# Designing an Online Monitoring System for Vehicle Electric Network and Its Fault Prediction aided by Fuzzy Logic

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**Widespread use of electronic equipments in vehicles has proved increasing importance of vehicular electric network performance. The reliability of the equipments, to some extent, depends on the reliability of its network. Therefore, the enhancement of vehicular electrical network is vital for automotive electronics industry. This paper presents a novel method to improve the reliability of "vehicular electric network" by using an online monitoring system. Voltage, current and network noise are selected factors, measured and sent to the central processing unit for analysis. The network information is measured by means of node sensors for which details are given. Having collected information across the network, fuzzy models of each region is developed based on its circuit profile. The outputs achieved by this model, determines the situation of vehicle power network and possibility of any fault occurrence in each area could readily be predicted. In practice, fault prediction helps to increase network reliability.**

## 1-Introduction

Extensive use of electronic and mechatronic systems in vehicular applications has caused to improve their importance and by controlling safety of critical equipments such as steer and brake systems, they have achieved vital role in vehicle industries. [4], [7] On the other hand, proper operation of electronic system depends on having reliable power resources, as any unstable power supply causes error in such system operation. As a result, importance grade of electric power network is gradually improved and now it is valued as vehicle safety critical equipment. [2],[5] This paper tries to introduce an effective approach for monitoring vehicle power network. By online monitoring, ability for network fault prediction will be provided.[13] Fuzzy logic, as an effective decision making method, might be suitable for detecting probability of any fault before happening. [10], [11] & [14]

Voltage and current as two basic variables are usually measured in electric analysis and, electric circuit situation can be monitored by them. In vehicle electric network monitoring system, measuring these two factors in each route is necessary. Using low DC voltage (12V, 24V) in vehicle to transfer electric energy is popular as average level of circuit current is definitely increased. [9] As a result, wire resistance and current drastic variations in network routes have non-negligible effect on voltage level. These phenomena portray importance of voltage and current variation factors. Ultimately, voltage and current level and their variations have basic role in such monitoring system.

### 2-1-Fault types in vehicular power electric network and their effect on circuits' parameters

Faults in vehicle electric network could be categorized into two groups. [9]
First group: faults related to routes and wiring
Second group: faults related to electric supplier and consumers
Faults in both groups affect the circuit voltage and their current in various ways. Therefore investigation to find fault types

and their effect can help to recognize fault reasons from circuit parameters and also in higher levels can provide ability of fault prediction before its happening. Usually electrical consumers in different states have distinctive electrical behavior, so it should be useful to analyze faults in each supplier and transition group and consumers group individually.

Table1: Faults related to wiring and power electric interface

| | Fault Type | How to affect on monitoring parameters |
|---|---|---|
| 1 | Short circuit(strong) | Current drastic escalating<br>Voltage drastic reducing |
| 2 | Short circuit(poor) | Current tangible escalating<br>Voltage non-tangible reducing |
| 3 | conflict | Expected current and real current is not match |

Common faults related to consumer equipments.[9]

- Current variation
- Short circuit
- Persistent noise on Voltage
- Voltage shock
- Current cutoff
- Current Leakage

Table2: faults related to consumer electric equipments

| | Fault Type | How to affect on monitoring parameters |
|---|---|---|
| 1 | Current variation | Voltage variation |
| 2 | Short circuit | Current escalating<br>Voltage reducing<br>Routes current is not match to consumer status(on, off) |
| 3 | Persistence noise on voltage | Increasing voltage noise amplitude on all network or parts of that |
| 4 | Voltage shocks | Sudden voltage increasing |
| 5 | Current cut off | Contradiction between real route current and active state expected current |
| 6 | Current leakage | Contradiction between real route current and disable state expected current |

**Fault in electric power supplier**

Usually suppliers consist of battery, generator and charging circuits. [8]

A) Battery faults
   1-sudden reducing battery voltage
   2-reducing chargeability
B) Generator and charging circuit faults
   1-abnormal voltage increasing
   2-reducing voltage in normal current network
   3-abnormal voltage variation in charging circuit

Based on this categorization table 3, 4 have been developed.

