. 8: Timing diagram of the positive difference Delta

ON set value is less than the OFF set value and the output is ON if $ON \le Ax < OFF$ as shown in Fig. 8. The complete flowchart of the algorithm which controls the whole operation is shown in Fig. 9, the algorithm implies the followings:

- Checking for the availability of NEE
- If NEE is available then check for under/over voltage cases
- If NEE is OK then switch on contactor C1 and the load will be supplied by NEE
- If any under/over voltage cases of NEE occurred or it isn't available then switch on contactor C2, this will block C1 and the load will be supplied by ZG
- In the absence of both NEE and ZG, PG can be used to feed electrical power to the load
- If the mains (NEE) is back or the ZG is operated while the operation of PG, then, a flashing light is operated to inform the operator or the owner of the house that NEE or ZG are available in order to switch off the PG and connect the available source

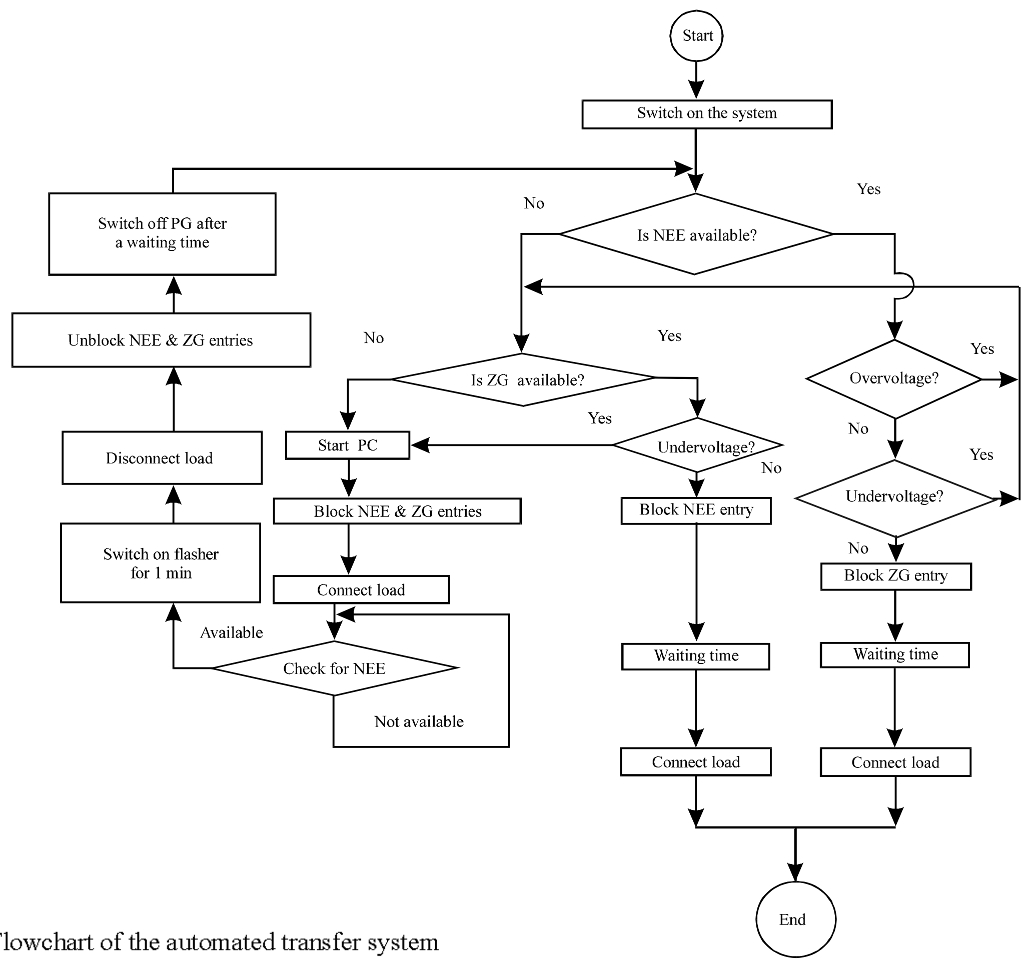

Fig. 9: Flowchart of the automated transfer system

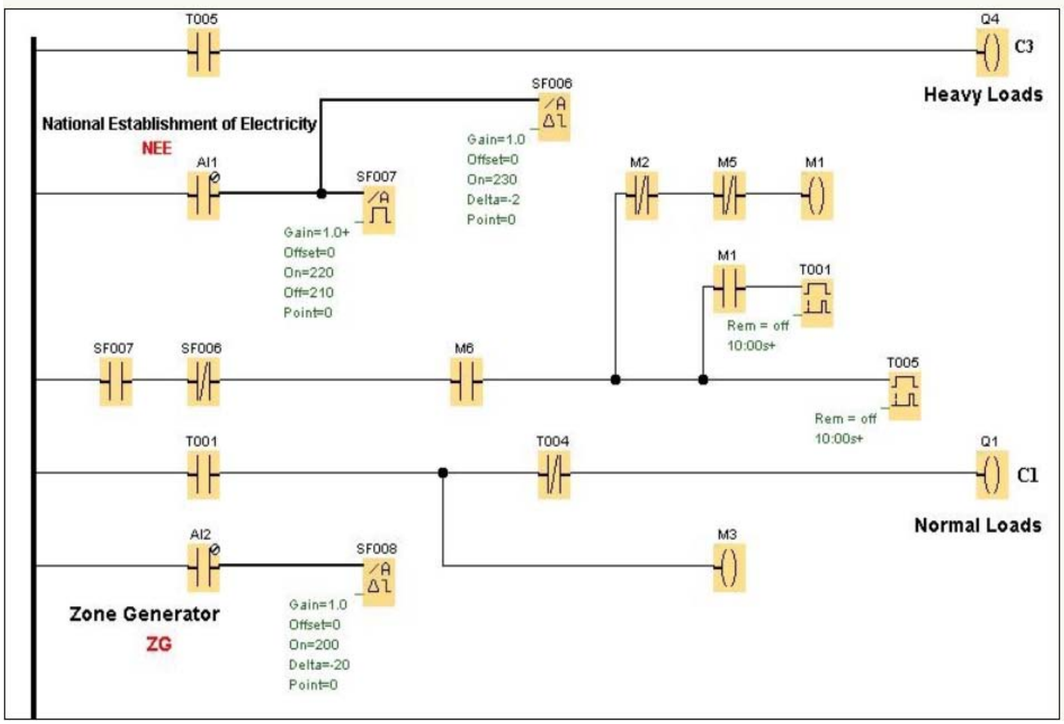

Fig. 10: First part of the control program containing the analog functions

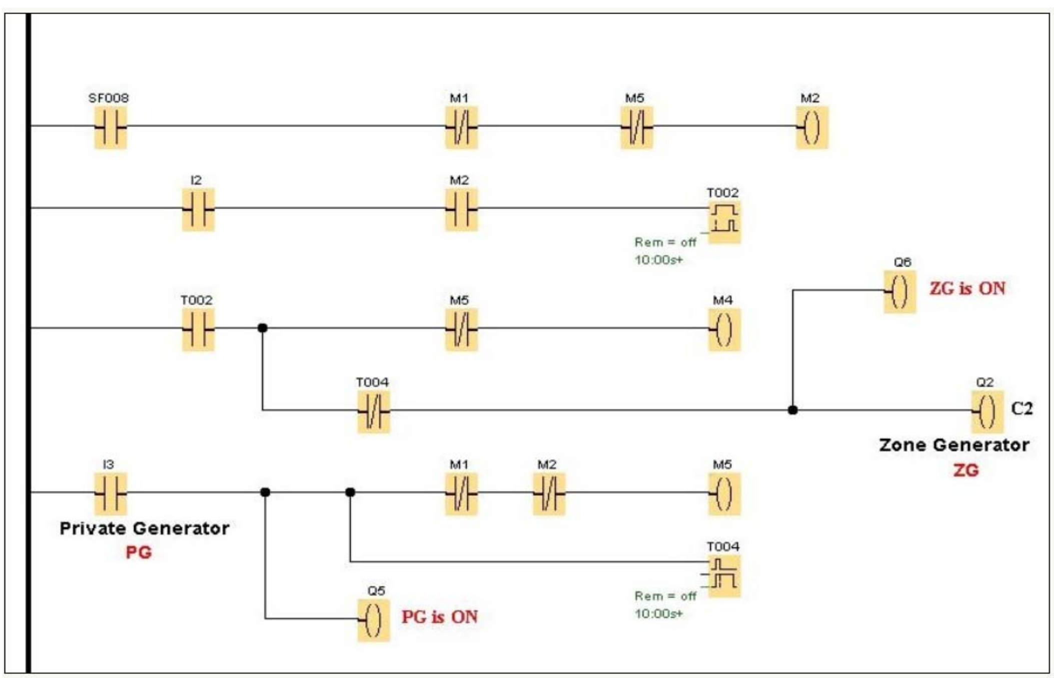

Fig. 11: Second part of the control program

Figure 10-13 describe the complete control program written in Ladder language and consists of four sections. The first section shows the application of the two analog functions available in this software, how they monitors

