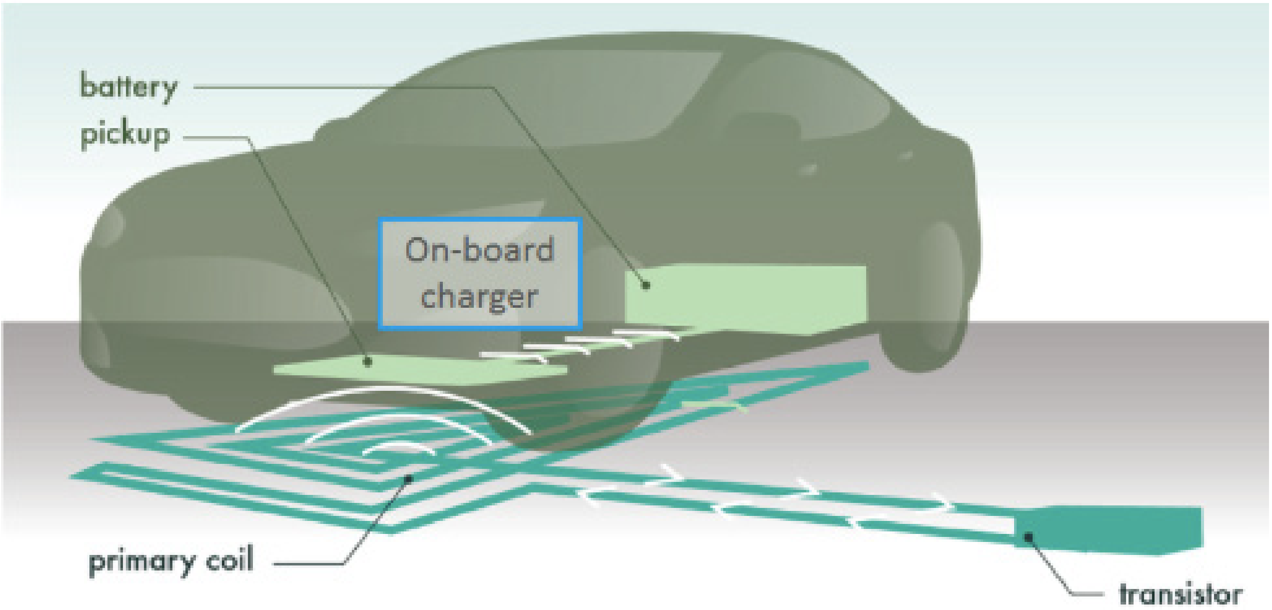
Wireless charging of EVs



An inductively coupled contactless power transfer (IPT) system is capable of efficiently delivering power from a stationary primary source to a movable or stationary secondary source over a relatively large air gap. Although the conductive charger has a lot of advantages such as simplicity and high efficiency, the inductive charger is easy to use and is suitable for all-weather conditions. This is because there is no direct electrical contact between the vehicle and the charger preventing the possibility of a shock or an electrical arc. In case of stationary/static charging, parking lots can be upgraded to charge EVs with the comfort of not plugging in any charging cables. Such systems can be buried or flush-mount, thereby not affecting the façade of a city and being safe from vandalism and unfavourable weather conditions. The main drawbacks of this charger are the high investment cost and the relatively higher losses when compared to conductive charging.

A possible solution for an inductive charger is shown in Figure 1. The principle is based on the magnetic coupling between two windings of a high frequency air core transformer. One of the windings is installed in the charger terminal while the other is embedded in the EV. Firstly, the main AC supply of frequency 50-60Hz is rectified and converted to a high-frequency AC power of <100 kHz within the charger station. This high-frequency AC current is then inductively transmitted to the receiver/secondary coil. Finally, this high frequency induced current in the secondary is converted to DC via a power electronic rectifier, which is suitable for charging the battery pack. Due to large airgaps, the leakage inductance of the air core transformer is comparable to its mutual inductance. This leads to low coupling coefficient (k<0.4) compared to k = 0.95 – 0.99 in conventional iron core transformers. Capacitors are placed in the circuit in either series or parallel configuration to negate the effect of this large leakage inductance. This results in resonant operation and thus leads to high efficiency of power transfer (>85%)

A very important aspect of inductive charging systems is the health risk associated with the exposure of individuals at radiation. The leakage fields that permeate the space around the charge-pad can impact both the health of a living entity in close proximity. It can also result in unwanted heating of foreign objects that are closeby. Different regulating bodies have published standards for limiting exposure - ICNIRP (International Commission on Non-Ionizing Radiation Protection), IEEE etc. There are different Z classes where Z is the air gap (distance) between the primary and secondary coils: Z1 (100-150 mm), Z2 (140-210 mm) and Z3 (170-250mm) and different power classes - 3.7, 7.7, 11, 22 kW as per upcoming standard SAE J2954.

