A SMART STARTUP AND SHUTDOWN SYSTEM FOR DOMESTIC ELECTRIC POWER GENERATORS

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ABSTRACT

Frequent and prolonged power outages in Pakistan have resulted in an increased reliance on alternate sources of backup power, such as uninterruptible power supply (UPS), Solar-cell systems and household electric generators. The startup and shutdown of most of the household electric generators is manual, which renders them less convenient as compared to the UPS and Solar-cell systems. A fully automatic electrical generator that starts and shuts down itself without any user intervention results in increased user convenience. This paper looks at the design and evaluates the results of a prototype smart system, developed to control the startup and shutdown operations of a typical household electrical generator. An ATMEL 89C51 microcontroller, relays, voltage regulators, current amplifier, automatic switching relay and step down transformers are used in the prototype circuit to control the functions required for startup, shutdown and switching onto and off the electric grid supply. Simulation of the developed system was performed in Proteus software and a prototype system has been implemented and tested with a 3500 W household electrical generator. The system performance has been analyzed for three different fuels i.e. Petrol, Liquefied Petroleum Gas and Natural gas.

KEYWORDS: *Automation, control system, electric generator, grid power, intelligent circuitry, microcontroller, mechatronics.*

INTRODUCTION

Energy is vital to the very existence of human life and has shaped the very form of modern civilization. The living standards and prosperity of any nation can be fairly judged with its per capita energy usage. The ever increasing human population and its rising per capita energy requirements have resulted in a huge strain on global energy resources. Developing sustainable sources of energy is a major challenge for the modern man. While for most nations around the globe, the challenge is to find sustainable sources of energy to maintain their rather luxurious standard of living. However, for many developing nations especially, Pakistan the challenge has transformed into a matter of economic survival or demise. Over the last couple of years Pakistan has experienced decreasing economic productivity because of crippling power shortage to industrial, commercial and domestic consumers. While industries and commercial consumers have mostly switched to huge automatic diesel powered generators, the domestic consumers are using uninterruptible power supply (UPS), Solar-cell systems and backup electric generators as alternate power sources. UPS is a preferred choice for its compact size and trouble free operation. The UPS offers some disadvantages as well, e.g. battery based systems require extensive regular maintenance and testing to maximize life expectancy and performance[1]. Moreover, during standby mode UPS still consumes energy. Similarly, solar-cell systems are costly, require large space, and are highly dependent on climate conditions[2]. With the uncertainties of these alternative sources, electric generators are a wise and cost effective solution in the event of a power outage. Table 1 provides a comparison of these alternative backup power sources.

Table 1: Comparison of alternative electric power sources

Alternative Source	Reliability	Cost	Space	Condition
UPS	Moderate	Little costly[3]	Small space	Need backup power for charging
Electric Generator	More	Affordable[4]	Small space	Meet performance in any condition
Solar System	Less	High cost[5]	Large space	Required good weather conditions

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The startup and shutdown of most of household electric generators is manual, which makes them less convenient in operation as compared to the UPS and Solar-cell systems. In an event of power outage, an automatic startup and shutdown system used in tandem with a faster and more reliable change-over mechanism is more desirable[6]. The Automatic startup and shutdown system for electrical generators automatically turns on the generator and switches the load onto the generator when there is a power outage. The system switches back over to the mains supply when power is restored and turns off the generator automatically. Automatic startup and shutdown system of a gaseous fueled generator has been developed and reported[7]. In system, a circuit with timers and relays for startup and shutdown is implemented[8]. Whereas, for large commercial usage, an automatic transfer switch is used in developed operational circuit[9]. Automatic Transfer Switches (ATS) monitor the power supplies and automatically switch from the normal supply over to the generator power in the event of a power outage[10].

In view of the aforementioned considerations, a microcontroller based intelligent electronic system has been developed that automatically starts up and shuts down an electrical power generator and manages the changeover of load between the grid and the generator. Furthermore, the system ensures that the generator's starting battery is not drained by providing recommended gap between successive attempts to engine ignition.

DESIGN AND SIMULATION

Topology of prototype circuit is shown in Figure 1. The main components of the circuit are a microcontroller, voltage regulators, current amplifier, step down transformer and integrated circuits.

