Design and Implementation of Hybrid Bike

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Abstract— This paper describes the process of planning, designing, testing and implementation a hybrid electric bicycle. It provides the solution to the challenges of modifying an existing mechanical system to an eco-friendly system. Through designing this system, with various non-human electrical inputs and feedback channels, a major challenge was centralizing the control of the system. The development of bike starts with establishing the criteria for speed, control, efficiency, and weight and ensure the easiness and safety of both rider and the integrated system.

Key words: Hybrid Bike, Design, Implementation, Renewable Energy, Integration, Fuel

I. Introduction

A hybrid bike is an eco-friendly vehicle, which is powered by renewable resources like solar, wind and noise for the purpose of fuelling. A hybrid bike is a light weight, low power vehicle designed and built with a single purpose of reducing the conventional fuel consumption by bikes. They have limited seating (usually one, sometimes two people). It does, however, offer an excellent opportunity to develop future technologies that can be applied to practical and sustainable applications. While designing a transportation vehicle, consideration of mechanical objectives, electrical objectives, safety criteria, comfort, and user friendliness is required. This project takes the challenge of designing a mechanical system and implementing electronic control to dictate the response and performance of the system.[2,4]

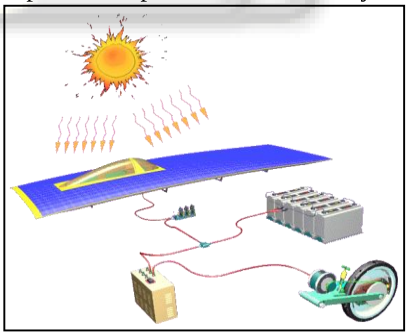

Fig. 1: Solar powered Bike

The goals of the paper is to design and integrate an additional eco-friendly power transmission drive an existing bike. We projected that systems synchronously would be controlled through electronic control interfaces. The project focus was primarily to design a system capable of forward drive and electrical regeneration.[7] Some additional goals or constraints to the project included the following:

– Reducing the costs of the system,
– Reducing the additional weight of the added drive and associated components,
– Maintaining the operation of the bike with the same ease when the electrical system is disengaged, and
– Integrating some of the mechanical features of the original system with those of the hybrid system. The selection of both the mechanical as well as electronic components is made carefully to design a system capable of both forward drive and effective regeneration. The objective of saving costs was constrained. [9, 10, 11, 12]

II. Design Targets and Goals

The main requirement of our system are to ensure efficiency of operation, and to meet the operating drive requirements. The size of the motor, safety concerns, and legal speed limits on the speed of conventional motorized bikes were calculated first and then the maximum speed of the bike were determined to be 20kmph.

The forward drive requires a motor and a set of sprockets to drive the to the front wheels. Based on the available torque calculated from the motor and the desired maximum speed that has been set, a two-stage design reduction was applied to minimize the size of the components in the system. By dividing the drive transmission into two stages the number of components increases as well as the overall system complexity of the design was increased. The only advantage of a two-stage design was the size of individual components decreases. This was more critical to our system as we need to reduce the weight of the system rather, than minimizing the number of parts. [2,4]

The two stage design is much more efficient than the other type of design. The advantages of this approach are its easy implementation, and high torque transfer to the rear wheel. There is a lot of disadvantages in this type of design due to the frictional losses of the tyre against motor. This design is also well acquainted with our objective of adding regeneration, but also modelling an efficient hybrid-electric integration. [3]

III. Design Calculations and Considerations

A. Power Requirements

In requirement for the bike to accelerate from a rest, a sufficient amount of torque needed to be delivered by the motor and drive transmission components. As a result, we require the motor to draw a heavy amount of current during the acceleration period.

Time to accelerate (s)	Velocity	Voltage Available (V)	Mass	Current Required (A)	Power Consumed (W)
20	11.2 m/s	12	60kg	15.4	369.6
40	11.2 m/s	12	60kg	7.7	184.8
60	11.2 m/s	12	60kg	5.1	122.4

Table 1: Power Requirement for various acceleration

B. Electrical Systems Design

The heart of a hybrid bike is the electrical system, which is made up of batteries and power electronics. Power electronics include the peak power trackers, the motor controller, and the data acquisition system. The primary work of the power electronics device used is to monitor and control the electricity within the system.

