Prediction effective capacity battery of cellular BTS for an effective maintenance

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Abstract. A cellular base transceiver station (BTS) systems must be operated continuously in transmitting signals to the mobile stations. Reliability operation must be performed by this BTS to serve users without any interruptions. In several cases the BTS are found failed due to several disturbances that occurred during operation. One of the disturbances is caused by electrical energy supply interruptions. Although the cellular BTS power supply system is usually equipped by battery as a secondary power supply, the reliability can be influenced by the health of the battery. The health of battery is inclined by instability of main electricity supply, temperature fluctuation of the battery environment, increment of battery aging, the number of charging and discharging cycles (CDC), and the number depth of discharging conditions (DOD) that occurred. The impact of these factors will affect to the strength of battery. This paper proposes an investigation method to the battery health to ensure the performance of BTS. The method is applied by considering the charging and discharging characteristics of the battery. Since the characteristic signals are not linear, the calculation is performed using fuzzy method. Early results show that this prediction method can be applied to support maintenance work. The proposed method gives an overview of the battery health that can be followed up by technician to ensure the reliability of the BTS.

1. Introduction

Cellular telecommunications network has been grown rapidly and widely used by the public today. The communication signal service is provided by a BTS transmitter that directly serves to the user’s handset involved in the telecommunications connection process. The operation of BTS uses the main energy supply from PLN electricity that is converted to dc voltage by a rectifier device. And to maintain the continuity of the electricity supply, BTS’s are backed up by batteries as secondary energy [1,14,15]. Furthermore, the availability of the BTS transmitter is expected to reach high availability value, and only a few percent allowed to be failed. The connection between the BTS and the battery shown in figure 1.
Batteries as secondary energy is a device that converts stored chemical energy into electrical energy. Each cell has a positive pole (cathode) and a negative pole (anode). A pole with a positive sign indicates that it has higher potential energy than a pole with a negative sign. A negative sign is a source of electrons that when connected to an external circuit will flow and provide energy to external equipment. When a battery is connected to an external circuit, electrolytes can move as ions inside it, so that chemical reactions occur in both poles. The transfer of ions in the battery will provide an electric current as an output that produces electrical energy [2].

Battery Charge Discharge Cycle (CDC) is a process of discharge cycles from 100 percent of battery capacity to the lowest specified capacity limit. The discharge process is not recommended until the battery capacity is empty, so it is necessary to set the value of a certain amount, for example, 10 percent or 20 percent, etc. called the State of Charge (SOC). The existence of certain SOC values is done to maintain the health of each battery cell [11-13]. As the opposite of the SOC value, then the value of the amount of battery discharge is usually referred to as the Depth of Discharge (DOD) which is presented as a percentage of Discharge AH / Real Capacity [2].

Battery performance influenced by several external factors i.e. due to the instability of PLN electricity supply give impact to increasing temperature of the battery environment, the number of charging and discharging cycles, and the number DOD will impact to decreasing battery performance [2-7,14,16-19]. Another factor which influence battery performance as well as an internal factor i.e. self-discharging which will reduce the battery capacity in a certain period [15]. And the correlation between battery capacity with Charge Discharge Cycle shown in figure 2.

**Figure 1.** Diagram battery vs BTS [1].

**Figure 2.** Correlation of battery capacity vs Charge Discharge Cycle [7].
Several researchers calculate an estimation of the battery capacity using artificial intelligence, including using the fuzzy logic method [13]. The fuzzy logic method has three main processes in implementing it on a device, i.e. fuzzification, rule, and inference system, and defuzzification [8-10]:

- Fuzzification is a process to change an input from a strict form (crisp) to fuzzy which is usually presented in the form of fuzzy sets with a function of each member.
- Inference System is as a reference to explain the relationship between input and output variables which are processed, and generated variables are fuzzy. To explain the relationship between input and output usually use "IF-THEN".
- Defuzzification is the process of converting these fuzzy variables into definite data (crisp) that can be sent to control equipment.

