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Modified Failure Modes and Effects Analysis for Electric Vehicle Using Fuzzy Logic Tools

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Abstract

Use of an electric vehicle is increasing day by day. The role of different electrical and electronic components has become very important for increasing efficiency of electric vehicles. Power electronic inverter is one of them. In this paper, we have studied and discussed different types of fault /failure modes, the effect of failure and causes of these failures using the fuzzy FMEA. The parts considered in traditional failure mode and effect analysis (FMEA) for risk assessment are severity (S), occurrence (O) and detectability (D) of an item failure mode. As a result of the subjective and subjective nature of the information and to make the analysis more certain and sensible, an approach using fuzzy logic is proposed. This approach reduces the drawbacks of traditional FMEA and also removes some limitations. The fuzzy linguistic evaluation model has been created utilizing toolkit stage of MATLAB R2017.

Keywords: *-Electric vehicles, Fuzzy logic, Fuzzy rule-based method, FMEA method, Inverters, RPN.*

INTRODUCTION

The overall impact of the electric vehicle ultimately benefits the people. Compared to gasoline-powered vehicles, electric vehicles are considered to be ninety-seven percent cleaner, producing no tailpipe emissions that can place particulate matter into the air. Particulate matter, carcinogens

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released into the atmosphere by gas-powered vehicles, "can increase asthma conditions, as well as irritate respiratory systems" [1]. However, people are generally unexpected against technology changes such as; for e.g. electrification of the drive train. Thus disadvantages will also present in their minds, namely low range, electrical and electronic components safety, long charging time and high vehicle price [1, 2]. In an electric vehicle, electrical and electronic components are an induction motor, battery pack, power electronic inverter etc. The inverter is the brain of an electric vehicle and it is vital for the consequences of the high-performance electric vehicle with the extreme balance of variable speed, travelling range per charge and acceleration performance. The issue of reliability studies conducted for the two main components in the electric vehicle; i.e. electrical machine and power electronic inverter is considered. The reliability study of power electronic inverter has been the scope of research in the operation where reliability is an important issue. Such as uninterrupted power supply, megawatt rated variable speed drive system [3, 4, 5]. There are some meaningful faults:

- Transistors failure
- Gate drive pulse failure
- Inverter leg open
- DC link capacitor faults

A Failure Mode and Effect Analysis (FMEA) is a technical approach habituated to explain, analyze and wipe out a known or potential problems, errors etc from the systems, design, process and service properly before coming to the customers. The car business has since a long time ago utilized FMEA as intends to enhance consumer loyalty and decrease non-conformance. It is being proposed here a modified failure mode and effects analysis (FMEA) and knowledge base system (KBS) to estimate the hazard utilizing scores from specialists. Fuzzy logic system (Zadeh, 1987) is a name for the system that has an association with fuzzy concepts (like fuzzy sets and linguistic variables) and fuzzy logic. There is also reliability assessment protocol by conducting FMEA and identify the top failure modes [6].

We take some references for the FMEA methods and also fuzzy based FMEA applied on different components of electric vehicles or other systems.

ELECTRIC VEHICLE SYSTEM

The electric vehicle (EV) is propelled by an electric motor, powered by

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rechargeable battery packs, rather than a gasoline engine. From the outside, the vehicle does not appear to be electric. In most cases, electric cars are created by converting a gasoline-powered car. Often, the only thing that clues the vehicle is electric is the fact that it is nearly silent [5].

Under the hood, the electric car has:

- An electric motor.
- A controller (Inverter).
- A rechargeable battery.

The electric motor gets its power from an inverter and the inverter gets its power from a rechargeable battery. The electric vehicle operates on an electric/current principle. It uses a battery pack (batteries) to provide power for the electric motor. The motor then uses the power (voltage) received from the batteries to rotate a transmission and the transmission turns the wheels [3]. Four main parts make up the electric vehicle: the potentiometer, batteries, power electronic inverter, and motor. See Fig.1.

The below figure demonstrates the power flow in an electric vehicle, the DC power flows from the battery packs to the inverter which changed it into a variable AC control. Presently this variable AC control is given to the induction motor (Because of variable frequency voltage speed of the vehicle can control i.e. depends on inverter circuit). The induction motor offers torque to the transmission system. Finally, it's given to the wheel which produces traction in the electric vehicles.

