Power Lander in support of Lunar Exploration and Development

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Abstract: An emerging Lunar industrial base and a sustained manned presence will require consistent high power capacities. Lacking any firm requirements, this paper proposes a first iteration design of a flyable electric power platform and grid as a capability reference. Eventually such a system will serve as an enabler of Lunar Development and Exploration, a single unit supporting a small facility or as part of a grid in support of an emerging industrial base.

Lunar Missions, Habitats and Facilities stand to benefit from an expected decade of non-stop operation, the economics of scale, Commercial Off-The-Shelf (COTS) availability, standardization of design, and logistical support for Lunar encampments provided by this architecture. The unattended and unmanned vehicle design is to be man- and robotics-serviceable after delivery by current and proposed heavy-lift boosters. Design continuity within a family of systems will improve reliability through ‘lessons learned’ in the field.

Further, various configurations of the proposed scalable architecture will provide reference platforms for the indigenous construction of similar power plant facilities from in-situ Lunar resources (ISRU). The baseline design should be directed towards those materials available on the Moon and expected to be manufacturable on-site within the first decade of operation.

Capabilities and Requirements

The PowerLander is proposed series of Power Management And Distribution (PMAD) system/vehicles, for scalable generation and management of Solar and Nuclear Energy; supporting crewed habitats, ‘grounded’ spacecraft and ISRU on the Moon and Mars. The concept allows for the evolution of *functionally identical* units built of indigenous Lunar materials.

Analysis of *in-situ* Resource Utilization (ISRU) and manned habitat needs suggests that one critical factor is electric power. A functional industrial base on the Moon will provide the logistical and industrial backbone for the entire sphere of CisLunar Space, including LEO, MEO, GEO, LaGrangian points, *etc*. Reliable power will be a great enabler of Lunar Exploration and Development. Standardization of design and power support for Lunar encampments provided by the PowerGrid and PowerLander architecture are key enablers of the entire space effort.

The PowerGrid is envisioned as a mass-produceable and standard interconnect for power collection and distribution, supporting crewed habitats, ‘grounded’ spacecraft and ISRU on Moon. A principal component of the system is the PowerLander, a proposed series of Power Management And Distribution (PMAD) system/vehicles for generation of thermal and electrical power. A PowerLander /Solar Module is a platform specific to the collection, conversion and management of Solar Energy. Such a platform is largely a parttime source of power although it would be a fulltime energy management system; see Figure 1.

Generation capacities are scalable through the expedient of adding compatible units to the regional grid. Implementation of ‘productized’ designs removes the need for every Lunar Exploration mission to design, qualify and launch unique power plants. Their Commercial Off-The-Shelf (COTS) availability will be indispensable to mission planners, providing known and standardized facilities to form compatible grids, thus serving as an enabler of Lunar Development and Exploration.

The principal operational advantage of a product is that design continuity within a family of systems will improve reliability through ‘lessons learned’ in the field. Other operational considerations can be designed into the series, *e.g.*, the design allows evolution to functionally identical units built largely of indigenous Lunar materials. These parts will be interchangeable among generations and production blocks of systems. Non-Recurring Engineering (NRE) costs are amortizeable across the life of a standardized family, conventional accounting which also reduces the per-unit costs of sustaining engineering and production.