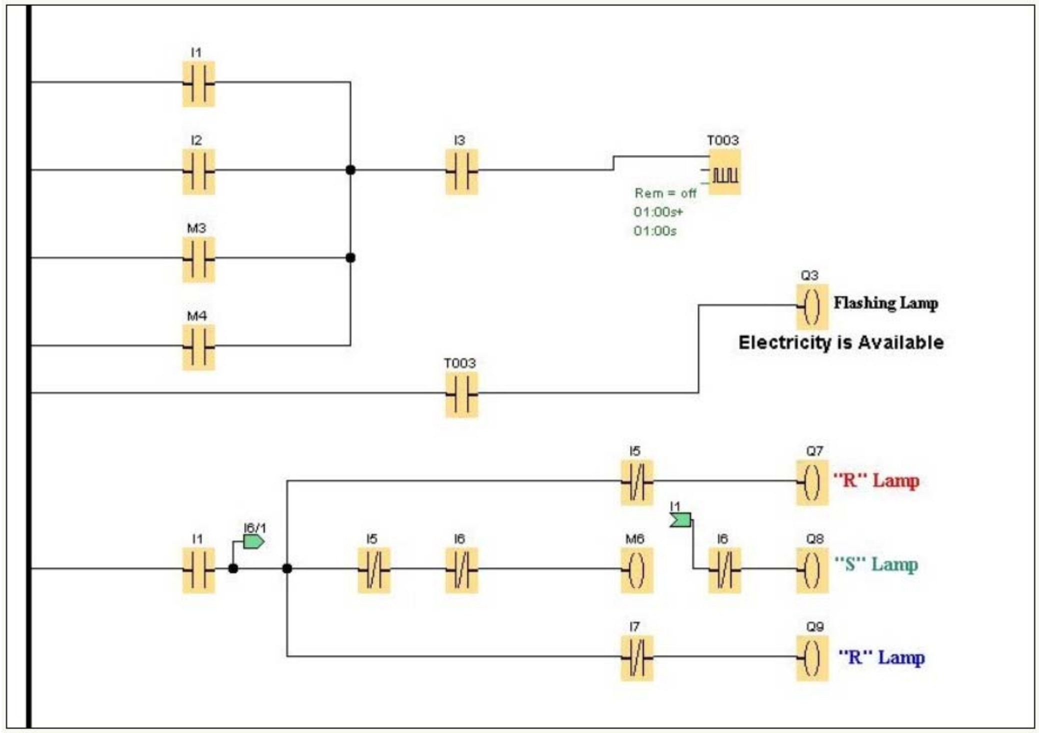

Fig. 12: Third part of the control program

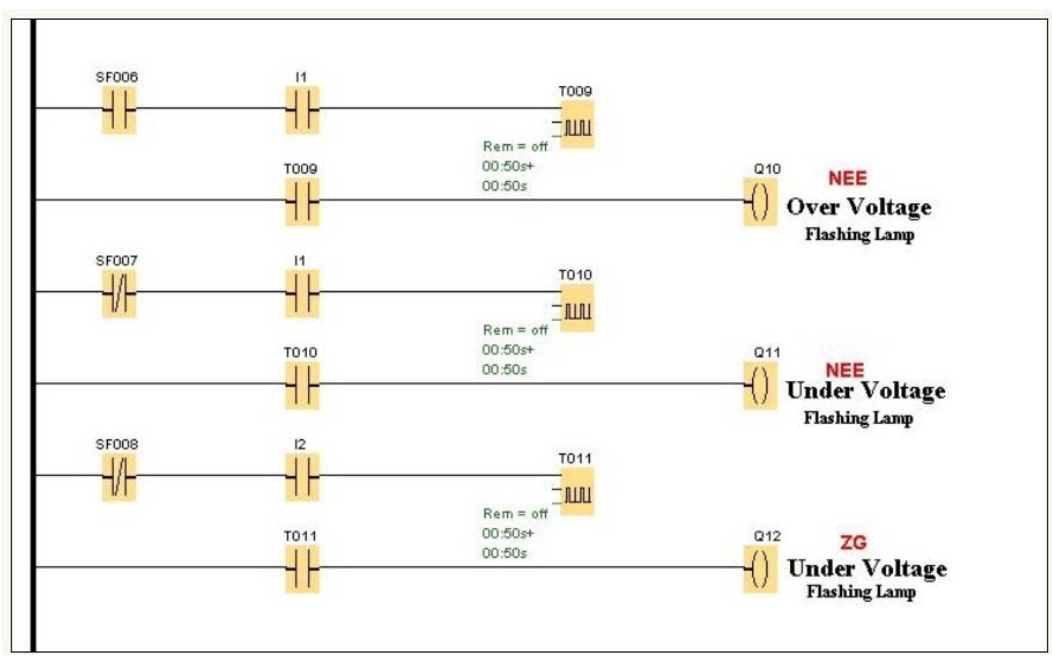

Fig. 13: Forth part of the control program

and manages the under and over voltage cases. The second section completes the duty of the first section and shows the role of ZG and PG in the operation. A time delay period of 2-4 min is set during the changeover operations to ensure protection of the household applications. Figure 12 shows the third section of the program which is responsible of two duties:

- It warns the user that NEE or ZG are available when PG is in operation or to be operated by a flashing light
- It monitors the availability of the phases of NEE

The forth section is responsible of monitoring and managing the over and under voltage cases of NEE and ZG.

RESULTS AND DISCUSSION

Various tests were carried out in this research which includes: under voltage and overvoltage tests were carried out to ensure that the supplied voltages from NEE and ZG are within the permissible limits between 213 and 227 V in case of NEE and 203 and 233 V in case of ZG, according to BS7671 (Scaddan, 2008) which states that:

Low voltage installations (lighting and household appliances circuits) supplied from a public low voltage distribution system with a rated voltage must not exceed ±3% of that rated voltage (Scaddan, 2008).

Low voltage installations (lighting and household appliances circuits) supplied from private low voltage supply with a rated voltage must not exceed ±6% of that rated voltage (Scaddan, 2008).

Figure 14 a, b clarify how our control system supplies the load according to the BS7671, by using the two analog threshold and differential trigger functions mentioned before that are available in the software used in this research.

Phase failure tests were carried out successfully also. Time delay periods for transitions from one source to another source were also checked to ensure that the setting time is 2-4 min. Checking the system performance during the operation of PG to ensure that there is no interference between PG power supply and other two sources.

The setup has been constructed and implemented as shown in Fig. 15. The voltage waveforms of the NEE, ZG, PG and load were recorded by a digital storage oscilloscope during the operation of the PLC for different states listed in Table 1 and shown in Fig. 16a-d.

Figure 16a-d show that the designed ATS based on PLC techniques has effectively fulfilled the required sequence of operation to supply a load with three different power sources under normal and faulty conditions.

