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Design of HMI Based Digital Electric Bike Using DC/AC Power Converter with Regenerative Feature

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***Abstract*-** **The research project introduces an efficient HMI-based digitally controlled electric bike hardware model. The system is designed using power electronics and LCD touch control. A low-cost model with regenerative features increases the acceptance of electric vehicles in Pakistan. The country is facing grave environmental issues and the transport sector has a major role in polluting the environment. Technology also promotes the environment-friendly electric vehicles Industry and reduces the growing pollution problem of the country. Economical transport with feasible milage is an essential need of the current time. Research provides the effective Electric-bike with digital security and improved mileage. A Six-Step DC/AC power converter drives the low-consumption BLDC motor. The project analyzed the real-time performance of the electric vehicle on HMI. A regenerative braking system generates power while reducing the speed of a moving electric bike. The modeling and simulation are performed using Proteus/Multisim simulating software. Results are verified using a hardware test model. The results will be helpful for design commercial advance HMI-based electric bikes in terms of motor requirement, machine behavior, charging/discharging analysis at a different speed and torque, charging the battery while driving, and their limitations.**

***Index Terms*--** **Bi-directional power converter, Digital Electric bike, DC/AC converter, LCD Touch system, regenerative braking**

I. INTRODUCTION

In the current era, worldwide environmental contaminations have become a big ecological and health problem due to the traditional consumption of fuel in generation and transportation. Electric vehicles (EV) or battery electric vehicles (BEV) are the optimum current solution for transportation to combat pollution problems globally.

In 2017, a major step forward in the electrification of vehicles was made when governments all over the world established goals to include fleets of electric vehicles (EVs) in their transportation sectors. Amid this development, many Petroleum Vehicle (PV) manufacturers of the world have decided to launch their EVs either by manufacturing their own or by partnerships. Environmental pollution is a potent threat to the Earth's atmosphere. Countries all over the world have realized the importance of Electric vehicles so they have decided to gradually incorporate EVs into their transport sector. According to the EV30@30 campaign, many countries have decided to reach a target of 30% EVs' sales shares by 2030 [1].

Pakistan has serious environmental problems, and the transportation industry contributes significantly to pollution. According to World Health Organization (WHO) guidelines, the concentration of environmental damaging elements is ten times the ideal level, resulting in the death of many Pakistani residents. In the coming future, its consequences will be much more devastating [2]. A rapid increase is observed in the transport sector of Pakistan depending on several factors. Pakistan has the fastest rate of urbanization in South Asia, currently, 40.5 percent of the population lives in cities and this number will rise to 50 percent till 2025. The total number of registered vehicles (cars, motorbikes, buses, and trucks) in 2018 was 23.58 million which reflects 9.6 percent growth of vehicles as compared to 21.50 million in 2017 [3].

Pakistan is currently struck by the worst smog ever. The nation is the world's fifth-most vulnerable to climate change. The transport sector is responsible for 43 percent of air pollution emissions, according to the Sectoral Emission Inventory for Punjab. Industry and agriculture, respectively, remain second, and third. Smog is dubbed the fifth season in Pakistan. Air quality is becoming increasingly unhealthy in Pakistan. It is not only occurring in Lahore but also in Islamabad, Pakistan's federal capital, surrounded by lush greenery. Meanwhile, Pakistan's government approved the country's first policy on electric vehicles in November 2019. Although the burning of gasoline has increasingly poisoned the atmosphere, and fuel prices are sky rocketing, it is a brilliant idea

to turn to environmentally-friendly electric vehicles. Currently, perhaps, this is the best way to boost air quality [4].
The E-Bike is an electronic bike that can use electricity to ride distances. It is composed primarily of a small motor, a battery and an electronic circuit. Regenerative principle enhances the ride time of e bike by reusing the energy of the battery. E-bikes have many benefits, such as lightweight, pollution-free bikes. Due to these benefits, e-bikes are becoming popular nowadays in many countries. Some electric bikes have bidirectional converters which is capable to exchange energy from source to load and vice versa. Power electronics system design is also playing important role in improving efficiencies and transient response under varying load [5]. These converters are very commonly used today due to the idea of energy storage and reuse. Depending on the demand, various types of converters are used. The step-up function or step-down function can be done by a Buck Boost Converter [6]. The paper [7] shows the typical design parameters for electric bike converter.

