This article will outline the ISS power system, starting with the Solar arrays and moving into stability analysis criteria of the rest of the power management system and loads.

A pinpoint beam of sunlight peeks through a truss-based radiator panel and a primary solar array panel on the ISS in Figure 1. Clouds can be seen over the Earth blanketed by the cold, blackness of space in the background.
The ISS needs power for life support, lighting, communication, experiments, propulsion and pretty much just about everything up there 220 miles above us on Earth. The system design for reliable power in such a remote region is, to say the least, challenging. If you lose power on Earth, you can call the electric company and wait for their service trucks to arrive. If you lose power on the ISS---all on board can perish.

Sunlight is plentiful up there is space, so the natural candidate for power would be solar energy. The design that NASA and its partners came up with for mounting the solar arrays was a “blanket.” The blanket is capable of folding up like an accordion for the launch into space and once in orbit it is deployed and fully spread out to its maximum size by a command from the ground controllers via radio signal.

The arrays always need to face the sun for maximum power efficiency, so gimbals are used to rotate them so that they face the sun all the time. Each of the eight solar arrays is 112 feet long by 39 feet wide. The entire solar array wingspan (240 feet) is longer than that of a Boeing 777 200/300 model, which is 212 feet. Together the arrays contain a total of 262,400 solar cells and cover an area of about 27,000 square feet (2,500 square meters) – more than half the area of a football field.

The 75 to 90 kilowatts of power needed by the ISS is supplied by this acre of solar panels. Eight
miles of wire connects the electrical power system.

Altogether, the four sets of arrays are capable of generating 84 to 120 kilowatts of electricity - enough to provide power more than 40 homes on Earth. To put this in perspective, just think about an active computer and monitor using up to 270 watts or a small refrigerator using about 725 watts.

The solar arrays produce more power than the station needs at one time for the station systems and experiments. When the station is in sunlight, about 60 percent of the electricity that the solar arrays generate is used to charge the station’s batteries. At times, some or all of the solar arrays are in the shadow of Earth or the shadow of part of the station. The on-board batteries power the station during this time.

On the ISS, the electricity does not have to travel as far. The solar arrays convert sunlight to DC power.

The ISS Electric Power System (EPS)

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The ISS power system is the world’s biggest DC power system in space. The Japan Aerospace Exploration Agency (JAXA) did the design and verification of the EPS. Electrical stability is critical in space with astronauts relying on life support systems, lighting, communications, stability controls and experiments. With so many switching regulators and converters in this design, stability had to be verified under all expected load and transient conditions.
The principles of small signal stability apply here for all electrical loads. Using the small signal stability criterion, a minimum gain and phase margin is chosen based on the complex load and source impedance requirements. R.D. Middlebrook introduced this method in 1976 while looking at the interaction of a DC/DC converter and its input electromagnetic interference (EMI) filter. The source impedance, $Z_S$, was the output impedance of the EMI filter. The load impedance, $Z_L$, was the input impedance of the switching regulator. Then stability conditions and performance of the interconnected systems can be derived.

Japan provided the Japanese Experimental Module (JEM) Pressurized Module (PM) attached to the ISS in 2008. The JEM module (called “Kibo”) performed impedance measurements and evaluation at various ISS power interfaces using JEM development models, JEM engineering module and JEM flight module with the ISS simulator during 1997 tests on the ground and then later in orbit. See Figure 5.
The ISS DC/DC Converter Units (DDCUs) in Node-2, in Figure 5, provide 120 VDC secondary power to the JEM Electric Power Distribution Units (PDUs). The JEM PDUs give 120 VDC power to the JEM Power Distribution Boxes (PDBs) and the PDBs in turn provide 120 VDC tertiary power to the JEM electric consumer equipment.

The PDUs and PDBs are critical in that they provide electric isolation of the downstream load and limit the over current and over voltage and hence prevent any fault current from the JEM downstream to the ISS upstream.

An important factor in a stable design on the ISS is for the secondary system to be flexible to handle a variety of cable lengths and loads, including those of future scientific payloads in the coming years.

**ISS Power flow**

ISS power is provided to each module in a 120 VDC bus voltage. See Figure 6
The primary power generated by photovoltaic (PV) modules is at 160 VDC and is distributed by cables to the Direct Current Switching Units (DCSUs). Then the DCSUs provide power to the Main Bus Switching Units (MBSUs) and routed to the DDCUs and then further routed and converted from 160 VDC to 120 VDC as secondary power. The secondary power is then sent to switchgear, cabling, and DC/DC converters to system equipment and payloads in each module throughout the ISS.

**Stability of the power system**

Essentially, two-port network analyses are done to represent the ISS power network. See Figure 7 which shows two system blocks in series. The source block has input-to-output transfer function of $T_s$ and the load block has input-to-output transfer function of $T_l$. 

![Figure 6: ISS power flow diagram (Courtesy of Reference 2)](image)

![Figure 7: A two-port analysis of an Electric Power Network (Courtesy of Reference 2)](image)
Then the transfer function of the source/load combination is equation 1.

\[
T_{sys} = \frac{V_{2B}}{V_{1A}} = \frac{T_S \cdot T_L}{V_{1B}/V_{2A}} = T_S \cdot T_L \frac{1}{1 + (Z_S/Z_L)} = T_S \cdot T_L \frac{1}{1 + T_m}
\]

With \( T_m = \frac{Z_S}{Z_L} \)

(1)

Essentially if \( Z_s \ll Z_L \) for all frequencies, then the input-to-output transfer ratio of the integrated power network, \( T_{sys} \), becomes approximately equal to \( T_S \times T_L \). This means that the integrated electric power network stability is assured over all frequencies.

Now for the impedance gain and phase margins to ensure stability. Using a Nyquist plot, the integrated system stability can be evaluated by plotting \( T_m \), the phase and gain margin of the loop gain. See Figure 8.

![Figure 8: The ISS Electrical system Nyquist plane gain and phase margin showing the “Forbidden Zone” for a 3 dB and 30 degree minimum gain and phase margin criterion. (Courtesy of Reference 2)](image)

So, in order to ensure that all regions of the ISS secondary power system are stable, Users need to follow the small signal stability requirement in the “ISS User Electric Power Specifications and Standards” which states, “The equipment will be designed to maintain minimum of 3 dB gain margin and 30 degree of phase margin at its interface with ISS Electric Power System. These margins apply to the complex ratio of the source impedance divided by load impedance at the interface. The minimum margin requirement will be satisfied over the range of impedance magnitude and phase values that can occur in operation on the ISS at each User’s interface with the ISS Electric Power System.”

The JEM EPS Simulator
Finally, a JEM EPS simulator was developed to perform power distribution, protection, line and source impedance simulation at major points in the JEM to verify stability. See Figure 9.

![Figure 9: The JEM EPS simulator block diagram (Courtesy of Reference 2)](image)

For greater detail and analysis with equations, please refer to Reference 2.

The ISS power system is continually being refined as actual performance is continually monitored over time.

References

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