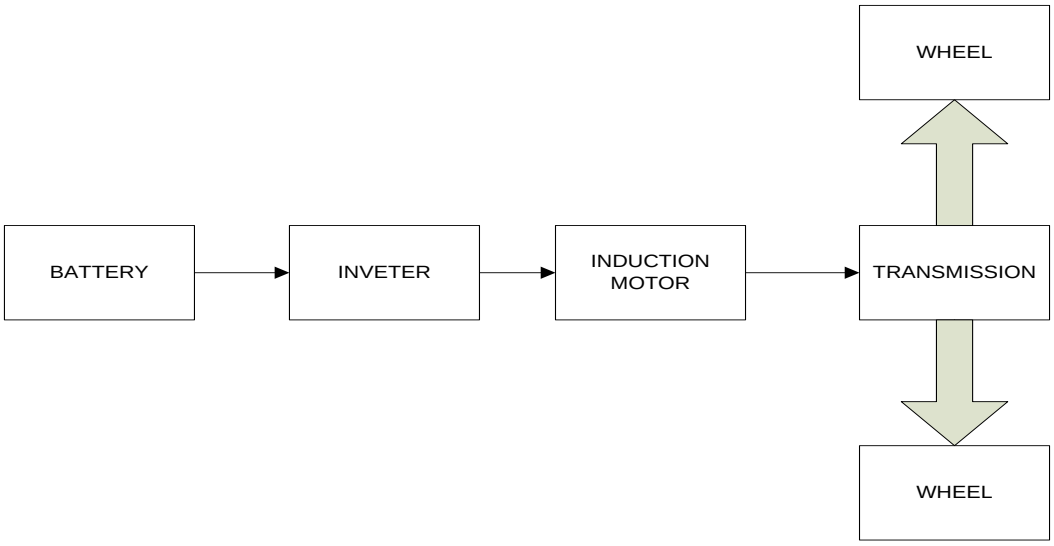


Fig. 1. Model of electric vehicle

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Description of Parts and their Functions:

1) ***Potentiometer:***It is circular in shape and it is hooked to the accelerator pedal. The potentiometer, also called the variable resistor, provides the signal that tells the controller how much power is it supposed to deliver.

2) ***Batteries:***The batteries provide power for the inverter. Three types of batteries: lead acid, lithium ion, and nickel-metal hydride batteries. Batteries range in voltage (power).

3) ***Power Electronic Inverter:*** The inverter takes power from the batteries and delivers it to the motor. The inverter can deliver zero power (when the car is stopped), full power (when the driver floors the accelerator pedal), or any power level in between. It needed 300V DC to drive the AC motor. This rating is converted to 240V AC and is sent to the motor with the help of the inverter in a controlled way [3]. The controller reads the setting of the accelerator pedal from the two potentiometers and regulates the power accordingly. If the accelerator pedal is 25 percent of the way down, the controller pulses the power so it is on 25 percent of the time and off 75 percent of the time. If the signals of both potentiometers are not equal, the controller will not operate [3].

4) ***Motor:*** The motor receives power from the controller and turns a transmission. The transmission then turns the wheels, causing the vehicle to run.

FUNDAMENTAL OF INVERTER CIRCUIT

Power inverters and converters are acclimated with adjusting the direct current (DC) (form HV battery pack) to alternating current (AC) for motors that push the vehicle down the road; they likewise change over AC to DC to charge the HV battery pack. Motor supplies from a variable frequency drive which controls motor speed (0-18000rpm) (i.e. $N \propto f$). By differing the frequency of power supply we can adjust the drive wheel speed. The inverters additionally taking kinetic energy released through regenerative braking and input to the battery. As result, the range of electric vehicles directly relevant to the efficiency of the prime inverters. The IGBTs are high-current, a high-voltage switch connected directly to the induction motor of the electric vehicle. Higher the efficiency of IGBT, lesser the power loss as heat wasted, coming about desire. The inverter which gives sine wave output (or)

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utilizing PWM method to generates a modified sine wave. Inverters have three phases as shows from Fig.2 – (1) oscillator (2) driver and (3) transformer output stage.

Oscillator:In this stage the generation of oscillating pulses either by IC circuit or transistorized circuit. The oscillations are generally the result of alternate battery positive and negative voltage peaks with an appropriate described frequency (no. of positive peaks per second). These oscillations in the pattern of a square wave. The generated square wave pulses are too weak, so that not able to drive high current output transformer. So these pulses are fed to the next amplifier stage.

Booster (or) Amplifier (Drive): Here the adjusted oscillating frequency is intensified to high current level using MOSFET (or) power transistors. The advanced response is an AC, but closed at the battery supply voltage level, so that cannot use to work for the electrical appliances which work at higher voltage AC.

Transformer output stage:In AC/DC power supply it's generally used for the step down the enforced input mains AC to the lower stated AC levels using magnetic induction of its two windings. In inverters, low-level AC from amplifier stage is enforced to the secondary winding, results in a generated stepped up voltage over the primary winding of the transformer. Figures and Tables.

