Design and Simulation of a fast- charging stationfor Plug-in Hybrid Electric Vehicles

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Abstract—with the increasing interest in green technology in transportation, plug-in hybrid electric powered vehicles (PHEV) have tested to be the excellent quickterm method to limit greenhouse fuel emissions. Despite similar interest, conventional vehicle motorists are still reticent in using such a new technology, substantially because of the long duration (4- 8 hours) needed to charge PHEV batteries with the presently being position I and II levels. For this reason, Level III presto charging stations able of reducing the charging duration to 10-15 minutes are being considered. The present thesis focuses on the design of a fast-charging station that uses, in addition to the electrical grid, two stationary energy storehouse bias. The power electronic converters used for the interface of the strength resources with the charging station are designed. The design also specializes in the electricity management so as to minimize the PHEV battery charging period as well as the period required to recharge the electricity storage gadgets. Design issues and simulation results for a typical Level III charger are presented.

Keywords— *plug-in hybrid electric vehicles, conventional vehicles, Level-III charging station, Ultra Capacitor, Off-board charger, Fly-wheel.*

I.INTRODUCTION

A PHEV is a hybrid automobile with a highercapability battery that may be recharged with the aid of connecting car to the electric community vehicles. Because of their short-time period economic and environmental advantages, nearly all major carmakers have invested substantially in PHEV development. The charging of such car batteries calls for the design and implantation of charging stations. The modern day paper critiques proposed standards and implementation requirements that have been carried out inside the PHEV/EV charging generation, after which proposes a fast charging station layout using a flywheel (FES) and a super capacitor (SC) as electricity garage devices. The simulation and outcomes for the charging procedure of a vehicle battery are given.

A. Background

This section defines what a PHEV is and describes compactly the outfit involved to charge it.

1. PHEV Definition

A Plug-in-Hybrid electric automobile (PHEV) is a hybrid automobile with a better-potential battery that may be recharged by using connecting the car to the electrical community. Whilst the battery is beneath 20% ability, a conventional combustion engine takes over and offers to the driving force the equal autonomy as a conventional car. The PHEV has been recognized because the first-class quick-term, economically possible opportunity for notably reducing oil dependency and CO2 emissions without changing motorists riding behavior. PHEV Charging Equipment: A completely important effect worries the development of the charging equipment for the market integration and day by day use of PHEVs. It's miles critical that this gadget has the capability to: • Snappily charge the auto battery. • Modulate the electricity costs with the time of day • Descry the state of charge(SOC) of the auto battery • Automatically bill for the electricity delivered • Acclimatize to colorful battery types and car models Existing PHEV'S A few American companies have already built prototypes of such fast charging stations: a prototype that boasts an expected 10 min charge time has been launched all through the third region of 2010, and the LSV-100 Zip prototype which could rate in less than 30 min. In Europe in January 2010, Renault-Nissan announced its fulfillment within the development of a quick-charging station this is able to replenishing 80% of an EV car battery in much less than 30 min.

2. Flywheel

Flywheel Energy Storage (FES) is an electromechanical tool that stores power in kinetic form in a rotating mass. Flywheels are beneficial while there exist an imbalance among the generated power and the power demanded via the weight. In such devices, the charging and discharging procedures are completed by way of varying the rotational pace of the mass: to save some strength. Some manipulate strategies have been discovered on the way to observe flywheels in EVs. One in every has been discovered in, wherein the charging method through the use of fuzzy common sense and a PI controller while the discharging is accomplished by means of sincerely applying the PWM method to the interfacing converter (AC/DC). FESs had been identified as being the cleanest energy storage devices and find their packages in the following areas: • Formerly, FESs has usually been used for short-time period power storage in rotating machines and engines to deliver smooth energy. • These days, they may be getting used for electrical energy storage. In such case the FES is known as a mechanical battery strength storage device: it usually shops kinetic power, and releases it in electrical form upon call for. This last benefit might be taken into consideration largely on this thesis. • For the following few years, researches are being carried out on the way to layout better unique strength density (kW/Kg) and better precise energy (kWh/Kg) density. The primary one relies upon absolutely on the motor/generator that drives it. Any FES is composed of 4 primary components: a rotor, a rotor bearing, a container, and an electricity interface.

