Optimum Design of Solar PV Solutions in Pakistan

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Speaker Info-Hassan A Khan

- BEng – Electronic Engineering, GIKI, Pakistan-2005
- MSc – The University of Manchester-2006
- PhD – The University of Manchester-2010

<u>Research Areas</u>

- Photovoltaics
- Semiconductor device modeling, characterization and fabrication
- Renewable Energy systems
- Energy conservation and management

Outline

1. Energy Scenario for Pakistan
2. Topologies for solar PV Systems
3. Technological Overview of Solar PV Components
4. Market Assessment for Local Needs
5. ROI Analysis
6. Roadmap for Future
7. Case Study – Deployment of a 42 kWp Grid tied System at LUMS
8. Energy and power research projects at LUMS

Humanity's core problems in 2050

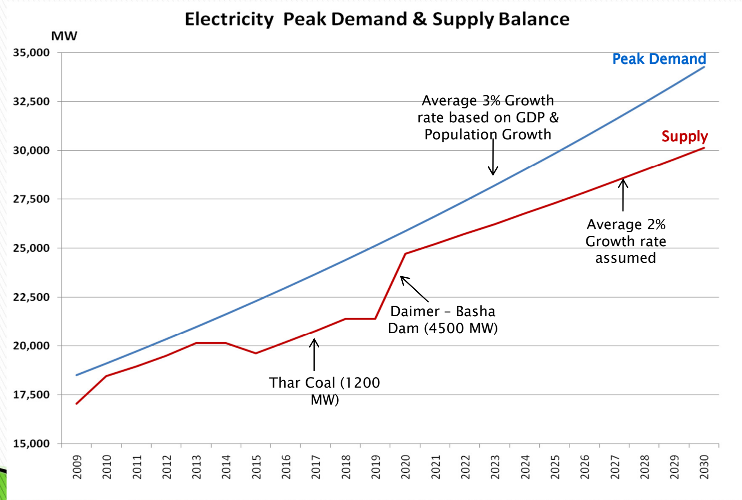
Richard Smalley, Energy & Nanotechnology Conference, Houston.

1. ENERGY
2. WATER
3. FOOD
4. ENVIRONMENT
5. POVERTY
6. TERRORISM & WAR
7. DISEASE
8. EDUCATION
9. DEMOCRACY
10. POPULATION

2012	6.9	Billion People
2050	9-10	Billion People

Global energy demands are currently unsatisfied.

1. Energy Scenario for Pakistan



Impact of Electricity Crisis

Electrification Rate : 56%

Supply Shortfall : 1100 – 7000 MW

Power Outage per day : 8 – 18 hours / day

	Impact / Year
Total cost of load shedding to the economy	2.5 Billion USD
Cost as percentage of GDP	2 % decrease
Loss of employment in the economy	400,000 jobs
Loss of exports	1 Billion USD

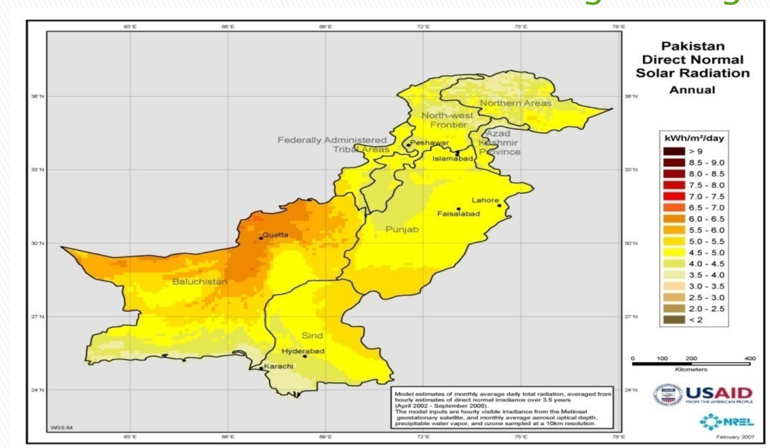
Source: State of the Economy – Emerging from Crisis 2008, Beacon House National University publication

Solutions to the Crisis

1. Power production through available conventional resources such as natural gas and ‘oil’.
2. Thar-coal project
3. Hydroelectric generation through dams – Kalabagh Dam and Bhasha Dam

➢ A rapid shift towards renewable energy resources; most potential lies in wind and solar energy

Surface Solar Insolation Among the Highest



Average energy received by Pakistan in ONE HOUR is more than the electricity consumption in Pakistan for FOUR YEARS!

