Electric Vehicle Charging Communication Test-bed following CHAdeMO

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***Abstract*— Among the challenges that slow down electric vehicle proliferation, one major factor is technological and progressive features associated with charging infrastructure. This paper presents the development and implementation of electric vehicle charging communication test-bed following the globally accepted charging communication standard "CHAdeMO". The developed test-bed has software and hardware modules for CHAdeMO message passing that helps in achieving communication of electric vehicle with the charging infrastructure. Graphical user interface created in MATLAB mimics electric vehicle and electric vehicle supply equipment and CAN module of vehicular network toolbox in MATLAB is used for data exchange in accordance with CHAdeMO standard in software. The hardware implementation is achieved using Arduino mimicking electric vehicle and electric vehicle supply equipment and MCP2515 CAN controller for message passing. The test-bed demonstrates different stages of message passing as per CHAdeMO standard both in software and hardware. In addition to fulfilling the purpose of a test-bed for electric vehicle charging communication the setup can also be used as a teaching tool for CHAdeMO protocol. The test-bed can be further extended by implementing message passing using other charging standards such as GB/T or CCS and other wired and wireless communication protocols.**

***Keywords*—CHAdeMO protocol, EVSE, Electric Vehicle, Test bed, Vehicular Network Toolbox ;**

I. Introduction

Automotive industry experienced a swift growth in past few decades due to changing lifestyles. The contribution of fuel vehicle in development of various sectors is remarkable, but its role in global warming and environment degradation cannot be disregarded [1, 2]. Though advantage of emission free vehicle over fuel vehicle are several, widespread use of green vehicle is not seen in last decade, making it less competent to fuel vehicle in automotive industry. The recent past has seen a drastic shift by most countries across the globe bringing a force in rush of electric vehicles (EV) in the automotive industry [3]. Government of India has announced various incentives under Faster Adoption and Manufacturing of Electric Vehicles (FAME) scheme for promoting the purchase of EVs [4].

Barriers in expansion of electric vehicle include less number of Electric Vehicle Charging Infrastructure, larger charging time and less driving range [4]. Numbers of charging stations are lesser than fuel stations which causes inconvenience for switching from conventional to electric vehicle [4]. Level 1 and Level 2 AC charging of electric vehicle require long hours to energize the battery to its full capacity while fuel tank can be refueled within few minutes in conventional vehicles. Development of DC fast charging or ultra-fast charging technology which can charge up to 80% of battery capacity in 15 minutes [5] reduces waiting time of vehicles in charging station, and indirectly can decrease the demand of large number of charging stations. It also reassures drivers for long drive. As battery parameters differ with respect to vehicle manufactures, necessary communication need to be established between charger and vehicle for efficient charging.

Combined charging system (CCS), GB/T, and CHAdeMO are the three well recognized and widely accepted standards in electric vehicle fast charging [5]. CCS and CHAdeMO partially complies with IEC 61851 while GB/T follows similar standard GB/T 18487[5]. CCS is a prominent international protocol which unifies three phase, single phase and DC fast charging under a single charging system [7] whereas GB/T is fast charging protocol used majorly in china [8]. The latest version of CHAdeMO, CHAdeMO 3.0 is updated to an ultra-high power charging standard having backward compatibility with existing DC quick charging standards such as GB/T, CHAdeMO, and CCS [9]. This ultra-high charging protocol also offers support to Vehicle to Grid (V2G) power transfer enabling EV to act as distributed energy storage. Implementation of vehicle CHAdeMO interface (VCI) can transform all EV occupied AC charging type to fast DC charging and enable V2G functionality using CHAdeMO vehicle unit[10].

This paper presents software and hardware framework for an electric vehicle charging communication following CHAdeMO based data exchange between EV and Electric Vehicle Supply Equipment (EVSE). This test-bed becomes handy for further research on addition of new functionalities in terms of operational capabilities and features to the electric vehicle charging communication protocols. The work involves the development and implementation of CHAdeMO message exchanges in MATLAB and in Arduino Uno. As CHAdeMO

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uses Controller Area Network (CAN) for message exchange, Vehicular Network Toolbox and MCP2515 CAN module are used to implement CHAdeMO message flow over CAN in MATLAB and Arduino respectively. User can simulate CHAdeMO based message flow in this setup as in real scenario. This test system also give user provision to see the behaviour of EV and EVSE under various operational conditions during charging in charger or vehicle.

