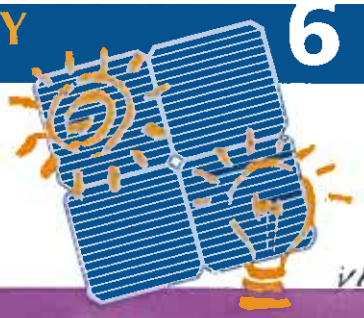
IEA INTERNATIONAL ENERGY AGENCY 6



PV POWER

Newsletter of the IEA Photovoltaic Power Systems Programme

DECEMBER 1996

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The Vulcano PV Plant in Italy has been used since 1984 as a test bed to study the viability and durability of large scale PV technology.

A POWER TO BE RECKONED WITH

An Interview with Robert Kelly

Bob Kelly is co-Chairman of the Managing Board of Amoco/Enron Solar. Since 1981 he has fulfilled a number of executive roles with Enron Corporation – one of the world's largest independent power project developers and electricity producers – including Executive Vice President and Chief Strategy Officer. He now heads Amoco/Enron's Solar Power Development Unit.

Firstly, could you give an insight into how two giants in the energy business – Amoco and Enron – came to join forces in a PV venture?

From Enron's point of view, we consider ourselves to be fairly forward-thinking, both in respect of investing in promising energy technologies, and in responding to new demands from our customers. PV fits well with our business strategy to provide clean energy services, and we believe that we can speed the process whereby PV electricity reaches economic, as well as environmental attractiveness for the grid-connected market. For its part, Amoco has been a long-term proponent of PV through its investment in Solarex – the largest US owned manufacturer and marketer of PV modules and systems.

During 1994, both parties were looking for possible technology partners – Enron was searching for manufacturers with real experience of the PV market and the potential to provide the hardware for large-scale projects, while Amoco (Solarex) was looking for partners with experience of the electric power market and financing expertise who could commit to PV production in volume. This joint venture, which has been gathering momentum during the past two years, seems to be the perfect marriage of skills.

The commitment to volume production is presumably the key to making the partnership work?

Amoco/Enron plans to increasingly focus on the grid-connected electricity market – PV in buildings and multi-MW solar farms. For large-scale plants in particular, modules have been the dominant cost component. So if we are to make these projects economic our starting point has to be low cost modules. This can only be achieved if production is significantly scaled-up.

Solarex, the manufacturing unit, is a separate business unit from my area, power project development, but obviously our concerns are closely interlinked.

Our new 10 MW facility in James County, Virginia is nearing readiness for full-scale production of the high-voltage, multi-junction amorphous silicon modules that we will use on our solar farms. There are possibilities for us to construct plants of similar size in China and India to tie in with the power projects we are chasing there.

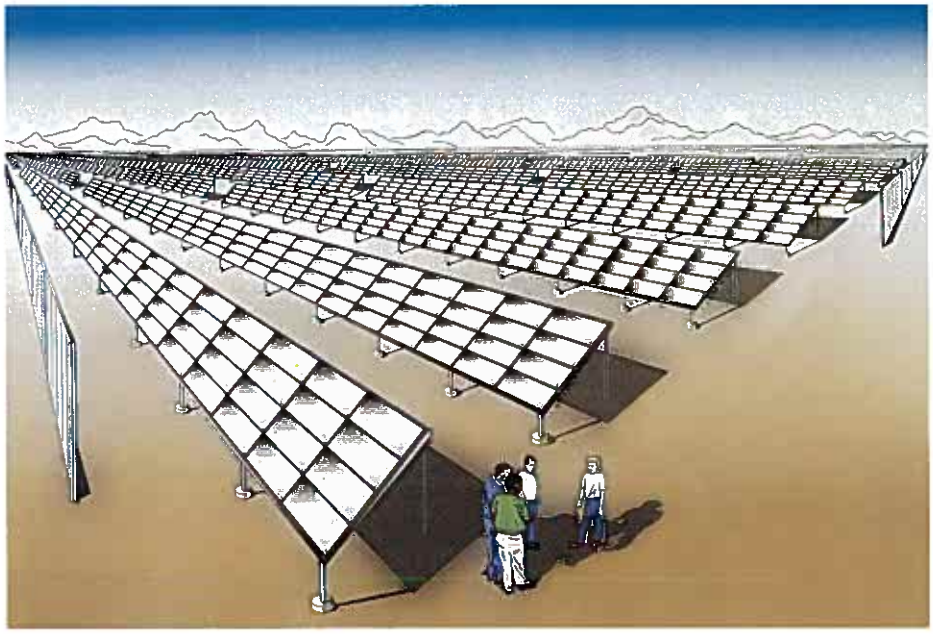
The job of the Power Development Unit is to attract business which will support such volume production. The two go hand-in-hand. These developments will give us both the means and market to fulfil our objectives: that is to be the main player in the business of providing clean, affordable power worldwide.

