A Scalable Model for a Life Cycle Inventory of an Electric Automotive Traction Machine

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Summary

This report describes a project with the aim to establish a scalable life cycle inventory for an electric permanent magnet synchronous motor intended for electric vehicle propulsion. Life cycle assessment is a frequently used tool when assessing the environmental impact of electric powertrains in vehicles. However, within the research field there is a lack of new and relevant inventory data for powertrain components, which can be scaled and adapted to match different powertrain requirements.

The SHC project T2:12 “A Scalable Model for a Life Cycle Inventory of an Electric Automotive Traction Machine” was initiated to establish a first version of the scalable PMSM LCI. The goal of the SHC phase has been to develop a model that gives weight and material configuration which scales based on the specified maximum power, and this has been accomplished. Active and passive parts of the machine scale differently when power requirements are altered for two different reference geometries which are combined into one dataset. In the next step, the model work will be finalized to include complete manufacturing data, formulated to match upstream data in version 3 of the Ecoinvent database (Weidema et al., 2013).

The total project budget is 870 000 SEK. 530 000 SEK has been funded by SHC. The SHC phase started in March 2015 and will finish in June 2015. The project is a horizontal research collaboration at Chalmers University of Technology, mainly between the divisions of Environmental Systems Analysis and that of Electric Power Engineering, both within the Department of Energy and Environment. China Euro Vehicle Technologies, Volvo Car Corporation and Volvo Global Trucks Technology participate in the reference group. Results will be disseminated through the life cycle inventory database of the Swedish Life Cycle Centre, in the form of an ESA report registered in the Chalmers Publication Library and by submission of a joint article manuscript.

General project description and background

Life cycle assessment (LCA) is a frequently used tool when assessing the environmental impact of electric powertrains in vehicles. All product life cycle stages are surveyed, from material acquisition to the product end-of-life. Data is gathered for inflows and outflows at each stage, and linked from cradle to grave. This results in a life cycle inventory (LCI) of inflows in terms of natural resources and outflows in terms of emissions to the surrounding natural system.

LCA of electrified vehicles for road transport, for example plug-in hybrid or full electric passenger cars, is an active research area where many case studies are conducted and published (Nordelöf et al., 2014). However, despite much activity in the field, few well populated and transparent inventory datasets have been published for electric vehicles and different electric powertrain components, especially considering production processes (Hawkins et al., 2012). Inventory data for version 3 of the Ecoinvent database, the most used and acknowledged LCI database worldwide (Weidema et al., 2013), has been published by Del Duce et al. (2014) for various components of an electric powertrain such as electric motor and different types of power electronic devices. However, these datasets have been specifically derived for an electric vehicle in the compact class (e.g. a Volkswagen Golf or similar) and they are formulated in fixed material compositions and production efforts per kilogram of each device.

Hence, there is lack of life cycle inventory data for electric powertrain components which can be scaled and adapted to match different powertrain requirements. Also, open automotive powertrain specifications are commonly expressed in terms of torque or power, whereas component weight sometimes can be difficult to acquire. Altered requirements do not only imply different component weights, but also that the overall material configuration and production efforts will change as various subparts scale differently to match the requirements. Additionally, there is a general need for more detailed investigations of vehicle production data (Del Duce et al., 2014, Hawkins et al., 2012), especially of electric powertrain components as they are less mature in terms of manufacturing and still often produced in small series compared to other vehicle parts (Nordelöf et al., 2014).

The purpose of the work described in this report is to establish a general scalable inventory for an electric permanent magnet synchronous motor (PMSM) intended for electric vehicle propulsion, including new manufacturing data. The starting point was two LCA master thesis projects conducted at Environmental Systems Analysis, one in collaboration with Volvo (VGTT) and one with Scania. In both projects component data for electrification of trucks were provided but could not be published directly, as a consequence of confidentiality. A pre study was conducted 2012-2013 with the aim to generalize the data based on data from master's thesis projects to allow publication. However, a key insight from the pre-study was that some basic assumptions regarding the motor design must be based on fundamental theoretical models and in order to achieve the desired combination of a realistic motor design and accuracy from an LCA perspective. In other words, it was found to be too difficult to start from diverse specific component data and merge these into a relevant dataset. Instead, more

feasible, a representative design can be constructed with software for virtual analysis and then validated with relevant industrial data.

As a response, the SHC project T2:12 “A Scalable Model for a Life Cycle Inventory of an Electric Automotive Traction Machine” was initiated to establish a first version of a scalable PMSM LCI. The goal of the SHC project has been to develop a model that gives weight and material configuration which scales based on the specified maximum power. The technical project report will describe the functionality and specifications of the motor, input data used for the material configuration and explain the scaling principle for all substances in different subparts. In a next step, following the SHC project, the model work will be finalized to include manufacturing data with energy use, losses and raw material input for the scaled design, formulated to match the availability of upstream data in version 3 of the Ecoinvent database (Weidema et al., 2013). Limitations of the model with relevant metadata for LCA will also be described.

