Asian Journal of Electrical Sciences
ISSN: 2249-6297 (P) Vol.8, No.S1, 2019, pp.25-28
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DOI: https://doi.org/10.51983/ajes-2019.8.S1.2313

Inductive Power Transfer to Charge Electric Bicycles

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(Received 24 February 2019; Revised 17 March 2019; Accepted 30 March 2019; Available online 7 April 2019)

***Abstract* - Inductive power transfer is nothing but wireless power transfer. That is transferring power from transmitter to receiver side without any physical contact. Nowadays this technique has wide applications. Mainly it is used to charge the batteries of the electric vehicles (EV). Due to the increasing pollution rate and scarcity of fuel in future days, the demand for the electric vehicles is increasing. Charging EV's using IPT is simpler and risk free when compared to traditional wired charging systems. Using IPT technique the battery can be charged in constant current (CC) and constant voltage (CV) modes without using any feedback. A switch (consists of 2 AC switches and capacitor) is used to change the mode from CC to CV. The current output from the CC and the voltage output from the CV mode are load independent. This can be obtained by proper selection of inductances and capacitors. Here the feedback control techniques are not required to regulate the output according to charging profile. This IPT technique to charge battery is economical because using a single inverter many batteries can be charged at a time. The possibility of this method of charging is tested with an experimental prototype for efficiency and using MATLAB/SIMULINK software the simulation results are obtained for stability of current and voltage output of CC and CV mode.**

***Keywords:* Electric Vehicles, Inductive Power Transfer, Constant Current (CC) Mode, Constant Voltage (CV) Mode**

I. INTRODUCTION

IPT technology delivers energy to loads from a high-frequency power source through magnetic coupling without any physical contact. Magnetic resonant coupling can deliver power to a load even through a reflecting large air gaps (around a few CM's) [1][5] unlike the conventional WPT technique that delivers power from only under a close proximity (few mm's) because of the scarcity of fossil fuel and the rapid raise in its cost in the present days, market have high demand for the developing electric vehicles and hybrid electric vehicles. EV's can be as large as buses and small as even EB's [12][13]. Thereby it's vital to develop an efficient and convenient way to charge the batteries of these electric vehicles. However, majority of electric vehicles are small charged using traditional plug-in systems which is inconvenient and may impose electric shock hazards in adverse weathers. The design and these plug-in charging systems for EV's are also complex and require large number of components. The IPT systems can offer relief from the above-mentioned problems and saves people from the complex annoying plugging systems. Thus, IPT system for charging will play an important role in people's daily life and has value in market prospect.

This paper demonstrates two different modes that can be employed to charge battery of EV's that is CV mode and CC mode independent on load that can be achieved without feedback control strategies or communication link between transmitter side and receiver side. The two different modes of charging are obtained using T equivalent modes derived from a series-series compensation network (that is LCL circuit for CV mode and CLC circuit for CC mode).

The modes of charging are switched between each other using 2 AC switches and an auxiliary capacitor at the receiver side. Usually, rechargeable Li-ion batteries are the essential power source of EV's. The typical charging profile of battery is shown in Fig. 1. Where the charging process include a CC charging mode and a CV charging mode [14].

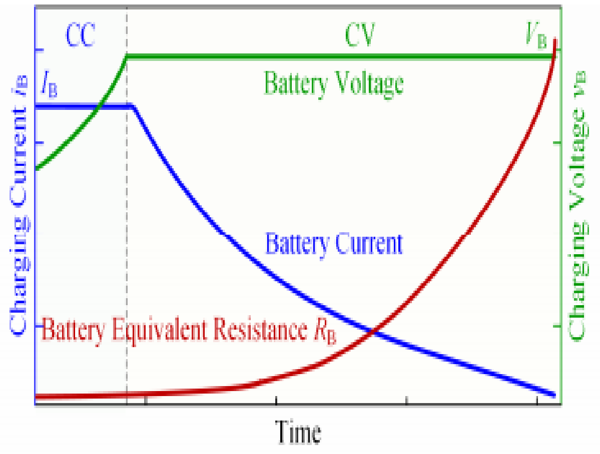

Fig. 1 Typical charging profile of a lithium-ion battery

Here, the battery is first charged in CC mode with a constant output current I_B, called the charge current later the mode is switches to CV where the voltage quickly raises to charge voltage V_B which is constant. In CV mode, the charge current begins to decay exponentially and reaches the end condition of charging, where the charging current is typically set as 1/10th of charge of charge current [15]. The battery load of IPT system of charging a circuit an equivalent variable resistance R_B as shown in Fig. 1 which is given by the rate of charging voltage (V_B) charging current (I_B). This IPT technique is a stationary charging technique where the EV's needs to the parked in the parking lot that can be host and charge reversal EV's at the same time.

