Photovoltaic Systems

Brief overview and future of energy - the role of photovoltaic power plants

Introductions – PV Revolution – Does solar energy really work? – The war over power – The nuts and bolts of solar energy – Solar PV and public safety
Randy Dunton, Photovoltaic power plant system developer, designer, & NABCEP instructor

Randy began his career as a certified (Swiss) industrial electrician in 1980 and transitioned to computer engineering R&D in Silicon Valley. Throughout his career in computer engineering, Randy developed electronic circuits, software, and integrated circuits for the computer, networking, and consumer electronics industry - creating numerous patents along the way.

In 2009 Randy transitioned to his newfound passion of solar power plant design and PV installer training. Using his self-developed curriculum, Randy has been a NABCEP instructor in community colleges & universities here in Arizona and abroad. Randy instills the art of properly developing and installing safe and long lasting PV power plants in the rapidly growing PV industry.

Randy currently develops & designs commercial PV power plants, energy storage, and electric vehicle charging infrastructure systems for Hawkins Design Group; with the goal to help the world transition to a cleaner, more economic, and more peaceful power source for our common future.
Hawkins Design Group (HDG)

Established in 1994

- Electrical design to include power, lighting, photometrics, energy calculations, equipment connections.
- Retail, manufacturing, industrial, office space, restaurants, auto dealerships, warehouse, multifamily, hotels, custom homes
- Construction documents provided for submission to local jurisdictions for permit and construction
- Special Electrical Inspections
- Construction administration
- Expert witness for judicial requirements
- Failure analysis

http://www.Hawkinsdg.com
HDG - Arc Flash/Coordination Studies

- Arc Flash – A flashover event of electricity where a violent explosion can occur, possibly causing injury or death.

- National Electric Code and NFPA 70E require all equipment to be labeled with hazard and appropriate PPE to be used.

- OSHA requirement should an accident occur.

- HDG studies your facility specifically to determine your hazard.

- Are your employees wearing the proper PPE to protect against Arc Flash??

- Coordination of breakers eliminates nuisance tripping and extensive downtime due to outages
HDG - Solar PV Design & Development/Training

EV Charging Infrastructure

• Full Solar PV design for systems ranging from 10kW to multi-megawatt power plants.

• One stop shop for complete system integration, engineering, installation, financing, monitoring

• Knowledge of local utility requirements

• Provide financial services for leasing and financing options

• NABCEP instructor and certification in-house.

• EV Charging Infrastructure Design
PV Revolution

SOLAR PV GLOBAL CAPACITY, 1995–2012

PV Module Price Per Watt

Slide 6
Solar Photovoltaic (PV) power generation has recently emerged from its long hibernation; a technology originally used in satellites and special applications is now available to everyman.

- Similar path to computers... consider the enormous impact computers have had to human society.
- Now consider that the energy market is larger than computers...

Modern society’s energy requirements can no longer be met with traditional sources of energy.

- We are all experiencing a fundamental and rapid transformation from traditional carbon and fission energy sources, to new and unfamiliar sources – largely photovoltaic – an energy revolution.

The rapid growth of PV is due to a convergence of:

- Governments looking for practical alternative energy forms to replace the unsustainable ones we greatly depend on today
- Modern manufacturing capability to reduce parts costs
- Our insatiable and growing energy needs of modern humans
- The electrification of our transportation industry
- World-wide abundance of free solar energy
Solar Energy Revolution
“It is not necessary to change. Survival is not mandatory.“

--W. Edwards Deming, American statistician, professor
The world is looking for alternatives to carbon and nuclear based fuels for geo-political and environmental reasons.

Citizens elect progressive governments, governments create policy and laws to address longer-term needs of the population (renewable portfolio standard, RPS, tax credits, etc.)

Due the support PV has been growing exponentially for over 10 years… (~45% year to year)

“We can not solve our problems with the same level of thinking that created them”
— Albert Einstein
The rate of change in energy consumption is unsustainable economically and environmentally.

The world’s population has grown by a factor of 3 in the last 60 years and the USA’s energy demand by a factor of 6 per capita.

China and India joining industrialized life further result in explosive growth.

