Replacement of Relay Box in Dump Truck Using Microcontroller and Solid State Power Devices

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***Abstract*—**In this paper, a method is proposed to overcome the problem of unconditional switching of relays in a Dump Truck. A Dump Truck has a Relay box containing Relays, which act as an electro-mechanical switch to control various parameters of the Dump Truck. These electro-mechanical switches (Relays) undergo unconditional switching due to mechanical vibrations caused by the uneven terrain of the mining areas. These relays are not soldered, instead they are plugged into the relay base. This is for ease of replacement of a relay if damaged. In some cases, the relay may jump out of its socket due to the vibrations. To overcome this problem, these relays are replaced with solid state power devices such as MOSFETs which are controlled by a Microcontroller.

Keywords*—Relay, Dump Truck, Solid State Power Devices, MOSFETs, Microcontroller.*

I. INTRODUCTION

The equipment on which this paper is based is BH60 Dump Truck. It can handle 60 tons of payload. It has a relay box which controls 26 electrical parameters of this truck. This equipment consists of components like:

1. A 24V Battery and an Alternator which act as source.
2. Switches like the Battery Cut-off switch, Engine Shut-off switch etc…
3. Protection system like the Miniature Circuit Breaker (MCB).
4. Set of wires (wire harness) which distribute power to all the components existing at various locations of the equipment.
5. Logical components (relays) for controlling various loads of equipment.
6. Switches and sensors like pressure and temperature actuated switches, hand operated switches etc…
7. Timer circuits to operate a load in a defined time frame after an event occurs.
8. Flashers to supply power to load intermittently.

These are some of the parameters which are currently controlled using electro-mechanical switches (relays). They are prone to malfunction due to vibrations in mining areas. So a technology has been implemented to overcome this problem by using solid state power devices in place of electro-mechanical switches. In the existing system installed on the BH60 Dump Truck the following parameters work in either one to one logic (one input and one output) or combinational logic (several input and one output).

1. High Beam Headlight and Headlight Auto Dimmer work in combinational logic.
2. Steering Hydraulic Pressure Bleed Down (SBDR), Engine Shut-off and Engine Control Module (ECM) work in combinational logic.
3. Reverse Blinking Lights and Reverse Gear work in combinational logic.
4. Starting of Engine and Neutral Gear work in combinational logic.
5. Body Up, Hoist and Hold in Range work in combinational logic.
6. Pay Load Monitoring System (PLMS) and Dump Brake work in combinational logic.
7. Low Beam Headlight, Parking Brake, Stop Lights, Central Warning, Horn, Battery Cut-off, Filter Clog, Over Speed, Check Transmission, CEC-2 Power and Flashers work in one to one logic.
8. Power Window works in Motor Logic (two input and two output connected to a motor).

II. EXISTING SYSTEM ANALYSIS

The analysis of the existing system includes a detailed survey on the floor plan and relay circuits of BH60 Dump Truck.

A. Floor Plan

The block diagram in Fig. 1 shows all the electrical components of the BH60 Dump Truck and the electrical connections to the respective operational blocks. It consists of Cabin, Transmission block, Chassis Block, External loads (lamps, buzzers), Relay box.

All these blocks are connected to Cabin through the connectors CN 1 to 5.

1. Connector 1 (CN-1) connects Cabin with Internal Loads in Chassis Block.
2. Connector 2 (CN-2) connects Cabin and Transmission block.
3. Connector 3 (CN-3) connects Cabin with the External Loads.
4. Connector 4, 5 (CN-4, CN-5) connects Cabin and the Relay Box.

