

## The Impact of Photovoltaic Generator Cost on Future Balance of Systems Technology Development with Reference to Pumping Systems

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### ABSTRACT

The successful expansion of the global use of photovoltaic generators (PVG) have resulted in an increased demand for PVG and accompanying reduction in cost. Higher reliability and the historical knowledge of life time behaviour of such generators place photovoltaic generators positively in the commercial arena of today as part of the energy landscape.

In sympathy with the status of PVG, the development of balance of system components (BOS) is also exposed to evolutionary characteristics present in its future. Ironically the past high cost of PVG guided technological development of BOS components in directions that may have resulted in lesser reliability, higher cost of such components, reduced serviceability, and diminished integration opportunity with existing infrastructure as well as aided the development of a wide range of diverse technologies to address specific functional needs, thereby complicating product offering.

An example of such a situation is found in water pumping systems. This study investigates the available product in the water pumping market, suitable for PVG operation and analyses trends and future direction. Applicable technology and materials development, product characteristics, envisaged market behaviour and expected product development trends are followed to ascertain the market behaviour and to determine the best way forward in new product development and product commercialisation.

The results presented include the impact of local market needs versus available global technologies, products and solutions and illustrates the increasing need and demand for local solutions, based on local market infrastructure such as manufacturing, knowledge and service and resource availability.

Conclusions include the, as yet, subliminal but possible significant impact that the PVG and accompanying BOS industry developments are starting to exhibit on the installed world of electricity and electrical power characteristics, with accompanying equipment as we know it today.

### NOMENCLATURE

AC	- alternating current
AM	- asynchronous motor
DC	- direct current
BOS	- Balance of Systems
MPPT	- maximum power point tracking
PM	- permanent magnet
PV System	- Photovoltaic System
PVG	- Photovoltaic Generator/s (from single panel to array of panels)
W	- watts
Wp	- watts peak

### INTRODUCTION

Various aspects influence the development of technology in any particular industry. In the case of PVG high cost at the time of inception demanded that efficiency of the BOS components were paramount and acted as a significant driver for technology and product development. Materials selection and technologies of choice were not necessarily in line with the main stream electrical and water pumping industry. In the area of water pumping this is demonstrated by selection of motors, pumps and power conversion components (power electronics such as inverters and DC/DC converters).

As the cost contribution of the PVG is reducing (considerably so in the last years) [1] the focus of industry is shifting towards finding better solutions in the BOS arena. Various opportunities exist since there are several cost components that make up the BOS portion of a PV system. These include soft issues, commercial issues, logistical issues and product issues. All of the above play a more or lesser role in the direction technology development is taking, resulting in the most appropriate products for future PV Systems.

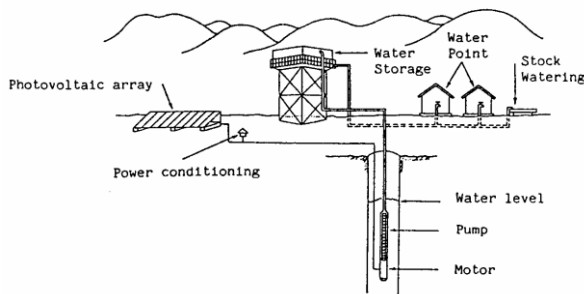
It is important to note that the more successful products to emerge probably will be the result of comprehensive product development programmes or processes, including inputs such as the "Voice of the Customer (VOC)" and even the "Hidden Voice of the Customer (HVOC)" [2]. This is brought about by

the fact that such a significant portion of the PV System cost is now taken up in commercial and other soft issues. It is not only hard technology that is driving the development process anymore.

Aspect such as available in-house technologies, infrastructure, manufacturing capabilities and supply chains are starting to play a major role in shaping BOS products becoming available. The water pumping industry serves as a particular example of this situation.

## SOLAR POWERED WATER PUMPING INDUSTRY

A PV water pumping system is made up of several components that are typical of a somewhat more complicated PV System.



