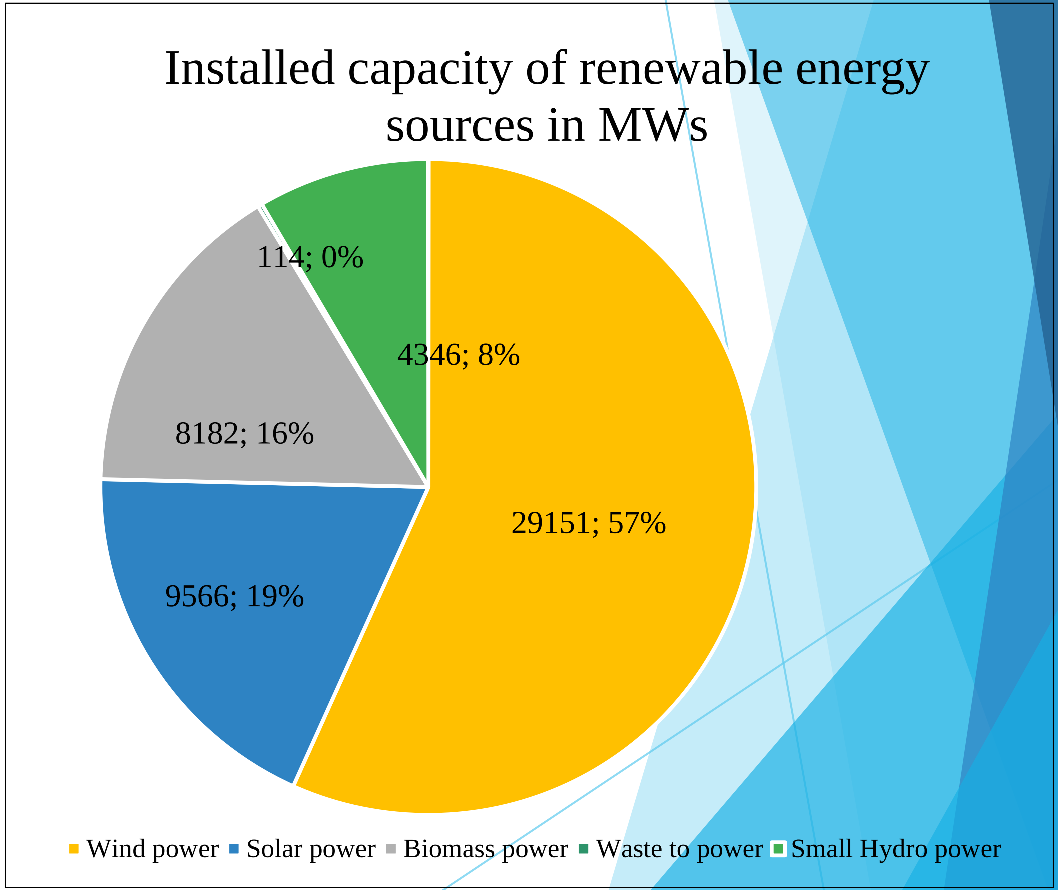
Assessing Impact of Energy Storage on System Operational Cost with Large scale PV Integration

Anoop Singh, Kalpana Singh, Parul Mathuria
Department of Industrial and Management Engineering
Indian Institute of Technology Kanpur, Kanpur, India

