Smart Energy Meter for Electric Vehicle Based on Bluetooth and GSM Technology

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Abstract*— Smart Energy Meter (SEM) has been successfully built for power consumption billing system of battery charger on electric vehicle based on bluetooth and GSM technology. The SEM has been tested using battery charger on electric bicycle as a load. Interaction between the customer (electric bike user) to the SEM is conducted by applying bluetooth and GSM. Duration time from customer requests to the SEM and SEM response is less than 1 minute. Communication between customer to the SEM is monitored by operator via SMS service from the SEM. Android-based application is built for bluetooth communication between the customer or operator to the SEM. The voltage and current measurement errors is reduced by the operator through unique code via bluetooth. Measuring errors are obtained at the values of 0.04% and 1.39% for voltage and current, respectively. THD on the current from the battery charger on an electric bicycle is too high at the value of 68.68%. Moreover, customer data and billing information are stored on SD Card storage media.

***Keywords*—SEM, electric vehicles, THDi, bluetooth, GSM.**

I. INTRODUCTION

The use of electric vehicles such as electric bikes, electric motors and electric cars is increasing nowadays. It is because these electric vehicles have advantages over the conventional vehicles using fossil fuels, such as: less noise, more easy maintenance and no pollution. There is also support on the electric vehicles development program from the Government of Indonesian through The Presidential Regulation Number 22 year 2017 about the General Plan of National Energy [1].

Electric vehicles energies are supplied by batteries which can store only limited amounts of electrical energy. These batteries are charged using an AC-DC converter that converts AC power from power lines to DC power. AC-DC converter is a non-linear electric device that can also produces high current harmonics [2]. Conventional AC-DC converter can produce a current Total Harmonic Distortion (THDi) of 77.9% [3].These high current harmonics can cause an increase in energy loss, a decrease in the quality of the electric network [4], an increase in the temperature of the transformer and also excessive load for high penetration of electric vehicles [5].

Electric charging stations are needed to provide the charging services for the electric vehicles. To customer convenience, the electric charging stations are placed at parks, schools, malls, and other recreational places because the time to charge the battery depends on the AC-DC converters quality. The electric vehicles stay to charge while the customer can leave its electric vehicles and the battery charging status can be monitored. The customer obtains infromations such as energy cost and its AC-DC converter quality. For this condition, a billing system is needed at the electric charging station that can provide access to the customer from a distance location at any point and time. To provide that access, the billing system should be equipped by long range communication technology that has been widely used and has high security such as: GSM. GSM is a communication technology for smart energy meter for billing system and load control [6]. The GSM-based energy meter and energy record result can be sent via Short Message Service (SMS) [7] to the user. This intelligent GSM-based energy meter for prepaid system can also provide the ability to prevent electrical theft [8]. This smart energy meter provides limited information only, ei., energy costs of customers in a certain period.

The current THDs content of the AC-DC converter needs to be informed to the customer to tariff basis strategy on energy costs. Smart energy meter for the purpose of the tariff strategy based on the current THDs content of the electric load has been designed in [9] but it cannot transmit the information to a customer or a power center in a long distance location. Electric loads with higher current THDs content are more expensive per-kWh tariffs. Meter calibration is conducted by changing the scale of the voltage and current sensors to guarantee validity of meter measurement in hardware. Meters ID or meter name is changed by updating data on meter throught microcontroller software. Both calibration and changing data on energy meter can be easier via bluetooth [10]. The module of the bluetooth is HC-05 module. This module sends information up to 14 meters distance without a barrier. While, barrier by the wall, this module sends data limited to 10 meters distance.

A Smart Energy Meter (SEM) for electric vehicles based on bluetooth and GSM technology is proposed in this research. Bluetooth is used for setup and calibration of the SEM by operator. Bluetooth and GSM are used to communicate the SEM and customer. Its communication is always monitored by operator via SMS. The paper is organized as follows: Method to design of smart energy meter is described in Section II. Next, hardware and software to implement smart energy meter design are depicted in Section III. Result and discussion are explained in Section IV. Finally, the conclusion is given in Section V.