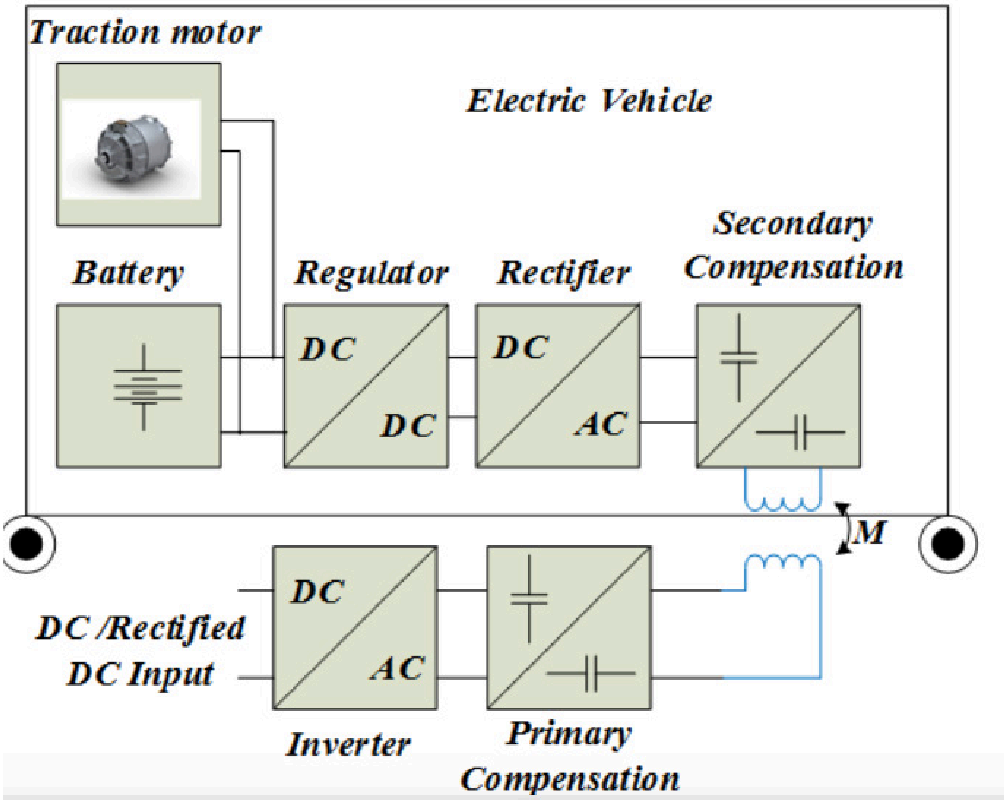


Figure 1: Parts of inductive power transfer system

Various systems have been developed over the last decade aimed for both charging of both personal and public transport vehicles. These prototypes range from 2kW to 200 kW of power delivered at frequencies around 40-100 kHz with overall efficiency from AC mains to DC battery ranging from 80 to 95% . Charging distances are 50mm-400mm for production cars and public transport vehicles. Guiding the magnetic fields in order to reduce the losses is required for these systems to be viable, as they have to be mounted close to the ferrous vehicle body. A third trend is to integrate the different powertrain components and controllers in the vehicle.

Practical examples of stationary inductive charging include bus based wireless electric vehicle charging systems (WEVC). Such systems have helped in reducing the weight of on-board batteries and have improved efficiency. For eg: Conductix-Wamplfler's[1] WEVC in buses at Torino, Geneo and s'Hertogenbosch in the Netherlands. Efficiencies of more than 90% are reported at 60, 120 or 180 kW. WAVE IPT[2], a spin-off from Utah State University is working on 50 kW IPT systems achieving more than 90 % efficiency. They are expecting to install IPT systems with 250 kW charging. OLEV[3], a spin-off from Korean Advanced Institute of Science and Technology (KAIST) developed a third generation of wireless power transfer in with a power transfer efficiency of 83% at a 20-cm air gap.