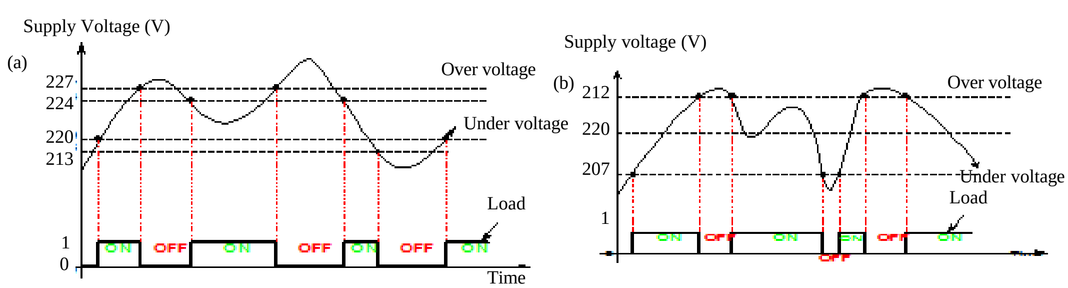

Fig. 14: a) Differential trigger function and b), Threshold trigger function

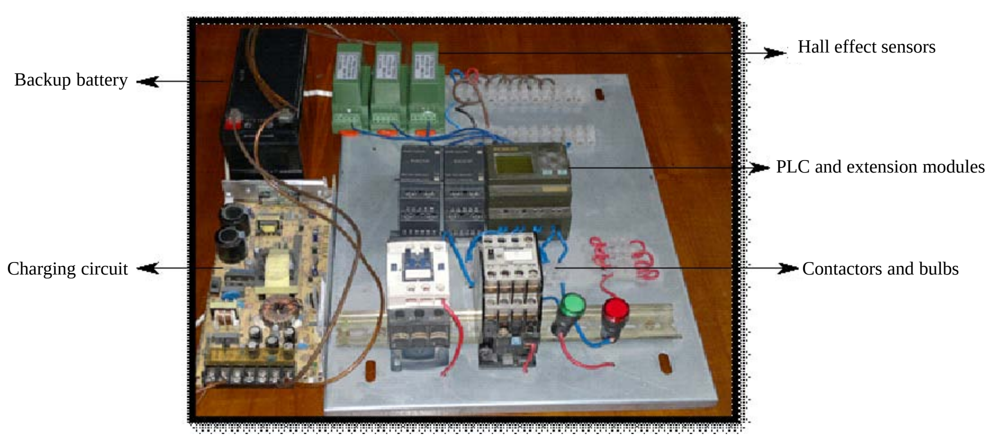

Fig. 15: The ATS

Fig. 16: a) NEE and LOAD; b) NEE and LOAD and c) ZG and LOAD and d) PG and LOAD

Figure 16a shows when the NEE is available and the load is switched ON, the electric power is supplied to the load after a time delay defined by the designer.

Figure 16b clarifies the shutdown of the load at the same time that the NEE goes OFF. Figure 16c shows the time delay period between operating the ZG and supplying the load. Figure 16d shows that when operating the PG, the load can be connected manually by the consumer.

CONCLUSION

The research presented in this research focuses on the design and implementation of an ATS with its capacity to transfer electrical power between three sources of power supply to the load by exploiting the abilities and techniques of the PLC. The NEE is considered as the primary source while the ZG is the secondary source whereas the third option is the PG. When the NEE is not available, the ATS transfers the load to the secondary source (ZG) and also switches back to the primary source (NEE) when the main source is restored. In case of the absence of both NEE and ZG, the user has an option to supply the load from his own PG. When one of the previous two sources is available, a lamp will start blinking indicating that NEE or ZG is available and PG must be shut down to transfer the load to the available power source automatically. Moreover, the design also has the capability of taking care of under voltages and over voltages whenever they occur to protect the load from damages. The ATS, also monitors the phase failure cases and manages them. The prototype of the system has been found simple, effective and quite satisfactory to be used in residential applications and with some developments it can also be used in commercial and industrial applications.

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