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REALIZATION OF EXTERNAL WIRELESS POWER SUPPLY TO SOLAR POWER SATELLITE USING INDUCTIVE COUPLING

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ABSTRACT

Solar Power Satellite offers a complete displacement of fossil fuel, nuclear and biological sources of energy. It is the only energy technology that is clean, renewable, constant and capable of providing power to virtually any location on Earth. This paper provides an analysis of wireless power transfer for Solar Power Satellite with an assessment of its practical applicability in terms of power range and efficiency. There are four types of solar power satellites are accessed, one is primary and others are secondary. The secondary satellites are placed in axis of triangle and primary satellite is placed at center of triangle for maximum power transfer .This assessment is obtained through the design and construction of a resonant inductive wireless powering system(in secondary satellites) suited to supply a main satellite transceiver(i.e. primary) for power range from 480-1920 watts with efficiency 75-90%. In this paper the formula for calculating the mutual inductance between circular coils with lateral and angular misalignment by using the approach of F. W. Grover is presented. This system is evaluated and designed by using MATLAB coding. Some major advantages of this working system includes increased power range with one solar power satellite, high directivity, high efficiency, concentration of power in single point and less losses. Once the working of this particular system would be implemented with better efficiency then, this would find its applications in power supply of various types of field like farm-house, small industry, power supply of maritime places & self generated power source upto 1.92 KW.

Keywords: Introduction; Need; Proposed System & Block Diagram; Grover's Formulas and Result

I. INTRODUCTION

One of the major issues of present day power system is the loss of electrical power due to resistance in the wire during transmission and distribution of electrical energy. The resistance of the wire may cause a loss of 26%-30% of the total generated energy. This loss decreases the efficiency of power transmission. Again, recent climate change due to "Green-house Effect" from burning fossil fuels has gain brought alter-native energy sources to public attention. Therefore, the time has come to move our attention to Solar Power Satellite (SPS).

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SPS is a concept to collect solar power in space and then transport it to the surface by microwave beam, where it is converted into electrical power for terrestrial use as shown in Fig. 1. In SPS huge solar panels are fitted in the large satellite which collects the entire solar energy present in orbit and beams it down to Earth. In space, the collection of Sun's energy is unaffected by the day/night cycle, weather, seasonal changes and the filtering effect of Earth's atmospheric gases. A major interest in SPS stems from the fact that solar collection panels can consistently be exposed to a high amount of solar radiation. Today, when the solar cell industry has matured, robotic assembly has revolutionized, space shuttle has proven the technology for reusable space transportation, and SPS can no longer be an idea but a reality [3] [13] [14] [15].

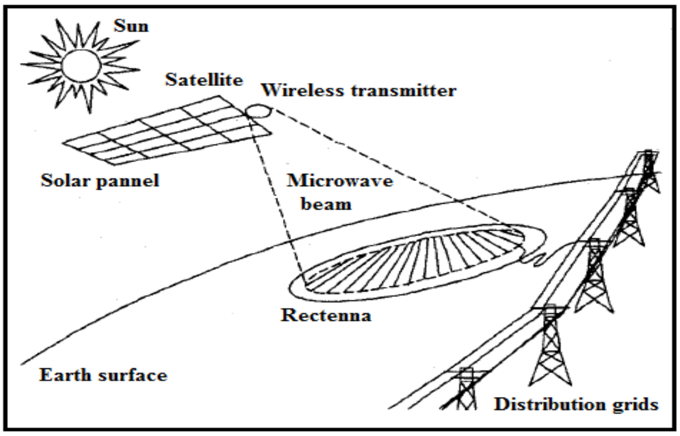

Fig. 1 Components of Solar Power Satellites & Basic Conversion Process

II. NEED

From the discussion provided by [2] [3] [4] [11], there are following main problems related to SPS (WPT) which requires research and development. This paper would provide solution and work related to following problems:

- Realization of internal supplying power to satellite moving on its orbit can lead to increase in weight & cost.
- The development of bus equipment in each satellite mission causes the accelerated obstruction of the utilization of satellites because it has disadvantages like an increase of design period and cost.
- SPS provides a limited power on the rectenna (Earth surface) according to number of solar panels, if number of panel is increased power also increased but it makes the satellite system complex and heavy.
- If we consider different satellites for different power level, it requires more different rectenna space and spots on earth for each satellite which makes the SPS concept complex and maintenance will be difficult.

III. PROPOSED FOUR SPS SYSTEM

For design of proposed four SPS systems following assumption and specifications are made:

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TABLE I Specification and Assumption for Design

S.No.	Assumption and Specifications of different Parameters	Values
1.	Resonant frequency Fr	200 KHz).
2.	Radius of transmitting coil	0.5 meters
3.	Radius of receiving coil	1 meters
4.	The relative permeability for medium for Ni-fe-Al-Cr	140000
5.	Power of each solar cell	1 Watt
6.	The efficiency of the converter and rectifier	90%
7.	Air gap distance	2 metres
8.	Angular misalignment	60^0
9.	Power range	0-1.9 KWatts
10.	Transformer turns ratio	1
11.	Input & output voltage range	220-230 V
12.	Maximum load	Resistive Type

The designed four SPS system is shown in figure 2.

