Dynamic Human-Machine Interface for Electrical Vehicle design guidelines

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***Abstract*— this article deals with a Human Machine Interface of Electric vehicles starting from the history of Electric Vehicles HMI, describes currently used system elements and provide evaluation of their advantages and disadvantages. A new concept of Dynamic HMI for Electric Vehicles is introduced to improve EV efficiency in terms of energy consumption and range distance, and consequently increase their popularity among users. This interface is capable to adapt itself to user or system needs and changes dynamically based on EV battery State of Charge or reachability of desired destination. Such implementation of HMI address one of the main reason why users still prefer conventional vehicles with internal combustion engine to EV – range anxiety phenomena.**

This article aims to be a guideline for a design of new concept of HMI for EV, studies user requirements and propose a methodology of system development including concept definition and user acceptance validation methodology on vehicle driving simulator.

***Index Terms*— HMI, Electric Vehicle, Hybrid Car, IVIS, GIS, Extended navigation**

I. Introduction

TODAY the environmental impact of transportation is significant, according to Europe Environment Agency transport sector is responsible for 19.7% of GHG (greenhouse emissions) in Europe and passenger cars responsible for 12% of this share. More over CO2 emissions from transport have risen rapidly in recent years, from 21% of the total emissions in 1990 to 28% in 2004 [1]. That's the reason why more and more countries all over the world have adopted a guidelines published in EU Directive Regulation CE/443, which is focused on limiting pollution caused by road vehicles

However, BLUE Map scenario published in 2011 by International Energy Agency predicts a decrease of CO2 emissions level produced by transport sector almost to the level of year 2005 by increasing sales of Electric Vehicles (EVs) and Plug in Hybrid Electric Vehicles (PHEVs) up to 100 million units per year until 2050. Unfortunately, until today, EV sales are still much less than 20,000 units in a 12 million new car market[2]. Several factors are slowing down penetration of EV to the market. Base on a survey [3] the most important of them are:

1. Distance with one recharge (Range anxiety Phenomena) – 32%
2. Car purchase price – 32%
3. Re-charge at home without private garage -25%
4. Re-charged time -9%
5. Max speed -2%

Range anxiety phenomena"- is a fear of potential driver that he or she will not be able to reach a destination point without recharge. Properly designed Human Machine Interface (HMI) for EV can significantly minimize this effect.

First attempt to introduce different HMI design for EV interface was mad in 1990s when Honda EV Plus introduced the digital monitor substituting dashboard with 3 x 7-segment display for speed integrated with battery SoC (state of charge) and distance to empty indicators. In 2000s LCD and touch screen displays has been developed, digital instrument clusters and navigation systems opened a new approach for HMI design. Some new features such as power flow display where introduced, however, representation of standard information obtained from a vehicle (the status from ECU) has not change a lot. The SoC, Range information, charging mode has not changed conceptually except that they appear more attractively. Recently performed studies [4] shows a demand to develop a new concepts of interaction with EV, which will help to improve efficiency of modern EV and make them more user-friendly and simultaneously increase an acceptance of EV technology by society

II. System currently in use

Let us assume that vehicle-to-driver (and vice versa) communication can be subdivided into display systems (the information displays and gauges), starting system, pedaling and charging system. Besides the intuitive design, interface needs to provide useful and relevant information sufficient to keep driver confident in vehicle functionality.

There are two approaches to design of EV display gauges.

