

An Electronic Protection Unit for Diesel Engine Standby Generators

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Abstract

Today diesel engine-driven standby generators for backup power supply have been adopted for residential, commercial, and industrial use—especially in some developing countries where power from the utility company is highly erratic. Although many of these generators function well in operation, certain engine conditions, such as low oil pressure, high oil and water temperature, abnormally high speed, etc., could lead to malfunction, failure, or complete breakdown of the engine. Therefore, the focus of this work is to present the implementation of a simple, but effective electronic protection unit (EPU) capable of mitigating the adverse effect which may arise as a result of these conditions. It is composed of two major sub-circuits—the main protective sub-circuit and the timing sub-circuit—realized using a combination of passive and active components. Unlike the common electrical relay-based protection system, this unit has an additional advantage of being able to keep the fault-indicating system of the generator working even after engine shutdown, thereby facilitating fault tracking. The unit has been tested on a diesel engine-driven generator and found to function satisfactorily. The test results are shown.

Keywords: diesel engine, engine fault, protection, standby generator

1. Introduction

The use of standby generators as backup electric power sources has become prevalent. Particularly, many continuous running industries that could not afford power failure due to sensitivity of their plants and machines operate continually on high-capacity diesel engine generators. Diesel engine is normally protected against costly damage when an abnormal condition (fault) occurs. It has a protection unit which is required to recognize the abnormal condition and respond by shutting down the generator faster than the operator would. The quality and reliability of a protection unit are very essential, as the degree of protection is only as high as the quality of the protective device used. Besides, the protection unit must not malfunction to initiate a false alarm, thereby tripping the generator unnecessarily.

Most diesel engine generators have their protection systems installed on them from the factory. These systems are electrically wired with relays, and, therefore, are prone to malfunctioning that ranges from cable breakdown, relay failure, and weak electrical contact which may falsely trip the engine. More importantly, during a fault condition, which causes the generator to shut down, this type of protection system makes the fault indicator for the particular fault to come on and go off as the engine completely shuts down and the low oil pressure indicator comes on. Because this system lacks the ability to retain the fault indicator after the engine has shut down, it takes a longer time to troubleshoot the fault, which ultimately leads to a longer generator downtime.

This paper presents the development of an electronic protection unit for diesel engine standby generators, which adequately caters for the drawbacks of the electrically wired protection system. It also has the advantage of functioning in redundancy with the factory installed protection system. The development involves design and building of a main circuit to shut down the generator under abnormal conditions such as low oil pressure, over speed, high water temperature and high oil temperature, which also has the ability to retain the actual fault indicator; design and building of a timing circuit to delay the low oil protection circuit for about 25seconds to allow the engine pressure build up before the low oil protection is armed or engaged; and a rugged, portable casing for the circuits. The rest of the paper is organized as follows. Section 2 presents a review of diesel engine protection, while Section 3 describes the operation and design of the protection unit circuits. Section 4 highlights implementation and testing, and conclusions are drawn in Section 5.

2. Review of Diesel Engine Protection

The protection system of a diesel engine-driven generating set is aimed at preventing costly damage to the generator in the event of a mechanical or electrical fault. The diesel engine is protected typically against low oil pressure, over-speed, and high oil temperature and water (coolant) temperature. The protection unit is designed to recognize any abnormal condition within the engine through individual sensors and respond to shut down the engine by operating the shutdown equipment which is either fuel shut-off solenoid or air shut-off valve (Detroit Diesel Allison). The block diagram of a diesel engine protection system is shown in Figure 1.