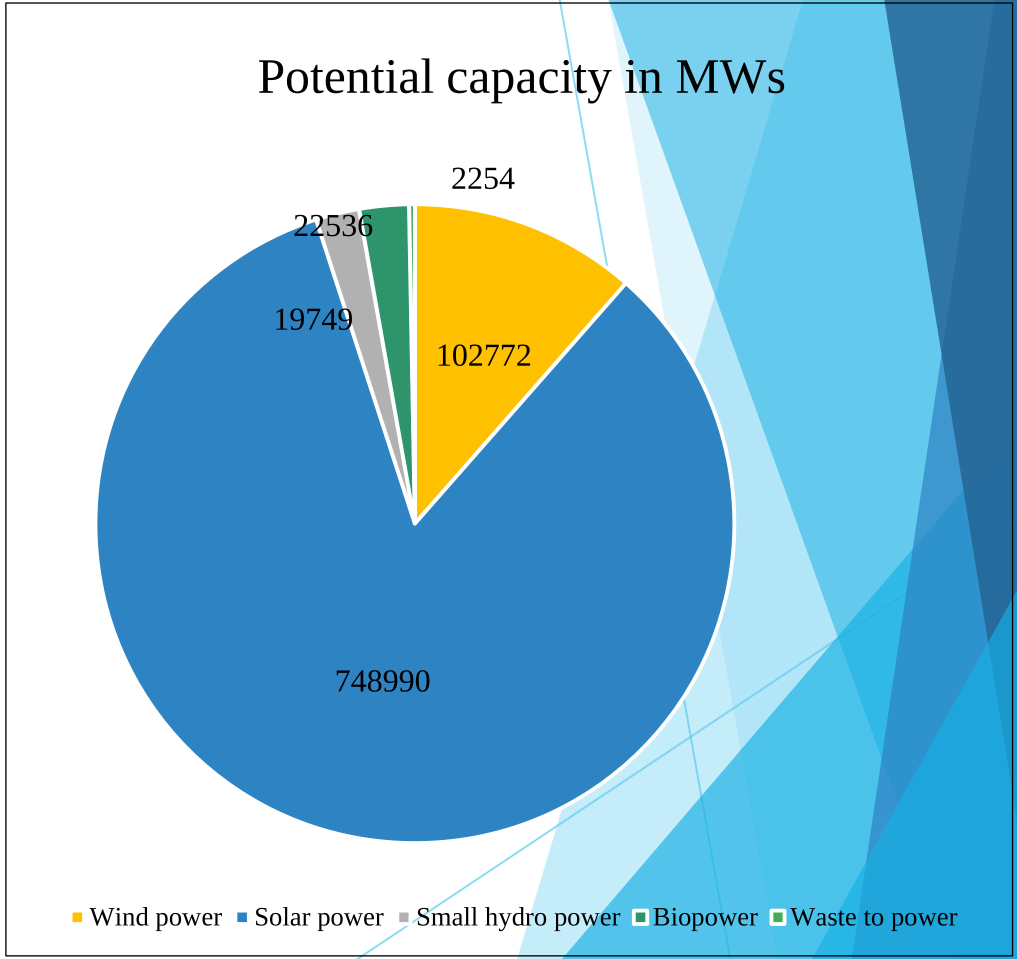
RENEWABLE ENERGY IN INDIA

- Total installed capacity of power generation
  - 329204 MW
- Installed capacity of RE sources is 51360 MW i.e. 17.3% of total capacity
- Gross electricity generation of the country is 1236 billion kWh
- As of April 2017, generation share – 76.4% coal, 3.9% gas , oil 0.03%, nuclear 3.04%, hydro 9.9%, renewable sources 6.6%



DEVELOPMENT OF RENEWABLES IN INDIA

- RE potential - 896.602 GW
- RE target – 175 GW by year 2020-22
- 100 GW from Solar, 60 GW from wind power, 10 GW from bio power and 5 GW from small hydro power
- MNRE aims above 17% share of RE in electricity mix by 2022



ISSUES WITH GROWTH OF RENEWABLE ENERGY SOURCES

- Variable renewable energy (VRE) sources like wind and solar are intermittent
- Unpredictability due to nature
- Sunshine and wind are not available throughout the 24 hours of a day
- Lack of coincidence with the demand pattern
- Location specific potential

SOLUTIONS TO ADDRESS ISSUES RELATED TO VRE

- Following approaches to address VRE utilization:

I. Better load forecasting

II. Load shifting

III. Energy Storage

- Energy storage systems (ESS) - characterized by power generation and storage capacity

