

Can we dream of 50% of India's Power in 2030 from Solar PV? Decentralized Approach: Game changer

100th Indian Science Congress, Kolkatta

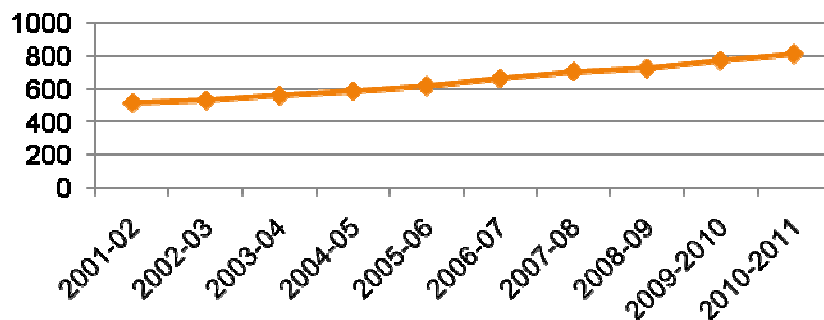
Ashok Jhunjhunwala, IIT Madras,
ashok@tenet.res.in

As India's Economy continues to grow

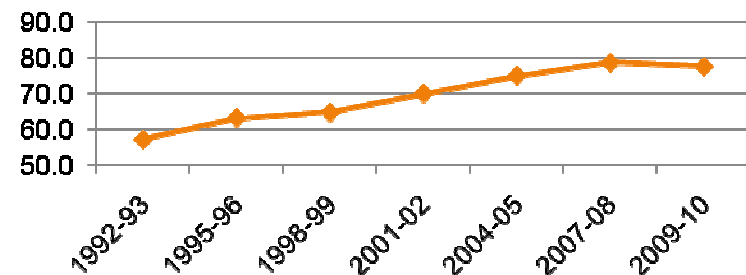
- India's average GDP growth during 2006-09: 8.6%
 - 7% world's GDP with 17% population
 - Increasing demand for energy from a low base
 - But **affordability is the key**: solutions that sell in india have to be at Indian prices
- Generation capacity continues to increase
 - Keeping pace with country's rapid (8 to 9%) economic growth

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

Energy Generated (BU)

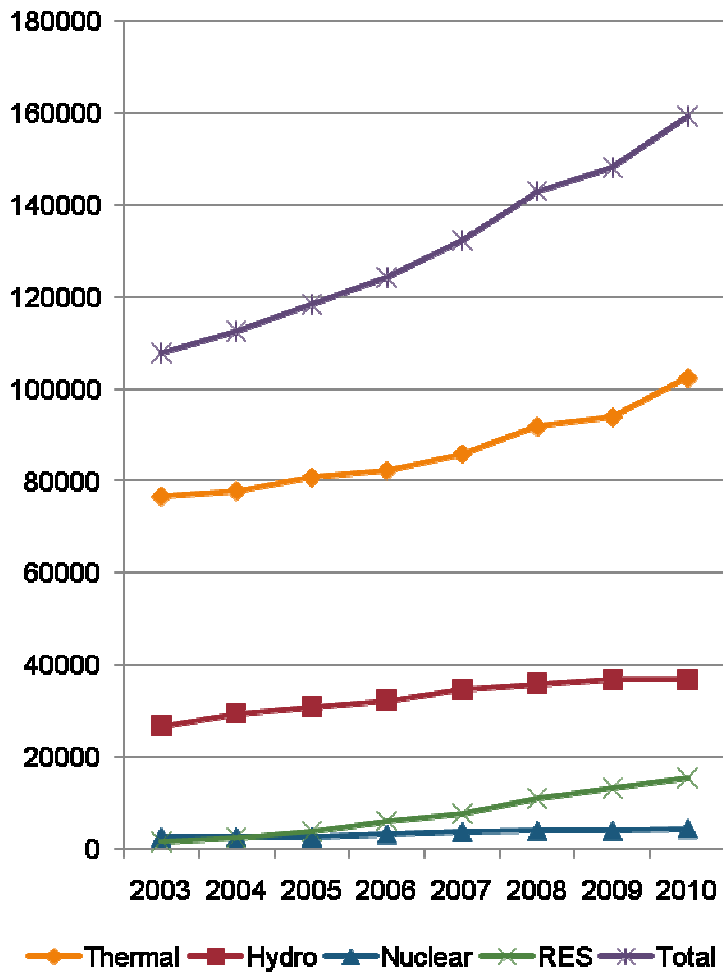


Plant Load Factor (%)