Table4: fault in power supplier (battery faults)

| | Fault type | How to affect on monitoring parameters |
|---|---|---|
| 1 | Reducing battery voltage | Global voltage reducing |
| 2 | Reducing chargeability | Battery voltage increasing in short amount of time |

| | Fault type | How to affect on monitoring parameters |
|---|---|---|
| 1 | Disability of regulation and charging circuit | Abnormal battery's voltage increasing<br>Noise on network voltage |
| 2 | disability of generator | Reducing battery voltage<br>Current cutoff from charging circuit |

Table 5: Fault in power supplier (generator and charging circuit)

**3-Monitoring system components**

In monitoring system, two groups of component have been defined. [6]
Nodes for reading, analyzing and broadcasting network information
Nodes for acquisition, management and monitoring network parts status
So, in the designed distributed monitoring system some nodes in different routs of electric power network are obliged for sampling various electric parameters, and then after initial analysis, sending achieved information to the central management node over vehicle control network. Finally, in management node those data all together portray status of vehicle electric power network. In higher levels, power network status contain valuable information which can be used for predict abnormal happening and notice probable failure with exact zone and position definition. Figure 1 has been designed based on such considered structure has been designed. In this figure some sensor nodes are located in different routes and are individually obliged to read and send data to the main monitoring node. This transaction is done over CAN bus. CAN bus as a popular vehicle control network, is intended for the connection between sensor nodes and main monitoring node. [1], [3]

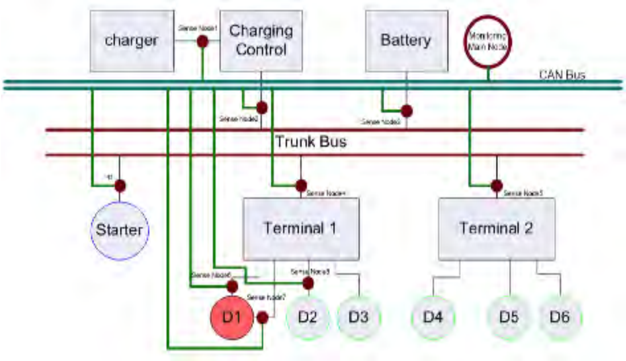


Figure 1: Structure and components of vehicle power electric network

### 1-3-Sensor nodes

Based on network factors definition, sensor nodes should be able to measure voltage, current and network noises concurrently. Another point is electric supply for these nodes, and it is not efficient to increase complexity of vehicle power network by monitoring nodes. As a result, two then occurred problems are nodes proper node operation and choosing effective nodes location.

### 1-1-3-Designing components and structure of sensor nodes

Sensor nodes are responsible for two basic tasks.

A) Power network voltage and current sampling; sensor nodes should achieve network information by measurement and initial analysis of monitoring parameters.

B) Having connection with central control system; sensor nodes are transfer obtained data to the central monitoring node over vehicle data network such as CAN or Flexray.[6] (Figure 2)

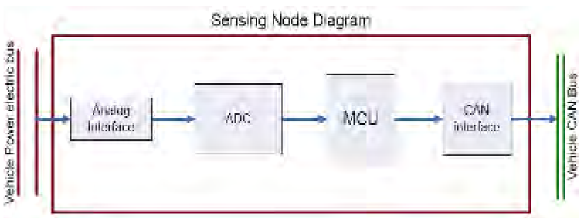


Figure 2: sensor node main components

This structure is completely compatible with vehicle which is equipped with multiplex network. So multiplex data network plays a basic role in full duplex data transferring between sensor nodes and central node.

