# INTEGRATION OF SPS WITH UTILITY SYSTEM NETWORKS

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## Introduction

This paper will discuss the integration of SPS power in electric utility power systems. Specifically treated will be the nature of the power output variations from the spacecraft to the rectenna, the operational characteristics of the rectenna power and the impacts on the electric utility system from utilizing SPS power to serve part of the system load.

## Dynamic Power Variations in the SPS System

As a first approximation the SPS system consists of a constant power source working into a constant load. However, in practice the available power degrades slowly over the 30 year lifetime and it is modulated by infrequent but relatively rapid fluctuations.

Table 1 lists some of the conceivable sources of relatively rapid power variations in the SPS system. They are listed approximately in sequence of the associated total yearly loss of energy.

It can be seen that among the listed items only the first two, maintenance and eclipse produce 100% outage and both of these fall into the scheduled down time category. These two sources cause scheduled down times of 1.36% and 1% respectively. The remaining effects are small and essentially random. Total energy loss is less than 2.7% per year if shut down and start up times associated with eclipses are also considered.

When it is necessary to implement scheduled or unscheduled output power level variations from the spacecraft several methods can be considered.

Table 2 shows 7 methods to control the power input into the rectenna. Reduction of power to zero will require a maximum .45 sec.

## Rectenna Inverter Control and Operation

The power conditioning system that has been recommended for the SPS is the current fed, line commutated inverter. This type of system is in common use in HVDC power transmission. Synchronous condensers control the ac voltage and the supply of reactive power.

The SPS should operate at full available output. To accomplish this, the inverter must present to the rectenna the optimum load impedance. It is assumed that the rectenna is basically resistive in nature and there is an optimum dc load resistance for maximum power transfer.

Normally the system would be operated at optimum resistance so that the rectenna would reflect a minimum of power. The power level would be adjusted at the satellite and would usually be set at maximum available power. If power reduction is required by utility considerations and it could not be accomplished at the satellite, the converter power can be adjusted by means of moving the resistance off optimum. Of course, RF power would be reradiated but that might be acceptable under the circumstances.

The converter module requires reactive power from the ac bus in approximate proportion to the active power being delivered to the utility network. This reactive power is supplied by static capacitors, harmonic filters and synchronous condensers.

Performance during the semi-annual eclipse periods can be made largely automatic. As RF power decreases during the partial eclipse period the converter, through its constant resistance load characteristics, will track the rectenna output and provide available power. The principle problem during these eclipse periods will be power dispatch in the ac system to preserve load and frequency. A mitigating factor will be that the power loss occurs at night when the ac system is most able to cope with it.

## SPS Operating Characteristics

Currently accepted response characteristics for electric utility system generating plants and measures of utility system reliability have been the basis for the integration of SPS power with electric utility systems.

Two of the power control methods, 2 and 4, described in Table 2 were deemed practicable and acceptable by utility system criteria. The response times and power control range for these two methods are compared with conventional generating unit characteristics in Figure 1. It is seen that the SPS response in both cases is better than that of conventional generation.

The SPS is unlike conventional generation in that it has no mechanical inertia and hence appears as a negative load to the system. Control of the incident power will be at the satellite antenna via communications link and this control loop, involving transmission of control signals through space, is the nearest analog of governor control of a conventional generation source.

The study of impacts on system reliability adding SPS generation to electric utility systems was based on a reliability model for SPS as shown in Figure 2. These probability plots were developed using the information in Table 1 combined with a failure analysis of the rectenna system. These curves, however, are too complex to be used directly in current utility system reliability planning models. A simplified 5-state outage model was used in a parametric approach to determine the impact of SPS power on utility system reserve levels for various amounts of SPS penetration. The results of this investigation are shown in Figure 3.

## Conclusions

The results indicate that if RF beam control is an acceptable method for power control, and that the site distribution of SPS rectennas do not cause a very high local penetration (40-50%), SPS may be integrated into electric utility system with a few negative impacts. Increased regulating duty on the conventional generation, and a potential impact on system reliability for SPS penetration in excess of about 25% appear to be two areas of concern. Assessment of more detailed models and advanced design parameters for the SPG system must be done before it would be possible to investigate the SPS/Utility System integration in more detail.