The fuzzy membership function is shown in figure 3. This paper is divided into five sections. The first section describes the background and purpose of the paper. The second section describes the research methodology used fuzzy logic in this paper. The next section describes the result and discussion comparison of the Mamdani defuzzification and Sugeno defuzzification. Finally, this paper is closed by a conclusion.

![Fuzzy membership function](image)

**Figure 3.** Fuzzy membership function [9].

### 2. Literature review

Recently many electronic devices such as cellular devices, electric vehicles, notebooks, cameras, music players, etc. have used lithium-ion batteries as secondary energy because it has many advantages compared to other types of batteries such as Nickel Cadmium [7,14,15,17]. Several kinds of research have been done to explore the performance of lithium-ion batteries. And in the energy sector, many studies have been carried out recently to observe lithium-ion batteries used in electric vehicles [6]. But just a few studies carried out to observe lithium ion batteries performance used in cellular system. In electric vehicle usage, the battery works after being fully charged and then used by the electric vehicle so that the SOC (State of Charge) voltage can be measured periodically. After completing the use of electric vehicles, the DOD (Depth of Discharge) value can be measured as well. The value of DOD is the opposite of SOC value. Another researcher evaluates the correlation of battery capacity with various temperatures, shown in figure 4.
Several researchers calculate the SOC value of batteries using artificial intelligence, including using the fuzzy logic method [6]. The use of the fuzzy method is done with consideration of intelligent fuzzy systems that can describe, knowing, and modeling human thought processes and design a system so that it can describe human behavior. By using a fuzzy process consisting of fuzzification, inference and defuzzification, the level of correctness of the determination of the output value obtained is more accurate. Another researcher performs monitoring performance of lithium-ion batteries used in electric vehicles [6]. The battery performance calculated by modeling and simulate the SOC value, cause of this manner considered more efficient than direct measurement such as open connection voltage.

By consideration until now most of the research is conducted on the performance of electric vehicles battery, and currently still not so much research on the performance of cellular BTS batteries, making it an interesting challenge to investigate it further. The cause of the battery of cellular BTS in the application is deployed widely in wide areas to cover all users in which every area has complex mains electricity conditions. Such as batteries in the urban area usually have more stable electricity than suburban areas. This means batteries in urban areas have less Depth of Discharge than suburban areas.

3. Methodology
This research was performed by several steps i.e.
- Designing diagram of the system
- Establishing the connection between sensors and the server
- Collecting data measurements
- Designing the Matlab simulink modeling
- Designing fuzzy logic functions
- Running fuzzy logic functions
- Representing the result

Here we measured several parameters of the battery, i.e. voltage value, current value, temperature value and the value of DOD. The parameter values are obtained from the sensors that have been installed which will send the measurement data periodically at a predetermined period that is every 5 minutes. Monitoring is carried out within 30 days of measurement. The data obtained then processed to become a simulation material using Simulink Matlab to determine the member function and designing crisp and rules used as input for the defuzzification process. With variations of these input parameter values and simulated with predetermined rules, a result of the fuzzy is obtained.

3.1. Parameters
Fuzzy logic member function represents facts and certain criteria according to the four measurement objects i.e. the voltage value, current value, temperature value, and DOD value. The measurement data we got then in the next step we use to create a member function of each input parameter with a certain
value such as low, moderate and high, shown in table 1. Noted here we do not apply the internal discharge in the calculation cause of the value is very small just in micro ampere unit.