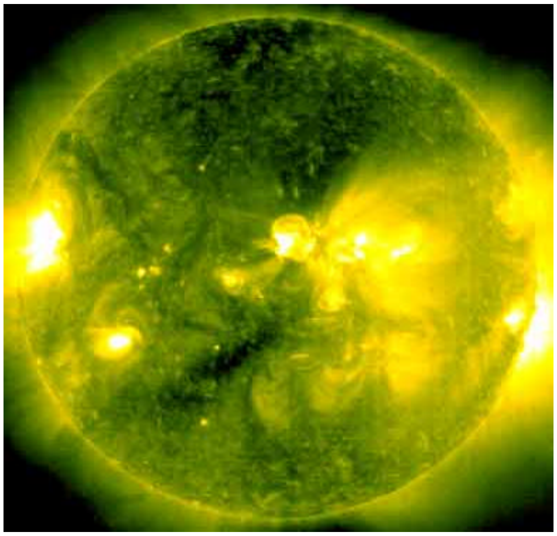

Figure 1. Part-time Source of Lunar Power

Another innovation offered by this system is the Thermal Servo, where the PowerLander serves as both a heat sink as well as a source. Electricity is a service secondary to thermal service reducing demands for electrically-generated heat (dissipative-resistive) normally expected for resource processing. Conductive pre-heating of regolith and other process materials (coarse control) and tool fixtures frees up available electric power for other applications Electrical energy is only necessary to servo the delta between the stack temperature and the process temperature setpoint, allowing precise temperature setting (fine control) to be electronic.

The ISRU community is in the driver's seat with this particular implementation since they offer the bulk of the consumer processes, and consume the heat normally wasted by a conventional electric generator. Expectations are that with any significant amount of ISRU, habitat and industrial shop activities, heat output of power sources of many types will be indispensable. Life in space, even with good insulation, may resemble persistent cold endured by submarine crews in times past.

Conversations with ISRU experts suggests a range of 50 to 250KWe in power demand for industrial process pallets. Given the limitations of current launch hardware, a modest 300KW number is the initial milestone to power both a number of pallets, machine shops or habitats, representing a total system energy capacity of 1MW. The actual mix of electric power and hot fluid demand can be allowed to vary by site, sink configuration, day *versus* night, *etc*.

An examination of one ISRU process, ‘cold’ hydrogen torch extraction of oxygen, confirms the premise presented earlier: a hundred KW of electricity can be used to preheat the hydrogen, or, the hundred KiloWatts can be delivered by a heat exchanger and the final working temperature servoed with AC kilowattage in single digits.

Energy Management Functions will provide supervisory metafunctionality, control redundancy enhancing overall system safety and service availability, assuring reliable power.

The PowerLander enables the entire CisLunar community through the provisioning of electricity and thermal energy to manned outposts and industrial infrastructure on the Moon. Reliable power removes considerable risk from Lunar enterprise.

Grid

In a recent paper[1] the author introduced the concept of implementing 400 cycle (Hertz), 3 Phase Delta Alternating Current as the backbone for development power on the Moon. There are significant advantages to implementing a grid architecture, shrink-wrapped and off-the-shelf, as a precursor to serious exploration. Discrete power plants have more value when deployed in a redundant fashion on a grid, where each unit adds to the total capacity. Each mission which adds to the grid also leaves a PowerLander on the grid once the mission has been completed.

Payload constraints require that any power facility delivered to the Moon be compact and light. These requirements suggest that power generation capacity should be distributed and dispersed, so that power collection closely resembles power distribution over the grid.

While others are developing microwave links for transmitting power long distances, we are proposing three-phase delta, 400 cycle A.C. as a regional grid. Regional grids can be interconnected with microwave into larger service areas. The singular advantage offered by microwave is that it would use less mass per kilometer or a mile of transmission line to implement than a three-phase cable.

The horizon-to-horizon distances on the moon have to be much shorter than the corresponding distance on Earth, which will reduce the range of *line-of-sight* connections. Microwave links have advantage if they can be sited upon mountain ridges without using a tower structure. Microwaves can convey considerable energy from point-to-point but should be considered to be quite an unseen hazard to vehicles and crews when used on the surface in this manner.

Three-phase A.C. power will convey a nearly optimal amount of power for a given wire (cable) guage, especiallly when compared to DC. This means that three lighter guage wires will deliver much more energy than two wires delivering a comparable Direct Current.