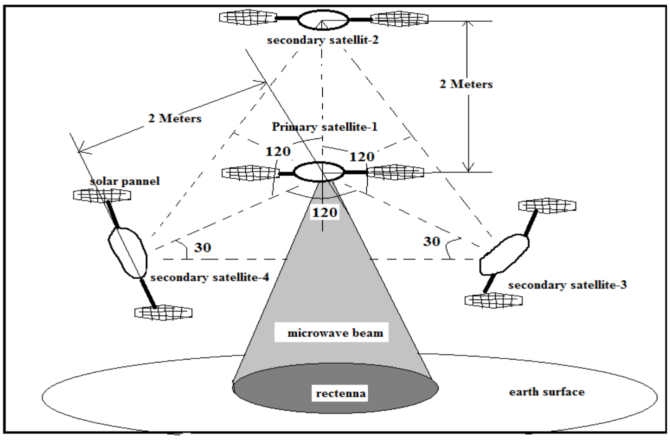

Fig. 2 Proposed SPS system

IV. SYSTEM BLOCK DIAGRAM

The diagram in Fig. 3 serves to clarify the distinction between the WPT systems two main functional parts, namely the Power train and the Control loop. Throughout the development phase, the control loop has been replaced by manual tuning of the operating frequency based on power readings from millimeters and an electronic DC load. As such, a greater part of the development effort has gone in to analysis and design of the Power train, which in the context of maximizing efficiency is by far the most critical component.

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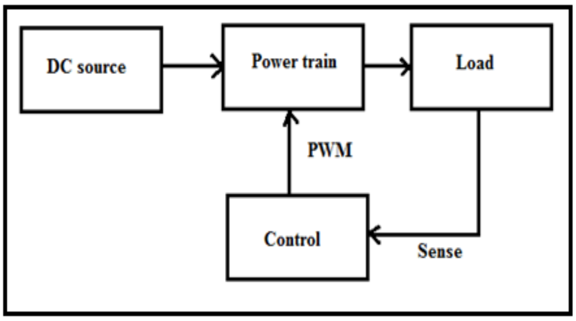

Fig. 3 System Block diagram

The "Power Train" block constitutes the magnetic link from source to load, while the "Control Loop" senses the supply and load scenario and adjusts the operating frequency accordingly. The diagram in Fig. 4 depicts the functional blocks of the power train which on the transmitting side consists of an inverter, matching capacitors and the transmitter coil. The secondary side similarly consists of a receiver coil and matching capacitors, along with rectification/smoothing and a DC-DC converter for output voltage regulation. These are the essential parts of the Power Train which shall in the following be described by each of its functional blocks.