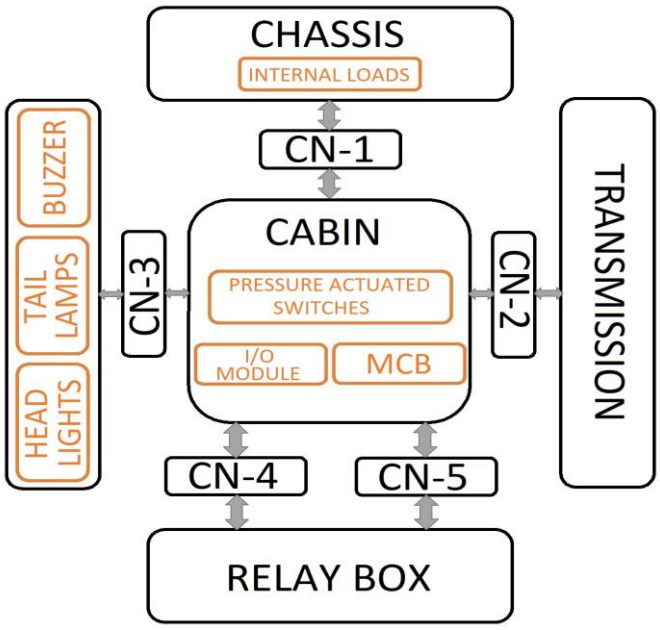

Fig. 1. Floor plan of BH60 Dump Truck

1) The Cabin

The cabin is the inside part of the truck, which is utilized by the driver of the Dump Truck. It connects the entire system through the connectors for the extensive use of the power supply. It consists of MCB that acts as a fuse to the battery (which is charged by an alternator) and supplies power to the entire system. The MCB protects the system from any sudden high voltage which might be generated by the alternator. The cabin contains different types of switches like manual switches, pressure actuated switches, and temperature actuated switches. Manual switches are operated by the driver to control parameters such as headlights, tail lamps, indicators. The pressure actuated switches get actuated automatically when the fluid used in the hydraulic gets clogged and the pressure reaches its threshold. The temperature actuated switches get actuated by the variations in the temperature around the system. The I/O module is a 42 pin device of which, 28 pins are reserved for digital signaling parameters and the rest 14 pins are for analog signaling parameters. This module indicates errors in the system in the form of buzzers and through LED display present in cabin.

2) The Transmission Block

The power to the transmission block is supplied through the connector CN-2 from the cabin. This block is responsible for the manual transmissions like the gear switching and steering.

3) The External Loads

The external loads consist of headlights, tail lamps, brake lights and buzzers. The various power supplies to these loads are connected through the connector CN-3 which is interconnected with the cabin.

4) The Chassis Block

The chassis is connected to cabin through the connector CN-1. The chassis block contains internal loads which are present inside the engine. It consists of loads like Filter clog sensor, which monitors the circulation of fluid in hydraulics.

5) The Relay Box

Relay Box is the main electrical part in the Dump Truck, where the problems arise. This project aims on replacement of the relay box with a suitable equipment which provides the same function as of the relay box but without its demerits. The main problem arising in the relay box is from the movement of the truck which causes the switching between normally open (NO) and normally closed (NC) points in the relays, causing undesired operations which may lead to severe accidents. To prevent such accidents, the relays are substituted with solid state power devices such as MOSFETs which are controlled using a microcontroller. All the functional blocks of the Dump Truck are connected to the relay box through the connectors CN-4 and CN-5.

B. Circuits in the Existing System

Below are some of the circuits used in the existing system.

1) Low Beam Headlight

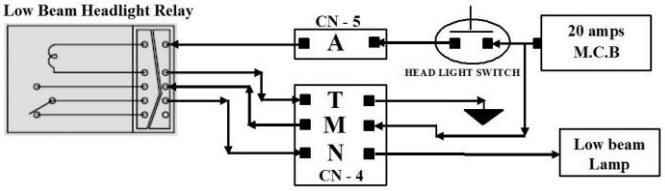

Fig. 2. Low Beam Headlight relay (one to one logic)

Fig. 2 shows the operation of Low Beam Headlight relay. When the headlight switch in cabin is pressed, the coil gets excited and the low beam lamp is connected to the 20A MCB.

