ISSN NO. 2320-5407

*Journal homepage: http://www.journalijar.com*

*INTERNATIONAL JOURNAL OF ADVANCED RESEARCH*

**RESEARCH ARTICLE**

# DEVELOPMENT OF AN IMPROVED LOW COST ELECTRICALLY ASSISTED BICYCLE WITH AN EFFICIENT PLUG IN CHARGER.

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## Manuscript Info

***Manuscript History:***

Received: 18 December 2015
Final Accepted: 22 January 2016
Published Online: February 2016

***Key words:***
BLDC hub motor, microcontroller, throttle controller, power MOSFET, Electronic Control Unit (ECU).

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## Abstract

There is an increasing demand for the electric bikes in the market. This is due to the fact that the user is looking for increased comfort and also reduced prices in the present day scenario. So E-bikes are an extremely efficient cost effective method to cater to all the needs of the consumer. Instead of investing money in a brand new model of bicycle, it is also effective to convert an existing model of the pedal powered bicycle into an electrically assisted one, which would be just as efficient as the new design, hence catering to all the needs and requirements of the consumers. Through this project a control strategy for driving a bldc hub motor is implemented and also a current controlled scheme is being introduced for better performance of the driving circuit.



## Introduction:-

An electric bicycle popularly known as e-bike, is basically a bicycle which uses an electric motor for traction and a battery system that supplies power to the motor. With technology taking giant and steady strides, the development of such a motor driven system also needs fine tuning synchronous to the other developments in the flanks of transportation. Recently new developments have been introduced in order to make the system efficiency impeccable. These developments include the design and selection of motor, control topologies, battery usage, modes of operation of motor etc.

New technology allows to customization of the e-bike thus making it more user friendly. For example, e-bicycles are now available with a conversion kit where a bicycle can be converted into an electric bike with the help of the conversion kit. The versatility of these bicycles allow the cyclists to ride on different terrains.

Apart from ease of access and user friendly topology, when technological aspects are concerned, it is necessary to look into the technical knowledge to bring out the design of such vehicles. In contrast with the past, gear drive system are being replaced with direct drive system by incorporating hub motors on the bicycle wheels. This not only reduces the space taken by the motor but also it makes the system mechanically robust as there is no moving parts or gears to wear out.

Here we are proposing a system which is a cost effective solution for the existing models as well as efficient by implementing a motor driving system on a conventional bicycle.

## Bldc motor fundamentals:-

A BLDC motor has a permanent magnet rotor which rotates and stator windings like that of a dc motor. The brush-commutator assembly of the brushed DC motor is replaced by electronic commutator, which continuously switches the phase to keep the motor rotating. The controller is basically a solid-state circuit which performs similar function as that of a brush-commutator system. In order for the rotor to rotate, it is necessary to track the current rotor position. This task is accomplished by the hall sensors which is usually embedded in the stator windings of the BLDC motor. The signals from the hall sensors is decoded and is given to a microcontroller which serves the purpose of switching the phases for the continuous rotation of the motor. So in general BLDC control drive systems are based on the rotor position feedback obtained at precise points typically every 60 electrical degrees for a six-step commutation of the phase currents.

Hall sensors are usually placed $120^{O}$ apart on the non-driving end of the motor. These elements work on the basic concept of Hall Effect theory. Hall Effect theory is explained as the production of a hall voltage across an electrical conductor, transverse to an electric current in the conductor and a magnetic field perpendicular to the current. This produced voltage, depending on the magnitude that is whether high, low or zero is given as signals and is decoded by the microcontroller. The output of the microcontroller is pulse which triggers respective power electronic switches in order to cause continuous rotation.

**Proposed motor driving system:-**

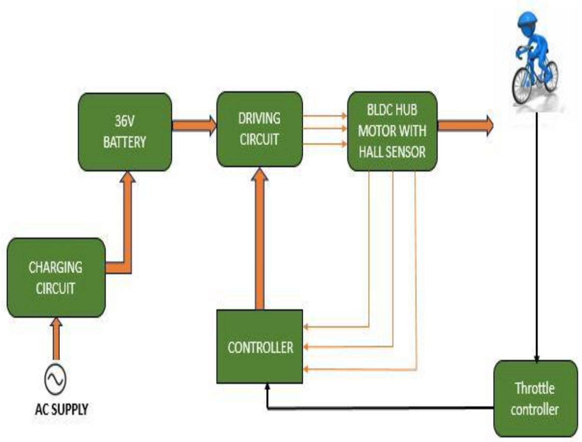



Fig.1:Block diagram.

