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Control of Wireless Power Transfer System for Dynamic Charging of Electric Vehicle

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ABSTRACT- In order to limit the production of pollutant gases, the transportation sector, both public and private, has turned its attention to Electric Vehicles (EVs). The most important barrier to commercializing and spreading EVs are the issues regarding the battery. The batteries are heavy, bulky, expensive, and have a limited lifetime. Furthermore, frequent charging and limited operating range due to the low energy density are other obstacles to developing EVs worldwide. Dynamic Wireless Power Transfer (WPT) is a possible solution in order to solve the problems related to the battery. In this solution, the battery of the EV can be charged when the vehicle is in motion. In this kind of charging system, the transmitter coils are embedded into the ground and the receiver coil is installed underneath the vehicle. Through a sufficient charging infrastructure large enough to charge the electric vehicle during driving, the size of the battery onboard can be reduced and the driving range of the EV can be extended. EV and without any establishment of the communication between vehicle and ground, even in the case of lateral misalignment or variations of the air-gap. Subsequently, the complete simulation of the system in static and dynamic charging conditions is performed and the operation in different charging conditions such a variation of the operating frequency, power demand, lateral misalignment, vehicle speed, and air-gap, is studied. The procedure for the construction of the charging lane with the development of the coils, the embedding procedure and implementation of the power electronic converter is presented.

KEYWORDS- Electric vehicles, power system, battery power, Dynamic Wireless Power Transfer.

I. INTRODUCTION

Due to several issues such as environmental effects, global warming, oil resources limitations, and energy security, the attentions to the investment, production, and usage of renewable energy and other energy sources as a replacement to the currently used fossil energies are increasing. One of the main consumers of oil and petroleum is the transportation sector. With high energy density and ease of use, petroleum is a suitable source of energy. Furthermore, due to the increase in the vehicle production rate worldwide, the fuel consumption is dramatically increasing. In order to limit and reduce the production of greenhouse gases, the attentions of the transportation sector in public and private parts to the electric vehicle (EV) are developing around the world. With the use of electric-powered transportation systems, it is possible to decrease the consumption of fossil fuels. Electric vehicles have many advantages over fuel-powered vehicles. They consume electricity which can be generated from different sources such as renewable resources. Furthermore, during the movement, CO2 and other gases emissions of EV are zero which can significantly help the reduction of air pollution in urban areas. In private EVs, vehicles are plugged into the grid and the battery is charged using electricity. Furthermore, by managing the charging process, the charging of EV could be done during the low demand periods such as at night when the stress on the grid is less and the grid has enough capacity for the EV charging. Different chargers have been proposed for the charging of the EVs at different power levels. According to the power level, the chargers are classified into three levels including level 1, level 2 and level 3 [1]. As shown in Table 1.1, the level 1 charger is a slow charger that is suitable for the charging of the electric vehicle at home during the night. This charger is compatible with the home electrical plug. The level 2 charger is a semi-fast charger which is considered as the main method for both private and public cars. Nowadays, the most attention is on level 2 chargers which can provide sufficient power and can be realized in most locations. Usually, level 1 and level 2 chargers are single-phase chargers. The level 3 charger is a high power fast charger and is used for massive charging of the EVs. Usually, these types of chargers are three phase chargers and the main purpose for implementation of them is for applications in public and commercial sectors. The level 3 chargers are able to charge the EV battery to 80% in only thirty minutes however they are not compatible in all EVs. At present, there is not any standard for level 3 chargers but this kind of chargers are available commercially. The electric vehicles such as Mitsubishi I and Nissan LEAF can be charged with level 3 charger [2].