The three-phase configuration should be a 'delta' and NOT a 'wye.' A wye presumes a stable ground reference and the Lunar surface is not a practical ground. It has an uncanny resemblance to a deep-water ship which has a multitude of welded and rivetted seams and joints - which defy any electrical continuity reliable enough for power applications, since the ship is constantly corroding due to the presence of caustic water. Such vessels use a three-phase delta to transmit 60 and 400Hz power throughout.

The power in a delta is unreferenced to any ground so that an unreliable ground is not employed as a return path to the generator. Since the power is delivered phase-to-phase rather than phase-to-ground, a delta can also diminish the shock hazard to personnel from accidental contact.

Using 400Hz instead of 60Hz or 50Hz offers a reduction of reactance mass to about one-seventh of the iron and such used terrestrially, which has the practical effect of reducing the requirements for massive transformers.

Another point is that 400Hz is about the end of the line for higher frequencies which can still drive sizeable torques directly and without format translations to DC or higher audio AC frequencies. A longer-range view of the entire power issue would encourage use of a practical alternating current instead of direct current for long-distance distribution and collection of power over a 'grid.'

Regeneration is the practice of using inductors (L) and capacitors (C), which are generally not resistive, or minimally so for a given reactance, in place of those components which are resistive and dissipate power. This can be accomplished in power transmission and power supplies by the careful application of switching diodes, Ls and Cs - and proper 'tuning' of the formerly resistive circuit. The object of the exercise is to return the energy back into the working cycle.

Applying regenerative methods used in high-efficiency power supplies to external transmission lines considerably simplifies assembly and robust operation of *ad hoc* power grids. These methods make the transmission lines quite tolerant of all sorts of noise and impedance issues.

Power Conditioning and a Regenerative Power Filter

Since the moon lacks a magnetosphere or an ionosphere it is susceptible to impinging electromagnetic fields from the sun and other sources. AC transmission lines can operate without shielding since filter circuits can be attached to the lines, thereby minimizing additional hardware like metallic conduit or sheath. This simplifies the ISRU issues, where an indigenous wire need only have an insulator on the outside.

The long cables of the grid also serve as an 'antenna', absorbing electromagnetic energy with long wavelengths. The conventional solution is to attempt to block such signals or shunt them off of the grid. With regenerative filter circuits any electromagnetic impulses originating as solar disturbances can be captured and applied to the grid; see Figure 2.

A Common Mode filter has windings which are 180° out-of-phase cancelling out noise which is ‘common’ to both signal lines by applying the inverted signal into the true signal. A Differential Mode filter has windings which are in-phase and so cancels out noise which ‘differs’ between two signals, or that which is ‘unique’ to either signal.

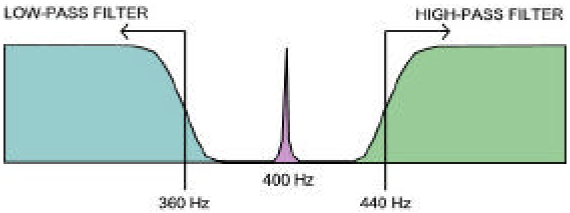

Figure 2. 400Hz Bandpass Filter

Phase-to-phase filter circuits translate impedance mismatches, DC, surge, ringing, phase-imbalances, switching transients and power factor correction on long distance transmission lines into energy opportunities, gating the power events significantly higher or lower than 400Hz into storage capacitors. The noise can be generated when power is switched and inductive ‘flyback’ and other phenomenon are not properly handled.