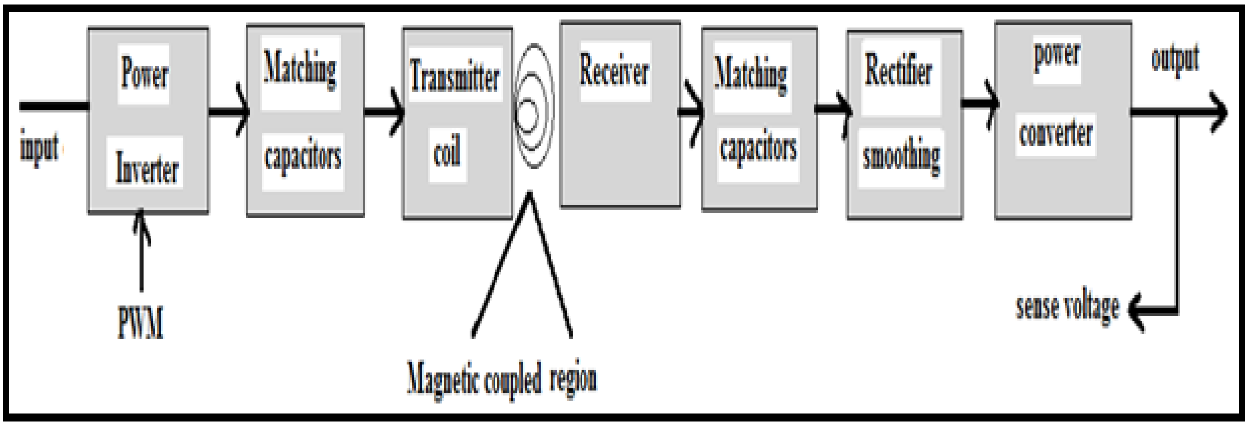

Fig. 4 Block diagram of system Power train

A.Transmitter and receiver coils

Considering that WPT system performance is critically dependent on the merits of the coil pair, they mark a sensible starting point for both design and evaluation purposes. As have previously been established, designing coils for optimum performance is a matter of increasing the coupling and decreasing the resistance. Both considerations aim to reduce the losses, since good coupling allows for lowering the circulating primary current, and less resistance translates to lower I^2R losses for the required magnitude of primary current. Since the coupling of coils is related to their size and distance, the limited available space of the intended application imposes constraints on the solution diversity. Though coupling is highly dependent on the coils axial distance, different coil geometries have different merits in terms of inductance and coupling.

B. Inverter

The primary coil is driven by a class-D half bridge inverter which, due to its switching nature does not compromise the overall efficiency of the entire system. The intended resonant operating region allows for zero-current-switching, - thus eliminating the losses usually associated with the state transitions of MOSFETs. The

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resonant network is effectively a band pass filter which attenuates all but the fundamental component of the driving square wave. This translates to near perfect sinusoidal circulating currents, which from an EMI perspective is desirable. As a side note, the class-D inverter can drive resistive, inductive and capacitive loads; a feature which is practical in relation to the possible further development of a frequency controlled wireless power system. Knowing that the inverter is operating at (or close to) the loaded resonance, the design analysis can be greatly simplified by assuming only the fundamental frequency of the driving square wave is present as proposed in. This approach is known as the "first harmonic assumption" and was applied to the design process of the inverter to get rough estimates of current and voltage magnitudes. The inverter is schematically depicted in Fig. 5, along with all the loading circuitry.

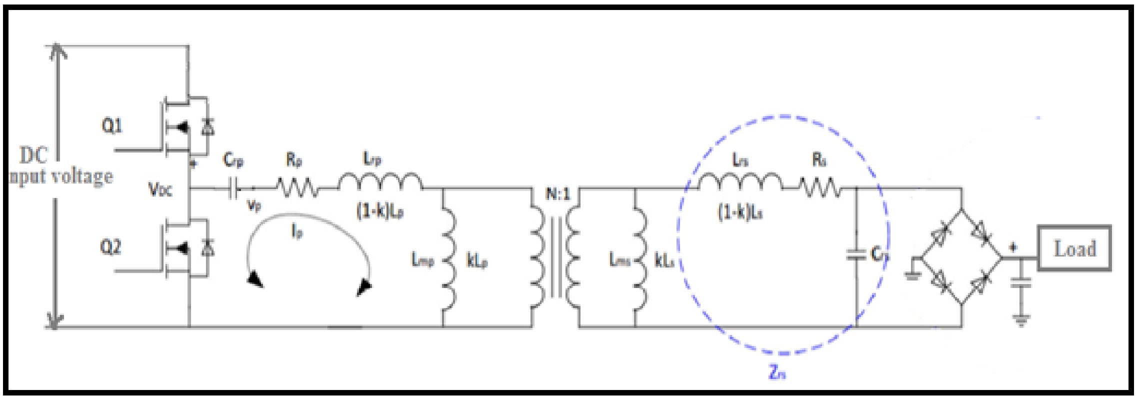

Fig. 5 Inverter and influential system

The magnitude of the current provided by the power stage is strongly tied to the total power dissipation of the secondary side. This dissipation consists of both losses and the power drawn through the load resistor. The efficiency of the converter and rectification are for the time being assumed to be 0.9.

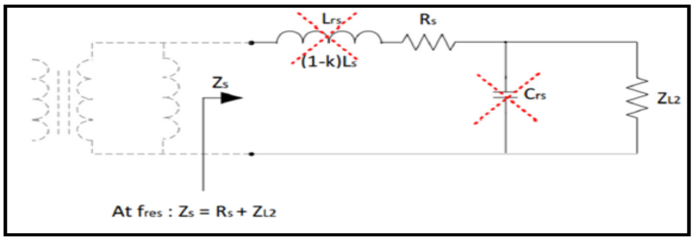

Fig. 6 Secondary resonant equivalents

As fig.6 suggests, the secondary circuit (assuming resonance) looks purely ohmic, thus justifying the substitution with an equivalent resistor. Referring the secondary circuit to the primary sides' FHA equivalent with the driving signal replaced with a sinusoid yields the circuit depicted in Fig. 7 below:

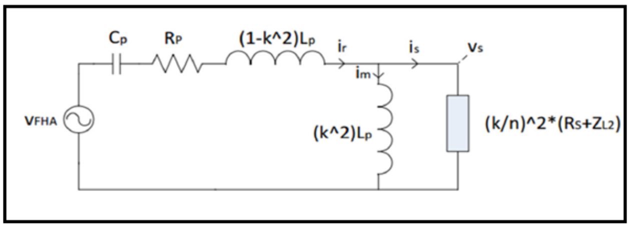

Fig. 7 FHA equivalents, primary referred

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This circuit resembles that of an LLC converter, which is the subject of interest and thus allows for the comparison between simulations and manually calculated electrical variables.

