Chapters 5 & 7 Impact of different dispatch methods on Azores Islands

Contributing Authors:
Chapter 5: Paulo Ferreira, Pedro M. S. Carvalho, and Luis A. F. M. Ferreira (Instituto Superior Técnico, Portugal)
Chapter 7: Yingzhong Gu, Le Xie (Texas A&M), and Marija Ilic (CMU)

Key Purpose

- To study the impact of different sized wind parks and different dispatch methods in Flores and St Miguel power systems

Key Findings

- Advanced Dispatch Methods, e.g., look-ahead model predictive control (MPC)-based dispatch, reduces overall generation cost by 1.5% as compared with static dispatch, in the Flores island.
- As variable resources get more and more, potential saving of advanced dispatch methods will be more significant.
- Distributed implementation of advanced look-ahead dispatch gets very close to solutions as compared with centralized look-ahead dispatch.

Mathematical Formulation

- Notations

  G : set of all available generators;

  G_w : set of wind energy generators;

  $\hat{L}(k)$: expected demand at time step k;

  $C_i(P_{G_i})$: cost function of generator i;

  $P_{G_i}^{\min}, P_{G_i}^{\max}$: minimum and maximum generation output ;

- Centralized Static Economic Dispatch with Inelastic Demand

$$\min_{P_G} \sum_{i \in G \backslash G_w} (C_i(P_{G_i}(k))),$$

Minimize the total generation cost

$$s.t. \sum_{i \in G \backslash G_w} P_{G_i}(k) = \hat{L}(k) - \hat{P_{G_w}}(k);$$

Energy balancing equation

$$P_{G_i}^{min} \le P_{G_i}(k) \le P_{G_i}^{max}, i \in G \backslash G_w;$$

Capacity constraints for generators

Note: in static dispatch, wind resources are treated as ***negative load***

TEXAS A&M UNIVERSITY ELECTRICAL & COMPUTER ENGINEERING

Mathematical Formulation (cont'd)

- Notations (complimentary)

  $\hat{P}_{G_w}^{min}, \hat{P}_{G_w}^{max}$: expected minimum and maximum wind generation output at time step k;

  R_i : ramping rate of generator $i, i \in G$;

  K : time steps in a look-ahead optimization period;

- Centralized Look-ahead Economic Dispatch with Inelastic Demand

$\min_{P_G} \sum_{k=1}^{K} \sum_{i \in G} (C_i(P_{G_i}(k))), i \in G$	Minimize the overall generation cost for the look-ahead period
$s.t. \sum_i P_{G_i}(k) = \hat{L}(k), i \in G;$	Energy balancing equation
$\hat{P}_{G_w}^{max}(k) = g_j(\hat{P}_{G_w}^{max}(k-1));$	Wind generation forecast
$\hat{P}_{G_w}^{\min}(k) \le P_{G_w}(k) \le \hat{P}_{G_w}^{\max}(k);$	Wind resources availability constraints
$P_{G_i}^{\min}(k) \le P_{G_i}(k) \le P_{G_i}^{\max}(k), i \in G \setminus G_w;$	Capacity constraints for conventional units
$\lvert P_{G_i}(k+1) - P_{G_i}(k) \rvert \le R_i, i \in G$	Ramping constraints for generators

TEXAS A&M UNIVERSITY | ELECTRICAL & COMPUTER ENGINEERING

Mathematical Formulation (cont'd)

- Notations (complimentary)

  $S_i(P_{G_i}(k))$: supply bid function of unit i

  $\lambda(k)$: price of electricity at time step k;

- Distributed Look-ahead Economic Dispatch with Inelastic Demand

$\max_{P_{G_i}(k)} \sum_{k+1}^{k+K} \hat{\lambda}(k)(P_{G_i}(k)) - (C_i(P_{G_i}(k)))$	Maximize profits of the market participant
s.t. $\hat{P}_{G_i}^{max}(k) = g_i(\hat{P}_{G_i}^{max}(k-1));$	Estimate the upper bound of the output
$\hat{P}_{G_i}^{min}(k) = h_i(\hat{P}_{G_i}^{min}(k-1));$	Estimate the lower bound of the output
$\lvert P_{G_i}(k+1) - P_{G_i}(k)\rvert \leq R_i;$ and,	Ramping constraint of the unit i
$\hat{P}_{G_i}^{\min} \leq P_{G_i}(k) \leq \hat{P}_{G_i}^{\max}$	Capacity constraint of the unit i

Expected prices $\hat{\lambda}(k)$ are updated at every step, by perturbation the price signals, supply bid functions $S_i\left(P_{G_i}(k)\right)$ could be generated.

TEXAS A&M UNIVERSITY | ELECTRICAL & COMPUTER ENGINEERING

Solution approach

- Dynamic Programming was utilized to accommodate inter-temporal dynamics

- Specificities
  - Flores has a small power system with significant contribution of hydro resources
  - The lack of water is compensated through an increase of diesel production

Flores Island

Source: http://en.wikipedia.org/wiki/Flores_Island_(Azores)