2) Combination of SBDR, Engine Shut-off, Engine ECM

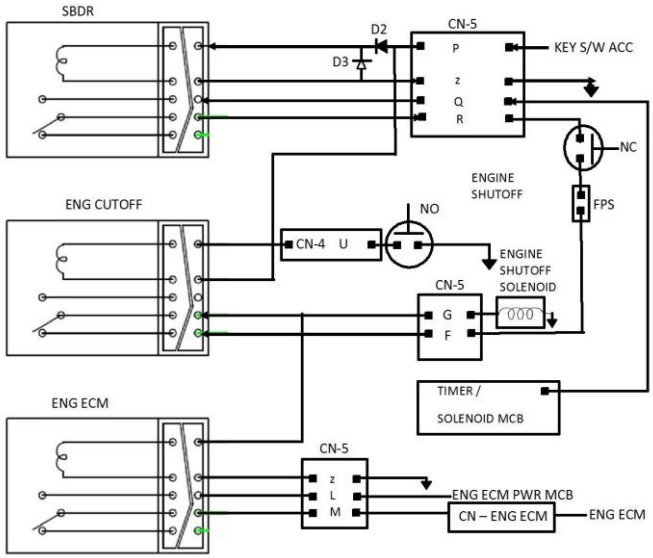

Fig. 3. SBDR, Engine Shut-off, Engine ECM relays (combinational logic)

Fig. 3 shows the operation of SBDR (Steering Hydraulic Pressure Bleed Down Relay), Engine Shut-off, Engine ECM relays. The engine doesn't switch on if the key is not cranked or if the Engine Shut-off switch is pressed or if the Fire Protection System (FPS) senses fire in the cabin.