II. Design Method of Smart Energy Meter

SEM uses microcontroller (Arduino Mega 2560), voltage sensor (ZMPT101B), current sensor (CT5 (60A / 2mA), GSM module (mini IOT GA6), bluetooth module (HC-05), electronic clock (RTC-DS3231), TFT LCD 2.4 inch, relay 1 module, led, buzzer, MCB, and storage media (SD Card). Fig. 1 shows the block diagram of the SEM for billing system of electric vehicles. Customer can request to use SEM for batteries charging on electric vehicles via bluetooth or GSM. All interactions between customer and SEM is monitored by operator via SMS from SEM. SEM can also be setup or calibrated by operator using android-based application.

Flow chart in Fig. 2 is separated into 4 parts. Part 1 is process to write main files on storage media. The main files are in the form of a txt file. Main files contain default data such as: SEM01, 1234, 154.00, 6.67, and 1600 for SEM name, password, voltage sensor scale, current sensor scale, and energy price, respectively. Part 2 is to setup process for bluetooth name and password at AT mode. Part 3 is setup or calibration SEM process using android-based application. Codes for SEM setup and calibration are listed in TABLE I. Part 4 is the communication process between customer and SEM. The methods for calculating of voltage (Vrms), current (Irms), power (Watt), Power Factor (PF), Distortion Factor (DF) and Total Harmonic Distortion of current (THDi) are formuled as in [9]. Energy consumption (kWh) of an electric vehicle is electric power multiple by time duration of battery charging. Energy cost is calculated by multiplication of kWh and the energy price per-kWh.

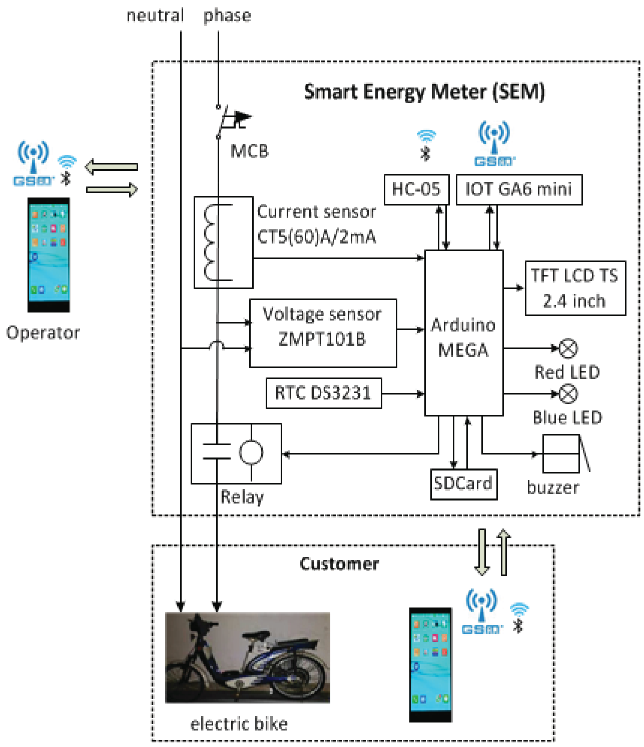


Fig. 1. Smart energy meter for electric vehicles

TABEL I. CODES FOR SETUP AND CALIBRATION

No.	Remarks	Codes
1.	To replace pswd	*010;old _pswd:new _pswd#
2.	To replace price	*301; pswd:new_price#
3.	To replace SEM name	*303; pswd:new_name#
4.	To replace Owner GSM no.	*909; pswd:new_GSM_no#
5.	Info @kWH price	*123#
6.	Voltage calibration	*701; pswd:Vref/VSEM
7.	Current calibration	*702; pswd:Iref/ISEM