Table 1: EV charger type classifications

Charger type	Supply voltage	Phase	Type of use	Energy supply interface	Power level	Charging time
Level 1	120 V	1 phase	Charging at home or office	Conventional outlet	1.4-1.9 kW	17 Hours
Level 2	240 V	1 or 3 phase	Charging at private or public outlets	Dedicated chargers	3.1-19.2 kW	8 Hours
Level 3	300-600 V	3 phase	Charging at station	Dedicated chargers	50-240 kW	30 minutes

II. PROPOSED SYSTEM

A 100-m charging system for dynamic charging of the electric vehicle has been implemented. The rating power of the charging system is 20 kW at the nominal air-gap of 25 cm. The system is necessary to charge the EV during the movement with the maximum lateral misalignment of 20 cm. The segmented topology with 50 transmitter coils has been chosen. All transmitter coils have been embedded into the ground and covered with cement. Each coil has been connected to one high-frequency converter. Each high frequency converter was connected to a 650 V DC bus and supplies the related coil with the current at the frequency of 85 kHz. The output power of the receiver has to charge the vehicle battery which its voltage varies between 250-400 V. The basic models of a WPT system is described. Due to the low coupling coefficient between the transmitter and receiver coils in wireless charging systems, the leakage inductance is high which limits the power transmission. In order to increase the power transmission capability and efficiency, some resonant capacitors are added to the transmitter and receiver side of the system. Various compensation topologies are discussed and their merits and weak points are investigated. Among all of these topologies, series-series topology is chosen due to the simple structure and good performance in dynamic conditions. The important equations of the WPT system with this capacitor topology are presented. The effect of the air-gap and lateral misalignment on the coupling coefficient of the coils is simulated. The rest of this chapter is dedicated to the control of the WPT system. Several control techniques are studied in this chapter. Then, two novel control strategies for the regulation of the output power at the presence of the mutual inductance variations are proposed. In these control strategies, the transmitter converter operates at a definite power level and the receiver can regulate the output power from zero power to the peak power according to the demand using a DC-DC converter or an active rectifier and without communicating with the transmitter converter. The results are composed of various tests such as power demand control, operation of the control system with the variation of the air-gap, operation of the control with the presence of the lateral misalignment and the identification procedure.

A. WPT for EV Charging

For the EV application, wireless chargers can be classified into three main categories according to the EV operation, namely static wireless power transfer, dynamic wireless power transfer and quasi dynamic wireless power transfer . In static charging of the EV, when the EV is parked right over the charging pad at the garage or parking, the battery charges. The second type of wireless charging system is dynamic WPT charging. In this charging system, the EV charges during the movement resulting in the increase of the driving range of the EV. Quasi dynamic WPT is another type of WPT charging system which its operating principle is between static and dynamic charging solution. The EV moves and then stops at certain places that are equipped with wireless chargers. The battery of the EV charges when the vehicle is completely stopped over the charging pads. Quasi dynamic WPT system is suitable for public transportation vehicles especially EV buses.

1) Static Charging

Static wireless power transfer provides a safe environment for the consumer and reduces the driver involvement in the charging process as it is not necessary for the consumer to plug in the charger to the vehicle. This would solve safety-related issues for instance hazards and electric shock. The power circuit of a WPT charging system is presented in Fig 1. The charging structure is composed of two parts including ground facility and onboard part. The ground facility is composed of the transmitter converter, transmitter coil, and the compensation network. The onboard part is composed of the receiver coil, compensation network, rectifier, DC DC converter, and the battery. Normally, the transmitter coil is installed under the ground and the receiver coil is mounted underneath the EVs. By energizing the transmitter coil with the transmitter converter, the energy is sent to the receiver coil. The received energy is converted to DC using a rectifier and then is transferred to the battery. Furthermore, in order to control the amount of the power received by the battery and manage the battery charging process, the DC-DC converter is employed before the battery. Moreover, with a communication line, the status of the battery could be transferred to the ground converter.

