Flexible Ramp Product Provision from Grid-Connected Energy Storage Systems

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Presentation Outline

- Background
- Power System Flexibility
- Contribution
- Scheduling Problem
- Data
- Case Studies
- Conclusions
- Key References

Background

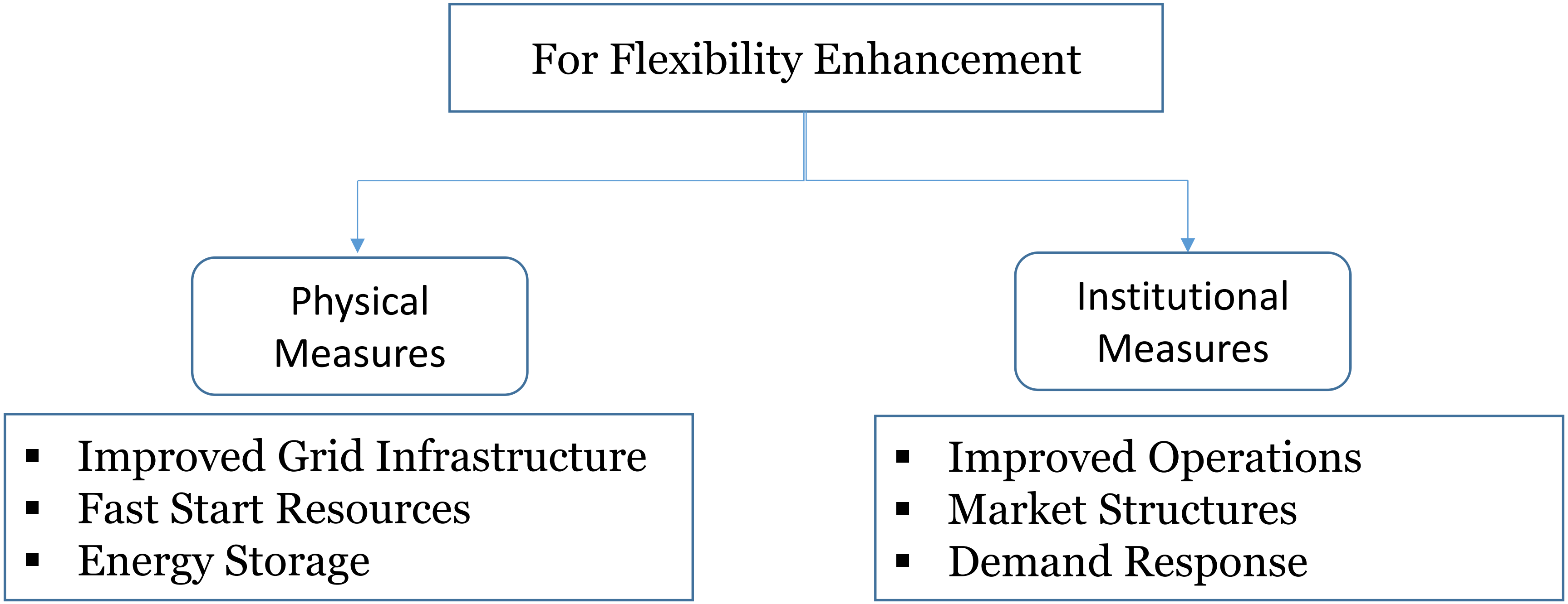
- Global power generation - A 62% increase between 2017 and 2040 [1]
- Coal fired & Natural gas plants - key role in supplying the demand (~60%)
- Dwindling fossil fuels, environmental concerns and policy implications → Clean and sustainable sources of energy
- Many nations are setting ambitious targets to increase the share of RES in the generation mix.
- Intermittency of RE → Challenges in power system operations

Background (Cont…)

- Traditional System - Variability of load and inevitable contingencies
- RE integrated systems - Variability of both demand and generation along with inevitable contingencies
- Steeper net load ramps → Controllable units with insufficient ramping capability
- Undesirable outcomes → The system must rely on regulation services, market efficiency (penalties), leaning towards interconnections/curtailments
- Necessitates flexibility requirements