1) Batteries

A hybrid vehicle uses the battery pack to store energy, which will be at a later time. The battery pack is made up of several individual modules wired together to generate the system voltage that is required to run the system. The different types of batteries used include:

- Lead-Acid
- Nickel-Metal Hydride (NiMH)
- Nickel-Cadmium (NiCad)
- Lithium Ion

The NiCad, NiMH, and Lithium batteries deliver better power to weight ratio over the more common Lead-Acid batteries, but are costlier to maintain.

The battery pack is made up of several individual modules connected together to generate the system voltage that is required. Typically, system voltages vary between 6 and 24 volts, depending on their electrical system. For example, Tesseract uses 512 li-ion batteries, spilted into twelve modules, which are equivalent to a bike battery individually, but only weigh 5 lbs each. Through an innovative pack design, the batteries are ventilated with even airflow to minimize temperature differences between the modules.

The batteries used in this hybrid bike are sealed lead acid batteries due to their low costs, and reasonably good energy density. The B&B HR15-12 batteries would fit the scale of the system. Assuming the motor operates at its nominal continuous rating of 600 W, drawing 25 Amps, we can expect the 15 Amp-Hr batteries to deliver current for the time of 20-25 minutes before it is needed to be recharged. The B&B HR15-12 Volt batteries were more than sufficient for use in the system for the time it is required to run.

2) Peak Power Trackers

The function of the peak power trackers is to condition the electricity coming from the solar array and to maximize the power and deliver it either to the batteries for storage or to the motor controller for operation. When the battery is getting charges by the solar array, the peak power trackers help to protect the batteries from being damaged by overcharging. Peak power trackers can be very lightweight and commonly gives an efficiency of 95%.

A maximum power point tracker (MPPT) is a DC-DC converter [7] that matches the output of a PV array to the battery voltage in such a way that increases the power generated by the PV array to its maximum.

The power generated by a solar array depends on the operating voltage of the system. PV power increases proportionally with operating voltage to a maximum possible, and then rapidly drops off as the voltage is increased further to the open-circuit voltage. A tracker permits the PV array to work at the maximum efficiency, independent of the battery voltage. For example, if your battery voltage is 12V and the ideal operating point for an array string is 2A x 12V = 240W, the tracker output will be 2.4A x 12V = 240W. In practice, there is always of 1-2% loss due to inefficiencies in the tracker circuits.

MPPTs are of three types:

- Down (buck) converters, which convert the PV voltage to a lower battery voltage;[5]
- Up (boost) converters, which convert the PV voltage to a higher battery voltage; and
- Dual (buck-boost) converters, which will convert either way, though usually with a penalty in efficiency.[7]

3) Motor Controllers

The amount of current actually consumed by the motor is decided by Motor controllers. This helps to accelerate, decelerate, or maintaining constant speed. This device has an efficiency of 90%.[7]

4) Telemetry

Data acquisition is obtained by telemetry which is used for two way data transmission and made of micro-controllers and radio modems. Data's like speed, battery voltage, power consumption and motor temperature is obtained. This information is passed to the rider. [3,4]

5) PIC Controller

The selection of PIC16F873A microcontroller was for the following reasons:

- Past experience with programming and debugging through E72 course
- In-Lab availability of software and programming utilities
- Smaller than handi-board, and can be easily adapted to system
- Two PWM output pins (CCP1 and CCP2)
- 2 digital I/O ports (B and C)
- Set of analog input pins with on-board A/D converter

The main concern with selecting a PIC was both its explicit financial costs as well as the implicit costs of having to purchase the evaluation boards and software for controlling the PIC. We also did not want to spend a lot of time learning to program another manufacturer's PIC or adapting one of the Handiboard controllers (used to control servo motors and drive LED displays) to our system. Given the number of input/output (Digital and Analog) pins available on the PIC16F873A, we thought it would enable us to meet our objectives of (1) motor control, (2) and feedback and safety communication between the PIC and other circuit elements. [8,9].

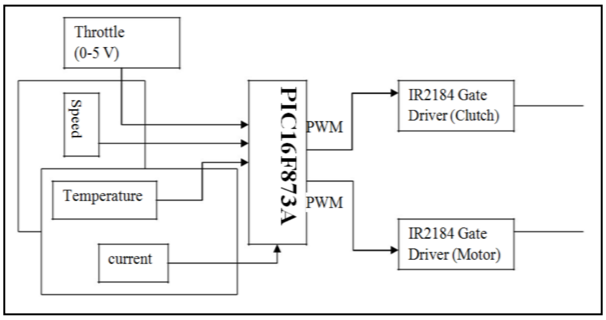

Fig. 2: Electronic control circuit of PIC Controller

The primary input to the PIC is the throttle input and the primary outputs are the PWM signals used to drive the motor control circuit. These inputs and output are the basis of the motor control circuit, whereas the other I/O devices are designed for optimization and safety.

