ANTENNA DESIGNS FOR WIRELESS POWER TRANSPORTATION : THE GRAND BASSIN CASE STUDY IN RÉUNION ISLAND

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1. Introduction

For more than 25 years, the SPS Solar Power Systems (fig.1) have been proposed as a clean and sustainable energy solution for mankind : built from lunar materials, giant power stations would deliver electricity to the major centers on the Earth by means of a microwave Wireless Power Transportation system (WPT).

But it may take another 50 years before such systems are fully operational. Meanwhile, it is both possible and useful to use WPT technologies to provide baseload energy to remote locations, especially where ecological reasons would make it difficult to use more conventional methods, which is the case in Réunion Island (fig.2).

An international task team with experts from Japan, Russia, Ukraine, Usa and France has conducted a two years design study for a 10 kW , 2.45 GHz, 700 m link to a group of tourist lodges located deep at the bottom of a steep canyon.

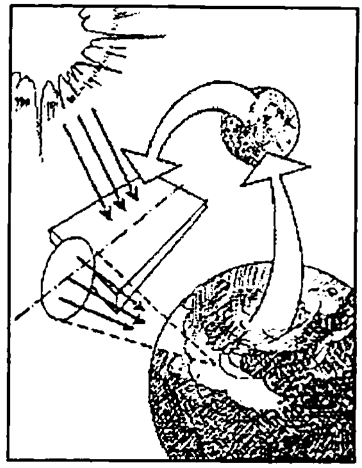


fig.1 : General SPS concept

2. Grand Bassin : A WPT energy solution to protect the natural environment

The Grand Bassin Canyon (fig.3) is a world-class tourist site in a breath-taking natural environment. The small photvoltaic arrays which equip the three tourist lodges provide electric light, but they are not sufficient to run the necessary modern household conveniences. WPT is a good candidate to provide the 10 kW or more that would be

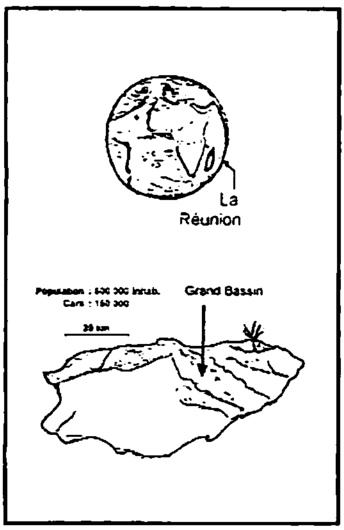


fig.2 : Réunion Island

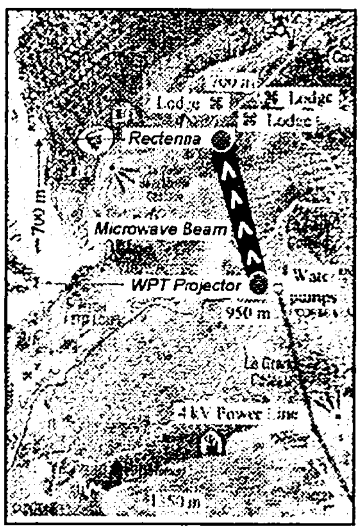


fig.3 : Grand Bassin

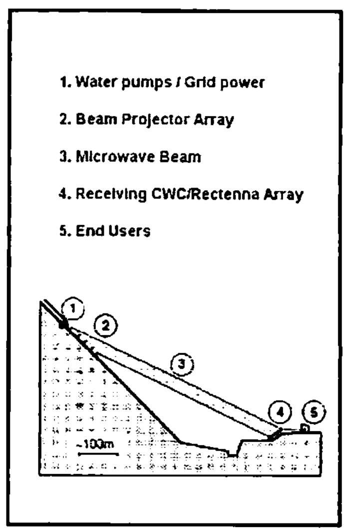


fig.4 : WPT link profile

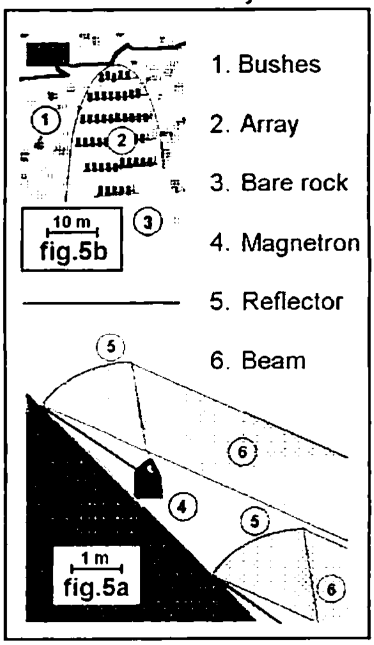
necessary, because it is less obtrusive than aerial lines, more regular and also less visually disruptive than large photovoltaic arrays, cheaper to implement than a buried power line and cheaper than a diesel generator to operate in the long run.