Each year energy demand grows by ~2% - and is expected to grow by 30-50% by 2020, almost doubling by 2050 from today.

There are large amounts of coal and natural gas, however the pollution from these fuels will destroy our current habitat.

Energy demand is unsustainable with current means.

The unsustainable rate of energy use must be reversed.

Who is going to solve this problem and how?

1) Graph and data source: Novatlantis

2) World Energy Council
PV revolution – crisis & path we are on

- The long term trends are all very alarming...
- *Peak-oil* production has occurred twice now (USA ~1976, globally ~2010)
- Replacing oil and coal will be monumental undertakings and will take decades of *concerted* effort
- The longer we wait the more difficult, risky, and expensive it will become
The government’s role is to protect its citizens – long and short term

One wise way to act is to set policies - to which industry can react with products and solutions for the benefit of the citizens

Industry’s role is to become profitable (in the short term)

To establish an energy portfolio that is sustainable for future growth governments have enacted various long-term energy polices to steer industry and people’s behavior

Solar is projected to play a large role due to it’s unbounded source of fuel and benign impact to nature

USA Federal level

- Federal tax credits, starting in 2006, helped spur the industry - however it has been the Emergency Economic Stabilization Act of 2008 and the American Recovery and Reinvestment Act of 2009 that have both been instrumental in the development of the U.S. solar market.

- Federal level (USA): Federal Investment Tax Credit (ITC)
  - tax incentives to make investments (in solar energy) – in effect through 2021
  - How it works: 30% of installed cost, tapering off in 2021
The RPS goals vary from state to state

- For example, **California** has committed to producing 33% of its electricity needs with renewable energy by 2020, 50% by 2030 - Hawaii is 25% by 2020, 40% by 2030, 100% 2045

- Arizona 15% by 2025 – modest goals…

- RPS is one tool for a government to direct industry and consumers towards a sustainable future, Hawaii is in a hurry since they are oil based, 37 states have an RPS

- Kansas and Virginia repealed the RPS, wonder why…
In 1960 PV silicon modules were approximately $1000 per watt, PV remained dormant – the world ran on cheap & abundant fossil fuels – no concept of CO2 emissions & global warming.

The USA oil crisis in the late 70’s, the nuclear disaster in Chernobyl, and the early beginnings of global warming sparked a renewed interest in alternatives.

With proper government incentives in Japan and Germany, the solar industry fueled the exponential ramp in automated manufacturing capability, production grew exponentially for over a decade, reducing costs dramatically.

Fukushima only underlined the need to transition, along with world-wide acceptance of global warming – cost of traditional sources of grid power continued to rise due to market manipulation and droughts – solar power costs are dropping.

With recent Chinese competition - the retail price in 2012 had dropped to ~ $0.60 per watt for a silicon module: a over 1600 x reduction in cost in 55 years (34c/W thin-film).

The 2015 United Nations Climate Change Conference, COP 21 was a global acknowledgement that we need to change our attitude towards global warming – never have we had such a large consensus by the USA and China.

USA the investment tax credit extension (2016 to 2022) for wind and solar energy gives the USA industry a new boom.
As the market drivers push the industry for adoption with incentives, the prices drop due to economies of scale.

With lower prices, the industry sees increased demand and builds larger factories, further reducing costs.

Incentives are no longer required in some markets, and the cost drops to the point where it competes with traditional energy sources.

California leads the way; favorable politics and higher energy costs.
We have to replace all of our traditional energy sources, other than hydro.

We produce about 1% with solar energy today, much work ahead.

Hiking up Everest…

Rapid growth, but a very long path ahead.

Agua Caliente Arizona, one of the larger photovoltaic power plants in North America. 100MW – growing to 348MW.
Will renewable energy be able to replace fossil and nuclear energy?

The war over power...
Can we power all of our energy needs with the sun’s rays?

- Yes - we have a handy fusion reactor in sky called “the sun” – it shows up for work every day, and just works…
- The world currently consumes 20 trillion kWh of energy annually, yet by covering a small area of the earth with solar power generators we can live our lavish lifestyles, including transportation and heating
- The roofs of existing homes and buildings will cover a large amount of the area needed.
- Storage will be required for night use and bad weather, the area used for providing this storage is much smaller

![Map showing solar energy distribution and storage location with 18 TWe capacity](image-url)
Can we store all the energy we need in batteries?