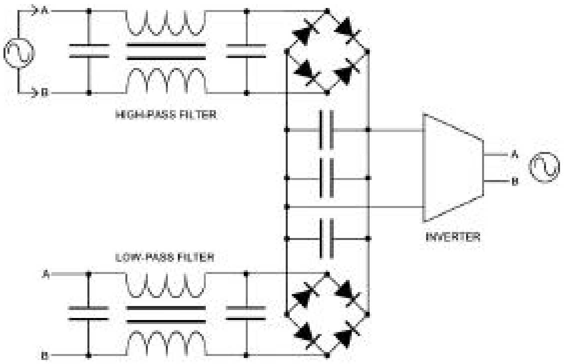

Figure 3. Regenerative Line Filter Subsystem

A rejection filter depicted in Figure 3 will ignore the 400Hz power signal plus or minus a 10% tolerance, routing only the offending noise through the high and low pass filters, rectifying and storing energy briefly in capacitors. Batteries can be used in parallel to the storage capacitors since they are, for all practical purposes, capacitors with a long time constant suitable for DC. This would provide the facility of storing extremely low frequencies and DC signal components, as well as delivering a higher instantaneous current to the inverter for conversion. Batteries and capacitors are complementary and serve to keep each other charged to the maximum available voltage.

After the power has settled down the inverter converts the captured energy to 400Hz AC and re-applies it to the grid, in-phase. Such a scheme may be implemented with a modest amount of hardware and one phase-to-phase filter (A - B) is depicted in figure 3.

Heat Service Loop

An essential difference between a conventional power model and PowerLander is the inversion of the usual power-generating paradigm in favor of a model driven by providing heat for ISRU industrial processes. Since ISRU activities require large flows of heat, heat becomes the principal utility provided by the system and electricity a secondary production. If the generator should be 30 to 40% efficient, then the heat source will provide 70 to 60% of the energy available from the system to endothermic processes.

The usual characterization of a powerplant is in terms of its' electric output, say 250KWe, dissipating the remaining 750KW as heat to vacuum. The PowerLander paradigm would insist that the system is a One MegaWatt facility providing 750KW of thermal energy and 250KWe of electrical energy to habitats and industrial processes.

With any significant amount of ISRU, habitat and industrial shops, heat output of power sources of many types will be valuable. Conductive pre-heating of regolith and other process materials (coarse control) and tools *frees up available electric power* for other applications. Electricity is also used to close the delta between available stack heat and the servo setpoint, allowing precise temperature setting (fine control) to be electronic.

The integration and adaptation of thermal power service to customers improves the economics of electrical power on the Moon. This is accomplished because 1) the thermal energy is consumed and not wasted, 2) a large radiator complex is considerably reduced in size, 3) electrical energy, derived at a diminished efficiency index, is not so obviously wasted by consuming electricity to redundantly produce industrial heat.

The condenser or heatsink exchanger is the point in the coolant loop where the surplus heat is transferred to industrial process (working) fluids or heatpipe fittings. This keeps the total plumbing loop small.

Standardized fittings allow thermal users a variety of process fluids, assuming that the plumbing and fittings are somewhat universal, using stainless steel or equivalent. This would allow a wide choice of working fluids: nitrogen, ammonia, helium, hydrogen, steam, freon, oils and so on.

An alternative to the fluid heat exchange is to use heatpipe-based conductive connections. This option is really a special case of fluid heat exchange and may not be practical in implementation because of the necessary mechanical interconnect.

Another innovation offered by this system is that of a Thermal Servo. The limit of the sink capacity is the radiator array, since it must handle the basic thermal load of generating electricity, assuming a zero heat load from any consumer processes. Field upgrades of water reservoirs and DC thermoelectric modules can further expand the overall system capacity with the continous improvement in efficiencies.

