XIX International Conference on Electrical Machines - ICEM 2010, Rome

Integrated Chargers for EV's and PHEV's: Examples and New Solutions

Saeid Haghbin, Kashif Khan, Sonja Lundmark, Mats Alaküla, Ola Carlson, Mats Leksell and Oskar Wallmark

Abstract -- **The battery is an important component in an electric vehicle (EV) or a plug-in hybrid electric vehicle (PHEV) and it should be charged from the grid in a cost efficient, preferably fast and definitely safe way. The charger could be an on board or an off board charger. For an on board charger it is possible to use available hardware of the traction system, mainly the inverter and the electric motor, in the charger circuit. This is called an integrated charger. In this paper, different examples of integrated chargers are reviewed and explained. Additionally, other possible solutions of integrated chargers are described.**

Index Terms— **AC Machines, battery chargers, converters, road vehicle electric propulsion.**

I. Introduction

THE battery has an important role in the development of EVs and PHEVs. Its energy density, power density, charging time, lifetime, and cost are still behind practical applications and subject of research. The charging time and lifetime of the battery have a strong dependency on the characteristics of the battery charger [1]-[4]. Several manufacturers are working worldwide on the development of various types of battery modules for electric and hybrid vehicles. However, the performance of battery modules depends not only on the design of modules, but also on how the modules are used and charged. In this sense, battery chargers play a critical role in the evolution of this technology.

Generally there are two types of battery chargers: on-board type and stand-alone (off-board) type. The on-board type would be appropriate for nighttime charging from a household utility outlet, or for charging during daytime at workplaces, malls or for emergency charging where no off-board charger is available. On the other hand, the off-board charger can be compared to a gas station used for an internal combustion engine vehicle, thus it is aimed at rapid charging. Because the on-board type of charger always should be carried by the vehicle, the weight and space have to be minimized. Of course, it is very important to minimize charger cost (especially the on-board versions). Also, considering the popularity of the electric vehicle in the near future, the harmonics and low power factor of the charger could be a serious problem to the electric distribution system.

On-board chargers are the preferred choice of customers due to its usage simplicity, but the problem is that high power level is difficult to achieve because of its weight, space and in total cost. Accordingly, although galvanic isolation is a very favorable option in the charger circuits for safety reasons, isolated on-board chargers are usually avoided due to its cost impact on the system. There is a possibility of avoiding these problems of additional charger weight space and cost by using available traction hardware, mainly the electric motor and the inverter, for the charger circuit and thus to have an integrated drive system and battery charger. The integration may also allow galvanic isolation. Other aspects to consider regarding integrated chargers are voltage level adaption, unwanted developed torque in the motor during charging, efficiency and mandatory unit power factor operation.

Different types of integration have been reported inside the vehicle system. Those that address integrated charging have been reviewed in this paper [5]-[13]. In addition, some new possible solutions are described which integrate the traction drive system components (converter and motor) in such a way that most of the desired features are achieved [14].

II. Battery Chargers in Vehicle Applications

Chargers can be classified in terms of power levels and time of charging [16], [17]. The choice of classification depends naturally on nationally available power levels. One example of classification that suits the US residential power source is given in [16]:

Level 1: Common household type of circuit in US rated to 120 V and up to 15 A.
Level 2: Permanently wired electric vehicle supply equipment used specially for electric vehicle charging and it is rated up to 240 V, up to 60 A, and up to 14.4 kW.
Level 3: Permanently wired electric vehicle supply equipment used specially for electric vehicle charging and it is rated greater than 14.4 kW.

Equivalently, above categories are known as; emergency charger which charges the battery pack of a vehicle in six to eight hours, standard charger which charges the battery pack in two to three hours, and rapid charger which charges the battery pack in ten to fifteen minutes (fast chargers).

Chargers can also be described as either conductive or inductive. For a conductive charger the power flow take place through metal-to-metal contact between the connector on the charge port of the vehicle and charger (off-board charging) or grid (on-board charging). Conductive chargers may have different circuit configurations but the common issues concern safety and the design of the connection interface.

Inductive coupling is a method of transferring power magnetically rather than by direct electrical contact and the

Financial support from the Swedish Energy Agency and the Swedish Hybrid Vehicle Centre is gratefully acknowledged.

S. Haghbin, S. Lundmark and O. Carlson are with the Electric Power Engineering division, Chalmers University of Technology, Gothenburg, Sweden (e-mail: saeid.haghbin@chalmers.se).
K. Khan, M. Leksell and O. Wallmark are with the School of Electrical Engineering, Royal Institute of Technology, Stockholm, Sweden.
M. Alaküla is with the Department of Industrial Electrical Engineering, Lund University, Sweden.