| NO. | SOURCE OF POWER VARIATION | RANGE % | FREQUENCY OF OCCURENCE PER YEAR | AV. DURATION OF OUTAGE PER OCCURRENCE MIN/YEAR | TOTAL OUTAGE HR./YEAR | MAX. POWER REDUCTION GW | AV. YEARLY ENERGY LOSS GW HR. | TIME TO MAX POWER LOSS | SCHEDULED YES | NO |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | SPACECRAFT MAINTENANCE | 0-100 | 2 | 2 x 3600 | 120 | 5 | 600 | 6 MIN | X | |
| 2. | ECLIPSE | 0-100 | 62 | 3376 TOTAL<br>71 MAX PER/ OCCURRENCE | 56.26 | 5 | 281.3 | 1 MIN | X | |
| | ECLIPSE WITH SHUTDOWN AND STARTUP | | | 5270 | 87.8 | | 439 | 1 MIN | X | |
| 3. | WIND STORM | 75-100 | 0.01 | 5260 | 87.6 | 1.25 | 109.5 | 5 MIN | | X |
| 4. | EARTHQUAKE | 90-100 | 0.01 | 1800 | 30 | 0.5 | 15 | 10 SEC | | X |
| 5. | FIRE IN RECTENNA SYSTEM | 80-100 | 0.01 | 840 | 14 | 1 | 14 | 30 MIN | | X |
| 6. | METEORITE HIT OF SPACECRAFT EQUIPMENT | 90-100 | 0.01 | 1200 | 20 | 0.5 | 10 | 100 MS | | X |
| 7. | RECTENNA EQUIPMENT FAILURE | 91.5-100 | 1 | 50 | 0.833 | 0.425 | 0.35 | 100 MS | | X |
| 8. | PRECIPITATION | 93.3-100 | 50 | 1 | 0.833 | 0.336 | 0.28 | 1 M | | X |
| 9. | POINTING ERROR | 94.2-100 | 5000 | 0.6 | 0.833 | 0.29 | 0.24 | 1 S | | |
| 10. | IONOSPHERE | 96.5-100 | 20 | 10 | 3.32 | 0.15 | 0.24 | 1 S | X | |
| 11. | GROUND CONTROL EQUIPMENT FAILURE | 95-100 | 5 | 3 | 0.25 | 0.25 | 0.06 | 0.3 S | | X |
| 12. | AIRCRAFT SHADOW | 99.99-100 | 20 | 20 M<br>1 M MAX/ OCCURENCE | 0.3 | 0.0005 | 0.0015 | 1 S | | X |

TOTAL WITHOUT SHUTDOWN/STARTUP: 331 HR (3.77%) 1030.8 (2.35%)
WITH SHUTDOWN-/STARTUP: 362 HR (4.12%) 1188.5 (2.71%)

Table 1. Characteristics of Available Power Variation in SPS System

| METHOD | EFFECT ON LIFETIME | RANGE OF POWER | TIME DELAY | ON | OFF | WHERE THE POWER GOES | ENERGY REQUIREMENT |
|---|---|---|---|---|---|---|---|
| 1. REDUCE KLYSTRON BEAM VOLTAGE | SMALL | 100-80 | 300 MS | X | | THERMAL RADIATION ON SPACECRAFT | NONE |
| 2. INTRODUCE QUADRATIC PHASE ERROR TO ANTENNA APERTURE | NONE | 100-50 | 300 MS | X | | INCREASES POWER AROUND RECTENNA. (~ 14 KM) | NONE |
| 3. RANDOMIZE ANTENNA PHASES | NONE | 100-0 | 450 MS | X | | INTO 1000 KM DIA. FOOTPRINT | NONE |
| 4. TILT OF ANTENNA PHASE | NONE | 100-0 | 1 SEC. | X | | OFF EARTH | NONE |
| 5. TILT OF ANTENNA | MODERATE | 100-0 | 216 S | X | | OFF EARTH | MODERATE |
| 6. DISCONNECT KLYSTRON RINGS | | 100-0 | 3 S | | X | AROUND RECTENNA | NONE |
| 7. TILT SOLAR ARRAY AND 6 | LIFE OF SLIP RING | 100-0 | 131 MIN. | | X | TO UNIVERSE | LARGE |