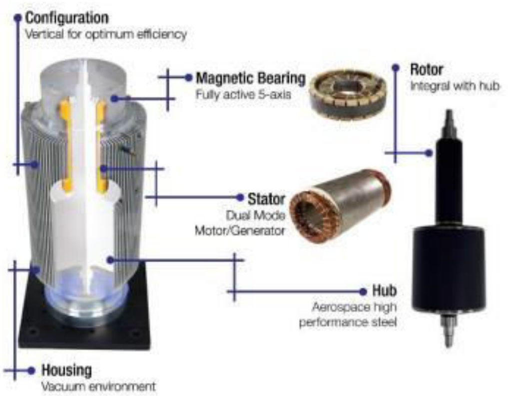

Fig. 1: Main FES Components

Fig 2: A Typical Supercapacitor

3. Super capacitor

Additionally known as electric double layer capacitors (EDLC) or Ultra-capacitors, such devices behave exactly like any regular capacitor with the variations of having a far higher capacitance (in the order ranging from tens to hundreds of Farads) and a higher strength density which lets them charge and discharge swiftly, and allows them to be used in programs to replace batteries. Such devices keep power using the subsequent mathematical relation that relates the strength stored E (in J) to the capacitance C (in F) and the voltage across it U

$$E = \frac{1}{2} C . U^2$$

They're categorized into 3 categories: • Double-layer capacitors rely on the double electric powered layer mechanism. • Electrochemical capacitors rely upon the fast Faraday oxide-reduction reactions. • Hybrid capacitors are a combination of the 2 preceding classes. A control method has been proposed for the supercapacitors to assist current peaks which can be momentarily demanded through electric street cars. Such a way is based on the fact that the supercapacitors need to be discharged as soon as the current demanded through the weight will become greater than the reference limit modern-day for battery discharge.

B. Charging Station

1. Classification

For decades the Society of car Engineering (SAE) has been working on preferred J1772, which classifies charging stations into 3 categories: a) Level I: charger is on-board and offers AC voltage 120V or 240 V with maximum modern-day of 15 A (preferred domestic outlet), most electricity of 3.3 kW. b) Level II: charger is on-board and affords AC voltage 240 V with maximum current of 60 A, maximum energy of 14.4 kW. c) Level III: charger is off-board. The charging station presents DC voltage without delay to the battery via a DC connector, with a maximum strength of 240 kW. Level III chargers are speedy chargers. The most energy furnished for Level-III charging equipment ought to be successful to top off greater than 1/2 of the capability of an EV battery in much less than half of an hour.

2. History of rapid charging station

The significance of a community of charging stations is already established as a critical a part of the PHEV and electric powered vehicle (EV) technologies. in the destiny, charging stations may additionally play the same position as gas stations today. In Israel (2011), Denmark (2011), Australia (2012) and Portugal, governments have already set objectives in region for a huge penetration of charging stations in the city surroundings. There may be presently a loss of speedy-charging units. As an opportunity, urban centers had been proposed in which the discharged car batteries would be swapped with charged battery packs. But, on the lately held alternative Fuels and automobile conference, a panel of representatives from some American electric powered car makers suggested that they would select fast charging stations to the battery swapping situation. The impact of rapid charging on battery degradation is a critical parameter that desires to be taken into consideration.

II. Rapid Charger Considerations

1. Level III Charger

Among the various 3 levels of charging stations, the level III is the most exciting and practical one for installations in public places like industrial areas because it enables an easier integration of PHEVs and EVs into the marketplace. For this reason, many evolved countries are making plans on the use of stage III, off-board quick chargers. In Japan, the Tokyo electrical energy business enterprise has announced the set up of two hundred 10-minute high electricity chargers, so that you can coincide with the advent of the Mitsubishi i-Miev EV, that's already advertized with a short-price DC plug. this is the result of a structural function of Tokyo, wherein drivers do no longer have access to a plug at their houses to charge their cars.