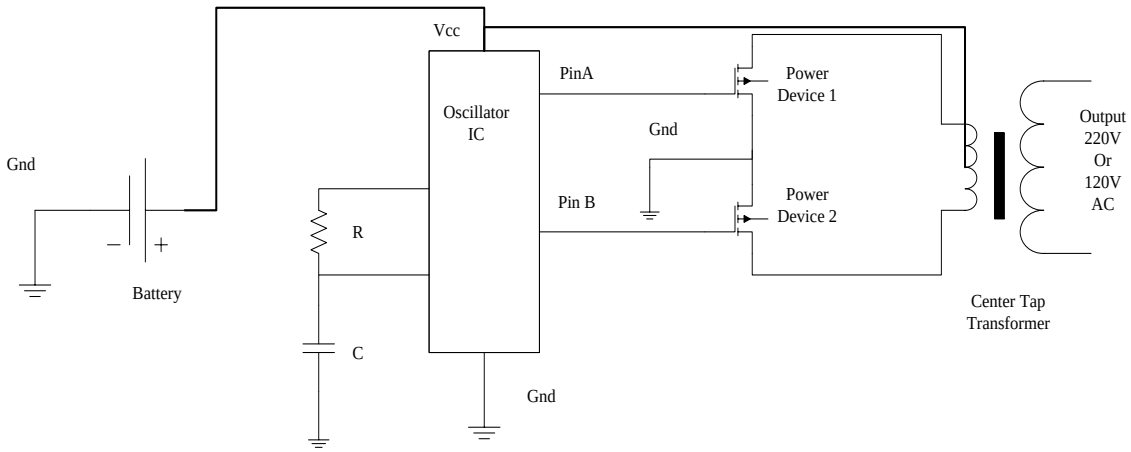


Figure: 2 Fundamental inverter circuit

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TRADITIONAL METHODOLOGY OF RISK ASSESSMENT IN FMEA

Basically, FMEA is a preventive quality assurance technique aimed at defect prevention at the source. If this is not possible, it aims at reducing the possibility of occurrence of the defect. It is interdependent to the process of characterizing what a design or process must do to appease the customer. Basically, there are four unique kinds of FMEA: System FMEA, Design FMEA, Process FMEA and Service FMEA. FMEA is a systematic group of activities proposed. In brief, the steps are involved in the evaluation of RPN as follows:

1) The system which has to be analysed is recognised. Then, dividing the system into subsystems and /or gatherings, so that the search for components can be localized and a list of components for each gathering can be developed.

2) The function of each component is analysed.

3) All possible failure modes that can affect the system performance have been determined which are associated with each item or components also determine their causes and the effects on the immediate function and the entire system.

4) The risk priority number (RPN) has been evaluated, by theequation

$$RPN=S\times O\times D \qquad (1)$$

5) Severity (S): Determine the Severity of the worst-case scenario adverse end effect.

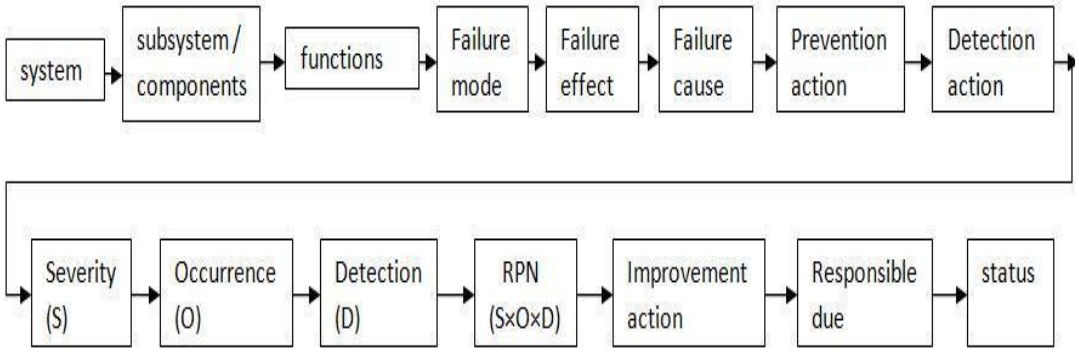


Fig. 2. Steps of FMEA

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6) Occurrence(O): an Occurrence is a ranking number associated with the likelihood that the failure mode.

7) Detection (D): The means or method by which a failure is detected.

(8) The RPN number decides that the corrective actions are needed or not. These actions can be:

- Compensatory i.e. for reducing the failures.
- Preventive for avoiding failures.

LIMITATIONS OF THE TRADITIONAL APPROACH

RPN is same for all cases. So we are able to remove it to a great extent by adopting Fuzzy based FMEA.

