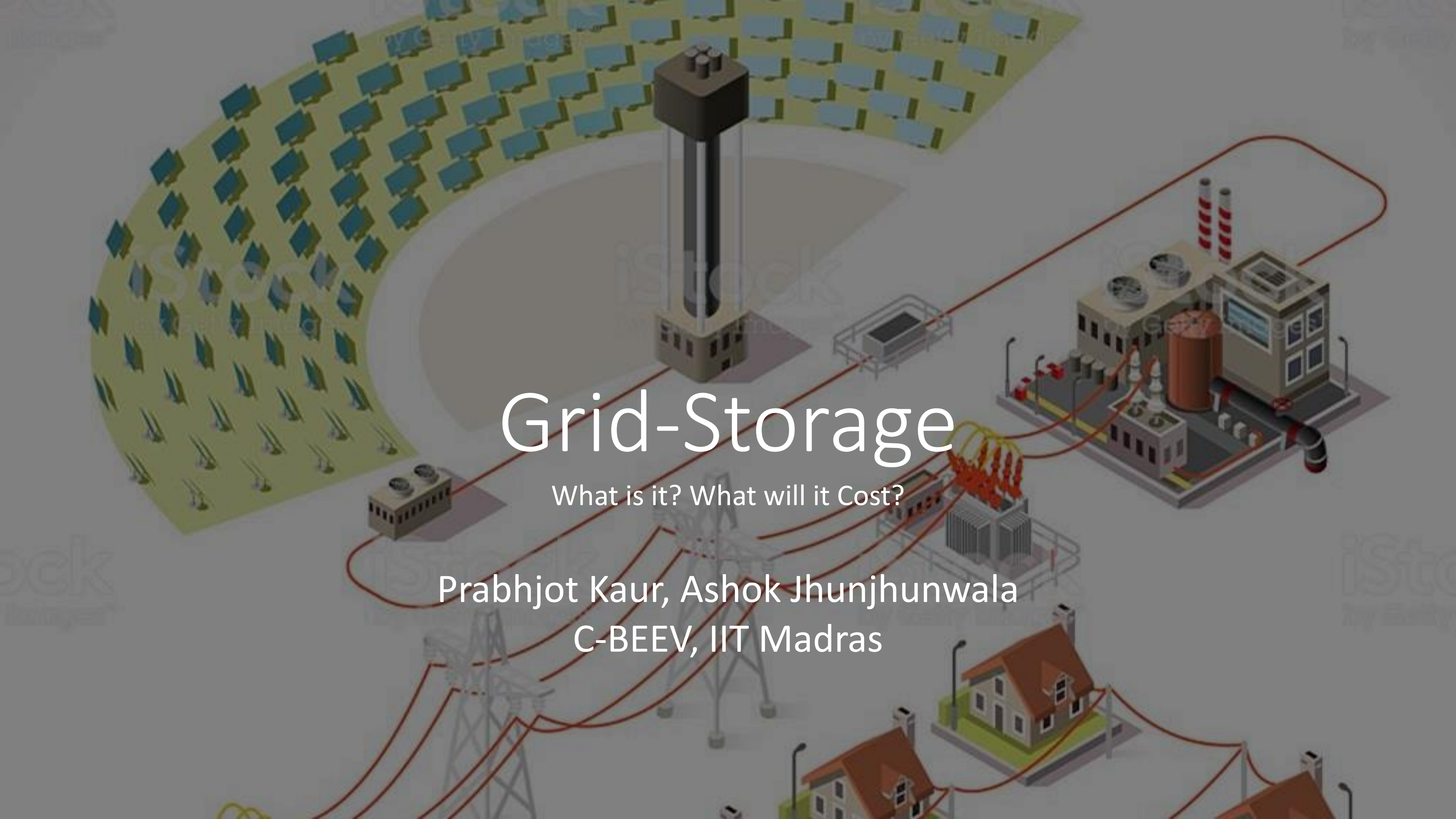


Grid-Storage

What is it? What will it Cost?