- Store the surplus generation, utilize it during low or no generation

LITERATURE SURVEY

i. **Black and Strbac (2007)** – quantified storage value, determined fuel costs for conventional and wind generation systems

ii. **Brown and Lopes et al (2008)** – value of pump quantified as the reduction it causes in fuel costs and dynamic reserves it provides

iii. **Schill and Kemfert et al (2011)** – game theoretical model in an imperfect market setting

iv. **Takaagi Masaaki et al (2013)** – marginal value of storage system in an optimal generation mix model

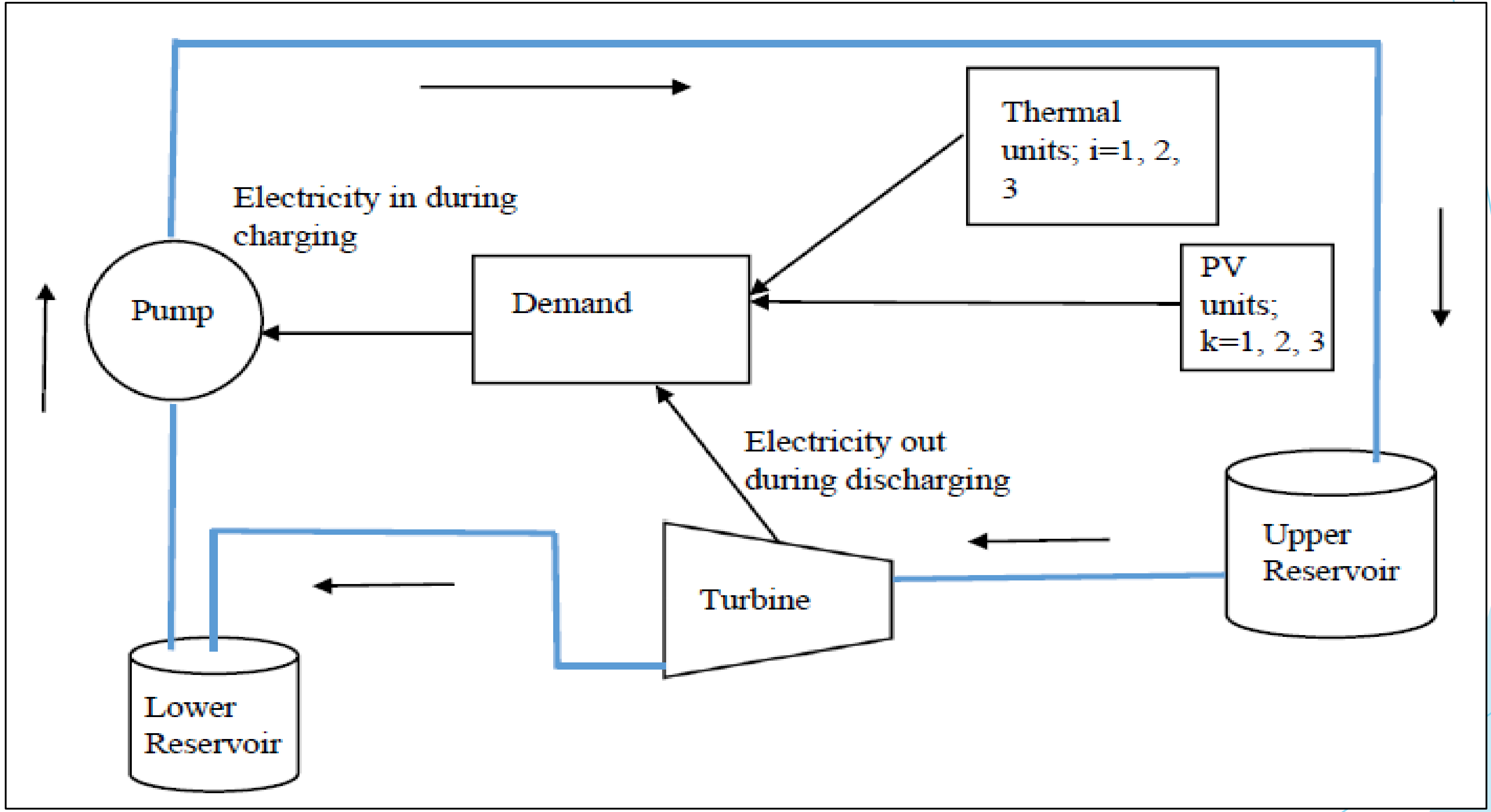
v. **Denholm Paul et al (2013)** – overall system operations cost with and without storage

vi. **De Siaternes et al (2016)** – storage value quantified in terms of reduction in CO_2 emissions