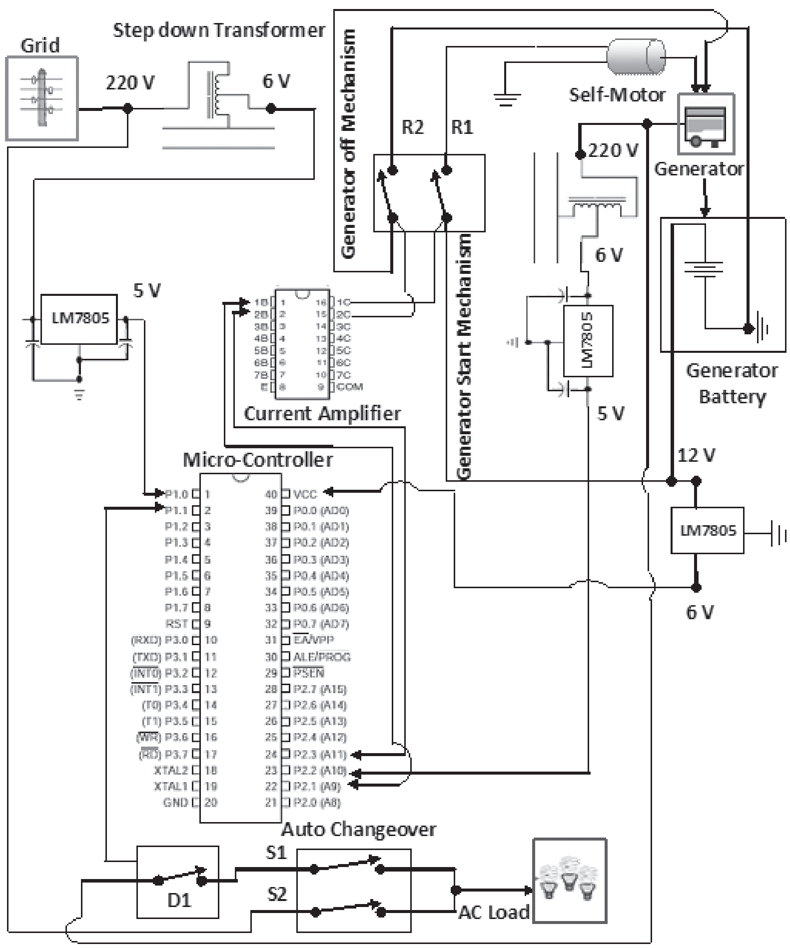

Figure 1: Topology of prototype circuit.

WORKING OF INTELLIGENT STARTUP AND SHUTDOWN SYSTEM

The intelligent startup and shutdown system prototype is designed to choose one among the two available power sources. In this case, the selection is between supply from the power grid of the water and power development authority (WAPDA) and the electrical generator. The system monitors the mains supply from the power grid and upon its failure switches over to the generator by starting the generator automatically and switching it OFF automatically when power on mains supply is restored. Figure 1 shows the working principle of the auto startup and shutdown system for house hold electrical generator.

The mains supply from the grid is sensed through port 1.0 of the microcontroller. The port monitors supply on the mains from the power grid. If power is available on the mains, the mains power supply is directly connected to auto changeover relay, whose output is connected to the load. Once contactor S2 has been energized, it feeds power to the load. As long as, this contact is closed, contactor S1 which controls the generator output stays de-energized. Thus separating the generator output from the load, hence, preventing the short circuiting of both sources. However, when power failure occurs on the mains line then the contactor S2 is de-energized. As a result of which, the normally closed contact of S1 opens, connecting the coils of S1 to the load. In a similar fashion, the mains line is disconnected from the load. S1 is not yet energized because the generator is yet to start. Microcontroller high port 2.1, energizes relay R1, connects the generator starter (Self-Start Motor) to the battery causing the generator to start. Once it has gathered momentum and has built up sufficient voltage, delay mechanism D1 becomes energized (since its coil is energized by the microcontroller based on delay mechanism). This causes S1 to activate and connects the load to the generator output, thus, restoring power automatically.

Once power is restored, the D1 de-energizes and prevents changeover back to WAPDA from occurring until after a preset time. This causes the normally open contact of S2 to close and thus de-energizing S1 and disconnecting the load from the generator supply. At the same time, S2 being energized, connects the load to the mains supply line. In a similar manner, the microcontroller high port 2.3 switches the generator ignition to its "off" position through relay R2. D1 is used to prevent change-over to generator by disabling S1. Thus, whether the generator is running or not its output is not fed to the load. This is necessary when it is required to warm the generator engine before operating it at higher revolutions per minute (rpm) under load conditions.