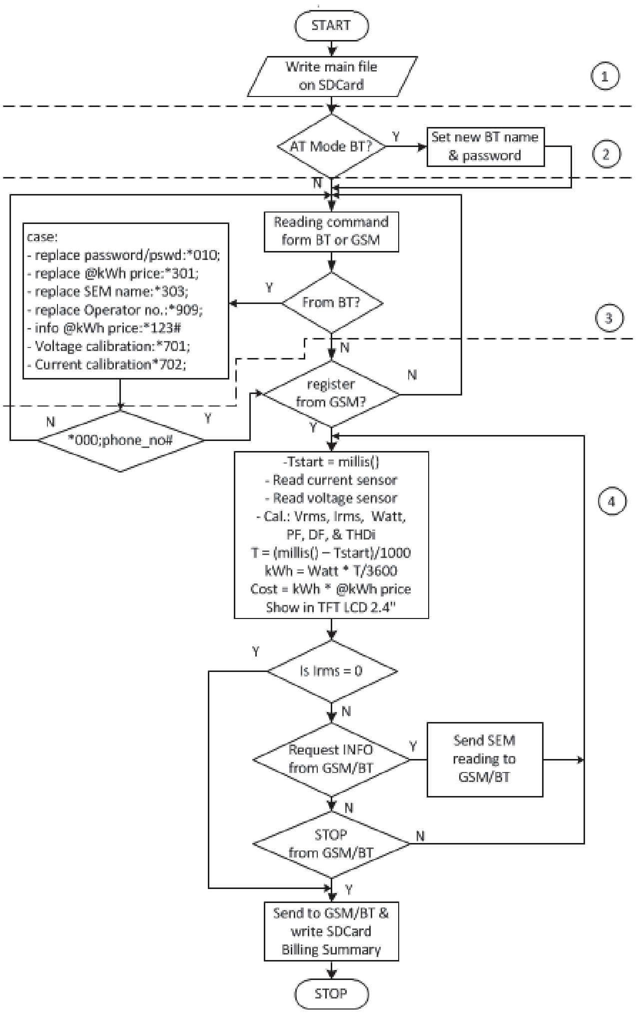


Fig. 2. Smart energy meter operation process flow chart

III. Hardware and Software Implementation

The circuits for current and voltage sensors are as in [10]. Fig. 3.a. shows the connection between IOT GA6 mini and the Arduino Mega. IOT GA6 mini is supplied by voltage (+5 Volt) from Arduino Mega. Pin 10 (Rx) and 11 (Tx) on the Arduino Mega are used as serial communication to the IOT GA6 mini. Fig.3.b. shows the connection between HC-05 and Arduino Mega. As IOT GA6 mini, HC-05 is also supplied by voltage (+5 Volt) from Arduino Mega. To enter AT mode, pin 34 must be supplied by voltage (+3.3 volt). Pin 14 (Tx3) and pin 15 (Rx3) is used as serial communication to HC-05.

The hardware of SEM for electric vehicles based on bluetooth and GSM is shown in Fig. 5. All processes such as: read the sensors, calculate the Vrms, Irms, power, power factor, distortion factor, current THDs, energy and energy cost are carried out by Arduino Mega. TFT LCD 2.4 inch is used to display informaton such as: guide for customer or billing of energy price. The RTC-DS3231 is an electronic clock on SEM. Relay 1 module is a breaker that can be controlled by the SEM for on/off power from SEM to electric vehicles.

This research uses software Arduino IDE 1.8.5 and App Inventor. The Arduino IDE 1.8.5 for programming on Arduino Mega. Meanwhile, The App Inventor is used to build an android application. Three main parts of the Arduino IDE program are initial declaration, setup and loop [11]. Variables and libraries are declared on the initial declaration part. The TFT LCD 2.4 inch libraries are Wire.h, Adafruit_GFX.h, UTFTGLUE.h and MCUFRIEND_kbv.h. The SD Card libraries are SD.h, and SPI.h. The RTC library is DS3231.h. The Fast Fourier Transform library is arduinoFFT.h. AnalogSmooth.h library is a filter to smooth sensors output. IOT GA6 mini libraries are SerialGSM.h and SoftwareSerial.h. The setup part is used to initiate variables, set pin mode, set the timer, set the serial port baudrate. The baudrate for serial communications are 38400 and 9600 bps for HC-05 and IOT GA6 mini, respectively. The loop part is the main function of the program that will be run repeatedly. Request connection process of customer to charge battery of electric vehicles, to read current and voltage sensors, to calculate Vrms, Irms, power, power faktor, faktor distortion, THDi, energy, and energy cost are included in this loop process.