III. PROPOSED SYSTEM DESIGN

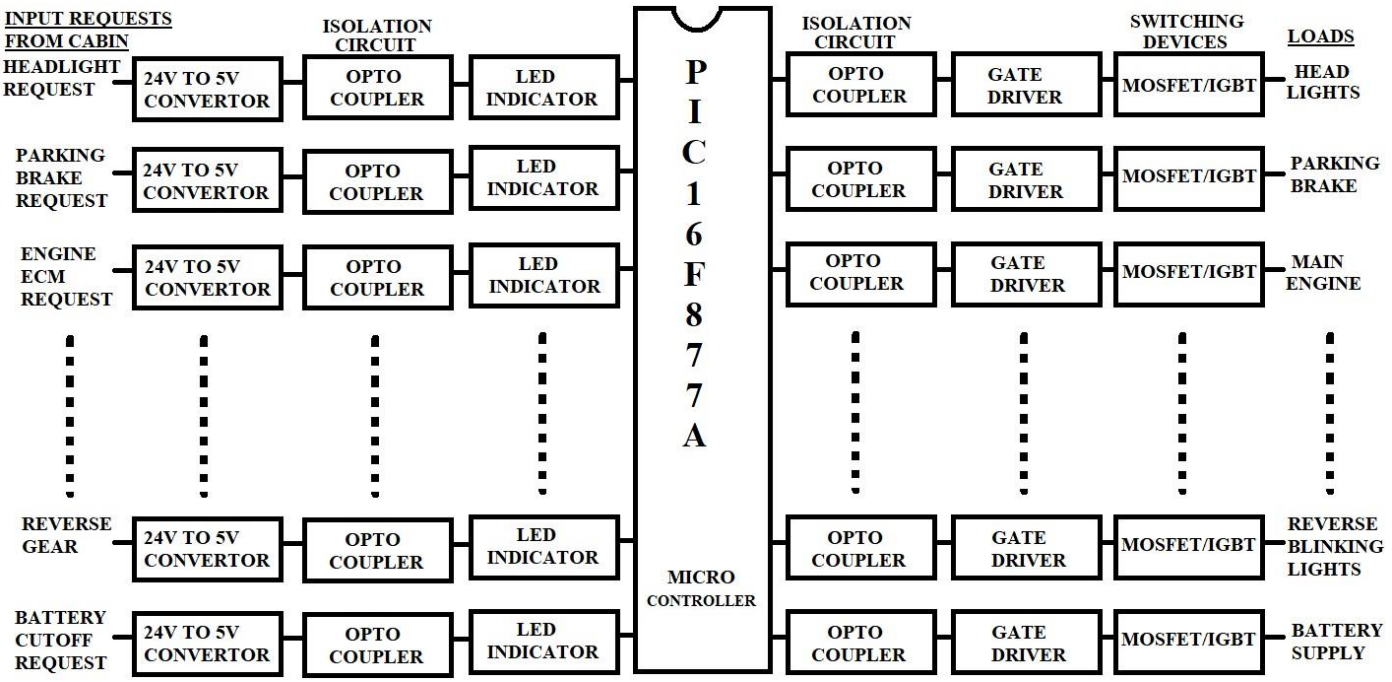

Fig. 4. Detailed Block Diagram

A. *Detailed Block Diagram*

Fig. 4 shows the detailed block diagram of the relay box substitute.

1. The voltage input to the circuit is from the connectors and as per the parameters request, input is given to its respective voltage converters.
2. Here the use of voltage converters is to reduce the direct dc supply to the microcontroller which can withstand current in the range of few milli-amperes. So the 24v input is converted to 5v. Further it is supplied to an optocoupler for current isolation.
3. These input signals are then fed to the PIC-16F877A microcontroller through the LED indicators which are used for input error detection.
4. The microcontroller then accordingly operates on the logics such as single logic, combinational logic, motor logic required to the external loads and sends the resulting signal to the output side optocoupler.
5. For the conduction of the solid state power devices, the gate drivers need to retain the active pulse from the optocoupler with a minimum range of few volts.
6. Then the resulting signals from the power devices are fed accordingly to their respective loads as per the input request.
7. In similar the way, 26 parameters such as parking brake request, engine ECM request, reverse braking request, horn request, engine Cut-off request etc… need to be monitored and processed in the microcontroller.

B. *Detailed Design*

There are 3 circuits which have been used in the modified circuitry of this project. They are explained in detail below.

1) Gate driver circuit for P channel and N channel MOSFET

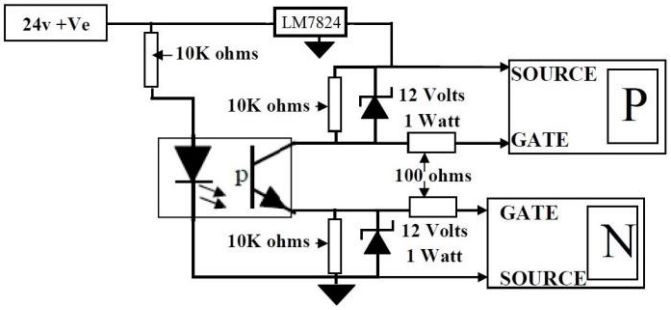

Fig. 5. Gate driver circuit for P channel and N channel MOSFET

The circuit shown in Fig. 5 uses an optocoupler to drive the gate of P channel and N channel MOSFETs. Here an optocoupler is used so as to isolate the output side from the input side if any sort of malfunction of load occurs. The BH60 Dump Truck has a 24V battery. A 10K ohm resistor is used to limit the current entering the optocoupler. Due to this current, LED turns on and the NPN transistor is actuated. The alternator of the Dump Truck may produce voltage more than 24V at times when the vehicle is at high speed. Hence a voltage regulator (LM7824) is used to maintain a constant voltage level across the circuitry and safeguard it. The 24V signal is divided equally into 12V signals using two 10K ohm resistors. These 12V signals are fed across the gate and source terminals of P channel and N channel MOSFETs. Though

both P channel and N channel MOSFETs have been shown in the Fig. 5, only one type is used based on the type of load it is connected to. So when NPN transistor of optocoupler switches on, 24V appears at the source of P channel MOSFET, 12V appears at the gate and a there is a difference of -12V across gate and source of P channel MOSFET. Due to this the MOSFET is actuated and the load which is connected to the drain terminal of the P channel MOSFET is driven by the 24V signal which comes from the source terminal. The operation of N channel MOSFET is similar to the P channel MOSFET, but source terminal is grounded here due to which a 12V signal appears across the gate and source of the N channel MOSFET. Zener diodes are used across the MOSFETs so that constant voltage is maintained across them.