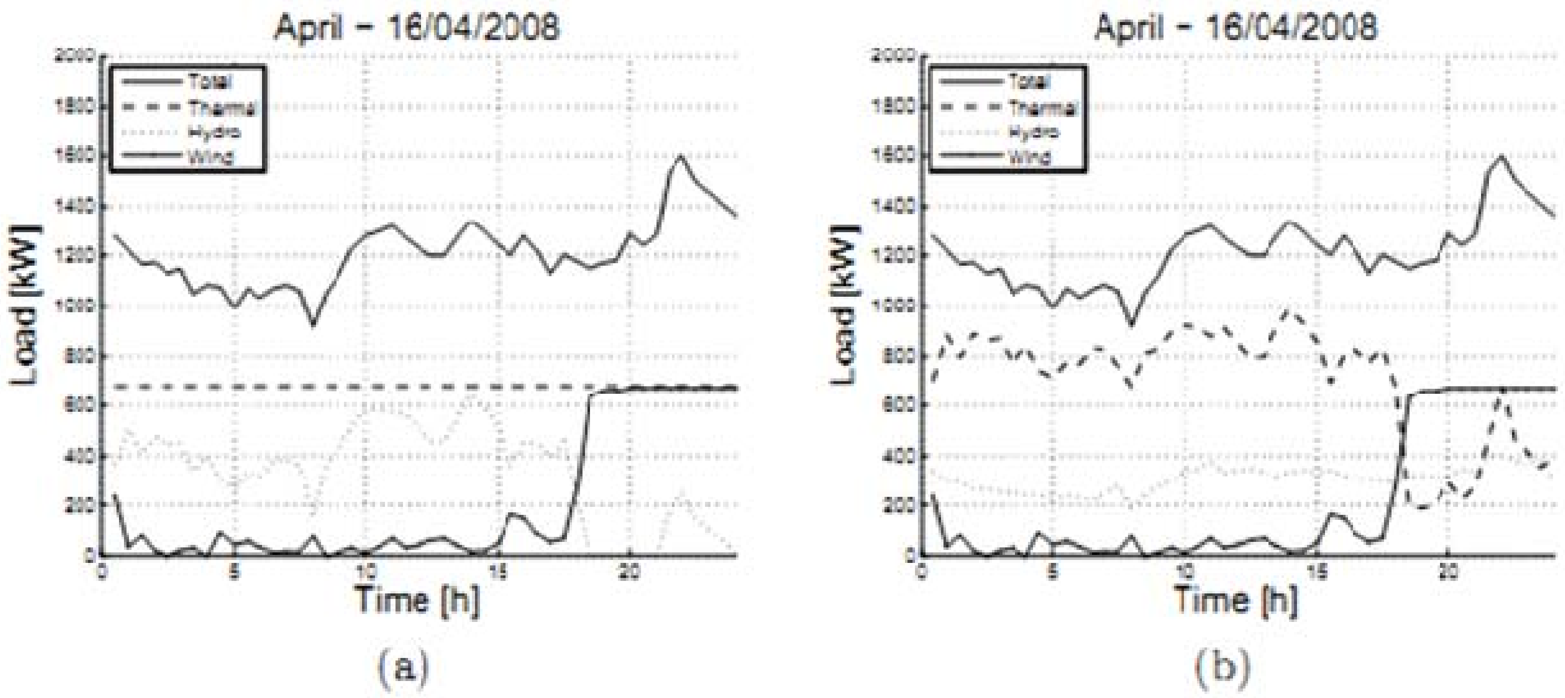
System Circumstances

Gen	Type	Capacity (MW)	Lowest Output (MW)	Marginal Cost ($/MWh)	Ramping Rate (%/min)
1	Diesel	2.5	0	261	100.0%
2	Hydro	1.5	0.15	87	5.1%
3	Wind	0.66	0	88	67.0%

- Diesel is the most expensive but is the fastest unit.
- Hydro in this island is a slow but inexpensive unit
  - Two scenarios studies: with and w/o reservoirs
- Wind is dispatchable and could be curtailed when it is required.

Illustration of static ED

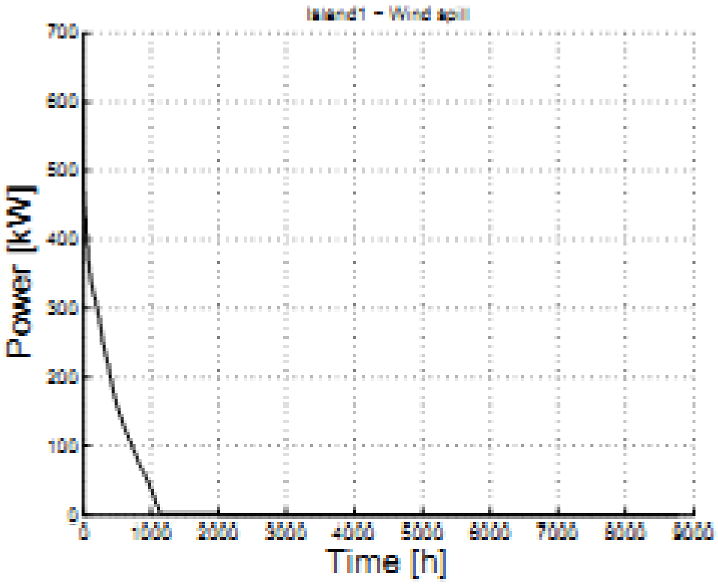
Impact of reservoir size



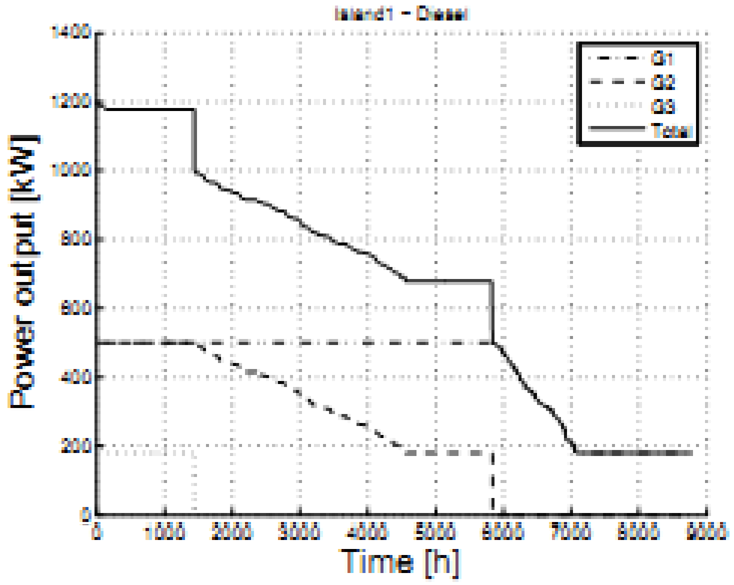
a) hydro generation with reservoir and b) hydro generation without reservoir. It is assumed that there are 2 wind turbines on the system.

