Artificial Intelligence for Charge Control: A Review

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Abstract— To enhance environmental sustainability, numerous countries will exhilarate their transportation systems in their unborn smart megacity plans. So the number of electric vehicles (EVs) running in a megacity will grow significantly. Electric vehicle (EV) charging is considered as one of the main issues that face EV motorists. There are numerous ways to recharge EVs' batteries and charging stations will be considered as the main source of energy. Studying and comparing among different charging control styles and characteristics are veritably important to be presented. This paper provides a comprehensive review of EV technology that mainly includes electric vehicle supply equipment (EVSE), ESS, and EV chargers. The different available power levels for charging are discussed.

Keywords: Electric Vehicle, Electric Motor, EV Charging Levels, Charging Strategies

I. INTRODUCTION

Due to the world's deficit of fossil energies, nations contend to secure enough reserves of natural resources for sustainability. Seeking indispensable energy sources becomes pivotal to a nation's future development. One of the major fossil fuel consumptions is transportation. Numerous vehicles are powered by gasoline. A major consequence of burning fossil fuel is the release of tremendous amount of dangerous gases, which constitutes the global warming effect and deteriorates people's health[23]. Global environmental concerns and the ever adding need for energy, coupled with a steady progress in renewable energy technologies are opening up new openings for application of renewable energy resources. Electricity is considered as the most universal form of energy, which can be converted from and to another form effectively. By converting the sufferable renewable energy, like solar and wind energy, to electricity, we can manipulate energy in an important cleanser manner. Electrification of transportation, like deployment of electric vehicles (EVs), can't only palliate our demand on fossil fuels, but also foster a better terrain for living. Thus, EVs will come the major factors in the unborn transportation system [34].

Substantially in metro metropolises air pollution is due to CO2 emitted by conventional gasoline vehicles. Now a day development in electrical vehicles is going to give volition for conventional vehicle engine i.e. ICE, development is going on in electric vehicles similar as Battery Electric Vehicles(BEVs) BEVs are also known as All-Electric Vehicles(AEV), Hybrid Electric Vehicle(HEV) HEVs are also known as series hybrid or parallel hybrid, Plug- in Hybrid Electric Vehicle(PHEV), Fuel Cell Electric Vehicle(FCEV).

Battery powered electric vehicles are gaining voguishness worldwide. This trend is driven by several factors including the need to reduce air and noise pollution, and dependence on fossil fuels [2][34]. The main disadvantage of present's electric vehicle is its limited range, and the long time duration that's needed to charge the electric batteries. In recent times, significant progress(through exploration and development) has been made to accelerate the charging time of the electric vehicle batteries through pulsation charging rather than supplying nonstop current and/ or voltage. The part to be centered on estimation of electrical parameters of the battery in the electrical vehicle, which is the most important factor to get information about possible available driving range. If the amount of remaining battery capacity can be displayed for the operators also it's possible to make decision on the time of recharging the battery. Currently, energy effectiveness is a top precedence, boosted by a major concern with climatic changes and by the soaring oil prices in countries that have a large reliance on imported fossil fuels. Large portion of oil consumption is in road vehicle run for transportation system by 2030 as per the report made by international energy outlook, transportation sector will increased its oil consumption share in world [34]. Aiming an enhancement of energy effectiveness, are elaboration in the transportation sector is being done. Large amount of money are spending in the exploration to modernize power electronics, mechanical structures and information and control system of electrical transportation system [1][15][19][24][34].

II. OVERVIEW

A. *Electric Vehicle:*

Recently, electric vehicles (EVs) have grown quickly as demanded green energy from the world. Generally in metro cities air pollution is due to CO2 emitted by conventional gasoline vehicles. Now a day development in electrical vehicles is going to give option for conventional vehicle engine i.e. ICE development is going on in electric vehicles such as;

- Battery Electric Vehicles (BEVs) BEVs are also known as All-Electric Vehicles (AEV)
- Hybrid Electric Vehicle (HEV): HEVs are also known as series hybrid or parallel hybrid.
- Plug-in Hybrid Electric Vehicle (PHEV)
- Fuel Cell Electric Vehicle (FCEV)