In this paper, section II deals with the literature survey done for the project and the conclusions derived from it., Section III gives detail about the system and its design, section IV gives a brief description of CHAdeMO protocol, Section V deals with the implementation of charging communication test-bed, Section VI discuss on results and Section VII concludes this work.

II. LITERATURE SURVEY

Complete adoption of electric vehicle for a cause of sustainable environment can act as a stimulant for fourth industry revolution in history [11]. Ongoing research in EV material, battery technology, and charging system can help in tackling many challenges to realization of the concept of green transportation. In fact, an increase in public EV charging station can have a big influence in EV penetration [1]. There are three different type of AC charging systems: Type 1 SAE J1772- 2009, Type 2 Mennekes VDE-AR-E 2623-2-2, and Tesla dual charger. Battery size and weight restriction made limitations in AC high power charging. Type 4 DC chargers can be used for rapid charging beyond 50kW [12]. DC chargers are of three types globally: Type 4 CCS, Type 4 CHAdeMO and Tesla. Since chargers are off board in DC charging, a communication infrastructure must be established between vehicle battery and charger. In addition to these charging standards, GB/T can also be added as one of the popular charging protocol. Proper standardization for charging process increases the interoperability between EV and EVSE [13].

An electric vehicle following a GB/T 18387-2017 and GB 14023-2011 is provided with solution which enable EV radiation emission meet requirements of national standards [14]. A comparison of CHAdeMO, ISO 15118 – 2 and GB/T is done based on certain criteria such as implementation easiness, CAN compliance, cost, safety aspect, certification cost, extendibility etc. Based on these parameters, GB/T is ranked higher than other two protocols and was implemented between EV and EVSE and a centralized management system was developed based on OCPP protocol [15]. A CHAdeMO protocol based test equipment was developed that would imitate the behaviour of EV and can inspect the quality of newly developed charging stations by reproducing error scenarios and charging operation of EVSE [16].

DC power generated from solar photovoltaic cell can be used directly to charge EV using MPTT algorithm and CHAdeMO rapid charger [17]. A bidirectional EV charger compatible with CHAdeMO and CCS is designed and developed which charge from both photovoltaic panels and power grid [18], thus reduces the dependency on grid. Due to poor performance of vehicle battery, EV cannot reach up to the level of traditional vehicle [19]. High power charger based on CHAdeMO protocol with power factor correction circuit can charge LiFePO4 battery at rate of 2C with reduced THD, minimizes charging time and maximize charging efficiency [20]. Improvising battery technology, inclusion of better functionalities to charger circuits can be an encouragement for EV and thereby increasing charging poles.

Open Charge Point Protocol (OCPP) is an international standard for message exchange between EVSE and central management system [21]. This protocol is extended by adding reservation feature that helps user to control the entire process in charging reservation like authentication, choice of charger and charge monitoring and payment [22]. A smart management system in a Smart city termed as SeeCharge (Secure Electric Vehicle Charging Ecosystem in Smart Grid) implemented with the help of OCPP, provide smart charging to EV and also responsible for maintaining customer and billing information securely [23].

There is a tremendous development from wired charging to wireless charging in past decade which also reinforce dynamic charging system. Wireless charging can resolve many issue that EV customer face such as battery size, user friendliness and no exposure to water or dust [24]. In addition to wireless charging, wireless communication between EV and EVSE can soothe the charging. But, existing standards support only wired communication such as CAN and Power Line Carrier communication. Therefore, wireless standards need to be introduced to charging communication that can make user more convenient to EV and lead automotive industry to next stage of revolution.

Significant research progress is to be achieved in fields of EV charging, charging communication and standardization of charging communication for successful diffusion of electric vehicle into the automobile market. As research in these areas are not viable in a real world setup due to time and cost, a test-bed is essential. This test-bed should have features necessary for performing different operations in EV charging with different protocols and a behavior similar to actual setup.