PUMPED HYDRO ENERGY STORAGE (PHES) SYSTEMS

- Well established commercially available storage technology
- Stores and produces electricity from a hydroelectric plant
- Water discharge from upper to lower reservoir during generation
- Water pumped back to upper reservoir from lower to store electricity
- Quick start up and shut down with tighter ramping capabilities
- Ability to track load changes and adapt

PUMPED HYDRO ENERGY STORAGE (PHES) SYSTEM



PUMPED STORAGE POTENTIAL IN INDIA

- Identified Sites 63
- Potential capacity 96,524 MW

Region	Potential Installed Capacity (MW)	Capacity Developed (MW)	Capacity under Construction (MW)
Northern	**13065 (7)**	**0**	**1000 (1)**
Western	**39684 (29)**	**1840 (4)**	**80 (1)**
Southern	**17750 (10)**	**2005.6 (3)**	**0**
Eastern	**9125 (7)**	**940 (2)**	**0**
North Eastern	**16900 (10)**	**0**	**0**
Total	**96524 (63)**	**4785.6 (9)***	**1080 (2)**

(SO: CEA)

MAJOR PUMPED STORAGE PLANTS IN INDIA

Location	State	Capacity (MW)	Year of Commissioning	Comments
Kadamparai	Tamil Nadu	4 X 100	1987-88	Operating in pumping mode
Srisailam	Andhra Pradesh	6 X 150	2001-03	Operating in pumping mode
Sardar Sarobar	Gujarat	6 X 200	2002-06	Not operating in pumping mode
Parulia	West Bengal	4 X 225	2007-08	Operating in pumping mode
Ghatghar	Maharashtra	2 X 125	2008	Operating in pumping mode
Tehri	Uttarakhand	1000	2006	In construction phase

OBJECTIVES

1. To setup a unit commitment power system model to analyse the impact of energy storage in a power system with large scale PV integration
2. To assess the economic value of ESS like Pumped Energy Storage System in a PV dominated power system

METHODOLOGY – SCUC MODEL

- Security Constrained Unit Commitment (SCUC) model determines optimal order of operation of power generators with the objective of cost minimization while maintaining certain constraints.
- Mixed integer non-linear problem (MINLP) formulated in GAMS
- A model characterizing a power system with PV generating unit, thermal units and pumped hydro energy storage (PHES) unit with two scenarios,