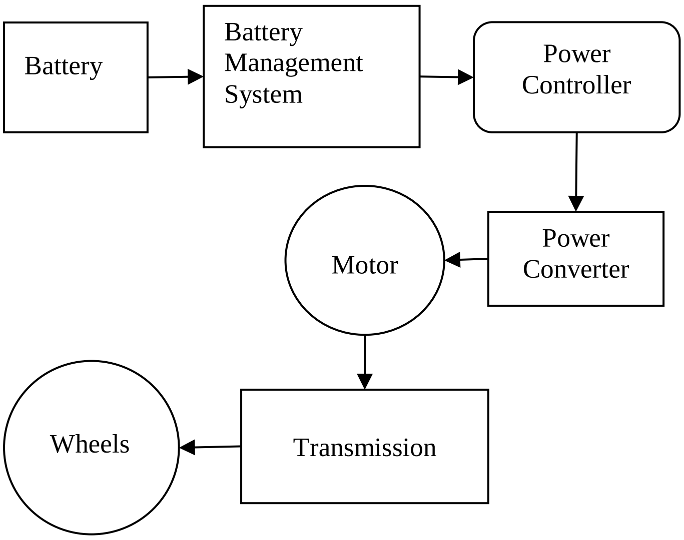

Fig. 1: Electric Vehicle Configuration

1) Battery Electric Vehicles (BEVs):

Battery electric vehicle (BEV) is based only on an electric motor and ESS and does not need the support of traditional ICE. They are plugged into an electrical supply to recharge their ESS (batteries) when they are exhausted. BEVs can also recharge their batteries through the regenerative braking process, which uses the vehicle's electric motor to assist in slowing down the vehicle and to recover the energy which is usually converted to heat energy by the brakes. Some commercially available BEVs are Tesla Model S, Nissan Leaf, BMW i3, Mitsubishi iMiEV, Smart EV, Ford Focus EV, etc [3][31].

The main advantages of BEVs are:

– Zero tailpipe emissions.
– No need for gas or oil refueling.
– Easy to be charged at home
– Fast and smooth acceleration.
– Overall low cost of operation.

Apart from the advantages, some disadvantages are:

– Shorter drive range as compared to ICE-based vehicles
– Expensive than ICE-based vehicles, however, the payback period from fuel savings is only about 2-3 years.

2) Hybrid Electric Vehicle (HEV):

Hybrid electric vehicles (HEVs) have two driving systems, ICE with a fuel tank and an electric motor with an ESS. Both, ICE and the electric motor drive the vehicle at the same time. Still, HEVs don't have the facility of charging from the utility grid, all their driving energy comes from the fuel and the regenerative retardation process in the vehicle. Or we can say “An electric vehicle uses a combination of an internal combustion (IC) machine with an electric motor that's powered from both fuel and electricity – known as hybrid electric vehicle(HEV)”. Some generally available HEVs are Audi Q5 Hybrid, Acura ILX Hybrid, Cadillac Escalade Hybrid, BMW Active Hybrid 3, BMW Active Hybrid 5, BMW Active Hybrid 7, Honda Civic Hybrid, Honda CR- Z Hybrid.

The Toyota Prius is broadly used hybrid electric vehicle. In HEVs, batteries supply electricity to the electric motor and diesel/ petrol propels for driving of the IC- engine. Batteries of the HEVs don't need to charge by plugging the vehicle into a power source at a charging station.

Series Hybrid Electric Vehicle In a series HEV, an electric motor takes power either from battery or from an IC- engine coupled generator unit. The IC- engine energizes the generator to supply power to the motor. The generator charges the battery also when the vehicle is operating under regenerative retardation mode

Parallel Hybrid Vehicle In a parallel HEV, both an electric motor and an IC- engine are connected in parallel with a transmission system to the wheels as shown in the figure1.7. Battery can be charged during regenerating retardation mode only. It can’t be charged when the vehicle isn't in moving condition. In the parallel HEVs, the electric motor produces power less than the total power produced by the vehicle. The IC- engine has capability to induce further power than the electric motor.

Combined Hybrid Electric Vehicle Combined HEV is a combination of both series and parallel hybrid electric vehicles. It's also known as power split type of HEV. In this type of HEV, an IC- engine is engaged for driving of vehicle and for the charging of the battery as well. Combined HEV consists of double connection between the engine and the driving paths – electrical path and mechanical path.

