Human Powered Hybrid Vehicle: A Review of History, Design and Development of Electric Bicycles.

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Abstract

The automobile industry is achieved to develop some alternative fuel technologies like natural gas, electricity, solar, hydrogen, biodiesel, methanol, etc. but still preference is given to petrol and diesel vehicles because of its advantages like torque, speed and fuels are easily available. The depletion of fossil fuel leads to increase in cost of petrol/diesel day by day and increase of pollution caused by these vehicle are also big issue that need to be solved. The human powered hybrid vehicles will provide an immediate solution to the fuel limitations and environmental pollution. Bicycles also are the best mode of transportation as it is totally dependent on human powered so they are named as Human Powered Vehicle (HPV). This paper is related with detail review of history, development, design and research of electric bicycles. The classification of electric bicycles, its components, Changes in the cycle and research area of electric bicycle is reviewed in detail. The electric bicycle research fields are reviewed based on prior studies to give helpful information to develop electric bicycles further.

Keywords: Human powered vehicle (HPV), Electric vehicles(EVs), Electric Bicycle(EBs), Effortless bicycle, sustainable mobility; future mobility etc.

1. Introduction

With the current issues associated with fossil fuels and environmental pollution caused by exhaust emissions of internal combustion engine such as hydrocarbons (HC), nitrogen oxides (NOx), carbon monoxide (CO), and particulate matter (PM), the need for alternate energy methods is greater than ever. In fact, including the United Kingdom, China, France, Germany, India, Ireland, Israel, and Norway, are planning to eventually ban all fossil-fueled vehicles to control environmental pollution [1]. Another approach to reduce environmental pollution is using electric vehicles (EVs) instead of fossil fueled propelled vehicles [3-7]. The health conscious people using bicycles for short commuting trips, like daily shopping, going to school, and going to work, is continually increasing. Electric bicycle is one of environmentally-friendly vehicles as well as a zero-emission. EBs is usually cheaper, low maintenance and also improves the health of the rider [9-11]. EBs does not require insurance, road taxes, and a license to ride in most of countries [8]. EBs can be classified into pure EBs, power-assisted bicycles and combine pure and power-assisted mode. The pure EB without pedaling utilizes an electric motor installed on the bicycle frame or wheels, and the driving power is controlled through a handlebar throttle. The power-assisted bicycle is a human-electric hybrid bicycle that assists the rider

When pedaling and it has motor along with a sensor to detect the pedaling speed and Pedaling force [12]. The force sensor will detect the force generated by pedaling and then send a signal to

an electronic control unit (ECU) to control an electric motor. According to the signal received from ECU electric motor creates additional power to assist the rider when pedaling [13].
The third type of EB is a combination of the pure and the power-assisted modes, in the pure mode, the driving power from an electric motor is only controlled through a handlebar throttle and for the power-assisted mode; the driving power is a combination of rider and motor power.

2. A short History of bicycle

The first step in the invention of this glorious machine can be tracked down in 1791 at Parisian Park a toy-like machine named Hobby Horse as a plaything for rich. Improvement in this was seen in 1817, now front wheel can be turned by a handle. This was named as Draisienne after German Baron von Draise or a Velocifer. The first treadle led true bicycle appeared in 1830 which was ridden with both feet's entirely off the ground by a Scottish blacksmith named Krikpatrik MacMillan. The Pedals were added to the front wheel In 1863. The Bone-shaker was launched and Riding velocipedes soon becomes a fad. In 1865 Radial (and torsion) spokes are introduced making bicycles lighter. Solid rubber tires are introduced replacing iron tires. Then the term 'bicycle' was first used in 1869. In 1870 Tangential spokes are used replacing radial and torsion spokes. J K Starley invents the Rover safety bicycle in the year 1888. In 1889 Pneumatic tires were first used. In 1896 Coaster brakes invented. Then in 1899 mile-a-minute barrier broken, Murphy completed a mile in 57, 75 second. Then in 1965 conservation movement and physical fitness buffs recognize the importance of bicycle and a bicycle boom begins. In 1972 for the first time ever, bicycles outsell cars in United States of America. Disc wheels were introduced in 1980 for competition bicycles to reduce the aerodynamics drags due to individual spokes. John Howard in 1985 sets the speed record at 152.28 mph.[2]

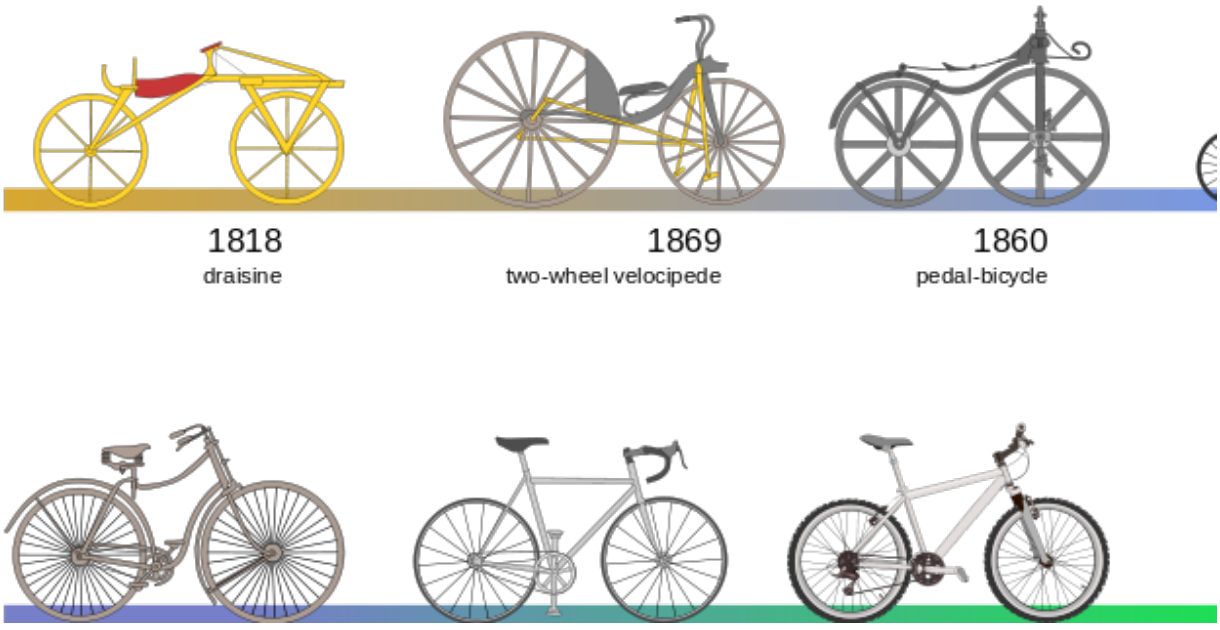

Fig.1. History of Bicycle [14]

In 1817 Baron von Drais invented a walking machine in which two same-size in-line wheels were used and the front one steerable. It was made entirely of wood and it was propelled by pushing rider feet against the ground. This device was not used for practical for transportation in any other place than a well maintained pathway such as in a park or garden.[15-16]

Fig.2. The Walking Machine [15]

In the the velocipede **or Boneshaker** pedals were applied directly to the front wheel. It was popularly known as the bone shaker and it was used in indoor riding academies.

Fig.3. The Velocipede or Boneshaker [16]

The makers realized that the larger the wheel,the rider could travel farther with one rotation of the pedals. The pedals were still attached directly to the front wheel and this machine was the first one to be called a bicycle.

Fig.4. The High Wheel Bicycle [17]

As the design changed, the front wheel was shortened. Earlier designs were known as bicycles, these designs were referred to as "ordinary".

Fig.5. The High Wheel Safety [19]

The pneumatic tire was first applied to the bicycle by an Irish veterinarian whose name was Dunlop. Because of comfort, safety and cost of bicycle was getting cheaper, everyone clamored to ride the bicycle. "The Safety Bicycle" was the most important change in the history of the bicycle and that became very popular beginning in the late 1880s. The Safety Bicycles were popular in the riders because of fewer risks, lighter in weight, mechanically simpler, and less expensive.

Fig.6. The Pneumatic-Tired Safety [20]

3. Development of electric bicycle

The electric bicycle can be propelled by human power or motor or both.