Prabhjot Kaur, Ashok Jhunjhunwala
C-BEEV, IIT Madras

Grid Storage a must as renewables grow

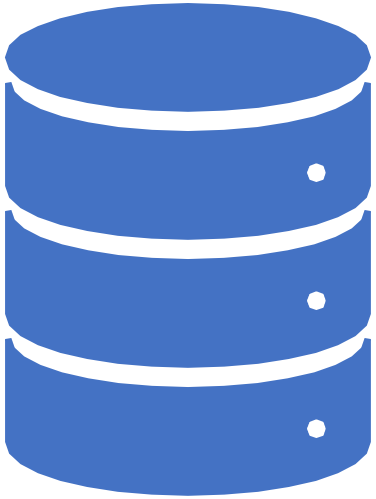
AC grid ⟷ **AC to DC bidirectional converters** ⟷ **Storage**

Renewable power source available only in certain hours and on certain days

Output determined by GOD (Nature), can not be controlled by humans

Will need Energy Storage so as to be available ON DEMAND

Two types of Grid-energy Storage



- Short-term storage for frequency control
  - Takes care of sudden demand-supply gap
    - Batteries with fast charging rate and very high number of charge-discharge cycles
- Energy-Storage for enhancing renewables on grid
  - To make renewable provide 24x7 power at low-cost

To help renewable usage 24 x7

- Renewable energy in India costs ₹2.50 per kWh
- With storage added, to use when renewable is not available, total cost per kWh of storage must add low amount
- How many cycles of battery charge-discharge will be used per day?
  - Depends upon mix of renewable energy and other energy available
  - Will I charge-discharge only once a day?
  - Or can I use it 1.5 times average on a day?
  - Or can I use the full storage 2 times or even 3 times day

Renewable Usage

- Assuming 70% of renewables is used when generated
  - Cost is ₹2.50 per kWh (unit)
- 30% of renewable energy passes through Storage
  - Let S be the cost to store 1 kWh in Storage and retrieving it later
  - Generation cost = (₹2.50 per kWh) + S
- Average cost per unit
  - 70% x ₹2.50 + 30% x (₹2.50 +S) = ₹2.50 + 0.3 * S per kWh

How much is S in India?

What is the cost of usage per kWh of Grid-Storage

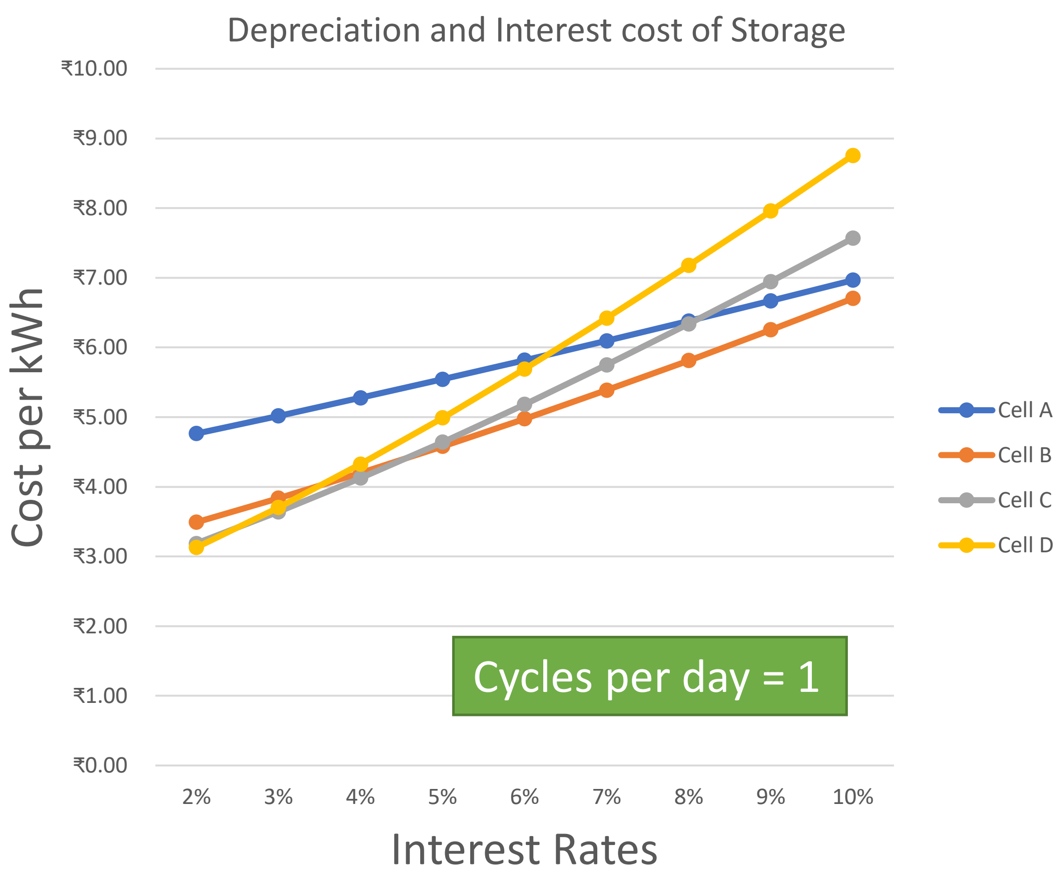
- Depends upon
  - Type of battery
    - Effective number of cycles
    - Capital cost
  - Number of cycles used per day
    - 1 to 3
  - End-to-end Energy efficiency
    - Assume 96%
  - Interest Rates: 2% to 10%