**Figure 1** Typical solar powered water pumping system

Such components include a photovoltaic array or photovoltaic generator, a power conditioner or converter (DC/AC inverter or dc/dc converter), electric motor (DC or AC either of inductive or permanent magnet design), pump (various technologies are found in this application, including centrifugal and several positive displacement techniques), piping, cabling and also water storage.

In the case of sub-surface (borehole or well) applications, the development of the borehole or well, as well as the cost of installation form a very significant part of the overall system cost. In the traditional borehole or well market, serviced by conventional electrical supply, products found in industry reach reliability and life time exceeding 10 years and even 15 years today. These components comprise virtual non-wear design and very wide range of specification such as installation depths of up to 300 meters, which cater for the wide anticipated installation possibilities and eventualities. Where such known industry needs are not met, premature failures occurred.

### Available product

The available product in the PV solar pumping systems environment span several decades since it was one of the first lucrative applications of PV power. For this reason many different products are still found in the market place that may have been more appropriate in the early years due to high efficiency, especially in the low power environment up to 300-500W. These pumps usually comprised a diaphragm pump or piston pump with dc motor of the brushed variety and later brushless. While extremely good efficiencies are achieved it

comes at a cost since interference fit designs or designs that contain wear surfaces such as diaphragm pumps are intolerant to grid and solids in the water.

In the meantime the borehole and well industry have all but optimised centrifugal multistage pumps for general pumping applications but not with a focus on efficiency. Additionally, although industry used and uses surface driven progressing cavity pumps with great success, the general industry have not pursued other options such as progressing cavity pumps for general application in submersible borehole or wells pumps, especially after the successful introduction of the multistage centrifugal pump, directly coupled to the submersible borehole motor, developed around the early 1970s.

Power conversion product (inverters, drives and regulators) followed the same route. Inverters (AC/AC and DC/AC converters) were more complicated, costly and less reliable than DC/DC converters until the late 1990s and that resulted in a preference given to dc motors and dc/dc power conversion equipment. However, since the early 2000s main stream drive manufacturers started offering solar water pump drives, indicating that standard AC drives technology is now competitive with any other form of power conversion, including dc/dc converters.

It is informative to work through the actual technology development and to follow the digression from technology (seeking maximum efficiency) as main driver through to commercial aspects and soft BOS (see later) taking over and how that is influencing the product development focus.

### Past technology development - 20th century

The past technology development (up until the late 1980s) gave preference to an efficiency focus since PVG prices at the time were such that it contributed up to 80% of the PV System cost. As pumping systems - especially liquid pumping systems - has been around for some time the least effort route was to lend from other applications where controlled liquids were pumped such as fuel or potable drinking water in the camping environment. These pumps (low power, compact, high efficiency and often dc powered) were aptly suited for adaption to pump water from pits, dams and boreholes.

Power ranges were limited to below 500W. This was acceptable at the time since large array installations were too costly due to the price of PVG. Many of these products are still available today. For large systems where institutional bodies were involved (and cost acceptable) existing pumps and motors were used, powered by dedicated variable speed drives, designed to handle PVG as supply source, making use of maximum power point tracking (MPPT) capabilities.

### New technology development – 21st century

At the start of the 21st century, development of solar powered water pumping systems became the target of mainstream manufacturers of components utilised in such systems. Drive manufacturers started to develop solar pump inverters based on existing product lines, pump manufacturers invested in improving the efficiency of existing pump products and motor manufacturers increased their interest in improving

motor efficiency and investigating other technologies with the aim of improving efficiency.

Some of these manufacturers had already developed complete pumping systems including components not part of their mainstream range of products and utilising technologies outside of their normal expertise and production. However the current trend is to rather improve core products to better meet the needs of a solar powered pumping system.

Established variable speed drive manufacturers are making wide ranges of solar powered drives available, building on their existing successful product ranges, incorporating high quality and proven features and benefits for which development costs have already been recuperated and distribution channels established. Examples are ABB, Vacon, Schneider and others. Pump and motor manufacturers are working on and investigating opportunities to increase products' efficiency, either spun off from existing product ranges or implementing new technologies (functional and material) to achieve higher operational efficiencies.