According to nodes obligations, some components are crucial for them. (Figure 3)

1) Protection unit
2) Electric supplier
3) Noise detector circuit
4) Voltage meter circuit
5) Current meter circuit
6) Fast ADC component
7) Processing unit
8) Bus control unit

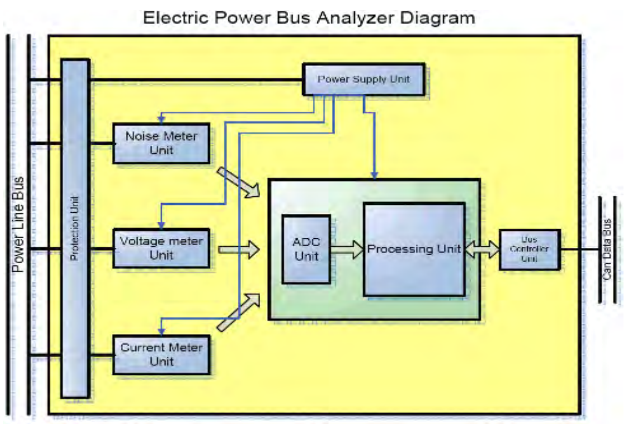


Figure 3: Sensor node component block diagram and their connections

### 2-1-3-Protection unit

Sensor nodes, as automotive electronic devices, have to tolerate vehicle harsh conditions, so in electronic element selection, circuit and PCB designing, automotive standards must be met. Shock voltage, wide range temperature and vibration are notable, usual phenomena in vehicles. In protection unit some components such as fast varistors, RC filters and Transient voltage suppression diode to be used for avoiding disturbances.

### 3-1-3-Electric supplier

Sensor nodes as a role base monitoring module must remain active during lack of input supply voltage. It means that node itself provide demand energy by battery in a limited period of time and send current cutoff status. As a result, supply circuit contain circuits for shock damping, noise canceling, voltage regulation and battery charge and discharge, as shown in fiqure4.

According to power supply definition the circuit has been designed which is shown in figure 5.

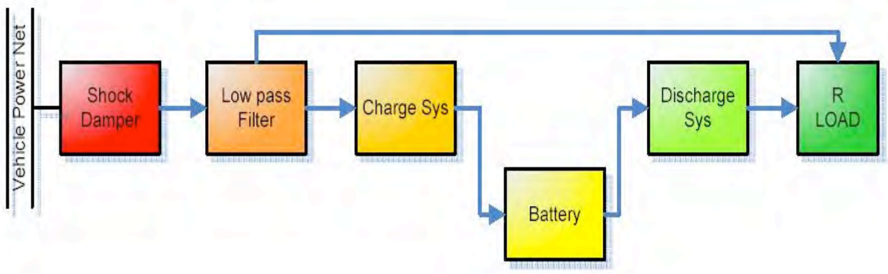


Figure 4: Power supply components and their connections

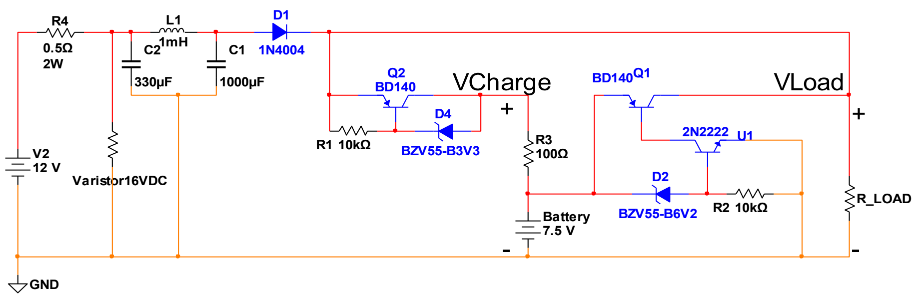


Figure 5: Power supply circuits

### 4-1-3-Noise detector circuit

Noise as unforeseen phenomena might occur in different types. So noise detecting circuit should be able to detect noise waves in distinctive frequencies and amplitudes. In this paper based on popular vehicle electrical treats, noise detection unit is focused on wave frequencies in range of 100 to 1 KHz.

This unit measures noises by this sequence:

1) Variation damps and noise canceling from input voltage and provides stable DC voltage as a first input.
2) Having comparison between first input and real network DC voltage and measures the difference.
3) Amplify difference between two signals.
4) Measures upper half wave and lower half wave voltage individually
5) Measure average voltage of each upper and lower half wave.
6) convert these average voltage to ADC

Component diagram and their connections are shown in figure 6.