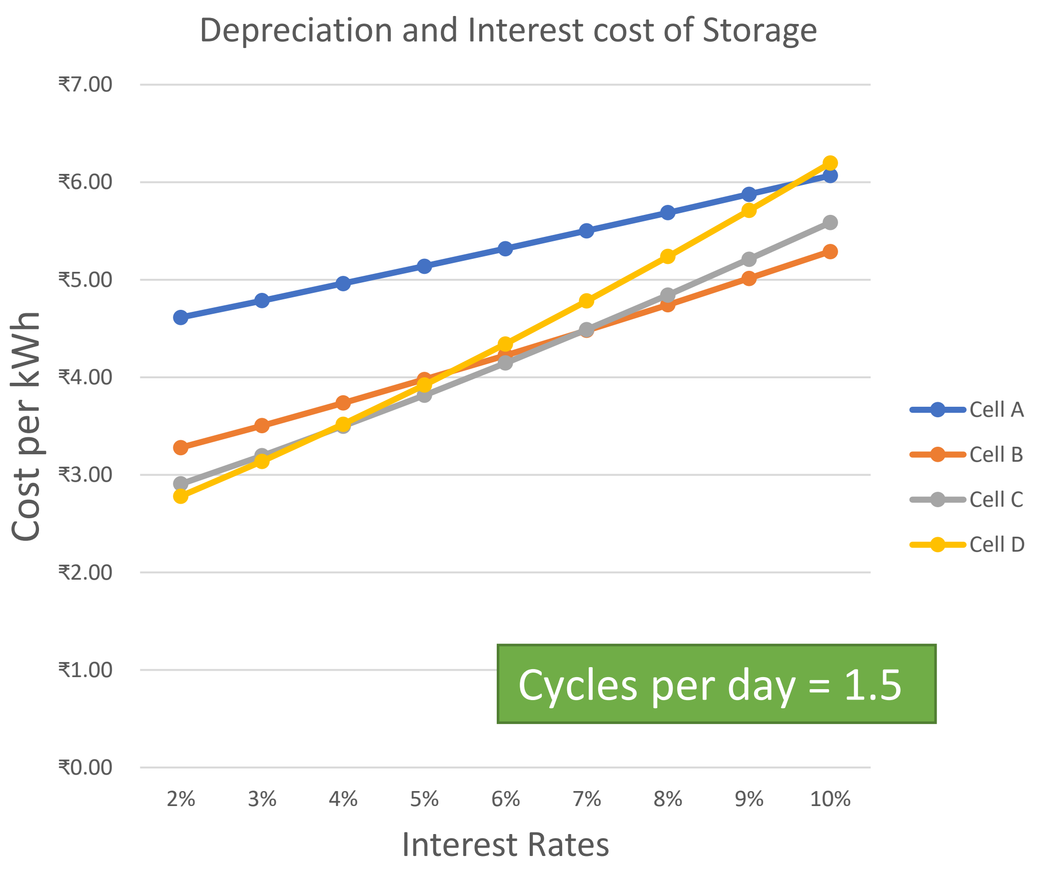
- Consider four type of batteries

	Cell A	Cell B	Cell C	Cell D
Cost (₹) per kWh	15000	20000	25000	30000
Cycles	3650	7300	10950	14600
Chemistry	**NMC**	**Adv NMC**	**LTO**	**LTO**