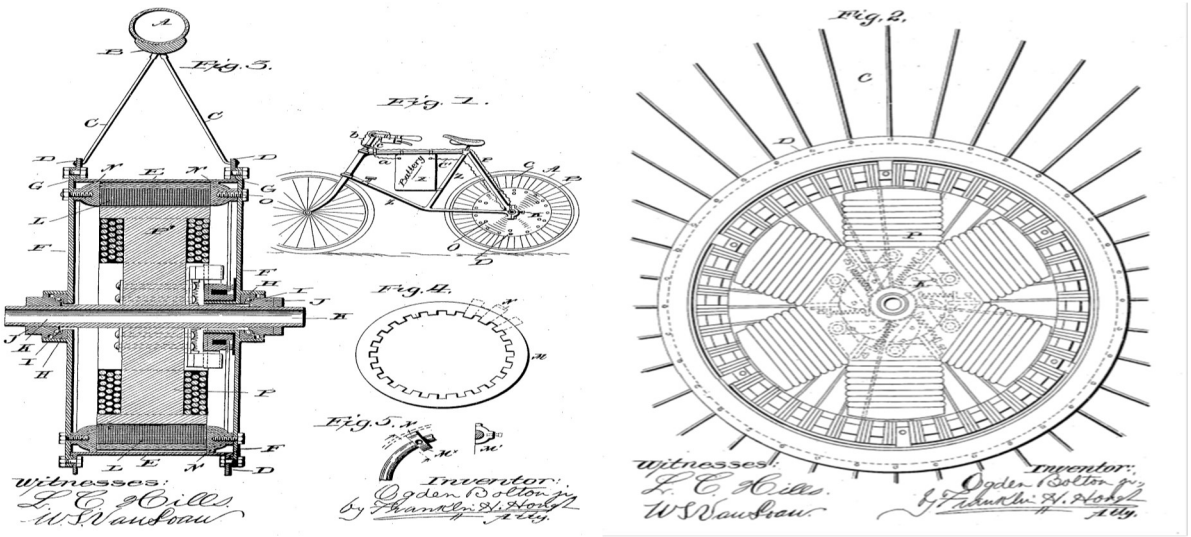

Fig.7. EB invented by Ogden Bolton [21].

Ogden Bolton [1895] invented an EB integrated with a six-pole direct current (DC) hub motor mounted in the rear wheel. The rheostat placed upon the handle-bar and Suitable construction made for the battery.as shown in Fig.7.

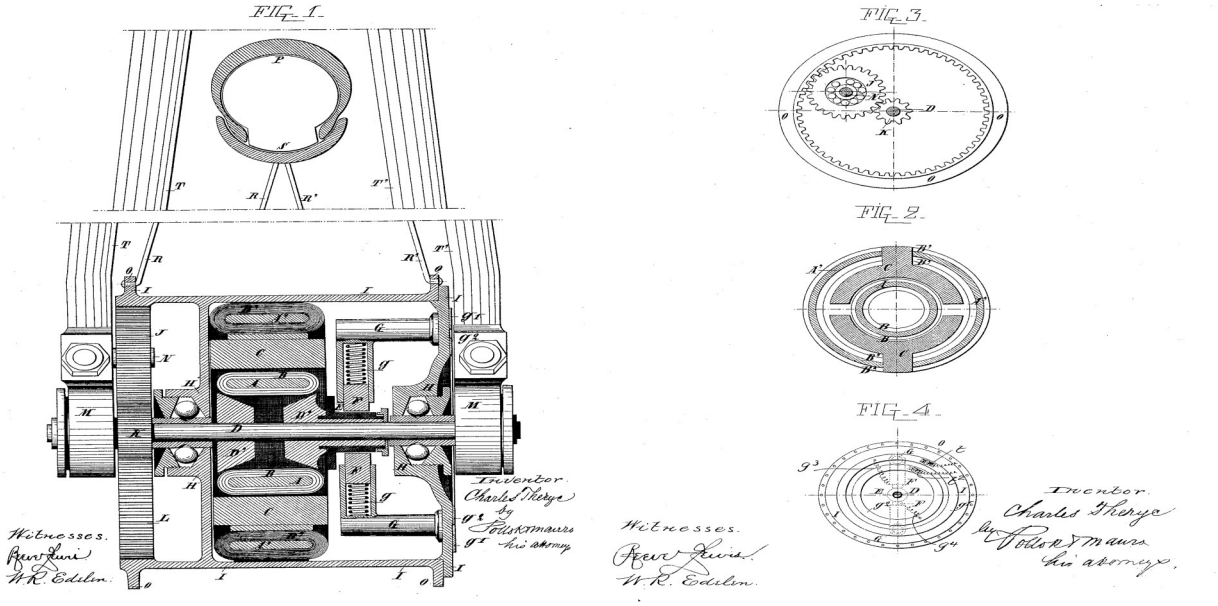

Fig.8. Wheel with electrical motor hub for vehicle by Charles Theryc[22]

Charles Theryc [1896] invented a wheel with an electric motor hub that could be applied to vehicles generally and bicycles. Because of this innovation it is easy to convert this self-moving bicycle into an ordinary bicycle.

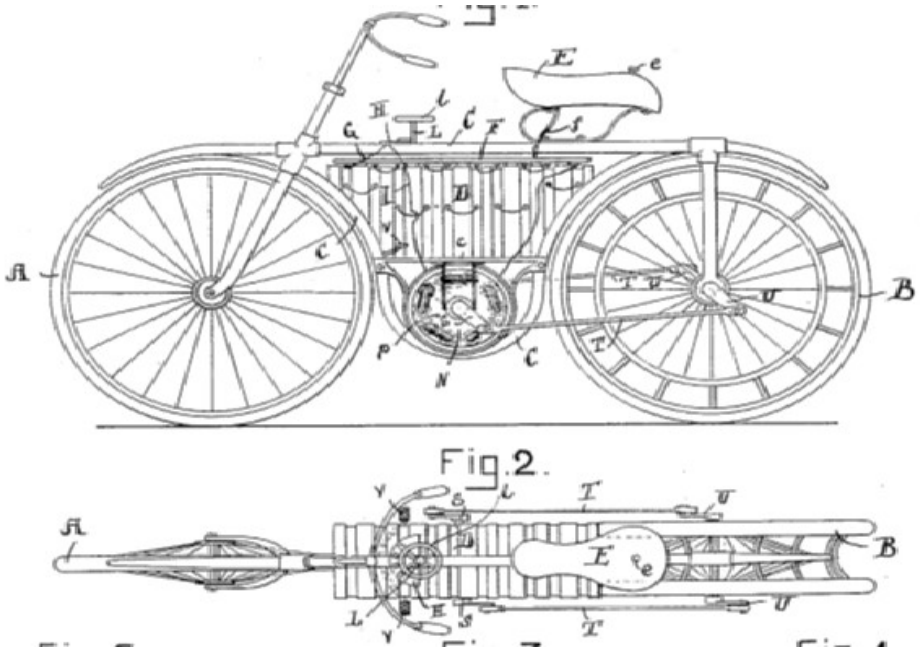

Fig.9. EB invented by Hosea W. Libbey [23]

He used double electric motor and rear double-treaded wheel for the driving-wheel.his invention shows that because rear double-treaded wheel for the driving-wheel, twice as much traction was obtained and thus the EB was more easily propelled.[23]

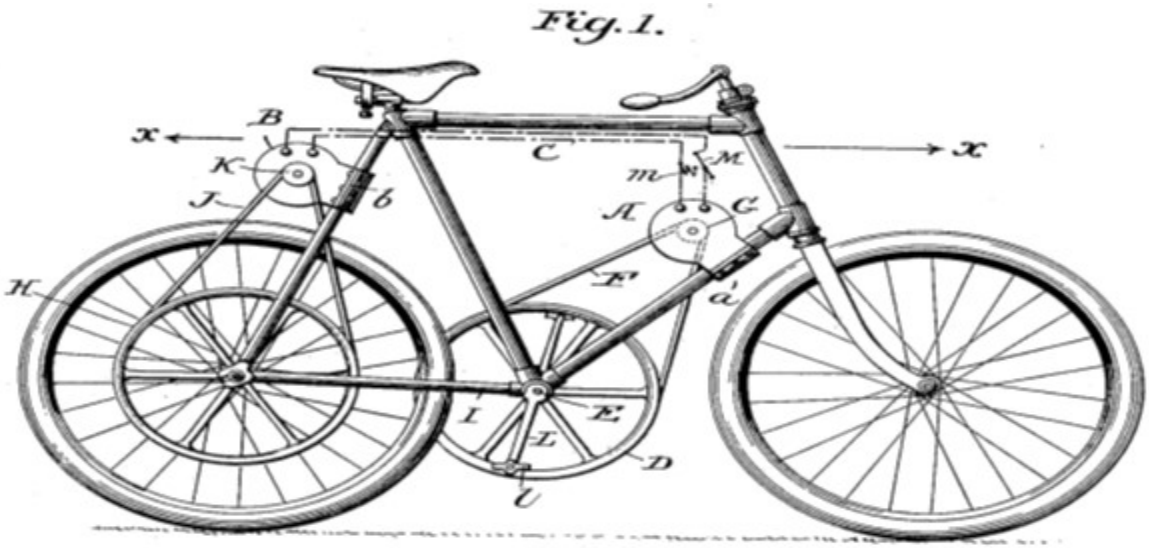

Fig.10. EB invented by Gordon John Scott [24].

