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An Introduction to Modern Electrical Power Supplies in order to develop Renewable Energy Resources

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Abstract— **Combination of Electro-mobility and renewable energies will make an important contribution to comply climate protection aims. One important aspect of developing Electrical Vehicles (EVs) is their technologies for charging. Contactless Power Supply (CPS) is the new generation of charging in EVs. In this paper, an introduction to "the Contactless Power Supply (CPS)" is presented as an important technology in development of Renewable Energy Resources (RESs). Some research works are investigated focusing on their proposed control algorithms. Such algorithms should be developed to control the amplitude of the primary current and the phase angle between primary side voltage and current to transmit energy with an acceptable efficiency. A minimum level of the losses is an essential requirement for battery charging for EVs. Thus, technical approaches are required to satisfy the mentioned criteria. In this research, possible solutions are investigated in order to optimize inductive battery charging in electrical vehicles. Proposed simulations for future works could be based on MATLAB and Ansys-Maxwell in order to analyze CPS operation and also to check the results before laboratory experiments.**

Keywords- Zoning algorithm, Contactless Power Supplies, renewable energy sources, harmonics.

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1. Introduction

Some environmental challenges like increasing air pollution, ozone damage, acid rain and global warming has been raised because of the combustion of fossil fuels. On the other hand, the world energy consumption due to the transport sector is expected to show dramatic growth of around 44% from 2008 to 2035 [1]. One of eco-friendly solutions is the development of Electric vehicles (EVs) with reduced air pollution, lower greenhouse emissions and, lower fuel usage. One important aspect of EVs development is analyzing and optimal designing of battery chargers [2-10]. This research will focus on DC-DC converters with the emphasis on harmonic depression of output waveform in Contactless Power Supplies (CPS). As mentioned in [11], *Elektromobilität* or *Electromobility* is another step by the German Federal Government in its strategy of lessening dependence on oil. Fig. 1 shows the typical structure of an Electric Car. Fuel Strategy and High-Tech Strategy (HTS) of the Federal Government confirm the importance of Electromobility. On the other hand, combination of Electromobility and renewable energies will make an important contribution to comply government climate protection aims as already set out in the Integrated Energy and Climate Programme (IECP). It can also help pave the way towards a new culture of mobility and modern urban and regional development planning [11]. Another essential goal of the federal government and German industry is *"establishing Germany as a lead market and lead provider in Electromobility"* [12]. The individual communities will address the following themes: Drive technology, Battery Technology, charging infrastructure and network integration, Standardization and certification, Materials and Recycling, Youth and qualification framework [13]. Storage mechanism is the main restriction in this field of research because electricity is a kind of energy which has been encountered many storage limitations. Therefore, complicated equipment will be required to save electricity and consequently, constructing of such storing system is not commercial and in high powers is not possible. As an alternative, contactless electrical energy transmission from a main power supply to a consumer has been playing a main role to use electrical energy in a widespread range of applications in order to reduce the need for fossil fuel in industrial products. Because of new flexible aspects of this technology, there is a widespread application of such systems.