The battery is the only energy source in battery-operated EV, and these batteries face problems such as less charging and recharging cycles, as well as low driving range response. The problems listed are solved by using batteries with any energy source, such as flywheels, super capacitors, electrochemical batteries, etc. To address this problem, some processes are introduced; regenerative braking is one of them. Regenerative braking is the mechanism by which, during deceleration, some of the kinetic energy is retained in the cars, which is converted and kinetic energy is stored in the battery and ultra-capacitor.

The motor used in electric vehicles/bikes is the BLDC (Brushless DC motor). Energy storage capacity is more important in modern technology, concentrating primarily on the ultra-capacitors, batteries and converters required to link the electricity grid to electric vehicles. There are different types of energy storing batteries available, like lead-acid, nickel metal hydride (Ni–MH), lithium ion (Li-ion), nickel-zinc (NiZn), etc. [8]. These type of EVs are typically driven by stored electrical energy. After all, main issue of EV is the short millage capacity due to the low energy storage ability with respect to density. So, effective storage system is critical challenge for designing EVs. Normally power system for E-bike have multiple voltage level available to power different devices like 48 to 12 and 12 to 5 etc. [9]. Latest human robot interaction algorithm is proposed for effective power assistant bike control system which improves the system efficiency [10]. The paper [11] introduce the dynamic control algorithm for charging level of EV battery. Data collection based [12] research provides the latest trend of EV in market and concluded that, E-bike is suitable and feasible for green environment.

In this research digitally controlled HMI based smart Electric bike analysis is evaluated by designing Six step voltage source inverter for BLDC motor. Bidirectional Power converter is designed to control power from both sides. Simulation analysis is performed with major design parameters. After computational analysis the hardware design with optically controlled MOSFET is discussed along with driver specifications. The GUI based touch screen displayed all the required parameters. At the end regenerative results are discussed and overall performance is evaluated.

II. Electric Vehicle System Overview

The electric bike design has several characteristics that it has no emission and does not pollute the environment, the operation is quiet if compared with others, good acceleration system, no fuel consumption and it is cost effective [13]. In the present time, most of the electric vehicles used BLDC motor for moving actions. BLDC motor is controlled by power electronic converter. Sensors are monitoring real time values which are integrating with controller and using HMI based GUI (Graphical User Interface) and all the parameters' values will be digitally shown on HMI. In this research project, digital security had also been implemented.

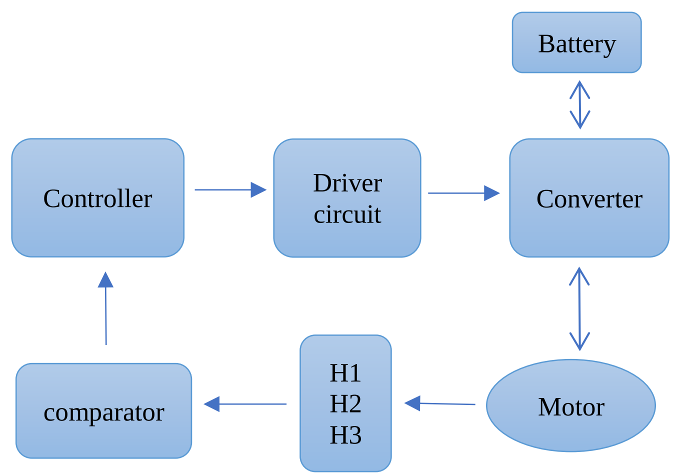

FIGURE 1: Hardware design structure of digital electric bike

Regenerating braking system is also implemented which is a process of harnessing the stored kinetic energy in the form of electrical energy during the deacceleration or braking period of vehicle. where the motor of the vehicle operates as a generator and charges the battery. The fig.1 describes the flow chart of the electric vehicle (EV) control system and the machine operation determined by the microcontroller.

The programable controller generates the sequence of pulses to run the BLDC motor by sensing the particular switching. The controller is programmed to provide the switching based on the decision manipulated by inputs signals i.e. PWM and hall sensors (H1, H2 and H3). The output is connected to the optical gate driver circuit that is used to provide isolation between the input low level signal and the power converter.

A machine is connected at the output of the three-phase converter as load. The hall sensors are helpful to catch the position of rotor, that is very important for giving perfect switching to the inverter. Necessary circuits such as PWM circuits, controller, gate driver circuits are implemented to develop digital EV system. The back emf at different speed is recorded to select the proper charging system. After that, using the proposed method the battery is charged and successful result is observed. Furthermore, back emf performances with varying duty cycles are noted. Based on gather data the energy regeneration is calculated for several speeds. Overall, the proposed system can explore the commercial sectors of the recent electric bikes and effectively stores the braking energy in the form of battery charging.