As already mentioned, the BLDC motor driving system needs a closed loop control in order to keep track of the rotor position. The whole circuit is wired around the microcontroller which executes the function of switching the motor phases in a proper sequence so as to cause continuous rotation. Figure 1 clearly illustrates the block diagram of the motor driving system. Out of all the existing models, what makes the proposed system different is that the software used for controlling the ECU reduces the complexity of the programming part. The programming part is done on a software called FLOWCODE in which the logic of the control is given as algorithms and loaded to the microcontroller.

The initial stage of the project starts with a battery charging circuit which is powered from ac supply. The charging circuit charges the rechargeable battery which supplies power to the BLDC motor. The driving circuit with the help of the controller forms the ECU drives the motor. A throttle controller has been incorporated in order to vary the speed of the bicycle.

For giving position feedback to the controller it is essential to know the current position of the rotor. In order to give the position feedback the logic behind the hall sensors are studied and according to the signals given by the hall sensors a lookup table illustrating the commutation sequence is made and loaded as hexadecimal values to the controller.

Table.1: Lookup table for position sensing.

| H1 | H2 | H3 | A1 | A2 | B1 | B2 | C1 | C2 |
|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | | ✓ | | | ✓ | |
| 1 | 0 | 1 | | ✓ | ✓ | | | |
| 0 | 0 | 1 | | | ✓ | | | |
| 0 | 1 | 1 | ✓ | | | | | ✓ |
| 0 | 1 | 0 | ✓ | | | ✓ | | |
| 1 | 1 | 0 | | | | ✓ | ✓ | |

From the lookup table it can be seen that according to the hall sensor signal combination, respective phases switch on and off in a proper sequence thus completing the circuit and hence allowing the motor to rotate continuously.

## Charging circuit:-

The purpose of battery is to supply the power to the motor. The selection of battery is done on the basis of cost as well as efficiency. Since the project is focused on a cost effective conversion of a conventional bicycle to an assisted one, the battery was chosen according to the cost. Lead acid battery being the most economical for electric vehicles, battery was chosen and a battery charging system was also designed.

The performance of a rechargeable battery depends on the effectiveness of charger. Fast charging helps charging the battery in a short period of time while it reduces battery life. So fast charging techniques are not employed in this project. Also the charging is done based on three level charging sequence which is essential for the lasting of battery. Figure 2 given below describes the charging circuit for a 12V lead acid battery.

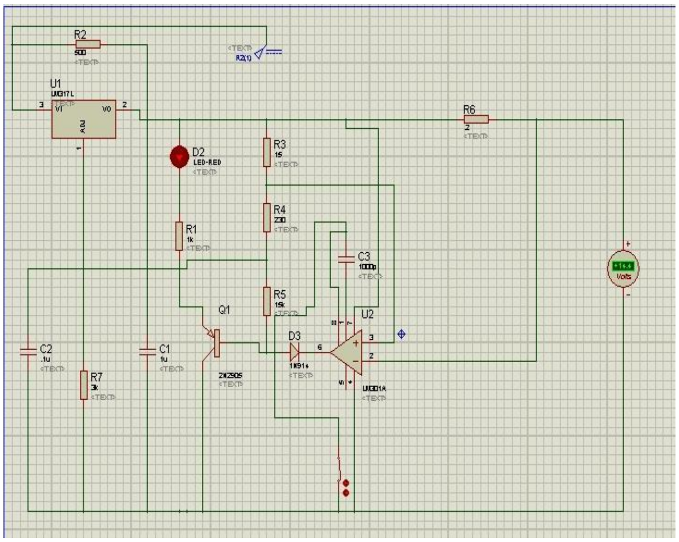



Fig.2: Proteus simulation of charging circuit.