### Product characteristics

Typical product characteristics are divided into two groups. These groups consist of low power and high power systems. This categorisation is broad and overlap exists between the groups. However, the technologies employed and the logistical support for the groups may vary significantly. Typical information gathered from company catalogues, representatives and websites are captured in Table 1 - Manufacturers of submersible solar-powered pumps.

**Table 1** Manufacturers/suppliers of solar powered water pumps [3]

Brand	Model/Series	Power Requirements/Ranges			Max Lift (feet)	Max Capacity (gpm)
		Voltage Range (volts)	Power (watts)	Max. Current (amps)		
Div watt	Solastar-3B	34-85 DC	1200	12	656	6.0
Fluixnos	Solaflux	20-70 DC	20-300	~4	492	4.2
Lorentz	PS150, PS1800 PS200, PS600, PS1200	12-50 DC	450/1400	~12.5	39-197	21.7-72.0
		24-48 DC	1200	Con-D	165-760	10-45
Grundfos	16SQF-10, 25SQF-3, 25SQF-6 40SQF-3, 40SQF-5, 60SQF-3, 75SQF-3	30-300 DC or 90-240 AC	1400	Con-D	50-100	25-75
		30-300 DC or 90-240 AC	900	Con-D	325-525	3.0-11
Kycocera	SD-Series SC-Series 500 and 1000	12-30 DC	20-140	10	100-230	2.4-4.5
		60-120 DC	140-1000	14	98.4 - 525	3.7-43
Solarjack	SDS Series - no longer made	12-24 DC	Con-D	Con-D	Con-D	Con-D
	SDS Series - no longer made	30-180 DC	140-2880	Con-D	800	50.0
Shurflo	9300	24 DC	155	4.6	230	2.0
Sun Pumps	SDS-Series SCS-Series (1/2 to 2 HP motors)	12-30 DC	95-184	6 7.1 -	115-230	1.3-5.0
		30-180 DC	320-2070	11.5	30-65	4.0-70
NAPS	SP-Series 400 and 1500	2 45-90 DC	150-1600	Con-D	43-656	0.64-30.1

The following points are noteworthy: voltages are mostly low; power is limited to 3kW and usually less than 1.5kW. Motors are DC and AC, PM or AM, while pumps are of varied technologies including piston, diaphragm, progressing cavity and centrifugal.

Often, where higher powers are required, company literature will simply refer to selecting standard three phase pumps and motors powered by VFD with MPPT. Such standard products are well documented and logistically supported within the company.

There seems to be a clear divide between "small solar pump kits" and larger "solar pump components". Considering cost and performance the "smaller" systems, which are of higher efficiency (compared to downscaling the larger components) end up being competitive since lesser rated PVG are required or so it seems. There is however a cost, often hidden and only uncovered later when growth is stumped. The distribution of these 'historically embedded' systems takes place at the cost of using specialised pumps, motors and materials (non-standard borehole equipment) that do not enjoy the same logistical support with respect to availability, cost, technical support and expertise market wide.

This results in higher cost on the BOS side and since PVG costs are reducing drastically, a shift in changeover from low power special system to higher power standard system is taking place. What is it that established these products so firmly in the historical solar water pump market place?

### Market behaviour and trends

In any specialised market, the end-user is often led by the supplier or installer, especially in cases where the end-user purchases one or perhaps two solar powered pumps in his life time.

However, where a farmer, or utility provider make several purchases of solar pumping systems and need to deal with the soft issues of maintenance, repair, operation and are exposed changing models, spares, technologies and even sources over time, it becomes cumbersome, a concern and costly. The original advantage of lower cost small systems start to dwindle and must now compete with standard technologies, even though 20-50% more panel power may be required.

Where customers are exposed to the availability of standard components for borehole pumping equipment the interest almost always peaks and the matter of serviceability, availability and enhanced support gets the attention.

### IMPACT OF (PAST) HIGH PVG COST ON (PAST) BOS TECHNOLOGY

While not always immediately visible, the past high cost of PVG had a significant impact on the direction that the development of solar powered water pumps took and that it diverged visibly from the traditional water pumping industry. This study aims to point out the divergence and suggest the likely way forward to serve the proliferation of solar powered water pumping systems.