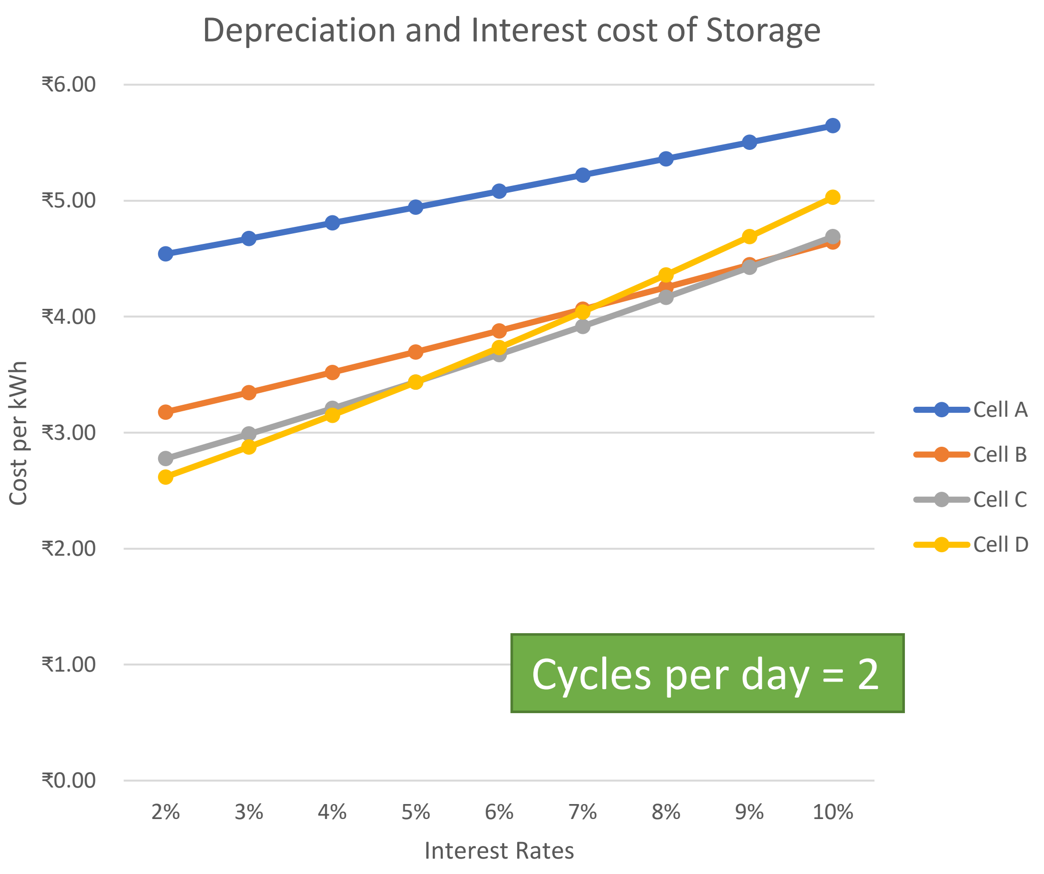
* with today's costs

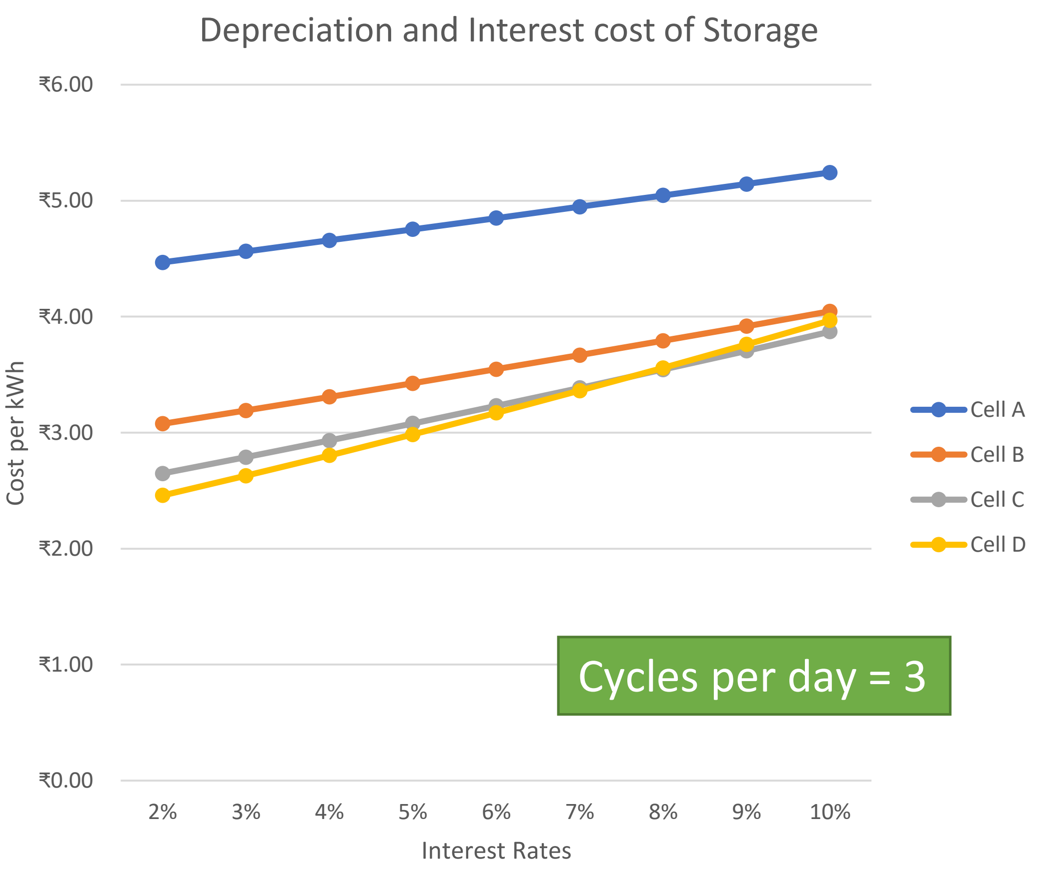
Cost of Storage per kWh





Cost of Storage per kWh





Cell B may be best

- Indian interest rates is 7% to 10%
- 1 cycle per day
  - Cell A or B will costs ₹7 cost per kWh
  - at 6% interest cost is ₹5 to 6 per unit
- 1.5 cycles per day
  - 10% interest: Costs ₹5.25 per kWh; cell B is best
  - 6% interest: Cell B costs ₹4 per unit
- In West at 2% interest rate, Cells C and D (LTO) make sense
- 2 cycles per day
  - 10% interest: Cell B best at ₹4.50 per unit
  - 6% interest: cost below ₹4 per unit; cell C will cost even less
- 3 cycles per day
  - 10% interest: all but Cell A at ₹4 per unit
  - 6% interest: Cell B at ₹3.50 per unit and ₹3 per unit for cells C and D
  - LTO cells better

Cost of Renewable Energy with Storage

- With 70% renewable energy used directly and 30% through storage
- Cost per unit = R = ₹2.50 * 0.7 + (₹2.50 + S)* 0.3 = ₹2.50 + 0.3*S

Renewable cost per unit	Cycles per day			
	1	1.5	2	3
Interest = 10%	S=₹ 6; cell B R= ₹4.30	S=₹5.25, cell B R=₹4.10	S=₹4.50, cell B R=₹3.85	S=₹4, cell B, C, D R=₹3.70