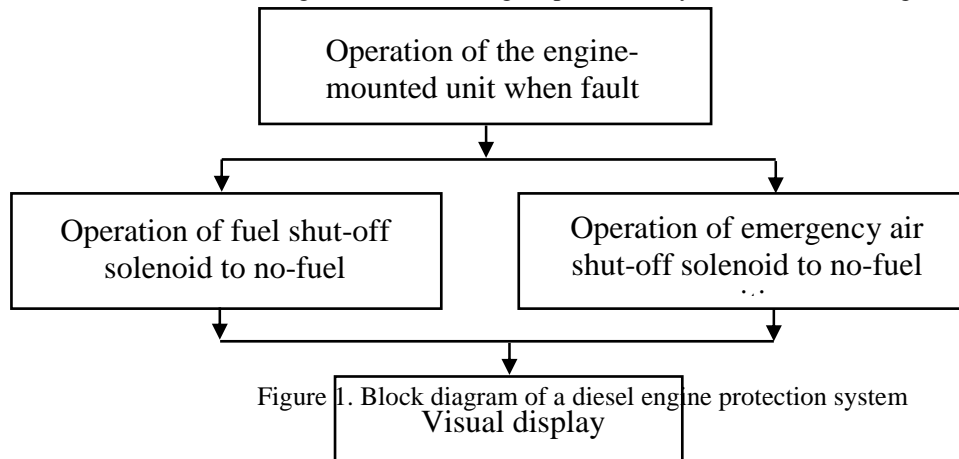


Figure 1. Block diagram of a diesel engine protection system

The diesel engine is protected against four major and minimum number of engine abnormal conditions. These conditions are;

- Low Oil Pressure.
- High Oil Temperature.
- High Water Temperature.
- Over-Speed.

2.1 Low Oil Pressure Protection

Basically, lubrication is essential to reduce friction, wear and tear, and to prevent engine seizure. Therefore, its failure has multiple effects on the engine. They are:

- Wear between the crankshaft journals and the bearings (main/connection rod) lead to engine knock.
- Wear between the piston and cylinder wall, which will cause high oil consumption.
- Wear between valve stem and guide that leads to malfunctioning of the engine.

To protect the engine from all these effects of low oil pressure a pressure sensing device (pressure switch) is used to sense low oil pressure fault and engage the protection circuit to shut down or trip the generator.

2.2 High Oil Temperature Protection

High oil temperature fault on generator is very dangerous as high temperature of the lubrication oil leads to low viscosity of the oil within results in poor lubrication that can make the engine to knock. Therefore, to protect the engine against high oil temperature a temperature switch is used to arm the protection circuit and shuts down the engine when the temperature exceed the normal running temperature as specified by the manufacturer.

2.3 Over-Speed Protection

Over-speed is possible through some abnormal condition for an engine to reach a speed above its normal operating range, which would cause the generator to deliver higher frequency than desired. Operating the generator above its allowable speed, could also cause the generator to "throw" its windings. Therefore, a reliable over-speed protection device must be used. In most cases, the tachometer switch is used and some engine uses magnetic speed pick up or a frequency relay. The normally open contacts are connected to the protection system. In case of over-speeding on the engine, the contacts close to engage the protection system and shut down the engine. (Detroit Diesel Allison)

3. The Operation and Design of the Main and Timer Circuits of the Protection Unit

The protection unit is designed for use on diesel engine generators irrespective of its rating. The unit is designed to:

- Operate with 12 V DC from the battery of the generator.

- Display the fault that tripped or shutdown the generator.
- Retain the fault until reset is carried out.
- Operate reliably to avoid initiation of false tripping of the generator.

The operation of the protection unit is explained based on the single stage diagram as shown in Figure 2.

As the unit is switched 'on' the green LEDs (D20 and D21) in the timer circuit, lights signifying that the protection unit is powered and that the timer is 'On' and goes off as the timer times out, to arm the low oil pressure protective circuit. Now, assuming, the oil pressure switch 'S' closes due to low oil pressure fault. This completes the voltage path and fires the thyristor Q 1. The relay is supplied and energizes to open the supply to the shutdown devices to trip the generator. D2 (red LEDs) comes on to display the fault that tripped the engine. Each of the protective circuit is to operate independently without affecting each other. Once a fault is displayed by the fault LEDs, no other fault LEDs should come on. Diode D6 is connected to separate the fault LEDs from each other to ensure that only one comes up at a time.

The gates of each protective circuit need to be separated from each other so that only one thyristor is fired per time. Diode, D11, is connected to realize this separation from each gate.

The protection unit could be prone to ignite false alarm that could trip the generator when there is no fault due to accidental closure of the protective switch and electric field from the power line (or alternator). To check this problem, a low pass filter is incorporated in the gate circuit of the thyristor to damp the ac current interference from the power line and thus avoiding erratic triggering of the thyristors. The fault displayed remains until the reset is carried out via the reset button. The main circuit consists of four identical stages of the type shown in Figure 2.