A BLDC motor is a manufactured using permanent magnet. The current in the DC motor is itself switched to other windings by means of a commutator. In BLDC motor, the rotor includes the magnets and the stator windings. As there are no commutation brushes so it is implemented electronically based on rotor position feedback. The response of BLDC phase voltages is trapezoidal and sinusoidal in the respective types of motor [fig 2].

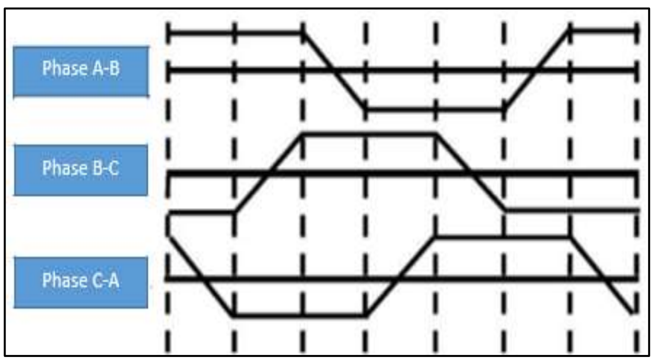

FIGURE 2: Voltage Phase Diagram of 3-Phase BLDC motor

III. Design consideration

Suppose the required average speed of electric bike should be 30Km/h with a supposed acceleration of $0.6ms^{-2}$. Total average weight face by rear body is nearly 65Kg and radius (R) of tire is 0.27m the required power will be,

$$T_{req} = Rma \tag{1}$$

$$= 0.27\times65\times0.6 = 10.53Nm$$

$$V = \omega R \tag{2}$$

$$\omega = \frac{8..3}{0.27} = 30.7 \text{ rad/sec}$$

$$P_{req} = \omega T_{req} \tag{3}$$

$$= 30.7\times 10.53 = 323 \text{ watt}$$

TABLE I
MACHINE PARAMETERS

Parameter	value
Rated voltage	36/48V
RPM	350-450 RPM
Rated power	350 watts
Max. Torque	18N.m
Max. current	10 Amp
Net weight	3.8 Kg

The battery capacity and backup can be estimated once required machine is finalized [14]. The machine parameters used in the E bike model is illustrated in table 1. To design power converter the current rating, PIV and switching capacity of devices should be considered. A IRF 250 MOSFET is selected for our converter design. A three-phase converter can also act as a three-phase rectifier in reverse direction. Regenerative braking collect energy from motor and send back into the battery, that will also increase the life of friction pads on traditional mechanical brake. However, for complete and emergency stop mechanical brakes are required [15].

A. Gate Driver

The driver IC used in research is IRF2110 which is a high-speed switching MOSFET Gate driver with separate high and low side output terminal. Working voltage range for driver IC is 10 to 20 volt and current rating is nearly 2A. The driver is designed using high current buffer stage which is helpful to reduce the cross conduction. Its less propagation delays make it feasible for high frequency applications. The output floating side is able to drive IGBT also with voltages up to 600 volts.

B. Controller

The Arduino mega series (Mega 2560) is used as controlled which is a microcontroller board based on the ATmega [16]. Controlled has 54 digital I/O pins that can be configure as input and output with 15 dedicated PWM outputs. It has 4 serial ports and 16 analogue inputs additionally controller has 16MHz crystal oscillator, reset option, USB connector, power pin and ICSP head. It has all necessary support required by microcontroller. We can power controller with a USB cable or DC adapter or battery.

C. HMI

We used 7" Nextion Human Machine Interface (HMI) LCDs in our research project. Resistive touchpad display makes it easy to construct a graphical user interface (GUI). It is a perfect solution for process monitoring and control, and is primarily applicable to IoT applications. For automation, there are many LCD display modules available with size varying from 2" to 7". The fig. 3 shows the GUI interface of digital E-Bike.