978-1-4244-4175-4/10/$25.00 ©2010 IEEE

technology offers advantages of safety, power compatibility, connector robustness and durability to the users of electric vehicles but on the expense of a lower efficiency and the need of new equipment at charging sites. The electric vehicle user may physically insert the coupler into the vehicle inlet where the ac power is transformer coupled, rectified and fed to the battery, or the charging could be done almost without driver action by wireless charging [18].

For inductive charging, among the most critical parameters are the frequency range, the low magnetizing inductance, the high leakage inductance and the significant discrete parallel capacitance [19], [20].

Different topologies and schemes have been reported for both single-phase and three-phase input conductive battery chargers. Usually the three-phase input solutions will be used in high power applications [21]-[24].

III. INTEGRATED CHARGERS

Fig. 1 shows a schematic diagram of a PHEV with parallel configuration (both internal combustion engine and electric motor can drive the vehicle simultaneously). The electrical part includes the grid connected battery charger, battery, inverter, motor and control system. It is here assumed that during charging time the vehicle is not driven and during driving time it is not possible to charge the battery pack except for regeneration at braking. In a classical electrical device arrangement in the vehicle, there are separate inverter and charger circuits for traction and charging from an external source. However, it is possible to integrate both hardware to reduce the system components, space and weight which is equivalent to cost reduction. For instance, the three-phase three-wire boost AC/DC converter that can be used as a battery charger is very similar to what hardware is available in the traction system. See [21]-[22] for different AC/DC rectifier schemes. Another example of the use of integration is to use the electric motor windings as inductors in the charger circuit. This reduces weight as high current inductors are large components compared to other components like switches for example.

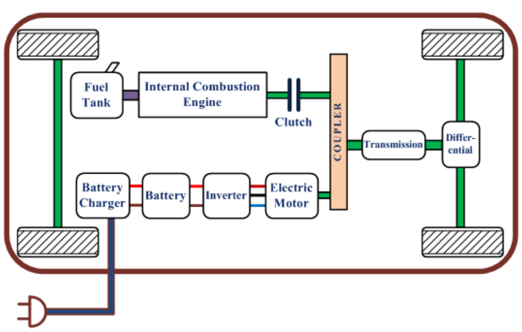

Fig. 1. A simple diagram of a parallel plug-in hybrid electric vehicle

A traction system based on an ac motor and a three-phase inverter is shown in Fig. 2. In some schemes a DC/DC converter is used in the system also [25]. The battery power will be transferred to the motor through the inverter. Bi-directional operation of the inverter allows energy restoration during braking time to the battery. Regarding different drive systems, different types of integrated chargers have been reported both in academia and industry and some of them are assessed here.

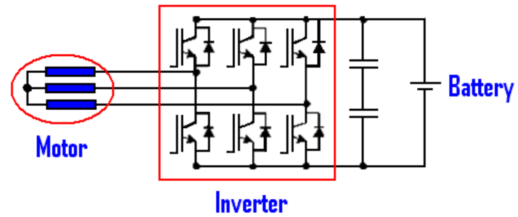

Fig. 2. Electrical traction in a vehicle

A. *A combined motor drive and battery recharge system*

An integrated motor drive and charger based on an induction machine was patented 1994 by AC Propulsion Inc. [5] and is currently in use in the car industry [6]. The main idea is to use the motor as a set of inductors during charging time to constitute a boost converter with the inverter to have unit power factor operation. Fig. 3 shows the functional schematic diagram of this non-isolated integrated charger system. By the means of inexpensive relays the machine windings are reconfigured to be inductors in the charging mode.

For example for a single-phase ac supply, LS2 and LS3 shown in Fig. 3 are the induction motor phase to neutral leakage inductances of the windings that act as inductors in the single-phase boost converter circuit. The battery voltage should be more than maximum line-line peak voltage in the input to guarantee unit power factor operation. As an example they used a 336Vdc battery pack with a 220Vac input. The relays K1, K2 and K2' shown in Fig. 3 are used to reconfigure the motor in motoring mode. Further, the inverter switches S1 and S2 are open in charging mode and switches S3-S6 are part of the boost converter. A common/differential mode filter is used to eliminate the switching ripples and spikes from the line side current. Moreover, a lot of electrostatic shielding is used to decrease the ground current and high voltage transitions. In traction mode, relays K2 and K2' are open and K1 is closed, yielding a classical three-phase drive system.

