University of Florida
Non-Contact Energy Delivery for PV System and Wireless Charging Applications

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Description:
Innovative non-contact energy delivery method will be used in photovoltaic energy generation system to accelerate the system deployment. Instead of delivering electric power using cables penetrating through building structures, magnetic field coupling allows power to be transferred wirelessly through building walls and roofs. In the meantime, the DC electric energy from photovoltaic cells is converted to AC energy. This enables the photovoltaic system to be quickly set up or relocated, and the collected solar energy from outdoor system can be conveniently delivered to indoor appliances. Techniques to achieve high efficiency at high power delivery through different building structures will be studied for this plug-and-play architecture.

In addition, the technique and the system can also be used for non-contact charging of electric vehicles. The transmitter/charger can be placed as a mat on garage floor or parking space. The receiver inside vehicle will pick up the energy delivery through magnetic coupling. This eliminates the need of connecting charging wires to vehicles and exposed metal contacts, which is a safer method of charging electric vehicles.

Budget: $ 252,000
Universities: UF

Executive Summary

This project studied an innovative approach to deliver electrical power from outdoor photovoltaic energy source to indoor electrical appliances without using any wire penetrating through building structures. The approach is based on wireless power transfer using near-field magnetic coupling. Operating in lower radio frequency bands of MHz and below, where the wavelength is much longer than the distance of transfer, the energy coupling occurs locally and does not radiate. Therefore it is safe to the environment and the residents. The technique would enable the photovoltaic system to be quickly set up or disassembled for relocation, and the collected solar energy from outdoor system can be conveniently delivered to indoor appliances. The technique can also be used for wireless charging of many portable electronic devices.

During the project, we focused on near-field magnetic coupling and studied different architectures of wireless power transfer. Two prototypes were built to demonstrate wireless power delivery of 38.3 W with 76% efficiency and 114 W with 65% efficiency, respectively, over a distance of one meter. Sensitivity to alignment and coil rotation pitch were also investigated. It was found that the system is not sensitive to alignment and rotation pitch as long as the coupling coils are not completely offset with zero projection overlap and not rotated by more than 45°. While large metal obstacles between coils may cause the efficiency degradation, small metal objects such as nails, wires, and rods have almost no effect on the system performance. The results demonstrated the effectiveness of wireless power system and the applicability of wireless power transfer technique to PV systems and wireless charging of electronic equipment.

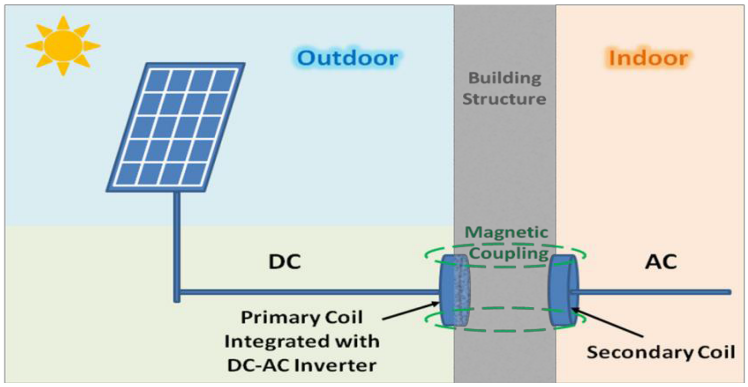

Figure 1: Concept diagram of the noncontact wireless power delivery system

Figure 1 shows the concept diagram of the noncontact wireless power delivery system. Since no wire is need to go through the building structures, the installation cost and time can be reduced. The system can be easily installed and uninstalled if necessary. No wire is exposed, making it suitable for conditions where full insulation is required. This technique has the potential to lower the installation cost and time and promote the use of solar energy.

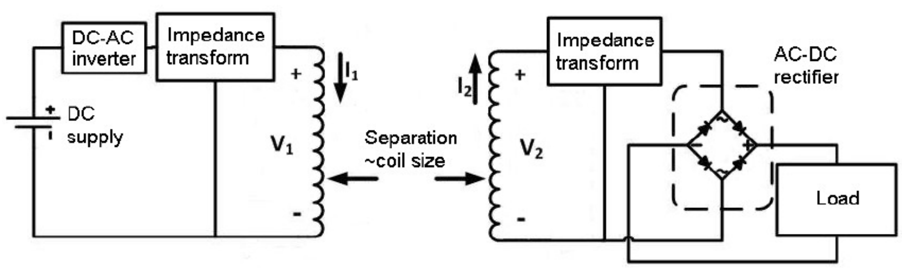

Figure 2: Block diagram of the wireless power transfer system using magnetic coupling.

Figure 2 show the block diagram of the of the wireless power transfer system using magnetic coupling. A DC-AC inverter converts the DC electricity from PV cells. After impedance transformation, the energy is coupled to the receiver through magnetic coupling. After coupling, the AC energy goes through impedance transformation and AC-DC rectifier, and the DC energy is delivered to the load. The wireless energy coupling is accomplished by two coils separated by a distance. Through the study, it was found that the optimum separation distance is about the dimension of the coil. In other words, to achieve a certain coupling distance, the dimension of the coil must be roughly equal to the distance. We have used both square shape and circular shape coils and both achieved good results.