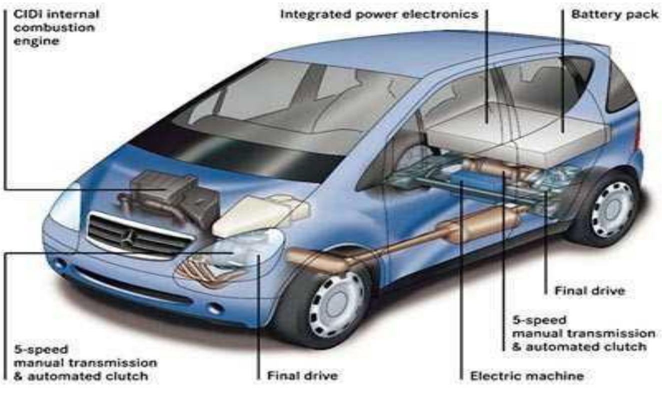

Fig. 1 The typical structure of an Electric Car

This new approach eliminates connectors, wires, cables, and slip rings to produce new flexibilities to supply mobile appliances with electrical energy and consequently, increases reliability and compatibility of systems such as conveyors, marine, medical, hybrid automobiles, public transfer applications like bus and train and, other applications where electrical contact might be hazardous, very problematic or, impossible. Electromagnetic waves including light, sound as well as electromagnetic field can be used in Contactless Transmission technology. Figure 2 depicts the application categories of Contactless Power Supply (CPS) systems. Capacitive or inductive coupling of the power supply with high frequency converters usually is the main part of a Contactless Power Supply system. Inductive Transmission make it possible to transmit power in a wide range of mW up to hundred kW and the Capacitive Transmission is appropriate for low power range such as power supplies for sensors [14]. Inductive Power Transmission approach has been extended to supply movable loads without direct electrical contacts like materials handling systems [15], contactless battery chargers, and power supplies to electric vehicles [16].

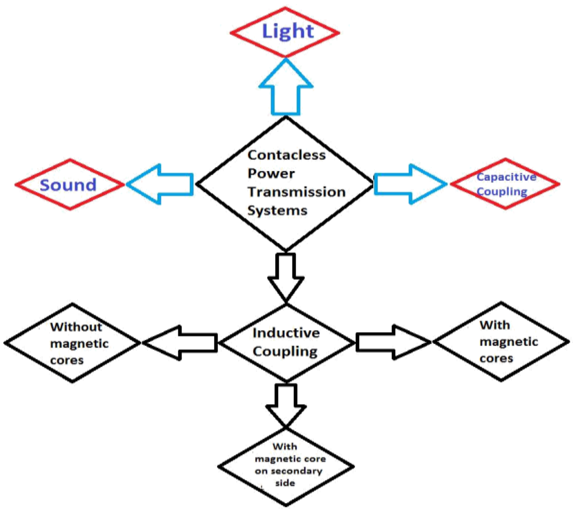

Fig. 2 Application categories of Contactless Power Supply (CPS) system

It should be mentioned that some researchers use term “wireless” [16-24] and others use “contactless” power supply; no commonly accepted nomenclature exists in Contactless Power Transmission research works. In most cases, the term “wireless” Power Transmission is used for systems where power transferred on a distance of at least several meters long, such as wireless-sensor or cellular phone applications [21]. In this paper, inductive coupled Contactless Power Supplies (CPS) will be investigated. Because of many specifications used in characteristics of a CPS system, it has to be modeled, analyzed and designed for every individual situation and there is no unique global methodology. This research will concentrate on the investigation of inductive power transmission system with a transformer which is used for battery charging applications in electrical vehicles. The primary winding of the transformer will be the energy transmitter and fixed while the secondary winding will be the energy receiver and placed on the movable device and an air gap will isolate two coils from each other's.

Smart grid technologies may be a solution to manage the Electrical Vehicles charging problem and to improve grid quality and energy storage aspects which is currently under study. Smart Grid is a gradual development process accompanied with the technology innovation, demands of energy saving and management's needs. In comparison with traditional grid, Smart Grid includes integrated communication systems, advanced sensing, metering, measurement infrastructure, complete decision support and human interfaces. There are many papers that present some solutions for designing of inductive power transmission systems [25-30], but in reality, there is no commonly used design and control solution. Essential requirement for battery charging for electric vehicles is the minimum level of the losses. The aim is "*the realization of an efficient contactless inductive power transfer to charge the battery in electric vehicles*" (Fig. 3). Thus, this criterion requires a technical approach which is based on low potential losses. In pursuing this research, for future works, possible solutions will be investigated in order to suppress harmonics of output waveform in CPS which consequently lead to optimize inductive battery charging in electrical vehicles.