It is possible to have a three-phase input supply with this scheme, but there will be developed torque in the machine during charging that should be considered. The one-phase charger can charge from any source, 100-250 VAC, from 200W up to 20kW and can be used for V2G (vehicle to grid) and for backup power and energy transfer to other electric vehicles. The filter bank at the front of the ac supply will smooth the harmonic contents of the charger line current also.

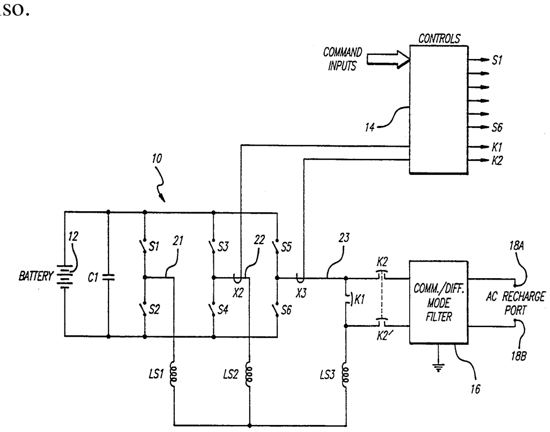

Fig. 3. Integrated charger based on boost converter [5]

Other similar alternatives have been patented in the US also. It has been tried to use the motor, inverter and capacitor components in the charging system. All of these solutions are bidirectional non-isolated type of chargers with unit power factor operation and single-phase ac supply. In [7] two solutions have been proposed by Rippel in 1990. In traction mode an inverter and a three-phase ac motor is used. Firstly the motor is not used in the charger circuit and an inductor has been used to be the energy storage device in the front-end boost converter. The inverter switches have been used in the system (part of the boost and DC/DC converter). Afterwards, a modified version was introduced to the circuit that led to inductor elimination. The machine leakage inductances have been used as part of the charger circuit. When the machine is used as three inductors, the inductors have self and mutual couplings. So the inductance matrix should be considered in this case. The leakage inductances are the part of inductors that have no coupling to the other inductances. No switching devices like relays are used to reconfigure the circuit for traction and charging mode (the same hardware in the traction and charging mode).

Another solution patented by Rippel and Cocconi in 1992 (the patent assignee is General Motors Inc.) uses the same idea of integration but there are two independent inverters in the system [8]. They proposed two alternative methods. One with two induction motors and another one with one induction motor (with double stator windings).

In the first alternative two induction motors and inverters have been used as the traction force. Each motor can be controlled by its dedicated inverter independently. Each motor can be connected to the wheel directly or through a gear that eliminates the need for a transmission and differential in the mechanical system. For the charging mode the supply will be connected to the neutral point of the motors after EMI filtering.

The second alternative is using an induction motor with double set of stator windings comprising two motor halves. The rotor can be coupled to a single wheel or to two wheels by means of a reduction-differential gear or a transmission-differential gear. Each winding set is connected to an inverter (each winding set includes three windings). In the charging mode the supply is similarly connected to the neutral points of the double set of windings after EMI filtering.

B. An integral battery charger for four-wheel drive electric vehicle

An integral battery charger has, also 1994, been reported for a four wheel-in motor driven EV by Seung-Ki Sul and Sang-Joon Lee [9]. The propulsion system includes four induction motors and four three-leg inverters with a battery on the system dc bus. By the use of an extra transfer switch the whole system will be reconfigured to a single-phase battery charger. Fig. 4 shows the system configuration in traction and charging mode. In the traction mode, four inverters connected to the system dc bus drive motors (each motor neutral point is float in this mode). In the charging mode (the transfer switch is in position 2) the single-phase ac source is connected between the neutral points of two motors. Utilizing the switches in inverter one and two, this configuration will be a single-phase boost converter with unit power factor operation capability. The third and fourth inverters with the use of two other motors constitute two buck-type converters. Fig. 5 shows the system equivalent circuit in charging mode where the motors are used as inductors. For each motor the winding currents are the same for each phase so there is no developed electromagnetic torque in the motors during the charging time. Further, in the charging mode, by controlling the PWM boost converter, the dc link voltage is kept constant. The constant current battery charging profile is achieved by the control of the two buck-type choppers. Of course, this integrated charger solution is a high cost solution and only appropriate for vehicles with four wheel-in motors.