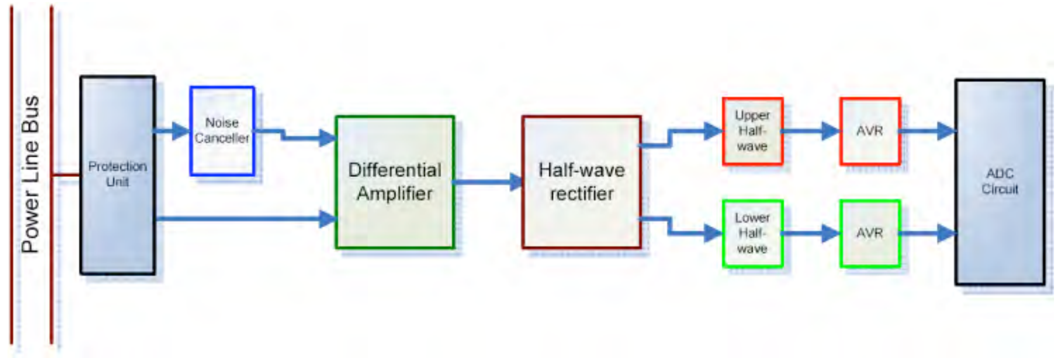


Figure 6: Noise detection and measuring block diagram

According to this structure based on differential amplifier and half wave rectifier, analog circuit is designed. (Figure 7)
By simulating the considered circuit in simulator software (NI multisim) proper operation of circuit has been proved.
Figure 8 show the simulation result. In upper curve, noise amplitude gradually increased. The lower curve as an output voltage concurrent with noise signal also has been increased.
Noise escalating depends on output DC voltage and has almost linear variation which is shown in figure 9.