SIMULATION

The designed prototype circuit is simulated in Proteus software (Labcenter Electronics Ltd., North Yorkshire, England). Circuit is implemented in software environment as shown in Figure: 2 and program is uploaded to microcontroller for simulation purposes. The circuit developed for the simulation contains a pair of LED's (LED-Green representing self-motor of generator and LED-Blue represents main supply source), a 5V battery supply (as a mains supply), electrical generator, and a push-button (showing ON and OFF for mains supply) connected to AT89C51 micro-controller.

During simulation, when the push-button is pressed, blue LED is ON which gives indication of on-grid supply so there is no change in green LED and self-motor as shown in Figure 3.

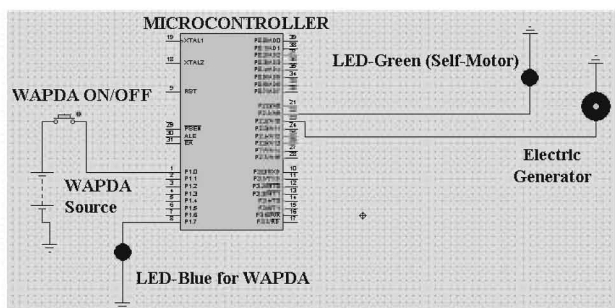

Figure 2: Prototype circuit simulation in Proteus.

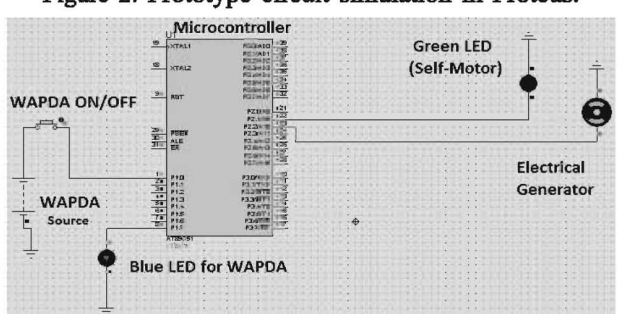

Figure 3: Simulation results for ON grid source.

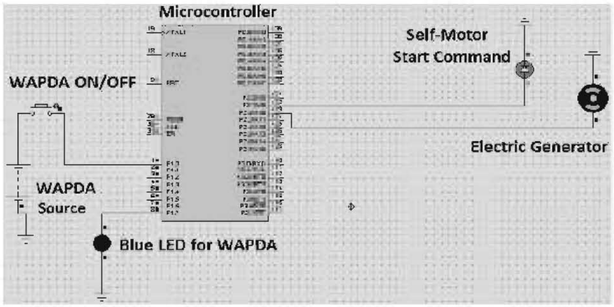

Figure 4: Simulation results for self-motor ON.

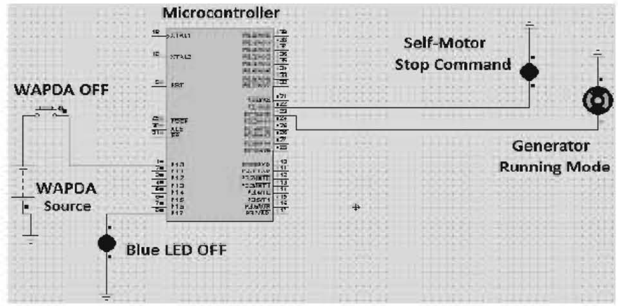

Figure 5: Simulation for generator in running mode.

Table 2: Main Components of prototype circuit main components

Component	Model	Manufacturer	Main Feature
Microcontroller	AT89C51	Atmel	Control all operations
Darlington Transistor	ULN 2003	Texas instruments	Current amplifier
Voltage Regulator	LM 7805	Texas Instruments	Fixed output voltage
Relays	RJ Series (6V)	Texas Instruments	Electronic control switch
Mobile Charger	220V-6V	Nokia Mobiles	Step down voltage to 6V and rectify AC to DC
Resistors	10 Ω	Kemet	Prevent power dissipation
Capacitors	10 μF	Kemet	Prevent power dissipation

And when the push-button is not pressed, it corresponds to no mains supply and the microcontroller turns on the green LED, indicating that the self-start motor has been turned ON. The green LED stays ON for five seconds as it represents working phenomena of self-motor as shown in Figure 4.