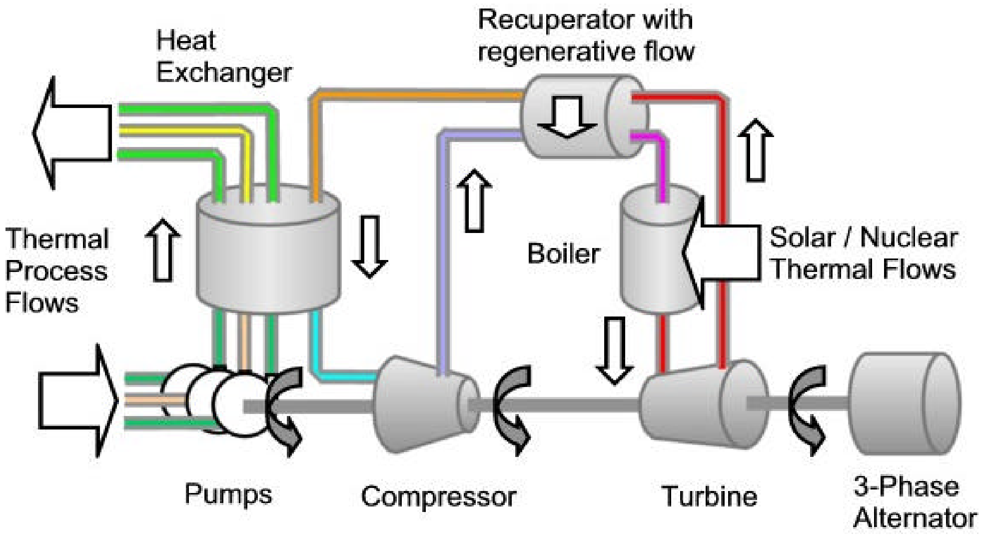

Figure 4. Brayton Solar Dynamic 400Hz PowerPlant Schematic

Brayton Cycle Alternator

The Brayton Cycle is thermally driven and is a distant cousin of steam turbine technology found aboard WWII vintage ships. Primary enhancements to earlier technologies includes the compressor driven by the turbine serves to increase the density of the hotside working fluid. This method further improves efficiency through the regenerative expediency of preheating the hot side fluid with the excess heat still available after the turbine. The temperature differential of the pre-compressor fluid versus post-turbine is narrower than the absolute operating temperature would suggest.

Significant heat still remains in the fluid which is ‘dumped’ in the Heat Exchanger to downstream habitat and industrial consumers, this is the point where industrial pallets can gain many BTUs for processing lunar regolith.

A large advantage of the Brayton system of Figure 4 is also a safety feature: the coolant remains in a small confinement and does not follow a ‘risky’ path through the radiator plumbing, a path which probably includes flex-joints required for deployment of the radiator from its' stowed transport position. Since the coolant is a gas, it works in a linear thermal region since it doesn't undergo phase changes to do its job.

Dual seal technologies are commercially available which provide three layers of barrier between coolant or working fluids and ambient, whether shirtsleeve or vacuum. These seals also communicate with a supervisory control to indicate whether leaks, bearing seizure or other failure has occurred or is imminent.

Generation of 400Hz power is accomplished with a rotating alternator, an electromechanical component which translates hot fluid flow into substantial wattage. With magnetic bearings, wired Stators and no commutators these plants should have a very high MTBF. A dual-turbine, dual-alternator configuration is recommended for redundancy as well as extending service life when loads are light and the units can alternate service.

An inverter in the 100 to 300KW capacity class would be substantial in size and mass and would be, optimistically, 95% efficient. This figure, in series with a generous figure of 20% for thermoelectric or thermionic primary conversion would offer a 19% efficiency. This compares to 30 to 40% for a rotating alternator system before optimizations are applied. There are available in the specialty power supply market switching power supplies with efficiencies in excess of 90%, and these proposed inverters employ the same technologies which we would suggest for smaller inverters - units imbedded in the regenerative filter subsystem.

Solar Furnace

Solar reflectors focus sunlight into an optical waveguide which is a fiber-optic bundle. This eliminates elaborate and failure-prone fittings and plumbing between the fixed platform and the two axis pivot of the collector. The parabolic arc of the reflector redirects all incident radiant energy to the focus, which is the lens of the optical waveguide. The solar reflectors heat coolant in the boiler which drives the Brayton Cycle alternators.

Nakamura, Comaskey and Bell[2] inspired the use of fiber-optic bundles to convey solar energy to the boilers. The flexibility of the glass fibers should survive ten years of slowly tracking the sun through the lunar sky. This coupling removes very risky flexible plumbing.

The Solar Furnace-based system utilizes heat (60-70%) as the primary service while three-phase alternators provide electricity for exploration, habitation and APU support for vehicles.