| No | Parameter      | Weight % | Range     | Criteria | Score | Output |
|----|----------------|----------|-----------|----------|-------|--------|
| 1  | Temperature    | 25       | 33-60     | Hot      | 1     | Bad    |
|    |                |          | 23-35     | Moderate | 2     | Moderate |
|    |                |          | 10-25     | Cold     | 3     | Good   |
|    |                |          | 40-45     | Low      | 1     | Bad    |
| 2  | Voltage (V)    | 25       | 44-49     | Moderate | 2     | Moderate |
|    |                |          | 48-55     | High     | 3     | Good   |
|    |                |          | 18-40     | High     | 1     | Bad    |
| 3  | DOD (%)        | 25       | 8-20      | Moderate | 2     | Moderate |
|    |                |          | 0-10      | Low      | 3     | Good   |
|    |                |          | 90-150    | High     | 1     | Bad    |
| 4  | Current (A)    | 25       | 50-100    | Moderate | 2     | Moderate |
|    |                |          | 30-60     | Low      | 3     | Good   |
|    |                |          | 0-35      | Low      | 1     | Bad    |
| 5  | Capacity prediction (%) | 25 | 25-70 | Moderate | 2 | Moderate |
|    |                |          | 60-100    | High     | 3     | Good   |

We define rule function with various of four parameter inputs which each parameter has three various memberships. All the various input parameters processed with IF-THEN operation to obtain the output. Totally here in this measurement we use 3x3x3x3 rules equal to 81 rules is shown in table 2 (part of total rules).

| Rule | Temp (C) | Voltage (V) | DOD (%) | Current (A) | Capacity Pred (%) |
|------|----------|-------------|---------|-------------|------------------|
| 1    | Cold     | Low         | Low     | Low         | Moderate         |
| 2    | Cold     | Low         | Low     | Moderate    | Moderate         |
| 3    | Cold     | Low         | Low     | High        | Moderate         |
| 4    | Cold     | Low         | Moderate | Low         | Moderate         |
| 5    | Cold     | Low         | Moderate | Moderate   | Moderate         |
| 6    | Cold     | Low         | High    | Moderate    | Moderate         |
| 7    | Cold     | Low         | High    | Low         | Moderate         |
| 8    | Cold     | Low         | High    | Moderate    | Moderate         |
| 9    | Cold     | Low         | High    | High        | Moderate         |
| 10   | Cold     | Moderate    | Low     | Low         | Moderate         |
| 11   | Cold     | Moderate    | Low     | Moderate    | Moderate         |
| 12   | Cold     | Moderate    | Low     | High        | Moderate         |
| 13   | Cold     | Moderate    | Moderate | Low        | Moderate         |
| 14   | Cold     | Moderate    | Moderate | Moderate   | Moderate         |
| 15   | Cold     | Moderate    | Moderate | High       | Moderate         |
| 16   | Cold     | Moderate    | High    | Low         | Moderate         |
| 17   | Cold     | Moderate    | High    | Moderate    | Moderate         |
| 18   | Cold     | Moderate    | High    | High        | Moderate         |
| 19   | Cold     | High        | Low     | Low         | Good             |
| 20   | Cold     | High        | Low     | Moderate    | Moderate         |
| 21   | Cold     | High        | Low     | High        | Moderate         |
| 22   | Cold     | High        | Moderate | Low        | Moderate         |
| 23   | Cold     | High        | Moderate | Moderate   | Moderate         |
| 24   | Cold     | High        | Moderate | High       | Moderate         |
| 25   | Cold     | High        | High    | Low         | Bad              |
| 26   | Cold     | High        | High    | Moderate    | Moderate         |
| 27   | Cold     | High        | High    | High        | Bad              |

The system design comprised of fuzzification process, rule function and defuzzification process is shown in figure 6.
3.2. Scenarios

In this paper we collect 500 data inputs from each sensor. To process the data which has been measured and collected from sensors in each of the parameters we process using Matlab simulink. The first step here is process various data input using fuzzy toolbox. The input data measurements are shown in table 3 (part of total data measurement).