6) Drive Train

The electric motor transmits the power to the wheel which caused the bike to move which is named as the drive train. Due to the low amount of power generated (less than 5 hp) usually only one wheel in the rear of the bike is driven by the electric motor. The motor types that have been used in solar bikes include

- brushed DC motors
- DC brushless motors
- Induction motors

PMDC motors are common place in hybrid bike. The Motor specification used here is:

- 600 Watt PMDC (Rad-2-go scooter) motor
- 3100 RPM
- 4.5 in x 5.5 in
- 24 V x 25 Amp continuous rating
- Peak ratings (intermittent duty)

Rare-earth, permanent magnets mounted on the rotor, reacts to magnetic fields produced by the motor's windings. Three-phase windings maintains constant torque to the rotor. A motor controller transmits signals to the windings, regulating the magnetic field around the rotor. The most common type of motor used in hybrid bikes is the dual-winding DC brushless. It is lightweight and has efficiencies of 98% at their rated rpm.[10]

The dual-winding motor is sometimes used as an electronic transmission. The speed of the motor is changed by switching the dual windings. The low speed windings provide high torque for starting and passing, while the high speed windings have higher efficiencies.

There are several variations of two basic types of transmitting power used in solar bikes.

- Single reduction direct drive
- Variable ratio belt drive
- Hub motor

Direct drive transmission is the most common where the motor is attached to the wheel through a chain or belt with a single gear reduction. This transmission is reliable and easily maintained if aligning the components are done carefully. Efficiencies above 75% can be achieved when designed properly.[11,12]

To increase the speed of the motor the gear ration of the variable belt drive is changed. This helps the motor to achieve higher starting torque at lower speeds, and allows the car to run efficiently and smoothly at higher speeds. Variable belt drives requires careful alignment of the bike to work efficiently.[13]

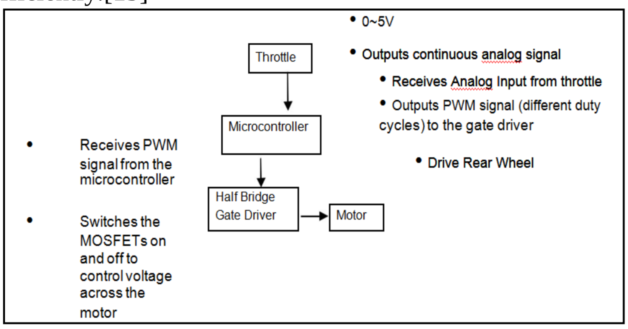

Fig. 3: Motor Control Circuit

C. Mechanical Systems Design

The mechanical systems of a solar bike are designed to minimize friction and weight while maintaining the strength needed to handle the various road conditions. The constraint of lightweight and strength-to-weight ratio is maintained using metals like titanium and composites. It includes:

1) Steering/Handle

The major design factors for steering/handle are reliability and efficient performance. The steering/handle system is designed with precise alignment because even small misalignments can cause significant losses and increase tire wear. Different bikes use different steering/handle mechanisms depending on their budget and other considerations. The SUNRUNNER utilized a rack and pinion system that uses a centre mounted handlebars, much like that on bicycles that connect to a rack-and-pinion steering system.[12]

2) Wheels

Wheels, however, are the least efficient part of a hybrid bike due to rolling resistance. About one third of the energy used by a hybrid bike is lost due to this factor. Due to this limitation, contact with the ground should be minimized.

Hybrid bike typically have two wheels. The common three-wheel configuration is two front wheels and one rear wheel (usually the driven wheel) two-wheel vehicles are sometimes configured like a conventional vehicle (with one of the rear wheels being driven). Other two-wheel vehicles have the two rear wheels close together near the centre (similar to the common three wheel configuration).Hybrid bike wheel designs are similar to those of bicycle tyres. Generally, the wheel's rims and hubs are aluminium while the spokes are made of steel. A Mylar film is attached with the spokes to increase aerial efficiency. Pneumatic tires are preferred over solid rubber tires because they weigh less and provide a smoother ride. The best tyres currently available are the Bridgestone Ecopia tyres made for hybrid bikes. They are very thin and operate at over one hundred pounds/inch pressure.[9]

3) Mounting Systems

In order to minimize the additional weight to the system, most of the mounting plates and devices are made from ¼” aluminum. The standard clearance holes were 17/64” and tapped holes, ¼”. The only bolts and mounting points that deviated from this convention were the water bottle clearance holes and the holes used to mount the pillow block bearings.