Do you foresee any risks in using your new multi-junction amorphous silicon modules for these ambitious projects?

This product has been rigorously developed for precisely this type of application and to meet our exacting standards. We are entirely confident that they represent the next generation of PV modules and they will prove their capability out in the field, where it really counts. Furthermore, Solarex has been producing both single and multi-junction amorphous silicon modules for several years already.

You mentioned India: the agreement you recently signed there must be very encouraging for you?

We are very excited about the power purchase agreement with the Rajasthan State Electricity Board. This 25 year commitment to buy up to 50 MW of power represents a change of gear in the development of the PV market. This is the kind of volume that will lead to economies of scale in module



Multi-MW installations, as shown in the artist's impression of a proposed Amoco/Enron amorphous silicon solar farm, could prove to be an excellent power source for countries that have a high power demand and limited fuel options.

The Solarex PV breeder – using solar power to produce solar power.

production which will enable us to achieve the cost breakthroughs that we all know are possible.

Our next objective is to finance the project. Amoco/Enron will obviously be making a significant capital investment, but we are looking to funds like the Global Environment Facility (GEF) and the Indian Renewable Energy Development Agency (IREDA) to contribute towards the USD 100 million costs.

What about other similar development projects?

We are firmly committed to the developing country market. The implications for the global environment of a massive increase in energy demand – which is happening as we speak – are potentially phenomenal. The industrialised world cannot sit back and watch while these countries try to balance economic and social development within the confines of greenhouse gas emissions directives.

There is a realistic sustainable development alternative. We know that PV can enable many developing countries to progress to a clean energy supply for the 21st century. We see ourselves as facilitators of this process which is why we have decided to put our money where our mouth is and actually start the ball rolling in places like India and China.

Having said that, Amoco/Enron is first and foremost a business, so we fully expect that this will also be a long-term profitable market for us. There is the distinct possibility that further agreements, in addition to the Rajasthan commitment, will be signed in India, and we are presently undertaking a feasibility assessment for the State Science and Technology Commission in the People's Republic of China for a 10 MW manufacturing facility and a 150 MW power plant.

If these come to fruition it will be great news for PV and great news for Amoco/Enron.

But presumably you are not concentrating only on the potential developing country market?

Certainly not. At home, we are currently negotiating with Hawaiian Electric Company and its subsidiaries to build a 4 MWp solar power plant on the Island of Hawaii. The facility, which will be brought on-line next year, is going to cost around USD 7 million, but we have already secured partial financial support from the DOE in the form of a USD 1,1 million award through the Utility Photovoltaic Group. This project will be an excellent showcase for us to demonstrate that our new generation thin-film modules can deliver the goods in the competitive US market. We estimate that the installed costs will be close to the 2 USD/Wp mark which is widely seen as the breakthrough price for cost-effective bulk power production.

And do you think you can compete in economic terms with conventional energy technologies?