Illustration of static ED

Impact of wind turbines size



(a)



(b)

a) Total wind spill for 4 turbines; energy spilled is about 6%.

b) Duration curve associated to diesel production. As expected, total diesel power never goes to zero.

ELECTRICAL & COMPUTER ENGINEERING

Summary of Impacts of Wind Turbines

No. Wind Turb.	Total Energy Produced [MWh]		Cost [USD]	
	Reservoir	No Reservoir	Reservoir	No Reservoir
1	8,063	9,884	2,104,300	2,579,600
2	7,238	8,991	1,889,200	2,346,500
3	6,458	8,235	1,685,400	2,149,300
4	5,955	7,708	1,554,300	2,011,900
5	5,585	7,331	1,457,600	1,913,400
6	5,293	7,025	1,381,600	1,833,600
7	5,039	6,769	1,315,400	1,766,600

For Flores, with and without reservoir

Total Operating Cost

	Version 1 Static Scheduling	Version 2 Centralized Look-ahead	Version 3 Distributed look-ahead	Savings (%)
Jan.16th	$ 4,017.11	$ 3,953.94	$ 3,970.28	1.598%
Apr.16th	$ 4,676.08	$ 4,604.45	$ 4,633.94	1.556%
July.16th	$ 8,287.53	$ 8,257.15	$ 8,290.98	0.368%
Oct.15th	$ 8,890.01	$ 8,890.01	$ 8,890.01	0.000%

Note:
Version 1
the static scheduling case

Version 2
the centralized look-ahead scheduling case

Version 3
the distributed look-ahead scheduling case (Version 1 price)

- Look-ahead economic dispatch could reduce the total operating cost compared with static dispatch by about 1.5%, given high wind penetration.
- The centralized look-ahead dispatch gives the best economic performance.
- Given the small duality gap between the distributed approach and the centralized approach (0.3% of total cost), the look-ahead dispatch could be implemented in *a distributed way without too much performance degradation*.

