Potential of Decentralized Solar PV DC Power in India

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As India's Economy continues to grow

- India's average GDP growth during 2006-09: 8.6%
  - 7% world's GDP with 17% population
  - Increasing demand for energy from a low base
    - But **affordability is the key:** solutions that sell in india have to be at Indian prices

Consumption	India	World
per-capita electricity (kgOE)	704	2752
average energy (TOE)	0.53	1.82

- Generation capacity continues to increase
  - Keeping pace with country's rapid (8 to 9%) economic growth
- Yet India is facing huge power shortage
  - At urban as well as rural areas

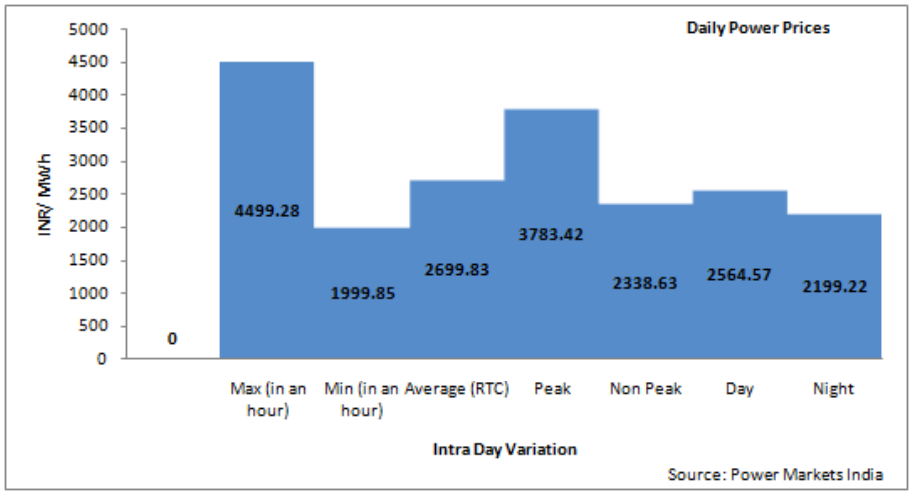
Power Supply Shortage

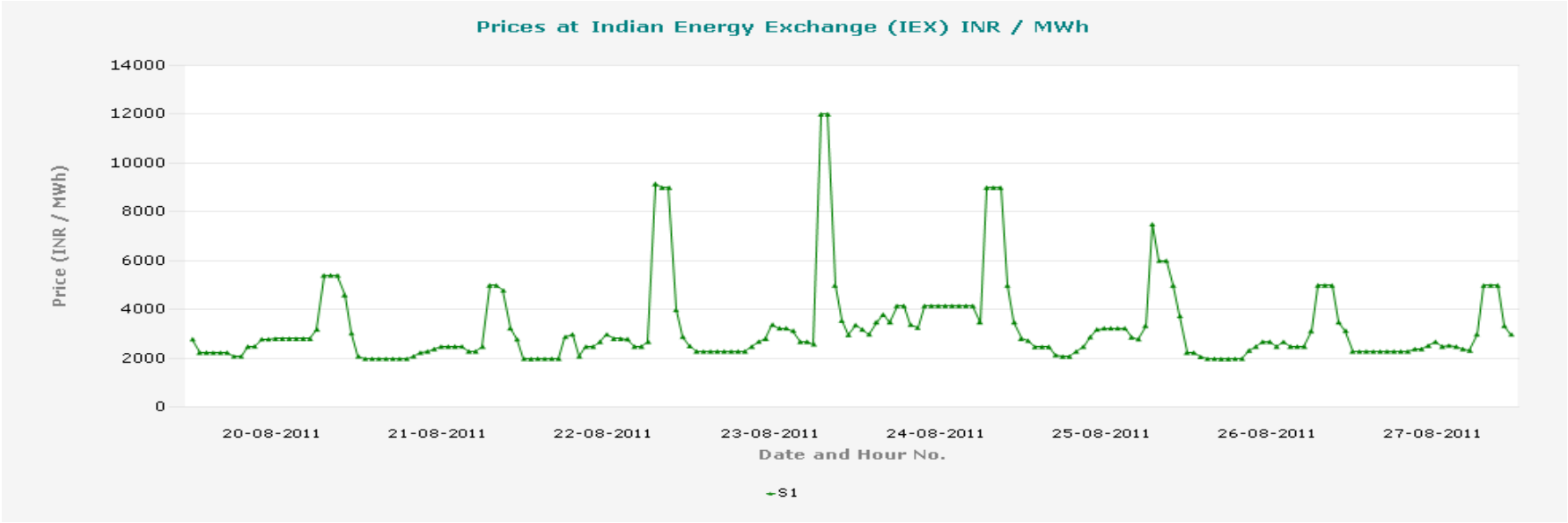
	Energy (MU)	Peak (MW)
Requirements	933741	136193
Availability	837374	118676
Surplus	-96367	-17517
Surplus %	-10.3%	-12.9%