2. Fast Charging Outcomes and disadvantages

Besides charging a battery automobile to 80% of its SOC in commonly 15 mins, rapid charging also decreases running expe nses and increases productivity in two approaches: • Fast chargers are recognized to be greater efficient than traditional chargers, and charging with less overcharging will increase increase the battery performance. • Fast charging era increases the automobile velocity. The primary issues in fast charging are living within the 4 essential failure mechanisms of industrial lead acid batteries: • Positive Active Material (PAM) shedding. • Corrosion of the advantageous plate grid • Imbalance amongst battery cells • Suffocation of terrible plate

3. Traditional Charging Schemes

In a bidirectional battery charger, charging can be done in two ways: a) In steady current/consistent voltage mode, the battery is first charged in regular current mode to 70% SOC then it's miles charged in regular voltage mode. b) In an effort to put in speedy charging, several algorithms and strategies had been determined, and among them is a completely digitized smart method related to a mixture of high non-stop regular charging current and a few charging pulse current. Such techniques take into account the actual charge nation of the battery and the battery previous charges and discharges.

III. STORAGE DEVICES

Level I and II chargers are acknowledged to be gradual due to the fact they draw their power from only a single AC source: the electrical grid. A way to make a charger faster as will be the case in the level III category is to let the charger draw electricity from multiple AC and/or DC resources. Those ultimate sources are referred to as energy storage devices due to their capability to accumulate some energy for a finite duration before restoring it to the circuit.

A. Stationary Storage Devices

The standard devices used as electricity storage are displayed in table I underneath.

TABLE 1

Assessment of some Electricity Storage technology

Storage Technology	Life Time (Cycles)	Efficiency(%)
Lead-Acid Batteries	200-300	75
Sodium-Sulfur (NaS) Batteries	2000-3000	89
Metal-Air Batteries	100-200	50
Li-ion Batteries	300-500	95
Flow Battery	1500-2500	75-85
Supercapacitors	10^4-10^5	93-98
FES	10^5-10^7	90

The prevailing phase lists the maximum popular stationary energy storage gadgets overall performance necessities, and then justifies the charging station devices desire.

B. Performance Requirements

The selected power storage devices should preferably fulfill all the following overall performance criteria with a view to maximize the fast charging station performance: • Dynamicity: The charging station is designed to charge a battery in a most 15 minutes (quick duration). The storage device must thus be capable of charge and discharge in this era. • High strength Density: The device has to be capable of supply a excessive quantity of power in a brief period of time. • High efficiency: The charging station should meet its most feasible efficiency. This last criterion relies upon the primary station elements: converters, storage devices, and so on. Consequently, it's must to consider the storage devices that have the best efficiency. • Environmentally Friendly: The device must have no or negligible negative impacts on the environment

C. Storage Device Choice

Batteries have huge impacts at the surroundings, own medium efficiencies, and relatively low strength density and range of life cycles. Therefore, they do not fulfill any of the overall performance requirements. However, the FES and the supercapacitors have both: low impacts at the surroundings, excessive efficiencies, electricity densities, and life cycles. Additionally they can both be charged and discharged in a length inside the order of minutes. The only drawback they both present is their low electricity density, which is not considered as problem for the reason that we are searching for high strength density instead

IV. STATIC STRENGTH SWITCHES

This segment covers the existing technology of static energy digital switches after which justifies the usage of IGBT as the first-class alternative for the layout of the converters.

1. Current Technologies

The maximum famous controllable static switches used inside the design of the power digital converters are displayed under

Table 2

Main Controllable Switches Comparison

Device	Power Capability	Switching Speed
MOSFET	Low	Fast
IGCT	High	Slow
IGBT	Medium	Medium

That allows you to permit bidirectional strength switch, the switches used in the converter legs have to behavior the contemporary in each guidelines. The switches should also be completely controllable. For that reason, the use of diode and thyristor is removed because the former is completely uncontrollable and the latter is semi-controllable.