Recalling that the spread inductance on the primary side is

$$Lrp = (1 - k2)\sqrt{LpLs} \quad (1)$$

This in the case of identical coils is equal to

$$Lrp = (1 - k2)Lp \quad (2)$$

The matching capacitor at 200 kHz is calculated by

$$Cr = 1/(2\pi f)\,2Lr \quad (3)$$

It depicts the secondary tank with a capacitor placed in parallel with the secondary side inductance to yield a voltage type output with purely ohmic output impedance (Ideally).In [1] and [9], Grover presented a formula for computing the mutual inductance *M* between two filamentary circular coils with inclined axes (e.g., see Fig. 8). The first coil has a radius R_P , and the second coil has a radius R_S. The distance between the coils' centers is *c*, and the distance between their axes is *d*. The resulting expression proposed by Grover for *M* is:

$$M = \frac{(2\times mew)}{\pi}\sqrt{RsRp}\int \frac{[cos\theta - \frac{d}{Rs}cos\emptyset]\varphi(k)]}{k\sqrt{v3}}d\emptyset \quad (4)$$

Where

$$\alpha = \frac{Rs}{Rp} \;\&\beta = \frac{c}{Rp} \quad (5)$$

$$v = \sqrt{1 - cos\emptyset^2 sin\emptyset^2 - 2(\frac{d}{Rs})cos\emptyset cos\theta + \left(\frac{d}{Rs}\right)^2} \quad (6)$$

$$k^2 = \frac{4\alpha v}{(1+\alpha v)^2+\varepsilon^2}, \varepsilon = \beta - \alpha cos\emptyset sin\theta \quad (7)$$

And $\varphi(k) = \left(1 - \frac{k^2}{2}\right)K(k) - E(k)$ (8)

In the last equations, *K* (*k*) and *E* (*k*) are respectively the complete elliptic integrals of the first kind and the second kind, defined as,

$$K(k) = \int_0^{\pi}\frac{1}{\sqrt{1-k^2 sin\theta^2}}d\theta, E(k) = \int_0^{\pi}\sqrt{1 - k^2 sin\theta^2}\,d\theta \quad (9)$$

One has to be careful as the elliptic integral functions implemented in most computation software such as MATLAB often use the parameter $m = k^2$ as the input argument, instead of the modulus *k*. One should note that the above formula corresponds to the general case when both lateral and angular misalignments are present. The derivation for the formula with magnetic vector is given in [9].

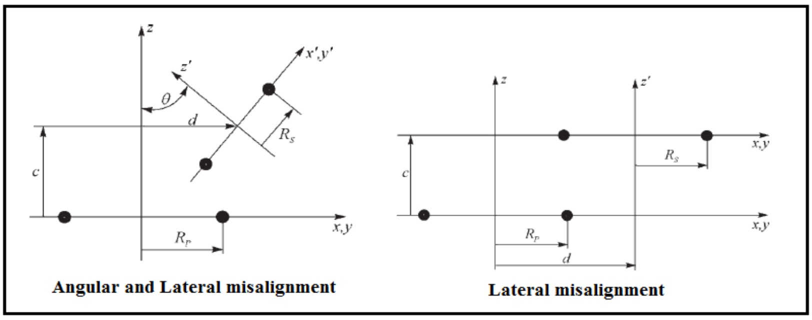

Figure 9 Filamentary circular coils with angular and lateral misalignment

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V. RESULT & DISCUSSION

The different combination of solar power satellites would be accessed according to entered load range for power.

- Case-I for more than rated value condition i.e. Power > 1920 Watts.
- Case-II for Initial base load i.e. Power< 480 Watts, Satellite-1 would be accessed.
- Case-III for slightly increasing load when 480<Power<960 Watts, Satellite-1 & 2 would be accessed.
- Case-IV for peak load i.e.960<Power<1440 Watts, Satellite 1, 2 & 3 would be accessed.
- Case-V for overload when 1440<Power<1920 Watts, Satellite 1, 2, 3 & 4 would be accessed.

In this paper result of case –IV (Overload) is presented. The specified power is in range of 1440-1920 Watts so satellite-I would be accessed along with Satellite-II, III & IV, the results are shown in figure 10-20. From figure 6.10 it is shown that the DC power from solar panel of satellite-IV is 480 Watts and DC/AC voltage of magnitude 230 Volts. The inverter produces square wave with amplitude 229.7 Volts. In this case for LLC, current in Lr=0.9 Amp, current in Lm=2.2948 Amp, capacitor voltage=10 Volts, total power from satellite 2 using resonance= 200 Watts with efficiency 75%.