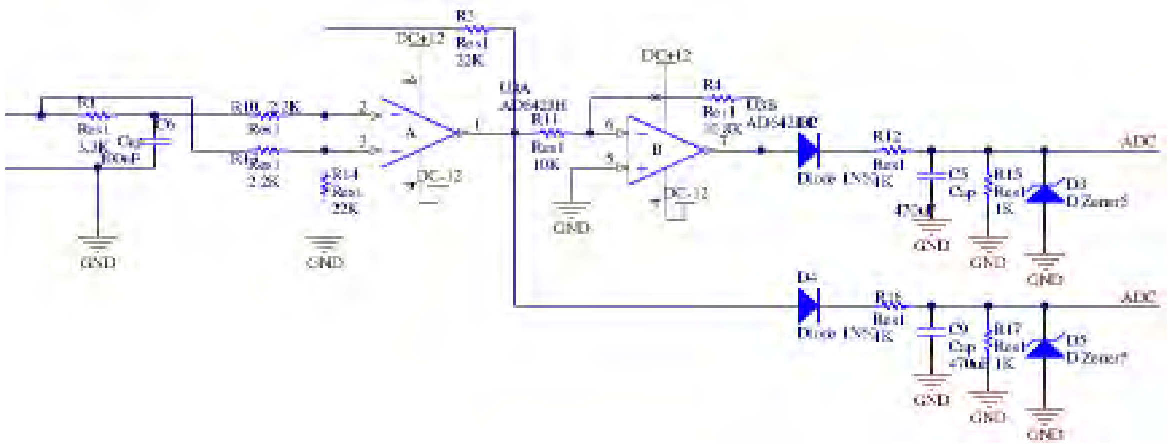


Figure 7: Noise detector and measuring circuit

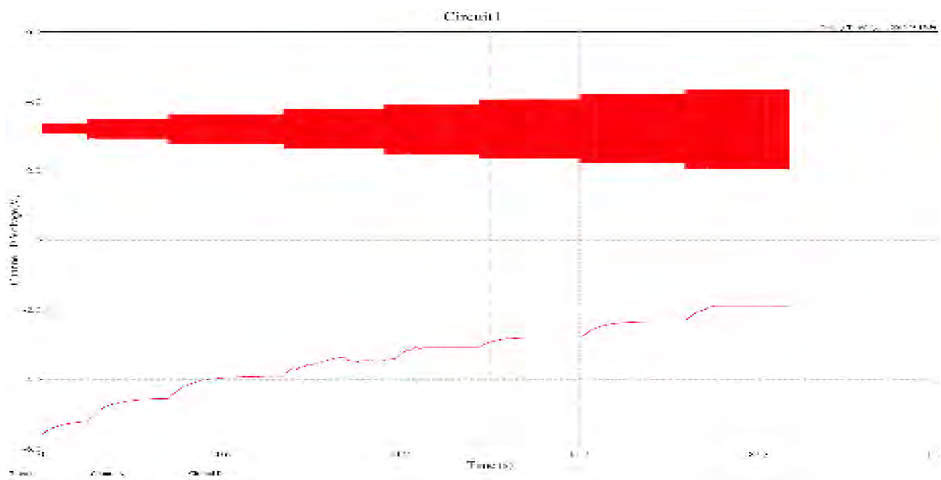


Figure 8: Noise detector circuit simulation result in NI multisim software

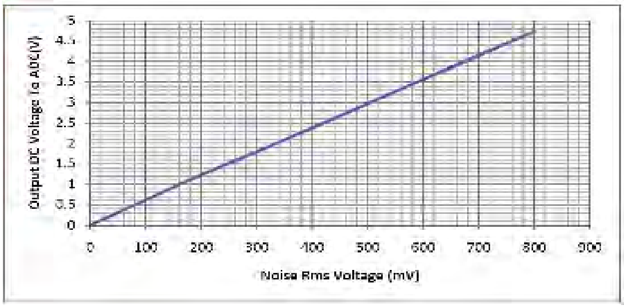


Figure 9: Output voltage curve depends on noise amplitude

### 5-1-3-Voltage and current meter circuit

The other electrical factors are voltage and current level have been measured by two components. Diagrams as shown in figures 10 and 11.

As it is pointed out the monitoring system is setup in vehicle control network. Figure 12 shown its position in multiplex network architecture

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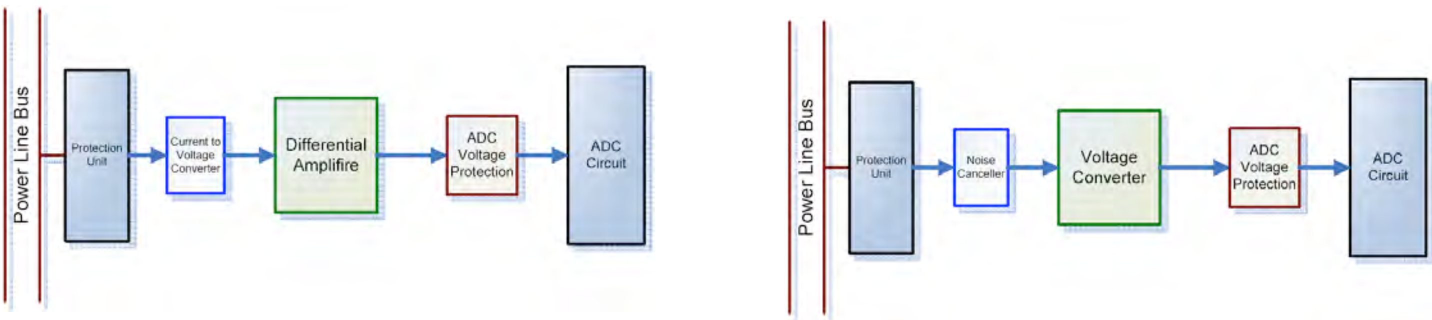



