

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

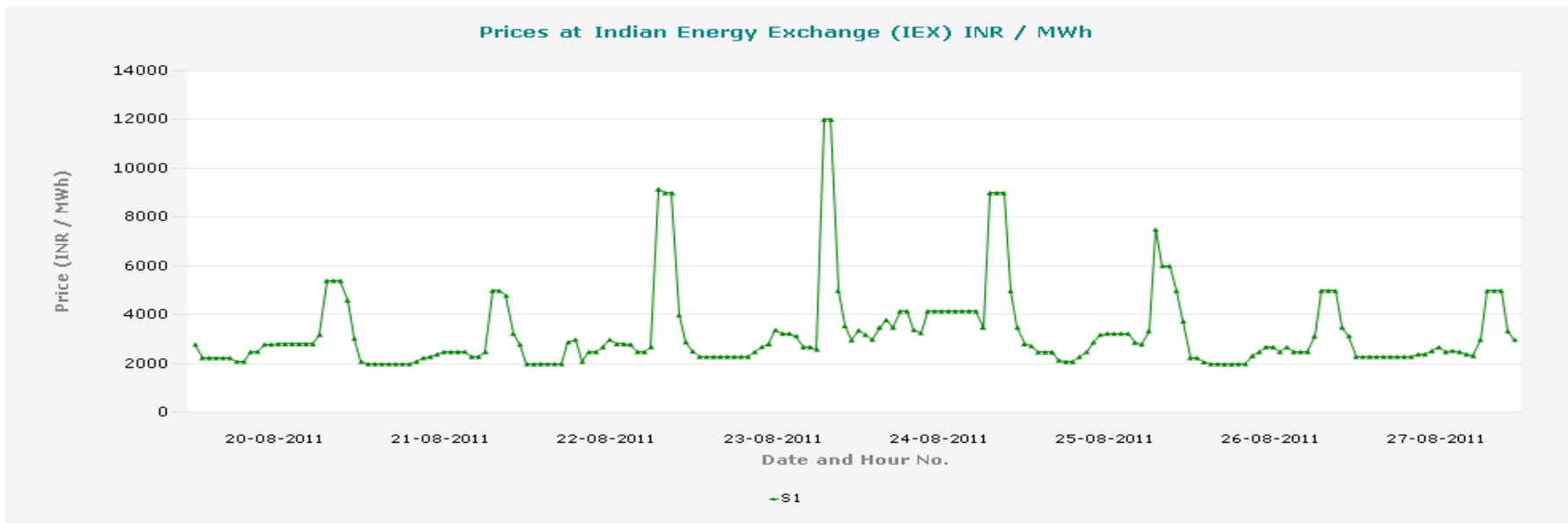
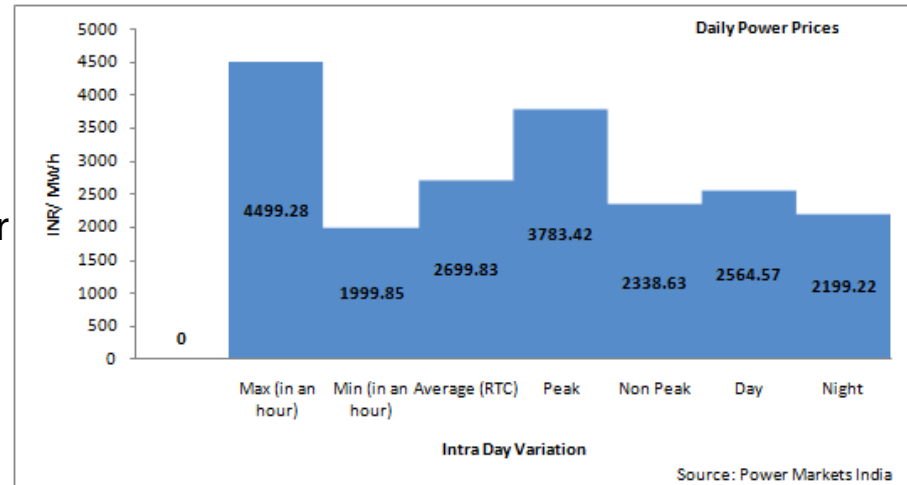
Power Supply Shortage

	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

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?