Some advantages of HEVs are:

– Longer driving range than BEVs
– Lower fuel consumption compared to ICE- based vehicles
– Lower emissions than ICE- based engines
– Some disadvantages of HEVs are
– Zero tailpipe emission isn't achieved
– The mechanism of operation is complex
– Precious to operate as compared to BEVs

3) Plug-In Hybrid Electric Vehicle (PHEV)

The plug-in hybrid electric vehicle (PHEV) uses an electric motor and ESS along with the ICE. The feature of having ICE in PHEV makes it a more suitable and promising option for long-distance journeys. The operation of PHEV is divided mainly into two modes; namely, charge depleting (CD) mode and charge sustaining (CS) mode. In CD mode, PHEV disables its ICE and draws vehicle driving energy entirely from the battery until it reaches a threshold state-of-charge (SOC), where SOC is a quantity that measures the percentage of remaining charge in the battery. Upon reaching the minimum SOC, PHEVs switch their operation to CS mode and the IC engine provides energy to drive the vehicle as well as to maintain battery charge above but near to the minimum SOC. For better fuel efficiency, a third mode, called charge blended (CB) mode has been introduced, in which electric motor and IC engine are optimally and dynamically employed during a drive cycle so that they are able to operate longer using the most efficient settings while achieving an overall reduction in the emissions [19]. Commonly available PHEVs are BMW i3, BMW i8, Cadillac ELR, GM Chevy Volt, Porsche SE, Ford Fusion Energi, Ford Cmax Energi, Toyota Prius Plugin. The advantages of PHEVs are: Long driving range. Low fuel consumption than conventional ICE-based vehicles. Low emission of pollutants in the environment [3].

Some disadvantages of PHEVs are:

– Environmental pollution is not eliminated
– Expensive to operate as compared to BEVs

4) Fuel Cell Electric Vehicle:

A vehicle which is powered by electric energy from the fuel cells is known as fuel cell electric vehicle (FCEV). A vehicle which is powered by electric energy from the fuel cells is known as fuel cell electric vehicle (FCEV). A fuel cell electric vehicle introduces to the different sorts of fuel cells based on the electrolyte used in it i.e. polymer electrolyte membrane (PEM) fuel cells, direct methanol fuel cells, phosphoric acid fuel cells, molten carbonate fuel cells, solid oxide fuel cells etc.

III. EV CHARGING STRATEGIES

A. *EV Charging Levels:*

State of a battery can be defined as a minimum amount of information that drive the charge of the battery from initial value at time (t0) to the final value at a finite time (tf).A battery can estimates two different forms of state – state of charge (SoC) and state of health (SoH) [12][13].

The EV charger basically consists of a charge control unit, charging cable and a vehicle control unit. The conductive charging system uses direct contact between the EV connector and the charge inlet. The charging levels are defined based on the power level of charging outlet. There are three levels in an EV charging technology [40].

1) Level 1 Charging:

Level 1 Charging is done at 120V alternating current and requires a dedicated circuit. Level 1 charging refers to standard household outlet. Level 1 Charging does not require any additional equipment; the cord that is used is a standard, three-prong household plug and on the other hand is a connector, which plugs into the vehicle. Level 1 charging generally takes 8 to 12 hours to completely charge a fully depleted battery. This type of charging can be implemented in home parking and can be done overnight. Almost all PHEVs come with a level 1 charging cord. One end of the cord is a standard connector that can be plugged directed to a wall outlet at home. The other end is a SAE J1772 standard connector that plugs into the vehicle's J1772 charge port. Therefore, there is no need for additional charging equipment. Level 1 charging can be provided, by using an on-board charger, up to 1.9 kW through 120 V single phase AC [32][36].

2) Level 2 Charging:

Level 2 Charging is done at 240V alternating current and require additional equipment at home or public charging facilities. Level 2 Charging equipment is compatible with Battery electric vehicles and plug-in hybrid electric vehicles. The connector cord at the vehicle end is the same as that of Level 1 Charger. Level 2 Charging generally takes 4 to 6 hours to completely charge a fully depleted battery. These chargers can be installed at residential places, apartments parking and commercial parking etc. This charging option uses the same SAE J1772-compliant charging cord as in level 1, but offers up to 19.2 kW output power by using an on-board charger. Level 2 charging is available to premises that are supplied with 3-phase AC at 208 or 240 V, and requires dedicated electric circuit to support a higher current up to 80 amp. This option is suitable for charging at home, as well as at public charging facilities, although residential level 2 charging operates at a lower current (about 30 amp) and a lower power of 7.2 kW, as compared to the public ones. Level 2 is preferred over level 1 for its shorter charging time [32][33][36].