PS Flexibility

- Flexibility - Generation, Transmission, Distribution, Market Operations and long term planning
- Ability of system to vary energy production in a certain ramp rate to cope up with variations and uncertainties in net-load at minimum cost [1]



For Flexibility Enhancement

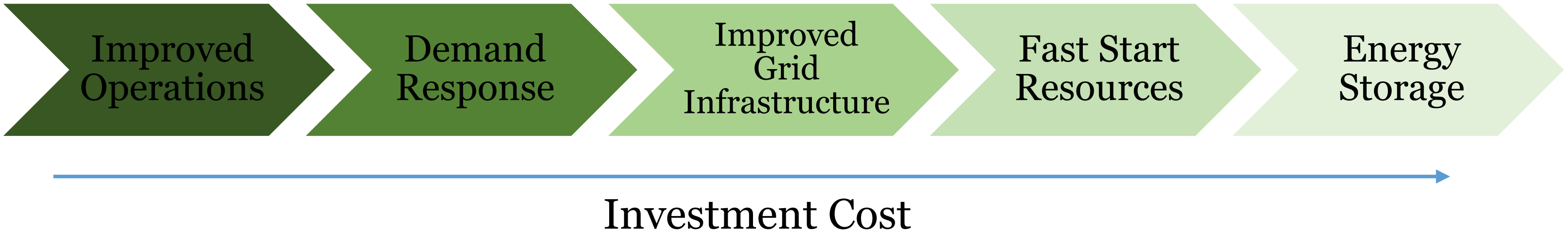
Physical Measures

- Improved Grid Infrastructure
- Fast Start Resources
- Energy Storage

Institutional Measures

- Improved Operations
- Market Structures
- Demand Response

PS Flexibility (Cont…)



Improved Operations

Demand Response

Improved Grid Infrastructure

Fast Start Resources

Energy Storage

Investment Cost

- Improved Forecasting
- Time resolution of scheduling

- Time shifting
- Curtailable loads

- Distribution and Transmission corridors
- Retrofitting

- Gas Power plants
- Peaking units

- BESS
- PHES
- CAES

PS Flexibility (Cont...)