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III. SYSTEM ARCHITECTURE

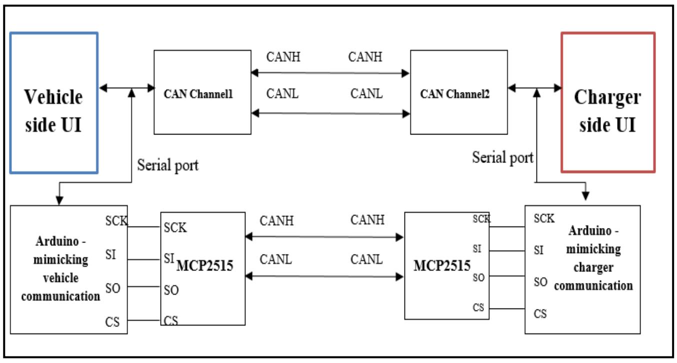

Fig. 1. System overview of CHAdeMO based charging communication test-bed

Figure 1 represents basic architecture of EV charging communication test-bed following CHAdeMO. A data exchange between EV and EVSE in accordance with CHAdeMO protocol is implemented with the help of MATLAB and Arduino. Since CHAdeMO protocol follows base frame format of CAN communication [13], CAN message function of standard format in vehicular network toolbox is chosen for transmitting and receiving CAN communication messages in MATLAB. In built functions like CAN channel, CAN message, transmit, receive is used for data transfer to CAN bus [25]. Since transmission rate of CAN messages in CHAdeMO is 500kbps [13], virtual CAN channel bus speed is set as 500000.

The same charging communication testbed can be used for data exchange mimicking EV and EVSE using Arduino Uno with the help of MCP2515 CAN controller. MATLAB support package for Arduino hardware enable communication between Arduino Uno and MATLAB. Arduino receive vehicle messages or charger messages from MATLAB through serial port. These messages are transmitted using MCP2515 CAN controller. Reception of message is indicated to the user through an LED and is sent to MATLAB through serial port.

IV. CHADEMO PROTOCOL

CHAdeMO or Charge de Move is a globally accepted quick DC charging standard developed by the association of Toyota Motor Corporation (Toyota), Nissan Motor Company (Nissan), Mitsubishi Motors Corporation (Mitsubishi Motors), Fuji Heavy Industries Ltd. (Fuji Heavy Industries), and The Tokyo Electric Power Company, INC. (TEPCO) [26] as development of rapid charger is a requisite for more penetration of electric vehicle into automobile industry. This level 3 dc charger can deliver up to 500kW providing maximum current 600A with its new version CHAdeMO 3.0 [9].

The charger uses constant current control method for charging vehicle battery treating vehicle as master and charger as slave.