Interest = 6%	S=₹ 5; cell B R=₹4	S=₹4, cell B R=₹3.70	S=₹4, cell B R=₹3.70 cell C costs less	S=₹3.50, cell B R=₹3.55 ₹3, cell C, D

Thus cost of Renewable with Storage will vary from ₹3.50 to ₹4.30 per unit

Additional cost due to storage

- Storage adds ₹1 per unit to ₹1.80 per unit with 7% to 10% interest
  - With 2% interest, cost addition would be in between ₹0.75 to ₹1 per unit
  - With an assumption of only 30% energy used through storage

- If the renewable is to be used 50% of time through storage, the addition becomes much larger
  - Addition of ₹1.75 per unit to ₹3 per unit with 7% to 10%
  - Making renewables with storage go to ₹4.25 to ₹5.50 per unit

- Makes sense to go up to 30% renewables through storage today
  - As cost of storage likely to drop by 50% in next 5 to 7 years
  - One may be able to increase use of renewables through storage up to 50%

Decentralised Storage on Grid

- Decentralised roof-top solar used widely today in office-complexes
  - Makes business sense: provide power in day-time
- Can such office-complexes use Storage
  - Yes, if Time of day metering is introduced
  - In fact, in addition to electric Battery-storage, one may also be able to use chilled-water storage

