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Review on Renewable Solar Satellite Power

Deepak Somani[1]* Priya Joshi[2] Sandeep Kumar[3]

[1,2,3] Department of Electrical Engineering, SS College of Engineering, Rajasthan Technical University, Kota, India

Abstract – The new millennium has introduced increased pressure for finding new renewable energy sources. The exponential increase in population has led to the global crisis such as global warming, environmental pollution and change and rapid decrease of fossil reservoirs. Also the demand of electric power increases at a much higher pace than other energy demands as the world is industrialized and computerized. Under these circumstances, research has been carried out to look into the possibility of building a power station in space to transmit electricity to Earth by way of radio waves-the Solar Power Satellites. Solar Power Satellites (SPS) converts solar energy in to micro waves and sends that microwaves in to a beam to a receiving antenna on the Earth for conversion to ordinary electricity.SPS is a clean, large-scale, stable electric power source. One of the key technologies needed to enable the future feasibility of SPS is that of Microwave Wireless Power Transmission. WPT is based on the energy transfer capacity of microwave beam i.e.; energy can be transmitted by a well-focused microwave beam. The whole content covers how the "SPS via WPT" can be come into action in future and its related researches how it can be improved and can be used practically on a large scale. The content covers its historical and theoretical background. Its recent technologies and researches of SPS and WPT-antennas and receivers. And then it covers the transmitter and receiver issues and answer for the space use. It also about its efficiency and its improvement measures. It also contains the environmental issues and solution to those issues.

Keywords – About Five Key Words in Alphabetical Order, Separated By Comma.

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I. INTRODUCTION

A major problem facing Planet Earth is provision of an adequate supply of clean energy. It has been that we face "...three simultaneous challenges -- population growth, resource consumption, and environmental degradation -- all converging particularly in the matter of sustainable energy supply." It is widely agreed that our current energy practices will not provide for all the world's peoples in an adequate way and still leave our Earth with a livable environment. Hence, a major task for the new century will be to develop sustainable and environmentally friendly sources of energy .Projections of future energy needs over this new century show an increase by a factor of at least two and one Half, perhaps by as much as a factor of five. All of the scenarios from reference 3 indicate continuing use of fossil sources, nuclear, and large hydro. However, the greatest increases come from "new renewable" and all scenarios show extensive use of these sources by 2050. Indeed, the projections indicate that the amount of energy derived from new renewable by 2050 will exceed that presently provided by oil and gas combined. This would imply a major change in the world's energy infrastructure. It will be a Herculean task to acquire this projected amount of energy. This author asserts that there are really only a few good options for meeting the additional energy needs of the new century in an environmentally acceptable way.

II. HISTORICAL BACKGROUND

In 1864, James C. Maxwell predicted the existence of radio waves by means of mathematical model. G. Marconi and Reginald Fessenden who are pioneers of communication via radio waves, Nicola Tesla suggested an idea of the wireless power transmission and carried out the first WPT experiment in 1899[1][2]. He said "This energy will be collected all over the globe preferably in small amounts, ranging from a fraction of one to a few horse-power. One of its chief uses will be the illumination of isolated homes". He actually built a gigantic coil which was connected to a high mast of 200-ft with a 3 ft-diameter ball at its top. He fed 300 kW power to the Tesla coil resonated at 150 kHz. The RF potential at the top sphere reached 100 MV. Unfortunately, he failed because the transmitted power was diffused to all directions with 150 kHz radio waves whose wave length was 21 km. To concentrate the transmitted power and to increase transmission efficiency, we have to use higher frequency than that used by Tesla. In 1930s, much progress in generating high-power microwaves, 1-10 GHz radio waves, was achieved by invention of the magnetron and the klystron.

After World War II, high power and high efficiency microwave tubes were advanced by development of radar technology. We can concentrate a power to receiver with microwaves. We call the wireless power transmission with microwaves as microwave power transmission(MPT).