- Improved operations helps in effective NL handling

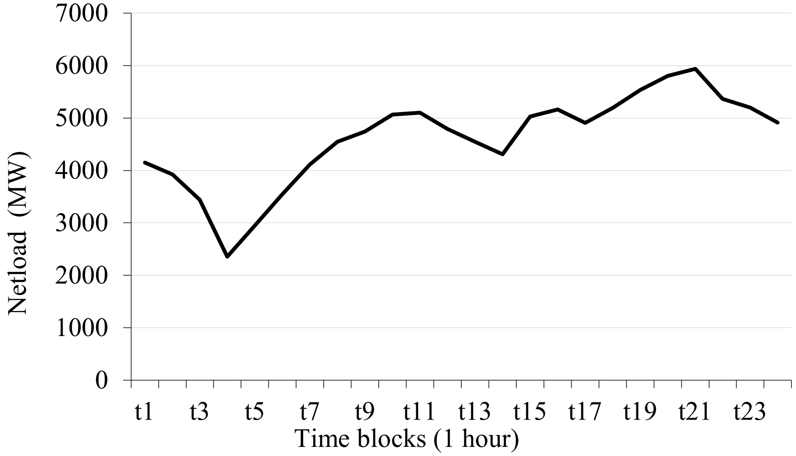


Fig.2: Hourly Net-load

- India

DA:15 min- 5 min

- CAISO

DA: 1hr-15 mins

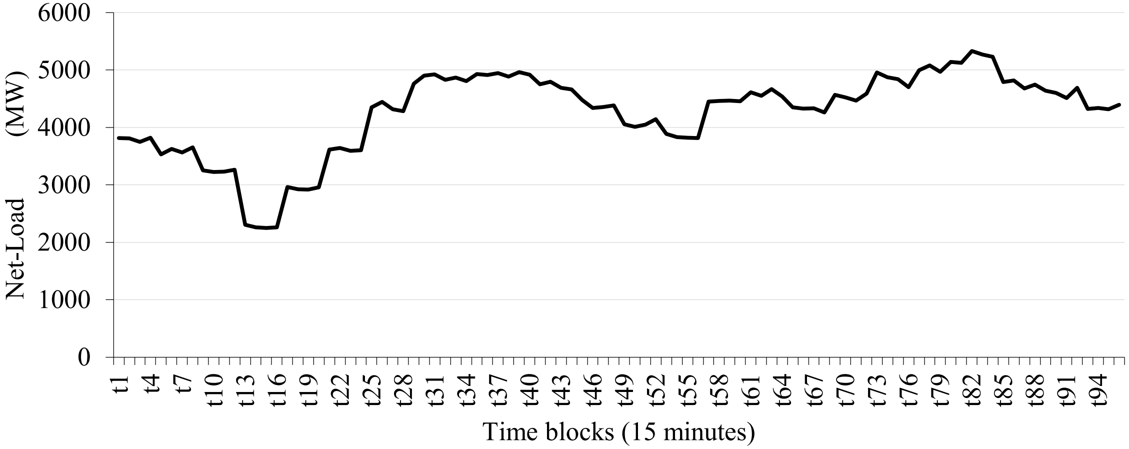


Fig.3: Intra- hour Net-load

PS Flexibility (Cont...)

- Market operators like CAISO, MISO etc., are implementing market-based FRP to address the RR in RT dispatch
- Unlike AS, FRP is the capacity deployed to meet RR of consecutive real-time dispatch intervals [3]
- FRP - FRU/FRD
- Energy Storage - quick start and ramping ability, ESS have become an increased interest [9]

RR- Ramp Rate, FRP- Flexible Ramp Products

Contribution

- Ability of PHES in FRP provision and its impact on system operations
    - ✓ Mature technology
    - ✓ High power density and energy density
    - ✓ 96% of total installed storage capacity

- A detailed modelling of PHES is incorporated in a 15-minute temporal DA SCUC and 5-minute RT re-dispatch
- Effectiveness of the proposed model is analysed on IEEE RTS 24 bus test system.
- Performance parameters like load and RE curtailment, operating cost and cycling of units are studied.

Scheduling Problem

- Objective Function:

$$Min\, C_{oper} = C_{ener}^{D} + C_{res}^{D} + C_{frp}^{D} + Lc^{RT} + Rc^{RT} \quad \text{...(1)}$$

Subject to- operational and network constraints of

- Generator minimum and maximum generation
- Generator up/down ramp
- Generator minimum Up/Down Time
- Transmission line limit

Scheduling Problem (cont...)

- PHES Modelling

$$P^{turb}_{ph,t} = (\eta_g \rho g H^{UR}).Q^{turb}_{ph,t} \qquad \ldots(2)$$

$$P^{pump}_{ph,t} = (\rho g H^{LR}).Q^{pump}_{ph,t} / \eta_m \qquad \ldots(3)$$

$$L^{UR}_{ph,t} = L^{UR}_{ph,t-1} + (Q^{pump}_{ph,t} - Q^{turb}_{ph,t})t \qquad \ldots(4)$$

$$L^{LR}_{ph,t} = L^{LR}_{ph,t-1} + (Q^{turb}_{ph,t} - Q^{pump}_{ph,t})t \qquad \ldots(5)$$

$$P^{g\_stor}_{ph,t} + RU^{stor}_{ph,t} \le P^{turb}_{ph,t} \qquad \ldots(6)$$

$$P^{m\_stor}_{ph,t} - RD^{stor}_{ph,t} \le P^{pump}_{ph,t} \qquad \ldots(7)$$

$$Q^{turb}_{ph,t}, Q^{pump}_{ph,t} \le Q^{\max}_{ph} \qquad \ldots(8)$$

$$L^{LR\_\min}_{ph,t} \le L^{LR}_{ph,t} \le L^{LR\_\max}_{ph,t} \qquad \ldots(9)$$

$$L^{UR\_\min}_{ph,t} \le L^{UR}_{ph,t} \le L^{UR\_\max}_{ph,t} \qquad \ldots(10)$$

Scheduling Problem (cont...)