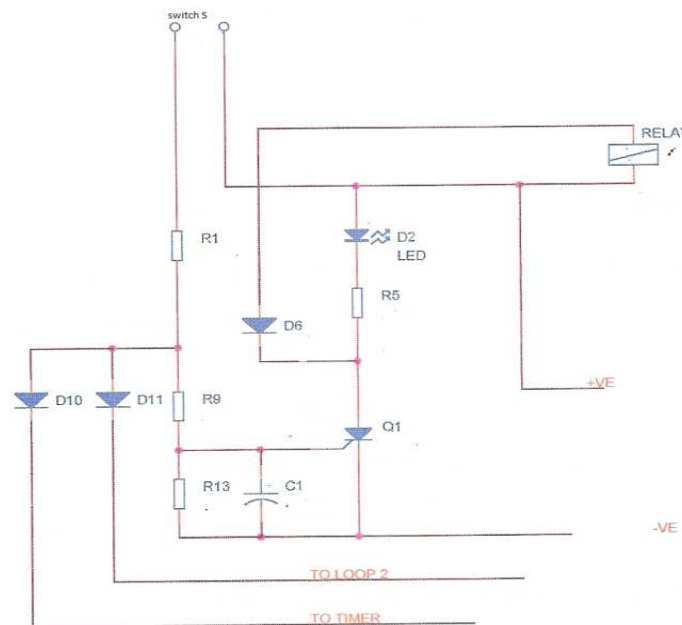


Figure 2: Main Circuit diagram for a single stage protective circuit.

3.1 Main Circuit (MC)

The switch 'S' has an open contact, which closes anytime it sensed any fault. The switch is a device that picks the signal that actuates a given stage. The sensed signal may either be low oil pressure, over-speed, high water temperature, and high oil temperature faults.

The Thyristor is used to turn on the tripping process in this project. The thyristor used have the following Data: CI06M: $V_{gt} = 1.0V$, $I_{gt} = 0.5mA$; $I_T = 2.5A$, $V = 60V$ (Farnell 2000). The choice of this thyristor was made because of its low gate current. Its minimum gate current (I_g) is about 0.5mA. This allowed the circuit to be designed with reasonable small sizes of components.

The Main Circuit consist a potential divider circuit. The current expected to flow through the potential divider is set at 2mA. Since the minimum current that can trigger the thyristor is 500mA. Higher current is better for the system to avoid erratic firing of the thyristor due to interference from the alternator or otherwise. This also helps to use small size of resistors (0.25W). Larger current means large wattage and bigger sizes of components.

To avoid accidental firing of the thyristor due to electric field interference from the power cable, the alternator

and momentary closure of the protective device switch, a capacitor is connected to offer a time delay of about 0.3 seconds before the thyristor could be fired. Diode D11, is a multipurpose diodes used to separate all the gates from each circuit and will not allow any circuit to come on, once one is already on. Before the relay is operated, these diodes are open circuited through the normally open contact of the relay but as soon as the relay operates, the contact closes to connect the diodes to the ground thereby draining all the current. For safe operation and long life of the LEDs a current limiting resistor must be connected in series with the LED or it's supplied from a constant current source.

The relay is normally close contact and is connected to through fuel solenoid valve and / or the air solenoid valve. So anytime it operates, the contact opens and the supply to the solenoids are cut off. Hence, supply of fuel and / or air stops thus stopping the engine (Rayer 1977). The relay is a magnetic device in which energy is stored in the field surrounding the coil, when current to the coil is interrupted, the magnetic field collapses, and produces a back electro-magnetic force (EMF) or Voltage. The back e.m.f. may damage the coil and associated items. This can be suppressed by connecting a diode across the relay coil. This diode conducts when the reversed e.m.f. appears, so suppressing it (Uppal 1982). Diode D 1 is connected across the coil of the relay to suppress the back e.m.f. resulting from the operation of relay.

After the system is operated due to fault, the reset must be carried out otherwise the generator will not start. Reset is achieved by momentary cutting off the supply to the system. A close contact push button is used for this project.