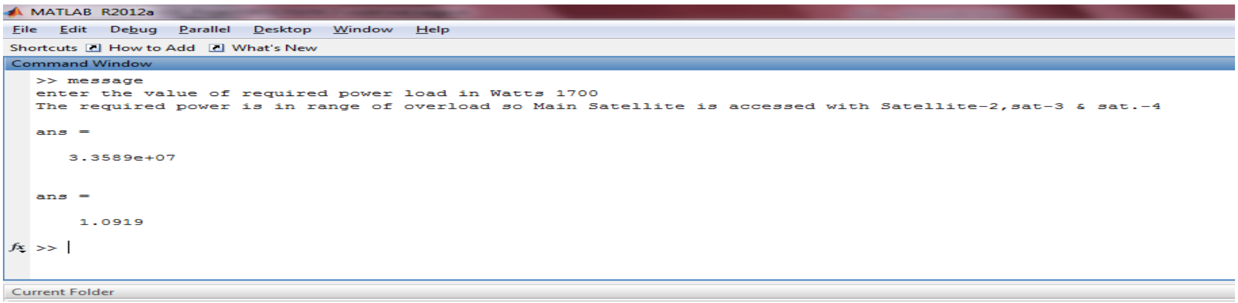

Fig. 10 Command window for Case-IV with specified power of 1000 Watts

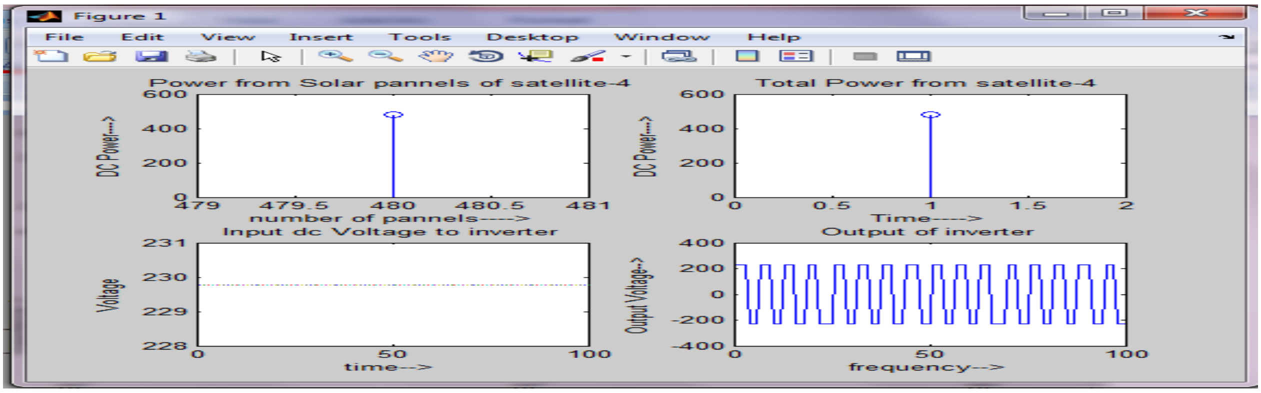

Fig. 11 Design of Satellite-IV and input/output of inverter

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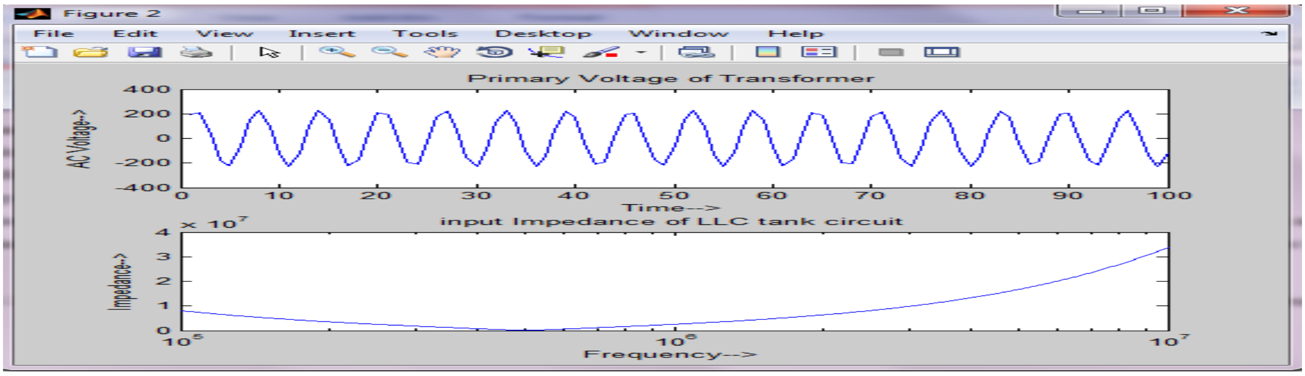

Fig. 12 Primary voltage of transformer and Input impedance of LLC circuit.