We are now negotiating with the Corporation for Solar Technology and Renewable Resources here in the US to build the first 10 MW of a solar farm of up to 100 MW in the Nevada Desert. We estimate that the project would be able to sell electricity profitably from that plant for 5,5 cents/kWh over 30 years. That's cheaper than the average price that the US government is now paying for its power. While the project relies on tax exempt financing, we are optimistic it can be done.

SOUNDS PROMISING – PV NOISE BARRIERS

This 100 kWp system, installed seven years ago on the N13 motorway near Chur, Switzerland, was the first PV sound barrier.

Incorporating photovoltaics with sound barriers is an application that has been steadily gaining interest since the installation of the first 100 kW grid-connected plant alongside the Swiss N13 motorway seven years ago. Since then utilities in several European countries have been 'sounding-out' the prospects for PV noise barriers.

The initial attraction of mounting photovoltaic modules on sound barriers is similar to that of mounting PV on buildings. A proportion of land and support structure costs can be avoided. Operating experience gained from a number of noise-barrier systems demonstrates the technical feasibility and electrical generation potential of such installations.

The Swiss plant mentioned above, for instance, has fed on average 110.000 kWh into the grid each year since it was installed. A 40 kWp system installed by the Austrian utility, Oberösterreichische Kraftwerke AG, shows similar performance promise: the solar generator, which extends for 264 m along the A1 near Gmunden, has produced some 31.500 kWh/year and has a mean performance ratio of 0,67 since it became operational in February '92. The entire installation process from design to completion took around 9 months at a cost of ATS 6,4 million (approx. USD 600.000), with by far the greatest single cost component being the module purchase, which constituted 43 % of the total.

Developments are now concentrating on true integration of PV to allow the complete substitution of a simple noise protection element with one that offers both noise protection and electricity generation capabilities.

In the Netherlands, a 52 kWp noise barrier integrated PV-system has been in operation since April 1995. Over the period from July '95 to July '96, a performance ratio of 0,73 was recorded from the PV generator.

The German utility Stadtwerke Saarbrücken AG, has installed two such integrated systems near the intersection of the A6 and A620 motorways on the German-French border. One is a 40 kWp design incorporated into a 232 m stretch of transparent sound reflecting acrylic plastic, while the other – a 20 kWp array extends 217 m along a highly sound-absorbing, non-transparent section of barrier. The systems were installed in the second half of 1995, so no performance data is available as yet. However, in respect of installed costs, 15 % of the total system costs can be offset through savings on conventional noise protection elements, resulting in installed costs of 8.000 ECU/kWp (approx. 10.000 USD/kWp).

Theoretically, there is a sizeable potential for electricity generation from PV sound barriers. TNC Consulting engineers have evaluated the short-term potential for Germany (based on sound barriers planned for erection in the next few years) to be 115 MW. Similar studies confirm that Switzerland also has a considerable resource.

264 Modules from BP Solar, each of 75 Wp, are incorporated into a 200 metre stretch of sound absorbing barrier on the Saartalbrücke in Germany. [COURTESY GEORG BECKER]

As part of an ongoing development programme funded by the Swiss and German governments, TNC recently organised a design competition to stimulate ideas which could take advantage of this potential. 19 teams composed of noise reduction and PV companies submitted a total of 31 competition entries. Six winning entries were selected, based on noise damping properties, PV power output, integration innovation, architectural design and cost. 10 kWp Prototypes of these designs will be built in the near-term to assess practical performance issues and to provide feedback to enable larger-scale installations (100 kWp) to be realised.

Conventional PV-barrier arrangements need to be sun-facing and inclined at a suitable angle to maximise electrical yields. This restricts their application largely to routes running in an East-West direction. One innovation which could extend the range to include many North-South routes as well is the bifacial or 'dual-sided active' module.