## **Perceptions with respect to efficiency, technologies and systems**

Perceptions (and real technology and commercial barriers) that exist and may impede the assimilation of solar powered water pumping systems in the general water pumping industry include efficiency considerations, motor and pump technologies used and the selection of suitable photovoltaic array sizes.

### ***Energy conversion efficiency – not the same as power conversion efficiency.***

While energy conversion efficiency remains paramount, it should not be a deterring agent in the design stages of a solar powered water pumping system. The danger lies in considering each subsystem component individually and targeting maximum efficiency for the latter. When considering the complete solar powered water pumping system – from design to commercial delivery – conversion efficiency focus may shift to include other significant attributes. Energy conversion efficiency should also not impede or take unwarranted priority over product availability, serviceability and integrateability factors during the design process.

While energy conversion efficiency was more important at a time when photovoltaic modules were priced disproportionately higher than other balance of system (BOS) components that is not the case today. In addition, new insight obtained with a systems design approach also opens up new reasons and motivations to reconsider subsystem efficiencies.

Another important factor is the difference between energy conversion efficiency and power conversion efficiency. Power conversion efficiency may be high but still result in a lesser energy conversion efficiency. Power performance measurement is instantaneous but not so for energy performance measurement. When varying conditions (such as insolation levels) and extended measurements (such as performance over a solar day are involved, verification and validation become more complicated.

### ***Technology superiority – often application specific***

The development of systems solutions should not be impacted on negatively by focusing on specific superior attributes of certain technological solution. Such examples (within the current subject matter) would include:

- Using pump technologies with relatively high efficiencies but designed to pump controlled liquids (no solids, clean) and designed to be cleaned regularly, this is not practical in borehole applications
- Using high efficiency motor technologies that are less suitable for liquid filled motors such as permanent magnet designs since windage and friction losses erode advantages
- Applying low production volume technologies in areas where alternative technologies are produced in orders of magnitude higher volume
- Relying on technology solutions that are difficult to service and maintain since the infrastructure does not exist to provide such maintenance
- Excluding technologies because of the perceived advantages of other competing technologies and thereby sacrificing a representative market offering such as may be

the case when arguing the efficiency advantages of progressing cavity pumps versus centrifugal multistage pumps and in the process losing sight of the fact that at higher flows and lower head conditions the opposite applies

- Forcing less appropriate technologies into moulds that do not suite it, such as offering photovoltaic modules at lower power ratings on pump applications to attain the higher voltage required to operate motor/pump assemblies up to nominal speeds, often resulting in higher photovoltaic per watt cost.

### ***Systems – a case where the parts are less than the whole***

In cases where system components are offered as separate boxed and itemised products, leaving it to the sales representative or customer to make informed decisions sometimes leave the situation wanting. Compatibility and fit are not always obvious and optimum. Design tools and integrated designs can alleviate such issues but need to be addressed at the design and conceptualisation stages to ensure congruent solutions that address the market demand.

It may be necessary to consider a modified business model in order to offer the right solution to the market. A telling example is the dilemma that a typical motor manufacturer experiences, should it consider moving into the solar pump market after identifying a particular pump technology that offers a good solution. Should such a motor manufacturer rely on the customer to make the right purchasing decision? Another example would be the case where a pump and motor manufacturer relies on the customer or user to purchase the right photovoltaic module from a module supplier without understanding the necessary detail and gravity of the module quality and specification. In both cases the offering of an optimum systems solution may be lost if such manufacturers do not expand their offering into areas of unfamiliar territory or new business models.

The case of solar powered water pumping systems is a good example of a more difficult system solution that may be experienced. Several disciplines make up the compounded system, with all components or subsystems relying on the other to be compatible, while at the same time adding variability to the mix. The designer of such a system needs to take cognisance of limited energy availability whereas in the past the selling of an incorrectly sized pumping system which may have resulted in excessive energy efficiency went unnoticed. Variability starts to impact since solar module selection is now not only dependent on delivered power but also delivered voltages.