The order in which the mounts were made was the following:

- Battery mount – 2 plates (13”x5”x0.25”), ¼ “ all-thread
- Jackshaft mount – 3 plates
- Motor mount – 3 plates
- Controller Box

IV. Testing and Safety Considerations

After developing the theoretical model for our motor driver, we designed experiments to test the model’s accuracy. We determined that we would test the circuit to observe electrical regeneration inside the lab, and thus at a much smaller scale than the actual system. The model we used in the lab included the following components and is shown in the diagram below.

Model Components	System Analogs
– 24 Volt PMDC connected via control circuits	600Watt, 24Volt PMDC Motor
– Coupling shaft to connect two motors	Power transmission system
– Independent power supply to apply constant DC Voltage across coupled motor	Rider pedalling the bike or transfer of potential energy to kinetic energy going down the hill
– 24Volt PMDC motor connected across the constant voltage source	Pedalling the bike

Table 1: Testing & Safety considerations

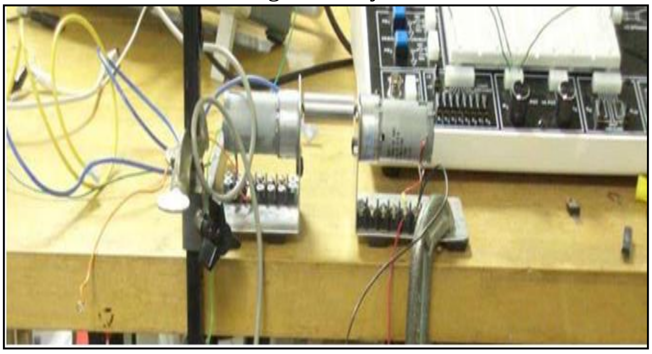

Fig. 4: Testing of Hybrid bike components

Through this setup, it was observable that the braking force during regeneration as well as record the battery current by inserting an ammeter into the circuit. The complete duty cycle is observed, and the transition from regenerative functions to forward drive.

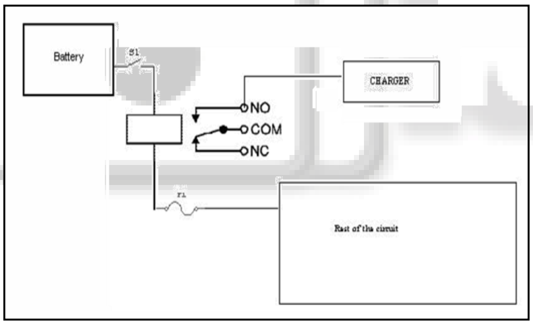

Fig. 5: Circuit isolation and safety circuitry

The safety components designed for the circuit include an automatic shutdown switch, a 40 amp relay (electromagnetic switch) and two 35 amp fuses. The user can conveniently turn on and off the controller by toggling the automatic shutdown switch. It appears redundant that we have both a SPST switch and relay in the same circuit. However, the reason why we used both a relay as well as a low current SPST switch was due to the difficulty we encountered in finding an SPDT switch with contact ratings similar to the relay. Since, the switch is designed to break the circuit, its contact ratings would have needed to be rated as high as other high-power elements in the circuit. When the switch is closed, the 40 amp relay will be connected to the circuit and provides a path for power to flow from the battery to the rest of the circuit.

V. Implementation and Block Diagrams

The figure above is a block diagram of the overall control system. When the automatic shutdown switch is closed, the relay will activate the circuit by permitting power into the circuit. By turning the throttle, a continuous of voltages from 0 -5 V is sent to the microcontroller's A/D conversion inputs pins. After interpretation of the throttle input, the microcontroller will provide the PWM signals to the gate drivers to drive the Mosfets. The motor is controlled by the switching rate of the Mosfets and transmits power through the transmission system to the rear wheel. There are a number of sensors throughout the system that send updates to the microcontroller about the state of the system. These sensors can also directly influence the state of the system through additional circuitry that has been designed.