i. without pumping action of pumped hydro unit

ii. with pumping action of pumped hydro unit

SCUC MODEL

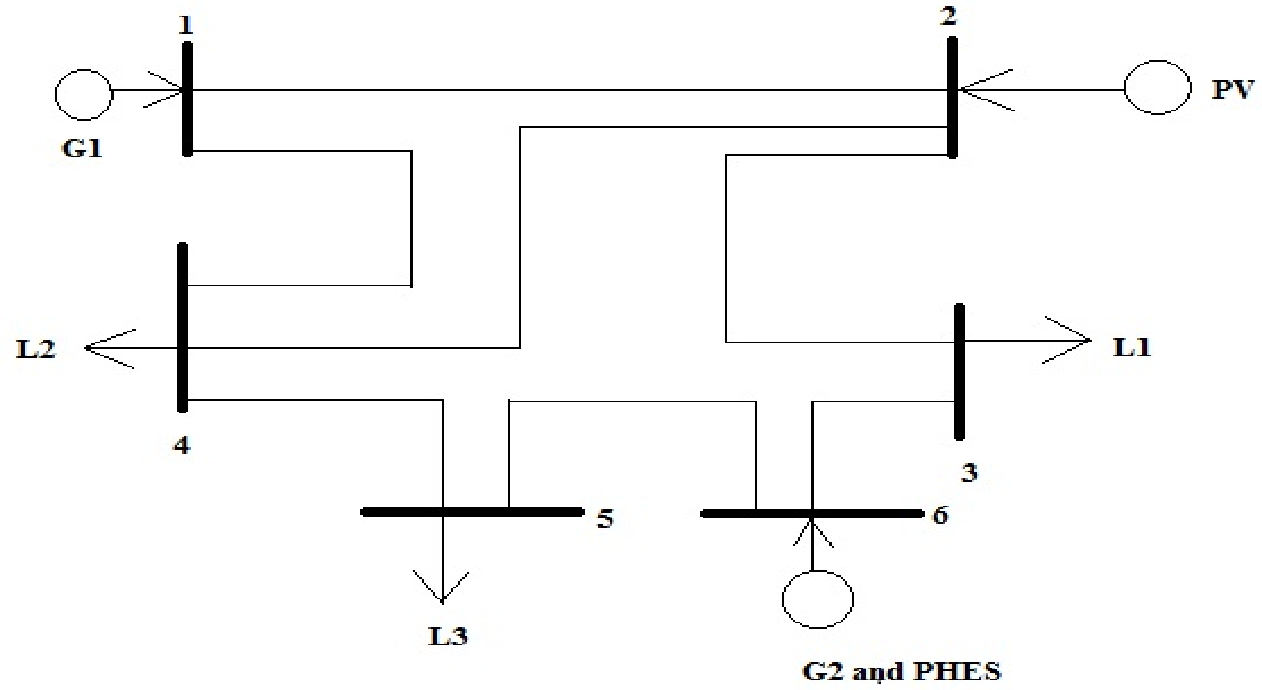
- SCUC model developed with: Power balance, power generation capability limits of units, ramp rate limits, minimum uptime and down-time and transmission flow limits of lines constraints and hydrological constraints of PHES unit like reservoirs' volume and discharge limits
- Objective of the SCUC model: minimize the total social cost of operation which includes the cost of generation and penalty for unserved load:

$$Min \sum_{i=1}^{I} \sum_{t=1}^{T} \{ (a_i * u_{i,t}) + (b_i * G_{i,t}) + (c_i * G_{i,t} * G_{i,t}) + SU_{i,t} \} + C_p \sum_{n=1}^{N} \sum_{t=1}^{T} E_{n,t}$$

a_i	Fixed cost of generation from unit *i* (Rs/hr)
b_i	Per unit variable cost of generation from unit *i* (Rs/MWh)
c_i	Per square unit variable cost of generation from unit *i* (Rs/MWh^2)
$u_{i,t}$	Commitment status of thermal generator *i* in time period *t*, 1 when it is on, 0 when off
$G_{i,t}$	Generation from thermal generator *i* in time period *t* (MWh)
$E_{n,t}$	Energy not served at bus *n* in period *t* (MW)
$SU_{i,t}$	Startup cost of thermal unit *i* in period *t* (Rs)
C_p	Penalty cost for unmet demand (Rs/MWh)