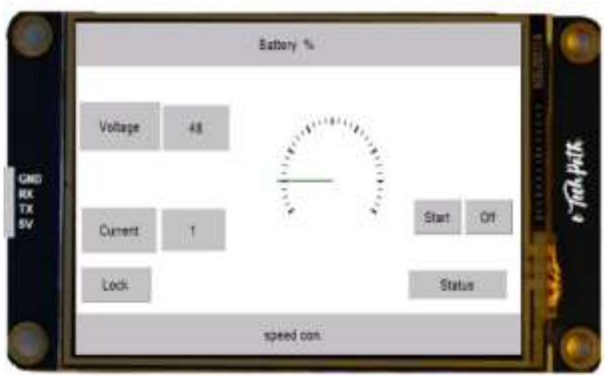

FIGURE 3: HMI Interface

D. Optical isolator

The objective of isolation is to block unwanted transient and surges between two systems. And to also protect the system from short circuits. Optical driver provides best electrical isolation between signal from controller and power converter. In research project P521 optocoupler Isolator IC is used.

IV. Simulation and hardware model

The modelling and simulation are performed using Proteus for verification of design. Further, additional library is added for required MOSFET and Driver IC. The fig. 4 shows the three-phase converter circuit for the simulation purpose.

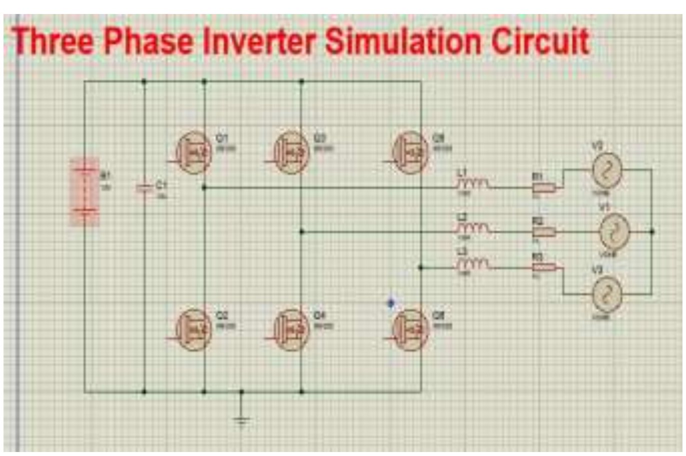

FIGURE 4: Six step three-phase converter

In this simulation, the switches have been operated following the previous operating principle. The L (1, 2 &3) and R (1, 2 &3) indicates the motor inductance and resistance respectively. V1, V2 and V3 are the back emf of BLDC motor [17-18]. The converter is built from of six solid state switches that are Q1 to Q6. The output of the three phase is taken from common point of each leg i.e. A, B and C. The generated back emf of the motor used in sinusoidal in nature. These three sinusoidal sources are used to justify the behavior of the BLDC motor.

Figure 4 represent the main power converter which is used to drive brushless DC motor. The input to the inverter is 48V and the load is rated at 350 W. Heat sinks are used to protects the MOSFETs from over heat. All the connections are properly placed on circuit board. The hardware implementation of the gate driver circuit and the three-phase converter Mosfets are shown in fig. 5. It represents the IRF2110 driver simulation in proteus with high-side and low-side MOSFET.

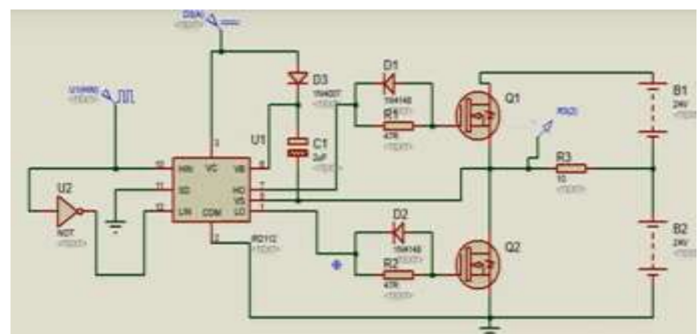

FIGURE 5: Driver Configuration

The fig. 6 below shows the output of Six step inverter whose switching is controlled from the hall sensor circuit. Switching sequence of each MOSFET is express in fig 7. The throttle is the input to microcontroller whose duty cycle control the speed of electric bike.