The DC-AC generation requires high efficiency inverter. Both Class-D and Class-E topologies for DC-AC inverter were studied. Class-D topology has been commonly used in power electronics, and has the advantages of less device stress and more robust to impedance variation. Class-E topology, on the other hand, has advantages of higher power delivery and uses only one transistor while Class D needs two transistors. With the same DC supply voltage, Class-E can deliver more AC power than Class-D. However, since Class-E has only one transistor, the voltage stress on transistor is higher in Class-E than in Class-D. Table 1 shows the comparison between these two topologies. It can be seen that to deliver same amount of power, the transistor drain voltage stress in Class-E is 2.112 times than in Class-D. However, for the same DC supply voltage, Class-E can achieve 2.847 times power delivery than Class-D. Initially, Class-E was adopted in our research. It was effective for shorter coupling distance. However, we later found out that the Class-D, especially the full-bridge Class-D, is better for mid-range wireless power system where coupling distance is about the same as the coil dimension. The efficiency remains constant when power level is changed, and is less sensitive to variation in distance when compared to Class-E. The full-bridge Class-D also requires half of the supply voltage of Class-D and is suitable for higher power applications when device breakdown voltage is a limiting factor. Figure 4 shows a picture of the full-bridge Class-D inverter we built.

	Constant variable	**Class E normalized to Class D**
[redacted]		
Drain voltage stress	Power delivery	2.112
[redacted]		
Supply voltage	Power delivery	0.593

Table 1: Comparison between Class-E and Class-D DC-AC inverters

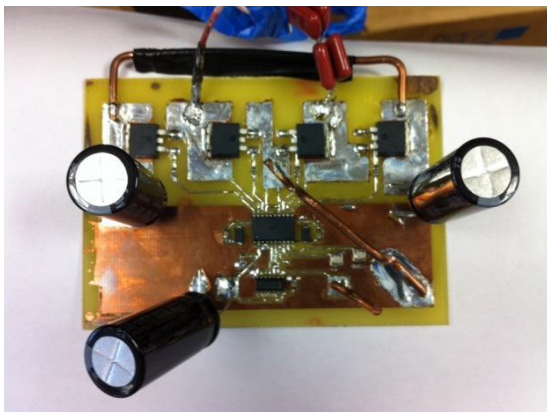

Figure 3: Full-bridge Class-D inverter.

Different impedance transformation circuits were studied. In the end, series LC resonant topology was chosen for its simplicity. In this configuration the system efficiency was derived as:

$$\eta = \frac{\omega^2 M^2 R_L}{(R_2 + R_L)^2 R_1 + (R_2 + R_L)\omega^2 M^2}$$

It can be seen that there are two methods to increase efficiency. First, the mutual inductance should be increased. This was achieved by making the dimension of the coupling coils similar to the distance desired. Second, the efficiency can be increased by reducing the parasitic resistance (R_1 and R_2) of the coils themselves (as well as the series resistance of any other components). To minimize these values, litz wire as well as ¼" copper pipe were used in the construction of the coils.

In our experiment, we built two systems to demonstrate the wireless power transfer. In the first system, two coils made of litz wire on wooden forms are used (Figure 4). Fixed film capacitors are used for series tuning. A full-bridge amplifier using IRF530 MOSFETs and a HIP4081A driver are used to power the system operating at 500 kHz. The maximum power transferred using this system is 38.3 W with 76% efficiency. The transmitted power is limited primarily by the high voltage that develops as a result of the series resonant circuit. The high voltage will cause arcing between turns of the litz wire and breakdown of the capacitor used to tune the circuit. These faults can damage the driving amplifier.

Figure 4: The first wireless power system achieving 38.3 W with 76% efficiency. The coils are made of litz wire: 6 turns, 1 m each side, 1725 strand, 48 AWG.

The second system utilizes ¼” copper pipe (Figure 5) to form two 1-m diameter helical coils. A higher voltage rated capacitor is formed from several film capacitors in parallel with a 10 kV vacuum variable capacitor for fine tuning. Using this system, a maximum power of 114 W was delivered to a 25 Ω load with 65% efficiency at one meter separation. Virtually all of the dissipated power is lost to the resistances of the coils, not in the amplifier, thus the amplifier should be able to supply up to 450 W without further modification, which should allow for received power to approach 300 W.

Figure 5: The second wireless power system achieving 114 W and 65% efficiency. The coils are made of ¼” copper tubing on PVC form: 9 turns, 1 m diameter.

The research results were published in several international refereed journals and conference proceedings and presented in several conferences and invited talks. The results attracted attentions from researchers worldwide. Three companies from Taiwan, Japan, and Korea sent their engineers to University of Florida for collaborative research projects. The collaborative research projects also brought in external funding from these companies. Overall, this project made an impact globally and attracted researchers and engineers to Florida. It also attracted research funding to University of Florida.

This Project is complete. The final report can be found here.