- Solar and wing energy is variable in nature
- If we transform all of our energy to renewables (electricity, transportation, heating) we would need about 200,000 GWh of storage
- *Two billion* Tesla “power packs” (100KWh ea.) is what it would take
- Lots of storage, however the number of cars and trucks on earth today is also 2 billion… humans have done this before…
- Keep in mind: renewable energy & storage is the only path we know of today
Established energy industries will continue to maintain the status quo as long as they can.

Change does not come with reasoning, but with a struggle.

Established energy industries and nations are politically and economically very powerful.

Media, funded by carbon-based industries, are spreading misinformation and fear.

Voters are misinformed and elect representatives that maintain the status quo.

Governments are swayed with political contributions to support the industries and not the people (governments that join the dark side…)

Who knows what the Arizona Corporation Commission does?

Fox “News” expert on energy: “Germany has more sun than the USA” that’s why it works there….

Woodland North Carolina: is banning solar: “solar panels will suck up the sun’s energy” “and cause cancer”

SRP management (Salt River Project) has ended distributed solar due to “not paying their fair share of maintaining the power grid” (solar is 0.6% of the SRP grid).
"ALL CHANGE IS HARD AT FIRST, MESSY IN THE MIDDLE, AND SO BEAUTIFUL AT THE END."

Mahatma Gandhi
The nuts and bolts (of solar)
Solar PV Applications

- Shortly after the silicon PV cell was invented in the 1950s the first commercial applications of PV were in rural telephone systems.

- Off-grid (residential, commercial)

- Outer space

- However the large applications today are
  - Utility scale
  - Suburban, residential and commercial -> grid tied
Configurations

- A utility-connected Photovoltaic (PV) system is the most common system configuration.

- Solar power-plant components can be arranged in many ways to design PV systems for different situations, but the most common configuration is a utility-connected system, a.k.a grid-tied.

- In most cases energy is not stored at the home (batteries) – instead the power is fed to the loads and the excess is sold to the grid – it is a power generator.

- In the future it is very likely that PV system will have storage...
Grid-tied systems operate as one of many generators in parallel feeding the utility grid, any number of these may be connected in parallel.

They will not operate without the presence of a grid; a common misconception.

The primary component in grid-tied system is the inverter, which directly interfaces the array to the electric utility network.

These systems vary in size by quite a magnitude, a typical home may be 3-15KW, and schools or warehouses may be rated at 2MW or more.
Grid-tied example

- Grid tied systems consist of an array and an inverter that feeds the utility grid (and loads)
- In Phoenix AZ the average size is ~7.5KW of DC power
- Other than some safety disconnect equipment, conduit and racking, the system is no much more than the inverter the array
- This system requires very little maintenance

Photo courtesy of SMA (inverter), Eaton (disconnect)
Grid-interactive or grid-tied systems will have an energy meter (kWh) in the system.

Net metering is an arrangement where any excess energy exported to the utility is subtracted from the amount of energy imported from it.

Dual metering keeps careful track of the energy produced by the PV system.

Either one or two meters are used; with one the net-effect of energy is recorded, with two the PV energy is explicitly tracked in the exporting meter.

Big controversy now on net-metering, is it fair or not?

Electricity Exporting

Net Metering

**Diagram:**
- Inverter
- AC Distribution Panel
- Utility Grid
- Bidirectional Meter

Dual Metering

**Diagram:**
- Inverter
- AC Distribution Panel
- Exporting Meter
- Bidirectional Meter
- Utility Grid
Next to hot water and air-conditioning, a pool pump will consume a large portion of energy of a typical household.