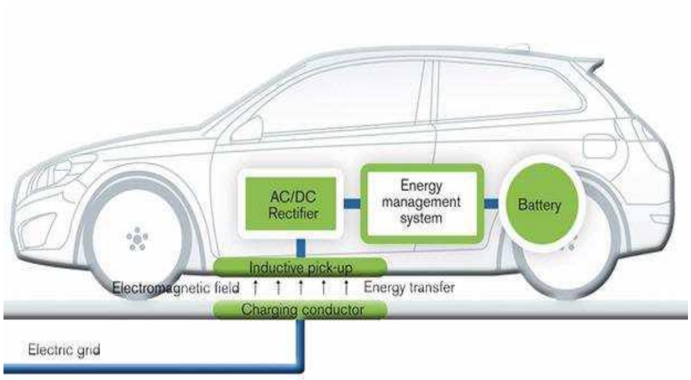

Fig. 3 Contactless Power Transmission to charge battery [22]

Simulations with MATLAB and Ansys-Maxwell will be performed to analyze CPS operation and check the results before Laboratory work. Analytical and simulation based approach and experimental verification can be extended on the laboratory Contactless system. This CPS prototype will cover following subjects:

- Control algorithm for primary current and the phase angle,
- Increasing total efficiency with optimization of all system components,
- Reliable and fast operation with high switching frequency to optimize system operation,
- Flexible to parameter changes of the main circuit.

2. Review of Principles

Four famous basic topologies such as Series-Series, Series-Parallel, Parallel-Parallel, and Parallel-Series compensation will be discussed. Four types should be modeled using a mutual inductance coupling model and will be analyzed for sinusoidal steady state to select the most appropriate model for the every individual prototype. The induced and reflected voltages in the model usually are specified in terms of the mutual inductance, the operational frequency, and the primary and secondary currents [32]. Four types of transformers are well known in inductive transmission. They can be classified in sliding transformers or pick-up, cascaded transformers, multiple secondary winding, and multiple primary winding.

For galvanic isolation of source and load in conventional transformers, usually a magnetic core is applied to produce a high magnetic coupling coefficient between primary and secondary windings. The main inductance in inductive coupled Contactless Power Transmission is very small in comparison with conventional transformers whereas leakage inductances are large. Thus, this high magnetization current can lead to high conduction losses and, large leakage inductances increase winding losses. Electro Magnetic Compatibility (EMC) is another problem for transformers with a relatively large gap. These mentioned disadvantages of the transformers should be minimized to optimize system operation. Soft switching techniques have been proposed for this aim. Stressful conditions occurs with application of hard switching power electronic devices because power switches usually switch the load current under the hard switching conditions within the turn-on and turn-off times. In all of soft switching techniques, the stored energy in the transformer is utilized (Fig. 4) [33]. Soft-switching techniques have been known as an effective solution to suppress EMI and have been applied to DC-DC, AC-DC and DC-AC converters. Various soft-switching techniques of DC/DC converters have been developed to satisfy the requirements for reduction weight, size and volume in comparison with low frequency transformer systems. Moreover, transformers by applying of such a critical system present much more flexibility to be applied in electric vehicles battery chargers, robotics applications [34], aerospace, biomedical applications and etc. In this research, resonant soft switching technique is considered. Hence, one section will investigate Resonant Conversion Technique. The concept of Resonant Conversion Technique is to use resonant tanks in the converters to produce oscillatory voltage and/or current waveforms so that zero voltage switching (ZVS) or zero current switching (ZCS) conditions can be created for the power switches. Reduction of switching loss is the main advantage of this technique and with the continual improvement of power switches, hundreds kHz of the switching frequency for the resonant converters is available. As a result, more power density of the converters can be transferred using smaller magnetic sizes. In spite of the development of various topologies for resonant converters, most of them suffer several problems. One challenge is that many resonant converters need frequency modulation (FM) for output regulation. Consequently, because of variable switching frequency operation, filter design and control is complicated. Also, resonant converters have higher peak values than conventional PWM converters, so there is higher conduction losses and higher V and I ratings requirements for the power devices.