3.2 Timer Circuit

LM 555 IC Timer is used because it is suitable for mono-stable operation. In the mono-stable mode, this IC timer is capable of producing accurate delays over a very wide range. This versatile device provides effective solution for many timing and pulse circuit applications. This IC timer is reliable, cheap and easy to use. Its greatest advantage is that it provides accurate timing. It is configured as a mono-stable multi-vibrator where the output a pulse and can be used to delay the protection circuit. The 555 IC timers have the following features: low external components, wide operating voltage range, and low power and supply current. Timing formula for mono-stable operation is $T = 1.1 R_A C$ (sec.), where C = capacitance in farads, and R = resistance in ohms (RS Electronics).

The low oil pressure protection circuit requires a time delay timer to allow the engine pressure build up before the protection circuit is armed. This timer could be used for all the protection circuit but only the low oil pressure protection circuit is connected in this project. The designed timer circuit is as shown in Figure 3.

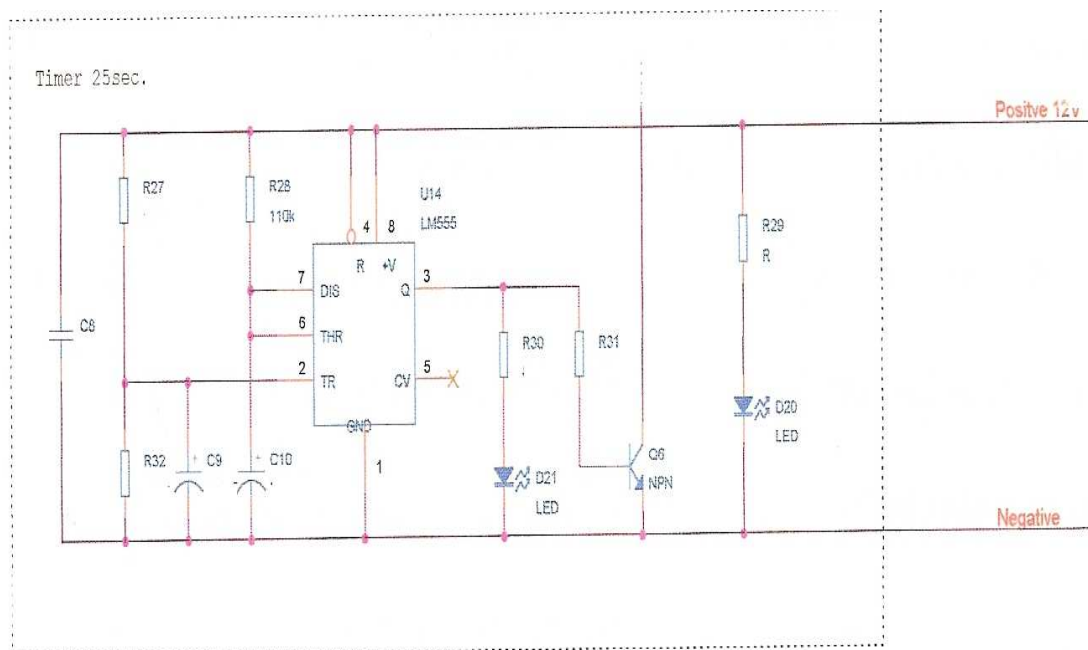


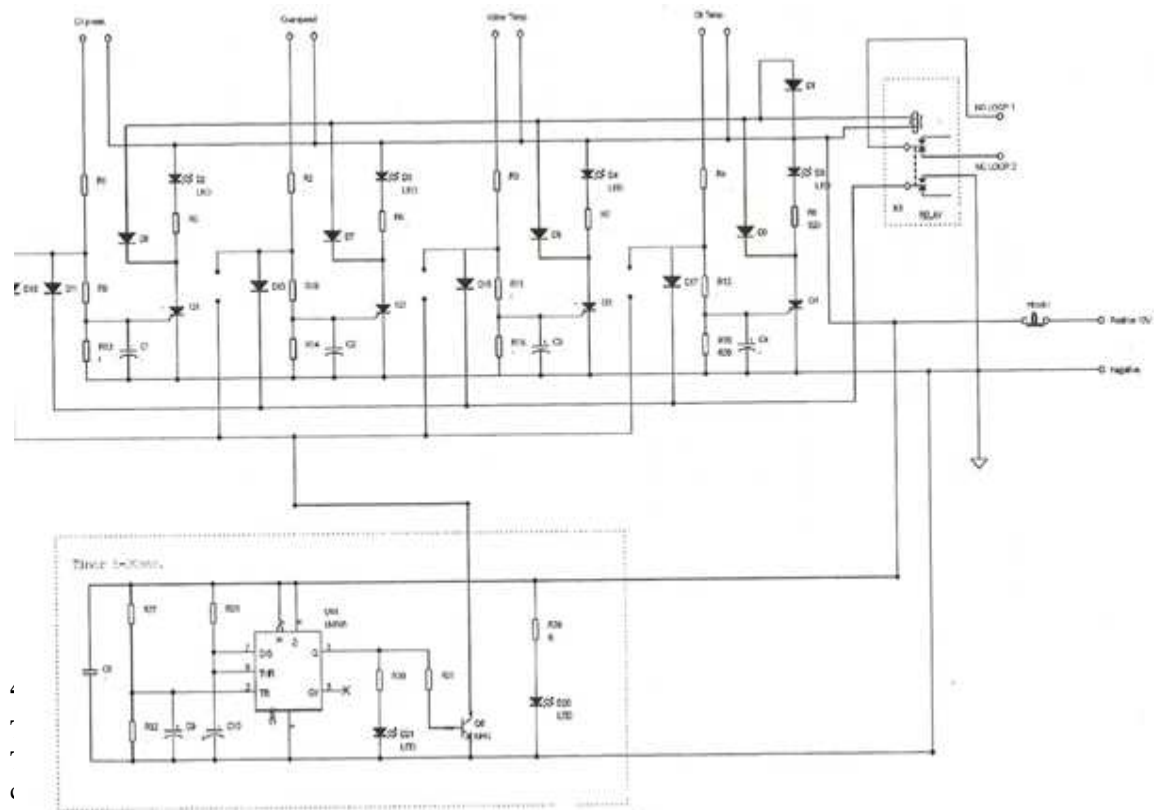
Figure 3: Timer circuit