One major advantage of this technique is that it can charge several batteries of EV's at the same time using a single inverter and multiple receivers also using any one of the two modes of charging as desired in the same station.

An example of IPT system with systems with a single inverters and multiple receiver of EB's is shown in Fig. 2 [13].

The major drawback in the design of wireless charging system for EV's is that not only the charging mode but also the equivalent battery resistances varies over time from vehicle during the different stages of charging as shown in charging profile.

With this challenge in design it generally requires separate power supply for each EV. This will result in high construction cost and maintenance cost. In order to provide the expected output current or output voltage for different levels of charge of the time variable load, various techniques of IPT system-based control strategies have been proposed.

The main classification based on the above proposed system are

1. DC-DC converter.
2. Phase shift modulator (PSM).
3. Variable frequency control (VFC).

Each of these above control strategies have their own drawbacks. For DC-DC converter technique, an extra DC-to-DC Converter is required along the transmitter side to control either the output current or output voltage as required [16][19].

This results in increased energy losses. Under PSM technique, PSM is to high frequency inverter in order to regulate the output voltage of inverter to satisfy the requirements of battery [20] [22]. In this system it is difficult to achieve ZVS with such wide variation in load with time, especially under light load conditions. Apart from this, a communication link is a must for control purpose.

Using VFC the system can operate with the characteristics of load-independent output current or voltage [23] [24]. However, frequency differentiation phenomenon may occur due to the varying load with time [25] [26], also the inverter cannot achieve (ZPA) [23].

Even under this technique communication link between transmitter and receiver side is necessary. Also, under any of these control strategies they can hardly charge of fault of EV's with a single inverter simultaneously. Besides these complex control techniques can either provide only CV mode for charging and not both simultaneously using a single system.

In addition, a dual topology to obtain CC and CV output by switching between series-series (SS) and series-parallel (SP) compensation is proposed in [29], however the circuit is employed containing a centre-tapped loosely coupled transformer, two capacitor and four switches.

II. METHODOLOGY

This paper provides a valid solution for all the above drawbacks and challenges. Here we clearly discuss the characteristics of T-circuit of SS compensation network with a voltage-source input. This IPT system of charging EV battery using hybrid topology with a single inverter employs a hybrid topology with 2 AC switches and an auxiliary capacitor at the receiver in order to obtain either CC mode or CV mode for charging battery without any reactive-power transfer between the transmitter side and receiver side.

This technique can be used to charge a fleet of EV's simultaneously using a single inverter and charge either by CV mode or CC mode which is load independent.

Use of a single inverter will reduce the construction cost, reduces complexity and the floor space required. This technique does not require any control strategies to obtained load-independent output or does not require any communication line between transmitter and receiver for any control purpose.

The two modes are achieved by turning ON/OFF the AC switches, which can be either two anti-series connected MOSFET's or two anti-parallel connection IGBT's. Also, ZPA can be achieved in both the modes. The applications of this technique are: wireless charging of biomedical implements, low power portable electronic device, under water power supplies, charging of EV's and even train applications [6] [11].

III. PARAMETER ALERTING BASED CC AND CV MODE REALIZATION OF IPT SYSTEM

The method to design the IPT battery charger parameters are given below with the 50% duty cycle from the DC voltage 'E', the inverter can regulate the output voltage V_i of the inverter. The first harmonic component of the output magnitude can be expressed as

$$|V_i| = (2(\sqrt{2})\varepsilon)/\pi$$

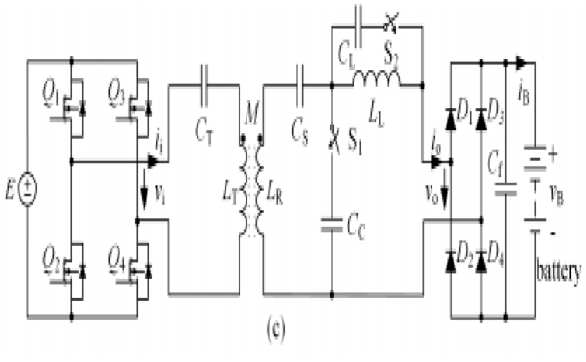

Fig. 2 Circuit diagram of Inductive power transfer to charge a battery using SS-compensation with T-configuration

The current source drives the full bridge diode rectifier at the receiver side and the input voltage is square wave as shown in Fig. 2. The relationship between the DC output voltage V_B and AC input voltages RMS value V_O of rectifier can derived by following equation.