- Cities and towns have huge power-cuts
  - Meerut (50 Kms from Delhi) routinely has 12 hour power-cuts in summer months
- Most of 600000 villages connected
  - 17% villages unconnected
  - Over 60% have power for 4 to 10 hours; Quite a few have power for less than 4 hours a day

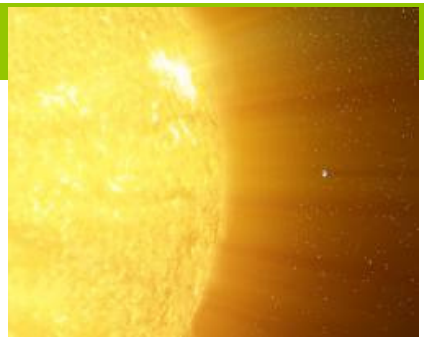
But average deficit is deceiving

- As evident from the fluctuating prices at Power Markets
  - Day variation of Rs 2000 to 4500 per MWh
  - Prices vary from Rs 2000 to 12000 per MWh in one week
- Huge power shortage during peak hours





Is there a solution?



Sun shines brightly over India

- India can certainly use solar energy, as capital goods prices fall
  - Solar photo-voltaic provides DC power for about six hours a day
    - Rs 60 per W capital cost: with 10% interest and payback in 20 years, amounts to Rs 7 per year (not computing costs of land)
      - Costs a little over Rs 4.35 / kWh assuming 10% losses **assuming no land cost**
        - **Installation costs may add another 10% to costs**
      - As opposed to **Rs 3 to 7 per kWh for grid power**

Solar PV power price computation			
PV cost per kWp	60000	sun-hours per day	6
interest rate %	10%	sun-days / year	300
depreciation (yrs)	20	total units gen per year	1800
yearly payment	Rs. -7,047.58	Losses	10%
	price per unit	**Rs. 4.35**	

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Energy Storage

- Batteries are expensive proposition for back-up
  - Lead acid battery: 1500 cycles if operated between 60 to 100% capacity
    - 1 kWh back-up will cost Rs 14/ kWh assuming single charge / discharge per day
      - Assuming Rs 6000 per kWh battery and 10% interest rate
  - LiFePo battery: 5000 cycles if operated between 10% to 90% capacity
    - 1 kWh back-up will cost Rs 16 per kWh assuming single charge per day
      - Assuming Rs 25000 per kWh battery and 10% interest

Lead acid battery

Battery cost (per kWh)	Rs. 6,000.00
discharge	40%
Number of cycles	1500
interest rate	10%
cycles used per day	1
Losses	10%

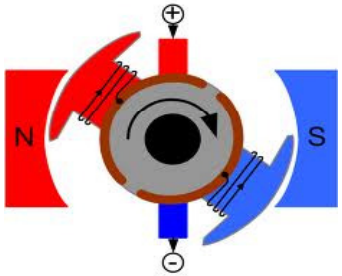
Battery cost (to deliver 1kWh)	Rs. 15,000.00
depreciation (years)	4.11
Storage cost per unit	-Rs. 14.09

Decentralized Solar PV

- Would be ideal in day time
  - To complement grid
  - Direct usage in offices / shopping malls can reduce the day time peak load requirement to a considerable extent
    - Makes economic sense today, provided there is space for solar PV installation
    - No additional land cost; T&D losses controlled
      - Excess demand can be drawn from grid / excess generation can feed to grid
- What about evening peak loads?
  - Solar cannot help here – will have to depend on grid
  - Reducing load by enhancing efficiency
  - Reducing consumption by **introduction of time of day metering**
  - Using some storage

Why continue to use AC appliances?