Scheduling Results on Jan.16th

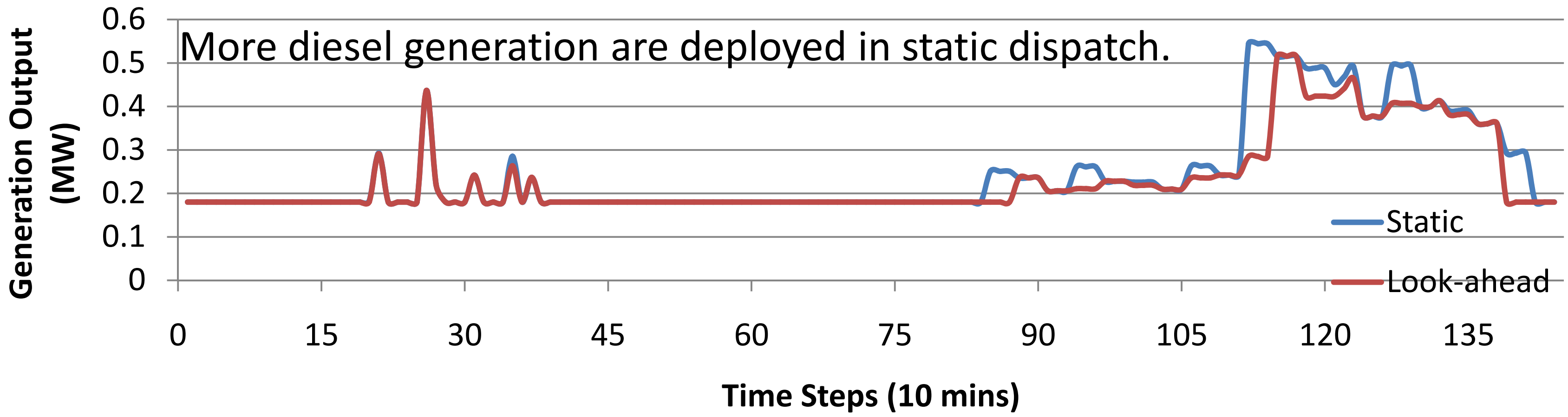


Fig. 1.a Generation outputs of Diesel Units on Jan.16th

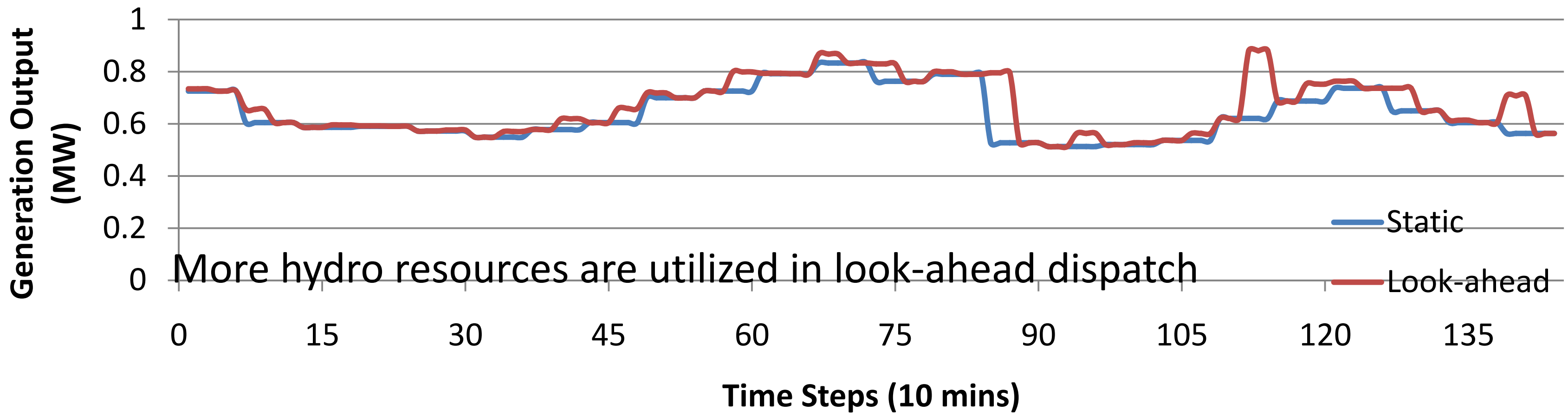


Fig. 1.b Generation outputs of Hydro Units on Jan.16th

Scheduling Results on Apr. 16th

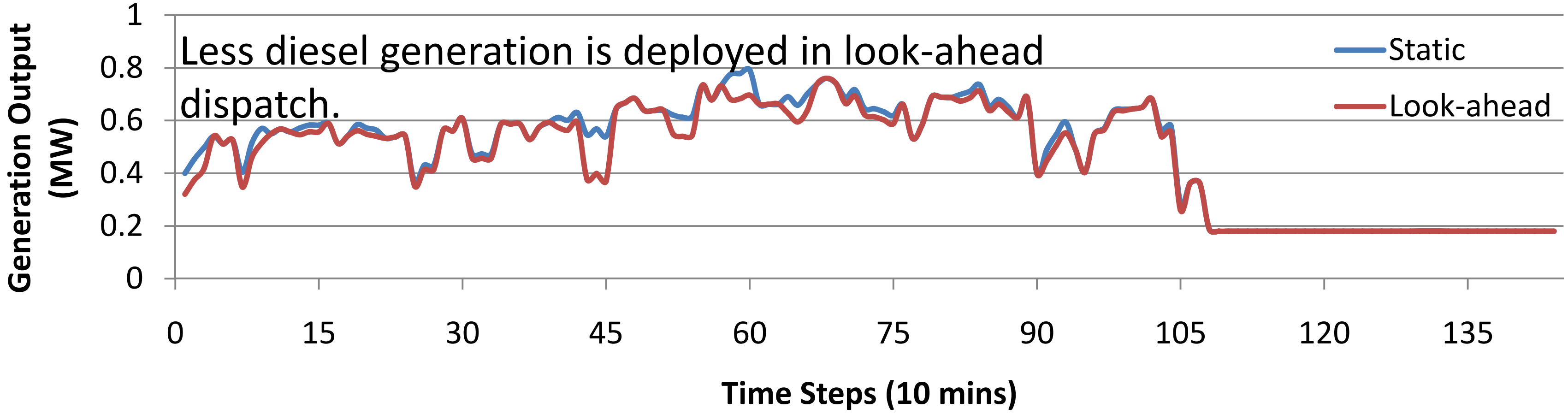


Fig. 2.a Generation outputs of Diesel Units on Apr.16th

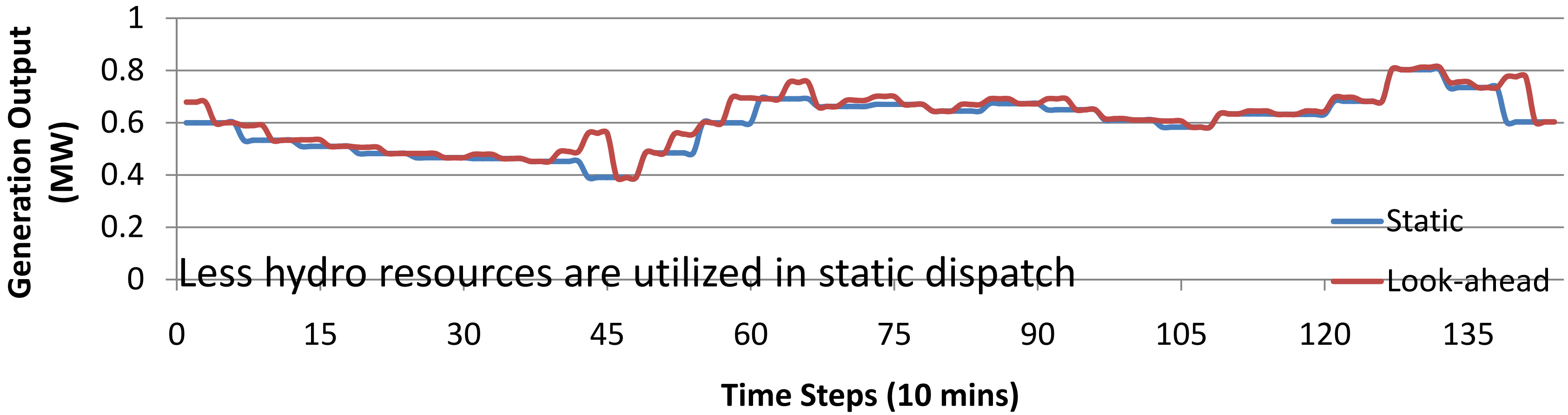
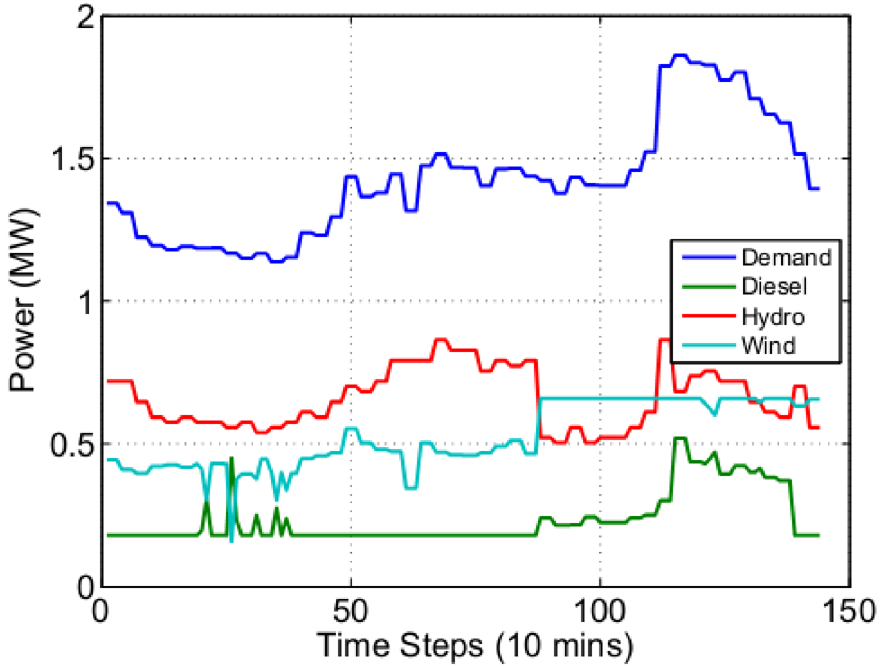


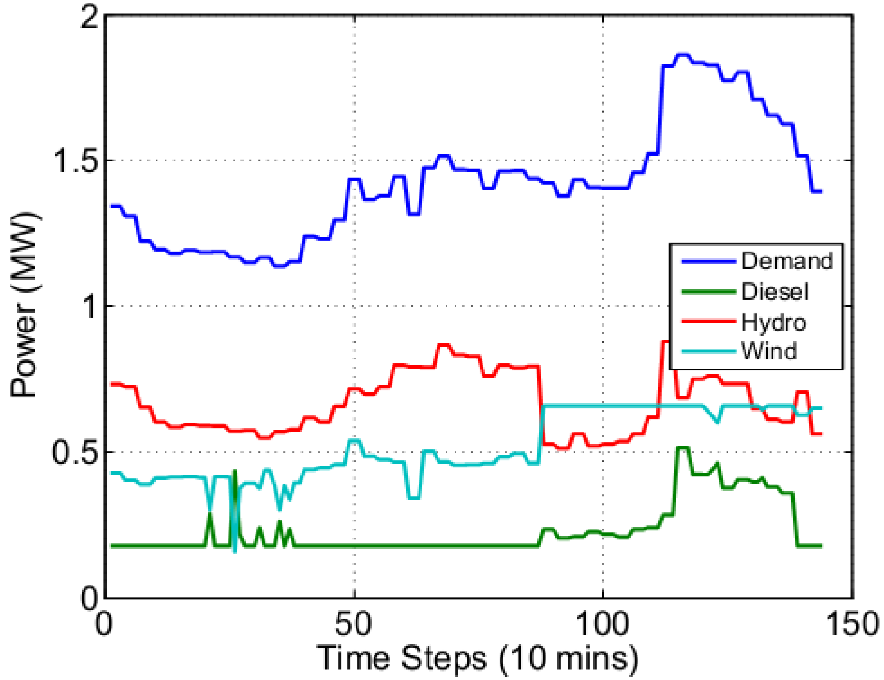
Fig. 2.b Generation outputs of Hydro Units on Apr.16th

TEXAS A&M UNIVERSITY ELECTRICAL & COMPUTER ENGINEERING

Scheduling Results for Distributed Look-ahead Dispatch



Centralized look-ahead dispatch



Distributed look-ahead dispatch

Fig. 3 Generation outputs: Centrailized v.s Distributed Look-ahead Dispatch on Jan 16

The distributed approach gives a similar dispatch results to the centralized approach without too much performance degradation.

St. Miguel Island

Source: http://en.wikipedia.org/wiki/S%C3%A3o_Miguel_Island

TEXAS A&M UNIVERSITY | ELECTRICAL & COMPUTER ENGINEERING

System Circumstances

Gen	Type	Capacity (MW)	Lowest Output (MW)	Marginal Cost ($/MWh)	Ramping Rate (%/min)
1	Oil	102.66	8.41	185	100.0%
2	Hydro	5.03	0	87	5.1%
3	Wind	30	0	88	67.0%
4	Geothermal	27.8	0	28.1	50%

- Oil is the most expensive but is the fastest unit.
- Hydro in this island is run-of-river (slow, nondispathcable)
- Geothermal units are also undispatchable