$$V_O = (2\sqrt{2}V_B)/\pi$$

The RMS value of receiver AC current I_O can be given as

$$I_O = (\pi\sqrt{2}I_B)/4 \qquad (1)$$

By substituting we get

$$|h_{VI}| = I_O/V_i = 1/\omega_m = (I_B\pi^2)/8E \qquad (2)$$

By solving above equation, we get the mutual inductance of loosely coupled transformer

$$M = 8E/(\omega I_B\pi^2) \qquad (3)$$

From the output current and input voltage as well as the operating frequency the mutual inductance is determined,

Voltage gain is given by,

$$|G_{VV}| = V_O/V_i = 1/(\omega^2 C_C M) = V_B/E \qquad (4)$$

By substituting equation 3 and 4 we get

$$C_C = (I_B\pi^2)/(8\omega V_B)$$

The value of inductor can be derived as

$$L_L = 1/(\omega^2 C_C) = 8V_B/(\pi^2\omega I_B)$$

The capacitor C_S can be calculated by

$$C_S = C_C/(\omega^2 C_C L_R - 1) = (\pi^2 I_B)/[\omega(\pi^2\omega I_B L_R - 8V_B)]$$

The capacitor C_T is given by

$$C_T = 1/(\omega^2 L_T)$$

The capacitor C_L can be derived as

$$C_L = 1/(L_L\omega^2) - (C_R C_S)/(C_R - C_R) = (\pi^2 I_B)/(4\omega V_B)$$

By taking the specified value of I_B and V_B of the battery,the parameters E, L_T and L_R can be determined accordingly. The L_T and L_R can be chosen to be any value, as they can be compensated by the capacitors.

IV. SIMULATION RESULTS

Fig. 3 shows the voltage and current waveforms of inverter and battery output. X-axis represents the amplitude/magnitude while Y-axis represents the time. Battery output represents both constant voltage output Vb in CV mode (charge voltage) and constant current output i_b (charge current) in CC mode.

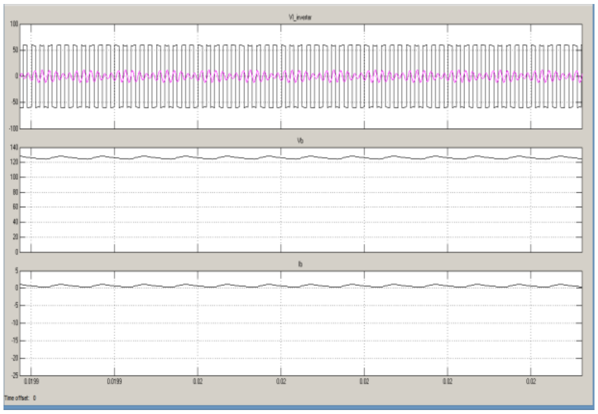

Fig. 3 Waveforms of inverter output (voltage and current) and Battery output (voltage and current)

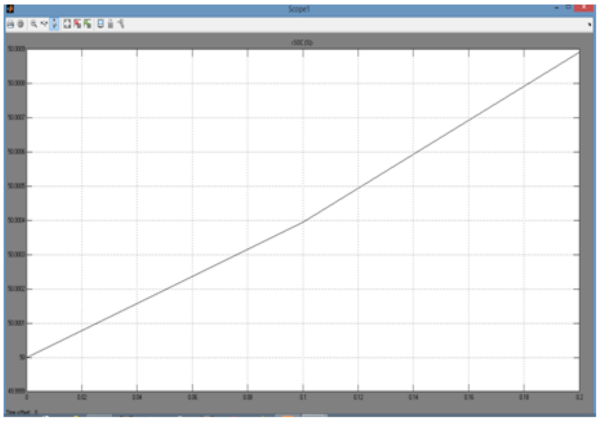

Fig. 4 shows the percentage of battery charge with respect to time

Fig. 4 represents the amount of charge present in the battery with respect to time and also the change of charging mode from CV mode to CC mode at 0.1 sec. It also shows that the battery charges faster with time in CC mode than in CV mode. Also, the amount of ripplees is less in CC mode of charging.

V. CONCLUSION

Study of series-series (SS) compensation circuit of inductive power transfer (IPT) system can be obtained by using T-equivalent model. Employing the hybrid topology with two ACS's switch and additional capacitor at receiver side. By switching of two ACS's for CLC - LCL topology to CLC topology is obtained from the characteristics of CC output and CV output. Both CC and CV modes, the IPT charging can be operated under ZPA method. This method can helps to improve the system efficiency and reduce the magnetic interference. Considering all these performance results proposing a method that adopt only one inverter to change multiple EB's at the same time. It can be a part of to improve the economic efficiency of the whole system and also it will reduce the construction cost and maintenance cost. During low power demand the system efficiency will be 68.19% and during high power demand the system efficiency can stay in a high level upto 92.81%. After considering or proposing all these methods this system has one of the most advantageous solutions to charge multiple EB's using only one inverter at a relative low cost.

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