2) 24 Volts to 5 Volts logic converter circuit

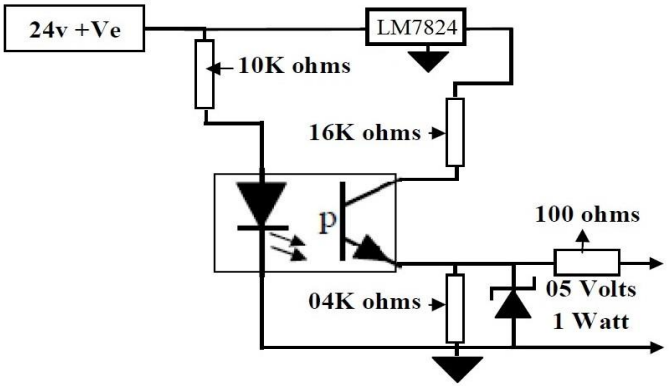

Fig. 6. 24 Volts to 5 Volts logic converter

The circuit shown in Fig. 6 is for conversion of a 24V signal into a 5V signal which can be given to a microcontroller as an input. The operation is similar to the previous circuit whereas the only change is that instead of two 10K ohm resistors, a 16K ohm and a 5K ohm resistor is used. Due to this the 24V signal is divided into 19V and 5V. This 5V signal is given to the microcontroller.

3) Microcontroller driven load circuit

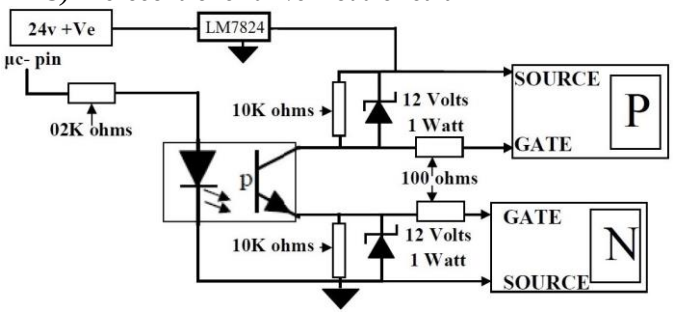

Fig. 7. Microcontroller driven load circuit

The circuit shown in Fig. 7 is for driving heavy loads of the BH60 Dump Truck by receiving the signal from a microcontroller pin. The operation of this circuit is entirely similar to the operation of circuit in Fig. 5, with the only change being that a 2K ohm resistor is used instead of a 10K ohm one. This is because the output signal from a microcontroller pin is of less current when compared to signal from a 24V battery. So a 2K ohm resistor is sufficient to switch on the LED of the optocoupler without damaging it.

C. Designed Circuits

1) Low Beam Headlight

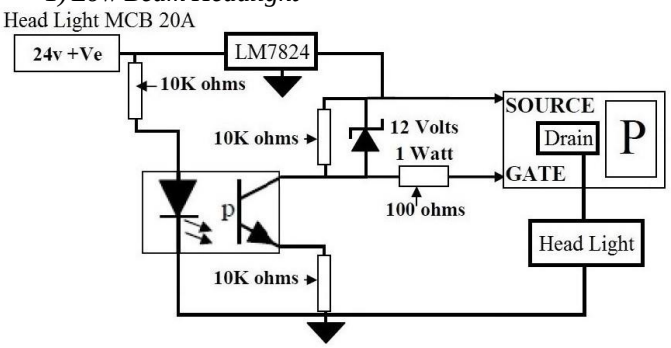

Fig. 8. Low Beam Headlight circuit (one to one logic)

Fig. 8 shows the designed circuit for Low Beam Headlight. When the headlight low beam switch is pressed, the 24V battery gets connected and the LED of the optocoupler glows. Due to this NPN transistor of the optocoupler is actuated which in turn actuates the P channel MOSFET. Hence the 24V signal connected to the source appears at the drain side and turns on the headlight.