In theory, a vertically mounted bifacial module oriented to face East & West (representing placement alongside a N-S route) could give electrical yields up to 6 % higher than optimally positioned single-faced modules. A design based on bifacial modules was among the six entries selected for further development.

DISPERSED GRID-CONNECTIONS: R&D PROGRAMMES

The Netherlands and the United Kingdom both launched experimental R&D Programmes in autumn this year to support the work of Task V of the PVPS Programme on grid-connection of dispersed PV systems. Both projects are assessing the influence of connecting numerous distributed systems to the grid. Specific problems associated with multiple connections include overloading in summertime, voltage profile instability and grid protection behaviour anomalies. New design methodologies as well as control and protection arrangements will be investigated. The Netherlands research will be conducted by KEMA, an organisation that has great experience of dynamic grid behaviour and familiarity with the dynamic behaviour of PV systems. EnergieNed and Novem will fund the project which is due for completion in 1997.

The UK's experimental programme will help to assess the impact of connecting numerous small embedded generators, like the one from Oxford UK shown here, to the mains grid.

The UK programme is managed by HGa, with technical management from EA Technology. The research will be carried out by Southampton University and CREST under funding from the Engineering and Physical Science Research Council, and by BP Solar with support from ETSU. There will be close cooperation between all involved parties in order to exchange information and results and avoid duplication of efforts.

GRID-CONNECTION NATIONAL OVERVIEW REPORTS

Two reports detailing the grid-connection practices of the countries participating in Task V of the PVPS Programme were submitted for approval at the April meeting of the PVPS Executive Committee. The first report presents an overview of the grid configurations and electrical parameters encountered in each participating country. The second is an overview of the existing guidelines for interconnecting PV systems with the grid. The reports are largely intended to assist the other tasks of the PVPS Programme, but will be available for distribution within Task V participating countries.

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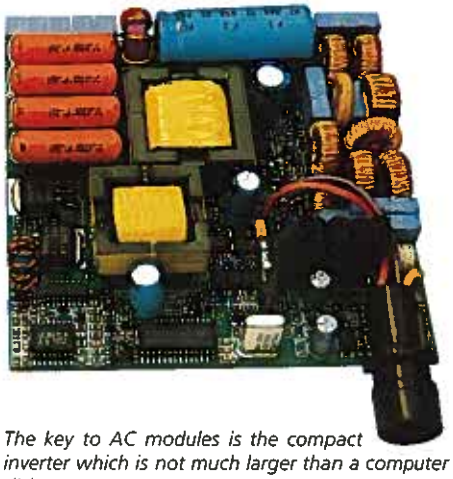
AC-MODULES: PERFORMANCE ASSESSMENT

In the Netherlands, two inverters for AC-modules are being developed: the Mastervolt Sunmaster 130 and the OKE Services OK4.

The energy yield of a 2 kWp system was monitored over a period of 1,5 years. Twenty AC-modules incorporating Sunmaster inverters were mounted in a free standing array. Over a twelve month period, the system yielded 830 kWh/kWp, clearly demonstrating that losses on the DC-level are extremely low. Ohmic losses due to cabling, fuses and switches are avoided and there are no mismatch losses between modules. The OK4 inverter has been on field test since the summer of 1995. Six AC-modules with OK4E inverters have been tested at the Netherlands Energy Research Foundation, ECN. The field results confirm values measured in the laboratory regarding efficiency, noise, etc. The tests revealed excellent MPP tracking with efficiency exceeding 99 % at power levels above 10 % of the maximum input power. Even at lower power levels, the inverter's MPPT still has an efficiency higher than 95 %. At the IEEE conference in the USA in May 1996, the OK4U – the US version of the OK4 – was demonstrated in boiling water. Even under these extreme conditions the inverter operated well.

Recently OKE-Services teamed up with NKF Kabel, Holland's largest cable manufacturer and supplier of transmission systems. NKF is now collaborating with Trace Engineering, which will be responsible for distribution in North America.