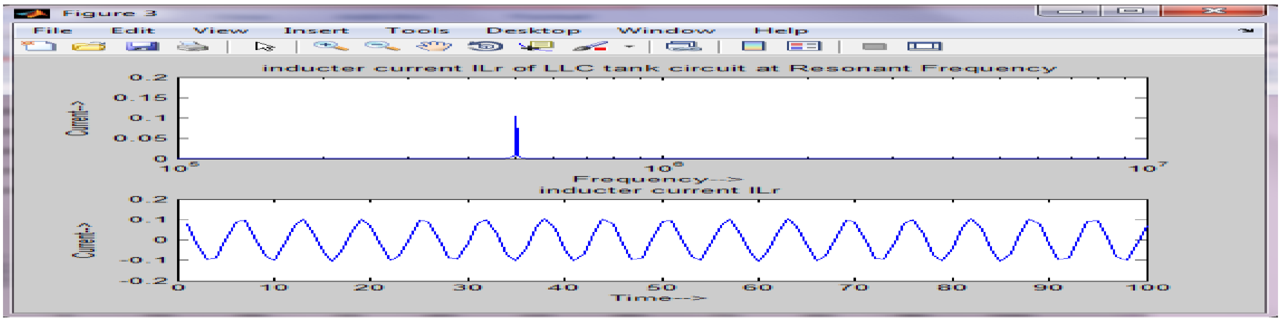

Fig. 13 Inducter current in Lr at resonant frequency 200KHz

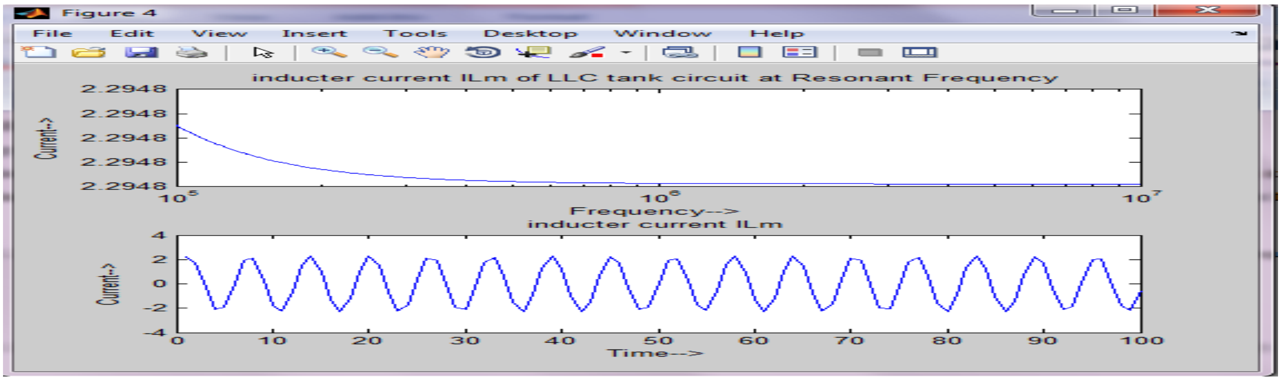

Fig.14 Inducter current in Lr at resonant frequency 200KHz

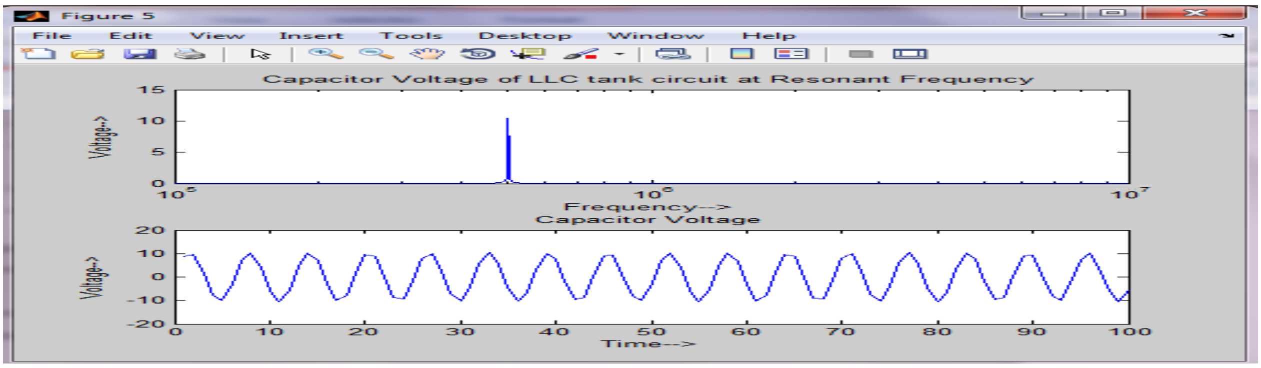

Fig.15 Capacitor voltages at resonant frequency 200KHz