C. An integrated charger for an electric scooter

A non-isolated single-phase (110 V ac and 60 Hz) integrated charger for an electrical scooter is another example described in [10]. The authors use the three-phase inverter as a single switch in the charging mode, see Fig. 6. Thus, the switches Ta-, Tb- and Tc- seen in Fig. 6 are to be operated all together as a simple switch. In turn, the circuit is a single-phase boost converter. All three windings of the motor are used in the charging process. A power rectifier and line filter are also used as extra components for the charging operation. It is expected to have unit power factor operation as is expected for boost converter and low THD in the ac line current due to use of the line filter. A 180 V dc lead acid battery (12 Ah) is used as the traction power source and the motor is a 6 kW axial flux permanent magnet motor. Moreover the 50 A and 600 V IGBT modules are used with a switching frequency of 25 kHz. At charging mode, the motor is used as three parallel connected 0.1 mH inductances. The currents through the inductances are thus unidirectional, thus no torque is developed in the motor, and the rotor can be at standstill. Of course, only slow, low power charging is possible with this solution.

D. An integrated charger for a fork lift truck

An integrated drive/charger system has been reported in 2005 for a fork lift truck [11]. In traction mode a 6kW induction machine is used to drive the truck. The battery voltage and rated motor voltage is nominal 48 V. A three-phase inverter is utilized for motor control based on the space vector modulation (SVM) scheme.

In charging mode, the motor is used as a low frequency step-down transformer. A wound-type rotor is used in the drive system and for the charging mode the rotor winding is used as a primary side of the transformer with the secondary side (the stator) connected to the grid (three-phase 400Vac). Naturally, there is a galvanic insulation between the grid and battery by the means of this transformer. Fig. 7 shows the system in charging mode. The air-gap in the motor (transformer in charging mode) will affect the system performance regarding the loss due to the need of large magnetization currents. Other disadvantages are the extra cost of the wound rotor (compared to a squirrel cage rotor), need of contactors and the need to adapt the motor windings to the charge voltage. Advantages include the possibility of bidirectional power flow, low harmonic distortion and a unit power factor. The rotor is at standstill during charging and a mechanical lock is used.

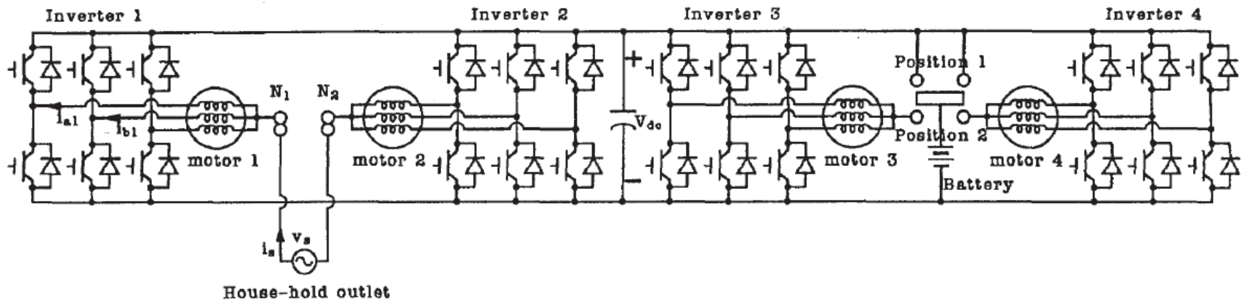

Fig. 4. Power circuit of integrated battery charger for four wheel drive [9]

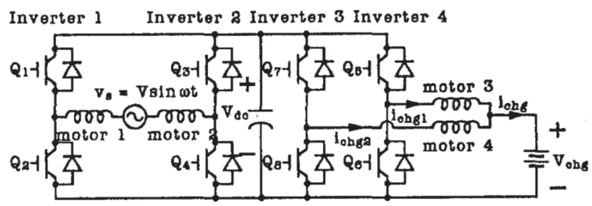

Fig. 5. System equivalent circuit in charging mode [9]

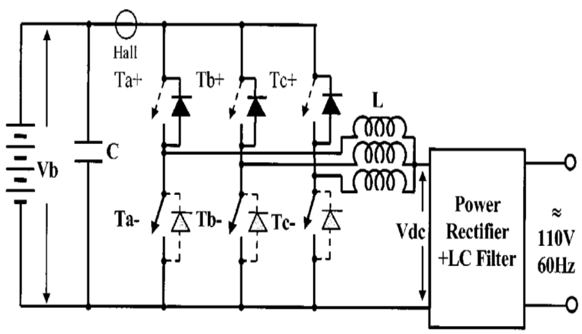

Fig. 6. Integrated charger for an electric scooter [10]