Total Operating Cost

	Version 1	Version 2	Version 3	Savings (%)
Jan.16th	$ 122,149.27	$ 122,149.27	$ 122,149.27	0.00%
Apr.16th	$ 99,451.98	$ 99,451.98	$ 99,451.98	0.00%
July.16th	$ 114,124.32	$ 114,124.32	$ 114,124.32	0.00%
Oct.15th	$ 168,017.17	$ 168,017.17	$ 168,017.17	0.00%

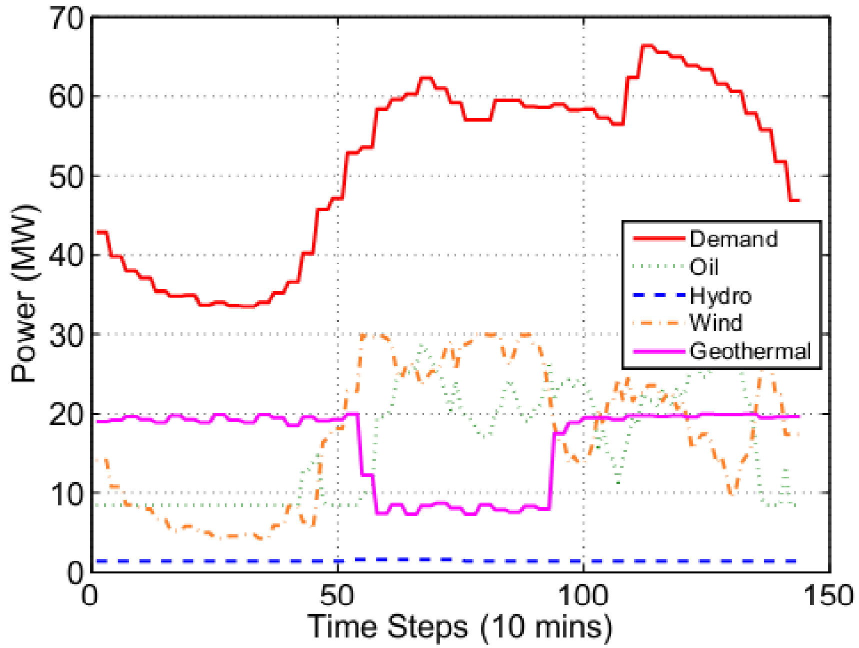
Note:
Version 1
the static scheduling case

Version 2
the centralized look-ahead scheduling case

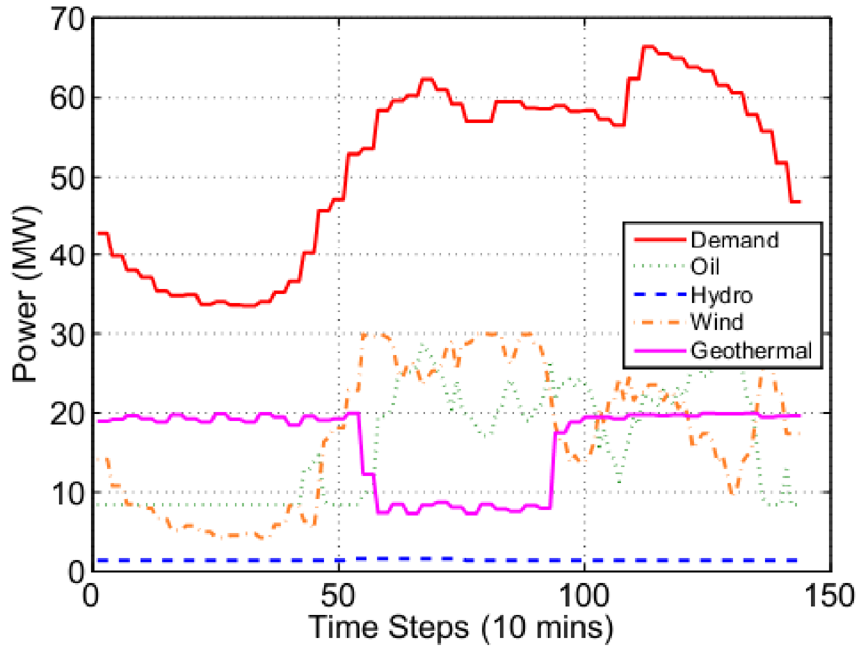
Version 3
the distributed look-ahead scheduling case (Version 1 price)

In St. Miguel Island, because the renewable resources (wind, hydro, and geothermal) are all non-dispatchable, they are treated as negative loads. Therefore, the cost-saving is very limited even given some advanced dispatch approach.