Figure 10, 11: Current and voltage measurement circuit block diagram

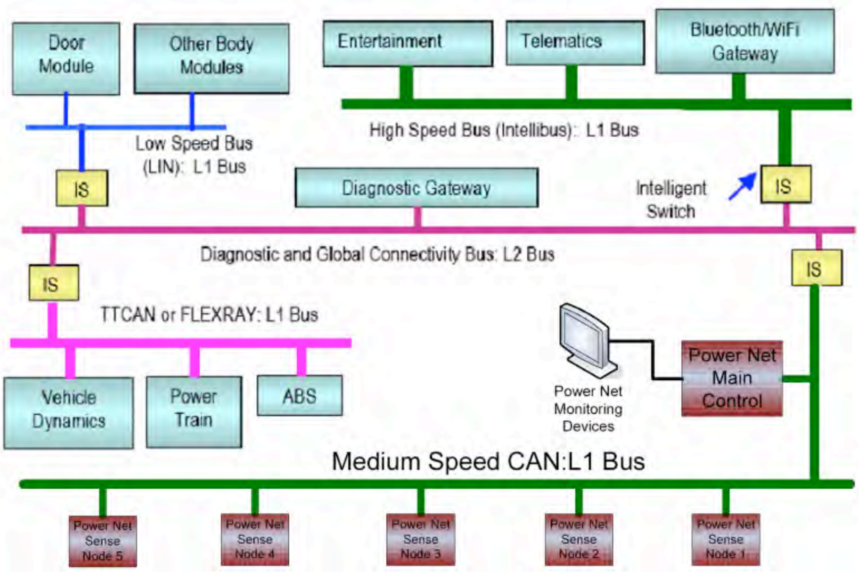



Figure 11: Monitoring position in multiplex vehicular control network

According to above diagram medium speed CAN bus is responsible for connecting sensor nodes to main controller. By intelligence switch ability of having connection with backbone vehicle has been provided. The power network main controller manages sensor nodes information and analyzes them. Sample decision approach has been discussed by using fuzzy theory, in the following.

**4-Power network fault prediction by fuzzy logic**

Having decision by fuzzy logic is done in three stages. [12]

1) Fuzzification
2) Inference
3) Defuzzification

In this application voltage and current level and noise amplitude are three input variables and also, network stability in each zone as an output variable have been defined. For each input variables, three Gaussian membership functions and for output five Gaussian membership functions has been selected. In power network monitoring system each node has an special specification. Based on these specification membership functions should be set. The fuzzy model which has been simulated in this paper is related to forward lighting of Peugeot 206. [15] (Figure 12, 13, 14 and 15)
And also the fuzzy rules based on level of noise variation (low, medium and high) are defined and organized in three tables. (Table 6, 7 and 8)

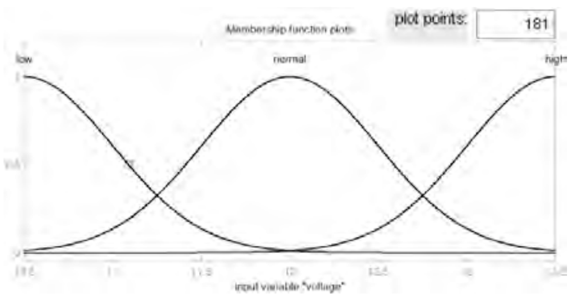


Figure 12: Voltage membership functions has extremum point on 10.5, 12 and 13.5 for low, normal and high level

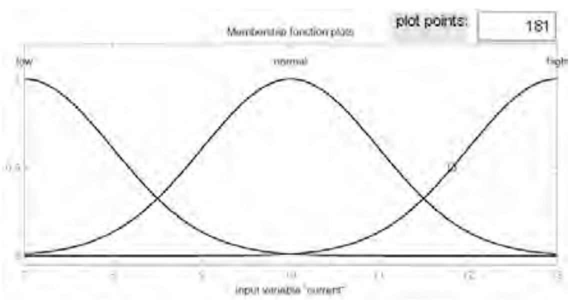


Figure 13: Current membership functions has extremum point on 7, 10 and 13 for low, normal and high level

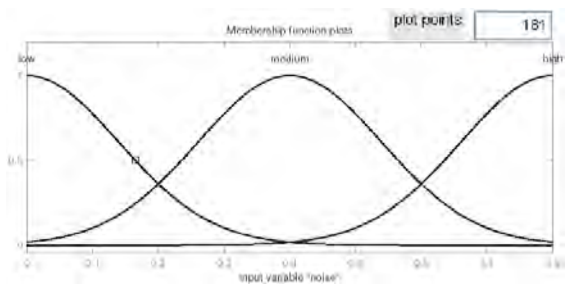


Figure 14: Current membership functions has extremum point on 0, 0.4 and 0.8 for low, medium and high level