2. Converters

a) Grid-side Converter

The grid offers single-phase AC voltage and current. On the way to be interfaced with the charger's dc bus, a bidirectional AC/DC converter is required so one can permit the station to operate in V2G mode as properly.

i. Converter Design

In order to switch on and off the controllable switches inverters and rectifiers, many styles of gating alerts can be used, among them are • Square wave inverters • Voltage Cancellation • Pulse-Width Modulation

ii. Electrical Specifications

The converter is designed with IGBT switches, so its efficiency ή is commonly 0.9, and it's far designed with an output DC electricity of 30 Kw

Table 3

Grid Converter Electrical Specifications

	Input side(RMS Values)	Output side(DC Values)
Grid Voltage(V)	220	600
Grid Current(A)	53	50
Real Power(kW)	33.3	30

b) Flywheel Energy Storage Converter

Whilst appearing as a generator, an FES converts kinetic electricity into electric power. This could be translated inside the following manner: when rotating at an angular pace ω (rad/s), the electricity is transformed into AC currents that ought to be transformed to DC currents via an AC/DC converter.

i. Converter Design

The FES converter must also be bidirectional as a way to permit both charge and discharge of the FES. The converter may be single-stage or double stage. I

ii. Electrical Specifications

The FES is designed to offer a maximum output electricity of 30.75 kW

Table 4

FES Converter Electrical Specifications

	Input side(RMS Values)	Output side(DC Values)
FES Voltage(V)	220	600
FES Current(A)	54.5	51.25
Real Power (kW)	34.17	30.75

c) Supercapacitor Converter

Like several conventional capacitor, a supercapacitor charges and discharges supercapacitor expenses and discharges in a DC environment. The interface here is as a consequence among DC portions, and a bidirectional chopper is required to permit each charging and discharging of the super capacitor.

i. Converter Design

In order too permit bidirectional strength flow, a buck-boost converter is essential. The switch technology selected for one of these converters is again the IGBT because it gives the converter a minimum performance of 90% and it is absolutely controllable. The manipulate technique used is again PWM, but in this situation, the control signal is nearly steady and the provider is a saw tooth sign (most usually used).

ii. Electrical Specifications

The supercapacitor is rated to provide a most output power of 35 kW.

Table 5

Supercapacitor Converter Electrical Specifications

	Input side(RMS Values)	*Output side(DC Values)*
SC Voltage(V)	245	600
SC Current(A)	61.25	22.5
Real Power (kW)	15	13.5

d) Output Converter

So that it will adapt to numerous battery car voltages, the charging station dc bus have to be interfaced with the battery through a widespread DC/DC converter that need to additionally be bidirectional to allow both of the battery charging and V2G modes

i. Converter Design

The output converter configuration seems precisely like the Supercapacitor bidirectional chopper. Since the dc bus voltage is constantly better than the battery voltage, the converter acts as a buck configuration in battery charging mode, and as a boost configuration in V2G mode.

ii. Electrical Specifications

The output converter input current is equal to the sum of the output currents of the three previously noted converters.

Table 6

Charging Station Output Converter Electrical Specifications

	Input side(DC Value)	*Output side (DC Value)*
Voltage(V)	600	270
Current(A)	123.75	248
Power(kW)	74.25	67

Complete Power Circuit

The prevailing section describes the combined design of the charging station, and then lists its electrical specs.

i. Circuit Design The electrical grid, the supercapacitor, and the FES are all interfaced through their respective power digital converters previously designed to a commonplace DC bus. The interface with the PHEV battery is likewise executed through a bidirectional DC/DC Converter.

ii. Electrical Specifications

The energy and strength requirements of every current source are summarized in table beneath

Table 7

Charging Station Electrical Specifications

	Electrical Grid	*FES*	*Supercapacitor*
Maximum output energy(kWh)	5.56	5.70	1.25
Converter Efficiency	0.9	0.9	0.9
Maximum Output energy(kWh)	5	5.125	1.125
Maximum time of charging operation(min)	10	10	5
Maximum Output Power(kW)	30	30.75	13.5