- Lighting
  - CFL is four times more energy efficient than tungsten bulb and neutral to AC or DC power
  - LEDs, 4 to 10 times more efficient than CFL, use only DC power



- Motor: a small BLDC motor can be 2.5 times more energy efficient as compared to an AC motor
  - Historically brush replacement needed – but not anymore
  - A fan is primarily a motor – a dc fan also allows better speed control
  - A refrigerator is essentially a motor
  - An air-conditioner has a motor (even-though it involves cooling)
  - A washing-machine / grinder is a motor

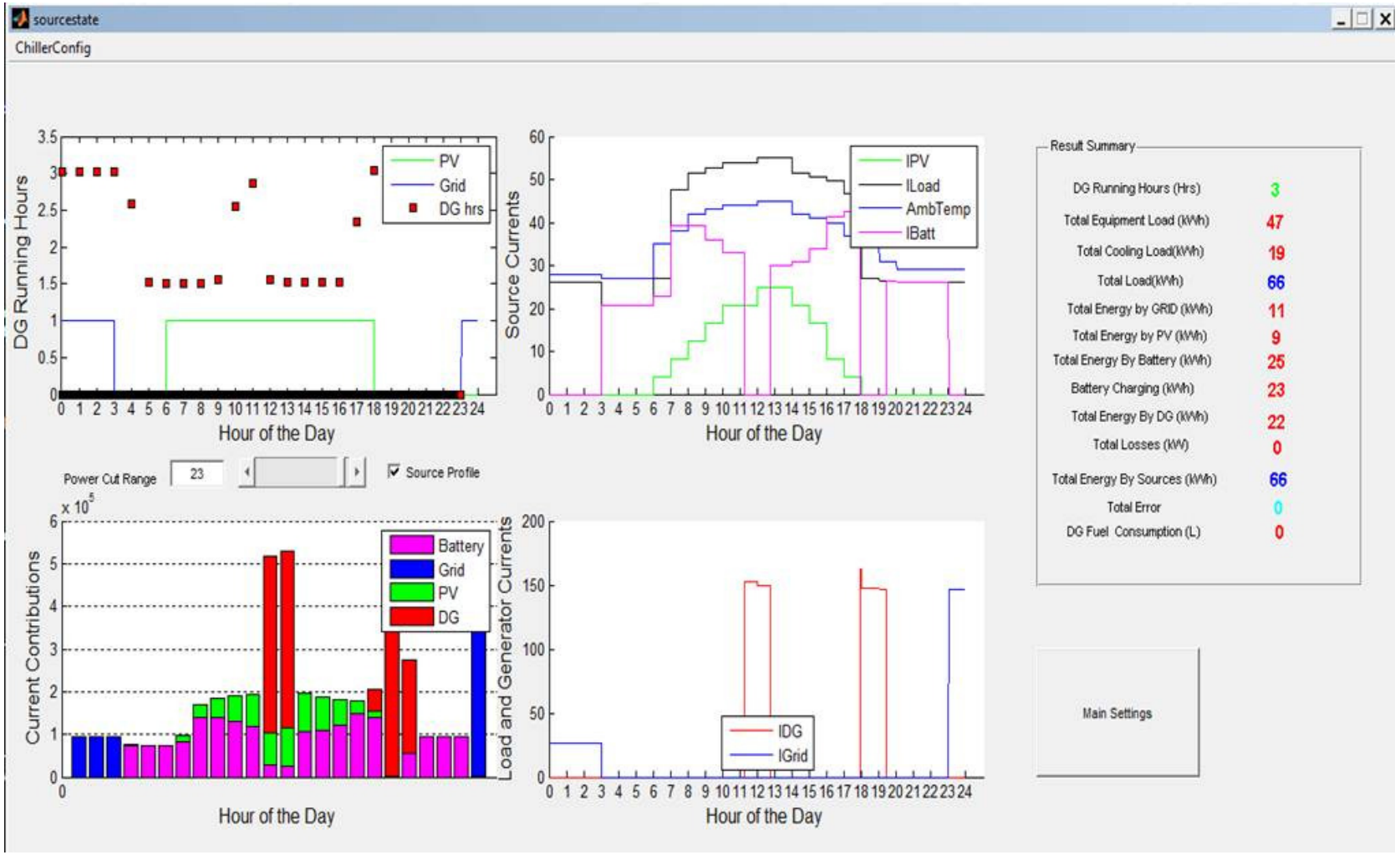
- Electronics: all electronics (mobiles/TV/Computers) use low voltage
  - Need an ac/dc power adaptor to charge
- World switched to AC primarily for transmission of power
  - Any ac / dc conversion or vice-versa implies 7 to 15% losses

Has time come to switch back – at least at customer's premises?