FUZZY RISK ASSESSMENT METHODOLOGY

The fuzzy risk assessment methodology gives a more adaptable and significant approach for evaluating the risk affiliated with the system or item failure modes. The parameters which evaluate the RPN i.e. S, O and D arefuzzified utilizing appropriate membership functions to demonstrate the degree of membership in each input. These inputs are assessed in the fuzzy inference engine,which is using utilization of all around characterized control base rule consisting of If-Then rules and fuzzy logic operations also, fuzzy logic operations are used to resolve criticality/riskiness level of the failures occur. After that, the fuzzy conclusion is defuzzified to find RPN.

TABLE I. LIMITATION OF TRADITIONAL FMEA

	Severity	Occurrence	Detection	RPN
Potential failure 1	2	5	10	100
Potential failure 2	5	10	2	100
Potential failure 3	10	5	2	100
Potential failure 4	2	10	5	100

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Higher the value of RPN, more risk will be the hazard and lower the value of RPN, lesser will be the hazard. The Fuzzy Linguistic assessment model was created utilizing toolbox of MATLAB (r2017b). The fundamental system comprises three principal modules, i.e. knowledge base module and input/output interface module as appeared in Figure 4. The principle parts related to the model areFuzzification; Fuzzy rule base; Fuzzy inference system; and Defuzzification [12].

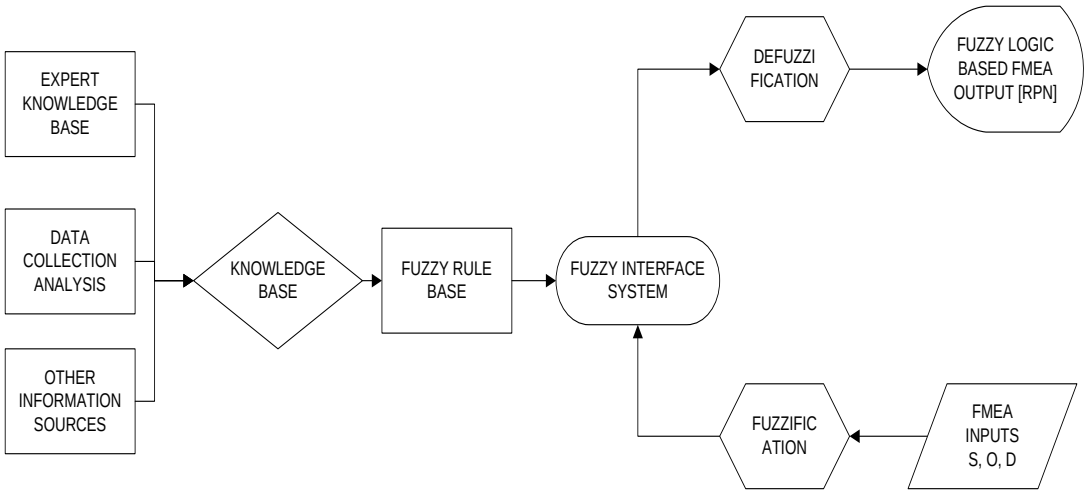


Fig4: System architecture of the fuzzy linguistic model

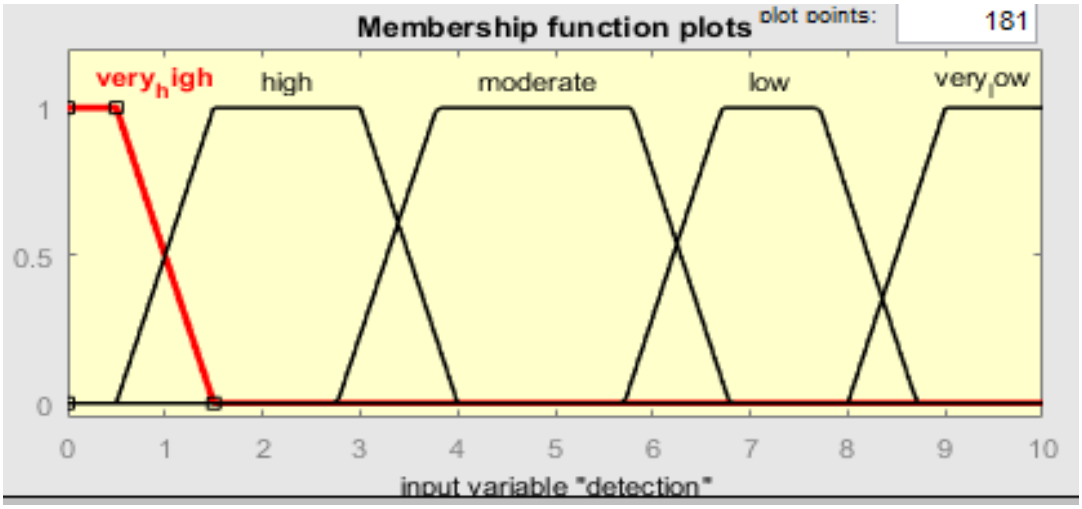


Figure 5. Fuzzy membership function for input variable (Detection)