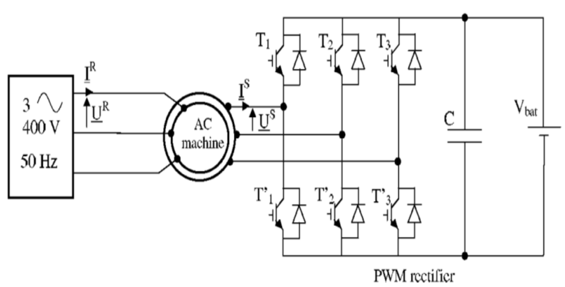

Fig. 7. Integrated charger based on the three-phase boost topology in charging mode [11]

E. Integrated bidirectional AC/DC and DC/DC converter for PHEVs

Conventional hybrid electric vehicles usually have two different voltage levels [12]. A 14 V dc bus supplied by a 12 V dc battery and a high-voltage 200-600 V dc bus that provides the propulsion power. Traditional loads like lightning systems and vipers are connected to the low voltage bus. The increasing number of additional loads motivates the car industries to replace the 14 V dc bus with a 42 V dc bus supplied by a 36 V battery. The high voltage and low voltage buses are connected to each other by the means of an isolated bidirectional DC/DC converter. Also, a DC/AC inverter is used to supply and control the ac drive system.

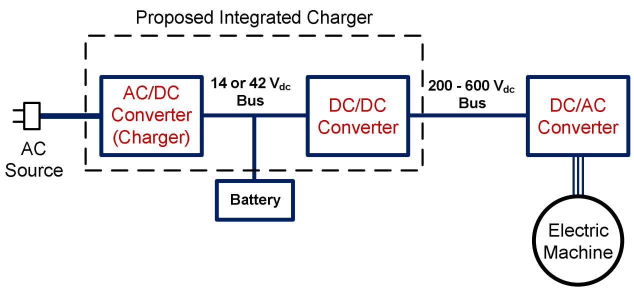

Fig.8. System diagram of voltage distribution in a HEV and the proposed integrated charger of Young-Joo Lee et al.

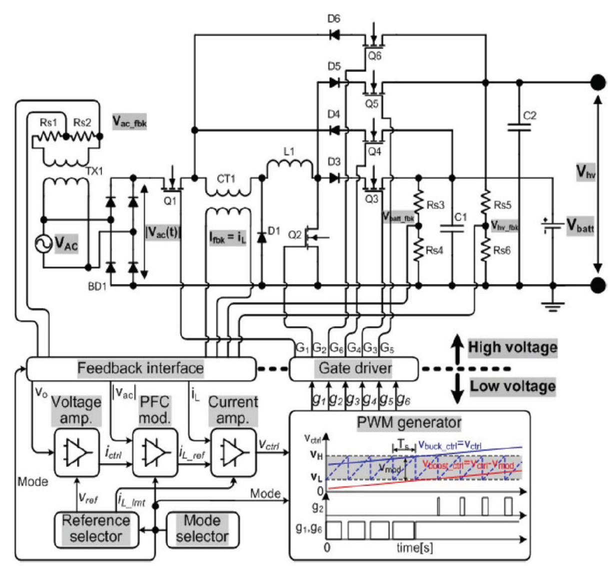

Fig.9. Integrated bidirectional AC/DC and DC/DC converter for PHEVs [13]

By combining the DC/DC converter and the battery charger (AC/DC converter) an integrated battery charger was proposed by Young-Joo Lee et al. 2009 in [13]. Fig. 8 shows a simple schematic diagram of the system structure. Moreover the proposed integrated charger can be identified from this figure. The charger/converter is a non-isolated version with reduced number of inductors and current transducers for the single-phase input supply. Fig. 9 shows the circuit diagram of the proposed system including control parts in which details are explained in [13].

IV. Other possible integrated chargers

As mentioned, non-isolated onboard chargers are very important options regarding the size and weight reduction perspectives. On the other side, isolated chargers are very interesting options for the safety reasons. To overcome this problem different possibilities are investigated with emphasis on a special electric machine configuration with an extra set of windings. All windings are used in traction mode and are then reconnected in the charging mode through a simple switching device. Fig. 10 shows a schematic diagram of the integrated charger first proposed in [14]. Different motor topologies are possible both concerning motor types and winding arrangement. One option with an internal permanent magnet synchronous motor was reported in [14] and [15]. The main idea is to introduce a multi terminal device called motor/generator set to act like a motor in the traction mode and like an isolated generator/transformer in the charging mode. Fig. 11 shows a simple schematic diagram of the system. This solution has bidirectional capability so it is possible to bring back power to the grid from the battery. Moreover, unit power factor operation is feasible. Depending on the type of machine and winding configuration, a single-phase solution is also possible. The charging power will be limited by the motor thermal limit and inverter power limit and limit of the supply, so high power charger (fast charger) is feasible in this configuration.