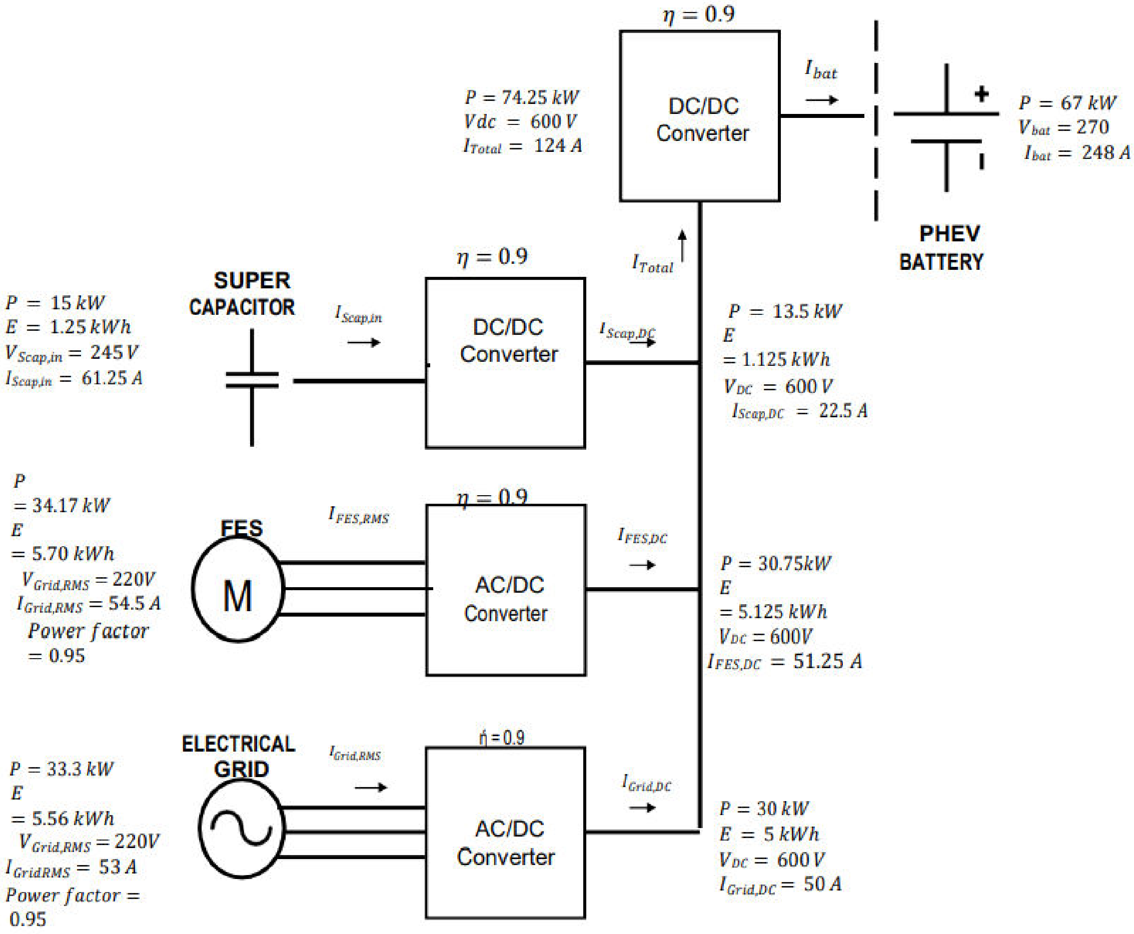

Fig 3. Charging Station Power Circuit

V. CONVERTER CONTROL

This section elaborates on the individual manage schemes of each of the 4 charging station electricity electronic converters.

1. Grid Converter Control

The grid side converter manipulate circuit consists of two nested control loops. The outer loop is for voltage regulation. In order to maintain the output dc bus voltage constant, the error between the reference DC voltage and the measured bus voltage is fed to a PI voltage controller that produces as an output the reference DC grid current. The internal loop regulates the output DC current, whose reference is the output of the previous outer loop. The mistake among the reference and measured DC current is fed to a current regulator whose output is sent to the grid converter switching scheme (PWM).