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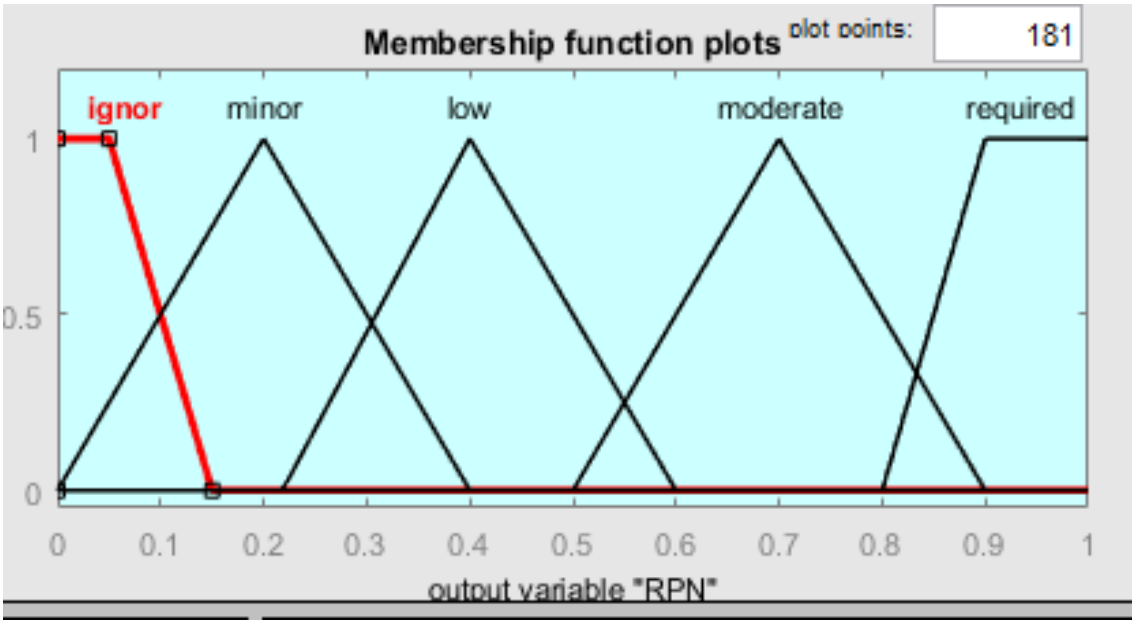