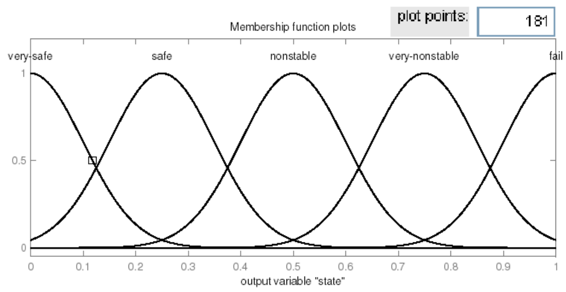



Figure 15: Network stability as fuzzy output variable set in five membership functions (Very safe, safe, unstable, very unstable, fail)

Table 6: First part fuzzy rules when noise level is low

| High | Normal | Low | Current / Voltage |
|---|---|---|---|
| Fail | unstable | Very unstable | **Low** |
| Very unstable | Very Safe | unstable | **Normal** |
| Fail | unstable | Very unstable | **High** |

Table 7: Second part fuzzy rules when noise level is medium

| High | Normal | Low | Current / Voltage |
|---|---|---|---|
| Fail | unstable | Very unstable | **Low** |
| Very unstable | safe | unstable | **Normal** |
| Fail | unstable | Very unstable | **High** |

Table 8: Third part fuzzy rules when noise level is high

| High | Normal | Low | Current / Voltage |
|---|---|---|---|
| Fail | Very unstable | Fail | **Low** |
| Very unstable | unstable | unstable | **Normal** |
| Fail | Very unstable | Fail | **High** |

By simulation of fuzzy model, relation between each two input variable and network stability can be shown in surface diagram. Figure 16, 17 and 18 portray power network stability status individually related to:

1) current and voltage level
2) Noise amplitude and voltage level
3) Noise amplitude and current level

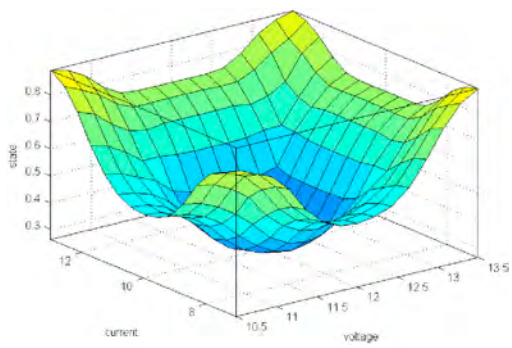
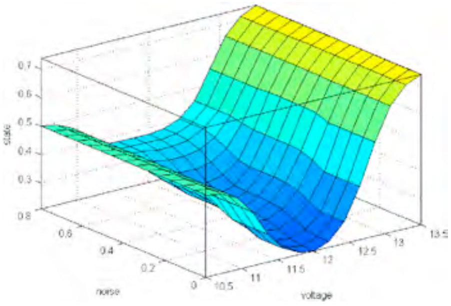


Figure16: Stability surface diagram depends on current and voltage variations




Fiqure17: Stability surface diagram depends on noise level and voltage variations

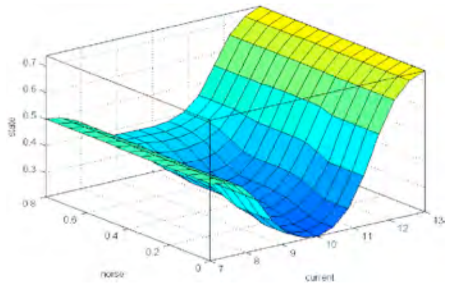



Figure18: Stability surface diagram depends on noise level and current variations

**Conclusion**

Vehicular control network provide facility of communication between automotive electronic modules. By this facility and using online system monitoring system in vehicle power network, distinctive stats of electric modules can be monitored. This information portrays the fault happening with its exact location. Furthermore, some electric network faults have several signs before occurring. By analyzing these signs, measurement probability of system faults will be possible. This fault prediction ability needs comprehensive information about power network. So using distributed data acquisition system for monitoring vehicle power electric network is an effective approach to improve vehicle reliability.

**Resources**

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