Flywheel-Based Fast Charging Station – FFCS for Electric Vehicles and Public Transportation

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Abstract. This paper demonstrates novel Flywheel-based Fast Charging Station (FFCS) for high performance and profitable charging infrastructures for public electric buses. The design criteria will be provided for fast charging stations. The station would support the private and open charging framework. Flywheel Energy storage system is utilized to offer advanced energy storage for charging stations to achieve clean public transportation, including electric buses with reducing GHG, including CO2 emission reduction. The integrated modelling and management system in the station is performed by a decision-based control platform that coordinates the power streams between the quick chargers, the flywheel storage framework, photovoltaic cells and the network association. There is a tidy exchange up between the capacity rate of flywheel framework and the power rating of the network association.

1. Introduction
Flywheel kinetic energy storage offers very good features such as power and energy density. Moreover, with some different-range vehicles, this technology can be enough to supply all the energy to the power train. The challenges to be met to integrate such technology in vehicles are the mass, the efficiency and especially the cost. Then, in this project, a techno-economic optimization of a flywheel energy storage system is presented. It is made up of a flywheel, a permanent magnet synchronous machine and a power converter. For each part of the system, physical and economical models are proposed. Finally, an economic optimization is done on a short-range ship profile.

Flywheel energy storage became one of the important energy storage in the world. That is why; flywheels energy storage used a lot in power systems and Microgrid recently as they are flexible, smart, and active. In addition to, they fit more with renewable resources and considered to be friendly to the environment [1]-[4].

Fast charging of modern energy storage has turned into a standard charging innovation because of the operational reserve funds, expanded profitability and wellbeing that this innovation offers. Clients have understood the advantages of fast charging and proceed to understand the advantages at assembling plants and dissemination focuses all through many applications.

This paper proposes a control system for module electric vehicle with Flywheel-Based Fast Charging Station (FFCS). The fundamental part of the FFCS is to trade off the predefined charging profile of PEV battery and incorporated with the arrangement of a hysteresis dynamic power converter supported to the power framework [5], [6].
In that sense, when the dynamic power is not being separated from the network, FFCS gives the power required to maintain the persistent charging procedure of PEV battery. A key trademark of the entire control framework is that it can work without any discrete correspondence between the frameworks tied and FFCS converters.

2. Fast charging vs. other charging approaches
An electric vehicle charging station, additionally called electric reviving point, charging point is a component in a foundation that provisions electrical energy charge for the energizing of electric vehicles, for example, module electric vehicles. Most of the charging platforms are on-road locations associated by electrical service networks and others are situated within retail commercial malls or to be worked through numerous privately owned businesses.

Charging stations are divided categorized into four main groups:

- Private charging stations: An EV connects to when returns home and then auto recharge through night times. A private station ordinarily does not need any client validation, nor metering system; and it is just need simple installation for a devoted circuit. Other convenient chargers will likewise need partition installation as in stations.
- Public stations: Businesses scheme for an expense or without fees that is serviced in organization through the holders of certain parking area. That charging process might as moderate mode that urges vehicles holder to charge the autos during they exploit adjacent shopping or any other stuff. It can incorporate stopping malls and centers or for a business' own particular representatives.
- Fast or quickly charging: for charging demand greater than 40 kW, conveying more than 120 km within timeframe of $[10, 25]$ minutes. They will likewise need routine utilization by suburbanites at metropolitan places, and to be charged during stopped for short and/or long timeframes, see Fig. 1.
- Swaps or changes Process for batteries in less than 15-20 minutes. Predetermined focus on zero- and low-emission vehicle and its range in less than 15 minutes. It can be done with vehicle battery by swaps and also on Hydrogen Fuel Cell vehicles. That plans by coordination the request to refill from customary holders.