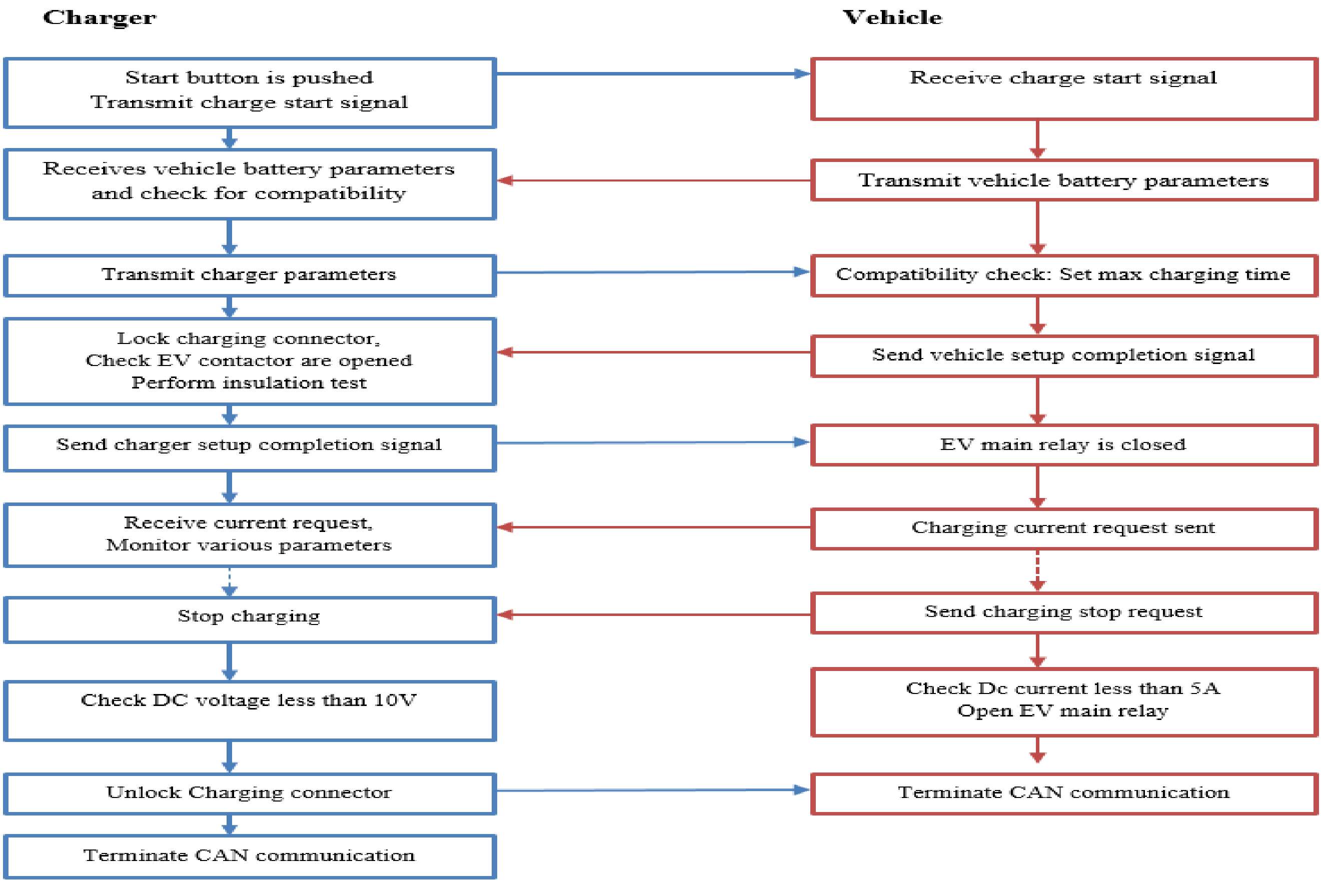

Fig. 2. Charge control flow for CHAdeMO

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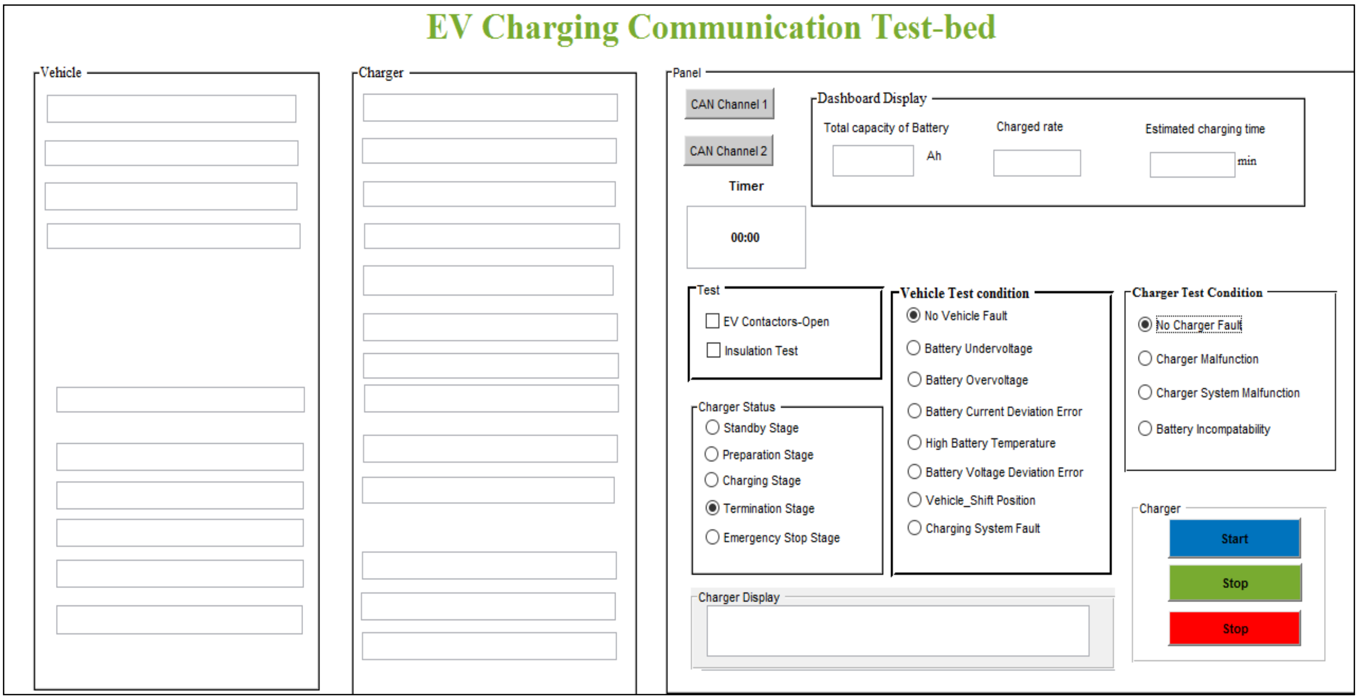

Fig. 3. EV charge communication test-bed GUI

Every message need to be transmitted in a cycle of 100 milliseconds. In addition to these messages, analog signals are also triggered for communication from vehicle to charger or vice-versa [10]. Charge sequence signal 1 is the initial signal given from charger to vehicle at the start of charging. Vehicle charge permission signal is an analog signal indicator of vehicle setup completion, transmitted from vehicle to charger. Connector proximity detection line tells the status of vehicle parking status [10]. Completion of charger setup is shown by state change in charge sequence signal 2 line.

The flowchart for charging following CHAdeMO is shown in figure 2. The process of charging starts on pressing charge start button on charger enclosure. A 12 V dc is supplied to vehicle through charge sequence signal 1 which excites opto-coupler. This is noticed by vehicle and transmits the first CAN communication. Vehicle sends total battery capacity, maximum battery voltage, and battery voltage to charger for compatibility check. Vehicle and charger are compatible when target battery voltage is lesser than available output voltage. Charger clears battery compatible flag and send charger parameters like voltage, current, protocol number. Vehicle receive these information, set the vehicle charging enabled flag and transmit to charger. Charger receive these information from vehicle and lock the charging connector for insulation test. Charger setup completion is indicated by a state change in charger sequence signal2 line voltage. EV detects the state change, closes main relay and sends its charging current request in a constant time interval to charger.

The charger receives and charge the vehicle with updated current value. The vehicle monitors battery parameters like voltage across vehicle inlet, charging current, temperature during charging. Similarly charger observes various circuit parameters. Vehicle sends a zero current request to charger indicating charging termination. It also clears vehicle charging enabled flag and drops the vehicle charge permission line voltage to 0V. Charger receives this request and stop charging. Charger checks voltage across dc output circuit and unlock charging connector while vehicle opens the main relay if current through vehicle inlet is less than 5A. CAN communication is terminated. Charger can initiate for charge termination process if charge stop button is pushed or any charger malfunction or vehicle malfunction occurs. Similarly vehicle can change to charge termination process if any malfunction occurs in vehicle or charger side or on-board battery charged rate attained a specific limit.

V. IMPLEMENTATION OF EV CHARGING COMMUNICATION TEST-BED

The charging communication test-bed can be used as learning tool which mainly focus on message exchange following CHAdeMO protocol between EV and EVSE during charging and behavior of the system towards different operational conditions. Test-bed GUI following CHAdeMO protocol created in MATLAB is shown in Figure3. Virtual CAN channels are created using VNT canChannel built in function. CanMessage in Vehicular Network Toolbox is used to create CAN message with IDs specified [24].