- RT ramp requirement:

$$NLR_m^{RT\_up} = \max(0, NL_m^{RT} - NL_{m-1}^{RT}) \qquad \text{...(11)}$$

$$NLR_m^{RT\_dn} = \max(0, NL_{m-1}^{RT} - NL_m^{RT}) \qquad \text{...(12)}$$

$$\sum_i RU_{i,m}^{RT\_gen} + \sum_{ph} RU_{i,m}^{RT\_stor} = NLR_m^{RT\_up} \qquad \text{...(13)}$$

$$\sum_i RD_{i,m}^{RT\_gen} + \sum_{ph} RD_{i,m}^{RT\_stor} = NLR_m^{RT\_dn} \qquad \text{...(14)}$$

Case Study

- The proposed model is implemented on IEEE RTS 24 bus test system with a peak load of 2650 MW
- Solar and wind generation - buses 3,5,20 and 23
- Solar radiation and wind speed - CAISO for July 2018 [12]
- Load Profile – normalized CAISO hourly load profile wrt peak demand of test case
- Costs:

Opportunity cost for the reserve : $3.34/MW

FRP procurement: 20% higher than the average market clearing price of energy.

Data (Cont...)

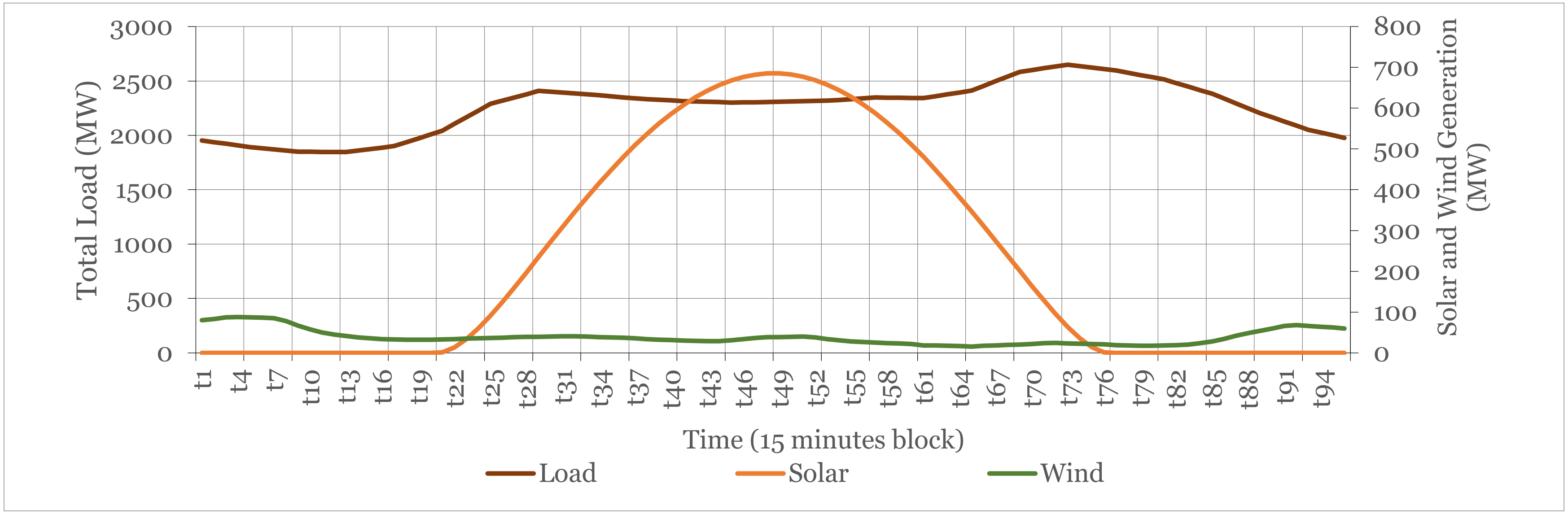


Figure 2. Day-ahead load and renewable profile at 30% RE integration

Case-1: FRP Provision from conventional units
Case-2: FRP Provision from conventional units and PHES

Result Analysis

Case-1:

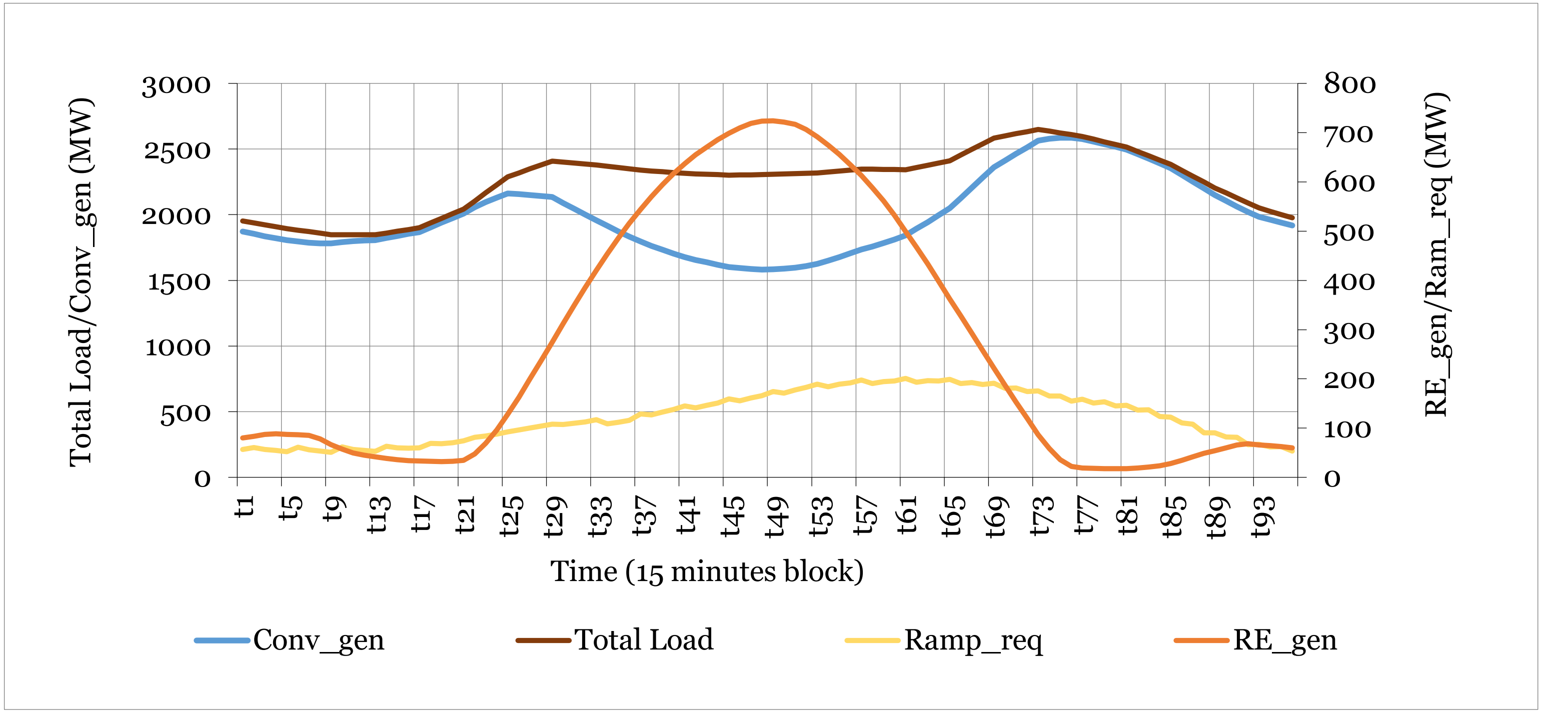


Figure 3. Day-ahead scheduling at 30% RE integration

- FRP in DA is estimated from the standard deviation of historical data

Result Analysis (Cont...)