![Fast Charging vs. Other Charging Approaches](image)

Figure 1. Fast Charging vs. Other Charging Approaches

A critical increment of EVs in develop control markets would animate a develop in power request giving some comfort to utilities working in energy markets as Fig. 2, while likewise helping framework administrators adjust control free market activity by means of vehicle-to-network ventures. The amassing of network associated EV batteries would likewise energy booster development by smoothing supply irregularity and encouraging their incorporation into the power network. As shown, there is high power demand for EV, which confirms the need for Fast Charging Infrastructures [7]-[9].
3. Flywheel technology

Flywheel energy storage systems utilize active kinetic rotation that can be stored the rotated mass with low levels of losses in the friction component, see Fig. 3. The input energy as electrical increases the acceleration of the mass to speed by means of an incorporated engine generator. That energy will be stored and depend on the moment of inertia and speed of the rotating shaft, and can be expressed as follows:

Kinetic energy: \[ E_k = \frac{1}{2} I \omega^2 \]  \hspace{1cm} (1)

Moment of inertia (I): \[ 2I = \int r^2 dm \]  \hspace{1cm} (2)

For a cylinder the moment of inertia: \[ I = \frac{1}{2} r^2 \pi a \rho \]  \hspace{1cm} (3)

Energy is increased if \( \omega \) increases or if \( I \) increases.

The optimization of the energy related to mass can be achieved by spinning flywheel with maximum possible speed.

- Max. Speed: \[ v_{\text{max}} = \sqrt{\frac{2K\sigma_{\text{max}}}{\rho}} \]  \hspace{1cm} (4)

The reasons for selecting Flywheel as energy storage system are:

- Higher Power Densities: Especially for EV and HEV applications, flywheel is significant to supply much power density than batty.
• High Reliability and Cycle Life: The power from Flywheels is not degraded, and remarkable by reliability and high cycle life.
• Environmental impact: The environmental impact of flywheels is so friendly where there is no hazardous substance than can be recycled.
• Temperature Sensitivity: Flywheels are for the most part less delicate to the surrounding temperature than batteries. Some essential warm breaking points are set by the temperature in: the windings, to abstain from softening; the magnets, to maintain a strategic distance from demagnetization; and the composite material, to abstain from blazing it.

4. Flywheel-Based Fast Charging Station – FFCS

4.1 Fast charging stations - design criteria
The design criteria of a fast charging station is to cover both of residential and public charging infrastructure, Flywheel-based Fast Charging Station (FFCS) will be built as shown in Fig. 4, 5.

4.1.1 Fast charging stations – covering factor
Fast Charging Stations can achieve a covering factor up to 95% of total electric charging demand. This can be achieved by three factors: 1. waiting time at the FFCS; 2. number empty charging spots per FFCS per time; and 3. maximum number of required charging spots per FFCS.

EVs can be charged at wherever that offers an electrical attachment. This incorporates open carports, auto parks, workplaces, grocery stores, healing centers, lodgings, homes of companions and colleagues, shopping centers, and neighborhoods. The increase of FFCS installations can replace some of the above electric charging options. This can be achieved by planning optimization and control.

![FFCS Integrated Model](image)

**Figure 4. FFCS Integrated Model**

4.1.2 Mobility behaviour
In MCD model, the mobility and charging demand of EVs is determined depending on the Mobility Behavior. Designing a fast charging station starts mainly by study the profile of the concerned charging load (These include social and technical analysis),

• Social: The population of the assigned region and how frequent they charges their EVs.
• Technical: the limits of the charging infrastructure.

The second step is the modelling that perform simulation of the real fast charging station within various scenarios.

4.2 Mobility integrated study:
The starting point for the mobility model can be with 50 groups of 1500 vehicles each. Each vehicle is controlled in its charging on the behavior of the owner:
• The case of the EV as per it is running or stopping (µv);
• The amount of consumed power from the electricity (µm);
• The places where the car usually stands at (µc); where it is house places, or working place or others.
• The vehicle model (µt); the sizing of the EV.