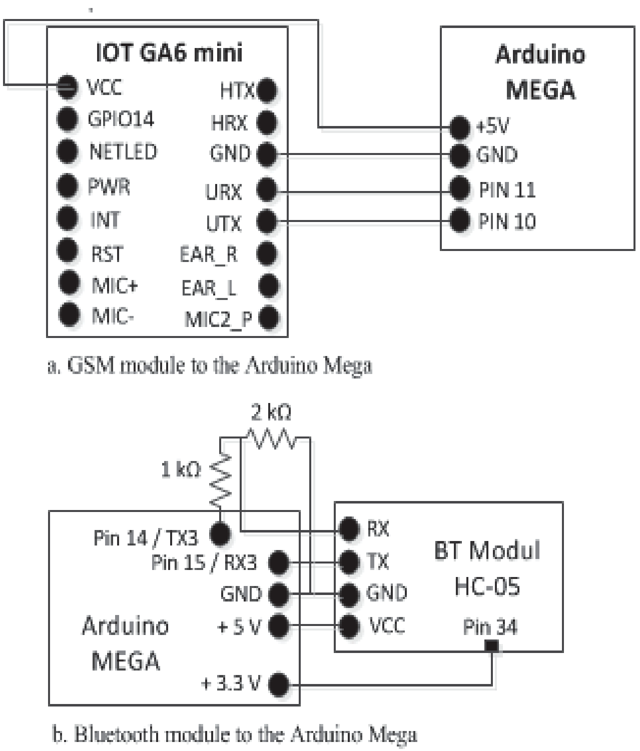


Fig. 3. Communication Module

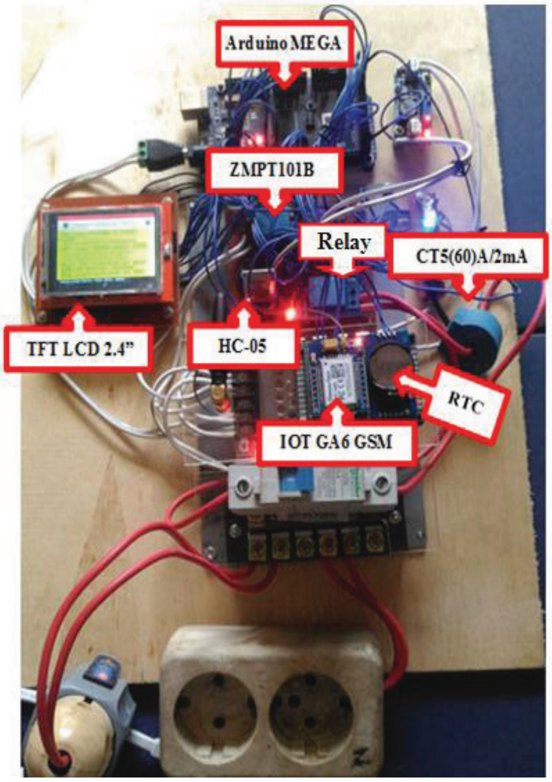


Fig. 4. Smart Energy Meter Hardware

Fig. 5. Android application for bluetooth communication

The App Inventor programming environment has three main parts namely component designer, block editor and android-based phone or android emulator to test the application [12]. Component designer is used to select applications and determine their properties. Block editor is used to create behavior for components. The main component in this study is the connectivity component (BluetoothClient) that used to comunicate between customer or operator and SEM. Fig. 5. shows design of android application on android-based phone.

IV. Result and Discussion

A. Smart Energy Meter Calibration

SEM calibration was done by replacing the sensor scale based on comparison to reference instrument (Multi 13S LM2330). Row 6 and row 7 at Tabel I show the code for voltage and current calibrations, respectively. Android-based aplication is used by operator to send a code "*701;pswd:Vref/VSEM" for replace the voltage sensor scale on SEM. Vref and VSEM are the Multi 13S LM2330 and SEM voltage measuring results, respectively. And, the code "*702; pswd: Iref/ISEM" for replace the current sensor scale on SEM. Iref and ISEM are the Multi 13S LM2330 and SEM current measuring results.

TABLE II and TABLE III are the results of voltage and current calibrations, respectively. The result shows that voltage error is decreased from 2.56% to 0.04%. Also, current error is decreased from 91.96% to 1.39%.