2. FES Control

The FES manipulate through itself is hard. a) FES Emulation It’s been tested that an FES should without problems be emulated through a PMDC (Permanent Magnet DC Machine). Such operation could substantially lower the machine length and cost. The FES system model will for that reason be replaced by using a DC device model. b) System Control The amount of electricity transferred in or out of the flywheel may be controlled by way of controlling the PMSM torque via enforcing either a effective or negative torque command within the PMSM controller, that's primarily based on field oriented Control (FOC) in a rotor body.

3. Supercapacitor Converter control

The supercapacitor manipulate design has similarities to the flywheel control design and is designed to permit charging and discharging of the supercapacitor. The DC/DC converter output current reference is produced via dividing the reference supercapacitor’s required strength by way of the dc bus voltage. The mistake in current is then fed to a PI current regulator with a purpose to keep the energy drift among the charger dc bus and the supercapacitor. Eventually the regulator output could be directed to the supercapacitor manipulate scheme. The mode of operation (charging or discharging mode) relies upon at the signal of the supercapacitor's reference power.

4. Output Converter Control The control scheme of the output converter may be very just like the grid converter manipulate, it's composed of two nested manipulate loops: The outer control loop is designed for voltage regulation. The mistake among the battery nominal reference voltage and the measured battery charging voltage is fed to a PI controller, whose output is the battery charging current reference. The internal loop regulates the battery charging current. The reference here is the output of the previous outer loop. The error between the reference and the measured current is likewise fed to a PI controller whose output is sent to the charging station output converter manipulate scheme.

5. Control Circuit Design

This phase offers an algorithm that combines the preceding individual controls in such that it minimizes the PHEV battery charging length.

a) Charging Station Central Control

A charging station cycle is composed of a PHEV battery charging period (stages) that doesn't exceed 15 mins, followed with the aid of a duration (one segment) at some stage in which the storage devices are absolutely recharged, which lasts a most of 7.5 minutes.

b) Central Control Algorithm

In standby mode, there may be no PHEV battery linked to the charging station, and the energy storage devices were fully charged. At this second, the FES rotates at consistent pace Ωo and as a result there is no energy transfer (dW = 0). The supercapacitor voltage maintains to boom asymptotically to its rated voltage, while its current has a tendency asymptotically to 0. The charging station stays in this mode until the appearance of a PHEV on the station

VI. SIMULATION RESULTS

The charger has been simulated for a Li-ion battery vehicle. The simulation has been run the use of Matlab/Simulink, and the parameters can be observed inside the appendix. The whole time required to charge the battery from 20% to 95% SOC is 13.25 mins.

A. Battery Characteristics

Fig. 4 below shows the evolution of the battery SOC (in %), the battery current (in A), and the battery voltage (in V), for the duration of the charging technique

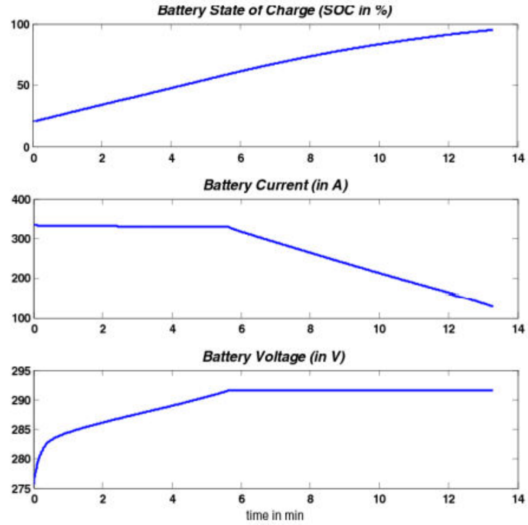

Fig 4. Battery Characteristics Evolution

B. Charger Characteristics

Fig. 5 under presentations the evolution of: the output DC/DC duty cycle (in %), and the grid, FES, supercapacitor, total currents (in A), and the DC bus voltage (in V) in the course of the charging process. It can be visible that the moment at which the steady voltage charging segment begins coincides with the moment the output DC/DC duty system cycle stabilizes.