The circuit makes use of a voltage regulator LM350 and a comparator IC LM301. The IC LM350 is an outstanding device which can be used for unlimited number of potential electronic circuit applications. Basically the main function of this IC is voltage control and can also be wired for controlling currents through some simple modifications. Battery charger circuit applications are ideally suited with this IC.

Referring to the circuit diagram it can be seen that the entire circuit is wired around the IC LM301, which forms the control circuit for executing the trip off actions. The IC LM350 is configured as the current controller and as the circuit breaker module. The whole operation can be analyzed trough the following points: The IC LM 301 is wired as a comparator with its non-inverting input clamped to a fixed reference point derived from a potential divider network made from R2 and R3.The potential acquired from the junction of R3 and R4 is used for setting the output voltage of the IC LM350 to a level that’s a shade higher than the required charging voltage, to about 14 volts. This voltage is fed to the battery under charger via the resistor R6 which is included here in the form of a current sensor. The 500 Ohm resistor connected across the input and the output pins of the IC LM350 makes sure that even after the circuit is automatically switched OFF, the battery is trickle charged as long as it remains connected to the circuit output. The start button is used to initiate the charging process after a partially discharged battery is connected to the output of the circuit. R6 may be selected appropriately for acquiring different charging rates depending upon the battery AH.

## Calculations for motor rating:-

The performance of a motor varies with loading the motor, it is essential to select the rating according to the load given to the motor. We approximated the weight being loaded to the motor to 120kg. This weight is the weight of the cycle assembly which includes the weight of the motor, cycle, battery and also the man weight. Next steps describes the calculations for choosing the motor rating

Assume that a m kg of mass is loaded to the motor. m≈ 120kg Speed changes from 0 → 25km/hr in 10 sec.

Acceleration a= (25-0)*(5/18)/10 = .694m/sec$^2$

Force is given by F=m*a =120 *.694= 83.33N

Torque developed by the motor= force *radius of the cycle wheel =83.33N* .33m

= 27.5Nm

Power developed = Torque * ω where ω is the angular velocity given by ω= (2π*.33*N)/60 radm/sec

=27.5* (2π*.33*250)/60

=237W

So the calculated power is about 237W. The next higher standard power rating is 250W. So a BLDC motor of 36V,250 W, 3000rpm where 3000rpm is the no load speed of the motor. When the motor is loaded, the maximum rpm obtained will be approximately 250rpm.

## Components selection:-

The rating of the selected motor is 250W and the rated voltage is 36V. So a current of 6.95A flows through the motor. But during loaded condition high current will flow through the motor.so MOSFET of high current rating has to be chosen.

In order for the MOSFET to withstand the current and to give the rated voltage to the motor we needed to use a MOSFET having higher voltage rating and high current rating. IRF3710 is a power MOSFET which is capable of withstanding current up to 57A.

Basic specifications: Vdss= 100V ID=57A

RDS (on) = 23mΩ

P-channels generally do not need boot strapping whereas N-channel do need. But P-channel MOSFETs tend to have higher on-state resistances than similarly rated N-channel MOSFETs,

so you will have higher losses for same/similar currents. Thus N-channel MOSFETs are preferred. Moreover, for high voltages, finding suitable P-channel MOSFETs is quite a difficult task and the level shifter circuit is more complicated than the bootstrap circuit. So we chose IRF3710 N-channel MOSFET. The most common way of driving MOSFETs in high side and low side is to use high-low side MOSFET drivers. Undoubtedly, the most popular such driver chip is the IR2110. So for driving the MOSFET IR3710, gate driver IC IR2110 is used.

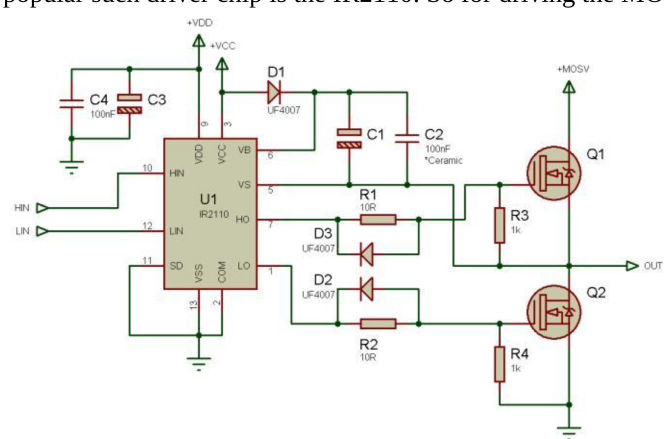



Fig.3: Boots strap circuitry.