- Commitment status and scheduling of committed units is considered
- Changes in net-load is supplied by up and down FRPs
- Ramping incapability between dispatch intervals resulted in load curtailment with a max. value of 285 MW at block m190

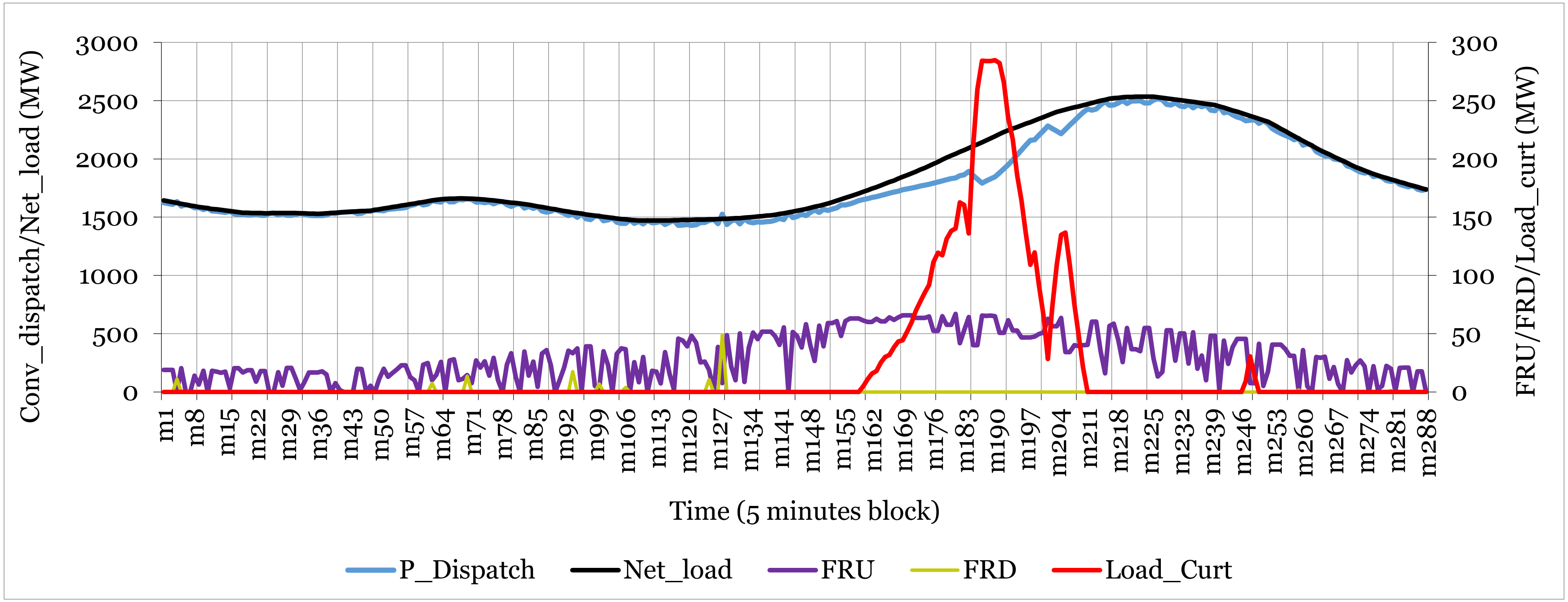


Figure 4. Real-Time Power balance at 30% RE integration

Result Analysis (Cont…)