3) Level 3 Charging:

Level 3 Charging has CHAdeMO technology, also termed as DC fast charging and is done at 480V DC plug. Most of the Level 3 chargers, charges 80% of the battery in 30 minutes. The Level 3 equipment cannot be used for all vehicles as currently there are no standards defined for this charging. The Mitsubishi "I" and Nissan LEAF can accept a Level 3 charger. This is a new charging option which is being developed by SAE to supply up to 130 kW for very rapid restoration of SOC, using 3-phase AC at 480 V and high current. Able to deliver between 50kW to 350kW of power .This 3-phase power distribution is common at commercial and industrial locations. To support the high output power, level 3 chargers are much larger in size and heavier in weight, compared to level 1 and level 2 chargers. Also, level 3 chargers require dedicated cooling equipment for high-power electronics. As a result, level 3 chargers are not installed on-board, but they are located externally (off-board). It is likely that SAE J1772 connector will not be suitable for this option [14][32].

B. *Charging Strategies:*

The electrical power grids were not designed for this new type of load, which corresponds to the batteries charging systems of EVs, therefore the impact caused by the proliferation of EVs cannot be neglected. The challenge is to rebuild the electrical power grids, as early as possible, as "smarter" as possible, and the most environment friendly as possible. EVs represent a new type of load that introduces new problems, but that also brings new possibilities of actuation. The problems arise from the possibility of occurring simultaneous charging of a large number of vehicles, which can overload the power grid, and from the effects of non-sinusoidal current consumption of the batteries charging systems [18].

Charging is an important term for the battery that is utilized for supplying electricity to the electric motor engaged in the EVs. The proposed work uses lithium-ion battery for supplying electricity and a battery charger is also essential with it for controlling the temperature and the charging time. Main drawbacks with the conventional methods of charging are the high charging time, high temperature during the charging, overcharging and undercharging. Therefore, different battery charging methods are introduced in this section. Extensive approaches have been proposed to tackle the problem in designing EV charging control strategy.

Lithium-ion battery charger is associated with the battery pack that is used to charge the battery and supplying electricity to the electric motor. The battery charger is designed according to the parameters of a lithium-ion battery. Specifications of a lithium-ion battery are given[32][35]:

a) Constant Current (CC) Charging strategy
b) Constant Voltage (CV) Charging strategy
c) Constant Current Constant Voltage (CCCV) Charging strategy
d) CT-CV charging strategy

a) Constant Current (CC) charging strategy: The constant current charging method is based upon the SoC estimation. It is a charging method in which the current is kept constant and the voltage is varied during the charging process. The output voltage of the battery reaches its maximum value at 100 % of the state-of-charge.
b) Constant Voltage (CV) charging strategy: It is also a simple charging method in which the output voltage of the battery increases with the decrement in the current till the output voltage reaches its maximum value. The charging current to be varied at constant voltage of supply according to the SoC estimation. In starting, the charging current decreases at the low value of state-of-charge. Further, the charging current reduces gradually with a large charging time at the high value of state-of-charge.
c) Constant Current Constant Voltage (CCCV) charging strategy: The CCCV method is more efficient method with less charging time to reach 100 % of the state-of-charge. It is the most commonly used charging method for the Li-ion battery that is a combination of two methods – constant current charging and constant voltage charging method. The CCCV method deals with the variation in the current and voltage. During the CC mode, the voltage increases across the battery. Further, the CC mode is processed into the CV mode. During the CV mode, the charging current decreases across the battery.
d) Constant temperature constant voltage Charging strategy (CT –CV): The constant temperature-constant voltage charging strategy can be employed for battery charging which is a closed loop charging strategy unlike its conventional method of Constant current-constant voltage. The temperature sensor provides the closed loop feedback path which generates an error signal. Based on the error signal a PID controller can be employed to produce a charging current. The temperature when reaches the set temperature limit of the battery, must be reduced. In order to reduce the temperature the charging current is reduced. Therefore, an exponential decaying current can be used to reduce the charging current. The charging current decreases and when the battery voltage reaches the set nominal voltage of the battery, the charging continues in the constant voltage mode same as in case of CC-CV charging. The temperature rises gradually in the CC-CV charging because the charging current is low. This temperature in this region can be increased by increasing the charging current. Although, now the temperature reaches the set limit early but fast charging is enabled and the temperature limits can be controlled with the help of closed loop feedback system. By using the CT-CV strategy the charging time of the battery can be reduced and also its life cycle and State of Health can be increased.

IV. CONCLUSION:

In this review paper, a different charging technique for a battery has been discussed. The CC charging method is not an optimal method due to the rise in temperature and heating of the battery whereas the CV charging method does not produce high temperature but this method takes long time for fully charge the battery. The CCCV charging method is more convenient due to the quick charge the battery in spite of overheating and overcharging of the battery.

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