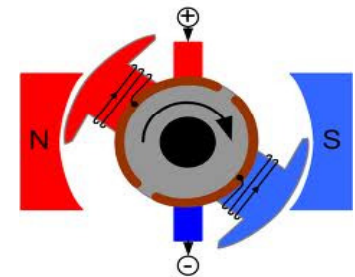
- **Lighting**

- 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

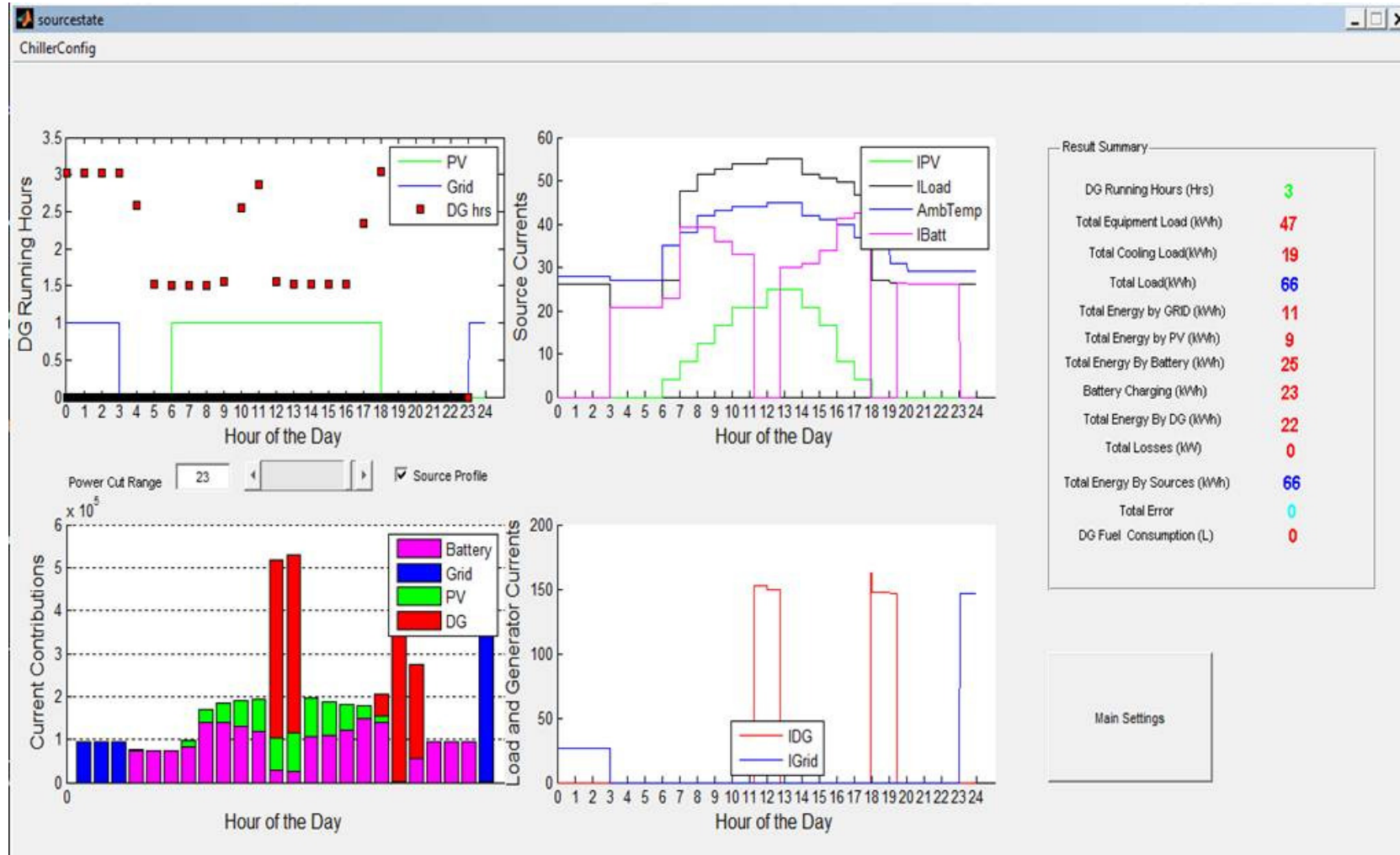
Has time come to switch back – at least at customer's premises?