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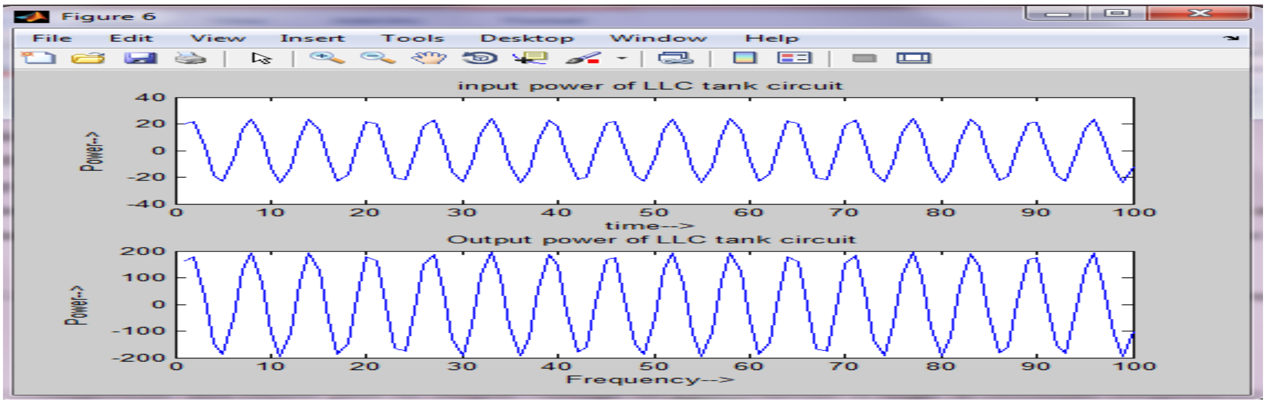

Fig. 16 Input and Output Power of LLC

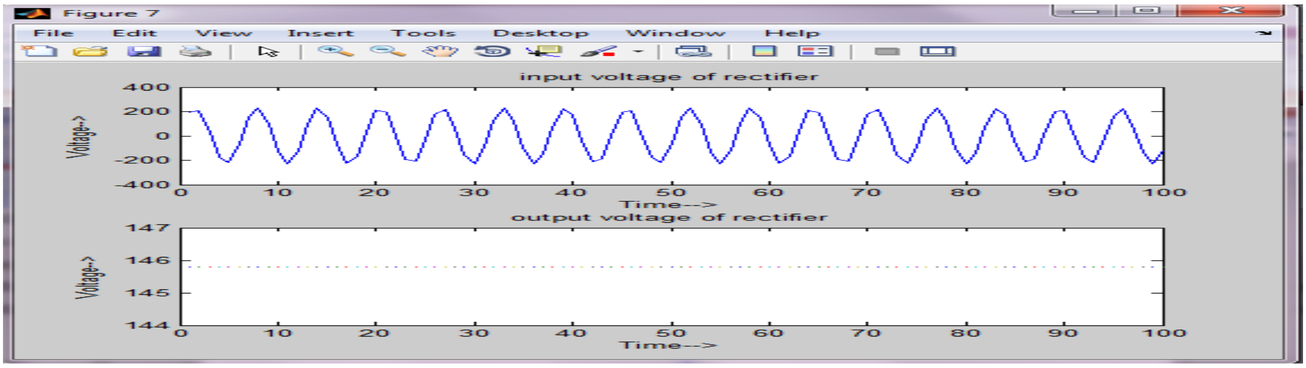

Fig. 17 Input and Output voltage of Bridge diode rectifier

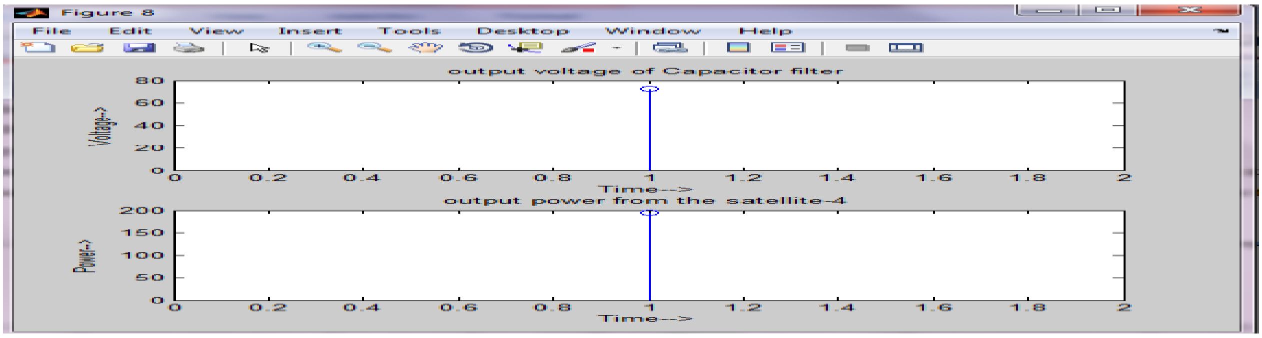

Fig. 18 Output voltages of capacitor filter and Total DC power from satellite-IV using resonance.