Figure 3 describes the boot strap circuitry for IR2110. D1, C1 and C2 along with the IR2110 form the bootstrap circuitry. When LIN = 1 and Q2 is on, C1 and C2 get charged to the level on VB, which is one diode drop below +VCC. When LIN = 0 and HIN = 1, this charge on the C1 and C2 is used to add the extra voltage – VB in this case – above the source level of Q1 to drive the Q1 in high-side configuration. A large enough capacitance must be chosen for C1 so that it can supply the charge required to keep Q1 on for all the time. C1 must also not be too large that charging is too slow and the voltage level does not rise sufficiently to keep the MOSFET on. The higher the on time, the higher the required capacitance. Thus, the lower the frequency, the higher the required capacitance for C1.

The higher the duty cycle, the higher the required capacitance for C1. There are many parameters involved I selection of capacitance, some of which may not known – for example, the capacitor leakage current. So, required capacitance was estimated. For low frequencies such as 50Hz, use between 47μF and 68μF capacitance. For high frequencies like 30 kHz to 50 kHz, I use between 4.7μF and 22μF. Since an electrolytic capacitor is being used, a ceramic capacitor should be used in parallel with this capacitor. The ceramic capacitor is not required if the bootstrap capacitor is tantalum.

D2 and D3 discharge the gate capacitances of the MOSFET quickly, bypassing the gate resistors, reducing the turn off time. R1 and R2 are the gate current-limiting resistors. +MOSV can be up to a maximum of 500V. +VCC should be from a clean supply. Filter capacitors and decoupling capacitors are used from +VCC to ground for filtering.

## Gate resistance calculation:-

A gate resistance is needed in almost all applications where high side and low side drive MOSFETs are used. A gate resistor limits the instantaneous current that is drawn when the FET is turned on. If a FET is driven directly from a low-current device (microcontroller or logic gate) then gate resistors are recommended. Anywhere from 5 to 100 ohms is fine. They also can be viewed as slew-rate limiting devices for the gate signal, or as devices to eliminate ringing at the rate. If the MOSFET is driven from something like a dedicated half bridge driver or similar, then they can be eliminated, the drivers are usually meant to be directly connected to the MOSFET.

From the data sheet of IRF3710, it can be seen that the gate voltage is fixed at 4.5V.

$V_{GS}$= 4.5V

The switching frequency is 50 kHz. Time period = 20μs.

From the graph showing VGS versus gate charge, considering =50V, gate charge can be taken as 45nC

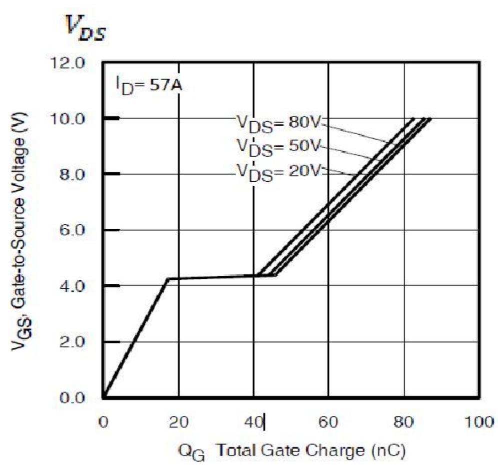



Fig.4 Graph between Vgs verses Qg Gate current = gate charge/ time period.

To attain this gate charge in shortest time, time period may be chosen as 1% of the total time period considering dead time.

So period = 1% of 20μs = 200ns.

Gate current = 45 nC/200ns = 225mA.

Gate resistance =Voltage/gate current

= 36V/ 225mA

= 20Ω

So the gate resistance to be connected to the gate is 20 **Ω**

## Driving circuit design:-

In a Brushed DC motor, commutation is controlled by brush position. In a BLDC motor, however, commutation is controlled by the supporting circuitry. The rotor's position must therefore be fed back to the supporting circuitry to enable proper commutation.