Since CHAdeMO protocol uses standard ID format, extended format in canMessage is set to false. CAN channel for vehicle is restricted to receive IDs (H’108 and H’109) while charger CAN channel receive IDs (100,101,102). Start button in GUI resembles the start button in Charger enclosure. This will start the CHAdeMO procedure as in real time. Estimated charging time, charged rate and total battery capacity is displayed to user through Dashboard display.

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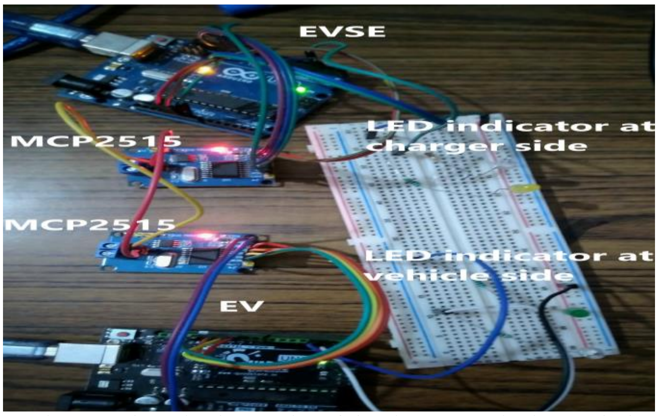

Fig. 4. Hardware implementation of charging communication test-bed following CHAdeMO protocol

Normal workflow continues if no vehicle or charger fault occur during process. User can choose any vehicle or charger error from the vehicle test or charger test panel to see how system behaves during error scenarios. Transmission cycle is 100ms as per CHAdeMO standard. Since this duration is very short for demonstration, time is scaled to one second. User can see different stages of charger - from start stage to termination stage in the complete operation of the system. The check box denoting EV contactors open and insulation test need to be checked within specified time after charging connector is locked.

User can simulate the scenario of failing insulation test by unchecking the insulation test box, followed by charge termination process. Instructions given to the customers during abnormal condition is displayed in charger display. CHAdeMO protocol is implemented in hardware using two Arduinos mimicking EV and EVSE as shown in figure 4. Arduino MATLAB communication is made available through serial port using MATLAB support package for Arduino. When CAN message is transmitted in test-bed through VNT, Arduino mimicking EV receive data from GUI through serial port and transmit to Arduino mimicking EVSE using MCP2515 and vice versa. CAN message reception is indicated to the user by LED blink combination. Arduino sends the data to the charger side in MATLAB GUI through serial port.

VI. RESULTS AND DISCUSSION

Software and hardware test of charging communication test-bed has been performed and analyzed system behavior in all scenarios including normal operation, vehicle error detection (battery under voltage, battery over voltage, high temperature, battery current deviation error, battery voltage deviation error, voltage shift position and charging system fault), charger error detection (charger malfunction, charger system malfunction and battery incompatibility) and emergency stop operation. Figure 5 shows the complete operation of EV charging communication including connecting, handshaking, charging, charging termination and disconnection with no error in vehicle or charger side observed. Charging termination can occur if any data frame is not received in 100ms (scaled up to 1 sec) leading to charging system fault or charging system malfunction.

Battery incompatibility occurs when available output voltage is less than target battery voltage. Battery incompatibility radio button need to be selected before start button on the