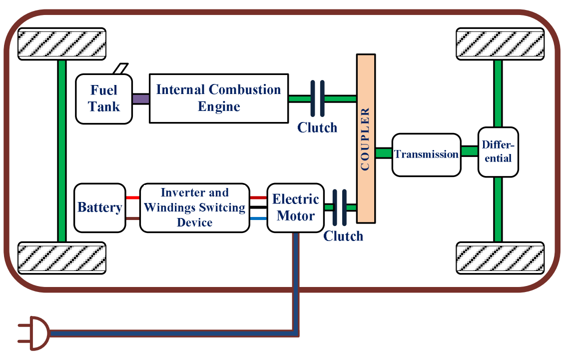

Fig. 10. Integrated charger based on the especial electric motor configuration

A. An integrated charger for the three-phase grid supply

By replacing the above mentioned motor/generator set in Fig. 11 by a PMSM, IPM or PM assisted motor with double stator windings it is possible to have the proposed integrated charger scheme. The motor winding connections can be reconfigured by a simple switching device for the traction and charging mode. During the traction mode the windings can be connected to act like a pure motor and in the charging mode, while the vehicle is parked, the windings can be reconfigured as a rotating transformer or a motor/generator set. In the charging mode the motor will rotate at the synchronous speed. Before connection to the grid, through the inverter-side stator windings, the battery and inverter will synchronize the voltage at the grid-side windings to the grid voltage.

After grid synchronization, the grid-side stator windings will be connected to the grid voltage. Now the inverter side windings are an isolated three-phase voltage source and the inverter can control the dc voltage and current at the battery side. One control objective is to keep the torque zero during synchronization with the grid. Another control objective is unit power factor operation. It is showed in [14] that it is possible to have unit power factor operation and current control.

To have proper boost converter operation the dc bus voltage should be more than peak ac line voltage. This can be solved in two ways: using an extra DC/DC converter or Y-Δ connection of the stator windings to reduce the voltage at the inverter side. The second approach has been selected to reduce the system hardware in this case. The detailed motor design is presented in [15].

Instead of PM machines, an induction machine can be used with the same principle of operation. In that case the motor will not rotate at the synchronous speed. The motor rotation is a key point to solve the high magnetization problem (equivalently low efficiency) compared to the other solutions (discussed in Section 3) where the machine is used as an air-gapped transformer. It is also an advantage that the developed torque can be controlled by the control of the converter. At the other side, this solution needs a switching device for winding reconfiguration and, due to machine rotation in the charging mode, a clutch is needed to disconnect the motor from the mechanical system.

B. An integrated charger for the single-phase grid supply

Another option is to use an extra winding on one phase of the stator to have transformer operation for a single phase ac supply. In this case the stator will have unsymmetrical windings. Fig. 12 shows this configuration for a system based on a synchronous reluctance motor (SynRM). The motor acts like a stationary air-gapped transformer. So there will be no rotation in the motor during the charge cycle. The rotor position will automatically be aligned to have maximum inductance after some cycles in charging mode. The extra winding can adjust the voltage level according to converter requirements.

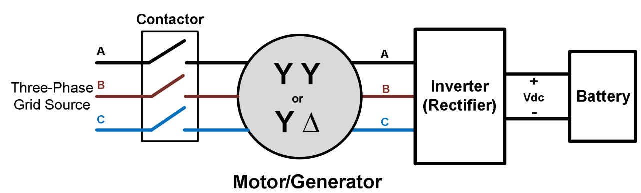

Fig. 11. Integrated charger based on the especial electric motor configuration

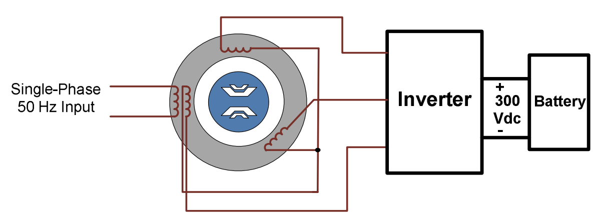

Fig. 12. Proposed single-phase integrated charger based on SynRM with an extra winding

V. Conclusions

Assuming that the battery charging of an EV or PHEV is happening during the time that the vehicle is parked, there is a possibility to use the available traction hardware, inverter and motor, in the battery charger system to have an integrated battery charger and drive system. Different integrated chargers are reviewed and assessed in this paper. Moreover, inventive galvanic isolated chargers have been described based on the novel machine winding configurations and connections.