- Even Plant Load Factors have also continued to increase along with generation
 - Plant load factor still low

India's Fuel-wise Generation-Capacity (MW)



- Coal: good for base-load
 - significant domestic reserves
 - proven reserves of 105 billion tonnes
 - could last 200 years at current production level
 - Not good for environment

- Natural gas share up from 4.4% to 10% in last 15 years
 - emit half as much CO2 per kWh as compared to coal-based plants

- Hydroelectric potential of 600 billion kWh per annum
 - Capacity of 148.7 GW
 - only 23% realised so far
 - High initial costs and developmental risks

- Nuclear: small

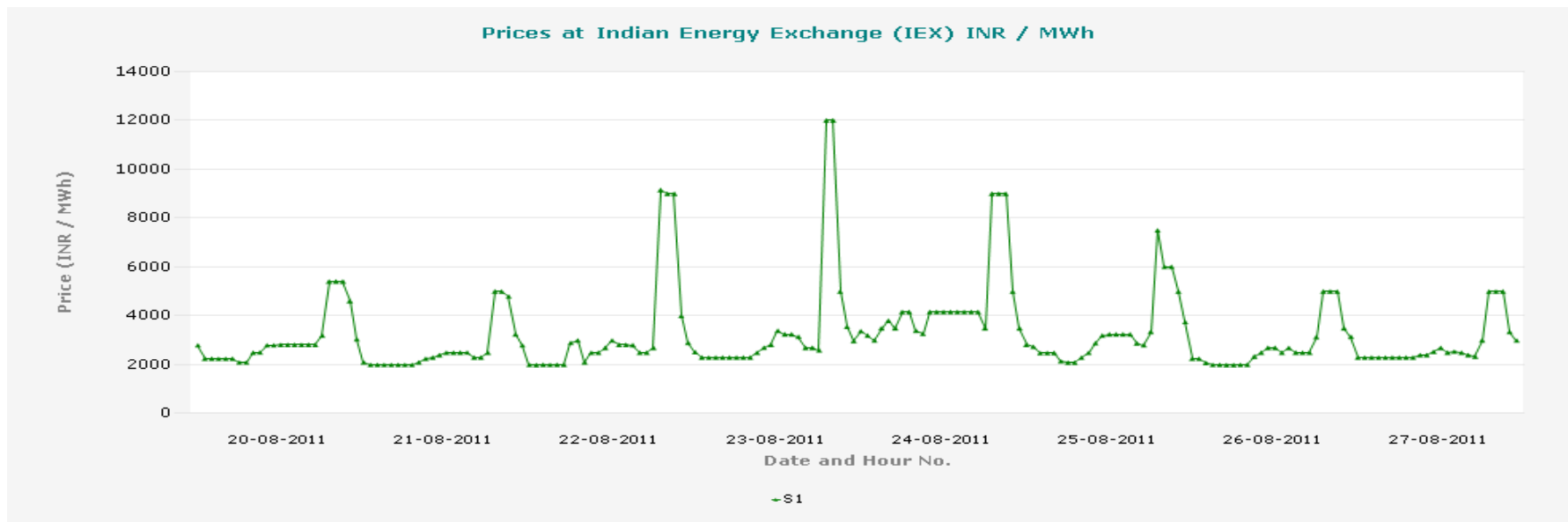
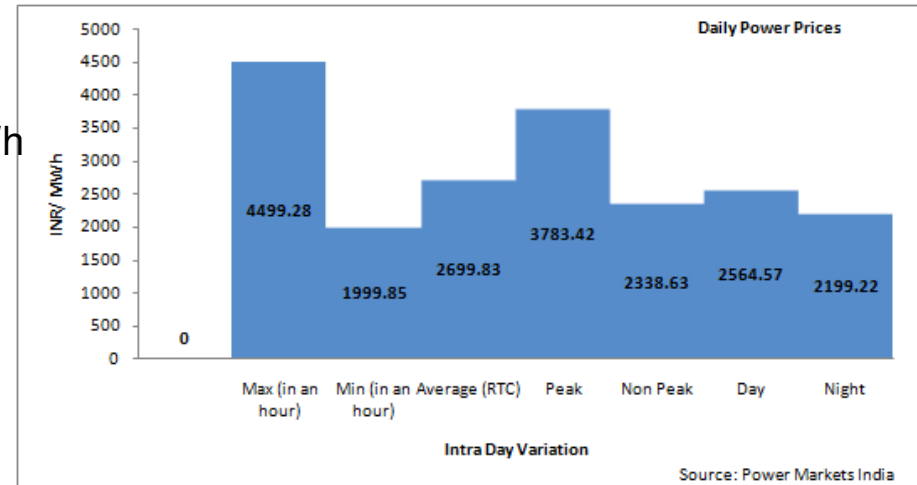
Power Supply Shortage