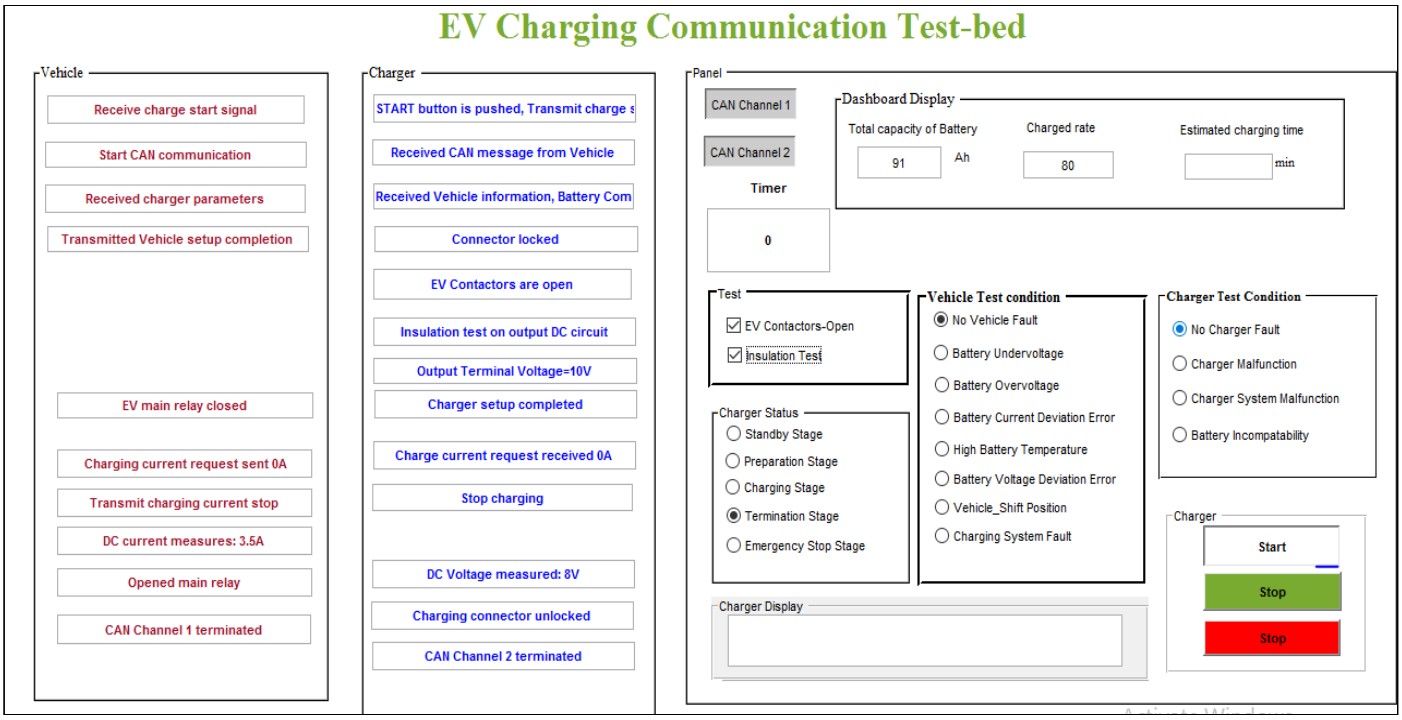

Fig. 5. EV Charging communication test-bed GUI during normal operation

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charger is pushed. It modifies target battery voltage to a higher value greater than available output voltage. User is informed via charger display shown in Figure 6 that the charger cannot charge the vehicle.

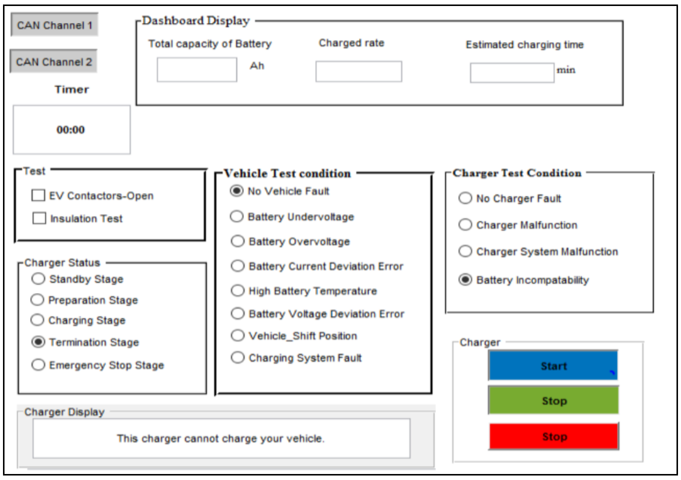

Fig. 6. Battery incompatibility scenario reproduced in test-bed GUI

User can reproduce the respective error scenario by clicking on radio button under vehicle test condition or charge test condition panel. Figure 7 displays an error scenario in which battery voltage is less than minimum voltage specified during charging. This can cause an immediate charging termination by setting flag corresponding to error. Likewise many error scenarios can be replicated using this GUI. Red colored push button labelled as stop is the emergency stop button. Emergency stop button is given the higher priority over all errors and action, leading to circuit breaker trip in charger side and contactor open in vehicle side.