In Gordon John Scott [1998] invention, the rider would pedal to rotate a generator (dynamo) through a pulley and a flexible belt. He used generator instead of battery and the power from that generator was used to drive a small motor.

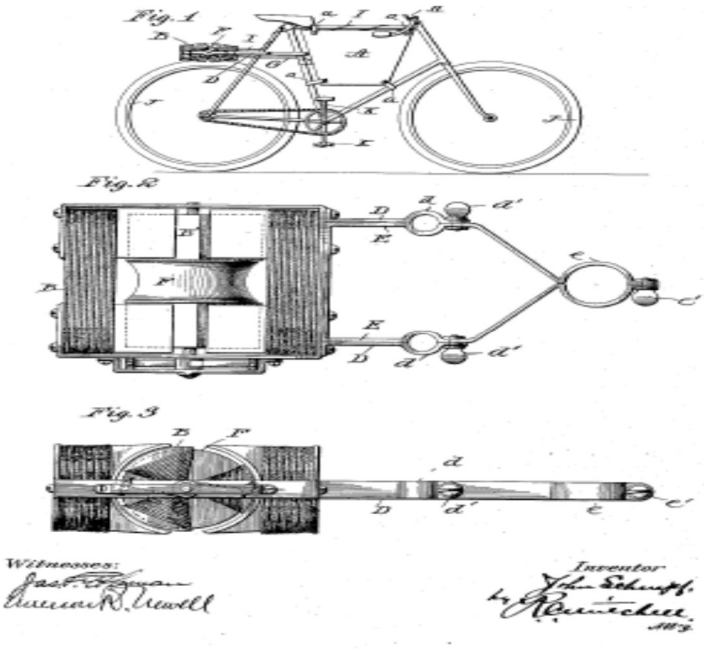

Fig.11. EB invented by JOHN SCHNEPF [25].

John schnepf [1998] invented device which may be utilized as a primary or auxiliary driving means. It may be used with any form of bicycle. It may be thrown into or out of action at the will of the rider. It can be used as the sole or supplemental driving power. Very little power is required in driving the same, because the power is applied at the periphery of the wheel only.

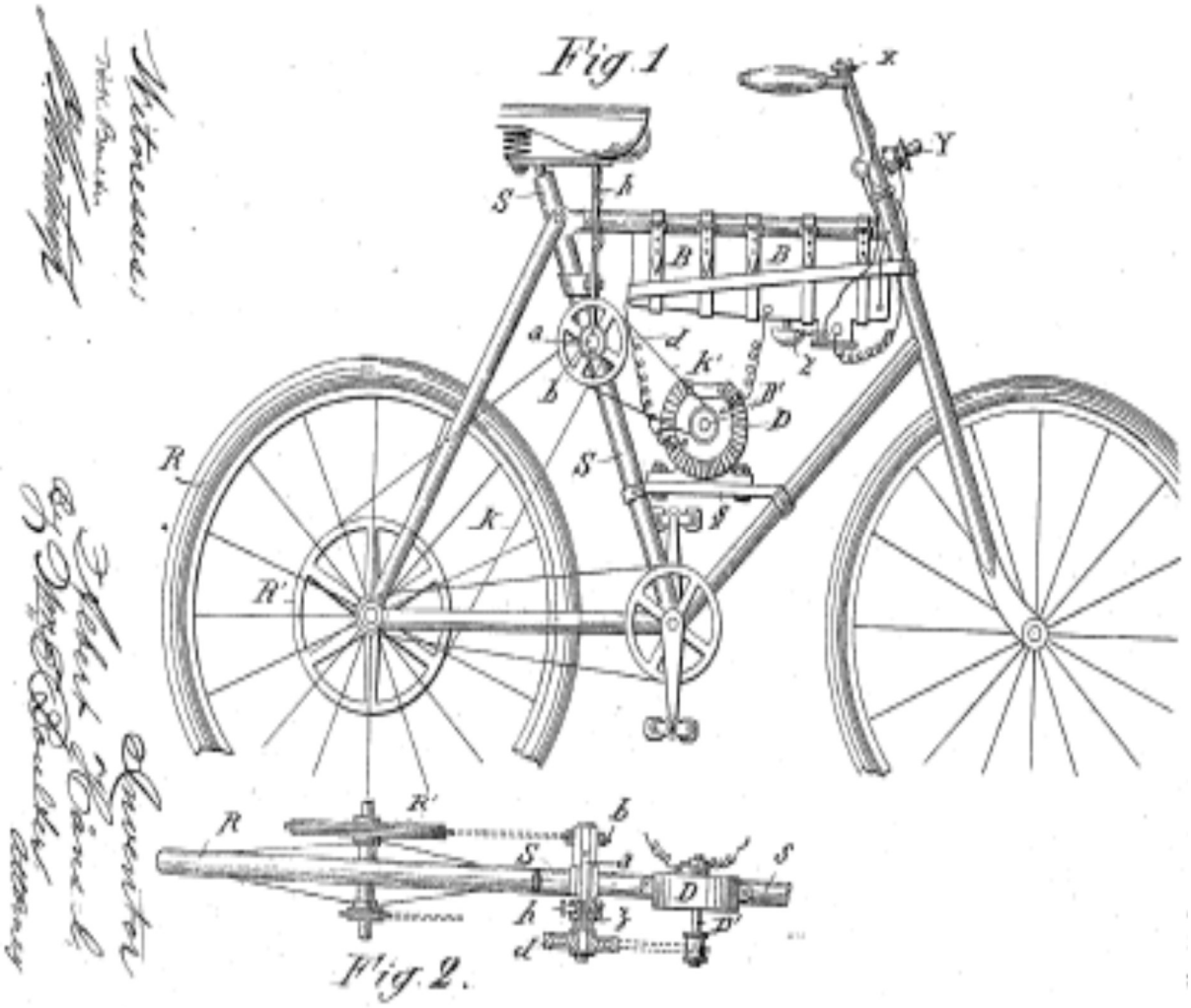

Fig.12. EB invented by Albert Hänsel [26].

Albert Hänsel invention relates to bicycles or similar vehicles, the object being to provide a driving mechanism which may be easily applied to such vehicles. Its complete form comprises an electric motor supported by the frame of the bicycle and mechanically connected with the drive-wheel, a storage battery will be charged from said electric motor as the bicycle runs down a descent. The storage battery being- intended to supply current or electromotive force to said motor for actuating the bicycle when hill-climbing.