What are the options when power fails?

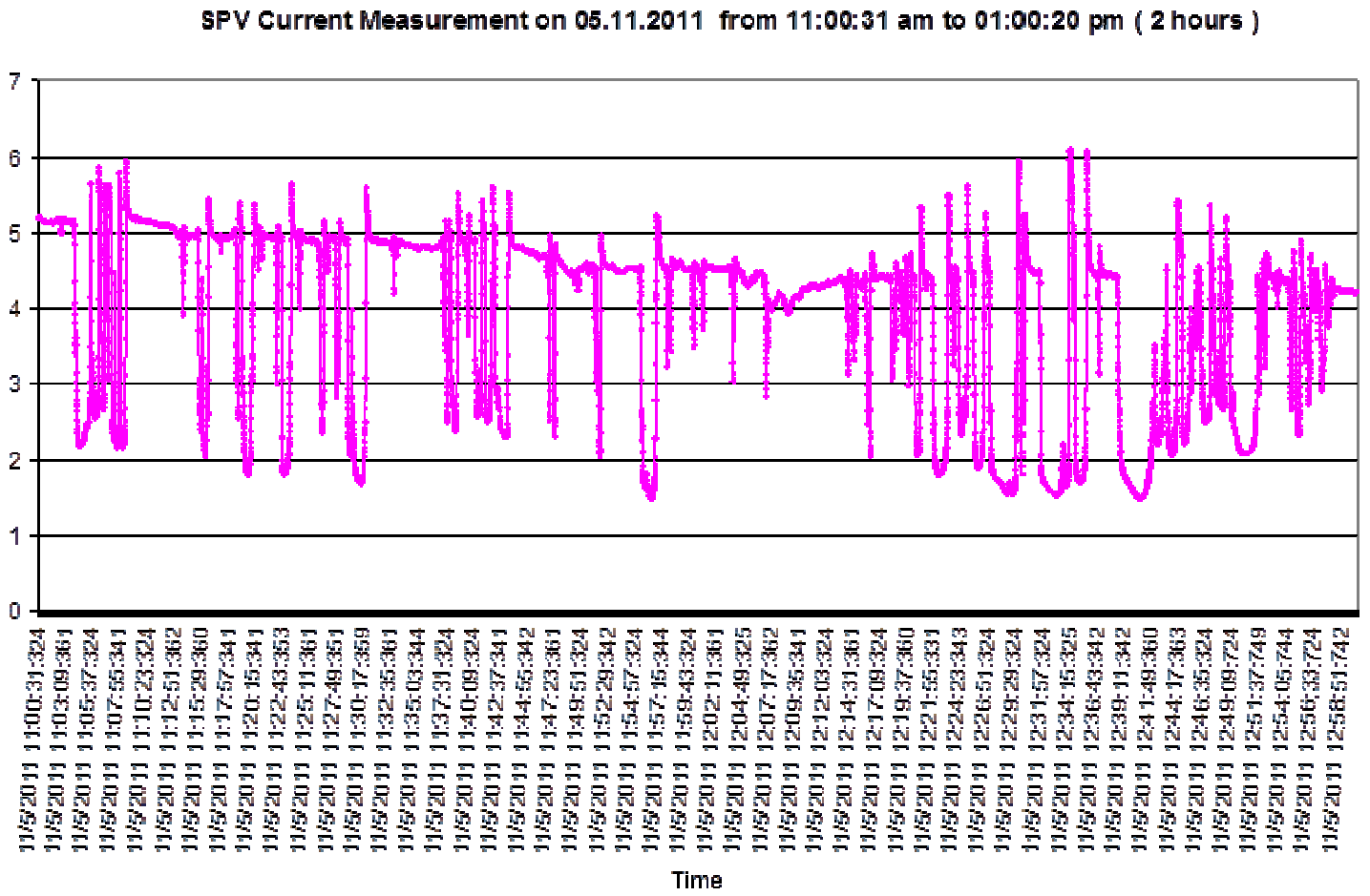
- Power-Sources:
  - Grid: Rs 5 per kWh: ram-bharose (as per god's will)
  - Diesel generator: Rs 17 per kWh when diesel is subsidized vis-a-vis petrol, when generator runs at 80% load: instantaneous
    - Much higher costs at lower load..
    - Costs will go over Rs 25 per kWh without subsidy
    - Primary use today in organizations / offices
  - Solar PV: under Rs 5 per kWh when dc is used: day six sun-hours
  - Electrical battery back-up: storage costs over Rs 15 per kWh
- Usage
  - Electrical Load: lighting, motor and electronics
  - Cooling Load
- What should one use when? How to optimize?
  - What to optimize? – costs, energy consumption, CO2