The parabolic reflector ‘nods’ on a horizontal axis and can rotate continuously around the vertical centerline of the vehicle, now the base. After sunset the reflector will be pointing at the horizon and the entire ensemble is rotated nearly 180° to the sunrise horizon, waiting about 336 hours for the sun's return. The Thermal Servo can adjust the solar input to the total thermal power demands through the simple expedient of pointing away from the direct solar bearing by a small angle.

Nuclear Reactor

A nuclear reactor can generate power nonstop, or be modulated by alternating operation with the solar furnace. There exists prior art which will determine the details here. Dual reactors would provide redundancy which can be configured for additional capacity or extending the lifespan or as spares for another unit.

For service considerations, the reactor can be imbedded into the Lunar surface after a hole has been bored and compacted with a binding agent. When the reactor itself must be serviced it is hoisted out of the hole, otherwise it uses a few meters of regolith for first level shielding. This reduces the amount of shielding shipped to the Moon to an upper cap which shields the PowerLander/Nuclear from the ‘hot’ reactor, allowing crew to service the Lander Module.

Solar furnace in tandem with nuclear reactor plumbing nearly doubles the service life of fissionable nuclear fuel cores, because either or both can drive the Brayton Cycle alternators. There will be some overlap during the transitions from day to night to day.

Thermal & Power Management

Interface standards will be devised for secondary power sources, including solar cell farms, electrochemical, nuclear/RTG plants, MHD and thermoelectric/thermionic stacks. Coolant interfaces will also be developed for thermoelectric generators and nuclear reactors to share coolant loops with solar-based PMAD.

Radiator petals are installed on the shadow side opposite the solar collector reflectors on the sunward-facing side; a dual use of the same structures for little additional mass.

PowerLander as a Spacecraft

The initial expectation is that Solar-based PowerLander PMAD vehicles can form grids with a mix of Solar Furnace, solar cell farms and Nuclear PowerPlants. The PowerLander descends to the Lunar surface and is positioned under automatic control. Frangible pads on the lander collapse upon touchdown, considerably reducing land-ing gear mass in favor of useful payloads. These pads also allow the PowerLander to be 'dragged' to a better position on the site.

With the addition of robot-friendly mechanics, electronics and protocol, a grid of Landers will be prepositioned and wired robotically.

Waistband of Solar Cells

As long as the vehicle is upright solar cells can collect sufficient power to reactivate the control and communications systems if a major fault were to take the powerplant down. Excess output from these cells is routed to the primary regenerative filters when not servicing loads.

Auxiliary Power Inputs

All external inputs from farms of solar cells and other miscellaneous AC and DC inputs are diode switched through the regenerative filters and therefore, to the primary power grid. Through the double layer of electric servo and thermal servos any auxilliary power input proportionately reduces the primary energy generation or supports additional load.

Line Switches/Breakers

To avoid damage from out-of-spec transients, the module is equipped with line switches and circuit breakers. These may be remotely monitored, cycled and serviced.

Navigation Beacon

Unless a Moon-local GPS satellite constellation is in place, a VOR or other Omni-Directional signal source would be situated high on the structure for use by suited Astronauts as well as orbital craft. There is a large reliability advantage to be gained when the power is so closely coupled to the transmitter. The plant would also sport red beacons and flashing strobes to facilitate visual acquisition of the installation, and the inevitable use of the plant as a landmark, much like grain elevators in the MidWest.

Cabling

The powerplant also would have one or more bays containing a length of cable. This would be used for connection to the power demand or to connect to the 'grid.' Plumbing, hoses and fittings for the process fluids would be supplied by consuming Industrial Pallets.

Modular Scalability

Versatile by design, PowerLander's modularity encourages enhancements, extensions and upgrades, evolving to meet new requirements. The PowerGrid is supported by point-to-point interconnects of PowerLander Modules, which are one of a small number of types. Module types would include, and not be limited to, specific functions:

- ✧ PowerLander/Solar
- ✧ PowerLander/Nuclear
- ✧ PowerLander/Microwave
- ✧ and CableLander.