When the push-button is not pressed, it signifies in the simulation, the absence of power on the mains supply and prompts the microcontroller to turn ON the self-start motor indicated by a glowing green LED in the simulation as shown in Figure. 4. After five seconds, the self-start motor is switched OFF and the electric generator starts as shown in Figure 5.

PROTOTYPING AND EXPERIMENTATION

Prototype circuit has been fabricated on a strip board as shown in Figure 6. The main components of the circuit, such as, AT89C51 microcontroller, voltage regulators, current amplifier, step down transformer and integrated circuits are soldered together on the strip board. The circuit components are carefully connected according to the designed topology discussed in Figure 1. Commercially available mobile-phone charger (Nokia AC2E) is employed in the prototype circuit to convert the WAPDA and electrical generator AC output (220 V, 60 Hz) into 6 V DC for circuit operations. The developed prototype circuit is mounted in a wooden box to ensure safety during testing. The summary of the main circuit components of circuit is given in Table 2.

For testing the operation of prototype circuit, it is integrated with a 3500 W electrical generator. The circuit is characterized for both power outage and power resumption scenarios. The power outage scenario is produced by unplugging the WAPDA supply line and the response of the circuit is obtained, when the system turns-on the electrical generator and starts transmitting electricity. After running the generator for some time, the WAPDA

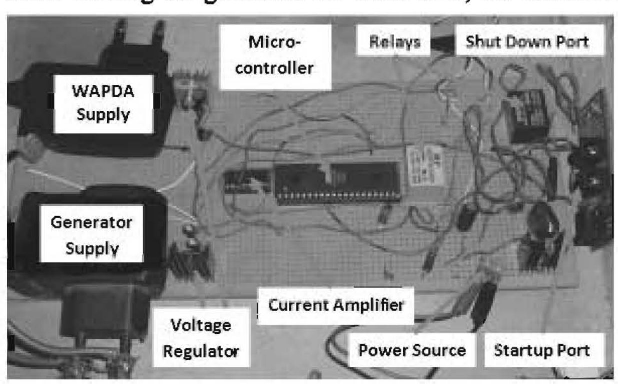

Figure 6: Developed prototype circuit.

supply is plugged-in again and the developed system's response is checked by switching the generator power off-line and alternately turning-off the electrical generator. The response time for ON and OFF states of the generator is obtained for three different fuels i.e. petrol, liquefied petroleum gas (LPG) and natural gas (NG). Using each fuel type, the system has been tested to turn ON and OFF the generator for at least 30 times, in both loaded (500 W load applied) and unloaded conditions.

The experimental setup for testing the circuit, when petrol is used as fuel is shown in Figure 7. Figures 8 and 9 show the startup and shutdown times respectively, for 30 trials. In Figure 8, when no load is connected to the generator, minimum and maximum values of start time are recorded as 2.8 and 3.41 s respectively. However, when the generator is subjected to a load of 500 W, minimum and maximum startup times prolonged to 3.21 and 3.81 s respectively.

For petrol as the fuel, the shutdown response time of the prototype circuit, with and without load is shown in Figure. 9. Without the application of the external load, the minimum and maximum shutdown response times of 2.06 and 2.51 s are obtained. With load, the prototype circuit shuts down the generator with a maximum time of 1.23 s and a minimum time of 0.68 s.

The slighter change in Figure 9 for shutdown time is due to fuel left in carburetor. With load, generator consumes fuel at higher rate as compared to without load circumstances.

Figure 10 shows the experimental arrangement, when LPG, is used as a fuel in the generator. For thirty trials, the starting and shutdown times given by the system when the generator is running on LPG are shown in Figure. 11 and Figure 12 respectively. In Figure 11, without any load connected to the generator, the minimum startup time recorded during trials is 6.98 s while the maximum startup time is recorded as 9.14 s. On the application of load, maximum and minimum times for startup are 11.32 and 8.64 s respectively.