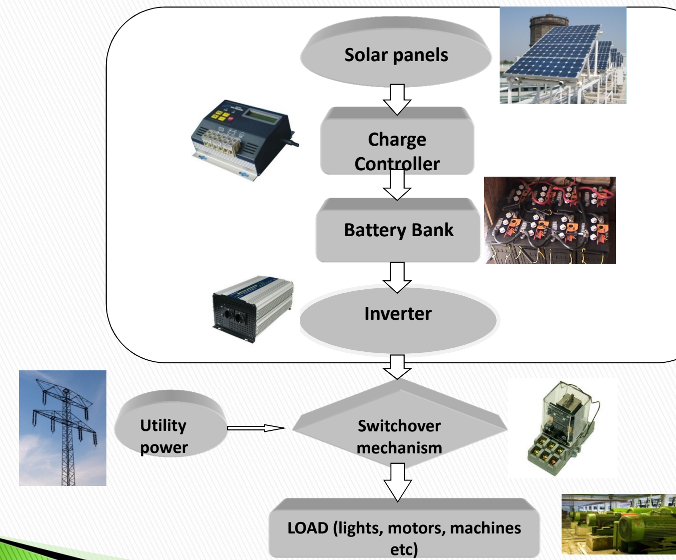
2. Various Topologies of Solar PV Solutions

a) Off-grid use as a backup (solar Powered UPS)

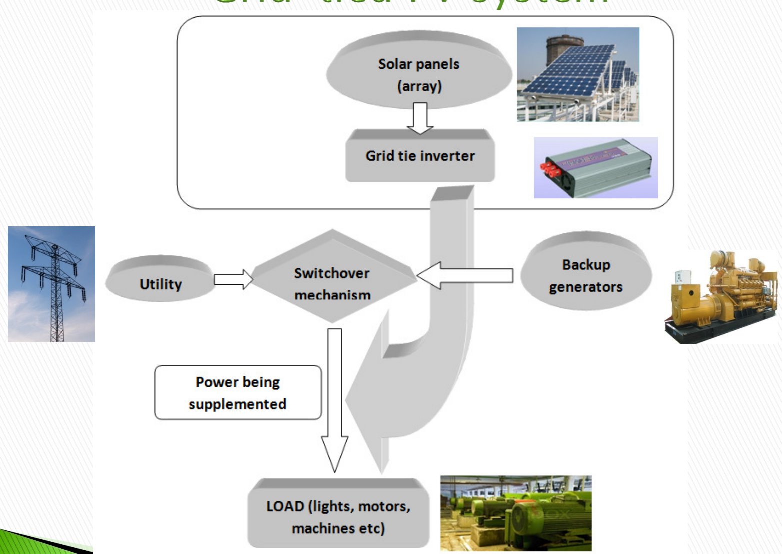
b) Off-grid Standalone systems (eg. CM's UJALA Scheme)

c) Grid tied solar systems

Back-up PV system



Grid-tied PV system



3. Technological Overview of Solar PV Components

- An overall backup system is comprised of;

  a) Solar Panels – solar cells
  b) Charge controllers
  c) Storage Bank
  d) Inversion Mechanism

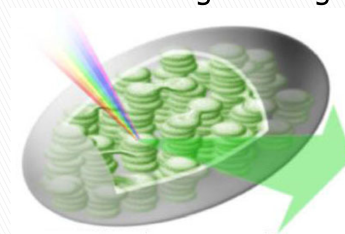
a) Solar Panels - solar cells

- various types of commercially available solar cells are
  - Crystalline silicon based
    - Poly-crystalline
    - Mono-crystalline
  - Thin film based
    - Amorphous silicon
    - Cadmium Telluride (CdTe)
    - Copper Indium Gallium Selenide (CIGS)

Solar Cells are Converters of Energy…

…But Not All Energy is Converted

- Like chloroplasts in plants, solar cells can only absorb specific wavelengths of light.