The complete (fig.4) system includes a microwave generation and beam projection array half-way down the slope, next to a water pumping station which is connected to the main utility grid, and a receiving array next to the group of houses, for collection, conversion and conditioning of the energy transported along a 700-m long microwave beam. The driving criteria and keys for success of the design are environment compatibility and low cost rather than technical efficiency. Whereas global system efficiencies of more than 50% have been achieved in laboratory experiments (typically 80% electricity to microwave conversion x 80% beam collection x 80% microwave to electricity conversion), only 60% x 60% x 60% = 20% efficiency is expected in this case thus requiring a 50 kW input for a 10 kW end output. The total energy flow in the microwave beam is therefore expected to be about 30 kW when it leaves the microwave projector. A slight focusing of the beam would allow the collection of about 15 to 20 kW on the receiving array, after consideration of the geometrical losses.

The choice of the beam sections derive from two independent limiting factors. One is safety for people and other life forms : during a test period under reduced power, the microwave energy density would be limited to the international standard of 5 mW/cm^2, then the power density would be increased to a maximum of 25 mW/cm^2, i.e. ¼ of the energy received from the Sun in the visible spectrum, which is considered safe by most experts. This calls for a minimum beam section area of 120 m^2 on the projector side and 80 m^2 on the receiving side with respective diameters of about 13 m and 10 m. The other limiting factor is the classical $D1 \times D2 = 2\lambda \times R$ geometrical relationship between the sizes of the antennas (D1 and D2), the distance between the antennas (R = 700 m) and the wavelength (λ = 0.122 m). This calls for respective dimensions of 15 m at the projecting end and 12 m at the receiving end. This should be the dimensions of the antenna systems.

3. The projecting antenna system : Polarised Wire Reflectors

For two major reasons, it is not conceivable to form the microwave beam by using a single source and a 15-m diameter parabolic antenna, which would be readily available technology. The first reason is that it would not be socially acceptable to have such a large disk sticking out in the landscape. The other reason is that beyond the lessons that will be learned from the Grand Bassin operational demonstration, we are looking at future larger system in which multi-source systems will be a necessity.



To generate the total power of 30 kW microwave energy, a set of 60 magnetrons is considered. These are modified 1-kW rated kitchen oven magnetrons operating at 500-W half power in order to extend considerably their operating life time, with added external circuitry to provide power and phase control capability.

Each of the beam-generating elements (fig.5a) is composed of a water-cooled magnetron, with associated control electronics, a small horn antenna and a 2.5 to 3 m^2 parabolic offset reflector (about 1.2 x 2 to 2.5 m). Because of the geometry of the canyon, the reflectors are looking down towards the receiving site at an angle of 20° with the slope. They are laid out in a way to form a more or less circular bundle of adjacent beams (fig.5b), as seen from the receiving arrays, in a pattern of about 5 or 6 horizontal rows of 10 to 12 units separated by distances of 6 to 8 m slope wise. Working in a projection mode, this layout is comparable to the layout of some large radio-astronomy arrays used by for reception of signals from the cosmos.

The magnetrons and horn antenna blocs are small enough to be inconspicuous. The reflectors are made of vertical parallel wires separated by distances of 1 to 2 cm, supported by sheets of transparent materials. The ground on which the array is installed is bare rock. With some voluntary irregularity introduced in the layout pattern, there will be no visual aggression for the passer-by nor for the distant watcher. The projector array will certainly be noticeable, but it will be well integrated into the surrounding landscape.

4. The receiving antenna system : Cyclotron Wave Converters and Rectennas

Because diversity contributes to aesthetics, and also for the purpose of testing different systems in an operational configuration, CWC devices are used as well as rectennas to convert microwave energy back to electricity.

A convenient 30° slope has been found near the end-user sites to accept the receiving arrays, but still, the incoming microwave beam is received at a 40° angle from the normal direction to the ground. Therefore, the array has an elliptic shape of 12 m x 16 m. A 6-m diameter patch of 6 to 10 separate parabolic wire or mesh reflectors is surrounded by a 3-m wide corona of wire rectenna arrays in a flower-like pattern (fig.6a).