The generator shutdown time for LPG as a fuel is shown in Figure 12. While there is no external load on the generator, the minimum and maximum shutdown times are recorded as 1.01 and 3.42 s respectively. However,

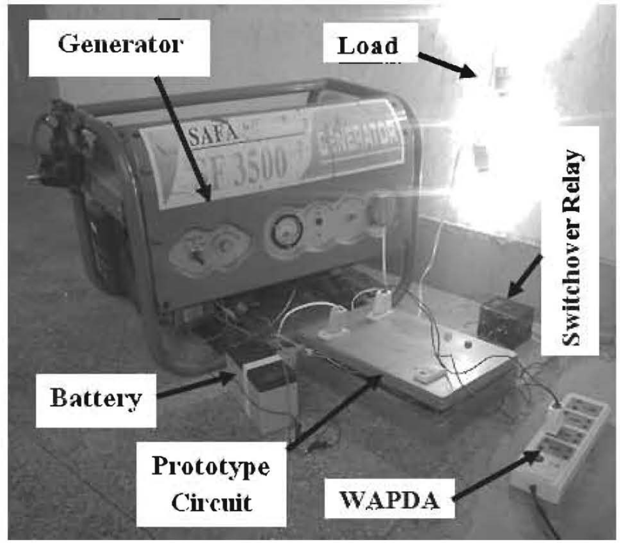

Figure 7: Prototype circuit testing with applying load to generator (in Petrol).

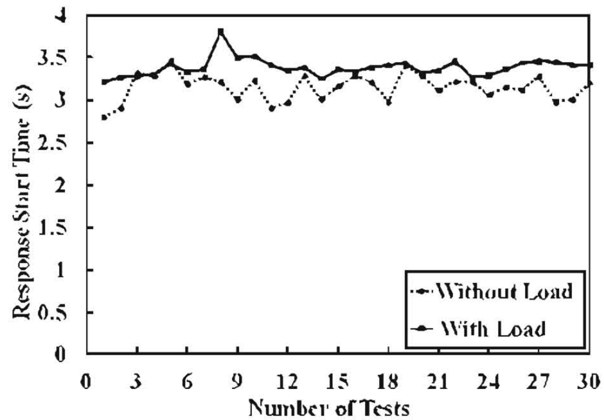

Figure 8: Starting time of electrical generator vs number of trials (in petrol).

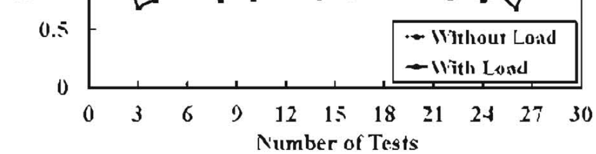

Figure 9: Shut down time of electrical generator vs number of trials (in petrol).

when load is applied to the generator, 0.75 and 2.98 s are being recorded as the minimum and maximum shutdown times respectively.

The setup for the experimentation of the prototype circuit, when NG is used as a fuel in the electrical generator is shown in Figure. 13. The startup and shutdown response times of the system while running the generator on NG is shown in Figure 14 and Figure 15 respectively. In Figure 14, without applying load to the generator, the minimum and maximum startup times have been recorded as 6.89 and 9.45 s respectively. And due to load application the minimum and maximum startup times surged to 7.06 and 11.78 s respectively.

Figure 15 represents shutdown time response of the system with 1.05 and 3.41 s being the minimum and maximum recorded values respectively under zero-load conditions. The minimum and maximum shutdown times dropped to 0.68 and 2.04 s respectively on the application of load to the generator.

The experimental results for different fuels (petrol, LPG and NG) show that the startup response times of the generator are high in case of LPG and NG. The reason being the lower fuel densities of LPG and NG resulting in leaner air-fuel mixtures as compared to petrol.

Figure 16 shows the probability mass function for the startup time of the electric power generator when operating under zero load conditions. The figure shows the probability mass function for all the three fuels. It can be easily noticed that the startup time in the case of all the three fuels more or less matches the normal distribution function. The distortion in the curves and their migration away from the normal distribution function can be attributed to various possible errors during the conduct of the experiments such as measurement of time etc. The probability mass function for the generator shut down times while operating on petrol, LPG and Natural Gas is way too wayward as evident in Figure 17.

In Figure 17, the reason for such abnormal behavior could be the fact that the shutdown times are smaller as compared to the startup times (in case of LPG and Natural Gas they are smaller by a factor of > 2), hence making them relatively more susceptible to errors such as measurement of the time duration etc.