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



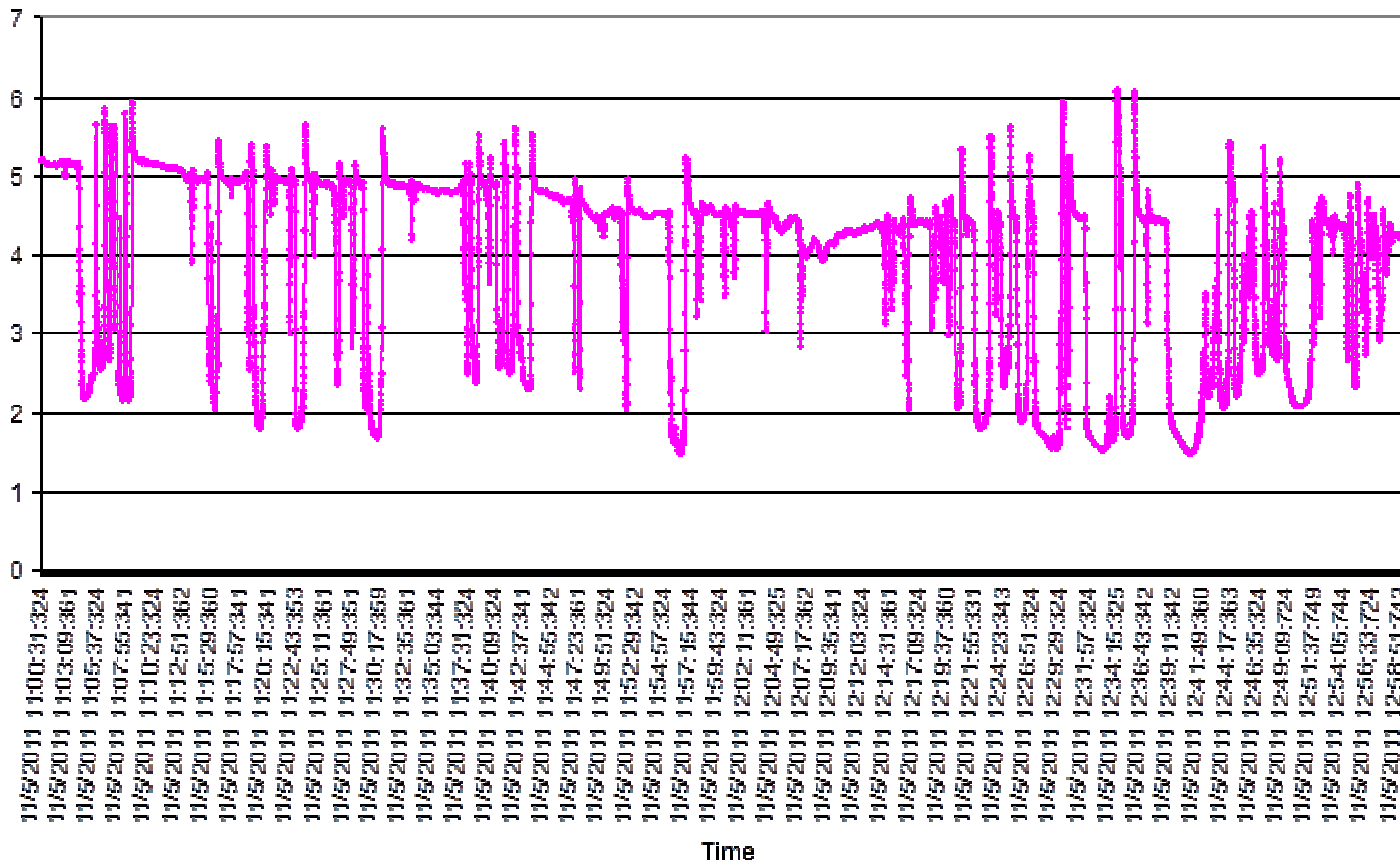
Simulations (optimization for different combination of sources and loads)