III. RECENT TECHNOLOGIES AND RESEARCHES OF WIRELESS POWER TRANSMISSION – BEAM CONTROL, TARGET DETECTION, PROPAGATION

A microwave power transmission is suitable for a power transmission from/to moving transmitters/targets. Therefore, accurate target detection and high efficient beam forming are important. Retro directive system is always used for SPS.A corner reflector is most basic retro directive system. The corner reflectors consist of perpendicular metal sheets, which meet at an apex (Fig.4.1(a)). Incoming signals are reflected back in the direction of arrival through multiple reflections off the wall of the reflector. Van Atta array is also a basic technique of the retro directive system. This array is made up of pairs of antenna spaced equidistant from the center of the array, and connected with equal length transmission lines(Fig.4.1(b)). The signal received by an antenna is re-radiated by its pair, thus the order of re-radiating elements are inverted with respect to the center of the array, achieving the proper phasing forretro directivity. Usual retro directive system have phase conjugate circuits in each receiving/transmitting antenna, (Fig.4.1(c)) which play a same role as pairs of antennas spaced equidistant from the center of the array in Van Atta array. A signal transmitted from the target is received and re-radiated through the phase conjugate circuit to the direction of the target. The signal called a pilot signal. We do not need any phase shifters for beam forming. The retro directive system is usually used for satellite communication, wireless LAN, military, etc. There are many researches of the retro directive system for these applications (Fig.4.2). They use the almost same frequency for the pilot signal and returned signal with a local oscillator (LO) signal at a frequency twice as high as the pilot signal frequency in the typical retro directive systems (Fig.4.1(c)).Accuracy depends on stability of the frequency of the pilot signal and the LO signal. Prof. Itoh's group proposed the pilot signal instead of the LO signal

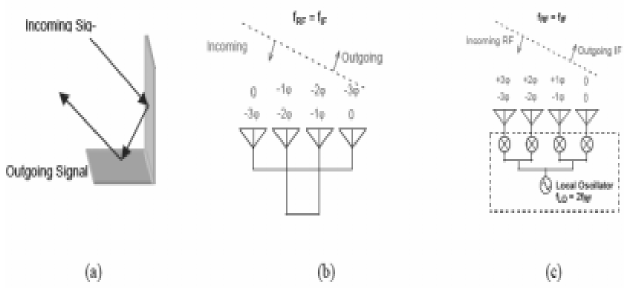

Fig. 4.1 (a) two-sided corner reflector, (b) Van Atta Array, (c) retro directive array with phase conjugate circuits.

IV. ENVIRONMENTAL ISSUES

Most MPT system adopted 2.45 GHz or 5.8 GHz band which are allocated in the ITU-R Radio Regulations to a number of radio services and are also designated for ISM (Industry, Science and Medical) applications. Conversely speaking, there is no allowed frequency band for the MPT, therefore, we used the ISM band. The bandwidth of the microwave for the MPT do not need wideband and it is enough quite narrow since an essentially monochromatic wave is used without modulation because we use only carrier of the microwave as energy. Power density for the MPT is a few orders higher than that for the wireless communication. We have to consider and dissolve interferences between the MPT to the wireless communication systems. One calculation of the interferences between the MPT of the SPS, mainly 2.45 GHz, to the wireless communication systems was done in Japan. If the harmonics of the MPT frequencies are, however, regulated by the ITU (International Telecommunication Union) power flux density (PFD) limits, some modulation might be necessary. Carrier noises, harmonics, and spurious emissions of the MPT signal should be quite small to avoid interference to other radio services in operation around the world.

Grating lobes and side lobes of the MPT beam should be low enough in order to make the affected region as small as possible. Also, grating lobes should be mitigated because they are a direct loss of transmitter power. The other interference assessment on 2.45 GHz and 5.8 GHz MPT of the SPS was published in Japan. They discussed mainly Japanese case. They discussed four main existent systems, terrestrial radio relay links on 5GHz (5G-150M) system and 11GHz (11G-50M) system, radars called ARSR(air route surveillance radar, 1.3-1.35 GHz), ASR (airport surveillance radar, 2.7-2.9GHz) and MR(meteorological radar, 5.25 - 5.35GHz), Space-to-Earth communications on 11-12 GHz-band, and applications in the ISM bands, wireless LAN and DSRC (Dedicated Short Range Communication).JAXA (Japanese Aerospace Exploration Agency) estimated the interference and submitted "Proposal of the extension regarding the termination year of Question ITU-R 210/1 to 2010 from2005"to ITU in 2004, and will submit in 2005. Responses to Question ITU-R 210/1 (1997) had been submitted to the ITU-R WP1A meetings by USA. Since the response (Document 1A/18-E,which was incorporated into Document 1A/32-E Annex8) in October 2000 [23], no response has been submitted.

