Plug-In Electric Vehicle Charging and Related Aspects

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Outline

• Why charging your car from the Grid is going to be necessary?

• The different modes of Charging and their impact on the grid.

• How we can try to simulate the Charging scenarios.

• Demo simulation of faults occurring during car Charging.

• Concluding remarks and Future work.

• Q & A.
The Problems at hand

- Rising global temperature.
  - Global surface temperature has increased by $0.74 \pm 0.18 \, ^\circ C$ ($1.33 \pm 0.32 \, ^\circ F$) during the 20th century. [IPCC]
- Rising oil prices.

[Fig.1] [Picture Courtesy: NASA Earth Observatory]

- Shift of emission from tail pipes to the power plants???
- Renewable energy sources.
- To give back to the grid.

Modes of Charging

- Residential/Domestic Charging.
- Commercial Charging.
- SAE J1772 Classification:
  - Residential/Domestic Charging: Level I (120 VAC, 1-Φ, 16 A)
  - Commercial Charging: Level II and Level III (240 VAC, 1-Φ, 80 A/??)

[Fig.3] [Picture Courtesy: General Motors]
Impact on the Grid

- Distribution systems are typically designed for specific load carrying capability based on typical load consumption patterns.
- PHEV’s will change the load demand.
- Period of overloading is a highly probable scenario.
- Both circuits and transformers are vulnerable to these overloads with the transformer being more susceptible to overloads.

![Fig.4](1)

<table>
<thead>
<tr>
<th>No. of PHEV's/household</th>
<th>% Increase in avg. electrical load</th>
<th>Transformer LoL.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10.67%</td>
<td>7%</td>
</tr>
<tr>
<td>2</td>
<td>21.33%</td>
<td>16%</td>
</tr>
<tr>
<td>3</td>
<td>32%</td>
<td>25%</td>
</tr>
</tbody>
</table>

[Table.1] (1)

The good things are...

- PHEV loads can be controlled.
- Smart Charging.
- Need incentives for the owners.
PHEV Charging : End To End

A charger topology with protective elements
A Simulation Model

Challenges

- A realistic model of the battery pack.
- Implementation of control.
- Power factor correction. (Not done in this simulation)
- Mitigation of harmonics.
A nonlinear model of the Battery pack

- Battery Terminal Voltage
  \[ V_{\text{batt}} = \text{OCV} - v_{\text{cd}} - i(t) R_{\text{batt}} \]

- Ampere Hour
  \[ \text{AHR} = \frac{1}{3600} \int i(t) \, dt \]

- State of Charge
  \[ \text{SoC} = \frac{Q - \text{AHR}}{Q} \]

- Open Circuit Voltage
  \[ \text{OCV}(\text{SoC}, dG, a) = V_0 - \frac{1}{96485} \left[ dG + a (8.3) (300) \log \left( \frac{1 - \text{SoC}}{\text{SoC}} \right) \right] \]
  
  $dG$: Gibbs' free energy measured between charged and discharged electrode
  
  $a$: Molecular interaction exponent

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Multi stage Battery Charging Algorithm

- Bulk Charging stage.
- Absorption Charging stage.
- Float Charging stage.
Multi stage Battery Charging Algorithm

![Graph showing Multi stage Battery Charging Algorithm](Picture Courtesy: http://batterytender.com/)

The SIMULINK™ Model

![SIMULINK Model](Fig.12)
Battery Charging Algorithm Simulated

200 V Battery Pack Charging from Grid
Open Circuit Fault simulation (Grid side)

[Fig.15]

Short Circuit Fault simulation (Rectifier [1])

[Fig.16]
Short Circuit Fault simulation (Rectifier [2])

Short Circuit Fault simulation (Dc/Dc Converter)
Concluding Remarks & Future Work

- Ac fault (grid side/rectifier primary) is relatively easier to mitigate.
- DC fault is very difficult to mitigate as there is no zero crossing of fault current.
- DC/DC converter almost has an inherent immunity against faults if the fault can be cleared in quick time.
- It is interesting to explore if a control algorithm can be developed to come up with a fault-tolerant model.
- A state space model can be developed for designing an optimal control algorithm.
- A faster charging method using higher currents may be investigated to design robust protection schemes for worst case scenarios.
- Impact of the faults on the distribution transformers can be investigated in details.
- SAE J1772 Level-III is supposed to use DC power (550 V) and that poses a new challenge for protection engineers.

References


[4]. MEEM 5900: Advanced Propulsion for Hybrid Vehicles with Specialization in Battery Engineering.