VI. REFERENCES

[1] I.A. Khan, "Battery chargers for electric and hybrid vehicles," *Power Electronics in Transportation, Proceedings*, 20-21 Oct. 1994, Page(s): 103-112.

[2] J. G. Hayes, "Battery Charging Systems for Electric Vehicles," Electric Vehicles - A Technology Roadmap for the Future," Digest No. 1998/262, IEE Colloquium on page(s): 4/1-4/8, May 1998.

[3] Chan, C.C. and Chau, K.T., "An overview of power electronics in electric vehicles," *IEEE Trans. on Industrial Electronics*, Volume 44, Issue 1, February 1997, Page(s): 3 – 13.

[4] Emadi, A., Young Joo Lee, and Kaushik Rajashekara, "Power electronics and motor Drives in Electric, Hybrid Electric, and Plug-In Hybrid Electric Vehicles," *IEEE Transactions on Industrial Electronics*, Vol. 55, No.6, June 2008.

[5] Alan G. Cocconi, "Combined Motor Drive and Battery Recharge System," US Patent no. 5,341,075 on 23 August 1994.

[6] AC Propulsion Inc. technical note, "AC Propulsion EV Drive System Specifications," 2008.

[7] Wally E. Rippel, "Integrated Traction Inverter and Battery Charger Apparatus," US Patent no. 4,920,475 on 24 April 1990.

[8] Wally E. Rippel and Alan G. Cocconi, "Integrated Motor Drive and Recharge System," US Patent no. 5,099,186 on 24 March 1992.

[9] S. J. Lee and S. K. Sul, "An integral battery charger for 4 wheel drive electric vehicle," in Conference Record of the 1994 *IEEE Industry Applications Society Annual Meeting*, vol. 1, 2-6 Oct. 1994, pp. 448–452.

[10] Luca Solero, "Nonconventional On-Board Charger for Electric Vehicle Propulsion Batteries," *IEEE Transaction on Vehicular Technology*, Vol. 50, No. 1, January 2001.

[11] F. Lacressonniere, and B. Cassoret, "Converter used as a battery charger and a motor speed controller in an industrial truck," *European Conference on Power Electronics and Applications*, 2005, Page(s): 7 pp. - P.7.

[12] A. Emadi, S. Williamson, and A. Khaligh, "Power electronics intensive solutions for advanced electric, hybrid electric, and fuel cell vehicular power systems*," IEEE Transactions on Power Electronics*, vol. 21, no. 3, pp. 567–577, 2006.

[13] Young-Joo Lee, Alireza Khaligh and Ali Emadi, "Advanced integrated bidirectional AC/DC and DC/DC converter for plug-in hybrid electric vehicles," *IEEE transaction on vehicular technology*, Vol 58, No 8, October 2009.

[14] Saeid Haghbin, Mats Alakula, Kashif Khan, Sonja Lundmark, Mats Leksell, Oskar Wallmark and Ola Carlson, " An Integrated Charger for Plug-in Hybrid Electric Vehicles Based on a Special Interior Permanent Magnet Motor, " *To be published in Vehicle Power and Propulsion Conference (VPPC) Proceedings, 2010, France.*

[15] Kashif Khan, Saeid Haghbin, Mats Leksell and Oskar Wallmark, "Design and Performance Analysis of Permanent-Magnet Assisted Synchronous Reluctance Machines for Integrated Charger," *To be published in International Conference on Electrical Machines (ICEM) proceedings, 2010, Italy.*

[16] Mark Rawson and Sue Kateley, "Electric Vehicle Charging Equipment Design and Health and Safety Codes," California Energy Commission, 1998.

[17] K.W. Klontz, A. Esser, P.J. Wolfs and D.M. Divan, "Converter selection for electric vehicle charger systems with a high-frequency high-power link," Power Electronics Specialists Conference, PESC 93 Record, 24th Annual IEEE, 20-24 June 1993, Page(s): 855-861.

[18] Chwei-Sen Wang; Stielau, O.H.; Covic, G.A. “Design considerations for a contactless electric vehicle battery charger*”, IEEE Transactions on Industrial Electronics*, vol. 52 no. 5.

[19] C.B. Toepfer, "Charge! EVs power up for the long haul," *IEEE Spectrum,* Volume 35, Issue 11, Nov. 1998, Page(s): 41-47.

[20] H. Sakamoto, K. Harada, S. Washimiya, K. Takehara, Y. Matsuo and F. Nakao, "Large air-gap coupler for inductive charger [for electric vehicles]," *IEEE Transaction on Magnetics*, Volume 35, Issue 5, Part 2, Sept. 1999, Page(s): 3526–3528.