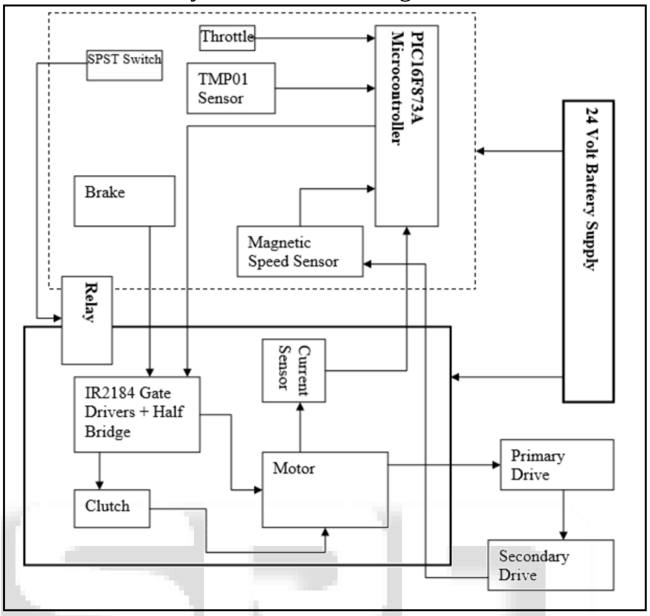

Fig. 6: Overall Circuitry

In order to conform the PCB to the system's scale, we determined that we needed to use a heavier copper, 1.5 oz/ ft2~2 oz/ft.2 After comparing different PCB manufacturers who used heavier copper traces, we chose APCiruits to produce our PCB due to their fast turn around and competitive prices. We designed the board in Ultiboard on two layers of copper to conserve space and allow for heat dissipation. After laying out our circuit in Ultiboard, we submitted the Gerber files (top copper layer, bottom copper layer, board outline) and NC drill file (contains drilling information) to APCircuits for fabrication.

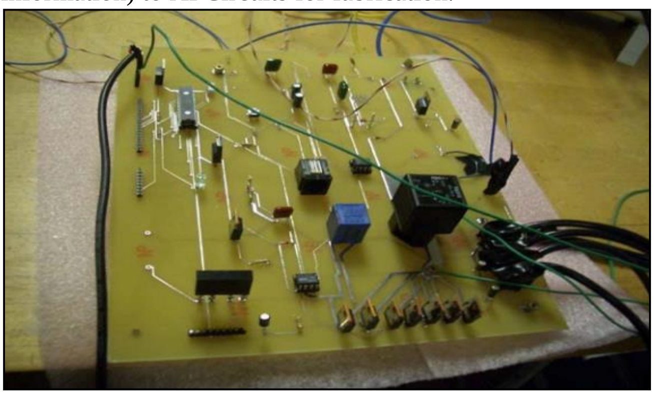

Fig. 7: PCB Controller top layer

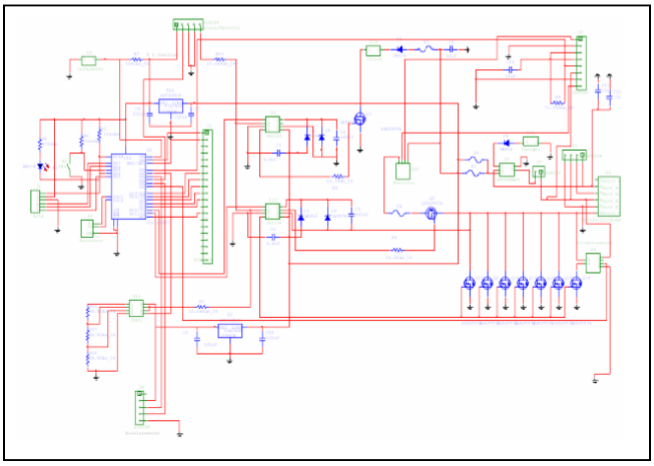

Fig. 8: Block diagram of PCB Controller

This figures below includes pictures of the final system during and after mounting of the hybrid bike.