Two different techniques can be used to determine rotor position- Hall sensor based commutation and sensorless based commutation.

In the Hall sensor technique, three Hall sensors are placed inside the motor, spaced 120 degrees apart. Each Hall sensor provides either a High or Low output based on the polarity of magnetic pole close to it. Rotor position is deter-mined by analyzing the outputs of all three Hall sensors. Based on the output from hall sensors, the voltages to the motor's three phases are switched.

In the sensorless commutation technique, the back-EMF induced in the idle phase is used to determine the moment of commutation. When the induced idle-phase back-EMF equals one-half of the DC bus voltage, commutation is complete. The advantage of sensorless commutation is that it makes the hardware design simpler. No sensors or associated interface circuitry are required.

The disadvantages are that it requires a relatively complex control algorithm and, when the magnitude of induced back-EMF is low, it does not support low motor speeds. When a BLDC motor application requires high torque, when the motor is running at low speed, or when the motor is moving from a standstill, the Hall sensor commutation technique is an appropriate choice.

Since the proposed model needs high initial torque, Hall sensor commutation is suitable for the proposed model.

So to drive and control the BLDC motor, the use of a motor controller was implemented. The overall system of a BLDC with the motor controller is represented in figure 5. The inputs to the controller include the speed and current signals that are supplied by the throttle. The DC power supply feeds power to the motor controller which then distributes the voltage and current necessary to drive the BLDC motor. The Hall Effect sensors provide the feedback needed for the motor to know the position of the rotor and to tell it when to supply the voltage stoke to the different phases of the BLDC motor.

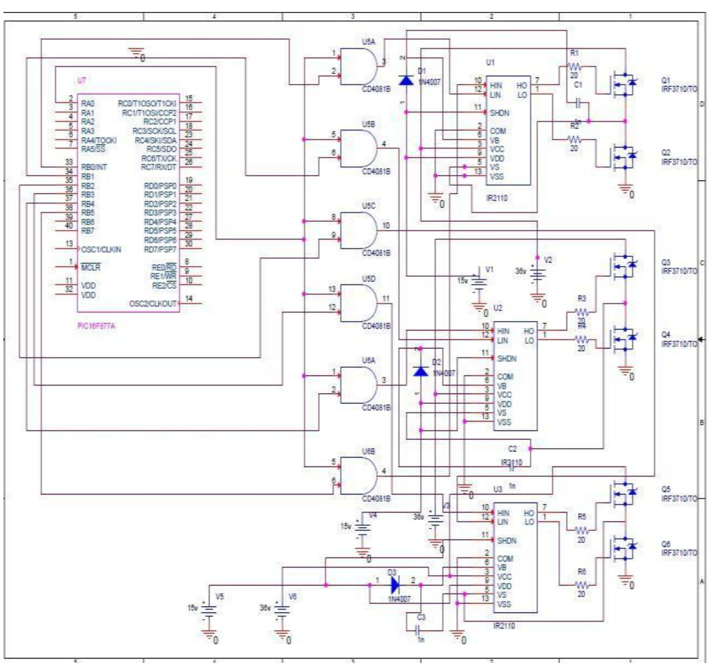


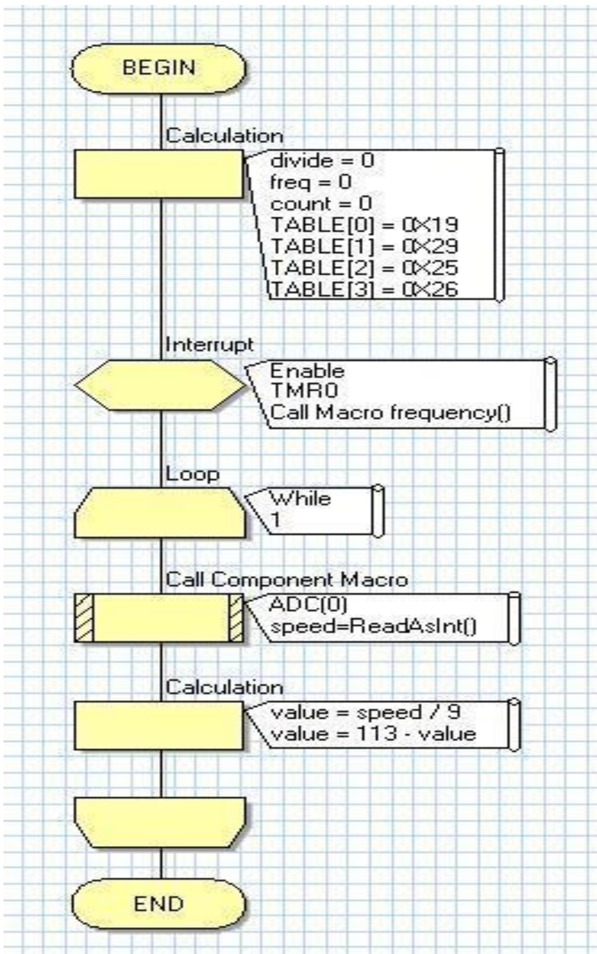
Fig.5 Driving circuit simulation.