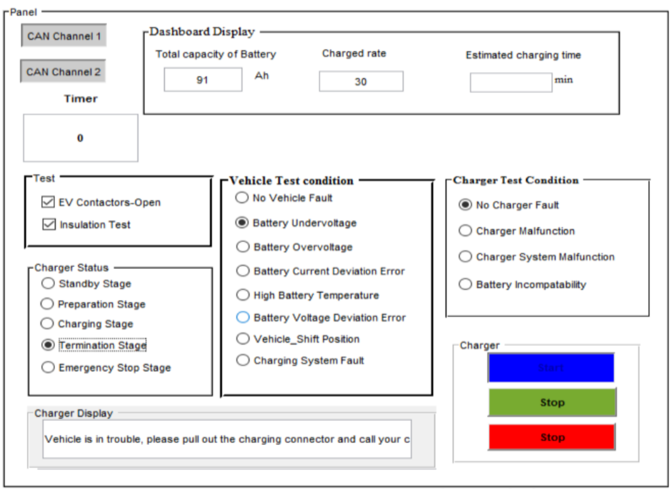

Fig. 7. Battery under voltage error scenario in test-bed GUI

Software simulation of CHAdeMO message passing between EV and EVSE is performed with the help of Vehicular Network Toolbox. Hardware support for the same GUI is done with the help of two Arduinos mimicking EV and EVSE and MCP2515. Arduino receives data from MATLAB through serial port and transmit the message through MCP2515 CAN controller. Figure 8 shows an LED blink during message reception from Arduino mimicking EVSE to Arduino mimicking EV through MCP2515.

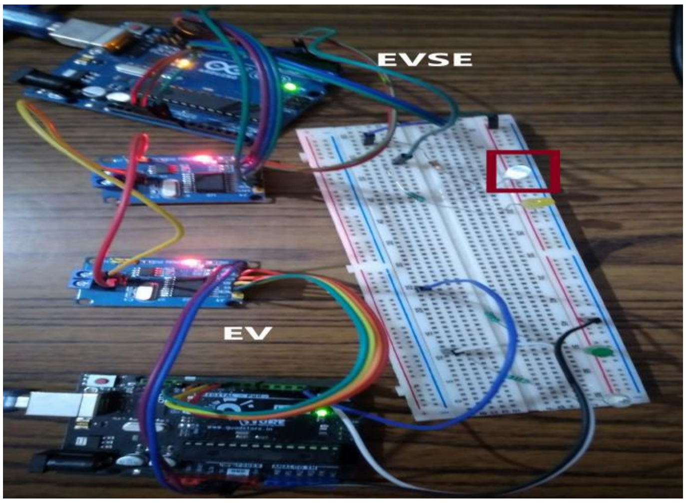

Fig. 8. A LED blinks in EV side representing charger message reception

VII. CONCLUSIONS

Standardization of charging communication between EV and EVSE will enhance interoperability and increase charging efficiency in dc quick charging. This testbed can be an aid to scholars, industry personnel doing research on enhancement in EV features as it simulate different scenario in EV charging communication using MATLAB GUI and hardware. Message exchange in CAN communication can be achieved in MATLAB with the help of VNT toolbox. The testbed is implemented in hardware using Arduino and MCP2515 CAN controller with the help of MATLAB hardware support package for Arduino.

Wireless charging communication can swipe away hurdles of long queue for charging as battery compatibility, V2G charger identification, charging cost can be known without charger vehicle connection physically. Inclusion of different protocol like CCS, GB/T and wireless technology in charging communication can be future extension to this test bed.

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