Tabel II. Results of voltage calibration

	$V_{Ref.}$ (Volt)	V_{SEM} (Volt)	Error (%)
Before calibration	231.80	237.73	2.56
After real time calibration	228.90	228.80	0.04

Tabel III. Results of current calibration

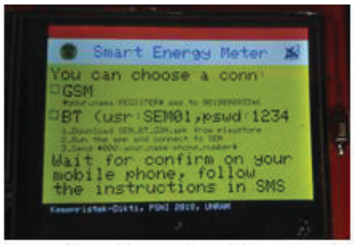
	I_{Ref} (Amp.)	I_{SEM} (Amp.)	Error (%)
Before calibration	0.00	0.00	0.00
	0.12	0.29	141.67
	0.24	0.56	133.33
Average before			91.67
After real time calibration	0.00	0.00	0.00
	0.12	0.12	0.00
	0.24	0.25	4.17
Average after			1.39

B. SEM simulation for electric bicycle

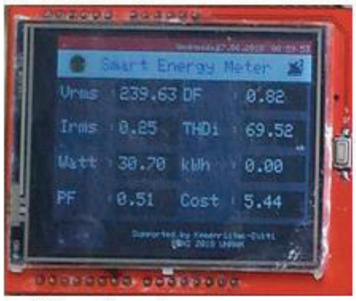
Customer guiding to Bluetooth or GSM communication between SEM and customer is shown in Fig. 6.a. As long as the customer energy demand is not approved, the relay from SEM is still OFF.

There are three SEM simulation scenarios for the customer. The first and second scenarios use GSM communication. And, the third scenario uses bluetooth communication. In the first scenario, the billing system stops due to customer requests. The second scenario, the billing system stops because the battery is fully charged.

In the first scenario, a SMS is sent by customer to SEM with the contents of the power supply access request to SEM. The SEM answers the request, as shown in Fig. 7.a. Next, Relay ON, electrical energy flows to the battery charger on the electric bicycle so that the SEM screen displays the electric variables (voltage, current, power, power factor, distortion factor, THD of current), kWh and energy cost is in rupiahs as shown in Fig. 6.b.

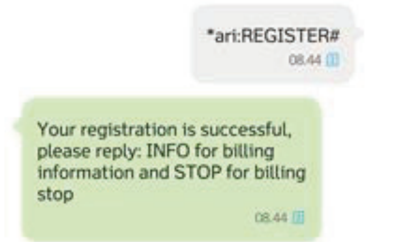


a. A guide to bluetooth or GSM comunication



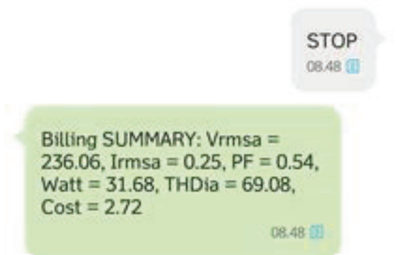
b. Billing information

Fig. 6. SEM Display



a. A request for using of billing, and SEM response

b. A request for information, and SEM response

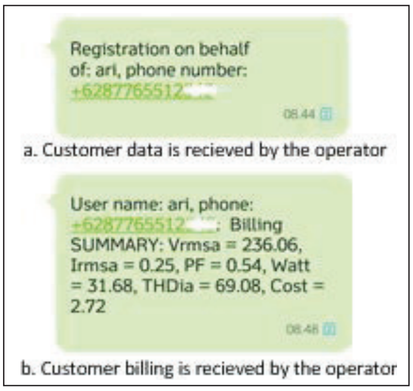


c. A request for stop, and SEM response

Fig. 7. Fisrt scenario: custumer to SEM by using GSM

Billing informations were monitored by customer via SMS by typing "INFO" as shown in Fig. 7.b. The Billing can be stopped via SMS by typing "STOP". And, SEM replied to customer the billing summary information as shown in Fig. 7.c. Then, relay was OFF.