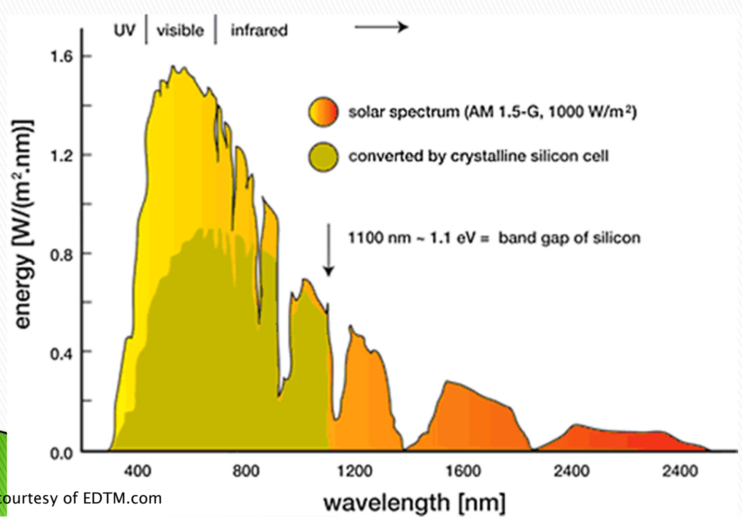


Chlorophyll molecules absorb blue and red light, but reflect green light

- Whether a certain wavelength of lights gets absorbed depends on its energy.

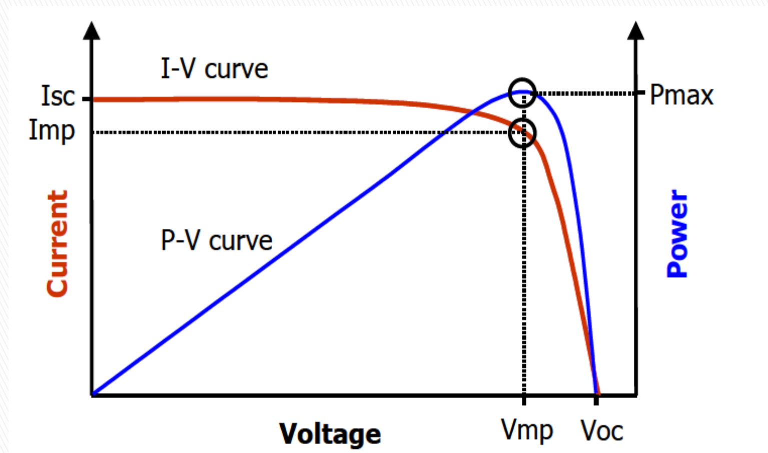
http://ebiomedia.com/prod/cyclops/images/image004.jpg

Solar Spectrum or spectral composition of sunlight



Picture courtesy of EDTM.com

I-V and P-V curves for a Typical Photovoltaic Device.



b) Charge controllers

- Basic purpose: to charge the batteries from solar panels
- Types
  - PWM charge controller
  - MPPT charge controller

c) Storage Bank

- Types of Batteries

1. Flooded Lead acid batteries

2. Sealed lead-acid batter
   - AGM
   - Gel Batteries
3. Lithium-ion Batteries

d) Inverters

- An inverter is a device that converts a voltage provided by a DC source to an alternating voltage of a desired voltage, frequency and waveform.
- Types of Inverters

1. Square Wave inverters
2. Modified Sine wave
3. Pure Sine Wave inverters

4. Market Assessment for Local Needs

- Current State of affairs in the country!
- There are several barriers such as:

a. Policy and regulatory barriers
b. Institutional barriers
c. Fiscal and financial barriers
d. Market-related barriers
e. Information and social barriers.
F. TECHNOLOGICAL BARRIERS

Claim by a PV solution provider…

- "2.5kVA system at Rs 360,000"
- "You can run AC/Fridge, lights, fans etc with 10 hrs backup"
- Highly unrealistic claims …. leads to customer dissatisfaction and stops any further funding in solar PV

Solar Panels

Two technologies are commercially available

- Crystalline Silicon based
  - High Efficiency
  - High negative temperature coefficient (– 0.45 to 0.5 %/ °C)
  - Not Suitable for general Pakistani environment
- Thin Film based
  - Low efficiency, low cost
  - Low negative temperature coefficient (– 0.22 to 0.25 % / °C)
  - Suitable for Pakistani environment (if there is no area constraint)