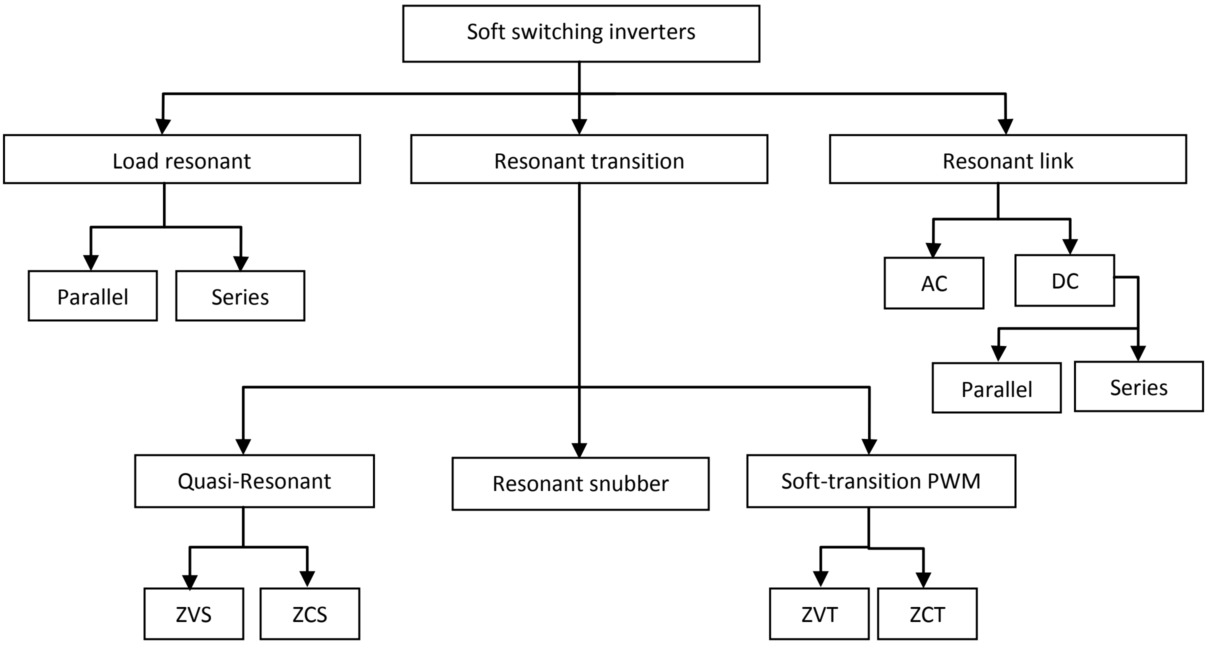

Fig. 4 Classification of soft-switching inverters [33]

Further progress in converter technology combines the advantages of conventional PWM converters and resonant converters to create new generations of soft-switched converters. These new soft-switched converters utilize the resonance in a controlled manner and their switching waveforms are similar to those of conventional PWM converters except that the rising and falling edges of the waveforms are 'smoothed' with no transient spikes. Resonance occurs just before and during the turn-on and turn-off processes so as to create ZVS and ZCS conditions. Moreover, they operate same as conventional PWM converters and with simple modifications; many customized control integrated control (IC) circuits designed for conventional converters can be employed for soft-switched converters. As a result of reduction in stress and switching losses, soft-switched converters can operate at very high frequencies in a range of 500 kHz to a few MHz. Famous switching technologies are Zero Voltage Switching (ZVS), Zero Current Switching (ZCS), Comparisons between ZCS and ZVS, quasi-resonant, ZCS-QRC, ZVS-QRC, and etc. Because of negative effects of Electro Magnetic Interference or EMI on control systems, EMI considerations have been a challenging subject in the Power Electronics research works. Hence, proposed approaches should consider this effect on Inductive Power Supplies.

3. Grid and Interface Aspects

Some requirements of necessary infrastructures for Electrical vehicles and some Standards, Laws and limitations such as harmonic standards, safety standards and, magnetic field standards should be scrutinized. Electrical Vehicles can cause some challenges for the distribution system and stability of the power system [35, 36]. Many practical questions are raised such as: Will the infrastructure be capable of supporting masses of Electrical Vehicle charging? What are the alternatives to costly upgrades of network assets?