## Bicycle assembly:-

As already mentioned, the basic aim of the project is to implement a motor driving system on a conventional bicycle. So in this case bicycle assembly is an important task. First of all a conventional bicycle was selected and its dimensions and design was studied. Since the hub motor which was bought is specially designed for electric bicycles the motor was bought along with wheel. Since the radius of the bicycle wheel and that of the motor incorporated wheel was different, the mechanical design was little complex in this case. First incorporating the motor on the rear wheel was tried, but due to the complexity in the implementation, the motor was incorporated on the front wheel. Later it was found out that incorporation of hub motor on front wheel is advantageous due to the better weight distribution and easy implementation though this method causes skidding while applying brakes.

After the fitting of motor on the front wheel, the next task was to find a space for placing the battery. Batteries should be kept in such a way that the mechanical design of a conventional bicycle is not altered and at the same time the weight is distributed correctly. With careful examinations and trials, it was decided to place the battery pack on the carrier of the bicycle. The controller was placed between the seat and carrier and was ensured that there is no electrical contact between the bicycle parts and the controller. By this pattern it was made sure that the whole system is balanced and will not be disturbed during traction

Fig.6: Main loop algorithm.

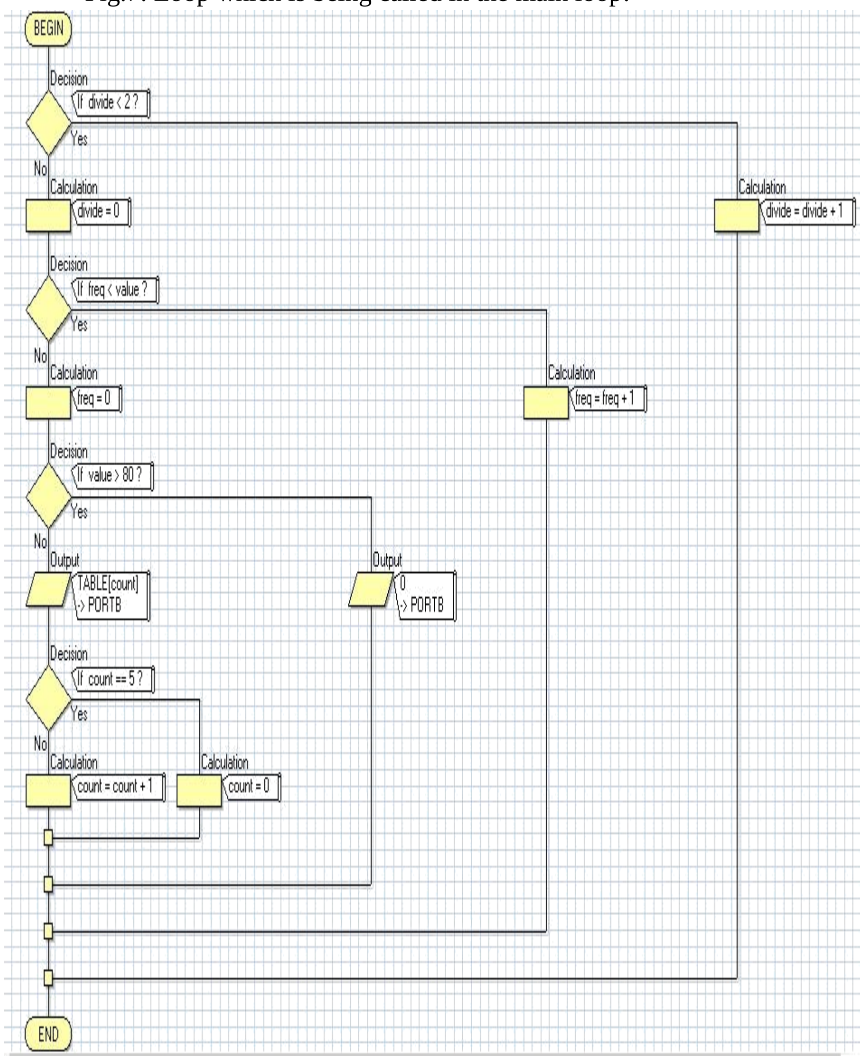


## Controlling using pic16f877a:-

As already mentioned, the BLDC motor driving system needs a closed loop control in order to keep track of the rotor position. The whole circuit is wired around the microcontroller which execute the function of switching the motor phases in a proper sequence so as to cause continuous rotation. This microcontroller has to perform the action of giving gate pulses to the MOSFET switches in the inverter circuit. The gate pulses should be given in a proper sequence so that the motor attains the required torque to rotate the motor continuously. So it is the duty of the microcontroller to decode the signals obtained by position feedback and to perform functions accordingly.

The working of hall sensors are studied and a lookup illustrating the nature of hall sensors ie high, low or zero and the switching of motor phases according to the hall sensor signals is made. This table is loaded into the microcontroller as hex codes and microcontroller performs further functions depending on the algorithm. The following flow charts describe the algorithm of the driving system. The algorithm is written on FLOWCODE software. Figure 6 describes the main loop of the program while figure 7 describes the loop which is being called in the main loop.

Fig.7: Loop which is being called in the main loop.