Simulations (optimization for different combination of sources and loads)

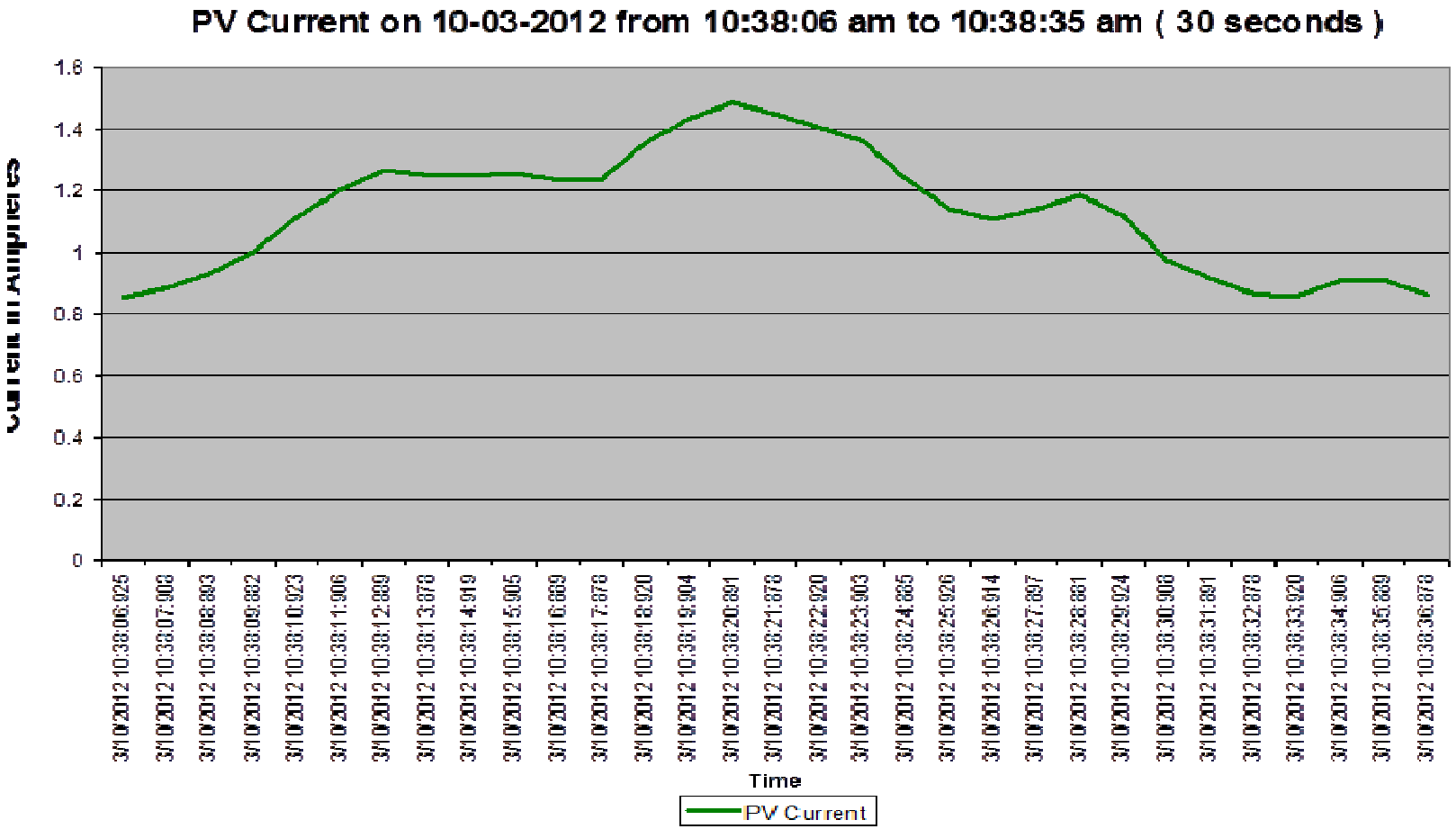


Problems to solve

I. Dealing with Solar PV Power variation



can vary by 50% even in seconds



Long-term Power variation

- Variation will remain even when one converts to AC
- Combining with an infinite source (grid) could help
  - But if power variation for all solar cells in an area is correlated
    - Combining with grid may cause grid-instability
- Long term variation (half hour or more) in solar PV power
  - finding alternate source of power (grid / generator / battery)
  - or would require load control
    - **Smart controller**: India's smart-grid component
      - Combines solar / grid and battery
      - Reduce power usage, if possible, to match generation
        - Reduce fan-speed or pump-motor speed; increase air-con temperature; cut-off one line
      - Alternative to Maximum Power-point Tracker (MPPT)

Short-term Power fluctuations

- needs alternate compensation technique
  - Some kind of capacitor
    - Super-capacitor costs are too high
    - Some battery capacitor

II. Work on alternative storage

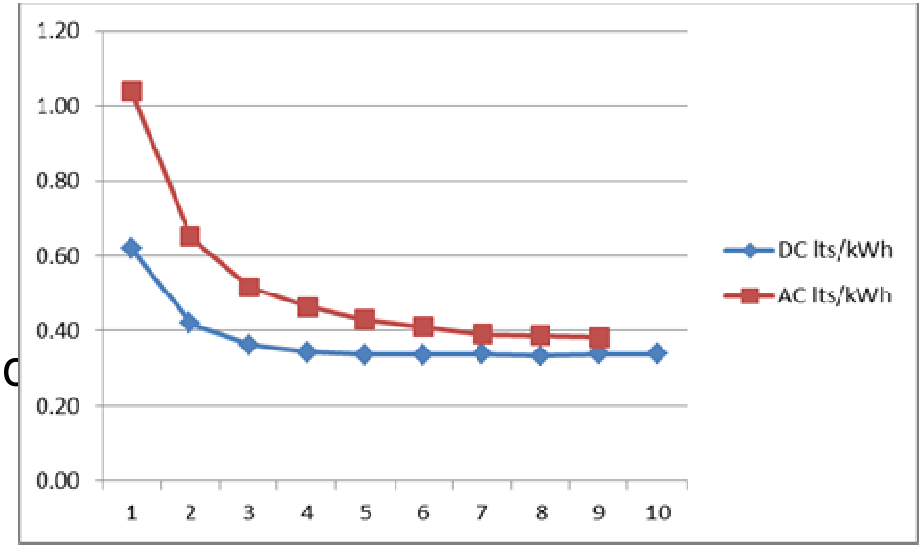
- Flow-battery may be answer to storage
- Work required on Redox flow-battery to make it inexpensive
  - Vanadium or Zn- Bromide Redox-flow battery
- Are there other options?
- Is it possible to store heat / coolness
  - Can even generate during off-peak hours and use it during peak hours.

III. DC diesel generator

- Today battery storage costs as much as diesel

- Diesel generator generates 3 kWh of power per litre of diesel
- But this is true only if generator is working at 80% load
  - Efficiency drops significantly at lower loads
    - Increasing costs of diesel power

- DC diesel generator does not have this problem
  - Fuel consumption is almost linear with load
  - May be ideal as evening solutic in absence of battery / grid or alternate solution



IV. Solar Water Pumps

- Solar PV ideal to drive agricultural water pumps (10 million)
- Water can be pumped when sun is there
  - More water when sun is strong, less water when sun is weak
  - During rainy seasons, lesser requirement of water

- Solar PV with a simple MPPT and VFD could directly drive water pumps
  - Need to figure out whether a battery will help
    - Does it impact the life of pump? Will we require some stabilization?
- Research Problem: How does one gets optimum water-pumping as solar power varies?