The key to AC modules is the compact inverter which is not much larger than a computer diskette.

TWELVE YEARS ON: STILL GOING STRONG

Since 1984, the Italian Electricity Board, ENEL, has been monitoring the performance of an 80 kWp PV plant located on the Island of Vulcano. Twelve years on, the plant is still operating perfectly and it has yielded some valuable performance data.

The PV array consists of 44 kWp of polycrystalline and 36 kWp of monocrystalline modules mounted on galvanised steel supports at 35° inclination and oriented due south. The plant is configured to operate in either stand-alone or grid-connected mode. In stand-alone configuration, the plant supplies AC power via a suitable inverter and two 1.400 Ah batteries to a low voltage local grid, feeding about 50 isolated houses. The grid-connected format utilises a different inverter and feeds power at 20 kV into the mains. At the time of construction the plant cost 40 million ITL/kWp installed, (about 46.000 USD/kWp today) but this was due in part to the high level of monitoring facilities that the system incorporated, partly to the experimental plant dual-mode operating arrangement and partly to high module costs which were equivalent to 18 USD/Wp – four times more expensive than would be typical now. Today, it is estimated that to replicate the entire plant would cost in the order of 14-18 USD/Wp.

Very few problems have been encountered during the life of the plant. A few modules have had to be replaced due to the cover glass cracking, and there has been some discolouration of cell contacts, but performance measurements confirm that there has been negligible degradation of the array over twelve years operation.

The inverters have also proved generally reliable, apart from a few early troubles (due to sizing errors for instance). The biennial maintenance regime has been sufficient to limit the faults in the stand-alone inverter to two in 10 years. The grid-connected inverter required no maintenance until the tenth year when some capacitors needed to be replaced.

As for the storage system, the original battery was replaced and storage capacity was increased in September 1991.

Recently a dedicated Data Acquisition System was installed to monitor characteristics such as battery State-of-Charge, component performance evaluation and to provide a continuous health status diagnostic facility.

Since commissioning almost twelve years ago, the plant has produced close to 800 MWh of electricity, split fairly equally between stand-alone and grid-tied mode. The overall Performance Ratio – that is the ratio of PV energy actually used to the PV energy theoretically available – during this period was 0,61, with a high of 0,81 being encountered during October 1994 when the plant was feeding to the grid.

On the whole, the plant has provided very positive performance results, which will assist utilities to evaluate the effectiveness of the technology both for interconnection with the grid as a 'fuel saver', and as a viable means of providing power to remote 'island' locations.

The Vulcano PV plant on the Island of Vulcano, Italy

PV SUITED TO AUSTRALIAN ENVIRONMENT

For the past decade, Australian researchers have been at the forefront of international PV R&D efforts. There is no national PV programme as such, but USD 25 million of public funds have been allocated to PV related R&D since 1985. Private investors, concentrating initially on PV devices, but now largely on the development of balance of systems components, have matched government spending. This groundwork is beginning to pay off, as electricity utilities start to recognise the long-term potential of PV.

Integral Environmental Energies' 'Pyramid' Transportable RAPS System. [COURTESY INTEGRAL ENVIRONMENTAL ENERGIES]

Per capita, Australian PV usage is one of the highest in the world. Not surprisingly, for a vast continent with such a dispersed population, the majority of systems to date have been in remote locations. Professional (non-domestic) applications like telecommunications, navigation aids, route signalling, and lately water pumping, accounted for almost three quarters of Australia's entire installed PV power capacity (estimated to be around 13 MWp) at the end of 1995. The public telecom utility, Telstra, is alone responsible for almost 20 % of all installed systems.