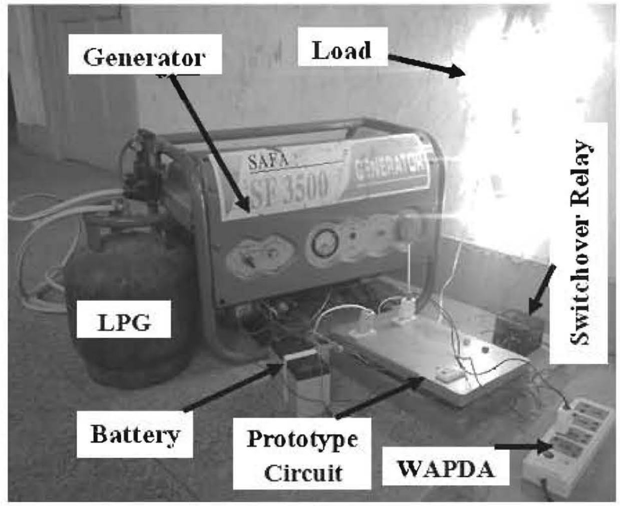

Figure 10: Prototype circuit testing with applying load to generator (in LPG).

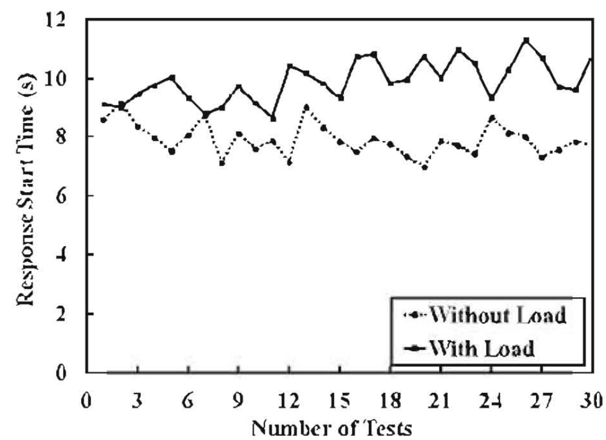

Figure 11: Starting time of electrical generator vs number of trials (LPG).

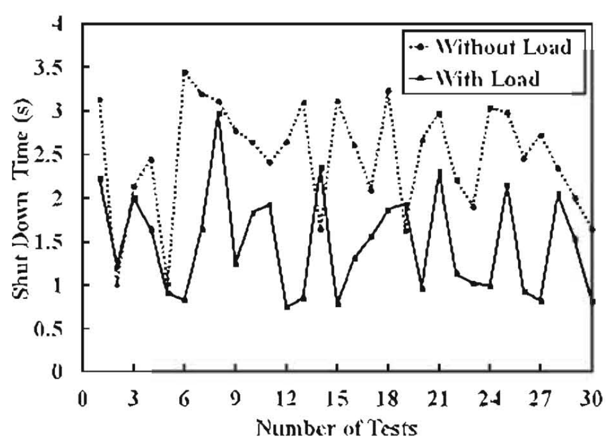

Figure 12: Shutdown time of electrical generator vs number of trials (LPG).

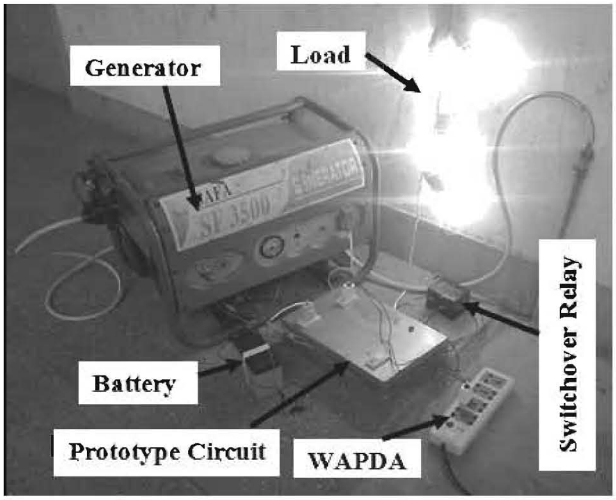

Figure 13: Prototype circuit testing with applying load to generator (in NG).

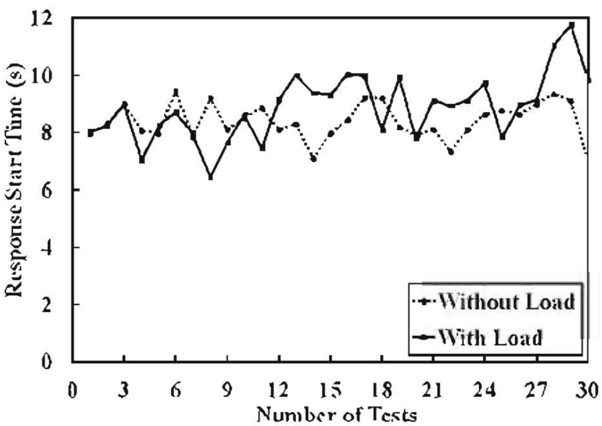

Figure 14: Starting time of electrical generator vs number of trials (in NG).