Figure 6. fuzzy membership function of RPN

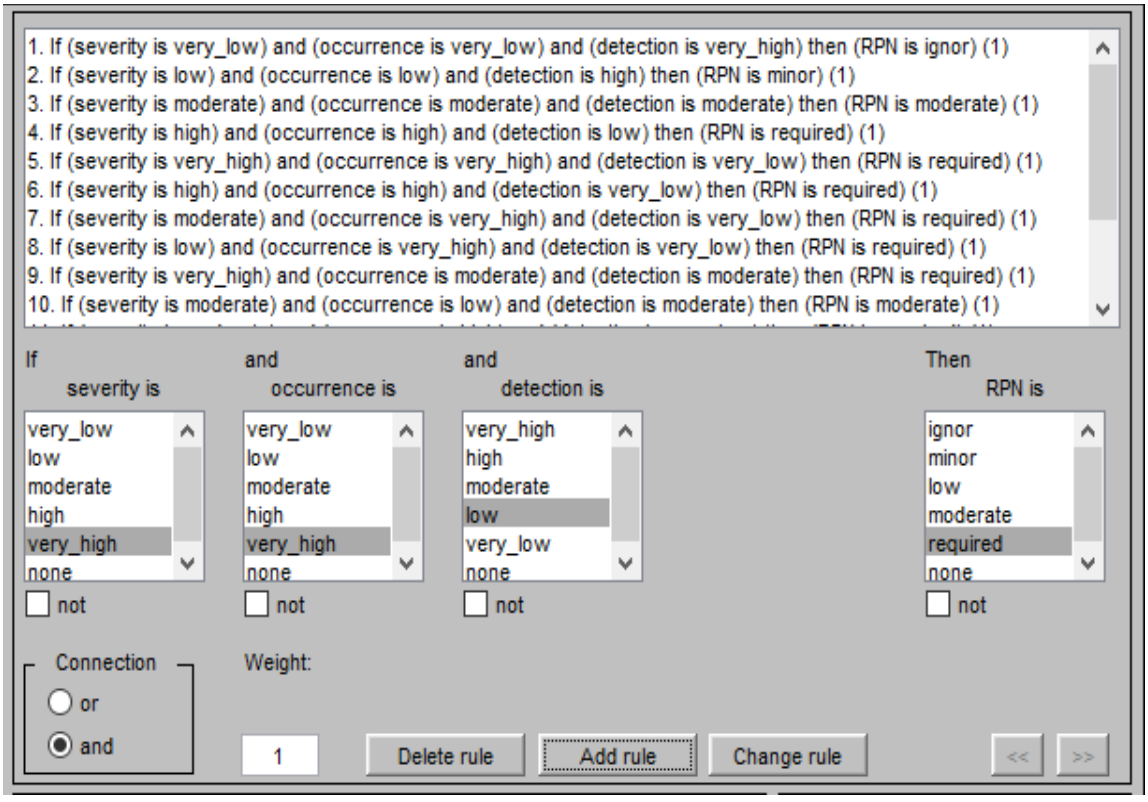


Figure 7. Rules framed on fuzzy inference system

ILLUSTRATIVE CASE

For exhibiting the use of recommended approach for doing system FMEA, an electric vehicle inverter process is studied. There are numerous practical functions in inverters, for example, to convert DC

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voltage into variable AC voltage, to provide a smooth power output at the varying level of current etc. Because of abnormal state comes, it has been chosen for leading failure mode investigation of a sub-system in order to remove or reduces that failure and also there causes to encouraging system work smoothly.

The FMEA table composed in above Table Ⅱ, in which RPN ranking is decided for the different types of fault, occurs in power electronic inverter of the electric vehicle system. The RPN numbers are decided with help of given

RPN = S (severity) ×O (occurrence) ×D (detection)

In light of, for the different S, O and D values the RPN is same so that to eliminate this problem uses fuzzy based FMEA (Fuzzy risk assessment).

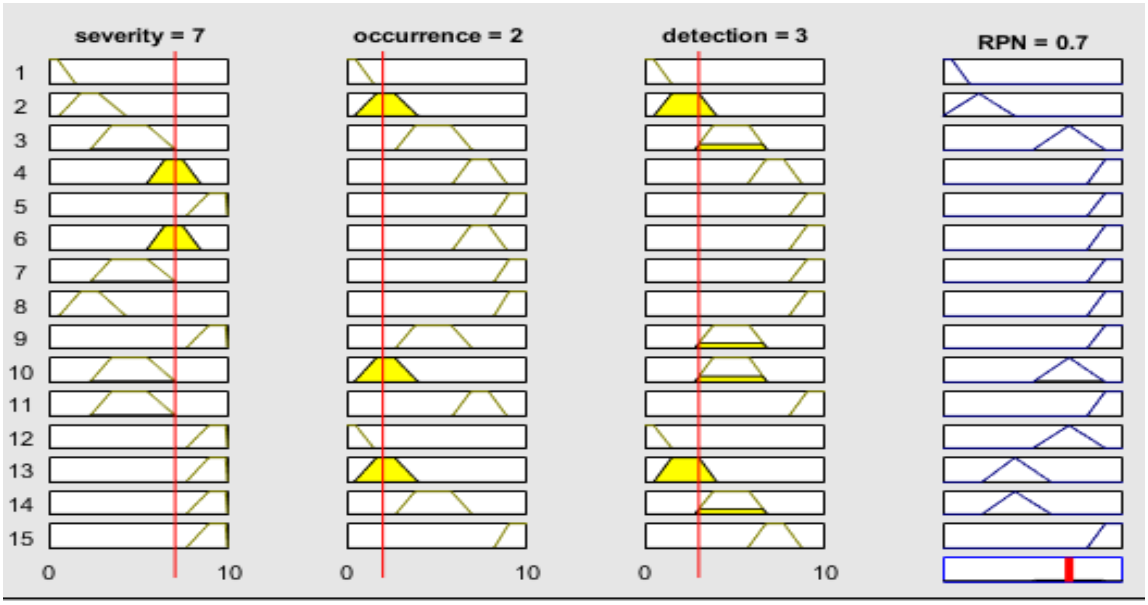
RESULTS

Fuzzy risk assessment has been completed after receiving a four-advance methodology (i.e. fuzzification, rule formation and evaluation and defuzzification) talked about already in detail. The outcomes so got have been introduced in Table Ⅲ.