- **Safety on Ground**

One of the characteristics of the MPT is to use more intense microwave than that in wireless communication systems. Therefore, we have to consider MPT safety for human. In recent years there24have been considerable discussions and concerns about the possible effect for human health by RFand MW radiation. Especially, there have been many research and discussions about effects at 50/60Hz and over GHz (microwave). These two effects are different. There is long history concerning the safety of the microwave. Contemporary RF/microwave standards are based on the results of critical evaluations and interpretations of the relevant scientific literature. The SAR (specific absorption rate) threshold for the most sensitive effect considered potentially harmful to humans, regardless of the nature of the interaction mechanism, is used as the basis of the standard. The SAR is only heating problem. The scientific research results have indicated that the microwave effect to human health is only heating problem. This is different from the EMF research. Famous guideline, the ICNIRP (International Commission on Non-Ionizing Radiation Protection) guidelines, are 50 or 10 W/m2 for occupationally exposed vs. the general public, at either frequency. The corresponding limits for IEEE standards for maximum permissible human exposure to microwave radiation, at 2.45 or 5.8 GHz, are 81.6 or 100 W/m2 as averaged over six min, and 16.3 or 38.7 W/m2 as averaged over 30 min, respectively, for controlled and uncontrolled environments. The controlled and uncontrolled situations are distinguished by whether the exposure takes place with or without knowledge of the exposed individual, and is normally interpreted to mean individuals who are occupationally exposed to the microwave radiation ,as contrasted with the general public. In future MPT system, we have to keep the safety guideline outside of a rectenna site. Inside the rectenna site, there remains discussion concerning the keep out area, controlled or uncontrolled area.

- **DC-RF Conversion Efficiency**

If we do not have to steer a microwave beam electrically in a MPT, we can use a microwave transmitter with high DC-RF conversion efficiency over 70-80 % like microwave tubes. However, if we need to steer a microwave beam electrically without any grating lobes, we have to use phase shifters with high loss. Especially in the SPS system, the optimum and economical size of the transmitting phased array and microwave power are calculated as around a few km and over a few GW, respectively. It means that microwave power from one antenna element is much smaller than that from one microwave tube or high power (over a several tens watts) semiconductor amplifier. It also means that phase shifter have to be installed after the microwave generation/amplification (Fig.6.3) if microwave beam will be steered to directions of larger than 5 degrees without grating lobes. In that case, development of low loss phase shifter is very important for construction of a phased array with high efficiency. In present, the power loss of the phase shifter is over 4-6 dB. It means that DC-RF conversion efficiency in the MPT system in Fig.6.4 is below 20% if we use over 70% efficiency high power oscillator/amplifier. However, the phase shifter problem will be solved if microwave beam will best ered to directions within 0.1 degree because the phase shifters do not need to be installed without grating lobes with large sub-array. Another way to solve the phase shifter problem is use of low power amplifiers after the high loss phase shifters (Fig.6.4).

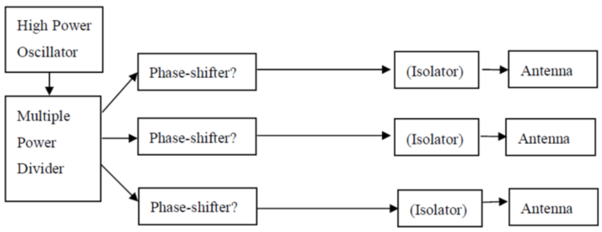

Fig. 6.3 Implementation of microwave transmission with a high power microwave oscillator and phase-shifters for high precision control of microwave beam direction to large angles without grating lobes.