Demand Energy Optimization

- Building with **Available-Power Responsive Loads (APRL)**
  - Three states of Grid: Deficit. Normal and Surplus
    - Load management in response to the grid supply-demand mismatch
    - When grid-supply exceeds demand, consume without restraint
    - When demand exceeds supply, use minimal electricity without significantly impacting the functionality and life-style of users
- Use Grid-prices to drive APRL Adoption
  - **When grid-power is deficit** (₹12 per unit scenario)
    - Use chilled water from storage and not use chiller
    - Increase set-temperature in offices by a degree, and use VFDs in AHUs and VAVs to reduce power-consumption
    - Use stored battery power to drive Load rather than grid (of-course use solar power to maximum)
    - Cut-off secondary output power to reduce consumption

Economic Incentive to use APLR

- **Surplus grid** (₹4 per unit scenario)
  - Chill water and push it to chilled water storage
  - Decrease aircon set-temperature slightly
  - Charge Storage battery to maximum

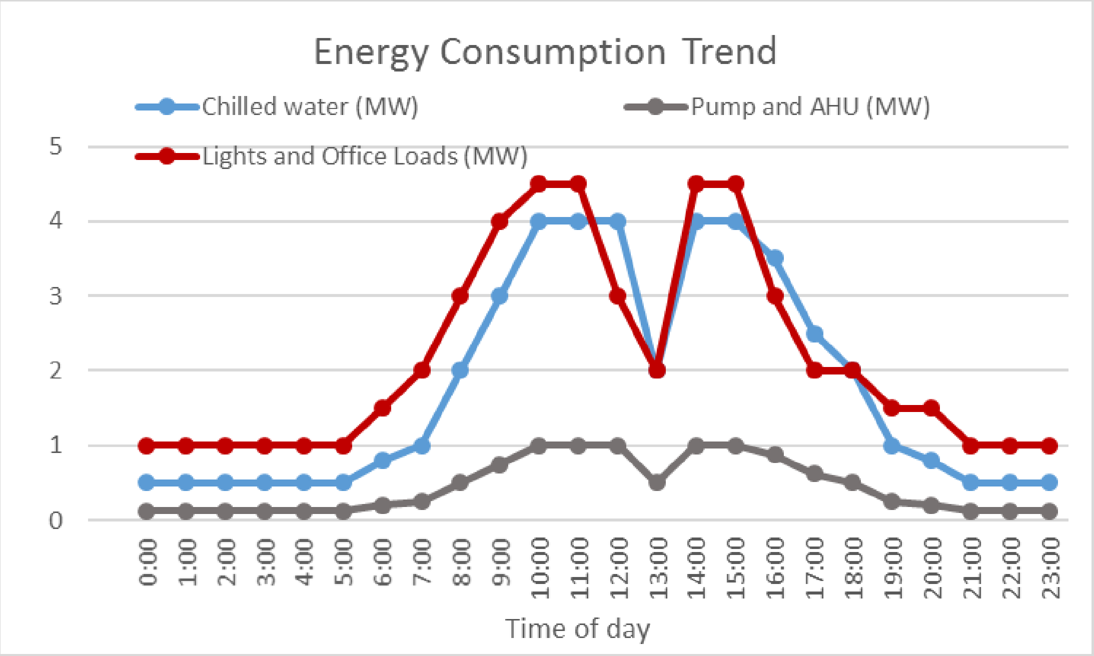
- **Normal Grid (**₹8 per unit scenario)
  - Depending on state of chilled water stored, use chiller to chill water being currently used
  - Use office power from grid, but not charge battery (of course, solar is to be used first)

Load – Supply Mismatch

Building Designed with APRL

Category	Parameters	Value	Remarks
Building Load with usage varying at different times	Peak Chiller power used	4 MW	Total energy used in 24 hours: 43.1 MWh
	Max power used by Pumps and AHUs	1 MW (25% of chiller power)	Total energy in 24 hours is 10.775 MWh
	Maximum power used for lights and for office equipment	5 MW	Total energy in 24 hours is 52.5 MWh
Rooftop Solar	Plant capacity	1 MW(p)	
Storage used	Electrical Battery storage distributed across different offices effective	10 MWh	I. 50% is assumed to be used as power back-up; 50% is used for APLR (8% of energy used in 24 hours) II. Maximum charge and discharge rate of 0.15 MW is assumed
	Chilled water Storage	20MWh	charged / discharged at a maximum rate of 4 MW. Storage is almost 50% of chilled water energy used in 24 hours
	Cold Air Storage in different offices		assumed to be able to reduce power consumption for maximum of 2 consecutive hours giving 25% savings in chilled water usage and pump and AHU power usage; also needs 2 hours to restore before used again.