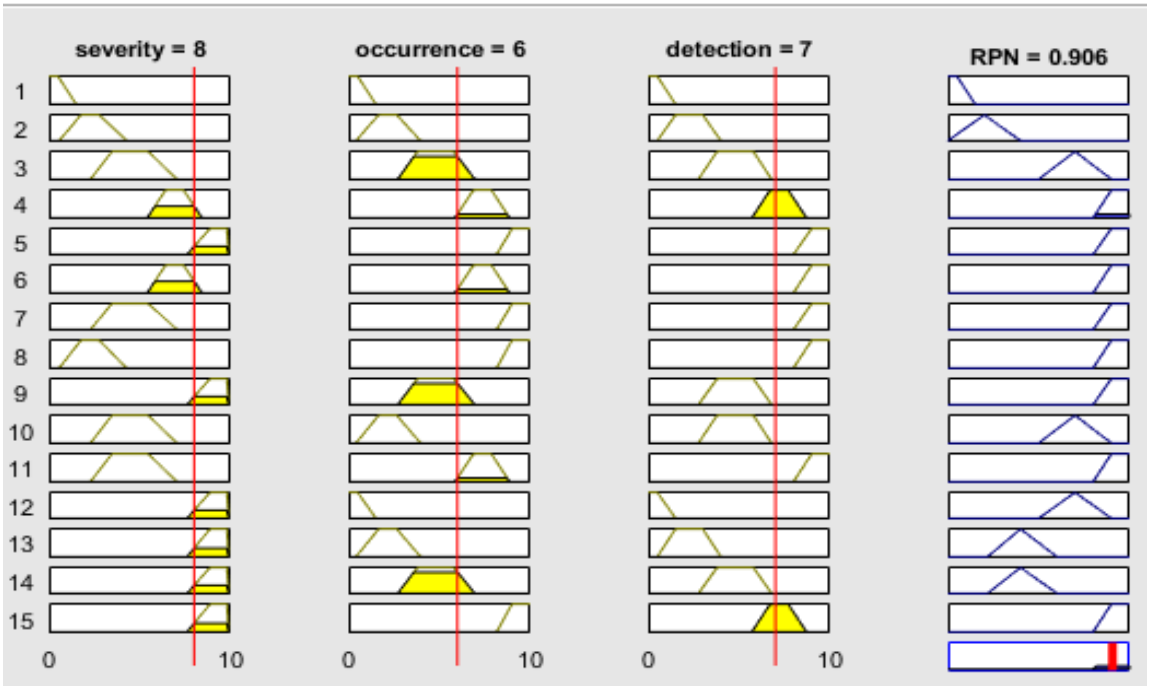
TABLE II. COMPARISION OF FUZZY OUTPUT AND TRADITIONAL RPN OUTPUT FOR VARIOUS FAILURE CAUSES

Potential failure cause	**Severity (S)**	**Occurrence (O)**	**Detection (D)**	**Traditional RPN output**	**Fuzzy (FIS) RPN Output**
Cause A	7	2	3	42	0.7
Cause B	6	7	8	336	0.916
Cause C	8	6	7	336	0.906
Cause D	7	3	2	42	0.5

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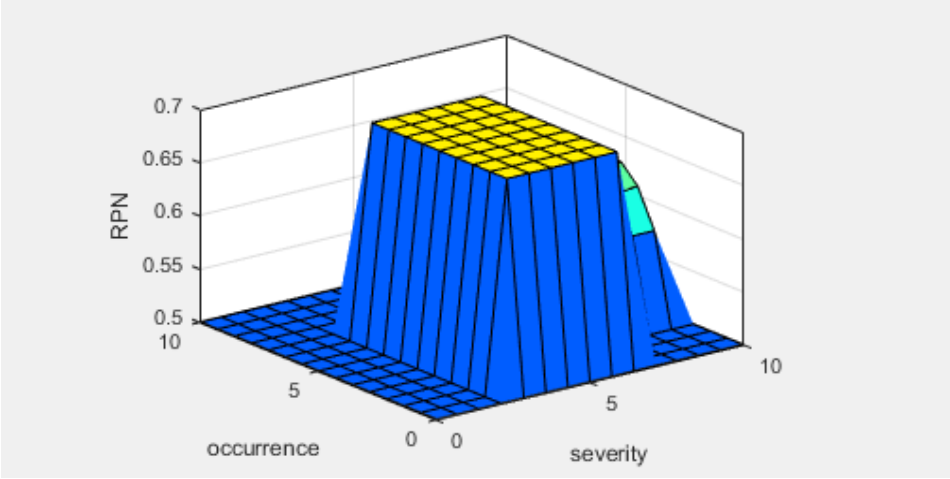
(a) Cause A