Other, still hypothetical, power sources might be integral with ISRU industrial process. These might be thermoelectric/thermionic or MHD in nature, attempting to recapture some of the excess system energy which may exist in some industrial processes.

While the grid can be expanded into a regional service the fluid heat service will be local due to limitations on hose lengths and thermal losses.

Serviceability

Designed for long service life, reuseability for multiple missions and durability, platforms are serviceable by suited service personnel or robotic auxilliary.

Many subsystem modules are repairable in a shop or lab although some sub-subsystems or components may not be repairable at a 'depot' level and may require replacement from the original manufacturer. These parts are usually precision-machined, special assemblies or high-density, high-performance circuit boards.

One assembly which will require special attention will be the optical waveguide since it snakes its way from the focus to the boiler.

Unattended Operations

Much of the installation, maintenance and operation of the devices described here may be performed remotely. High MTBFs and design simplicity (*e.g.*, fiberoptic waveguide) are used to advantage to minimize single points of failure and the need for a service representative to make an appearance. Prepositioning multiple platforms to establish a power grid redundancy would enable deployment of ISRU operations prior to crew arrival.

Comparative View

When a solar furnace is compared to other technologies, the result is favorable. Solar furnace-based technologies (30-40%) are superior to solar cells (6-8%) in conversion efficiency, collector area, reliability and yield. Solar cells offer NO useable HEAT OUTPUT and single-digit conversion efficiencies - solar furnace has valuable residual heat (60-70%) after generating electricity.

For a given demand for electric power a corresponding area of solar cells is required for daytime operation. To operate the same facility full-time, instead of shutting down during the Lunar Night, requires an additional two to three times the area of solar cells. The total capacity required is 4x the daytime solar cell area, see Appendix A, Continuous Solar Energy Delivery Model.

Conversion efficiency for batteries and fuel cells varies widely and is dependent upon operating temperature and other factors, including electrolyte chemistry. The mass of batteries is often overlooked in discussions of solar cell power scenarios. Additional masses of cables and connectors for power collection will add mass disproportionate to lightweight solar panels. Any mounting hardware required to position the panel optimally to the sun will further add to the mass budget and installation complexity.

Installation of solar panels can be labor intensive unless the process is maximally automated. Two interferences to solar panel operation are micrometeoroids and regolith dust. The former abrades the optical surface of the cell and occasionally penetrates the substrate. The latter quickly obscures the already inefficient cells causing a miserly power yield and the presence of the abrasive regolith directly on the panel creates an opportunity to marr the optical finish if they are mechanically ‘cleaned.’

It is not suggested that solar cells do not have utility or advantage. The point is that when measured *in toto*, the mass to be transported to the Moon for deployment is far less effective than a comparable solar furnace. Pending studies will quantify this assertion in the near future. It has been suggested that solar cells be manufactured on the Moon and employed in space, a more benign environment with a higher duty cycle for operation.

A ‘hidden’ advantage that the tandem Solar and Nuclear PowerLanders offer is the ability to deliver a 200% Peak Capacity if an energy emergency must be met. This would be during the Lunar day with both plant types operating.

Robustness in Redundancy

Designing for ‘hot spares’ provides a fault tolerance not otherwise available. Having twin nuclear cores in tandem with the Solar Furnace, twin Brayton Alternators and control redundancies allows for several configurations to be available *on-the-fly*. These features when combined with other scalable units on the grid provides maximum assurance of mission and settlement success.

Summary

The complexity and value to Lunar Exploration and Development strongly argues that powerplants should be prepositioned on the Lunar surface in advance of automated industry and crewed habitats. ISRU will be capable of augmenting these power facilities with indigenously-derived silicon solar cells and other collection and storage technologies which the PowerLander can integrate and manage as a grid asset. Solar cell technologies may not be a realistic backbone of Lunar Exploration and Development scenarios. The appeal of Solar Cells is esthetic, while in practice on the Lunar and Martian surfaces their application will be found to be limited. Flight and Exploration Crews should not be at risk for lack of high energy sources.