An SMS was sent from the SEM to the operator for every agreed customer request, as shown in Fig. 8.a. An SMS was also received by the operator from SEM after the billing was stopped, as in Fig. 8.b.



a. Customer data is recieved by the operator

b. Customer billing is recieved by the operator

Fig. 8. Information from the SEM to the operator

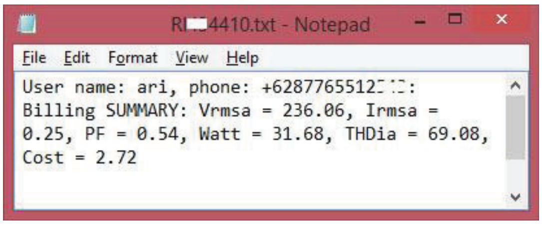


Fig. 9. Txt file for the first scenario on the SDCard

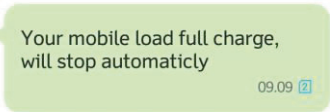
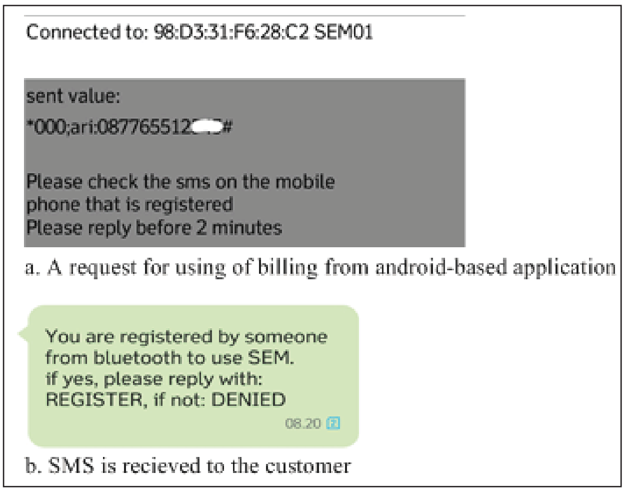


Fig. 10. SMS from SEM to customer

Billing summary was stored on SD Card in a txt file. Fig. 9 shows a txt file for the first scenario. The file name was taken from two last letters of customer name, plus two last numbers of customer GSM number, plus minutes and seconds when the customer request was approved. Duration time of customer requests and SEM response of the requests such as: access to power supply, billing information or billing stop were less than 1 minute.

The second scenario, customer makes a request to SEM as same as first scenario processes. But, without request to stop, the billing system will stop automatically when the battery on the electric bicycle was fully charged. Then, customer received SMS from SEM as shown in Fig. 10.

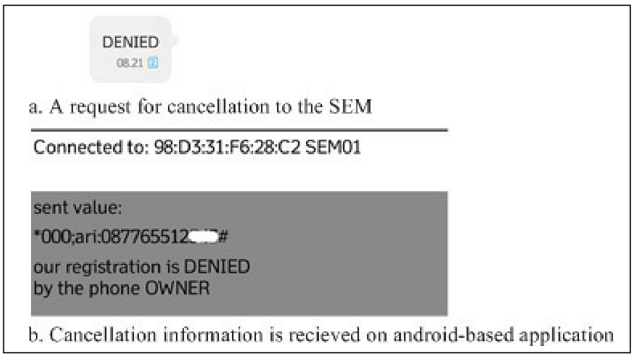
Third scenario, bluetooth communication is used by customer via android-based application to charge electric bicycle battery, as shown in Fig. 11.a. In this scenario, the SEM sent SMS to the GSM number of customer as in Fig. 11.b. The customer can cancel the request by typing SMS to SEM as shown in Fig. 12.a. Cancellation information is received by customer on android-based applications as shown in Figure 12.b. When customer request was continued, the same information was received by customer as same as the first scenario with additional authority to access SEM from the android-based application as shown in Fig. 13. SEM gave the private key for that access. Private keys were three random numbers from 100 to 999 that were created when a customer requested by using android-based application. Billing information or billing stop were done by customer using private key, as shown in Fig. 13.a. or Fig. 13.b., respectively. Information via SMS was still received by operator and customer. Meanwhile, data transaction was stored in SD Card.