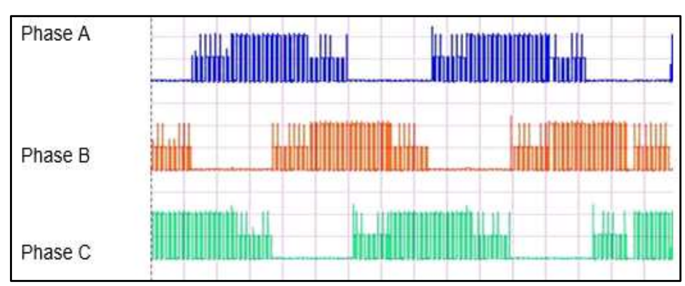

FIGURE 6: Converter output response

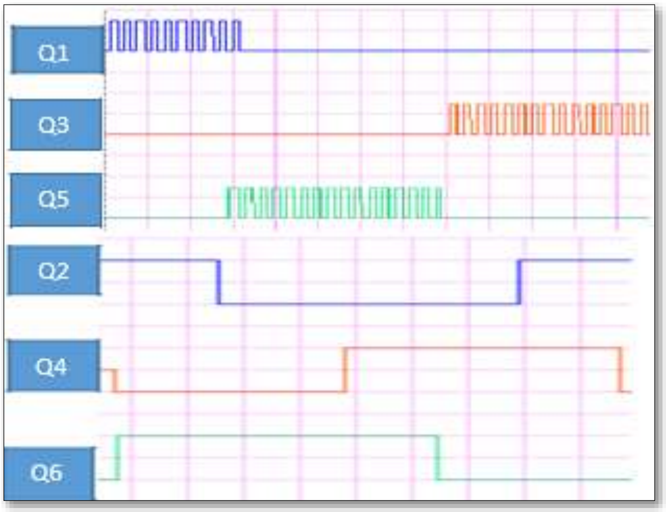

FIGURE 7: Switching sequence

The power converter average output can be varied by changing width of applied switching pulses (PWM) [19]. In hardware 1.5KHz switching frequency is used with duty of 50%. The battery that is used has a rated voltage of 48V. The output voltage has a phase difference of 120° and 48V peak voltage. Fig 8 represent the hardware model of power converter and optical isolated driver circuit.

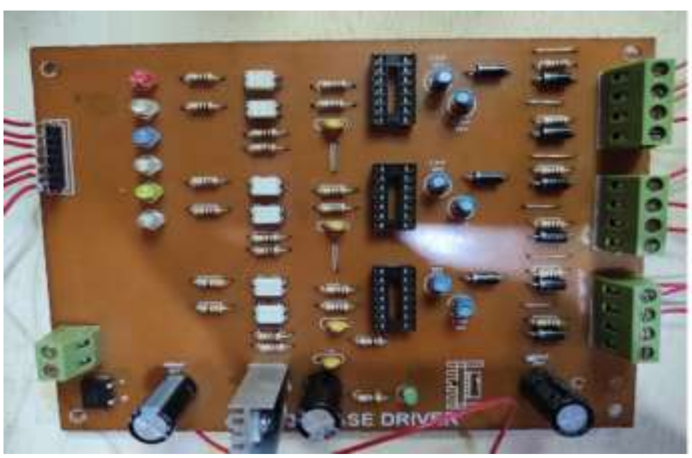

FIGURE 8: Hardware model

The practical hardware response of three phase six step converter with hall sensor switching is observed using digital oscilloscope. The outputs of the hall sensor which are generated during motor rotation are used as sensing element for desire switching as shown in fig 9. The hall signals are given as input to the microcontroller that is coded according to the desired operation.

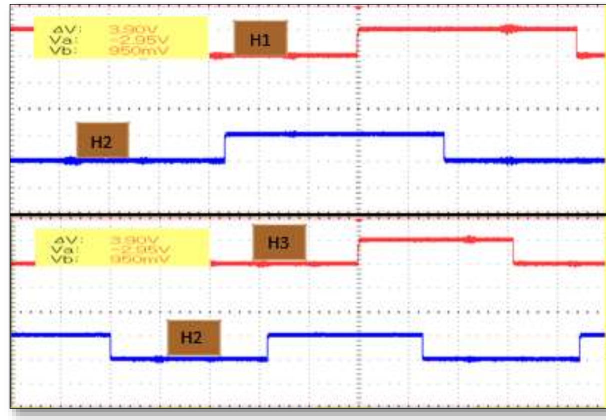

FIGURE 9: Hall sensor sequence

The figure 10 shows the line voltages of the three-phase power converter observed from digital scope. 48V is the DC input to the converter and has a peak voltage of 48V. The output waveforms have been observed on with 50% duty cycle.