![System design](image)

**Figure 5.** System design.

![Current data input](image)

**Figure 6.** Current data input.
Table 3. Data measurement.

| Data | Temp (°C) | Voltage (V) | DOD (Times) | Current (A) |
|------|-----------|-------------|-------------|-------------|
| 1    | 29.9      | 53.6        | 2           | 87.4        |
| 2    | 29.8      | 53.6        | 0           | 82          |
| 3    | 29.8      | 53.6        | 18          | 78.7        |
| 4    | 29.9      | 53.7        | 31          | 75.8        |
| 5    | 29.8      | 53.6        | 34          | 81.6        |
| 6    | 29.8      | 53.6        | 29          | 81.6        |
| 7    | 29.8      | 53.7        | 4           | 82.2        |
| 8    | 29.8      | 53.6        | 38          | 76.2        |
| 9    | 29.8      | 53.6        | 28          | 76.2        |
| 10   | 29.8      | 53.7        | 40          | 81.6        |
| 11   | 29.8      | 53.7        | 10          | 78.1        |
| 12   | 29.8      | 53.7        | 6           | 78.1        |
| 13   | 29.7      | 53.7        | 17          | 85.2        |
| 14   | 29.7      | 53.7        | 1           | 85.2        |
| 15   | 29.8      | 53.7        | 36          | 73.6        |
| 16   | 29.8      | 53.7        | 24          | 73.6        |
| 17   | 29.7      | 53.7        | 22          | 76.3        |
| 18   | 29.7      | 53.7        | 36          | 74.2        |
| 19   | 29.7      | 53.7        | 1           | 73.7        |
| 20   | 29.7      | 53.7        | 16          | 78.9        |
| 21   | 29.7      | 53.7        | 26          | 79.1        |

- Fig. 6 shown the various current data input of total 500 data.
- Fig. 7 shown the various temperature data input of total 500 data.
- Fig. 8 shown the various voltage data input of total 500 data.
- Fig. 9 shown the various Depth of Discharge data input of total 500 data.

In next step we perform defuzzification process by implementing Mamdani method and Takagi Sugeno Kang method. The consideration of implementation these 2 methods is to have comparison of the 2 outputs result. Furthermore we could have recommendation which method more optimum to the battery prediction measurement.

Figure 6. Current data input.
Figure 7. Temperature data input.

Figure 8. Voltage data input.

Figure 9. Depth of discharge data input.
4. Result and discussion

We calculate various of four inputs criteria in fuzzification process and rule inference process, shown in figure 10.

![Figure 10. Rule and inference process.](image)

We see in figure 11 the Mamdani output battery capacity prediction with various parameter input criteria i.e. various current criteria, various temperature criteria, various DOD criteria, and various voltage criteria. The temperature range criteria shown mostly have a not radical fluctuation pattern. In other side voltage and current range criteria sometimes have a radical fluctuation pattern because of discharge occurred in the battery. And the DOD range criteria are shown several fluctuation patterns. Finally, we get the output with various criteria. The DOD range fluctuation shown is an important factor impact on capacity reduction. The high DOD range shown give high impact on the battery capacity reducing, with the lowest capacity is 30 percent, we know is a bad condition. In order to have comparison of the defuzzification output result we implement another method i.e. Sugeno method, shown in fig. 12. We see the output pattern of Sugeno method is most similar with Mamdani method. But Sugeno method have a lower range of the output criteria than Mamdani method. This occurred because Sugeno method apply different weighting factor in defuzzification process.

![Figure 11. Mamdani output battery capacity prediction.](image)
5. Conclusion

From the analysis it can be concluded that the prediction effective capacity of the BTS battery can be calculated by performing a fuzzy process of the input parameters in the form of current value criteria, temperature value criteria, voltage value criteria, and DOD value criteria.

Defuzzification with the Mamdani and Sugeno methods give almost the same output pattern, but the Mamdani method provides a larger output range. The fluctuation of the input range will give impact to the battery capacity, and from the graph shown the high Depth of Discharge gives a high impact on battery capacity reducing. The lowest prediction shown battery capacity prediction is 30 percent of nominal capacity, and this is a bad battery condition. Furthermore, after the cellular engineer knows the battery capacity condition, they should take proper action for example replace the bad battery with the new one by on-time action.

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