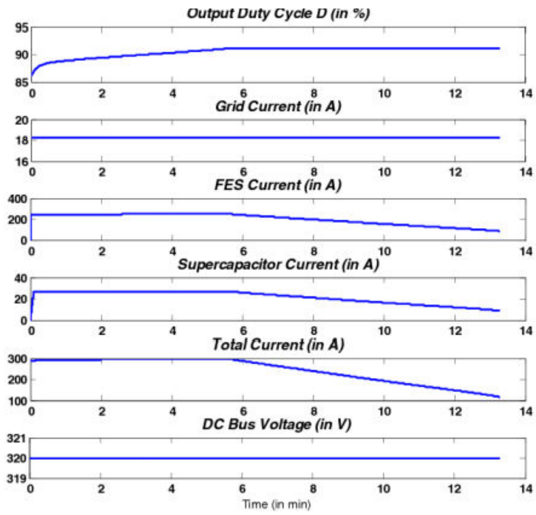

Fig 5. Charger Characteristics

VII. CONCLUSION

The paper discussed works which have already been performed within the PHEV/EV speedy charging manner. The simulation confirmed that the proposed design using a FES and a supercapacitor falls nicely within the level III station class. Certainly a regular PHEV battery has been charged from 20% to 95% SOC in 13.25 minutes whilst remaining within equipment technical specs and the output power does now not exceed 240 kW.

REFERENCES

[1] "Hybrid Cars & Alt Fuels," About.com, para. 1, 2010. [Online].Available:http://alternativefuels.about.com/od/glossary/g/pluginhybrid.h tm

[2] The Associated Press, “GM unveils Volt electric car.” cbc.ca 2008. [Online]. Available:http://www.cbc.ca/technology/story/2008/09/17/gmvolt.html.

[3] L. Dickerman, J. Harrison. "A New Car, a New Grid,"IEEE power & energy magazine, vol. 8, no. 2, pp. 58-59, March/April 2010

[4] S. Lemofouet, A. Rufer, “A Hybrid Energy Storage System Based on Compressed Air and Supercapacitors with Maximum Efficiency Point Tracking (MEPT)” in Industrial Electronics, IEEE Transactions, vol. 53, pp. 1105-1115, Jun, 2006

[5] Henry Oman, "Making Battery Last Longer," AES System Magazine, IEEE , vol. 14, pp. 19-21, Sep. 1999.

[6] Electric Vehicle Fast Chargers - Level 3, “Electric Vehicle Fast Chargers - Level 3” BTCPower. [Online]. Available: http://www.btcpower.com/products-andapplications/electric-vehiclechargers-level-3/.

[7] “Investigation on Storage Technologies for Intermittent Renewable Energies: Evaluation and Recommended R&D Strategy,” Jun. 17, 2003. [Online]. Available: http://www.itpower.co.uk/investire/pdfs/flywheelrep.pd f

[8] The Associated Press, “GM unveils Volt electric car.” cbc.ca 2008. [Online]. Available:http://www.cbc.ca/technology/story/2008/09/17/gmvolt.html.

[9] B. Yang, Y. Makarov, J. Desteese, V. Viswanathan, P. Nyeng, B. McManus, and J. Pease, “On the Use of Energy Storage Technologies for Regulation Services in Electric Power Systems with Significant Penetration of Wind Energy” in Electricity Market, 2008. EEM 2008, 5th International Conference, May 28-30, 2008

[10] J. Alvarez, J. Marcos, A. Lago, A. Nogueiras, J. Doval and C. M. Peiialver “A Fully Digital Smart and Fast Lead-Acid Battery Charge System” in Smart Lead-Acid Battery Charge System: Power Electronics Specialist Conference, 2003. PESC '03. 2003 IEEE 34th Annual, Jun 15- 19, 2003

APPENDIX

A. Grid Parameters:

-AC side: Vl1,rms= 208V

-DC side: dc bus voltage= 320V

B. Supercapacitor Parameters:

-CScap = 100F

-VScap,ref = 400V

C. Battery Parameters:

- Maximum charging voltage = 291.5 V
- Maximum continuous charging current = 400 A
- Nominal voltage = 250 V
- Minimum voltage = 208