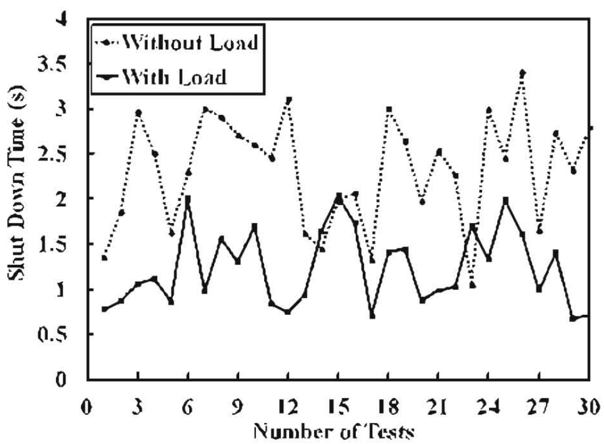

Figure 15: Shut down time of electrical generator vs number of trials (in NG).

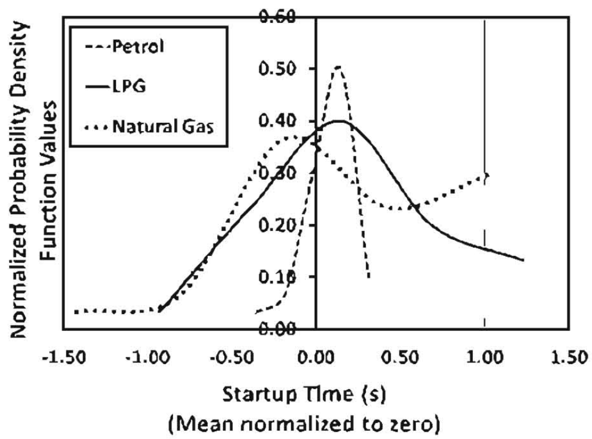

Figure 16: The probability mass function for the startup time (Zero Load) of electric power generator using petrol, LPG and natural gas as fuels.

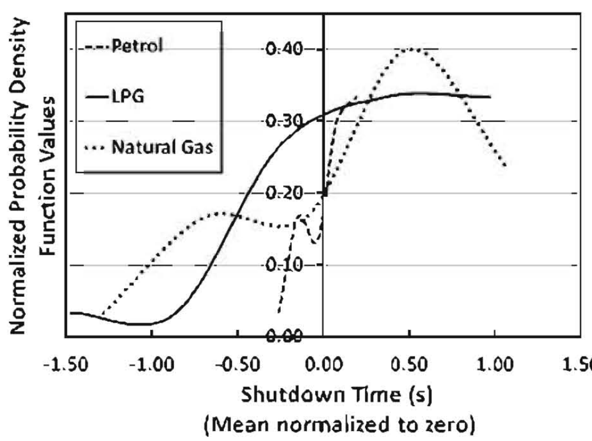

Figure 17: The probability mass function for the shut-down time (Zero Load) of electric power generator using petrol, LPG and natural gas as fuels.

CONCLUSIONS

An intelligent startup and shutdown system for household generators has been developed and tested using three different types of fuel (petrol, Liquefied Petroleum Gas and Natural Gas). In petrol and without any load connected to the generator the mean startup time is 3.15 s and mean shutdown time is 2.31 s. However, when 500W load is applied, mean values obtained for startup and shutdown times are 3.38 and 0.90 s respectively.

For liquefied petroleum gas and during unloaded condition, the startup and shutdown times have mean values of 7.9 and 2.48 s respectively. Whereas, with load, mean values for startup time is 9.91 s and that for shutdown time is 1.49 s. When the generator is operated on natural gas and under zero loading, the mean value for startup and shutdown times are 8.4 and 2.32 s in contrast to 8.9 and 10.23 s respectively when load is connected to the generator.

The experiments have shown that the performance of the system is best in Petrol as a fuel in electrical generator, as generators are specifically designed for Petrol.

As a measure to further improve the developed system, it is recommended that overload protection be incorporated into the design and a mechanism to control the flow of fuel, especially natural gas, be provided so that the number of trials to get the generator started is reduced in case of varying gas pressure on the utility line.

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