Batteries

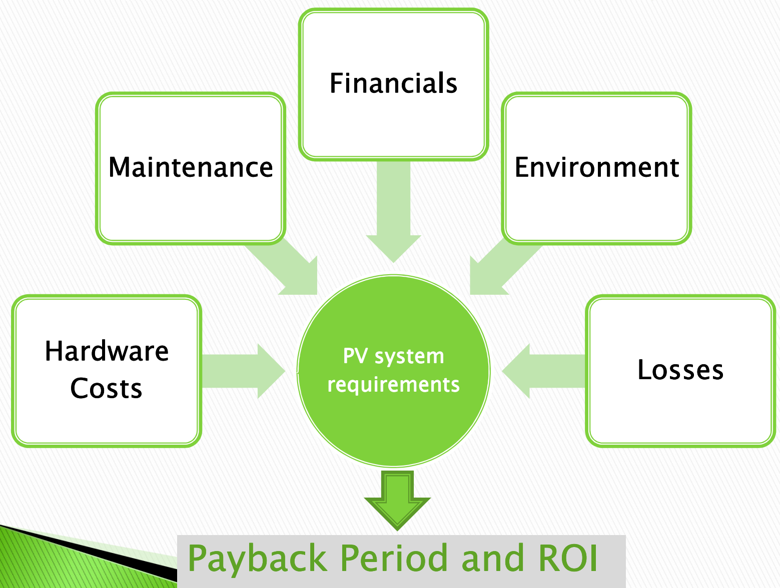
- Flooded lead acid battery being excessively used.
- AGM battery (49 °C limit)
- Valve Regulated Sealed lead acid battery (Gel Battery) optimum for use.

Charge Controllers and Inverters

- PWM controllers
  - Efficient Charging
  - Extend battery life
- MPPT controllers
  - Improve Power extraction from the solar panels
  - Charging through PWM

- Modified sine wave for Standalone/Backup installations
- Sine wave inverter for grid tied applications

Return on Investment (ROI)



Return on Investment (ROI)– continued

Hardware Costs

- Panel Cost per Watt
- Inverter Cost
- Charge Controller Cost
- Wiring & Fixtures Cost
- Storage Capacity (Ah) & Storage Cost

Maintenance (Expected Life)

- Storage (carefully designed system has battery life of around 6 years)
- Inverter (~7 years)
- Charge Controller (~7 years)
- Solar Panels (25 Years)

Financials

- Electricity Cost/kWh
- Expected Increase per Year (%)
- Inflation rate (%)

Return on Investment (ROI)– continued

Environment

- Average Sun hrs/day (kWh/m^2/day) 5.2 for Pakistan
- Panel Temperature Coefficient (loss % /^{o}C)
- Avg. cell Temp (^{o}C)

Losses

- Effective Efficiency at Operating Temp (%)
- MPPT losses (%) ~10.00%
- Power Electronics Comp Losses (%) ~10.00%
- Wiring and Other losses (%) 5.00%
- Efficiency loss/Year 1.00%

ROI sheet

			Panel Sizing (Watts)	Backup Capacity(Wh)	Storage (Ahx12V)	
System Capacity (W)	10,000					
Backup (Hrs)	2		17,161	23,529	5,490	150
Storage Type	150 Ah			23,000	37	
Grid-Tied	N					

	Panel	Inverter	Charge Controller	Storage	Installation	Total (PKR)	Cost/W (PKR)
System Cost (PKR)	2,659,917	50,000	100,000	851,000	100,000	3,760,917	376