However, the recent major restructuring and privatisation of part of the electricity industry has served to arouse increased utility interest in PV, both for off-grid, domestic remote area power supply (RAPS) systems, and latterly for the grid connected market. Utility interest in PV RAPS is understandable: in New South Wales, for instance, rural customers account for 74 % of the distribution network line length, but only 2 % of the load. Australia wide, some 10.000 permanent residences are not currently connected to a mains supply. Taking holiday homes into account, the potential market for domestic RAPS systems could be 70.000 units. The provision of mains quality AC power through PV-diesel hybrids incorporating (largely home-produced) deep-cycle batteries, inverters and control systems is a cost-effective alternative to diesel only generators and is generally more reliable.

More than 3 MW of PV, with an average array size of 0,6 kWp, is now installed for domestic off-grid power supply. Innovative product developments, such as fully integrated transportable PV-diesel hybrid power supplies, coupled with government measures such as one state's requirements for electricity distributors to employ least-cost electrification practices, should help to further strengthen PV's position in the RAPS market.

With the off-grid market reasonably well established, demonstration activities have been transferred to the grid-connected market which is expected to grow rapidly over the next 5 to 10 years. More than 20 demonstration systems, ranging in size from 600 W to 20 kW have been installed since 1994, with utilities contributing 50 % of the funds for these activities.

As with the RAPS market, there are a number of interesting innovations in the grid-tied field: on the product development side, novel approaches to PV-building integration include concentrating modules for roof-tiles and integrated mounting systems for frameless modules.

Market stimulation measures include the Victorian utility, Citipower's, PV panel buy-back scheme, while a number of distributors are developing purchase agreements for buying back surplus PV power and premium payment arrangements for 'green' power.

Telstra Microwave Repeater Station, Central Australia. [COURTESY TELSTRA]

As for education, one flagship project has seen the installation of a 1 kWp system on the roof of a high school in Sydney. Pupils can analyse real-time system data and so gain familiarity with the technology, its uses and performance characteristics.

Aside from further cost reductions and more widespread information efforts, the major issues to be addressed for grid-connected systems relate in particular to interconnection and building integration issues – including system and component standardisation and safety and performance standards. Australian participation in the PVPS Program will address these factors.

1 kW grid connection array, Fort Street High School, Sydney, NSW. [COURTESY PHOTOVOLTAICS SPECIAL RESEARCH CENTRE]

PVPS: WORLD BANK COOPERATION

The IEA, through the Developing Country Team of the PVPS Implementing Agreement, is cooperating closely with the World Bank. The move will strengthen programmes aimed at bringing power to some of the 2 billion people without electricity in the developing world.

The World Bank, which is one of the major sources of finance for investments in developing countries, regards PV as a serious electricity supply option and is actively investigating ways of financing programmes to hasten the spread of PV throughout the developing world, where there is an immediate and cost-effective market for the technology.

The Bank's 'Solar Initiative' was launched to facilitate the use of the Global Environment Facility (GEF) and other suitable financial resources for precisely this purpose. The GEF was replenished with USD 2 billion in 1995, half of which could be used for greenhouse gas mitigation projects – which includes PV – over the next three years. The Solar Initiative also aims to encourage and support R&D and international collaboration appropriate to the particular needs of specific developing countries.

Although the financial resources are available, the widespread lack of awareness of the economic viability of PV in target countries, has prevented PV from being successfully incorporated into mainstream lending programmes. Under the terms of the cooperation, PVPS will provide assistance with publications, quality standards and certification, recommended practices, as well as providing a pool of expertise. All are urgently needed to accelerate the development of bankable PV projects. The first activity, which is currently underway, is to prepare a Solar Photovoltaic Power 'Theme Note', as one of a series of World Bank Publications. It is also anticipated that targeted workshops will be organised under the auspices of PVPS in association with the World Bank. These will address specific issues where results from PVPS tasks can be applied in the regions concerned.

PV can make a real difference to lives and businesses throughout the developing world.

IEA-PVPS

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PV POWER is written and edited by IT Power under the auspices of the IEA PVPS Programme Information Dissemination Project (Task I). Layout and production is by De Boer & van Teylingen, The Hague, Netherlands.

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