Scheduling Results for Jan. 16



Centralized Static Dispatch

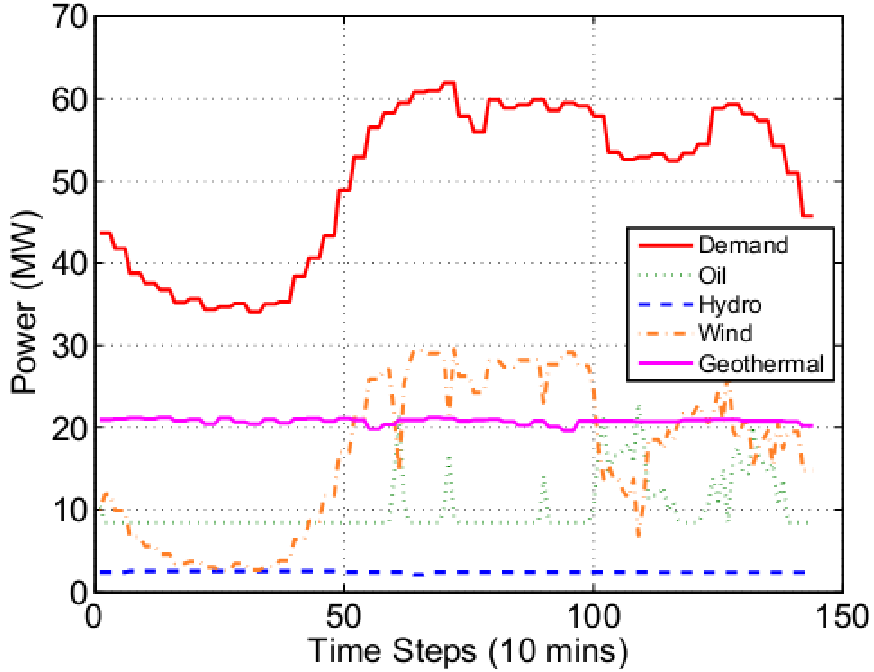


Centralized Look ahead Dispatch

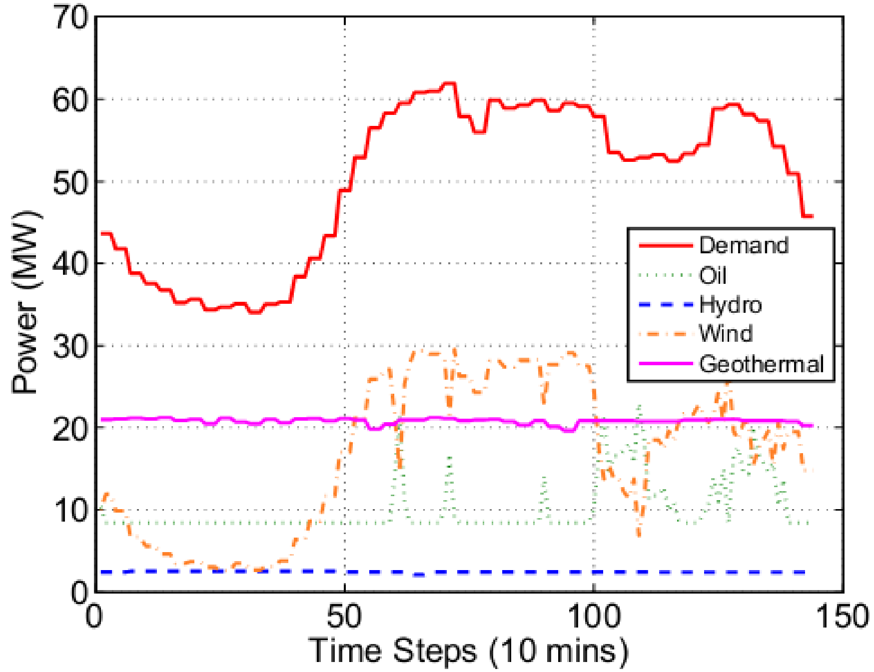
Fig. 4 Generation outputs in St. Miguel on Jan16