SYSTEM CHARACTERISTICS OF 6-BUS TEST MODEL

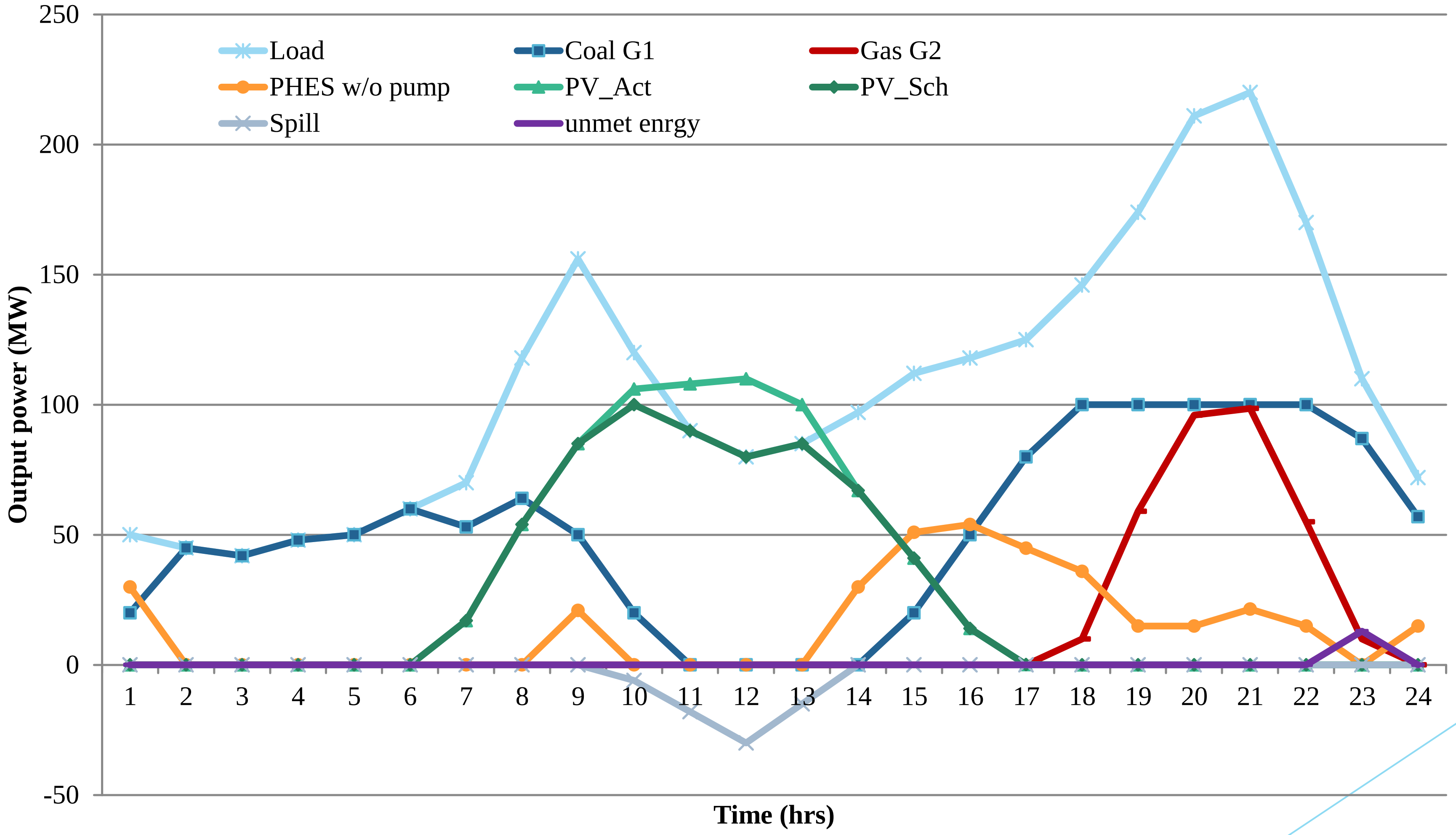
- The 6-bus test system - 2 thermal units – one coal fired (100 MW) and one gas fired (120 MW), 1 PV generating unit (150 MW), 1 PHES (230/200 MW) and 7 transmission lines