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The first one tries to make the appearance of the system maximally similar to ordinary ICE (internal combustion engine) vehicles Analog gauges with pointers are used to display additional information related to EV systems operation. Smart for Two or Tata Vista are good examples of such design, where power in/out gauges and battery state of charge represented similar to fuel tank capacity gauges of ICE (Figure 1)

Fig. 1. Example of analog gauges dashboard with SoC and Power in/out gauge

Familiar appearance makes the interaction intuitive for a user familiar with ICE vehicles and makes the transition from ICE to EV more comfortable. Location of gauges and manner of information is carried out on the assumption of the general knowledge and standards. According to ANSI (American National Standards Institute) [5] the indicators standardization is not electric vehicle specific, this means that general rules for a in vehicle displays are applied here. Thus, instead of tank fuel level, there is SoC indicator, energy consumption and energy flow status are usually associated with the revolutions counter. Gauges usually located similarly to ICE vehicle (Mitsubishi iMiev, Nissan Leaf), but there can be some changes like in Tata Vista EV, where the main speedometer is located at navigation panel location, or Smart Fortwo Electric Drive where energy use and SoC indicators are located above the navigation panel. In addition, information representation can be different, for instance, SoC indicator can show battery charge level in percent, in km or in scale value.

Second approach is quite innovative. It differs not only in location of interface components but also uses external and portable devices such as in-vehicle display (BMW i3). Never the less, both approaches need some additional functionalities, such as extended navigation features. Information about

Fig. 2. ProtosCar HMI extended BMW ActiveEsystenavigation features.

closest available charging station is crucial in case of limited travel distance of EV. These systems usually use external sources of information to find charging station in vicinity and to estimate EV distance range. Good example of such a system is a ProtosCar where elevation profile is used to estimate vehicle range more precisely. (Figure 2), or BMW ActiveE system, were all charging stations, positions of which are known to the system, are displayed on the navigation screen (Figure 3). To function properly such systems need reliable, continuous and, in ideal case, centrally distributed source of information, where information about all available charging station and their occupancy (in case of BMW, only a fraction of stations, with which BMW have an agreement, are displayed) are stored and distributed among vehicles. Information about traffic conditions, road elevation profile and weather forecast can additionally improve precision of consumption calculation up to 3% for different weather

Fig. 3. BMW ActiveE system navigation features.

conditions and up to 30 % in case of different elevation profile [6]

As it was mentioned before pedaling and starting system of EV are a part of HMI interface, and they deserve additional attention. One important issue occurs because of the fact that EV does not need a starter (electric motor which is used to start ICE vehicle), and there is no feedback users used to, consequently they are not able to tell if the vehicle is "Ready to Go" or in "Turn off" mode. Car manufacturers address this problem differently, some of them uses READY message on a

Fig. 4. Ready state indication on: Audi A8 hybrid , Mersedes S400, Chrysler Aspen Hybrid

dashboard or uses speedometer pointer to point on Ready position (0 km/h speed), or uses Audi feedback (Figure 4)

In case of pedals, because of regenerative breaking feedback from pressing the pedals in EV is different from ICE vehicles. Regenerative braking is the conversion of the vehicle's kinetic energy into chemical energy stored in the battery, where it can be used later to drive the vehicle. Due to this fact EV decelerates with bigger rate when acceleration pedal is released in comparison to ICE vehicles, and it is possible to stop EV by using only acceleration pedal, thus, it makes it possible to drive with one pedal only. Power Flow displays of different kinds were introduced as a part of EV HMI to educate users on the concept of regenerative breaking and encourage them to use it as much as possible. Eco-feedback or EcoGuide® interfaces used in new Ford Focus Electric is a good example of such a system (Figure 5).

Fig. 5. Ford Focus Electric Smart Gauge®

This system already offers a lot of customization possibilities to a user, for instance, information displayed on left and right side from the speedometer can by chosen by a user. Efficiency Leaves gauge teaches the user to drive more efficiently by it displays a green tree with leaves where the amount of leaves depends on how efficiently driver is manipulation with his car.