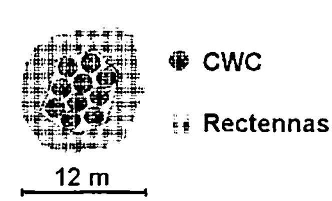


fig.6a

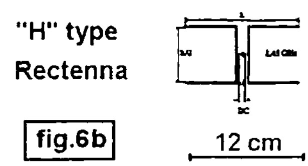


fig.6b

The CWC devices can be installed either directly at the focal point of the reflectors, or in the power conditioning block, at the end of wave-guides. Both solutions can be used for comparison. They are expected to provide one half of the received power.

Some 5 000 rectennas are expected to provide the other half of the received power. The enhanced "H" wire rectennas (fig.6b) use parallel/series bridge arrangements of inexpensive NEC 1SS97 or similar diodes with unit output in the order of 1 W.

One of the claims of SPS/WPT systems is the capability for dual use of the receiving site, for energy collection and simultaneously for agriculture under the receiving systems, and this has to be demonstrated by the Grand Bassin energy receiving system. This is possible because of the rather long wavelength of the 2.45 GHz microwave beam (122 mm) as compared to the solar spectrum (around 1 µm). There is no competition between the frequencies, and the mesh construction of both the reflectors and the rectenna sub-arrays allows the sun light to go through. The receiving system is installed at about 3 m above the ground, and it is possible to continue the culture of vegetables on the small piece of land. Whatever microwave energy goes through the receiving devices will not be dangerous for the workers, for the animals or for the plants. It may even contribute to a small beneficial local greenhouse effect that may enhance the growth of the vegetables.

5. Designing SPS/WPT ground antennas : a task for artists

There are many ways to design antennas, this is especially visible in the consumer market for TV and VHF antennas where many concepts and many shapes can be seen in the display rooms and on the catalogues. The design vary, often based more on individual taste than on actual technical performance.

In the case of Grand Bassin, technical efficiency is not a driving factor. Any global efficiency above 5% will bring a beneficial margin in the operation cost of the system when referred to the cost difference between utility grid energy cost and the cost of present alternate sources (photovoltaics, small diesel, etc..).

The key issues are to provide a safe, permanent, convenient and most of all environmentally clean way of transporting electricity to remote locations in sensitive areas. Safety, availability, convenience are technically built in the WPT systems.

The most visible components of the Wireless Power Transportation systems are the antenna arrays for projection and reception of the microwave beam. They can be easily designed to be non-intrusive and readily socially acceptable. But this is rather a job for artists, architects and landscape designers than for technical engineers who often tend to favour pure technical performance at the cost of many other human factors. Let the artists design WPT antennas first, and then let the engineers and the technicians manufacture them in the best possible way to improve efficiency and other technical factors

6. Conclusion

WPT is a new area for antenna design. WPT antennas may resemble somehow the antennas used for communication systems. They may resemble the antennas use in radio-astronomy. They may resemble the antennas used in SAR radar systems. But they are a new business, a different business, even if the laws of propagation remain unchanged.

Because of their inherent large size and high visibility, good integration in the landscape is likely to be the N°1 factor of social acceptability of the systems. This has been evidenced in the Grand Bassin case study and solutions have been found, looking from the environment approach.

As was mentioned by "Bill" Brown of Raytheon, one of the "fathers" of WPT, it took for electricity one generation to expand from the signal business (telegraph, telephone) to the energy business (DC and AC for homes and for the industry). Today the use of the electromagnetic field for signal transmission is very much commonplace. The use for energy transportation has come of time. But many more WPT operational demonstrations will be needed to achieve significant progress, in terms of service to humanity as well as in technical terms. New considerations at antenna design will be necessary for the subject to mature and then the subject of antennas for WPT may possibly become fully a new branch of the trade.

fig.7 : SPS antenna arrays

7. Acknowledgements

Setting path into new domains of application is a challenging and exciting adventure. The author would like to thank all the participants in the Grand Bassin study case, and especially : Lucien Dechamps, Director of SEE, France, who introduced him to the subjects of SPS and WPT, Denis Clément, head of the Regional Environment Authority in Réunion and Guy Mairesse of EDF, who suggested the site of Grand Bassin, Jean-Daniel Lan Sun Luk, Jean-Pierre Chabriat and Alain Celeste of the University of Réunion who conceived the overall system for this specific case, Makoto Nagatomo, Susumu Sasaki and Yoshihiro Naruo of ISAS, who gave us valuable insights in rectenna and wire reflector designs, Yuri Pirogov, Vladimir Savvin and Vladimir Vanke of Moscow State University, who gave us a brilliant demonstration of the CWC systems, Joseph Hawkins and his team at the University of Alaska, who gave us excellent advice on magnetron systems for microwave beam generation and Nobuyuki Kaya, of the University of Kobe, who brought the whole group together during the WPT'95 conference where the Grand Bassin task team was confirmed.

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