Cost of Ownership

Year	kWh	Cost/Unit	Discount Factor	Maintenance	Cumulative Cost	Net Earnings	Cost	Earnings	
1	26,280	20.00	100.00%	0	3,760,917	525,600	3,760,917	525,600	0.139753
2	26,096	22.00	92.59%	0	3,760,917	1,057,186	3,760,917	1,099,713	0.292406
3	25,913	24.20	85.73%	0	3,760,917	1,594,826	3,760,917	1,726,816	0.459148
4	25,732	26.62	79.38%	0	3,760,917	2,138,589	3,760,917	2,411,802	0.64128
5	25,552	29.28	73.50%	0	3,760,917	2,688,546	3,760,917	3,160,011	0.840224
6	25,373	32.21	68.06%	851,000	4,340,093	3,244,765	4,611,917	3,977,280	0.862392
7	25,195	35.43	63.02%	150,000	4,434,619	3,807,319	4,761,917	4,869,983	1.022694
8	25,019	38.97	58.35%	0	4,434,619	4,376,281	4,761,917	5,845,082	1.227464
9	24,844	42.87	54.03%	0	4,434,619	4,951,722	4,761,917	6,910,183	1.451135
10	24,670	47.16	50.02%	0	4,434,619	5,533,716	4,761,917	8,073,593	1.69545
11	24,497	51.87	46.32%	0	4,434,619	6,122,339	4,761,917	9,344,386	1.962316
12	24,326	57.06	42.89%	851,000	4,799,598	6,717,666	5,612,917	10,732,473	1.912103
13	24,156	62.77	39.71%	0	4,799,598	7,319,772	5,612,917	12,248,680	2.182231
14	23,986	69.05	36.77%	150,000	4,854,753	7,928,737	5,762,917	13,904,833	2.412812
15	23,819	75.95	34.05%	0	4,854,753	8,544,636	5,762,917	15,713,849	2.726718
16	23,652	83.54	31.52%	0	4,854,753	9,167,550	5,762,917	17,689,837	3.069598
17	23,486	91.90	29.19%	0	4,854,753	9,797,558	5,762,917	19,848,209	3.444126
18	23,322	101.09	27.03%	851,000	5,084,751	10,434,741	6,613,917	22,205,799	3.357436
19	23,159	111.20	25.02%	0	5,084,751	11,079,182	6,613,917	24,780,994	3.746796
20	22,996	122.32	23.17%	0	5,084,751	11,730,961	6,613,917	27,593,880	4.172094
21	22,835	134.55	21.45%	150,000	5,116,934	12,390,164	6,763,917	30,666,395	4.533822
22	22,676	148.00	19.87%	0	5,116,934	13,056,874	6,763,917	34,022,503	5.03
23	22,517	162.81	18.39%	0	5,116,934	13,731,177	6,763,917	37,688,380	5.571976
24	22,359	179.09	17.03%	851,000	5,261,872	14,413,160	7,614,917	41,692,618	5.475125
25	22,203	196.99	15.77%	0	5,261,872	15,102,910	7,614,917	46,066,447	6.049501

Roadmap for Future

- Identification of best technologies for PV solutions in Pakistan and system parameters for ROI calculation
- Solar PV System Characterization Lab for Quality Standardization in Research and Commercial Applications
- Mapping of available technology with international standards
- Design and development of high efficiency, low cost components to improve ROI

Case Study – Deployment of a 42 kWp system at LUMS

Key Parameters

1. Readily available Grid power & Captive generation
- Grid tied systems (No cost associated with battery bank)

2. Limited space – Rooftop installation
- Selection of crystalline PV
- Shadowing effects

3. Safety concerns
- Cater for high winds
- 4-inch deep bolts sealed with Epoxy

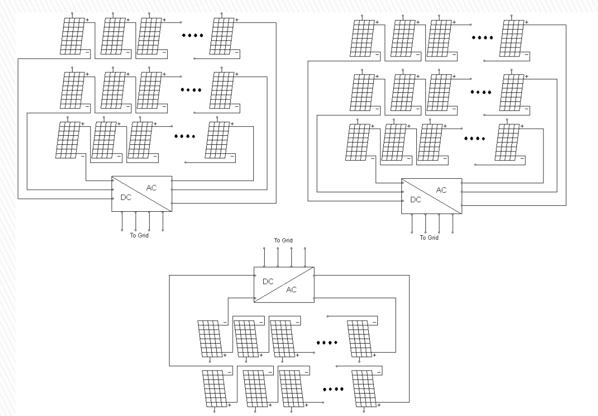
4. Maintenance Requirements
- cleaning requirements

5. Monitoring station
- Wind speed, solar irradiation, ambient temperature
- Daily energy output

System Orientation

- 176 panels (240 Wp each)
- Stationary and mounted at 30° (optimum for fixed installations in Pakistan)
- 3 SMA grid tied Inverters rated at 17kW
- Series connection of 22 panels
  - 3 strings of 22 panels (16 kWp)
  - 3 strings of 22 panels (16 kWp)
  - 2 strings of 22 panels (10 kWp)
- Scalability!