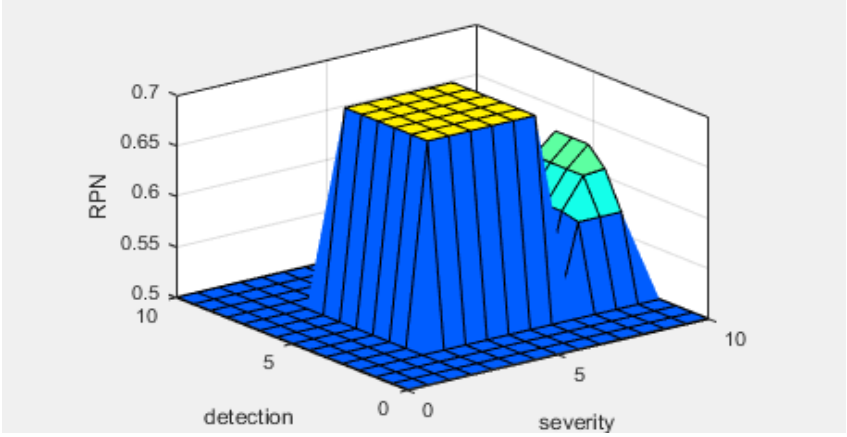
(b) Cause C

Figure 8. (a) and (b) Representation of system output for failure Cause A and Cause C

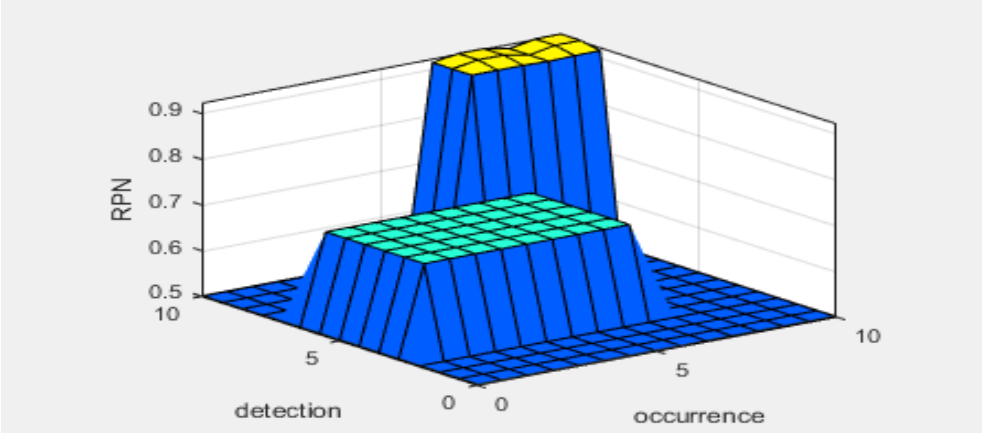
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(a) Control surface plot of occurrence and severity w.r.t RPN



(b) Control surface plot between detection and severity w.r.t RPN



(c) Control surface plot between detection and occurrence w.r.t. RPN

Fig 9. Control surface plot

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TABLE III. FMEA TABLE FOR THE ELECTRIC VEHICLE INVERTERS

Item	**Requirements**	**Potential failure mode**	**The potential effect of failure**	**A potential cause of failure**	**Causes**	**Severity (S)**	**Occurrence (O)**	**Detection (D)**	**RPN**
Inverter	To convert DC voltage into variable AC voltage	Improper installation of the inverter	The vehicle could not start	Combination of components does not follow the user manual recommended and selecting improper cable type, inline fuse	Causes A	7	2	3	42
	To provide a smooth power output at the varying level of current	Electromechanical Wear on capacitors	Effect of Capacitor failure on motor performance reduces its efficiency	Capacitor extremely temperature sensitive. Because of high current flow, it may damage	Causes B	6	7	8	336
	The inverter works within the specified limit	Overuse (or) inverter uses beyond their operating limit	The motor works with reduced efficiency	Due to oversight (or) lack of knowledge	Causes C	8	7	6	336
	Transmit motive power to the	Unintended motive power loss	Damages the components in	Over-current and over-	Causes D	7	3	2	42

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	induction motor		the device	voltage caused by excessive heat generated by the spike in current (or) voltage					

Here we get, the RPN value is different for the different S, O and D although its multiplication same.

CONCLUSION

This paper at first presents the definition and significance of traditional FMEA. Taking the power electronic inverter of electric vehicles, for instance, introduces the classification and determination of RPN using traditional FMEA. The failures related to inverters have been introduced. But for some failures, the RPN values are same although they have different S, O and D values. So that the altered FMEA strategy in view of the fuzzy rule base.

It helps to enhances the accuracy and reliability of FMEA applications, extending the extent of use, while looking at the risk order of each failure mode, presenting weight of every variable, thinking about the significance of each variable and the risk preference of decision maker, it has overcome the limitations of traditional FMEA just through the computation of RPN to decide the risk ranking.

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