2) Combination of SBDR, Engine Shut-off, Engine ECM

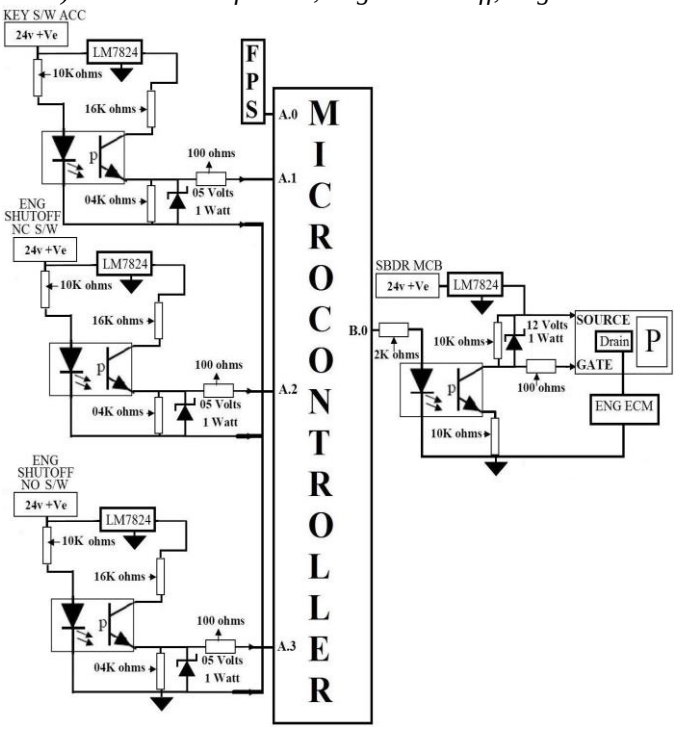

Fig. 9. SBDR, Engine Shut-off, Engine ECM circuit (combinational logic)

Fig. 9 shows the designed circuit for SBDR, Engine Shut-off and Engine ECM request. The input part shows the circuit for conversion of a 24V signal into a 5V signal which can be given to a microcontroller as an input. The microcontroller processes the input signals which are key switch, NC Engine Shut-off switch and NO Engine Shut-off switch and gives the output accordingly. The output part shows the circuit for driving heavy loads of the Dump Truck by receiving the signal from a microcontroller pin.

D. *Flowchart*

Fig. 10 shows the flowchart of the methodology used to control the neutral gear, starting of engine, key switch, NC Engine Shut-off and NO Engine Shut-off switch parameters which monitor the ignition of the engine.

IV. IMPLEMENTATION RESULTS

A. *Low Beam Headlight*

This circuit possess one to one logic, due to which it doesn't use the microcontroller. When the headlight switch in cabin is pressed, the coil gets excited and the low beam lamp is connected to the 20A MCB.

TABLE I. TRUTH TABLE OF LOW BEAM HEADLIGHT

Low Beam Headlight Switch (Input)	Headlight State (Output)
1 (Switch Pressed)	1 (Headlight On)
0 (Switch not Pressed)	0 (Headlight Off)

B. *Combination of SBDR, Engine Shut-off, Engine ECM*

This circuit possess combinational logic with the use of microcontroller. The engine should not switch on, if anyone of the following conditions is true.

1) If the key is not cranked.
2) If an error signal is received from Engine Control Module
3) If the Engine Shut-off switch is pressed.
4) If the Fire Protection System (FPS) senses fire in the cabin.