System Schematic



Other projects at Energy and Power Cluster EE LUMS

- Characterization facility at LUMS
- Induction Motor Drives
- Energy conservation through LEDs and smart meters
- Implementation of DC MICROGRID for distributed generation in remote villages
- MPPT based Solar PV back-up systems for industrial use
- Solar-thermal heat solutions for industrial use

Research and Graduate Programs in EE

Research Labs: Advanced Communications Lab (AdCom); Signal, Image and Video Lab (**SIV**); Cyber Physical Systems Lab (CYPHYNETS); Embedded Systems Lab; Networks & Communications Lab (NCLab)

Abubakr Muhammad	PhD, Georgia Tech	Robotics, Control of Hydro-systems
Aamir Rashid	PhD, Toulouse	Computational Electromagnetics
Adeel Pasha	PhD, Rennes-I	Low Power Micro-architectures, EDA
Hassan Abbas Khan	PhD, Manchester	Photovoltaics, Device characterization
Ijaz Naqvi	PhD, INSA	Wireless Sensor Nets, Ultra-wideband
Jahangir Ikram	PhD, UMIST	Computer Architecture, VLSI for DSP
Khurram Afridi	PhD, MIT	Power Electronics, Automotive
Momin Uppal	PhD, Texas A&M	Cooperative Communications, Coding
Naveed ul Hassan	PhD, Paris	Cross Layer Design in Wireless Nets
Nadeem Khan	PhD, Eindhoven	Multimedia Systems, Video Compress.
Nauman Zaffar	MS, UPenn	Smart Power Grids
Nauman Butt	PhD, Purdue	Electronic Devices, VLSI
Shahid Masud	PhD, Queen's	VLSI for DSP, Computer Systems
Syed Azer Reza	PhD, UCF	Optical Sensors, Interferometry
Tariq Jadoon	PhD, Strathclyde	Performance Modeling of Networks
Waqas Majeed	PhD, Georgia Tech	Medical Imaging, Neural Plasticity
Zartash Uzmi	PhD, Stanford	Routing Protocols, Adhoc Networks

Areas/Clusters: Signal & Image Processing; Electronics and Embedded Sys; Networks & Communication; Devices, Optics & Electromag.; Energy and Power Systems; Robotics & Control

MS → PhD

Deadline April 30, 2013

Funding oppurtunities

PhD 4 yrs Fully funded

Full tuition fee waiver with minimum stipend of 18,000Rs

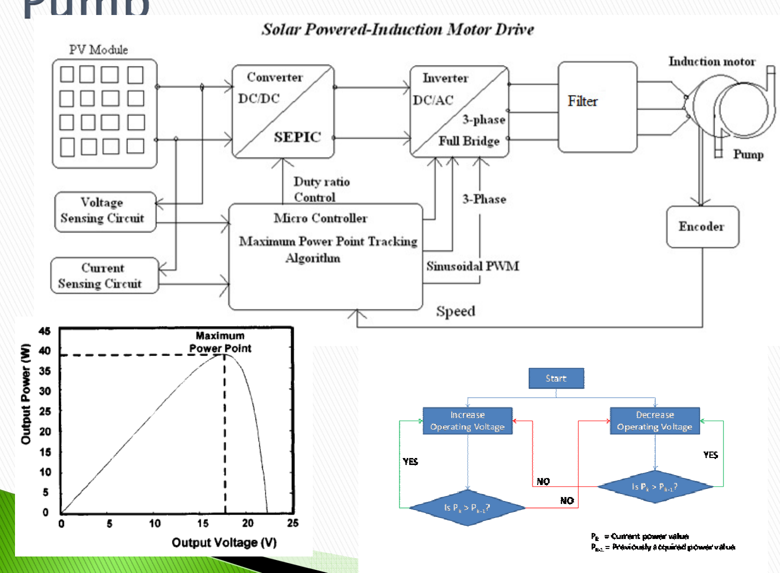
MS (1.5-2 yrs Thesis/non-thesis options)

- Merit Scholarship (2−5)
- National Outreach Program (NOP) full funding possible for deserving students
- Financial Aid
- RA/TA opportunities

Visit: lums.edu.pk/admissions

- Thank you
- Discussion

Project: Solar PV based Water Pump



Smart Metering: LUMS Energy Usage

- LUMS Energy needs: > 2MW
- Lighting load: ~0.5MW
- LUMS Annual Energy Usage: ~**8 million units**
- LUMS Annual Energy Cost (@Rs 14/unit): **Rs. 112 million**
  - > Rs. 9 million per month
  - > Rs. 300,000 per day
  - > Rs. 12,800 per hour 24 hours/day
- *Where* is it being used? *Why* is it being used? *What* is the consumption profile? and *How* to reduce consumption/wastage