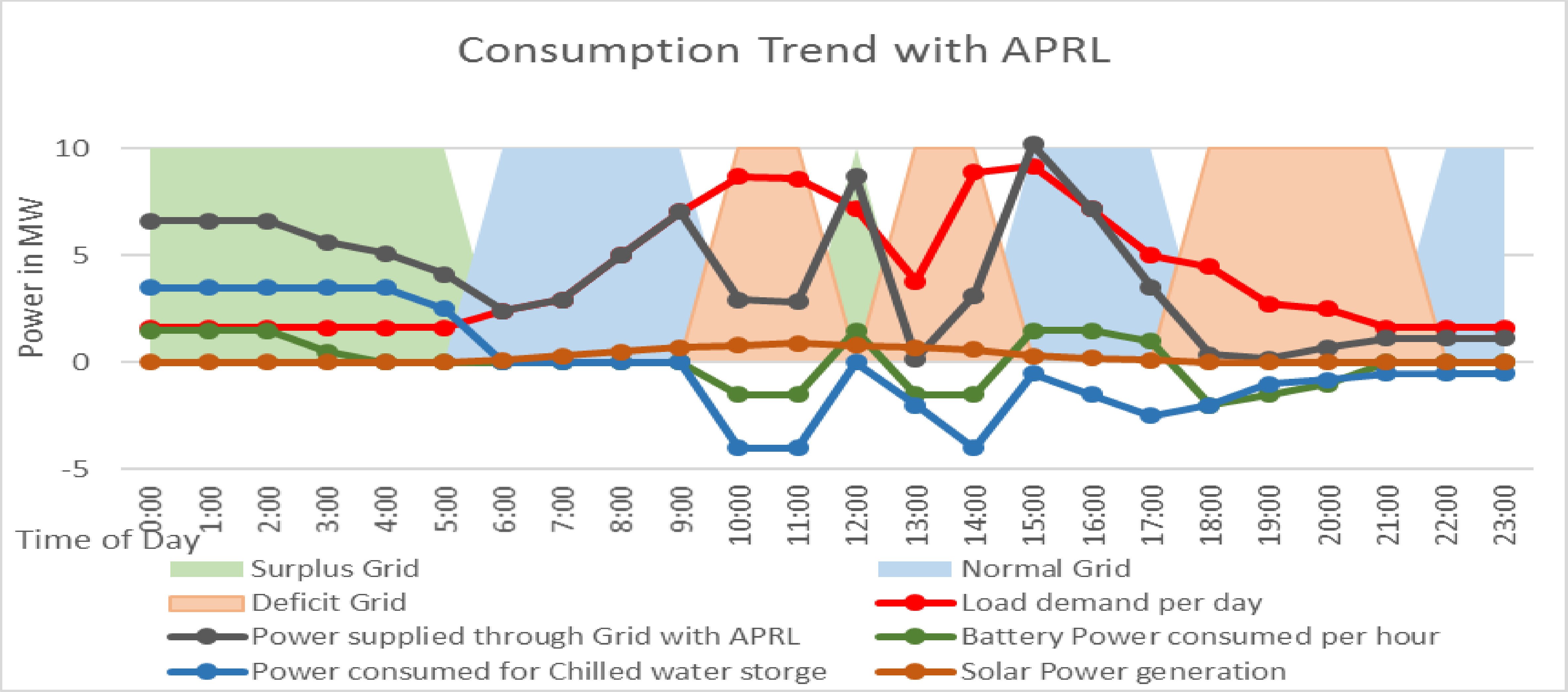
APRL through Grid Control



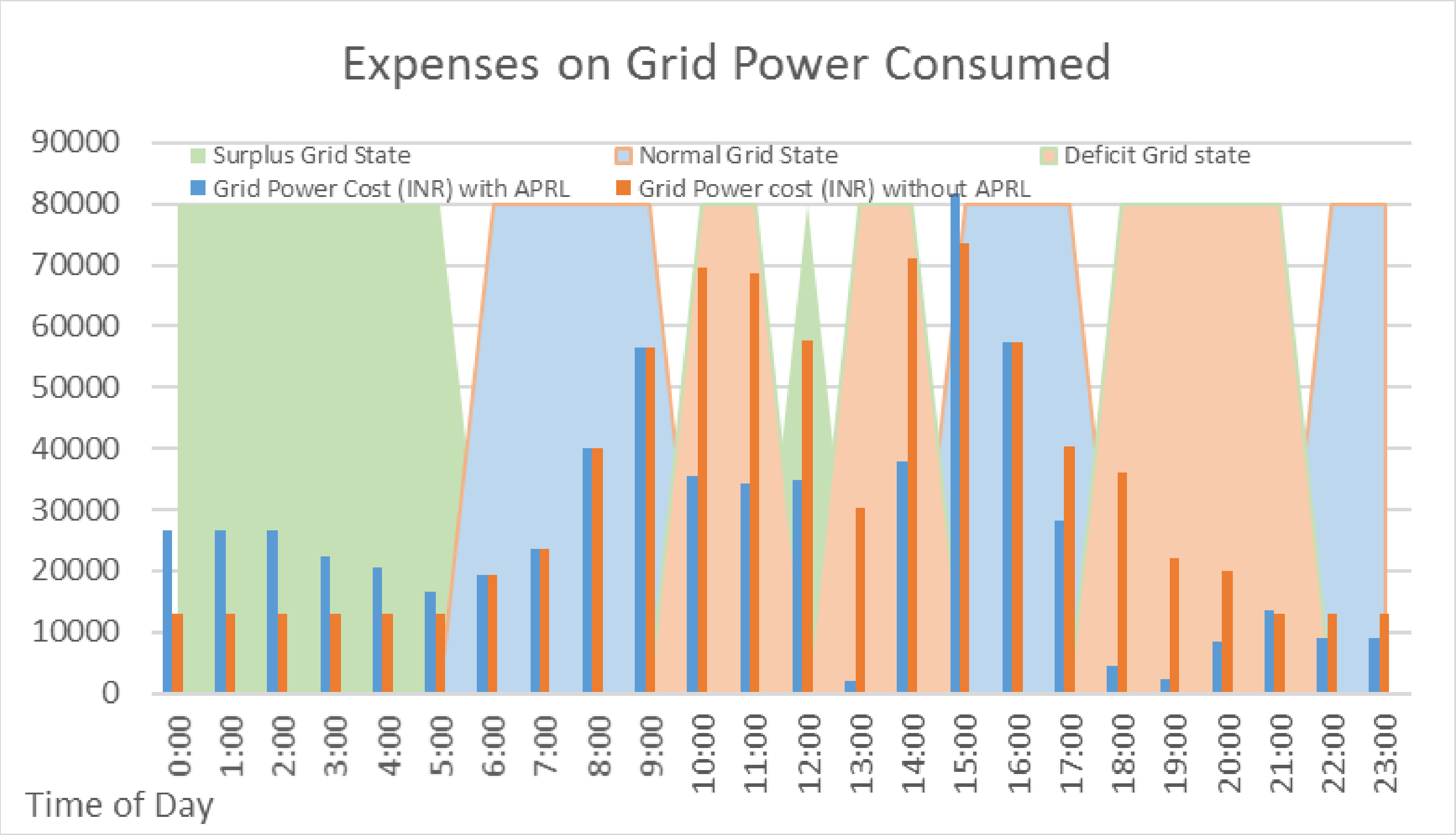
Logic used

- Charge storage (electrical battery, chilled water storage and Cold Air storage) at maximum rate, when power is surplus.
- Use storage to the maximum extent during deficit grid date.
- charge or discharge storage during Normal grid state, taking account grid-state pattern learned from previous days, so as to enable minimum power usage during deficit state.

Generation, Storage and Usage with APRL



Consumption with and without APRL



- The total cost saving due to APRL amounts to ₹1.6 lakhs per day or about ₹50 lakhs per month.
  - Amounting to a little over 20% of the total electrical costs.

Note: Savings shown are over and above the savings envisaged due to use of DC equipment, use of VFD in AHU and VAVs and use of roof-top solar.

Summary and Conclusion

- Promoting a good mix of Renewables with Grid requires storage, an appropriate selection of battery chemistry is important depending upon %age share of mix, interest rates (of specific nation), usage frequency.
- Demand load management and Optimized consumption through APRL clubbed with different types of storages is a huge electricity cost saver
  - Bridges load demand gap during peak times and flattens demand, not only beneficial to consumers but also to DISCOMS
- Expandable to all sectors of energy consumption
  - Industry, domestic and transport sector