a. A request for using of billing from android-based application

b. SMS is recieved to the customer

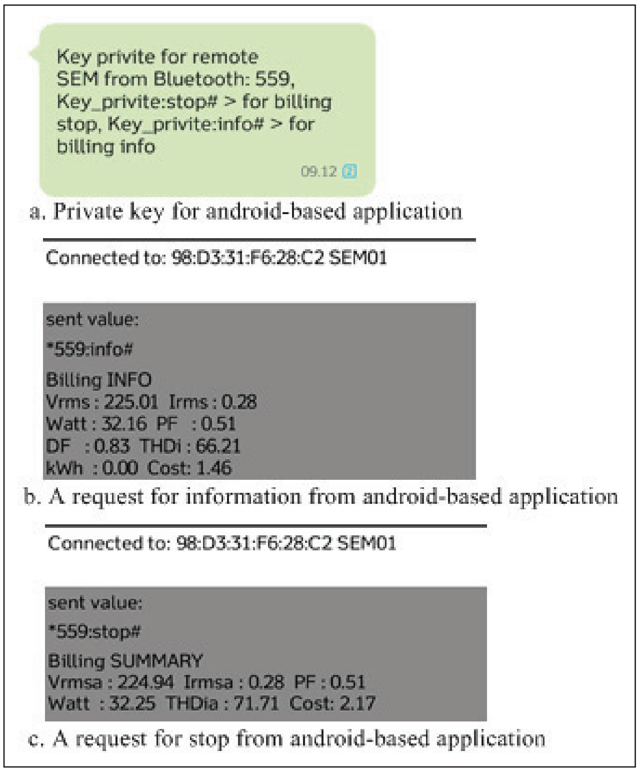
Fig. 11. Communication of customer using bluetooth



a. A request for cancellation to the SEM

b. Cancellation information is recieved on android-based application

Fig. 12. Customer to cancel the request



a. Private key for android-based application

b. A request for information from android-based application

c. A request for stop from android-based application

Fig. 13. Private key for android-based application

C. *Analysis battery charger current of electric bicycle*

The current waveform of the battery charger on an electric bicycle was not pure sinusoidal as shown in Fig. 14.a. The harmonic spectrum of the current waveform is shown in Fig. 14.b. Fig. 14.b. shows that there is a dominant harmonics at odd frequencies of 150 and 250 Hz. Total Harmonic Distortion in the current consumed by the battery charger on the electric bicycle was 68.68%. The simulation results show that the power factor of the battery charger on an electric bicycle was low at the value of 0.52. The distortion factor of that battery charger was 0.82. So, the power factor at the base frequency (50 Hz) was obtained at the value of 0.63 as formalated in [9].

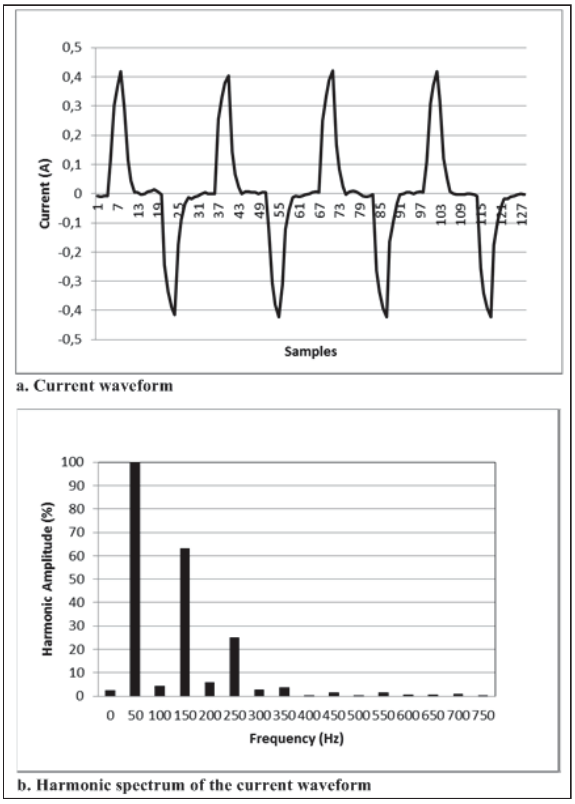


Fig. 14. Battery charger current of an electric bicycle

V. CONCLUSION

In this research, SEM for electric vehicle is developed to a billing system for power consumption of battery charger. This device combined bluetooth and GSM with energi meter based on Arduino Mega in one frame. This device is applied to calculate energy cost and current quality of battery charger on electric bicycle. In this field test, interaction between operator or customer and SEM work properly by using bluetooth and GSM. Duration of time from customer requests and SEM response is less than 1 minute for both communications. SEM calibration processs is done by operator via bluetooth. The results show that measuring error for the SEM reduced to 0.04% and 1.39% for voltage and current measurements after calibration. THD current of battery charger on an electric bicycle is very high, at the value of 68.68%.

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