Case- II

- PHES participation in energy, reserve and FRP markets resulted in low operating costs

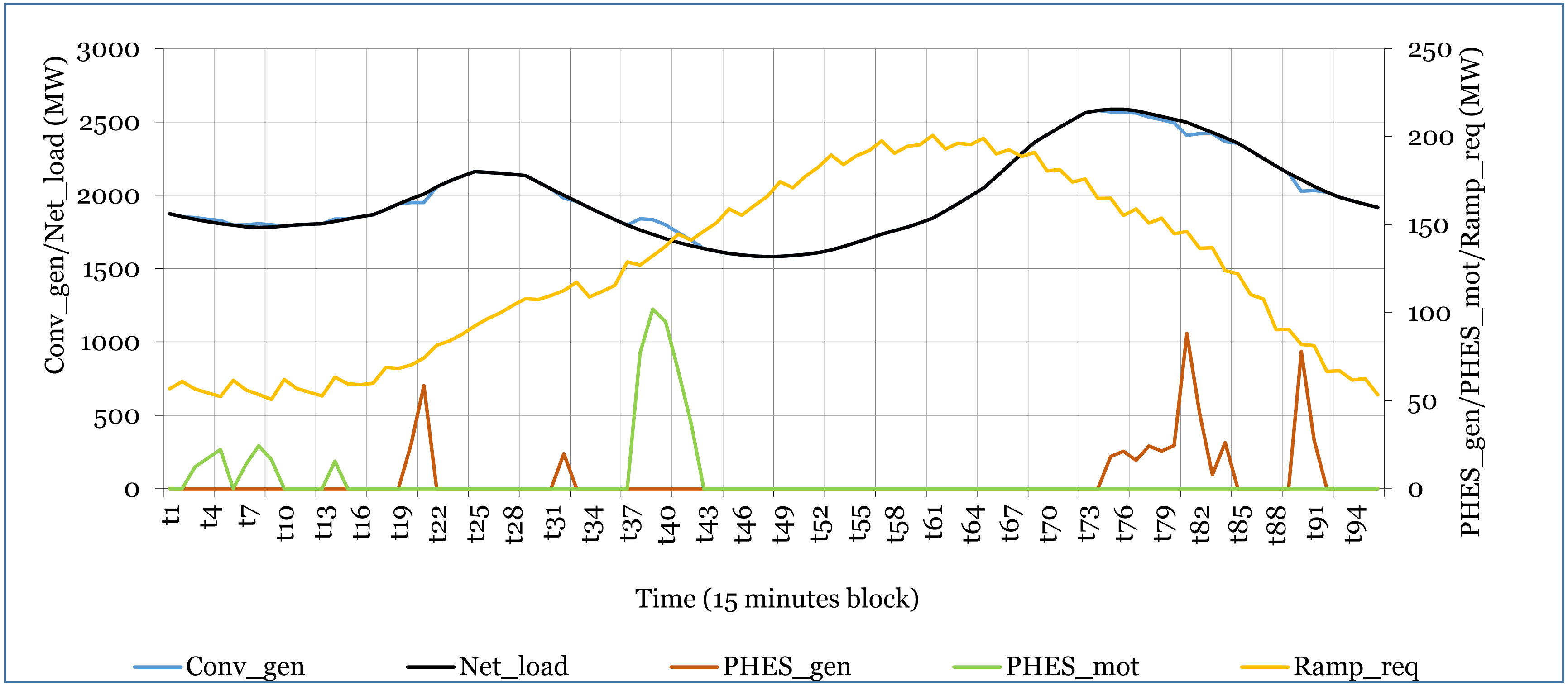


Figure 5. Day-ahead scheduling of conventional units and PHES at 30% RE integration

Result Analysis (Cont…)

- Maximum Value of load curtailment in the case has decreased to 136 MW
- Deviation of PHES pumping in real time is observed compared to its day-ahead schedule