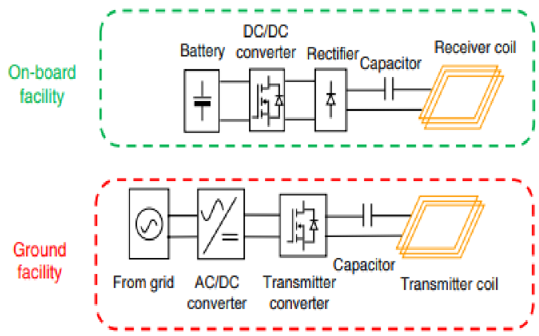

Figure 1: Basic configuration of a wireless charging system

2) Dynamic Charging

The most important barrier in commercializing and wide spreading electric vehicle is the issues regarding to the battery. The batteries are heavy, costly, bulky and with a limited lifetime. The size of the battery is very big and it takes up most space of the EV. Furthermore, the frequent charging and limited operating range due to the low energy density are other barriers in developing EVs world widely. The charging time of EV is generally high. The fast chargers available in the market are able to charge the battery in around 30 minutes which is still more than the fueling time in a conventional vehicle. Generally, the batteries are made of lithium. Due to the material and technology used in the construction of the battery, they are very expensive and account for more than one-third of the electric vehicle price. Considering the electrification of the buses, it requires too many battery packs resulting in the increase in the cost, size and charging time. The problem associated with static WPT is that EV can be charged only when it is parked at home or garage. This kind of charging method cannot solve the battery problems such as limited range and big volume. Dynamic WPT could be a solution in order to solve the problems related to the vehicle energy storage system. In this solution, the battery of the EV can be charged when the vehicle is in motion. Thus, the size of the battery onboard can be reduced and the driving range of the EV can be extended. The structure of the dynamic WPT system is similar to the static WPT. The transmitter coils are embedded into the ground and the receiver coil is installed underneath the vehicle. The difference of dynamic WPT with the static counterpart is that in the dynamic charging system, the number of the transmitter coils embedded into the roadbed is increased. Thus, when the EV passes over the transmitter coils, frequent charging of the EV during the movement can be possible. According to the dynamic WPT topologies presented in the literature, two main dynamic charging solutions namely long track topology and segmented track topology exist. In long track topology or long track coupler, the size of the transmitter coil is much longer in comparison to the receiver coil. The basic diagram of dynamic WPT with long track topology is illustrated in Fig. 1.2.The main advantage of this topology is that the coupling coefficient is constant along the track and it is not dependent on the position of the vehicle. For the energizing the whole track, only one H-bridge converter is necessary which makes the control much easier. In spite of these interesting merits, there are several drawbacks to long track topology. The size of the transmitter coil is much longer and because of that, the coupling coefficient between the transmitter and receiver coil is very low. Low coupling coefficient results in having high stray magnetic field and low power transfer efficiency.

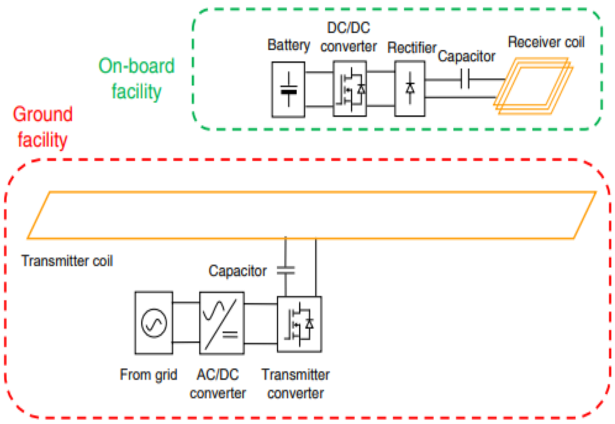

Figure 2: Diagram of dynamic WPT with long track topology

III. CONCLUSIONS

The application of WPT for charging an EV during movement is a feasible solution for solving the limited driving range of EVs. Starting two decades ago, many wireless charging solutions have been presented in the literature, and some of them have been developed practically for various transportation applications. However, there are still several critical issues, especially regarding the control of the charging process during the movement of the vehicle. This research goal was the construction and testing of a 100-m dynamic wireless charging prototype with a rating power of 20kW at a nominal air gap of 25cm as well as an operating frequency of 85 kHz. This proposed system provides solutions to the power control strategies limitations which have not been addressed before.

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