The triggering pulse is applied to pin 2 via resistors (R27 and R32) and capacitor (C9) arrangement as shown in Figure 3. This is to allow the internal state of the flip flop to set at charging state with a pulse of about 0.1 second and to set the capacitor voltage to a value higher than 1/3 of supply voltage (set at 6V). The resistors are to allow quick discharge of the capacitor. The Capacitor C10 charge through R28 and it is called the timing capacitor. The

desired time is 25 seconds.

The output voltage is the same as the supply voltage. It is referred to as high and when there is no output it is referred to as low. At high state the switching transistor offers low resistance and drains the current from the low-pressure protection circuit by so doing the circuit is disarmed until the time lapses. After time lapses the timer output is said to be low. At this state, the switching transistor offers high resistance to the flow of current. Hence, low oil pressure protection circuit is armed.

The transistor use for this switching is BC337 with base current of 1.2mA. Therefore, current limiting resistor (R31) is connected at the base.



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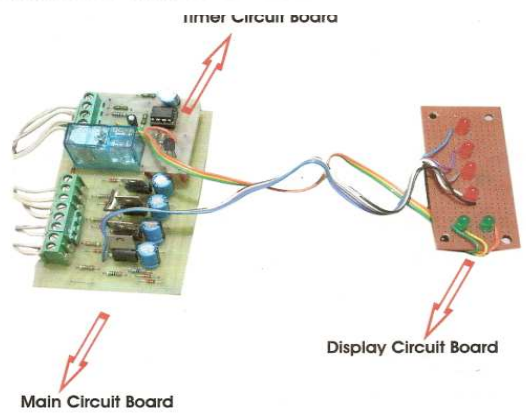


Figure 5: Printed Circuit Board

The display board is the fault and operational mode indicators. LEDs are used and implemented on a vero board as shown in figure 5 above. Red colored LEDs diagnosis faulty conditions while the green LEDs shows operational mode.