Companies like Witricity[4], Qualcomm Halo[5], Conductix-Wampfler, Bombardier, Momentum Dynamics, HEVO Power etc. are building market ready charge-pads for electric vehicles charging using IPT systems. Witricity that started out of Massachusetts Institute of Technology, have developed systems that deliver 91 – 93% efficiency at 11 kW power transfer. HaloIPT that started out as a spin-off from the University of Auckland, works extensively in a patented "Double D"magnetic structure for power transfer. Qualcomm acquired Halo in 2011 and they are involved in developing systems from 3.3 kW to 20 kW with > 90% efficiency.

Dynamic charging is the concept of charging the battery of EV or even using it for traction when the vehicle is in motion. This is usually achieved by having sectional IPT systems/ repeated charge-pads on the road. An example of dynamic charging IPT systems on the road was demonstrated at Oak Ridge National Laboratory

(ORNL). Dynamic charging can enhance battery life by charging with small packets of energy while nullifying range anxiety in long trips caused due to limited battery size. For example, for an EV with a battery of 24 kWh, 500 km range can be achieved by IPT system of 25 kW with 40% road coverage[6]. In a related study in California, the combination of dynamic and static charging is shown as cost effective compared to gasoline vehicles fuelled at \$2.50 and \$4 per gallon[7].

Operation principle

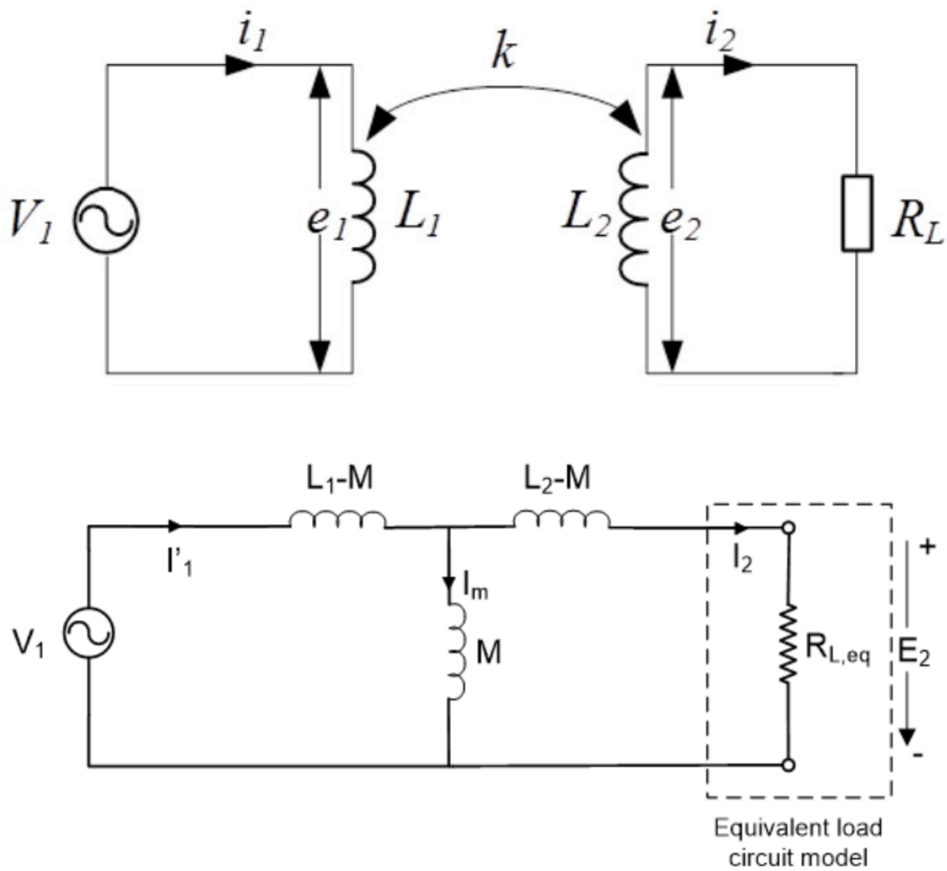


Figure 2: Air coupled inductive power transfer circuit (top) and its equivalent circuit (bottom)

Let us understand the operation principle of an IPT system where coils exchange power over air (air core configuration). The air gap in a IPT transformer configuration is typically large in order of tens of mm. So, they have a large leakage inductance (L_1-M, L_2-M) and low mutual coupling (k) which implies a large magnetizing current.