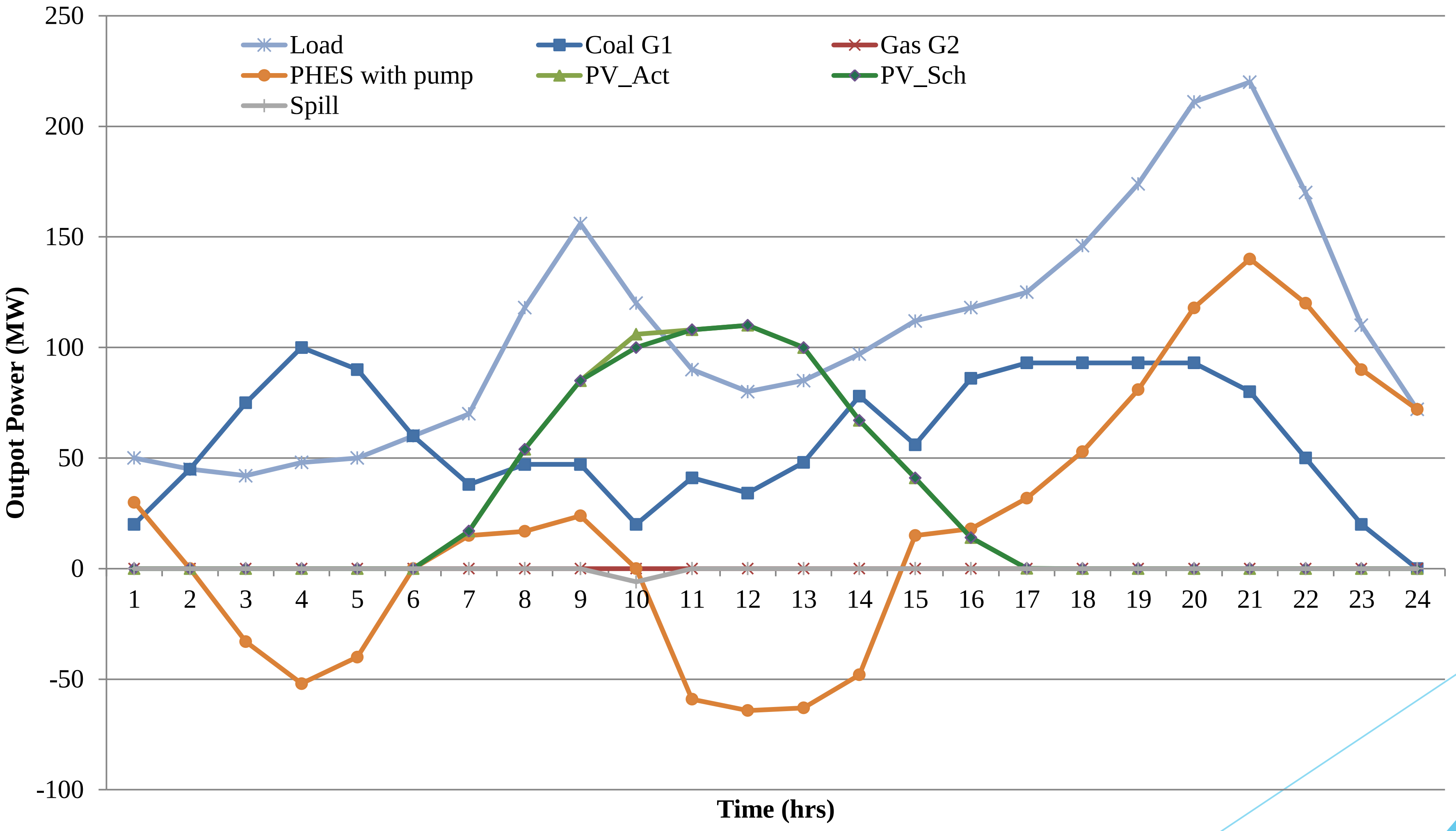
Line diagram of 6-bus test system

- ***Now also implemented on IEEE standard 30-bus system**

RESULTS (PHES without pumping)



RESULTS (PHES with pumping)