A majority of users report that the usefulness of the information presented be Power Flow displays reduces the longer they own the vehicle. [8]

Regarding charging EV differs from ICE vehicles dramatically, recharging of EV can take hours and should be done in specially equipped (CS) charging stations. That is why a development of infrastructure and V2I communication is an important issue for EV development. HMI can help user in transaction from ICE to EV in terms of “refueling/recharging” faster and more convenient. Numbers of ready-to-use solution already exist on the market proposed by special companies (General Electric, Eaton, Siemens etc.) as well as by electric cars manufacturers (Tesla Motors etc.) these CS can be available on the market as public CS, corporate stations for

Fig. 6 Examples of EV charging stations: corporate station at Transportation Faculty, CTU in Prague (left), Tesla public charging station with solar energy source (upper right), home charge station by Easycharge (bottom right)

companies supporting the development of green technologies, or for private use at homes. Examples of a CS are represented in Figure 6. Specially designed mobile application or WEB application provides user with a possibility to monitor CS occupancy and location, unfortunately there is still no centralized data center, and user have to visit / open more than one sources to find closest available CS.

III. System Concept

As it can be seen from all mentioned above there are a lot of opened questions related to design of HMI for EV such as:

- What changes can be made to HMI to reduce range anxiety phenomena
- What is the optimal HMI design for vehicle charging feedback
- How to inform the driver of the location of charging points in the near vicinity
- How to encourage drivers to safely adapt their driving style or chose routes, such that efficiency is improved

Answering these questions and by eliminating disadvantages of already existed HMI systems and using new available technology it is possible to increase EV efficiency and consequently increase EV technology acceptance among users. We propose to use a lifecycle represented on Figure 7 to

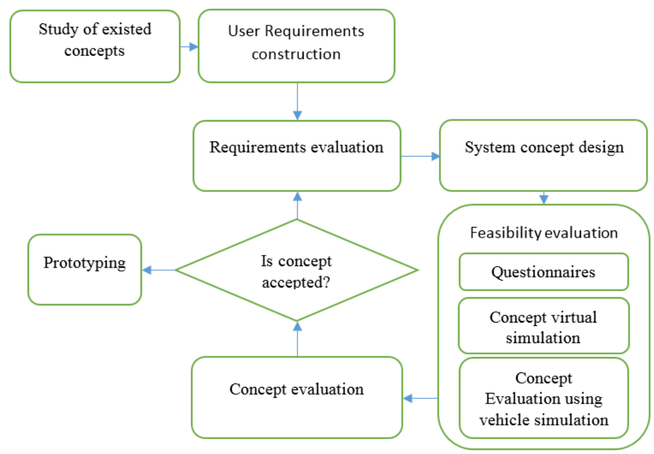

Fig. 7. HMI concept design Lifecycle

design a new HMI interface

A first part of the article was descried already existed solutions. There are some studies related to user requirements to newly design HMI of Electric vehicles [7]. These requirements are usually associated with HMI for EV:

1. The system should not be limited in functionality compared to ICE vehicles
2. The system should improve user’s safety and comfort.
3. The system should help to deal with energy shortage.
4. The system should be attractive and intuitive.
5. The system should not limit a user in drive style.
6. The system should provide a functionality to improve vehicle energy consumption
7. HMI design should reflect early adopters’ self-perception as modern and environmental individuals with affection to new technologies.

There are some contradiction requirements that cannot be solved with conventional HMI approaches. A user does not want to be limited in choosing his drive style and at the same time wants the system to help him drive more efficiently in terms of energy consumption. We propose to use Dynamic Dashboard interface to satisfy user needs. It is an interface, which can be adjusted due to user request or special state of the vehicle. Dynamic speedometer [9] is an example of such a system already known and introduced by vehicle manufacturers. In case of EV we can speak about dynamic dashboards as a whole system, where not only a contest and appearance of a dash board or a secondary display can be changed for different profiles, but also, the behavior of the vehicle. By behavior, we mean different state of IVS (In vehicle systems), such as climate control, lightening, and vehicle performance). Haptic pedals or AFFP (Active Force Feedback Acceleration Pedal [10]) pedals in combination with different audio and visual feedback help to regulate vehicle dynamics and HMI should adopts to provide a user with information related to these changes..