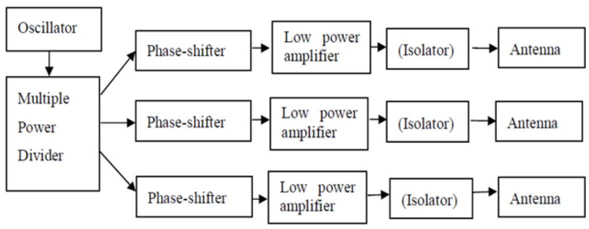

Fig. 6.4 Implementation of microwave transmission with phase-shifters and low power amplifiers for high precision control of microwave beam direction without grating lobes

ADVANTAGES

- The full solar irradiation would be available at all times expect when the sun is eclipsed by the earth. Thus about five times energy could be collected, compared with the best terrestrial sites
- The power could be directed to any point on the earth's surface.

- The zero gravity and high vacuum condition in space would allow much lighter, low maintenance structures and collectors.
- The power density would be uninterrupted by darkness, clouds, or precipitation, which are the problems encountered with earth based solar arrays.
- The realization of the SPS concept holds great promises for solving energy crisis
- No moving parts.
- No fuel required.
- No waste product.

DISADVANTAGES

- Launch costs
- Capital cost even given cheap launchers
- Would require a network of hundreds of satellites
- Possible health hazards
- The size of the antennas and rectennas
- Geosynchronous satellites would take up large sections of space
- Interference with communication satellites

V. EVOLVING WPT MARKETS

Markets that will be made accessible with WPT will have a profound influence on global business activities and industry competitiveness. The following are examples of the future commercial opportunities of WPT:

1. Roadway powered electric vehicles for charging electric batteries with WPT from microwave generators embedded in the roadway while a vehicle is traveling at highway speed, thus eliminating stops to exchange or recharge batteries greatly extending travel range.
2. High-altitude, long-endurance aircraft maintained at a desired location for weeks or months at 20 km for communications and surveillance instead of satellites, at greatly reduced costs.
3. Power relay satellites to access remote energy sources by uncoupling primary electricity generation from terrestrial transmission lines. Power is transmitted from distant sites to geosynchronous orbit and then reflected to a receiver on Earth in a desired location.
4. Solar power satellites in low-Earth or geosynchronous orbit or on the Moon to supply terrestrial power demands on a global scale.

VI. CONCLUSION

1. There is little doubt that the supply of energy must be increased dramatically in coming decades. Furthermore, it appears almost certain that there will be a shift toward renewable sources and that solar will be a major contributor. It is asserted that if the energy system of the world is to work for all its people and be adequately robust, there should be several options to develop in the pursuit of and expanded supply. While the option of Space Solar Power may seem futuristic at present, it is technologically feasible and, given appropriate conditions, can become economically viable. It is asserted that it should be among those options actively pursued over coming decades. The challenges to the implementation of Space Solar Power are significant, but then no major expansion of energy supply will be easy. These challenges need to be tackled vigorously by the space, energy and other communities.
2. Finally, it should be emphasized that if we fail to develop sustainable and clean energy sources and try to limp along by extrapolating present practices, the result is very likely to be thwarted development of economic opportunities for many of the Earth's people and, almost certainly, adverse changes to the planetary environment.
3. The resolve of the synthesis problem of the WPT shows that WPT efficiency may be improved by using special current discontinuous distribution on the antenna. Here we have three possibilities:
4. To use a discontinuous equidistant array with the quasi Gauss distribution.
5. To use a discontinuous non-equidistant array with the uniform distribution.
6. To use uniform continuous phase synthesis antenna array.
7. All of these methods are original and they have been modeled only in the frame of

International Science and Technology Center Project.

8. The possibility of decrease of the wave beam expansion permits to make the WPT systems less expensive. Such approach to the problem of the continuous radiators and of the real antennas, which can be created, is new.

9. Due to high launch costs, SPS is still more expensive than Earth-based solar power and other energy sources. Yet, even now, a small SPS system could be economically justified to provide otherwise unavailable emergency power for natural disaster situations, urban blackouts and satellite power failures

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Corresponding Author

Deepak Somani*

Department of Electrical Engineering, SS College of Engineering, Rajasthan Technical University, Kota, India