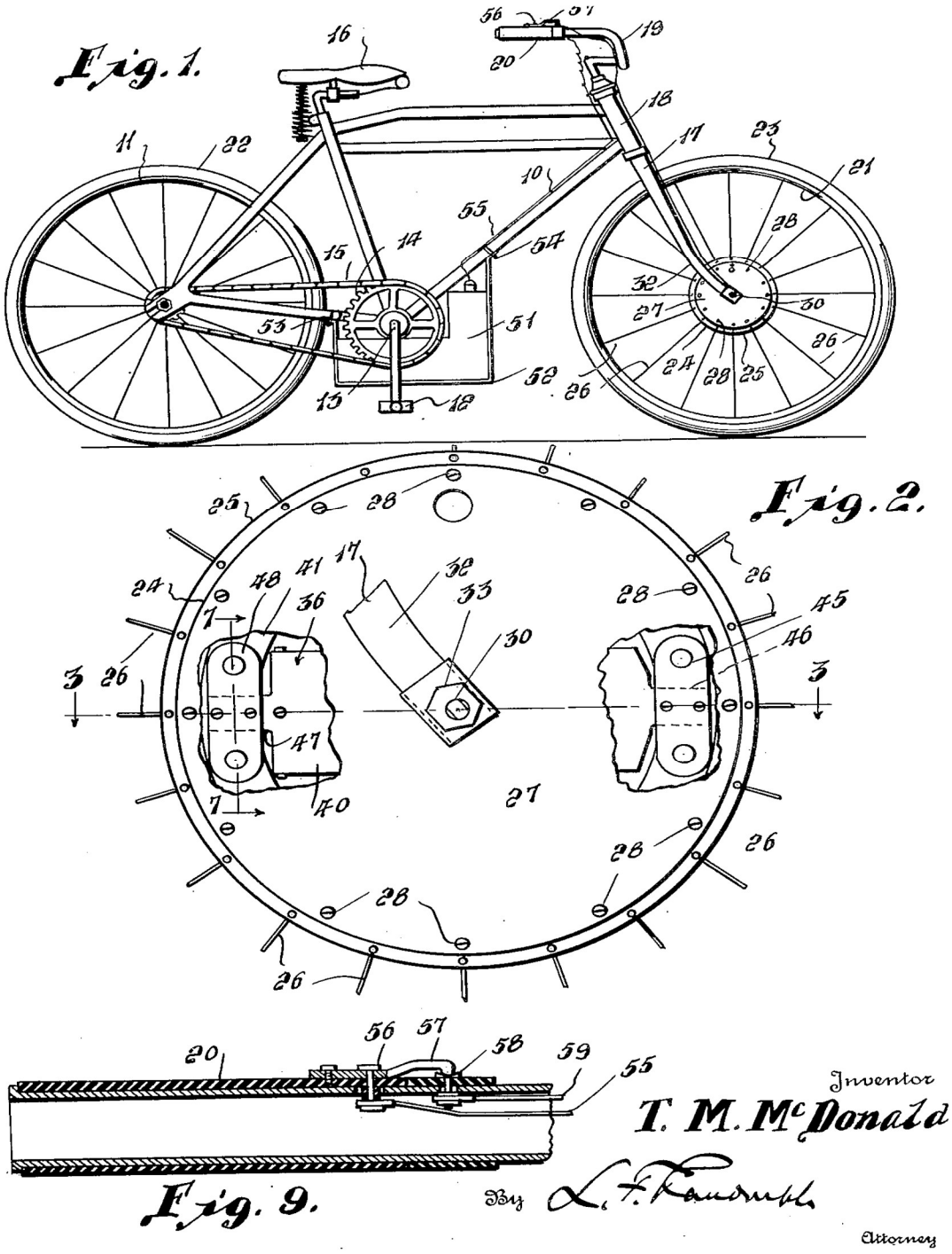

Fig.13. EB invented by Albert Hänsel [27].

The first EB that utilized an electric hub motor mounted in the front wheel was invented by Thomas M. McDonald [38]. His EB used primary, secondary electric batteries and It is further aimed to provide such a bicycle which will be capable of Operation by power alone and selectively.

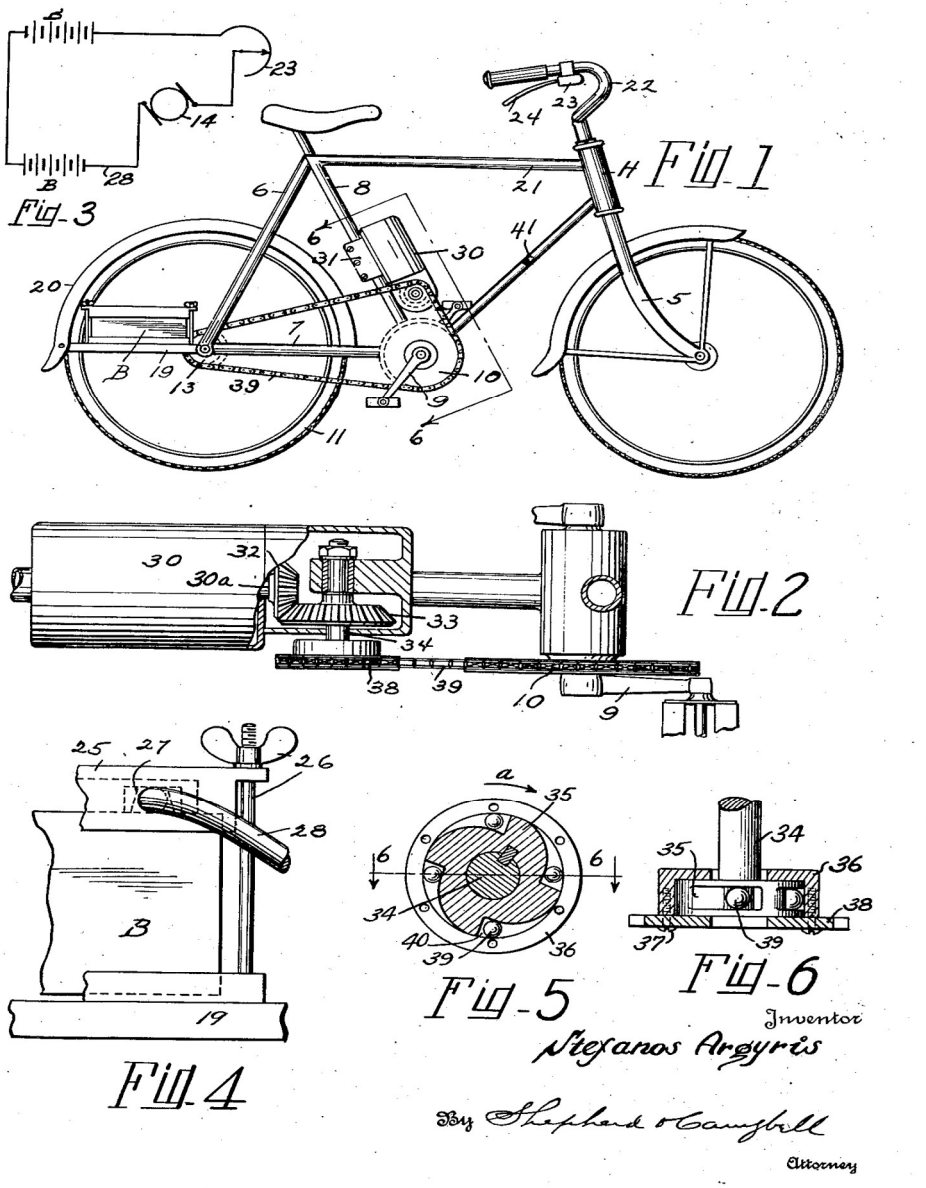

Fig.14. EB invented by Stefanos Argyris's[28]

The object of Stefanos Argyris's invention is to provide means for easily and quickly attaching electrical propulsion means to existing conventional. Attempts have been made in past years to propel bicycles by electric motors and batteries. However, the great weight of the batteries, the rapidity with which they became exhausted and the long time required to re-charge.EBs motor ran inline with the chain to assist the rider when pedaling.

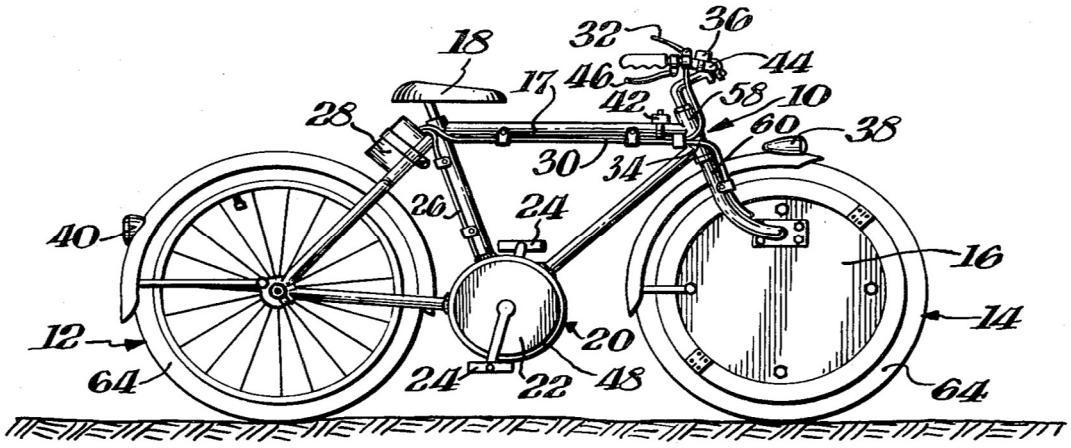

Fig.15. EB invented by Augustus B. Kinzel [29]

In accordance with Augustus B. Kinzel invention a power operated cycle includes a manually powered generator which supplies energy to drive a motor associated with any one of the wheels of the cycle for thereby imparting motion to the cycle. He showed that a short circuit means may be provided for the motor to act as a brake for the cycle and switch can be provided to control the speed.