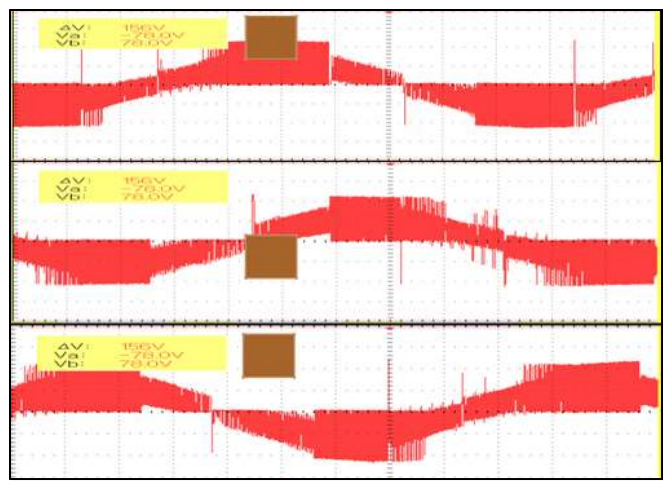

FIGURE 10: Experimental response of Power converter

The experimental behavior of power converter average voltage and E-bike speed (PRM) with different duty cycle of throttle is summarized in fig 11. The speed is directly proportional to the duty cycle. The speeds at different duty cycle of throttle signal are noted and then using the rectifier that exists on the opposite side of a three-phase converter, the generated three phases sinusoidal back emf is rectified to charge the battery.

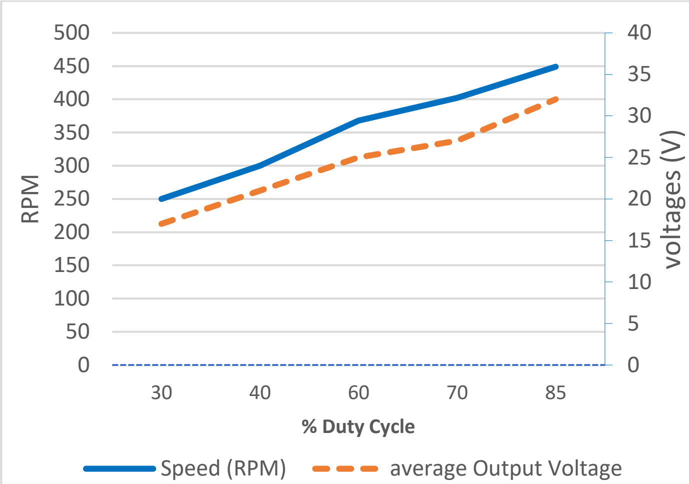

FIGURE 11: RPM vs duty cycle

We have measured the magnitude of regenerative voltage at different speed. The change of regenerative energy and speed is measured with respect to various duty cycles that are varied by the throttle as shown in table II.

TABLE II
REGENERATIVE ANALYSIS

Sr No.	Duty cycle (%)	Speed (RPM)	Regenerative voltages (V)
1	15	129	10
2	20	157	16
3	24	212	17
4	30	234	20
5	35	245	23
6	45	265	27
7	56	285	28
8	63	302	29
9	75	345	31
10	84	423	33
11	100	520	35

The simulation and hardware results provide the design approach of investigating the electrical and mechanical parameters of electric bikes. The research guides the procedure to predict the power requirement for designing electric bikes with desirable speed. The power converter waveforms help estimate converter performance parameters. Driving and regenerative mode behavior are useful for estimating battery SOC. In particular, one switch like a single pole double throw is used to change the operating modes. Finally, braking current at different speeds and the braking current time are noted. The regenerative braking will certainly decrease electricity consumption for charging the battery from supply and will charge the battery on the go while running on the road [20].

VII. CONCLUSION

Research provides the economical HMI-based electric bike for the local user of the country with advanced features. Simulation and hardware model results will helpful for designing electric bikes and useful for EV industry. It reduces the growing air quality index (AQI), especially in Lahore and Karachi. Digital security provides a user-friendly feature for the user. Particular regeneration is worthy as it eliminates the energy wastage that takes place in the traditional braking system. The detailed component specification is presented with their basic characteristics and operation. The research guides to analyzed the power requirement for specific desirable speed of E-bike for commercial purpose. Regenerative energy analysis tends to increase the mileages of future smart bikes. The converter design parameters are helpful to produce commercial drive units with driving and regenerative mode.

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