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

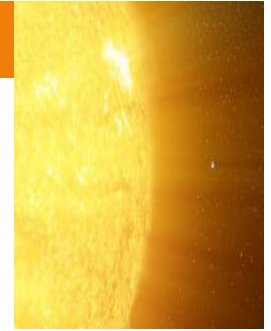
- Cities and towns have huge power-cuts
 - Meerut (50 Kms from Delhi) routinely has 12 hour power-cuts in summer months
- Most of 600000 villages connected
 - 17% villages unconnected
 - Over 60% have power for 4 to 10 hours; Quite a few have power for less than 4 hours a day

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**
 - Assuming DC Power can be directly used
 - As opposed to **Rs 3 to 8 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 15 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	14%
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. 15.35



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 (Rs 25 without subsidy) when diesel is subsidized, when generator runs at 80% load: **instantaneous**
 - Much higher costs at lower load..
 - Primary use today in organizations / offices
 - Solar PV: under Rs 5 per kWh when dc is used: **day time only**
 - Conversion to AC may add Rs 2 per unit; land may add ???
 - Electrical battery back-up: storage costs over Rs 15 per kWh
- Usage
 - Electrical Load: lighting, motor and electronics
 - Cooling Load



Appliances are AC: Can one use DC?

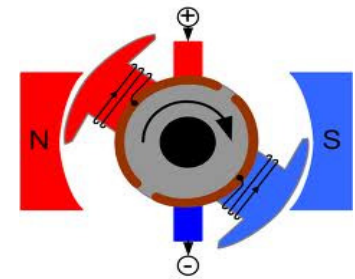
- **Lighting**

- 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 twice 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?

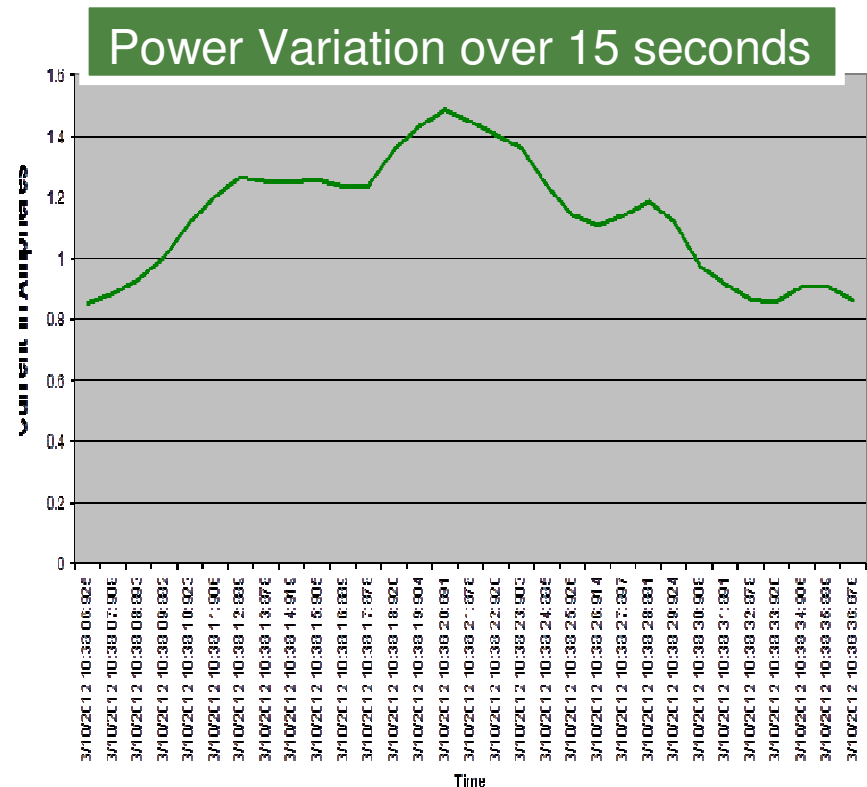
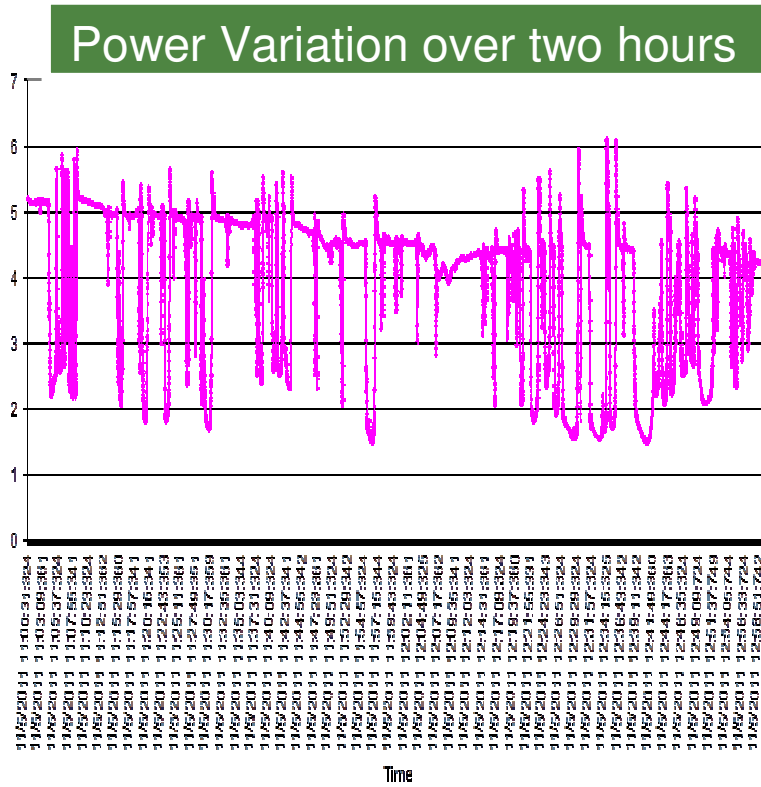
Decentralized Solar PV