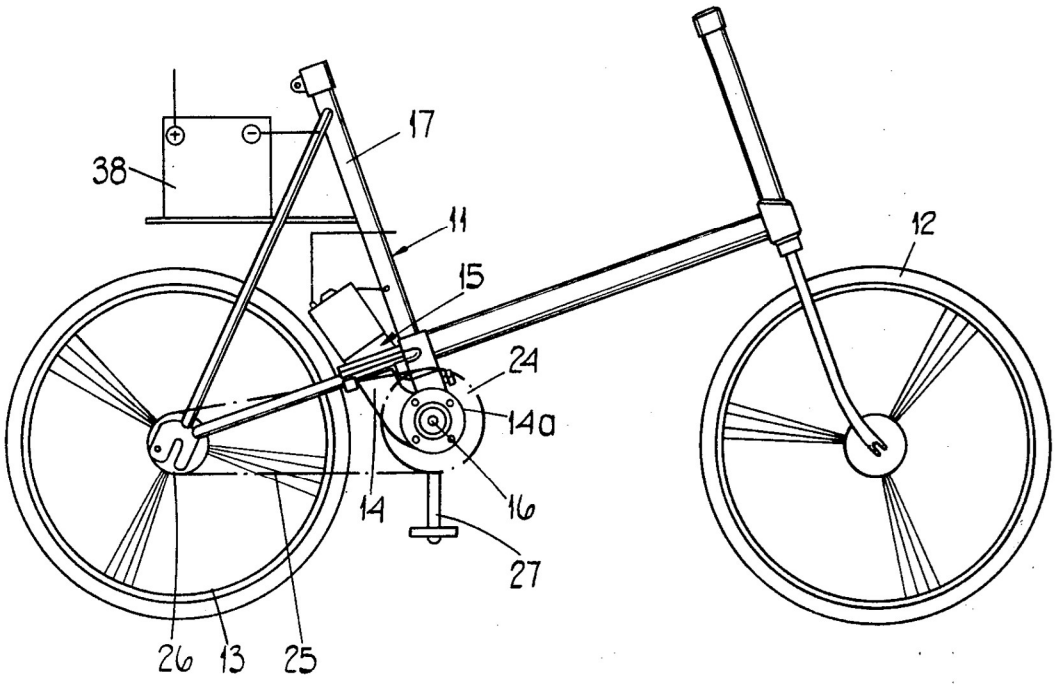

Fig.16. EB invented by Peter Watson Leighton [30]

Peter Watson Leighton invention is related to an electrically assisted pedal cycle. The motor is coupled to the ground engaging wheel in such way that the motor can drive the ground engaging wheel, so as to assist the rider in propelling the cycle.

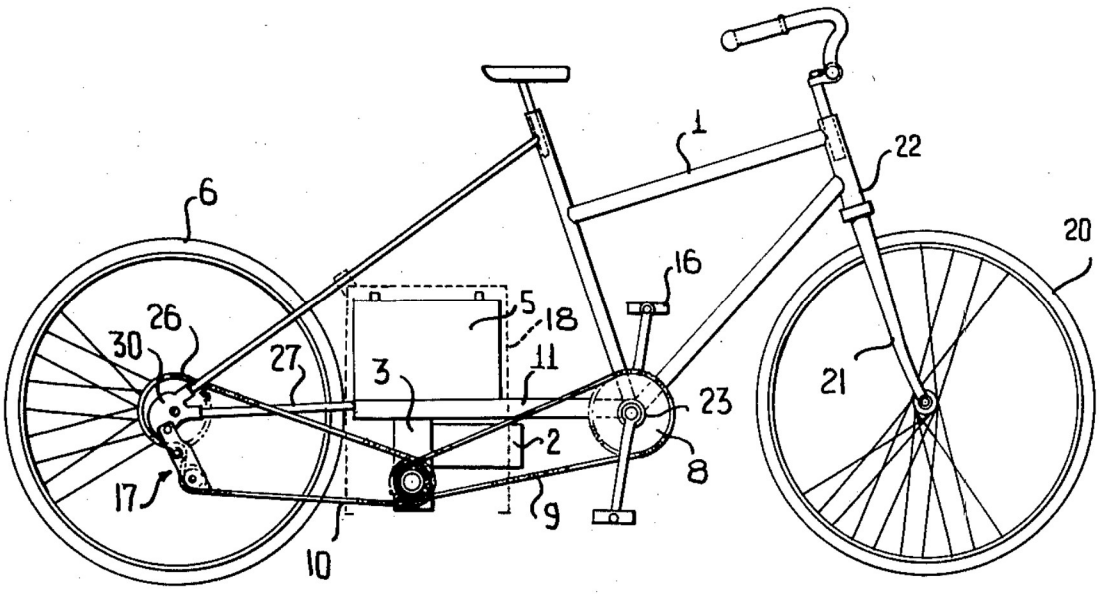

Fig.17. EB invented by Lawrence Rudwick [31]

Lawrence Rudwick developed EBs in such way that the storage battery and motor may be mounted between the pedals and the rear wheel for a more stable and smooth ride. The motor and pedals are efficiently coupled so that either or both simultaneously may propelled the driven wheel.

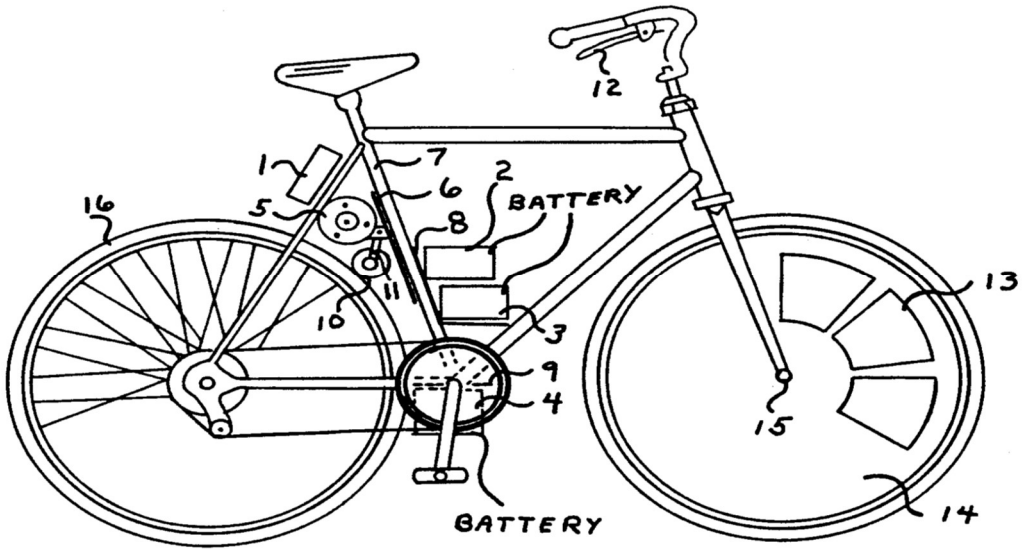

Fig.18. EB invented by Henry M. Gannon [32]

The invention of Henry M. Gannon relates to an electric propulsion system and a rotatable coupler conducts the solar Charging current from the solar cells to the plurality of batteries.