Achieved results

A generic and scalable LCI model of a PMSM intended for automotive traction applications has been established. It takes into account that active and passive parts of the machine scale differently when power requirements are altered. Two different reference geometries, where the radius is fixed and length is scaled up and down, have been analysed with ANSYS Maxwell, a design software and support tool for electric motor development. Maximum speed (revolutions per minute) and internal parameters such as number of poles, magnetic flux density, winding fill factor are held fixed in the design. Complex design issues have not been in focus and data precision has been balanced based on relevance from an LCA perspective. For example, the permanent magnet composition has focused on the content of the main constituents and a representative modelling of the rare earth metal content, whereas plausible minor alloys of the magnet like copper and aluminium have been disregarded, as these substances are included in much larger quantities in other subparts such as windings and housing.

In the model file the user specifies the maximum power value and receives data for the material configuration and weight. Options are available for calculation of the inventory with or without shaft, with or without one, or both, endplates including bearings on each side, and with or without housing. This allows for large flexibility in the inventory analysis if the motor under study is mounted alone or integrated with other powertrain parts such as a transmission or inverter.

Some manufacturing data has also been investigated within the scope of the SHC project and a new dataset for the making of electrical steel from hot rod coiled steel has been collected from Surahammars Bruk AB. It constitutes the foundation for the making of both the stator and rotor steel laminations. However, collection or adaption of data for manufacturing of magnets, motor laminations, housing and complete assembly remains for the second part of the project. The second phase will also

include a validation of the model with industry data, and a more thorough description of how to use the model from the perspective of an LCA practitioner.

Timing and finance

The SHC project T2:12 started in March 2015 and will finish at the end of June 2015. The project then continues with funding from Chalmers Energy Area of Advance, with the aim to finish during the fall 2015. The total project budget is 870 000 SEK. 530 000 SEK has been funded by SHC.

Executors and collaboration

The project is a horizontal research collaboration at Chalmers University of Technology, mainly between PhD student Anders Nordelöf at the divisions of Environmental Systems Analysis and PhD student Emma Grunditz at division of Electric Power Engineering, both within the Department of Energy and Environment. Researcher Mikael Alatalo, located both at Electric Power Engineering at Chalmers and part time at Aros Electronics AB in Mölndal, has contributed with both supervision and work within the project. Professors Anne-Marie Tillman of Environmental Systems Analysis and Torbjörn Thiringer of Power Engineering have provided supervision to Anders and Emma. Finally, some advice about the system requirements for electric motors has also been given by Associate Professor Anders Grauers at the Department of Signals and Systems, Chalmers.

A reference group has been established for the project. It consists of Johan Hellsing, electric motor specialist at China Euro Vehicle Technologies, Axel Edh, environmental advisor at Volvo Car Corporation and Maria Wallenius Henriksson, LCA specialist at Volvo Global Trucks Technology.

The project has a sister project in the form of a model for a scalable inventory of a power electronic inverter. There are several overlaps between the projects, such as the structure of the model file, manufacturing data collection etc.

Dissemination of Results

The aim and the setup of the project was presented at the SHC cross thematic meeting in Hallsberg on 11-12 of March. The resulting model file will be published in the CPM LCI database, i.e. the life cycle inventory database administered by the Swedish Life Cycle Center. The full and detailed technical and methodological model report will be published as an ESA report and registered within the Chalmers Publication Library (CPL). Finally, built on these two references, the main goal of the project in terms of deliverables and publications is to submit a journal publication during the fall 2015.

References

Del Duce, A., Gauch, M. & Althaus, H.-J. (2014). Electric passenger car transport and passenger car life cycle inventories in ecoinvent version 3. The International Journal of Life Cycle Assessment, pp. 1-13.

Hawkins, T., Gausen, O. & Strømman, A. (2012). Environmental impacts of hybrid and electric vehicles – a review. The International Journal of Life Cycle Assessment, 17, pp. 997-1014.

Nordelöf, A., Messagie, M., Tillman, A.-M., Ljunggren Söderman, M. & Van Mierlo, J. (2014). Environmental impacts of hybrid, plug-in hybrid, and battery electric vehicles—what can we learn from life cycle assessment? The International Journal of Life Cycle Assessment, 19, pp. 1866-1890.

Weidema, B. P., Bauer, C., Hischier, R., Mutel, C., Nemecek, T., Reinhard, J., Vadenbo, C. O. & Wernet, G. (2013). The ecoinvent database: Overview and methodology, Data quality guideline for the ecoinvent database version 3 [Online]. Switzerland: The Centre for Life Cycle Inventories. Available: www.ecoinvent.org 2014-2015.