PHES - ECONOMICS OF SYSTEM OPERATION

		Without pump	With pump
Total cost of operation (million Rs.)		2.87	2.11
Total generation from thermal units	Coal Unit G1 (MWh)	1246	1407
	Gas Unit G2 (MWh)	328.5	0
Total Cost of generation from thermal units	Coal Unit G1 (million Rs.)	1.86	2.11
	Gas Unit G2 (million Rs.)	0.88	0
Total energy demand shed (MWh)		13	0
Cost of load shedding (million Rs.)		0.13	0
Reduction in system cost (mill. Rs.)			0.76 (0.63)
Reduction in unit cost (Rs./kWh)			0.3 (0.25)

ECONOMIC VALUE OF PUMPED STORAGE

- Assumptions: same SCUC operation and same demand pattern throughout the year, life of PHES unit – 30 years and discount rate – 15%

6-bus test system	Overall system operation cost without penalty		Overall system operation cost with penalty	
Daily cost of operation (million Rs.)	Without pump	With pump	Without pump	With pump
	2.74	2.11	2.87	2.11
Savings / year (million Rs.)	231		279	
Present value (million Rs.)	1748		2107	
Value of pump facility (million Rs./MW)	8		9.6	

- Thus, the pumping facility of a hydro unit adds a value equivalent to Rs. 9.6 million /MW and Rs. 8 million /MW excluding the penalty costs.

CONCLUSIONS

- Spillage reduced by 91% in 6-bus test system. In a 6-bus test system, presence of pump reduced cost by 26.5 % and by 23.48% excluding the penalty cost
- Translates to present value of Rs. 9.6 million/MW including and Rs. 8 million/MW without the cost of unserved energy

Policy and regulatory insights

- Emphasises proper utilisation of existing PHES systems in India to avoid RE spillage.
- Prioritise development of potential PHES capacity alongside push for high RE penetration in the country.
- Change in operational code for PHES (currently - night pumping (high freq.)) to store curtailed RE.

SHORTCOMINGS AND FUTURE SCOPE

- Increasing the granularity in time period.
- Economics of storage can be evaluated in a life-cycle context with a longer modelling horizon
- The current model limited to a standardised 24-hour duration. Can be extended to cover a season or across a year.
- Impact of geographical diversity on PV generation profile.
- Impact of a mix of Solar and Wind

REFERENCES

- International Energy Agency - Key world energy statistics, 2016 Retrieved 6 April 2017
- Generation, Ministry of Power, Accessed June 2017, Available [Online]:http://powermin.nic.in/en/content/overview
- J. D. Guy "Security constrained unit commitment." *IEEE Transactions on Power apparatus and Systems* vol. 3, pp. 1385-1390, May 1971
- Cohen, Arthur I., and Miki Yoshimura. "A branch-and-bound algorithm for unit commitment." *IEEE Transactions on Power Apparatus and Systems* vol.2, pp.444-451, 1983.
- Black, Mary, and Goran Strbac. "Value of bulk energy storage for managing wind power fluctuations." *IEEE transactions on energy conversion* vol.22, no.1, pp.197-205, 2007.
- Takagi, Masaaki, et al. "Economic value of PV energy storage using batteries of battery-switch stations." *IEEE Transactions on Sustainable Energy* vol.4, no.1, pp.164-173, 2013.

REFERENCES

- Schill, Wolf-Peter, and Claudia Kemfert. "Modeling strategic electricity storage: the case of pumped hydro storage in Germany." *The Energy Journal* pp.59-87, 2011.
- Brown, Paul D., JA Peças Lopes, and Manuel A. Matos. "Optimization of pumped storage capacity in an isolated power system with large renewable penetration." *IEEE Transactions on Power systems* vol.23, no.2, pp.523-531, 2008.
- Denholm, Paul, et al. "The value of energy storage for grid applications." Contract vol. 303, pp. 275-3000, 2013.
- De Sisternes, Fernando J., Jesse D. Jenkins, and Audun Botterud. "The value of energy storage in decarbonizing the electricity sector." *Applied Energy* vol.175, pp.368-379, 2016.
- Salient features of Purulia pumped storage project, 1 January 2000, Accessed June 2017, Available [Online]: http://www.waterpowermagazine.com/news/newssalient-features-of-purulia-pumped-storage-project-3

Thank You!