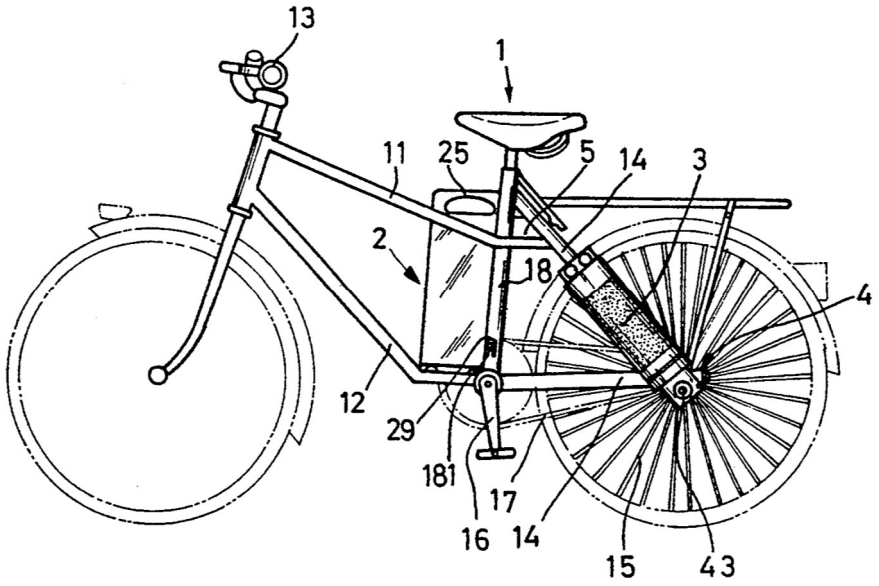

Fig.19. EB invented by Wen-Cheng Chou [33]

An improvement to electrical bicycles is provided by Wen-Cheng Chou invention. An output of bevel gear wheel of a D.C. motor is engaged with the large bevel gear wheel to directly drive the hub in a forward direction. The hub may also be pedal driven so the function of the pedals is not changed.

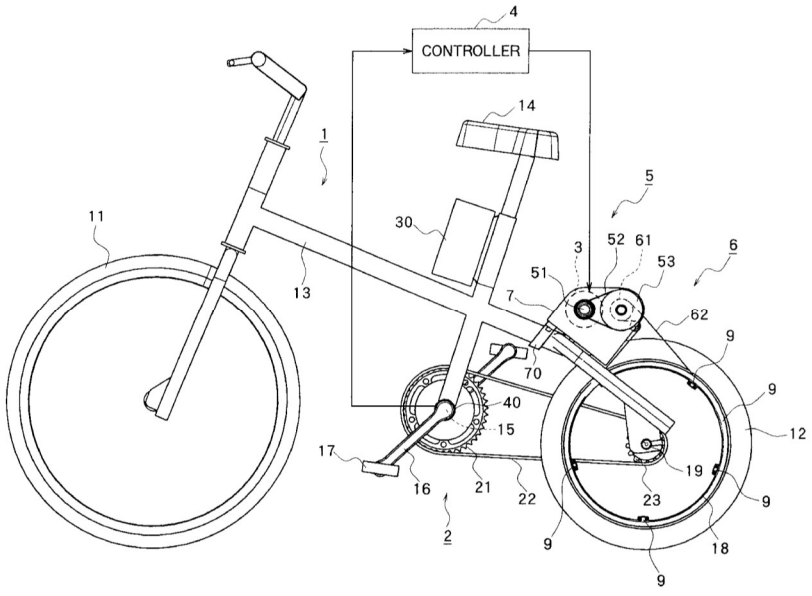

Fig.20. EB invented by Seiji Murakami [35]

The invention of Seiji Murakami is about an electric bicycle in which an electric motor mounted on the bicycle between the Saddle and the outer periphery of the rear wheel. The belt transmission mechanism used to transmit power from driving pulley and driven pulley.

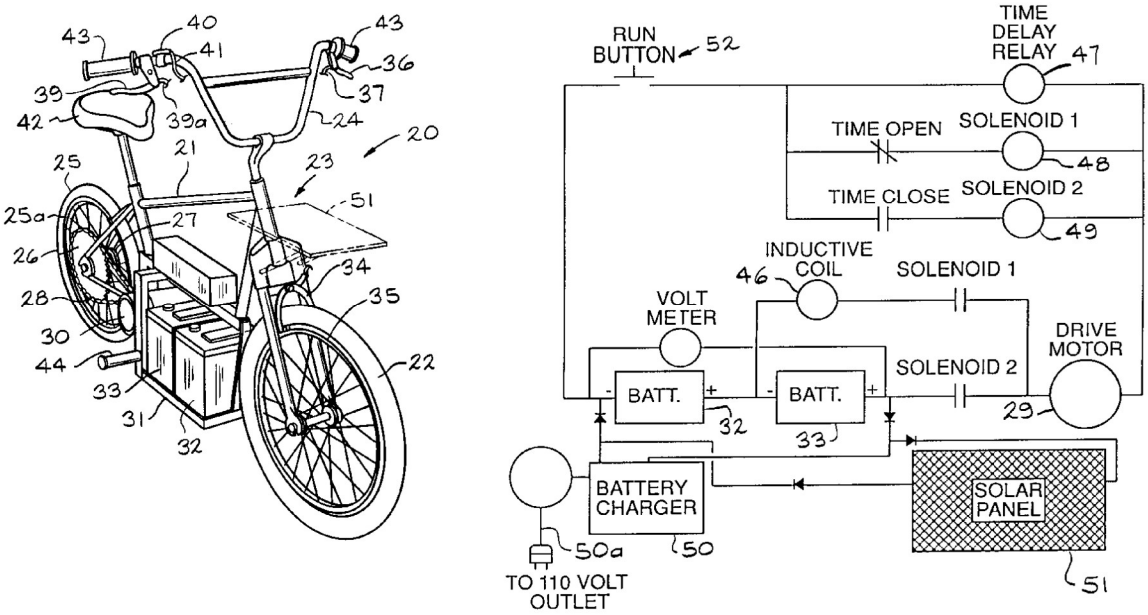

Fig.21. EB invented by Seiji Murakami [36]

Ronald Whittaker developed an electric bicycle provided with a lightweight, high performance DC electric motor and a tuned centrifugal clutch assemby. His invention is provided with a front wheel mounted regenerating wheel rotor assembly which is adapted to recharge batteries as needed and because of solar panel it having more advantages as compare to previous ebike.

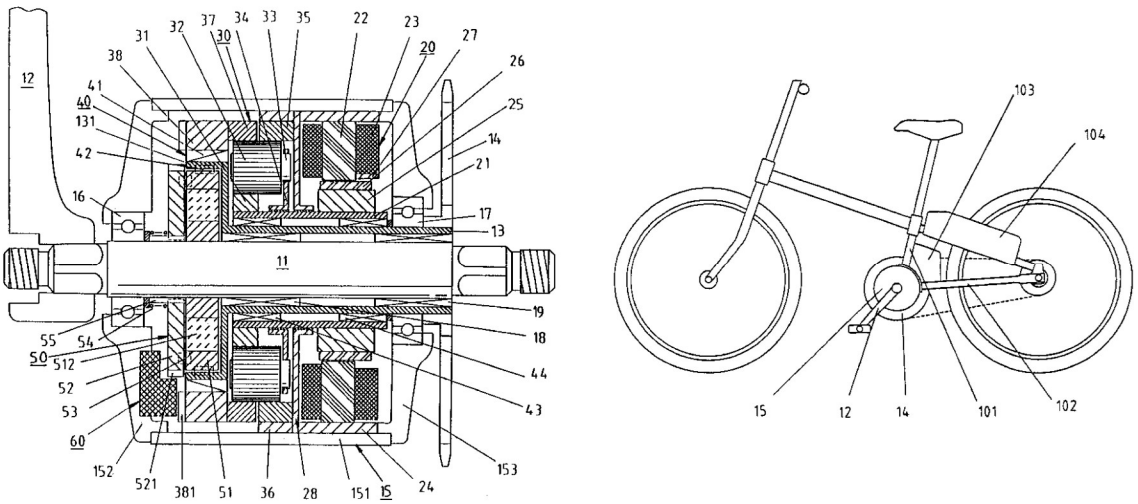

Fig.22. EB invented by Chin-Yu Chao [37]

Chin-Yu Chao invention related with a power transmission and pedal force Sensing System for an electric motor.In his invention EBs includes an electric motor, a gear reduction train, a pedal force Sensing System, and a power combination mechanism. These systems are concentrically, closely mounted in a single casing The pedal force Sensing System includes a pedal force transmitting sleeve having an elastic device mounted therein, and a pedal force Sensing sleeve mounted outside the pedal force transmission path for converting the means pedal force into an linear displacements(axial).