## Conclusion and future scope:-

This project brought together several components and ideas to achieve a common goal; to prove that it is possible to convert a conventional bicycle into an electrically assisted one. Using different concepts of battery charging and motor driving, an electrically assisted bicycle which would run with a maximum speed of 20km/hr was designed and implemented. The controller part was done using FLOWCODE software which reduced the complexity of programming codes.

An electric bicycle system is an area where lots of improvements are coming day by day. The proposed model is only a revolutionary model with a purpose of making it accessible to the general public. Scope of improvement is huge and the system can be enhanced to a wholly larger extent by the addition of concepts such as regenerative braking. Regenerative braking is a concept of energy recovery mechanism which slows a vehicle or object down by converting its kinetic energy into another form, which can be either used immediately or stored until needed. This contrasts with conventional braking systems, where the excess kinetic energy is converted to heat by friction in the brake linings and therefore wasted.

The most common form of regenerative brake involves using an electric motor as an electric generator. In electric railways the generated electricity is fed back into the supply system, whereas in battery electric and hybrid electric vehicles, the energy is stored chemically in a battery, electrically in a bank of capacitors, or mechanically in a rotating flywheel.

Another concept where future experiments can focus on is a current control scheme for driving the motor. Usually it is very difficult to control the current drawing by the motor especially in loaded conditions. The current drawn by the motor increases abruptly disregard of the motor rating. And this can burn the motor windings or the power electronic switches in driving circuit. So a current control scheme would be breakthrough in the field of electrical bicycle system.

There are currently more advanced ways solar cells can be mounted on the bike. There are bendable forms of solar cells and can be applied around the frame to conserve space and lower weight on the bike. Solar cell wheels that act like hub caps to the bike are also available. They are more energy efficient and have higher output voltage and wattage. There are also different forms of solar cells being made besides the typical solar panels. Inflatable solar balloons,

“hair like” solar nanowires, and printed solar panels are among the different types that have recently been made. These new forms of solar cells are currently working and are trying to be more efficient than current forms. They can possibly be used on the bike to conserve even more space.

The above mentioned concepts which when implemented will have a great effect on all those existing models. Such models will provide greater accessibility to people riding them as well as satisfaction to the designers to a greater extend.

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