There is similar concepts described in [11]. Where more than six different HMI layouts were proposed for different types of profile. We can emphasize five main profiles such as:

Energy Saving mode when the IVS of the EV adjust their consumption state to maximize a range of EV by limiting comfort system functionality, and Dash Board interface changes to provide a driver with instruction about desired acceleration/deceleration rate and speed on a road part to minimize energy consumption. AFFP system regulates driver acceleration/ deceleration mode to save energy.

City mode system adjust the behavior based on current traffic information, it periodically monitors and recalculates the route to the destination based on updated information Driver is informed about battery state and reachability of the destination on current charge. Additionally system adjusts IVS and vehicle performance itself based on the type of the destination if the destination is Home or Office, where the user is unlimited in charging possibilities or if it is a round trip where charging is impossible or limited.

Rural traveling mode consumption on a rural roads can be minimized by driving with a proper speed within speed limits and applying brakeless concept of driving, the system provide a driver with suitable dashboard HMI to minimize EV consumption. In addition, adjust IVS consumption model based on trip type (round trip, destination with/without charging station,) and reachability.

Destination reaching mode in this mode the system continuously monitors remaining driving range and compares it to the distance to the destination, in case of a conflict system propose a solution such as switch to Energy saving mode or routing to available charging points.

Careless mode is the mode where the performance of EV and state of IVS are not limited by the system and Dash Board interface is adjustable by the user

A curtail point for such a system is a reliable and precise energy consumption model of the EV. A conventional consumption model of rolling, drag, acceleration resistance should be extended with an adaptive driver model (where the system learns about drivers driving habits such as acceleration deceleration levels, max speed and etc.) and, so called, “current traffic model” where the system is able to anticipate traffic conditions based on external information). Weather influence and charge station location should be also taken into account. Such model was described in [6] Additionally with the development of V2V and V2I communication a breakeless concept of driving can by introduced where the driver is instructed by means of HMI (either visual/audio or tactical) when is it better to release acceleration pedal to approach next speed region without applying mechanical breaks.

Such systems should not be only the part of the vehicle but should be integrated with mobile devices or mobile applications to provide an access to vehicle data and road planning ahead of particular trip. This integration should be treated as a part of HMI itself, which means it should be considered in all design steps listed above.

IV. System concept evaluation

As it was mentioned, before moving to a stage of prototyping the concept should be evaluated. It is obvious that to evaluate a HMI system for a vehicle, user should try this system during driving. In case of concept definition, it is feasible to create a “virtual” prototype of the system, where a system functionality is simulated by means of computer graphics and preform several sets of experiments on a driving simulator to give user a chance to test the system functionality.

Fig. 8 driving simulator Octavia II developed by FD CTU in Prague [12]

Modern simulators usually consist of parts of real vehicles (Figure 8), with which a driver interacts through actual vehicle control components such as steering wheel pedals, and other vehicle HMI interface, and the complex system of computer-generated virtual reality. Virtual reality should cover the widest possible range of operator’s sensor input, so that it can induce a sense of realistic environment. Modern simulators provides researches with a possibility to monitor driver performance during different predefined situation. These situations are composed into scenarios, which should be design to represent different real life driving situation, where interaction of a driver with HMI of the vehicle

Results obtained from driving simulator in combination with specially designed questionaries' should provide enough data to evaluate concept design before moving to the next stage of development.

V. Conclusion

A new dynamic HMI for EV vehicles can potentially increase popularity of EV technology. However, a proper validation of the concept is needed to ensure than new HMI conforms to the requirements of users, and does not have a negative impact on primary driving task. A methodology of the concept design and evaluation was proposed in the article. This methodology consist of 5 basic steps

1. Creation of user requirement for a new system
2. Creation of a concept of the system
3. Evaluate a feasibility of proposed system
4. Preform set of experiments on vehicle simulator to obtain user feedback
5. Evaluate the system concept and repeat the cycle if needed.

Experiments preformed on a vehicle simulator should provide researches with data to evaluate propose HMI and make a conclusion about the design.

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