- Would be ideal in day time: 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
 - Gradual shift to DC usage will add cost and energy-efficiency
- What about **evening peak loads**? Solar can not help
 - Reducing consumption by **introduction of time of day metering**
 - Can one start and close office early!!
 - Reducing load by enhancing efficiency
 - Using some storage

Problems to solve

I. Dealing with Solar PV Power variation



Over the day power generation starts at 6 AM, peaks at noon and goes down by 6 PM

Power variation and Supply-Load Match

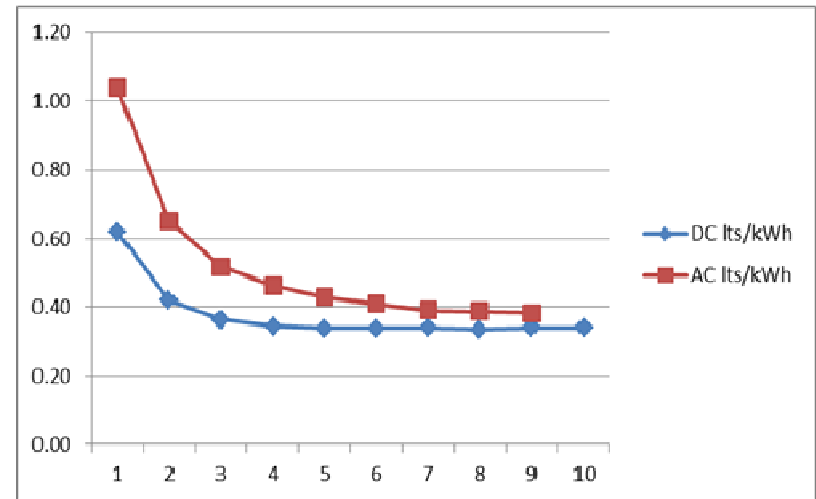
- Variation will remain even when one converts to AC
 - Combining with an infinite source (grid) could help
 - But if power variation for all solar cells in an area is correlated
 - Combining with grid may cause grid-instability
- Need **Power Electronics** and combining with alternate source of power (grid / generator / battery)
 - or would require load control
 - **Smart controller**: India's smart-grid component Combining multiple power sources
 - Reduce power usage, if possible, to match generation
 - Reduce fan-speed or pump-motor speed; increase air-con temperature; cut-off one line
- Natural Supply-Load Match helps
 - When cooling is most required, solar power generation is at its peak

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
- New Lithium Ion battery promises Rs 7 per unit costs
 - New Lead Acid battery promises similar advantage
 - Need Validation
 - Need Intelligent Power Electronics to manage each cell
- Is it possible to store heat / coolness
 - Can even generate during off-peak hours and use it during peak hours.