When complex system designs are considered it often results in a proportionate committee size to deal with the design and development, with the accompanying result that subsystems are allocated to different teams. Often the end result “separates” into speciality subsystems which do not support the original market demand or even the original concept.

### ***Cost, availability and integratability***

If lower power pumps and motors, manufactured with alternative technologies, materials and production methodology

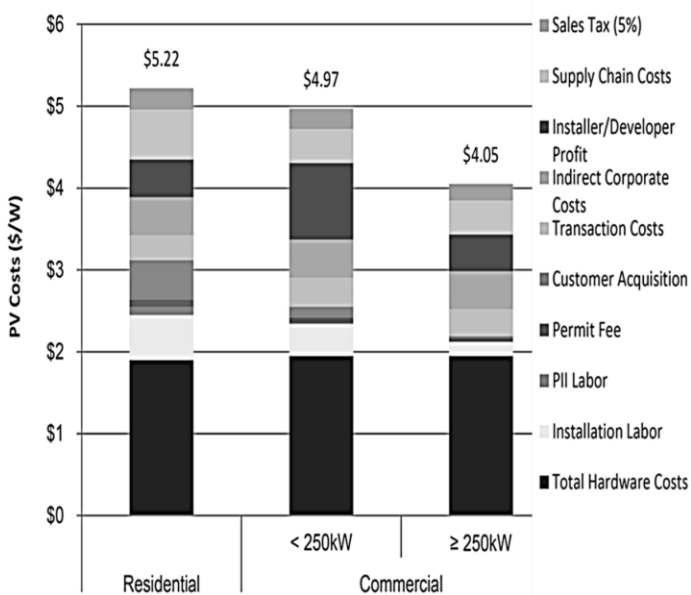
can be considered special for the purposes of this discussion, such special components, materials and designs may be manufactured in lower volumes and attract higher cost. Standard production items, produced to an order (or two orders) of magnitude larger, attract less cost, components are more readily available and are usually far more compatible with existing infrastructure, expertise and available service.

### CURRENT DAY DRIVERS OF BOS TECHNOLOGY DEVELOPMENT

A clear distinction is made today between the time when the PVG cost overshadowed all other costs and the current period where the BOS components (hardware and software) costs now are the greater cost contributors.

#### PVG cost now push BOS to the fore

An NREL study [4] found that: "According to our analysis, the soft costs accounted for a significant portion of total installed PV system prices in the first half of 2012: 64% of the total residential system price, 57% of the small (less than 250 kW) commercial system price, and 52% of the large (250 kW or larger) commercial system price."



**Figure 2** Total PV system price, by sector and system size (first half of 2012) [4]

If we consider a solar water pumping system to be in the same class or category as a residential system then 64% of the price tag accounts for BOS components and soft cost. BOS soft costs are:

- Sales Tax (5%) - this example refers to a USA example. Taxes nevertheless will always play a role and cannot be impacted on significantly through design, materials or technology.
- Supply Chain Costs - This may become a significant area of cost cutting in the case of solar powered water systems.

Product that reduce stockholding (using same components, subassemblies) offer great benefits to cost reduction.

- Installer/Developer Profit - Simplified design, standardisation, service support and training are all areas that increase installer profit. This can be achieved by using standardised motors, drives and even solar modules to eliminate variability.
- Indirect Corporate costs - These costs are increased significantly by the need to develop new skills, support small numbers of large variability such as when the various pump duties are accommodated by using a design or technology for each case. It is much more manageable if all duties are accommodated by the same pump, motor and drive technology and supply.
- Transaction Costs – standard components always attract lesser cost
- Customer Acquisition - "Customer-acquisition activities can add considerable time and cost to PV installations, perhaps especially in states with less-mature markets where perceived technology risk and unfamiliarity with PV might increase bid-failure rates. Expenses related to customer acquisition—such as lead generation, bid and pro-forma preparation, contract negotiation, and system design—increase the cost of doing" business.
- Permit Fee - There may be issues that need to be dealt with but these are more or less common to all systems.
- Installation Labour - As can be expected this is not a cost to ignore. This is also one area that can be impacted on significantly by using similar, familiar and existing pumps, motors and control gear. Especially he experienced installer will gain from the use of components that are familiar and with which he/she feels comfortable.
- Total Hardware Costs - This cost would include all hardware components. These are the components under discussion.