The power supplies for the second wave exploration effort should be reliable and high performance, and should not potentially be cast as the risk proposition. There are many

ISRU opportunities which are fundamental to exploration and development efforts. These opportunities will require energy for success.

The PowerLander, while borrowing heavily from prior art, offers novel ‘tweaks’ to the current paradigms: 1) development of a space-qualified, *production* powerplant; 2) the principal powerplant output is *heat* for industry and habitats; 3) the secondary output is 400 cycle, 3-phase *AC electric power*; 4) the PowerLander Thermal Servomechanism will serve as both a heat sink as well as a source; 5) the grid provides for scalability and realtime operational redundancy; 6) the reference design manufactured on Earth will evolve into a unit interoperational and interchangeable with those built of Lunar indigenous materials.

PowerLander can provide sustained high-impulse energy to assure long duration mission success.

Power Lander in support of Lunar Exploration and Development

Requirements for Solar Cell Power Production to a normalized unit

Dominated by the efficiency of the Storage Batteries
Charge/Discharge assumed to be symmetric
Stacked efficiencies is product, *e.g.*, 0.9^5 => 0.59

		Direct Consumption	**Storage w/25% efficiency**	**Storage w/42% efficiency**	**Storage w/56% efficiency**
Area	units	100	300	300	300
Power	units	100	300	300	300
DC Regulator Efficiency			0.9	0.9	0.9
Output to Mains	units		270	270	270
Storage Efficiency			0.5	0.65	0.75
Stored Power	units		135	175.5	202.5
Source Efficiency			0.5	0.65	0.75
Recovered Power	units		67.5	114.075	151.875
Inverter Efficiency		0.9	0.9	0.9	0.9
Output to Mains	units	90	60.75	102.6675	136.6875

Appendix A. Continuous Solar Energy Delivery Model

Curriculum Vitae

Claude Russell Joyner II
Discipline Chief, Pratt & Whitney Space Propulsion
Expertise: Space System and Propulsion Design

Mr. Joyner is Discipline Chief for Space Systems and Mission Analysis at Pratt & Whitney Space Propulsion. He has 25 years experience in the gas turbine and rocket propulsion field and most recently heads up the advanced in-space propulsion efforts and developing advanced concept design processes. Relevant Publications: ‘A Closed Brayton Power Conversion Unit Concept for Nuclear Electric Propulsion for Deep Space Missions’, 2003, STAIF Conference, ‘Closed Brayton Power Conversion Unit Coupled to a Gas Cooled Reactor for Nuclear Electric Propulsion for Deep Space Missions’, Adv. Space Propulsion Workshop, 2002, Education: Masters of Science Space Studies.

Curriculum Vitae

Gary ‘ROD’ Rodriguez
President and Systems Architect, *sys*RAND Corporation

A bits and bolts technologist from 'way back, Rod designs and develops products with electronics or intelligence content for the industrial world. His oil patch, avionics, mining, systems and industrial automation customers have mass-produced his designs in oil well controllers installed on five continents, avionics flying in commercial and military fleets worldwide as well as the President's Helicopter Fleet, specialized test equipment and numerous other products. These devices are often, although not exclusively, embedded controllers operating in hazardous environments.

He holds a Bachelor's degree in Math and Computer Science, having grown up with computers since the sixties. He is a VietNam-era veteran and a sometimes-current private pilot.

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[1] *Power Architectures for Lunar Resource Development*, Space Resources Roundtable, Lunar/Planetary Institute, Oct. 2003, Michael Duke presiding.

[2] Development of Optical Components for Space-Based Solar Power System for ISRU and Regenerative Life Support, AIAA 2002-0462, T. Nakamura, B Comaskey, M. Bell.