Even without Electrical Vehicles, many countries distribution systems are frequently overloaded (e.g., hot climate areas with increased air conditioned usage) [37]. Adding Electrical Vehicles to this already fragile situation may collapse the grid. Smart grid technologies may be a solution to managing the Electrical Vehicles charging problem which is currently under study [37, 38]. Smart Grid is a gradual development process accompanied with the technology innovation, demands of energy saving and management's needs (Fig. 5). People will have their own understanding for Smart Grid, no matter if they are facility suppliers, IT companies, consulting firms, public power companies or power generation companies. From the earlier smart intelligence metering to electrical intelligence, from transmission and distribution automation to a whole intelligent process, the concept of smart power grid has been enriched substantially. Smart Grid is basically overlaying the physical power system with an information system which links a variety of equipment and assets together with sensors to form a customer service platform. It allows the utility and consumers to constantly monitor and adjust electricity use. [39]

The management of operation will be more intelligent and scientific based on the dynamic analysis of needs both from user-side and demand side which can increase capital investment efficiency due to tighter design limits and optimized use of grid assets. In comparison with traditional grid, Smart Grid includes integrated communication systems, advanced Sensing, metering, measurement infrastructure, complete decision support and human interfaces.

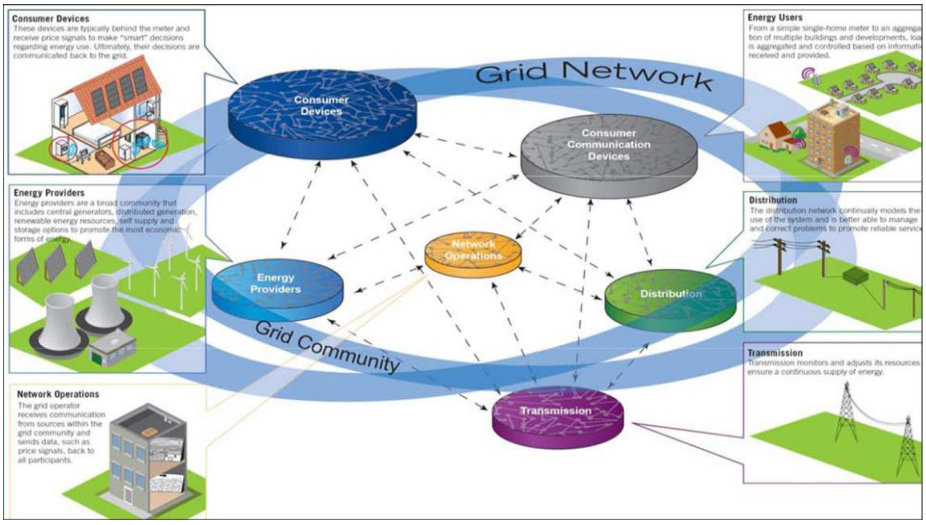

Fig. 5 Smart Grid's Structure [39]

4. Summary

In this paper, an introduction to “the Contactless Power Supply (CPS)” is presented as an important technology in development of Renewable Energy Resources (RESs). Some research works are investigated focusing on their proposed control algorithms. It should be proved that efficiency increases with designing an appropriate control algorithm for amplitude of the primary current and the phase angle between primary side voltage and current. Minimum level of losses is the essential requirement for battery charging for electric vehicles. Thus, this criterion requires a technical approach which is based on low potential losses. The proposed concepts in new research works should minimize the transmission losses for inductive battery charging in electric vehicles. MATLAB and Maxwell software programs can be used to simulate CPS system and get results before Laboratory works. Analytical and simulation based approach and experimental verification should be extended on the laboratory Contactless systems with essential requirements. The prototype should cover control algorithm for primary current and the phase angle, increasing total efficiency and minimizing harmonic components with optimization of all system design, reliable and fast operation with high switching frequency to optimize system operation and, flexible to parameter changes of the main circuit.

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