TABLE II. TRUTH TABLE OF ENGINE STATE

Conditions (Input)	Input State	Engine State (Output)
Key Crank	0	0
Engine ECM	1	0
Engine Shut-off S/W	1	0
FPS	1	0

V. CONCLUSION

This paper proposes an advanced method in which the usage of solid state power devices which are controlled by a microcontroller overcomes the problem of unconditional switching of relays. The problem of wear and tear of mechanical switches is solved. System complexity is also reduced since the number of wires used for connections are less. It is perfectly feasible as the microcontroller can be reprogrammed if there are any hardware changes in future. Since the hardware specifications are easily available in the market, cost of the final product is less, when compared to cost of relay box used in the existing system. Replacement of electro-mechanical switches with electronic ones make the Dump Trucks more efficient, safe and fault resistant. Due to the above advantages of this method, it can be applied in other vehicles which work under harsh conditions like mining areas.

ACKNOWLEDGMENT

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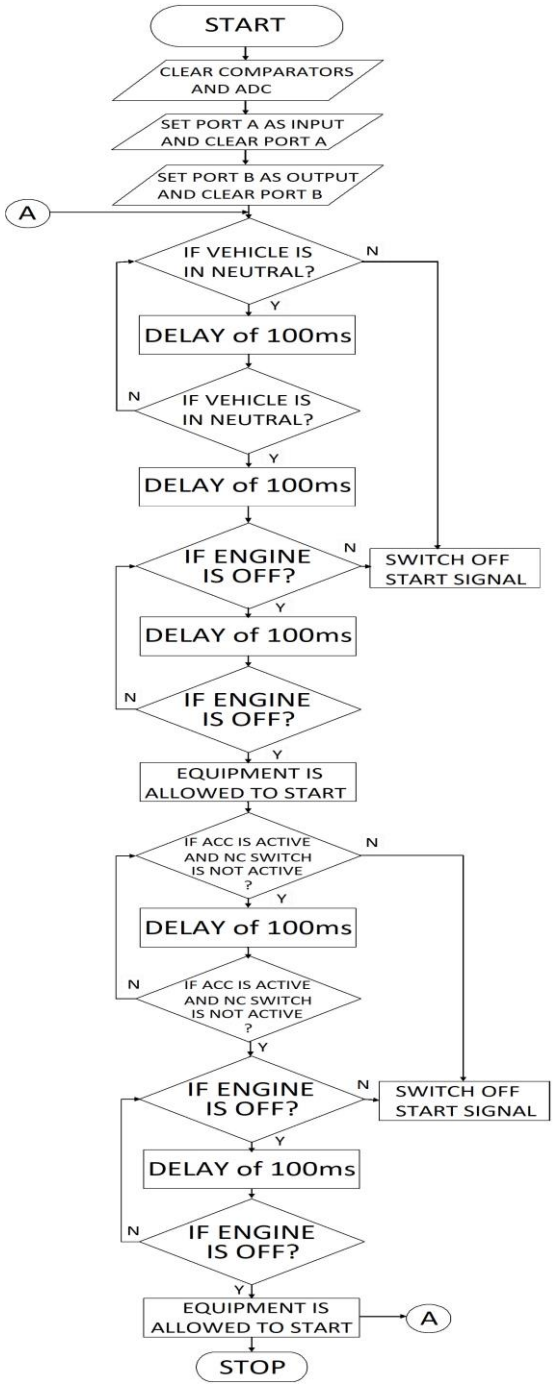

Fig. 10. Flowchart

REFERENCES

[1] Muhammad Ali Mazidi, Rolin D. McKinlay, Janice Gillispie Mazidi, "The 8051 Microcontroller and Embedded Systems Using Assembly and C", 2nd ed., India: Pearson Education, 2007.

[2] Mohan, Undeland, Robbins, "Power Electronics: Converters Applications and Design", 3rd ed., Media Enhanced, 2007.

[3] Muhammad H. Rashid, "Power Electronics: Circuits, Devices and Applications", 3rd ed., Pearson, 2003.

[4] Relay box to the Part No: 958-EG-02115 of BH60M Dump Truck, "The Improvisation of the Komatsu and Haulpak Design Meant for BH50M Dump Truck".