TEXAS A&M UNIVERSITY ELECTRICAL & COMPUTER ENGINEERING

Scheduling Results for Apr. 16



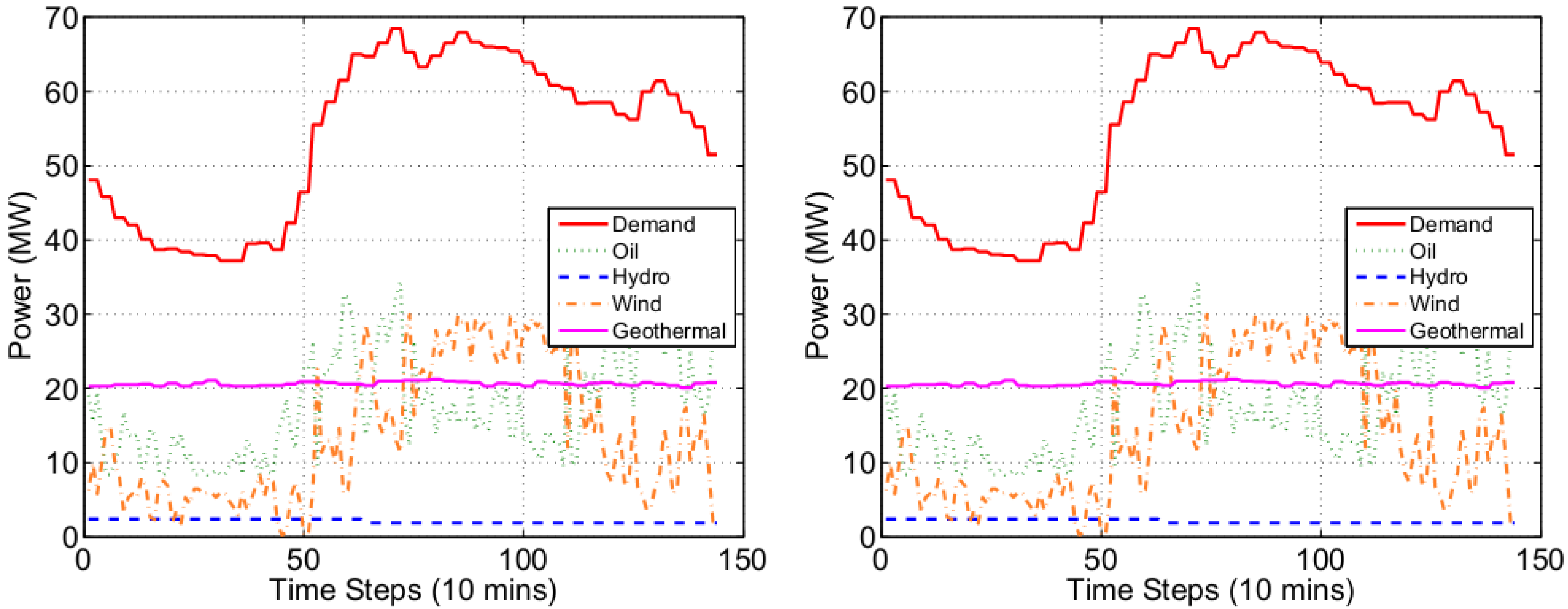
Centralized Static Dispatch



Centralized Look ahead Dispatch

Fig. 5 Generation outputs in St. Miguel on Apr 16

Scheduling Results for July. 16

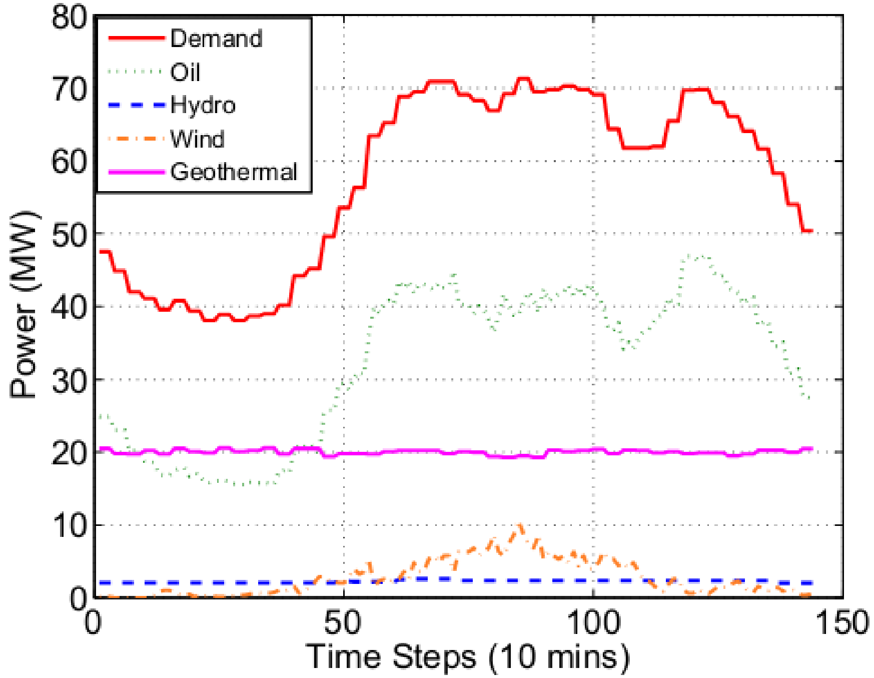


Centralized Static Dispatch

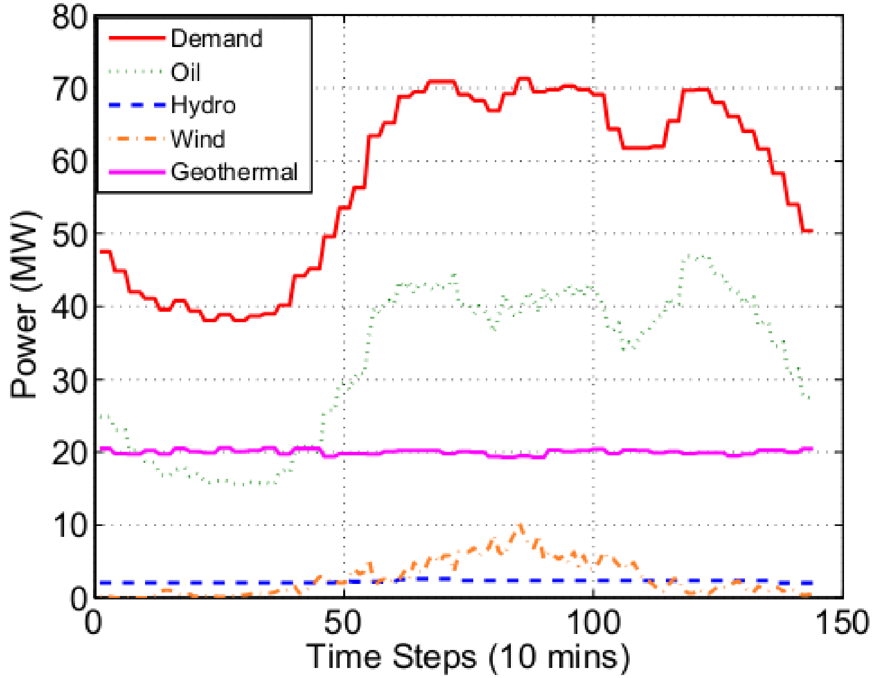
Centralized Look ahead Dispatch

Fig. 6 Generation outputs in St. Miguel on July 16

Scheduling Results for Oct. 15



Centralized Static Dispatch



Centralized Look ahead Dispatch

Fig. 7 Generation outputs in St. Miguel on Oct 15

TEXAS A&M UNIVERSITY ELECTRICAL & COMPUTER ENGINEERING

Conclusions

- Three different dispatch methods are applied in Flores and St. Miguel.
- The cost savings of advanced dispatch methods depend on (1) *relative cost* (2) ramp rate (3) controllability.
- In Flores, look-ahead approach can save about 1.5 % of the total generation cost.
- In St. Miguel, the benefits are limited because of the uncontrollability of hydro, wind and geothermal units.

Thank You

Le Xie (Lxie@ece.tamu.edu)
Assistant Professor
Department of Electrical and Computer Engineering
Texas A&M University
www.ece.tamu.edu/~lxie