A small direct-coupled system with a small array (2-6 modules) utilizes the PV power, converted to 3-phase AC, to drive a very efficient motor (brushless).
PV and public safety

PV and public safety – new and unique features

- Today’s power plants are kept behind fences, and located far away from the public
- Centralized generation required this due to pollution, gigantic scale, and geographic dependency
- *Distributed generation* for the first time allows us to have power plants among residences and businesses – this is an entirely new circumstance, creating new challenges
- All power plants operate for many decades, they must be built to withstand the effects of time and exposure while at the same time being exposed to the sun and temperature extremes – quality and reliability is expected
PV and public safety – new and unique features

Today’s new distributed power plants are no longer kept behind fences…

- Have 1000V conductors within 8 ft. of the ground no conduits, system components within reach
- Systems that are live and can kill even when turned off or destroyed in a fire
- Systems designed by untrained designers, built by untrained installers, inspected by untrained inspectors (soon to be remedied)
- Constantly evolving technology, many mistakes of the past are being remedied, making it difficult to maintain proper training
- No way to slow down progress, must find new ways to keep up

1) Images Randy Dunton, NFPA Fire Fighter Safety and Emergency Response for Solar Power Systems
PV and public safety – case in point: Target fire

Now that we have power plants in public places – what can go wrong?

- In 2009 a PV system on a Target retail store in California caught fire due to a number of factors
- The firefighters were unable to put out the fire due to design failures as well as installation mistakes
- To extinguish the fire an electrician was ultimately called to the site to open fuses! There were no DC disconnects on the roof
- The cause was an expanding and loose conduit connector, very long conduit runs (~400 ft), incorrect expansion joints, and pinched conductors with a ground fault that had remained undetected from construction
- After a lengthy investigation, the NEC was revised, new solar PV standards created, and new equipment was developed
- One major change was to address the “ground fault blind spot” with “ungrounded” arrays, next came rapid shutdown (NEC 2014)

- In addition to the code changes (ungrounded DC systems, disconnects, rapid shutdown) proper expansion joints (not as shown) are required on straight runs
- NEC 300.7(B) shows expansion rates (3.7” in this case for over 400 ft. and 113F delta temp.)
- High voltage insulation testing needs to be performed at installation
NEC 2011 & 2014 changes

- National Electric Code (NEC) 2008 – a good foundation - prior to this release solar PV was unclear and problematic to interconnect (bus bar ratings, etc.)

- 2011 – clearance of conductors below roof (DC safety), grouping of conductors from separate systems (AC, DC), AFCI required in the inverter, disconnecting means for replacement of fuses (DC), Arc-fault detection on rooftops, beginning of 1000V systems

- 2014 – many changes: better GFP, rapid shutdown of the DC system outside the array (>10ft), more flexibility of the interconnection point (bus or conductor rating), AFCI everywhere including on AC side of system, easier to implement 1000V systems, >1000V for non-residential systems, auxiliary GEC for array, grouping of conductors (DC/AC) is required
Wrap up....
Imagine a world where everyone makes their own energy....

- Distributed PV has two unique advantages over all forms of energy; solar modules fit on rooftops, close to the load.
- By bringing energy production and consumption together - something fossil fuel power plants and other renewable energy (wind & hydro) can't do – distributed generation (DG) is without transmission losses and reduces the stress on the grid.
- Being distributed, PV actually competes with retail power delivered by the utility – not wholesale (energy is worth more at the home).
- And solar energy is clean – and worth more than other forms, not all KWh are the same...
- Imagine a world with solar on every possible rooftop - and electric vehicles in every garage...

- Every person becomes an energy entrepreneur.
- The sun never sends a bill.
- No wars over energy, no man-made environmental disasters...

PV Revolution

The future is already here – it's just not evenly distributed.
— William Gibson
Further study – societal collapse & energy

- “Collapse” by Jared Diamond
  - What caused some of the great civilizations of the past to fall?

- Where did all the oil originate from:
  - Stream (free) “Crude – the incredible journey of oil”

- How dependent are we on oil?
  - Rent: “FUEL”
  - [http://thefuelfilm.com/](http://thefuelfilm.com/)

- What future do we face?
  - Rent: “A Crude Awakening”

- What about Electric cars?
  - Rent: “Revenge of the electric car”
  - [http://www.revengeoftheelectriccar.com/index.html](http://www.revengeoftheelectriccar.com/index.html)
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