III. DC Sources and Loads

- Diesel generator generates 3 kWh of power per litre of diesel
 - only if generator works at 80% load
 - efficiency drops with lower loads
 - Not so with **DC diesel generator**
 - May be ideal as evening solution in absence of battery / grid
- **DC Motors**
 - BLDC motors for all kinds of applications
 - Ferrite and Rare-earth Magnets: efficient power-electronics
- **DC Powered Air-conditioners**
 - Solar PV with MPPT and VFD driving
 - New Power electronics and robust motor required
 - New type of air-con with energy-efficient DC motors (BLDC or SRM)
 - consumption of 55-60% of regular AC (but 30% more expensive)
 - when sun is brightest, it is expected to be hottest and vice-versa
 - Natural Load – Demand Match
- **Also DC Powered Air-coolers**



DC Sources and Loads

- **DC Powered cold-storage:** Technology and Economics
- **Solar Agricultural Pumps** (10 million)
 - Water can be pumped when sun is there
 - More water when sun is strong; during rainy seasons, lesser requirement of water: natural Load-demand match
 - Efficient power-electronics for solar PV to directly drive pumps
- **DC Fans and Lights:** costs and availability
 - Need to figure out right DC voltage
 - Wiring losses: Can they use existing wiring harness? Speed / brightness control
 - DC power protection; earthing
 - Minimize dc-dc conversion – losses and costs
 - Design and proliferate SME for manufacturing and distribution
- **DC Powered-Electronics**
 - What should be the right voltage? Standards?

IV. Higher efficiency solar-PV and panels

- Require cost-effective solar panel with higher efficiency
 - From current 13% to 20% efficiency at panel costs Rs 40 per W(p)
 - When can we get 30% efficiency at similar costs?
 - Need long term financing at lower interest costs
 - Priority-sector financing
- Solar cells are very thin and are light
 - Almost paper-like, but may be brittle
 - Panel Mounting at lower costs
 - For mounting on all roofs, aesthetics is equally important
 - Needs periodic water spray and scrubbing

DECENTRALIZED SOLAR PV

Short-term (2 to 5 years) possibilities

Solar powering of Agricultural Pumps

- Significant savings possible of subsidized electricity
 - Important that it is not subsidy driven but commercially viable for farmers
 - Current pump-sizing determined by 1-2 hour power availability
 - Solar Agricultural pumps could be run for 10 hours
 - Need much smaller sizing pumps : will pump required water
 - Would reduce solar array size
 - Minimise costs as well as minimal shaded agricultural land
- Solar water pumps along with drip-irrigation desirable

Solar-powered Commercial Buildings

- Primarily used in day time
 - Roof-top Solar PV can play a major role in complementing electrical grid
 - Drawing shortage from grid and feeding excess to grid
 - Take advantage of natural Supply–demand match for air-cooling
 - Smart-controller helps: when sun-light is poorer, reduce consumption
 - Use of dc fans, lighting, electronics air-conditioners will help
 - Can one use DC distribution (grid) within the building
- Can be used in schools, colleges, campuses
 - And even in manufacturing industry
- Also Solar powered homes



Solar village-electric plant

- 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
 - Evening powering needs alternatives
 - Some Storage: at village level / home level
 - Will Diesel generators be economic?
 - Can wind energy / bio-mass energy / micro-hydel help?
 - Can also power agricultural pump-set
- 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
- Can we get state government to use this instead of free electricity
 - architecture, economics, protection

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?
- **Report:** Powering Cellular Base Stations: A Quantitative Analysis of Energy Options -- solar PV, Diesel Generators, Batteries and Electrical Grid
http://tcoe.in/download/1/Download-Section_190/1/1.html



Need Intensive R&D

- **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, protection**
 - 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
 - Such Solar panels should be included in Priority-sector lending
- Subsidy
 - Should enable early commercial viability, rather than making subsidy and end-game
- 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**
 - 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 by the year 2030 or so**
 - Can transform India