Table 2. Various Methods to Reduce Power Into Rectenna

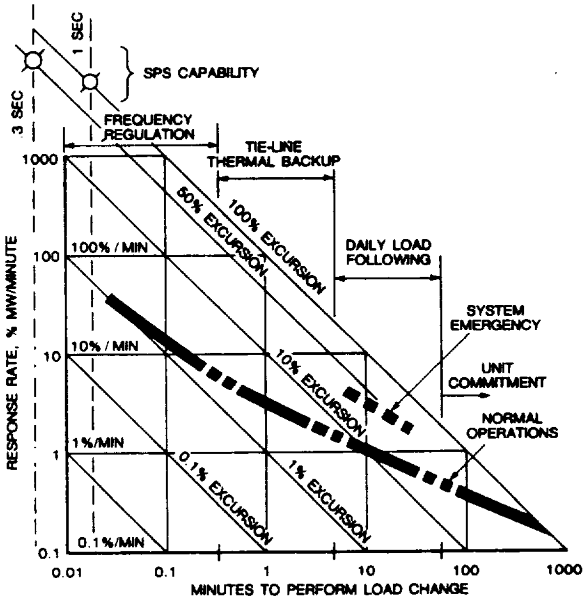

Figure 1. SPS Response Capability Compared with Conventional Generating Units

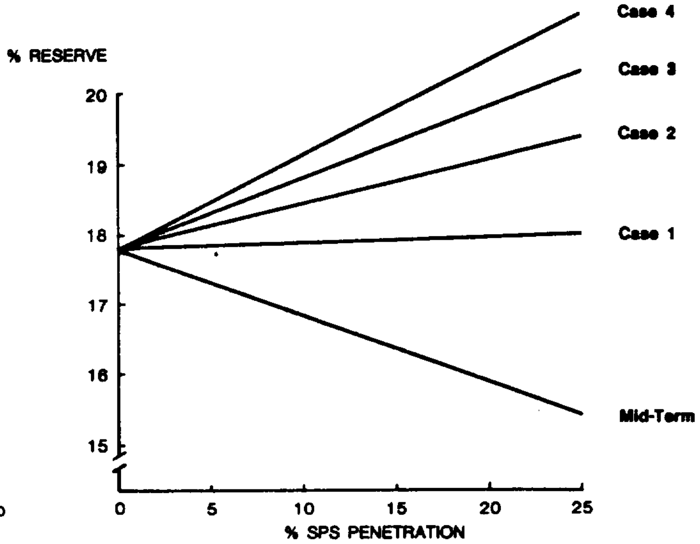

Figure 3. Utility System Reserve Levels vs. SPS Penetration

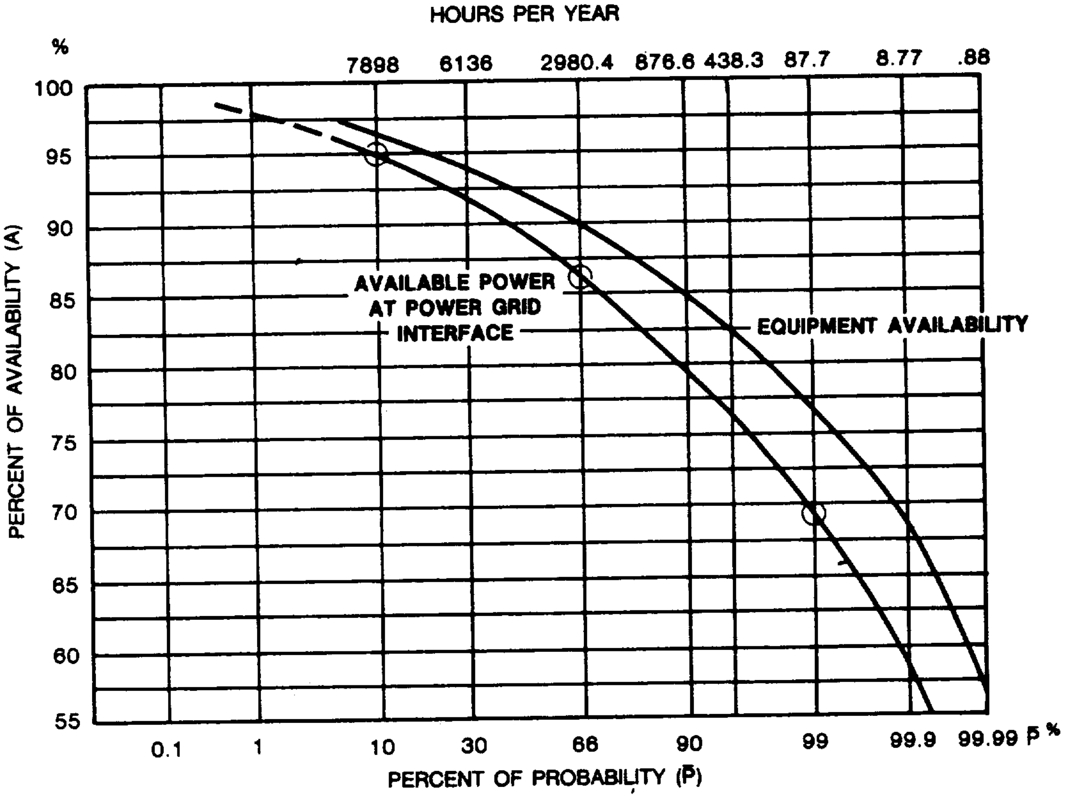

Figure 2. Utility System Reliability SPS Reliability Model