#### National programme to reduce BOS cost

Perhaps the most important influence in the current development of technology in the area of solar powered water pumps has not been felt yet. This is because real attempts to shift focus from PVG cost reduction to BOS cost reduction to soft issues started to take place only over the last couple of years.

The SunShot Vision Study undertaken by the US DOE sets admirable goals but more importantly focuses attention on the areas where the next drive towards cost reduction should be aimed. [1]

Benchmarked 2010 inverter prices were about \$0.40/W for residential systems. In this study inverters are read to be VFD used for pumping systems and freestanding solar water pumping systems are regarded as residential systems. Considering the SunShot targets for power electronics prices are \$0.12/W for residential systems.

Similarly benchmark 2010 BOS prices were about \$3.00/W for residential systems. The SunShot targets for BOS prices are \$0.84/W for residential systems. These targeted reductions are substantial and will probably shift the complete solar water

pumping systems components' selection and/or preference back to products and components that are pervasive in quality, substantially available, is serviced aggressively, is backed by innovation and is available at good value.

A special interest in the soft BOS aspects will become influential in current product development considerations. Included are:

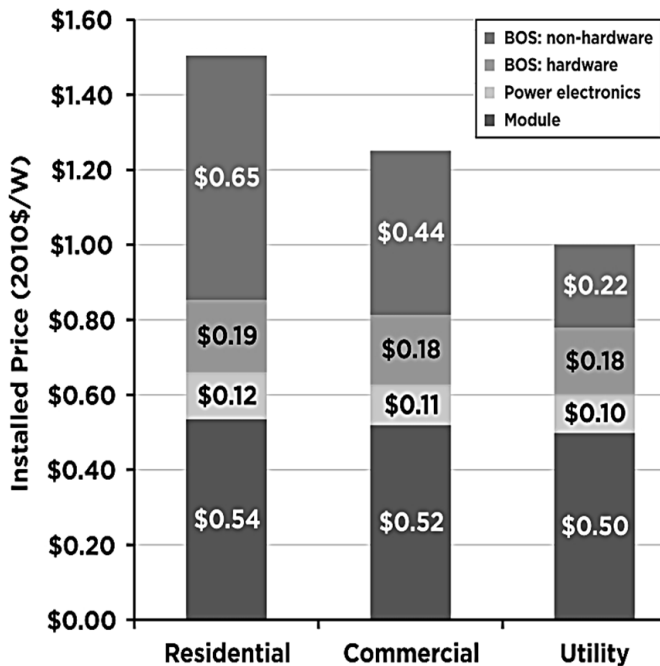
- Identify strategies for streamlining permitting and interconnection processes and disseminate best practices to a broad set of jurisdictions
- Develop improved software design tools and databases – Address a wide range of policy and regulatory barriers, as well as utility business and operational challenges
- Streamline installation practices through improved workforce development and training, including both installers and code officials
- Expand access to a range of business models and financing approaches
- Develop best practices for considering solar access and PV installations in height restrictions, subdivision regulations, new construction guidelines, and aesthetic and design requirements
- Reduce supply chain margins (profit and overhead charged by suppliers, manufacturers, distributors, and retailers); this is likely to occur as the PV industry becomes more mature.

the full product range to reduce stock levels and improve service back-up will increase in importance. This will lead to more homogeneous product and blend the idea of a divide between small and larger solar powered water pumping systems. It is envisaged that “small systems” based on the more exotic very high efficiency drivers of the past will gradually disappear.

At the same time, the successful ‘complete systems offering’ similar to that found for smaller systems, will impact on systems in general and a growing ‘systems offering’ approach will replace traditional boxed product sales.

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**Figure 3** Estimated Subsystem Prices Needed to Achieve 2020 SunShot Targets

## RESULTS AND CONCLUSION

The soft BOS as drivers will give preference to local market capabilities; stock holding and the use of similar components in solar powered water pumping systems across