Problems to solve

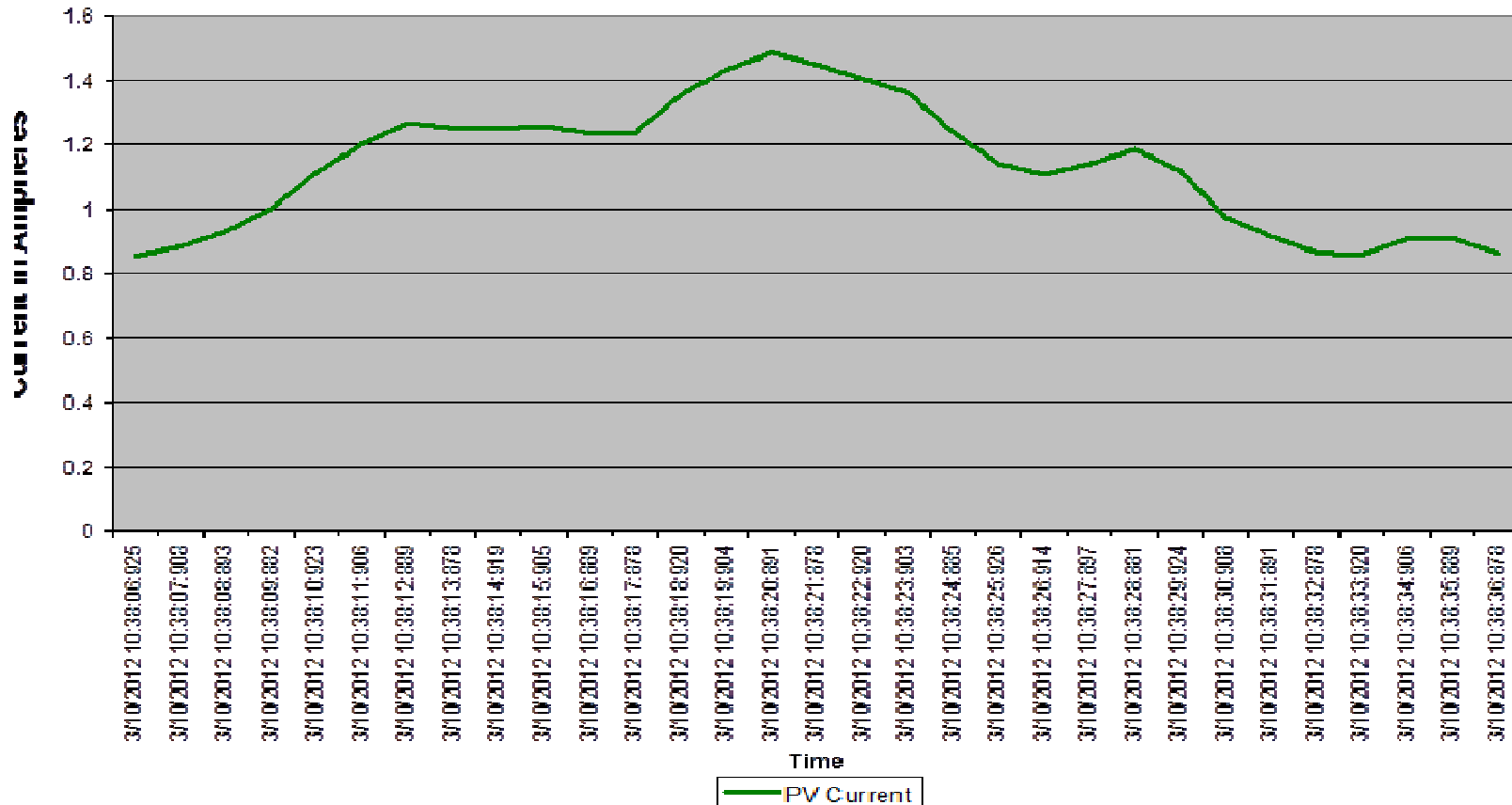
I. Dealing with Solar PV Power variation

SPV Current Measurement on 05.11.2011 from 11:00:31 am to 01:00:20 pm (2 hours)



can vary by 50% even in seconds

PV Current on 10-03-2012 from 10:38:06 am to 10:38:35 am (30 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

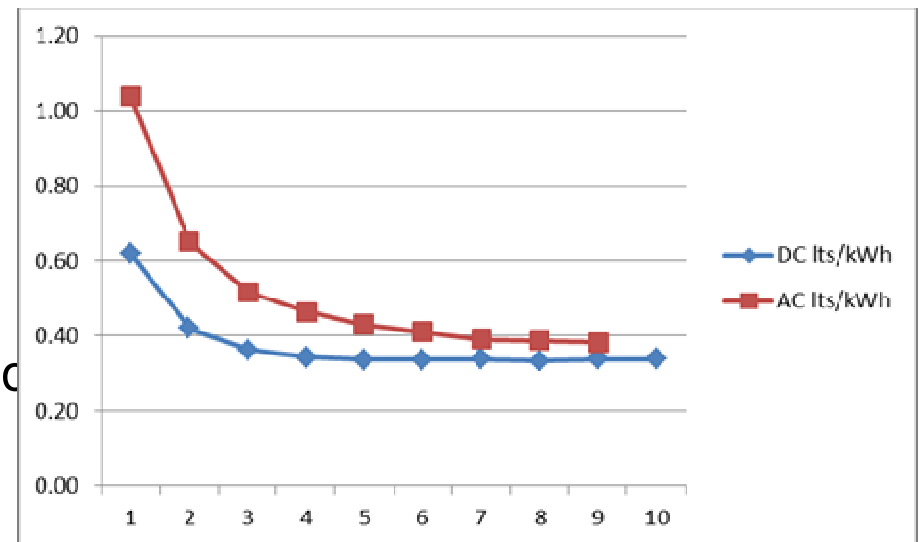
II. Work on alternative storage

- 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 solution 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