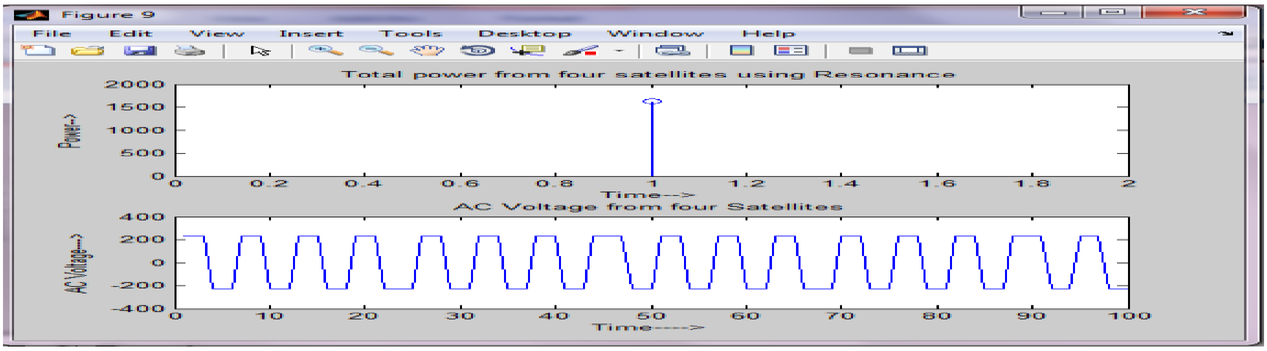

Fig.19 Total power from Four the Satellite and inverter output

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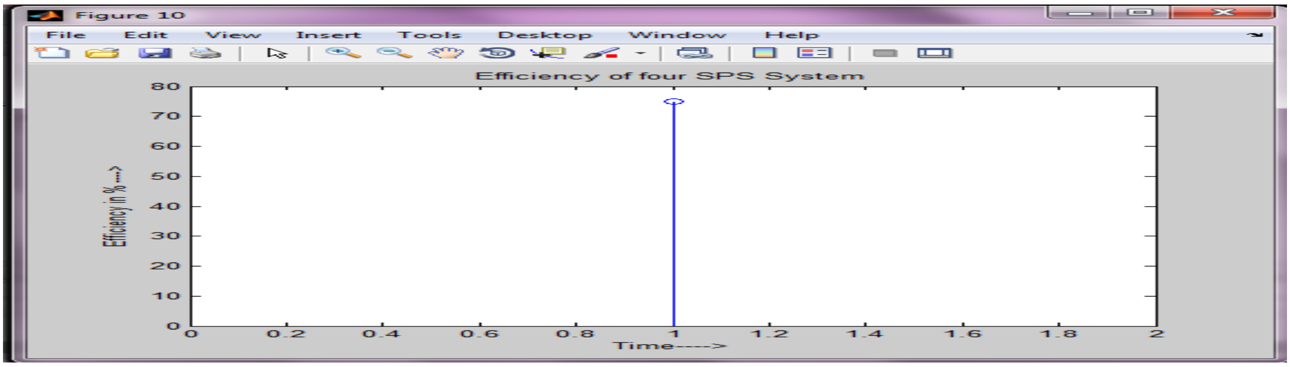

Fig.20 Efficiency of Four SPS system 75%

VI. CONCLUSION

A wireless power transfer system for solar power satellite, capable of transferring the required amount of power has been studied and presented with the concept of resonance. The maximum transferrable power is thus only a matter of the tolerable level of resistive losses. However the technology is still young and it will be interesting to monitor its development through the course of the next few years. Furthermore it allows us to build cleaner, and certainly cheaper and environmentally friendly solutions of sustainable energy and it will bring us one step close in solving the world's energy crisis. In this paper we made an attempt to show the potential uses and solution of problem of energy requirement, and a different novel approach for self generated power supply using solar power satellite with efficiency of 75-90% for power range of 480-1920 Watts. It is More Reliable than ground based Solar Power Generation and wired electricity transmission. There are following matters which require future implementation for proposed methodology.

- Implementation of different types of control methods and their comparison.
- Implementation for High Power ranges in M Watts.
- High efficiency with increasing distances.
- Hardware implementation.
- Better work can be done to minimize the initial cost

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