Fig.23. An illustration of a electrically power-assisted bicycle(pedelec) [38].

The world first commercial electrically power-assisted bicycles were available in this period [38], as illustrated in Fig.23.

4. Types of electrical energy sources

The muscular power,battery and solar energy are the energy sources of an EBs. Solar energy is intermediate sourse of energy and which is in diluted form.Use of solar energy still in developing stage and it having great exposer in the field of EBs. The battery is one of the energy sources of an EB and most commonly used in EBs. Battery is the heart of electric vehicle and its important

properties include light weight, high energy density, fast charging, low discharge loss, safety, long lifespan, low cost and Eco-friendliness. The patent of for a zinc-carbon battery filed by Hosea W. Libbey of Boston, Massachusetts, on January 27, 1894 [39], which was then used for the EB he invented in 1897 [40]. Other power sources like zinc batteries, sodium batteries, fuel cells, and solar energy can be used for EBs. Due to its high efficiency of fuel cell is receiving considerable interest from researchers, which could enable EBs to travel long distances. Because of high cost and the difficulty in storing hydrogen fuel on an EB are challenges for using fuel cells on EBs.

4.1 Lead-acid battery

It was invented by Gaston Planté in 1859. Lead-acid battery was the first battery that could be recharged by passing a reverse current through it[41]. During discharge process it generate water, lead sulfate and energy. During charging, the water and lead sulfate are electrochemically converted to sulfuric acid, lead dioxide and lead by an external electric source. Lead-acid batteries are cheap, recycle easily, tolerant of overcharging and can deliver very high currents. it can be easily delivered to customers due to many suppliers worldwide. Lead-acid battery is heavier and It has a low energy-to-weight ratio and low energy-to-volume ratio. Lead-acid battery can cause dangers such as chemical burns for the skin, generating flammable gases, so more safety needed. Its negative electrode is lead, which is a toxic metal for environment means polluting the environment.[41]

4.2 Nickel-cadmium battery(NiCd)

The first Ni Cd battery was invented by t Waldemar Jungner in 1899.the Ni Cd is a rechargeable battery type with components including a nickel oxide-hydroxide positive electrode plate, a cadmium negative electrode plate, a separator and an alkaline electrolyte (KOH). Nicd battery has more capacity , faster charge rate, required fewer maintenance and It can operate with a wide temperature range. it has a long life along with simple transportation and storage is also one of advantages of NiCd battery.These battery can be created with a wide range of sizes depending on performance. NiCd battery contains cadmium which is a toxic metal and hard to recycle and for same capacity it is expensive as compare to lead acid battery[42-43].

4.3 Nickel-metal hydride battery (NiMH or Ni–MH)

Stanford Ovshinsky invented and patented improvement of the NiMH battery and founded Ovonic Battery Company. General Motors purchased Ovonics' patent and By the late 1990s, NiMH batteries were being used successfully in many electric vehicles, such as the General Motors EV1 and Dodge Caravan EPIC minivan. NiMH is a rechargeable battery type, in which the chemical reaction at the positive electrode is similar to that of the nickel cadmium (NiCd) battery; however its negative electrode uses a hydrogen-absorbing alloy instead of cadmium (Cd) [44]. Hydrogen ions are stored in a metal-hydride structure that is the negative electrode of the NiMH battery. Polyolefin nonwovens are used as a typical material for separator in NiMH batteries. it is simple in transportation, storage, environmentally friendly and less susceptible to

memory effect than a NiCd battery. NiMH battery also offers more energy per unit volume or weight compared to NiCd battery types. NiMH batteries have replaced NiCd for many roles, especially small rechargeable batteries. NiMH batteries were frequently used in prior-generation electric vehicles, as of 2020 NiMH batteries have been replaced by lithium batteries almost entirely in all-electric and plug-in hybrid vehicles, but they remain in use in some hybrid vehicles like Toyota Highlander 2020[44].

4.4 Lithium-ion battery

Sony Corporation had announced first commercial product of lithium-ion battery. During discharge lithium ions move from the negative electrode to the positive electrode and back when charging. The negative and positive electrodes of a Li-ion cell are made from carbon and metal oxide respectively. The electrolyte used in Li-ion battery is a lithium salt in an organic solvent. Li-ion battery is one of the most popular rechargeable batteries with great sales and it has a high energy density with lightweight. Its cost is higher than that of NiCd and NiMh batteries. Li-ion battery could be damaged due to over-heating, over-charging, and over discharging. It is required protection to ensure its safe operating limits and aging is depends on number of charge discharge cycles[45].

4.5 Lithium-ion polymer battery

Lithium-ion polymer (LiPo) batteries use polymers with high conductivity semisolid (gel) to form an electrolyte.It can use a solid polymer electrolyte such as poly (acrylonitrile) (PAN), poly (vinylidene fluoride) (PVdF) and poly (ethylene oxide).LiPo polymers batteries has a high energy density with lightweight, and can be created in a wide range of sizes. Life span of LiPo polymers batteries higher and good in safety performance.The cost of LiPo batteries is higher, Energy density and cycle number of LiPo battery are smaller than Li-ion battery[46].

5. Electric motors

According to function and location of electric motor on EBs can be classified into either brushed DC or brushless DC (BLDC). Brushed DC motors are more robust and cheap but are noisier, heavier, and require relatively frequent maintenance service. As compare to brushed DC motor, BLDC motors are quieter, lighter, and do not need to be serviced as often. BLDC motors are generally smaller than brushed DC motors, which makes them feasible for compact EB designs. The electric motors are located in the front wheel (hub motor), the rear wheel (hub motor), in a mid-drive position or special arrangement for motor, as illustrated in fig.24 & fig.25. Front wheel hub motors are convenient for maintenance and creates a better weight balance between the rear and front of the EB. However, front wheel hub location EBs have some disadvantages Such as include possible front wheel slippage when moving on slippery terrains and uphill , possible hindrance of EB control and steering, and generally less power than that of a rear wheel(Hub motor). Front wheel hub motors are convenient for maintenance and creates a better weight balance between the rear and front of the EB. However, front wheel hub location EBs has some disadvantages Such as possible hindrance of EB control and steering and includes possible front wheel slippage when moving on slippery terrains and uphill. The rear wheel hub

motor does not seem to cause wheel slippage because its weight is distributed at the rear of the EB. However, locating the motor on the rear wheel hub can put great pressure on the rear wheel and the rear wheel hub motors are available in a wide range of power and control options.

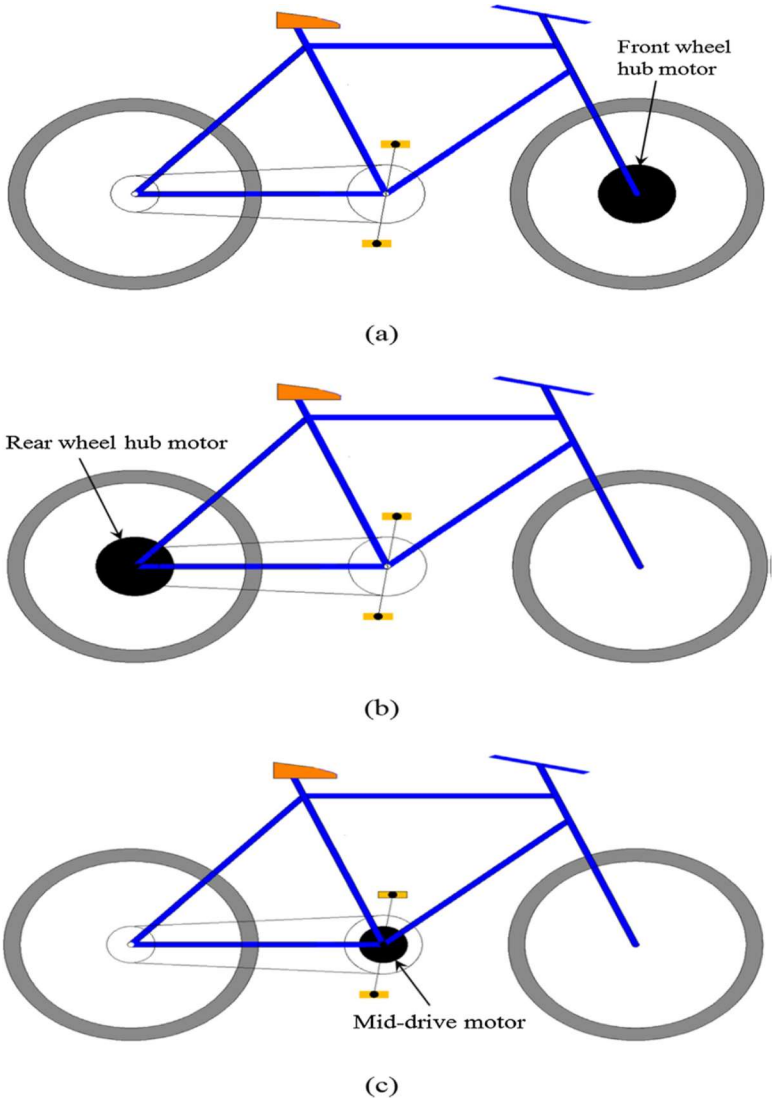

Fig.24. location of motor on EB[60].