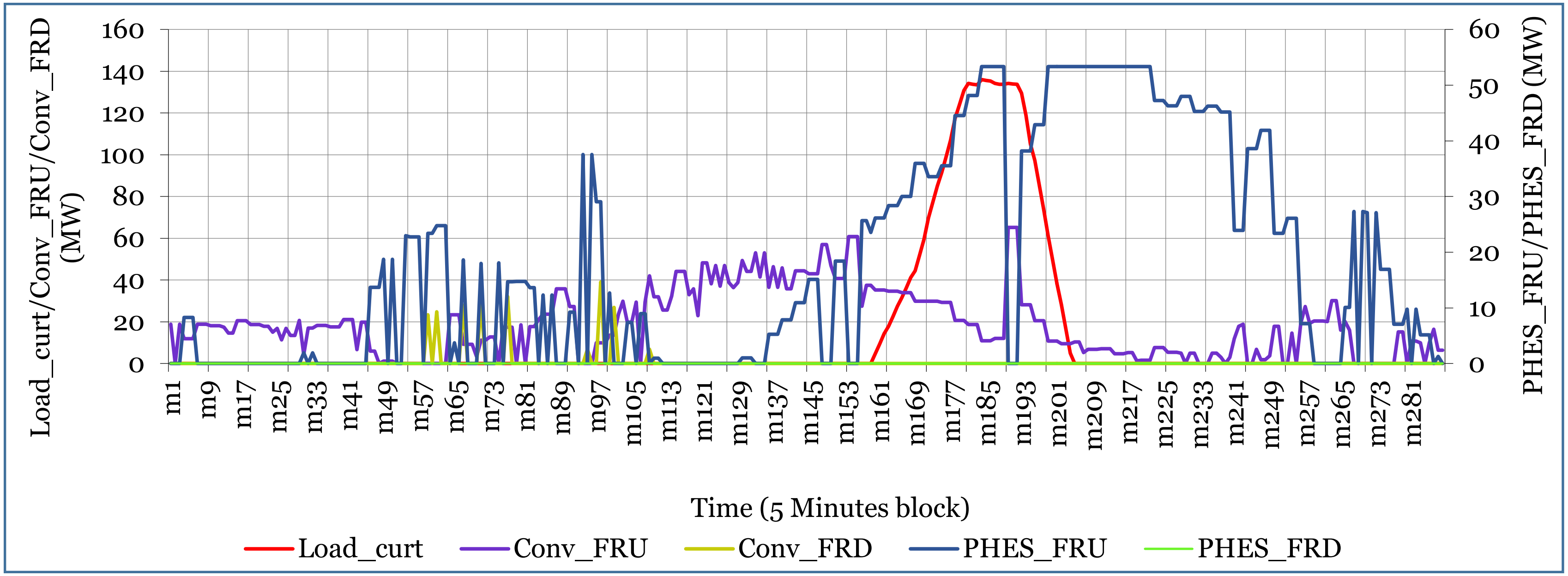


Figure 7. FRP provision from conventional units and PHES in real-time at 30% RE integration

Result Analysis (Cont…)

Table 1: Comparison of cases at different RE Integration

Parameter	30% RE Integration	40% RE Integration
Case-I		
Operating Cost ($)	4596032	4165769
Load Curtailment (MWh)	515	358
FRU deployed (MWh)	716.25	740
FRD deployed (MWh)	10	22.5
Case-II		
Operating Cost ($)	4170586	3904470
Load Curtailment (MWh)	307	250
FRU deployed (MWh)	799.16	861
FRD deployed (MWh)	18	13

Conclusion

- Variability and uncertainty associated with RES necessitates flexible resources in the system.
- Improved operations+ Energy Storage
- Flexibility product from the coordinated operation of conventional units and PHES is proposed along with improved operations
- Integration of fast start units like PHES resulted in reduction in cycling of conventional units.
- Use of peaking units decreased with FRP from PHES
- Load curtailment and operating costs decrement with PHES participation at different RE penetrations is observed.

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Thank You !!

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