- Solar water pumps along with drip-irrigation

V. Solar Powered air-conditioners

- Can air-conditioners be similarly powered using solar PV?
  - Solar PV with MPPT and VFD driving devices?
    - will they work reliably? will equipment get hurt when sun-light varies
- New type of air-con with energy-efficient DC motors (BLDC or Switched Reluctance motor)
  - consumption of 55-60% of regular AC (but 30% more expensive)
  - Power with Solar (DC): voltage controls air-con speed
    - when sun is brightest, it is expected to be hottest and vice-versa
      - Natural Load – Demand Match: best with solar power
- Can they be used gainfully for cold-storage?
  - What is the economics?

VI. Solar-powered Offices

- Primarily used in day time
  - Roof-top Solar PV can play a major role
    - Complementing electrical grid
      - Drawing shortage from grid and feeding excess to grid
  - Use of dc fans, lighting, electronics will help
  - Can DC be directly used to drive air-conditioners?
  - Can DC directly drive water pumps
    - Requires Smart-controller: when sun-light is poorer, reduce consumption
    - What should be the DC line voltage for distribution?
    - What should be the appliance voltages?
      - What should be the wiring harness? Protection? Earthing?
      - What will be dc-dc conversion losses? Costs?
- Can be used in schools, colleges, campus

VII. Solar Powered Lighting and Fans

- LEDs are DC powered
  - Can be powered straight from solar PV
- CFLs are neutral to ac / dc power
  - Requires design of appropriate controller

- BLDC fans
  - Technology well-known; but somewhat expensive and not easily available
  - Design and proliferate SME for manufacturing and distribution

VIII. Need new solar-panels

- Solar cells are very thin and are light
  - Almost paper-like, but may be brittle
  - Panels need to be designed to be least cost (manufacturing as well as erecting) and integrated with roof
    - Needs 15 degree slope (in Chennai) and south-facing
      - Needs water spray once in a month or two
  - For mounting on all roofs, aesthetics is equally important
    - Can one vary the tilt of the roof-panels to track sun inexpensive manner

IX. Solar village-electric plant

- Is it possible to have solar PV based RESCO (Rural Electric Supply Company)
- A PV plant to feed electricity in the village?
  - Excess can be fed to grid
  - Shortage can be picked up from grid, if available
  - Does storage make sense
    - Central level, home level
    - Should diesel generators be used?

- Does it make more sense to have DC grid?
  - 200V DC as primary feed
- Converted if needed at each home: can feed fans, lighting and electronics (TV?)
  - Higher efficiency will help

- Can we get state government to use this instead of free electricity
  - architecture, economics, protection

X. Rural Cellular Base Stations

- Remote Base-stations providing communications
  - Electrical grid is off for 16 to 20 hours
  - Primary operation costs for operators: diesel costs
  - How to use battery back-up, diesel generator and solar power optimally to operate the base station?
    - Will DC generators help?
  - Can we save energy at base station?
    - Especially energy needed for cooling
    - Will DC motors (for exhaust fans) and CFL / LEDs help?
- Can chiller be used instead of air-con?

Development of Key Components

- Solar panels: leverage world's availability
  - Continuously evolving technology
  - Need R&D to catch up with the world
  - Manufacturers willing to set up solar cell manufacturing in India
- Power Electronics, smart controller, combining grid-solar-battery judiciously, system design
  - India has the ability
  - Need focused work
- Storage
  - Research needed on new electrical batteries
  - Storing energy in other forms: for example heat / coldness storage

Policy Issues

- Long-term financing of decentralized solar panels at lower interest rate
  - Solar panels as Priority-sector
  - Subsidy which can not be mis-utilized
- Time of day metering
  - At least for commercial and industrial load for day time peak
  - Evening peak also to be priced high so as to shift power usage pattern

To sum-up

- Solar PV today is a god-sent opportunity for India
  - A year to two of work can make solar power work for us – dc power usage will help
    - at least in the day time; **storage solution will be another game-changer**
  - Solar PV power fluctuates rapidly
    - Use as much natural load-demand match at possible
- Smart-grids for India
  - Key is to match load with available power
  - At local-level as far as possible – if necessary by selective power-shedding
- Number of technical challenges need to be overcome
  - System design issues are critical
  - pilot deployments are key to prove viability
    - Early pilots are three to four months away
- Policy actions to promote solar PV – instead of subsidy
- **One can dream of getting 50% of India's power requirements using solar PV in 15 years or so**
  - Can transform India