Fig. 9: Motor Mount: Bottom and side plate

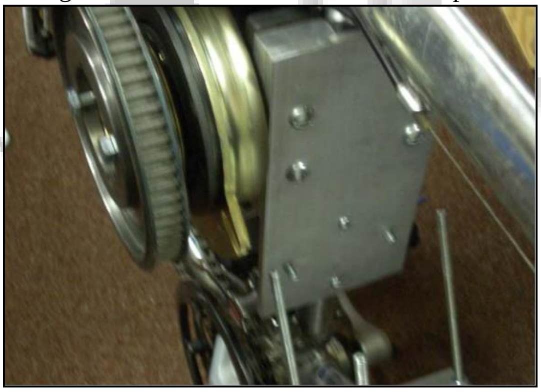

Fig. 10: Timing belt pulley, clutch and jackshaft mount

Fig. 11: Solar, Wind and Noise meter display of Hybrid Bike

Fig. 12: The overall hybrid bike after assembly

VI. Conclusion

At the conclusion of the project, full system integration was done physically. The major challenge remaining is creating a set of software that the microcontroller can use to control the system given all the feedback systems that communicate with it. Some additional features we may implement include creating a display and circuitry for monitoring the battery state. In conclusion, we have designed an electric hybrid bike with a minimal amount of additional weight, an integrated control system, based on the decision-making of the rider and microcontroller, and that is capable of greater efficiency than typical hybrid bikes through its use of regenerative motor control and various other feedback control mechanisms.

References

[1] A. Muetze and Y. C. Tan, Electric Bicycles, IEEE Indus try Applications Magazine, July/August, 12-21, 2007.
[2] A. Muetze, A.G. Jack, and B.C. Mecrow, Brushless-dc motor usingsoft magnetic composites as a direct drive in an electric bicycle, Proc. 9th European Conf. Power Electronics and Applications (EPE), Graz,2001, 350.
[3] B. Kumar and H. Oman, Power control for battery-electric bicycles, in Proc. NAECON '93—National Aerospace and Electronics Conf., 1, 1993, 428–434.
[4] C. Cherry, Electric Bike Use in China and Their Impacts on the Environment, Safety, Mobility and Accessibility, UC Berkeley: UC Berkeley Center for Future Urban Transport. Retrieved from http://www.escholarship.org/uc/item/8bn7v9jm 2007.
[5] E.A. Lomonova, A.J.A. Vandenput, J. Rubacek, B. d'Herripon, and G. Roovers, Development of an improved electrically assisted bicycle, Proc. 2002 IEEE Industry Applications Soc. Ann. Meeting, 2002, 384–389.
[6] J. Rouwendal, An Economic Analysis of Fuel Use per Kilometer by Private Cars, Journal of Transport Eco-nomics and Policy, 30(1), 1996, 3-14.
[7] Alonso García, M. & Balenzategui, J., 2004. Estimation of photovoltaic module yearly temperature and performance based on Nominal Operation Cell Temperature. Renewable Energy, Volume 29, pp. 1997-2010.
[8] Arrhenius, S., 1896. On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground. Philosophical Magazine and Journal of Science, pp. 237-276.
[9] Atkinson, D., 2012. 2013 e-Bikes roundup - hub motors, shaft drives and more.... [Online] Available at:

http://road.cc/content/news/66564-eurobike-2012-e-bikes-roundup [Accessed 24 February 2014]
[10] Badescu, V., 2002. 3D isotropic approximation for solar diffuse irradiance on tilted surfaces. Renewable energy, Volume 26, pp. 221-233.
[11] Bolton, O. J., 1895. Electrical Bicycle. U.S., Patent No. 552271
[12] Breyer, C. & Schmid, J., 2010. Population Density and Area Weighted Solar Irradiation: Global Overview on Solar Resource Conditions for Fixed Tilted, 1-Axis and 2-Axes PV Systems, Sonnenallee, Germany: Q-Cells SE.
[13] Gladdis, K., 2013. London's 4.000 Boris bikes cost taxpayers €1,400 for each bicycle every year despite sponsorship from Barclays. Dailymail, 11 July.
[14] Green, M. A. et al., 2013. Solar cell efficiency tables (version 43). Progress in Photovoltaics: Research and Applications, Volume 22, pp. 1-9.
[15] Gulin, M., Vasak, M. & Baotic, M., 2013. Estimation of the global solar irradiance on tilted surfaces. Dubrovnik, Croatia, 17th International Conference on Electrical Drives and Power Electronics
[16] Langford, B. C. et al., 2013. North America's First E-Bikeshare: A Year of Experience. Transportation Research Record: Journal of the Transportation Research Board, Volume 2387, pp. 120-128.
[17] Martin, N. & Ruiz, J. M., 2001. Calculation of the PV modules angular losses under field conditions by means of an analytical model. Solar Energy Materials & Solar Cells, Volume 70, pp. 25-38.