The entire project is housed in a rugged but nice metallic box as shown in figure 6a and 6b.

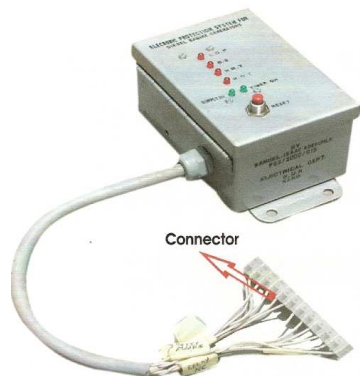
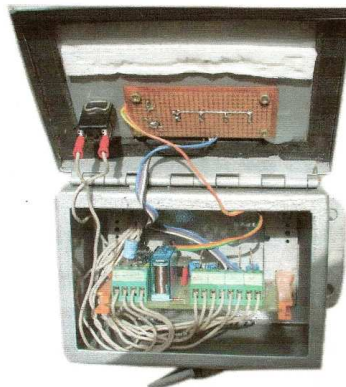


Figure 6a: Complete Metallic Casing



b. Internal Arrangement of the PCBs in the casing.

5. Testing of the Protection Circuit

The protection circuit was first tested by applying 12V (D.C) to the supply as indicated 011 the circuit diagram. Then a piece of wire (jumper wire) was used to short the protective device for high water temperature (temp. switch). The LED - D4 came on because the relay operated with its fault indicated. Other protective devices (over-speed, low oil pressure, and high oil temperature switches) were shorted one after the other to know if any can ignite any of the faulty LEDs. The result was that none was able to come on; therefore, the system is working as designed. The fault Light remained until the reset button was pressed.

Another test that was carried out is the test that reveals the minimum operating voltage of the protection unit. This is necessary because, at starting of a generator the battery voltage often goes down due to the starting load. Also batteries can run down to a voltage level that cannot operate the unit. This test was carried out by varying the 12V (D.C) input voltage when one of the protective devices was shorted. It was discovered that the unit would operate until the voltage drops to about 6.0V.

The timer circuit was also tested separately to confirm that the time delay is as desired (25 seconds). 12V (D.C) was fed to the timer circuit and a stopwatch was used to check the time. The time by the stopwatch is approximately 25seconds. The Timer operation and timing is satisfactory.

6. Functional Test

The complete protection unit was installed on 1500-KVA Blackstone diesel engine generator to check its operational characteristic. Table 1 shows the connections of the protection unit as installed on the generator and cables from the protection system are numbered and marked as in table 2.

Table 1. Connection of the Protection Unit Installed On the Generator.

1(+)	2(-)	3	4	5	6	7	8	9	10	11	12
SUPPLY		NC. CONT.		SW1		SW2		SW3		SW4	

Table 2. Cable markings by number

CABLE NO:	CONNECTION
1 - 2	Supply (1 is positive, 2 is Negative)
3 - 4	Relay Contact (Normally close)
5 - 6	Sw 1- Oil Pressure Switch
7 - 8	Sw2 - Overspeed Switch
9 - 10	Sw3 - Water temperature Switch
11 - 12	Sw 4 -Oil Temperature Switch

After connection to the engine, the protections were tested one after the other by shorting the protective devices (switch) to ensure, and confirm if the engine will be shut down. The result was satisfactory as the engine was shut down on each test carried out.

The electronic protection unit was left on the engine for about two weeks and during this period; the protection system tripped the engine on high water temperature fault and was indicated by the LED. On troubleshooting, it was discovered that one radiator fan was burnt, and this lead to high water temperature, which closes the temperature switch hence shut down the Engine. In addition, within this period, the protection unit did not raise any false alarm or signal. Therefore, it could be said that the circuit is adequately free from interference from the power cable or the alternator.

7. Conclusion

The major aim of this study was to design and implement an electronic protection unit (EPU) for diesel engine generators, and has been achieved as the test result shows that it operated as intended. This electronic protection unit is reliable and able to discriminate the faults initiating shut down on diesel engine generators and also retain the fault indicator until a reset is made. Due to the high reliability electronic components offer, solid-state semiconductor devices were used in implementation of this electronic protection unit for diesel engine generators.

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