The Figure 2 shows the circuit representation of a inductive charging air core transformer. L_1 and L_2 represent the self-inductance of primary and secondary winding respectively. M is the mutual inductance between the transformer winding and k is coupling coefficient ($0 \leq k \leq 1$) such that:

$$M = k\sqrt{L_1 L_2}$$

For IPT system with air as a power transfer medium, k is small and so is M. This results in a large leakage inductance which reduces the power transfer efficiency. The leakage inductances L_{L1} and L_{L2} on the primary and secondary side can be described as:

$$L_{L1} = L_1 - M$$
$$L_{L2} = L_2 - M$$

Ideally, one wants a large value of mutual inductance and a low value of leakage inductance. In the case of a ferrite core transformer, the coupling ratio is very high, i.e. k~1 and therefore $M >> L_{L1}$. But in IPT systems, since k is low, this however does not occur. Consequently, a large amount of reactive power is drawn from the source to provide the reactive power of the leakage inductance. Hence, very little power is transmitted to the load resistance R_L if the coupling coefficient is low, say below 0.4.

Compensation

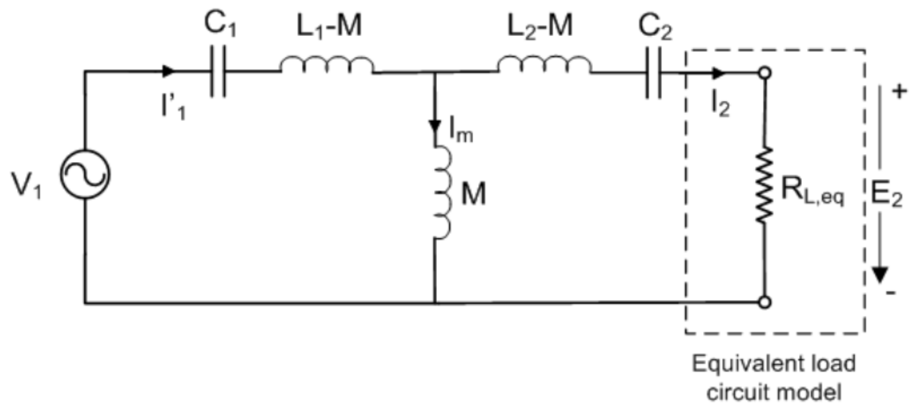


Figure 3: Basic compensated coupled inductor power transfer circuit

For the air coupled inductors, the low coupling (k<<1) and the high leakage inductances prevent the system from delivering power to the load at high efficiency. However, it can be compensated for that. The impedance of an inductor is in the positive j direction while that of an capacitor is in the negative j direction. Compensation capacitors are used in IPT applications to increase the efficiency and the capability of the system they are used in. Capacitive compensation is used in both the primary and secondary windings of the IPT transformer. These capacitors essentially store and supply reactive power to and from the secondary and primary windings, reducing the amount of reactive power drawn from the supply. By connecting two capacitors into the circuit as shown in Figure 3 referred to as series-

series compensation, one can remove the effect of the high leakage inductances if it can be ensured that:

$$\omega = 2\pi f$$

$$\omega^2 = 1/L_1C_1$$

$$\omega^2 = 1/L_2C_2$$

This is in fact creating a resonance between the L-C components on the primary and secondary side. By doing so, the current drawn from the source is purely used to provide the load power and the reactive power needed by the leakage inductances are provided by the compensation capacitors. The capacitive compensation thus helps improve the overall power transfer capability and efficiency of the system even when the coupling coefficient is low.

Concept: Inductive power transfer for EV charging

In this video, you will see why wireless charging of electric vehicles through Inductive power transfer (IPT) is a convenient method of charging for an EV user.

References

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