4.3 FFCS – multi-level circuit design
Multi three phase 2-level AC/DC converter as grid interface and flywheel converters is shown in Figure 6, it depends on Fast DC/DC converter to quick charging where Each component is installated by connection via a common DC bus, see Fig. 6.
4.4 Control of flywheel by hysteresis controller

Points of interest of utilizing hysteresis control, as in Fig. 7, are significant dynamic response and capacity to control the peak demanding and current swell in assigned hysteresis band range. It is likewise extremely successful for physically execution [10]-[13]. Likewise, it diminishes the harmonics, where it takes a shot at essential by identifying consonant current to compute the measure of the compensated current required for sustaining back to the power framework.

5. Discussion and analysis of fast charging

DC Fast Chargers replace Level 1 and Level 2 charging stations, and are intended to accuse electric vehicles rapidly of an electric yield extending between 50 kW – 120 kW. Most present day completely electric vehicles can be charged with DC fast charge capacity, and there are right now about 2,200 rapid chargers in the Assembled States fit for adding huge range to an EV in very little longer than the time it takes to fill your gas tank.

Fast charging can be achieved using Level-2 (basic) or Ultimate (Level-3)
AC Level 1:117V 16A Max (Normal Charging), AC Level 2:240V 32A or 70A (Basic Fast Charging)
Charger Specifications Level 3 (Ultimate - Direct DC) by FFCS:

- Input 3-phase 200V
• Output:
  Max DC 45-50 kW (can reach 200 kW)
  Max DC Voltage 700V
  Max DC Current 750A

Fast Charging by FFCS has such benefits to demand charge distribution network in big cities which is very congested and peak demand reduction is a topic of interest. These benefits are grid services to provide peak power by turn peak load into base load. In addition to, grid stabilization can be achieved by support for grid expansion and maintain promised levels of supply.

Demonstration and experimentation are done through capabilities of software and hardware in Energy Safety and Control Lab (ESCL), University of Ontario Institute of Technology.

Table 1. Gas vs. Electric Charging

| Charging Vehicle | Charge as per 100 km | Cost per unit | Cost    |
|------------------|----------------------|--------------|---------|
| Electric FFCS    | 16 kWh               | × $0.08/kWh  | = $1.28 |
| Gasoline         | 8.4 L                | × $1.35/L    | = $11.40|

As another comparison, Fuel = $0.13 per km , EV = $0.02 per km
Electricity is Cheaper 9 times more than Gasoline
Electricity saves around $2,000 - $3,000 a year per car, based on 30,000 km / year

Table 2. Charging Time of different charging categories

| considering 100 km, charging time | Voltage | Max. Current | Power  |
|-----------------------------------|---------|--------------|--------|
| 6–8 hours                         | 220 Vac | 16-18 A      | 3.2 kW |
| 3–5 hours                         | 220 Vac | 32-36 A      | 7.4 kW |
| 2–3 hours                         | 400 Vac | 16 A         | 10 kW  |
| 1–2 hours                         | 400 Vac | 32 A         | 22 kW  |
| 20–30 minutes                     | 400 Vac | 63 A         | 43 kW  |
| 20–30 minutes                     | 450–505 Vac | 120–135 A | 50 kW  |
| 10 minute                         | 350–550 Vac | 320–380 A | 120 kW |

Table 1 shows the difference between gas and electric charging while Table 2 shows the charging time of different charging categories.

ROI and Benefits of FFCS
The benefits and ROI ratio between normal charging and FFCS is between: 3-6 times

* With respect to production within same time Frame:
  For X kwh of charging production, in time $t$
- The amount of normal charging = $X$ kwh, The amount of FFCS charging = 3X kwh

* With considering saving of time reduction of FFCS:
For fixing X kwh of charging production
- The production time of normal charging = 3t to 6t, The production time of FFCS charging = t

6. Conclusions
The proposed FFCS is analysed in view of user and technology requirements, where fast charging is proposed based on flywheel technology. Advantages of fast charging over traditional charging is expressed, in particular when dealing with congested cities where short charging time is critical. The design of FFCS is presented based on flywheel energy storage platform (FESP) which is presented to implement fast charging for transportation infrastructures. Implementation schemes for eBuses and EVs.

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