[21] Singh B, Singh BN, Chandra A, AL-Haddad A, Pandey A and Kothari DP, “A review of three phase improved power quality AC- DC converters*”, IEEE transactions on industrial electronics*, Vol.51, No. 3, pp. 641-659, June 2004.

[22] B. Singh, B. N. Singh, A. Chandra, K. Al-Haddad, A. Pandey and D. P. Kothari, "A review of single-phase improved power quality AC-DC converters", *IEEE Transactions on Industrial Electronics*, vol.50, No.5, pp.962-980, October 2003.

[23] E. H. Ismail Bnd R. W. Erickson, "A New Class of Low Cost Three-phase High Quality Rectifiers with Zero-Voltage Switching," *IEEE Transaction on Power Electronics*, Vol. 12, No. 4, pp.734-742, July 1997.

[24] V. Vlatkovic, D. Borojevic, X. Zhuang, and F. C. Lee, "Analysis and Design of a Zero-Voltage-Switched, Three-Phase PWM Rectifier with Power Factor Correction," *Proceedings of the IEEE Power Electronics Specialists Conference*, 1992 Record, Page(s): 1352-1360.

[25] R. Jayabalan, B. Fahimi, A. Koenig and S. Pekarek, "Applications of Power Electronics-Based Systems in Vehicular Technology: State-of-the-Art and Future Trends," *35th Annual IEEE Power Electronics Specialists Conference*, Aachen, Germany, 2004.

VII. BIOGRAPHIES

Saeid Haghbin was born in Varamin, Iran, in 1977. He received the Master degree in electrical engineering from Sharif University of Technology, Iran, in 2003. During 2003-2007 he was working in the industry in Iran. Afterwards he started the PhD study in 2008 in Chalmers University of Technology, Sweden. His main research interests are power electronics and drive systems.

Kashif Khan was born in Layyah in Pakistan, on March 23, 1983. He graduated form the Univeristy of Engineering and Technology Lahore, Pakistan in 2006. He completed his M.Sc degree from Chalmers University of Technology, Göteborg, Sweden in 2008. He is currently working as a PhD student at the Laboratory of Electrical Machines and Power Electronics, Royal Institute of Technology, Stockholm, Sweden. His research interest includes design and modeling of electrical machines.

Sonja Tidblad Lundmark was born in Gävle, Sweden, in 1966. She received the MSc (Eng) and Ph.D degrees from Chalmers University of Technology, Göteborg, Sweden, in 1992 and 2005, respectively. Since July 2008 she is an Assistant Professor at the Division of Electric Power Engineering at Chalmers University of Technology. Her research interests are in the areas of electrical machines and drives and numerical analysis of electromagnetic fields.

Mats Alaküla was born in 1961 in Sweden. He graduated in Electrical Engineering in 1986 from Chalmers University of Technology in Gothemburg (Sweden). He got his Licenciate degree in 1989 from Chalmers University of Technology and his PhD degree in 1993 from Lund University. Since 1994 he is appointed as full professor in Industrial Electrical Engineering at the Faculty of Engineering of Lund University.
He is the coordinator for the Electrical Machines and Drives area in the Swedish Hybrid Vehicles Center. At present time he combines his academic duties with a position as Senior Specialist in Hybrid Technology at Volvo Powertrain.

Ola Carlson was born in Onsala, Sweden 1955. He received the M.Sc. and Ph.D. degree in Electrical Engineering from Chalmers University of Technology, Gothenburg, Sweden in 1980 and 1988, respectively.
He is currently an Associate Professor at the Department of Energy and Environment at Chalmers University of Technology. He has three years of industry experience in the areas of variable-speed systems for wind turbines. His major interests are electrical systems for renewable energy systems, especial wind. Hybrid electric vehicles are also an interest.

Mats Leksell received his M.Sc. degree in electrical engineering in 1983 and his Tekn. Lic. in 1993, both from Royal Institute of Technology, Sweden. Currently, he holds the position as a researcher at the Laboratory of Electrical Machines and Power Electronics and his main research interests is sustainable energy solutions.

Oskar Wallmark received his M.Sc. degree in in engineering physics in 2001 and his Ph.D. in electric power engineering in 2006, both from Chalmers University of Technology, Göteborg, Sweden. Currently, he holds the position as a Researcher at the Laboratory of Electrical Machines and Power Electronics, Royal Institute of Technology, Stockholm, Sweden. His main research interests include control and analysis of permanent-magnet synchronous machines with particular focus on automotive applications.