The motor is located in the middle of EB, removing of front and rear wheels is easier in mid-drive motor.Mid-drive motors are generally smaller and better hill-climbing characteristics Compared with hub motors of the same power and can be directly integrated into the frame of the Electric bicycle [60].

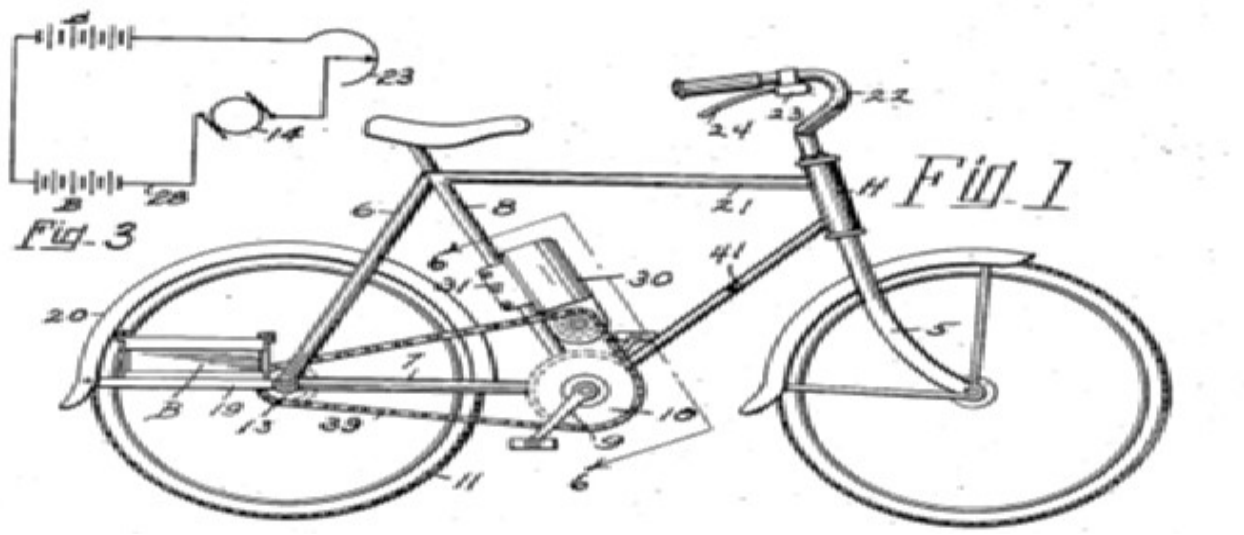

Fig.25. location of motor on EB[28]

Special frame arrangment have done for the motor in some electric bicycle.Fig.6. Power of electric motor is trensmitteted to either rear wheel or pedal.

5. Control method.

The electric motors and control methods have made great contributions to improving the operating performance of EBs. Hung et al. presented experimental study of the operating performance of an EB that used a BLDC motor installed in the rear wheel hub of the EB. The objective of his study is to investigate the dynamic characteristics and optimize the required power of an electric bicycle equipped with a semi-automatic transmission. They applied proportional integral-derivative (PID) controller and fuzzy logic controller, to control the wheel speed of the EB, in which the input voltage for the electric motor was used as a control variable. They set the speed value 26 rad/s and their designed fuzzy logic controller showed better stability when it reached a set value without any significant oscillation, as compared with using the PID controller. They also conducted an experimental study to support the simulation results and their study showed that the simulation results were validated by the experimental results[47]. Lukas Bergmann and his team (2021) proposed a battery management control system based on a nonlinear model predictive controller (NMPC) for pedal-electric drive units that takes into account cyclist fatigue and information of route. In their study, the proposed NMPC is able to guarantee a predefined target SoC at the end of the track while keeping the estimated cyclist's fatigue low[48]. Abagnalea et al showed,t he experimental test rig can simulate the resistant torque of a predetermined track and it aims of research was to test and to optimize the control strategy available on the electronic control unit[49]. Okan Uyar et al. presented an enhanced fuzzy logic control strategy considering the human-bike interaction.Their study showed new transmission mechanism and intelligent control system for an electric bicycle are designed and validated through simulations and experimental setup and they compared PI, PID, Fuzzy PID,

and Hybrid Fuzzy algorithms simultaneously. They found Fuzzy PID and Hybrid Fuzzy methods are close to each other in terms of time analysis parameters and performance criteria[50]. K. H. NAM et al. have proposed a pedaling torque sensor-less power assist method and have applied it to the experimental pedelec (power assisted) electric bike. They designed an impedance model and used power assist control algorithm, consists of a PI-type feedback controller, an inverse model-based feedforward controller, and a pedaling torque observer. Finally they performed experiments and confirmed the effectiveness of a proposed power assist control method[51].

6. Transmission

The transmission System is a key system affecting the dynamic performance of an EB. The transmission system generally consists of a gearbox, clutches, drive and driven shafts, and a control switch. The main objective of transmission systems to provide different outputs for the speed and torque of the gearbox. The location of the gearbox on an EB is depending upon the requirements and design purposes for each EB. Hung and team presented simulation and experimental study on the operating performance of an EB integrated with a semi-automatic transmission[47]. Abagnale et al. [52] showed the motion transmission from the motor to the pedal shaft was achieved by two different gearboxes including a planetary gearbox and a simple bevel gear. Wu and Sun [53] designed speed-changing wheel hub with an integrated electric motor and their design purposes were to make the transmission systems more compact.

7. Charging methods

Good charging methods of EBs will contribute to improving efficient utilization as well as further promote the use of EBs in the real world. The charging methods for EBs include constant current [54], constant voltage [55] and combination of constant current and constant voltage [56,57] . The charging voltage is controlled to maintain a constant current charge to the battery in the constant current charging method. The battery is charged at a constant voltage and charging current can be initially high then decrease gradually to zero when the battery is fully charged in constant voltage charging method, [58]. In this charging overheating is eliminated but this method requires a long time to fully charge the battery. So combination of constant current and constant voltage charging methods is useful for charging of batteries. The charging methods for EBs can be classified either plug-in charging or wireless charging. The battery of the EB is charged through a wired connection in the plug-in charging method between the EB and a charging port. Because of unsafe when using old electric wires, an alternative method, wireless battery charging was developed and it having many benefits such as providing power without physical contact, being maintenance-free, and unaffected by dirt, water, or chemicals [59]. Wireless charging methods are usually based on inductive power transfer (IPT) technology.

8. Summary

This paper reviewed and summarized EB-related literature to show the history and development of EBs worldwide. Due to its many benefits EBs could be expected to become a tremendous worldwide. EBs was discussed in terms of their various types, and different energy sources, different types of motors, transmission and charging method. This development EBs could be a useful reference for manufacturers as well as researchers to investigate and further develop EBs. We also elucidated development of EBs in various research fields such as electric motors and controls, various energy sources, charging methods and transmissions. These research fields were reviewed based on many previous studies conducted on EBs, providing good references for readers and researcher to develop their research ideas based on the previous studies. EBs faces many challenges such as limited moving distance, safety during riding or charging battery, and battery recycling. It is necessary to develop new technologies that aim to increase capacity, reduce weight of battery and optimization of force required to drive EBs. Using battery management systems and assisted power systems should be encouraged to improve safety and increase operating performance of EBs.

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