Load Management Integrated Economic/Environmental Electric Power Dispatch

Caisheng Wang, *Senior Member*, *IEEE*, Michelle M. Rogers , *Student Member*, *IEEE*
Shawn P. McElmurry, Carol J. Miller, Junhui Zhao, *Student Member*, *IEEE*
Wayne State University

IEEE Power & Energy Society 2012 San Diego,CA
New Energy Horizons
Opportunities and Challenges

ABSTRACT

Load or demand side management (DSM) has been considered as an effective tool for power system operation and management. This paper presents a load management scheme using integrated economic, emission and economic/ environmental power dispatch algorithms for generation cost and emission reduction. The algorithms have been implemented using Matlab optimization toolbox and tested on a 5-bus, 3-generator system. The simulation results are presented, compared and discussed for different scenarios with different levels of load management. The results show that load management can help reduce generation costs and emissions.

OBJECTIVES

Various techniques have been proposed to reduce the negative environmental impacts of increasing electricity generation. Emission sensitive power dispatch is an important method for reducing emissions due to electric power generation.

Load management also shows great potential in reducing emissions due to electric power generation [1]. As intelligent appliances and plug-in hybrid electric vehicles (PHEV) enter the market and smart meters are increasingly deployed, more residential loads become controllable. Large electricity consumers also show great interest in DSM for emission reduction [1].

A load management integrated economic/ environmental dispatch (LMIEED) algorithm is presented to explore joint optimization strategies to reduce **emissions** and **cost** for power systems.

Though DSM methods can reduce the total electric energy consumption through efficiency improvements, it is assumed that the load management will not change the total electricity consumption in a given period of time (e.g., a day).

The optimization problems of load management integrated *economic* dispatch, *emission* dispatch, and *economic/emissions dispatch (EED)* will be addressed respectively.

Generation Cost, Emission and Load Models

Cost:

$$F_C = \sum_{k=1}^{NT}\sum_{i=1}^{NG} F_{C,i}(k)$$

$$F_{C,i} = a_i + b_i P_{G,i} + c_i P_{G,i}^2$$

NOx Emission:

$$F_E = \sum_{k=1}^{NT}\sum_{i=1}^{NG} F_{E,i}(k)$$

$$F_{E,i} = 10^{-2} \times \left[\alpha_i + \beta_i P_{G,i} + \gamma_i P_{G,i}^2 + \delta_i \exp\left(\theta_i \times P_{G,i}\right)\right]$$

Load Profile Management:

$$L(k) = \sum_{i=1}^{NL} L_i(k) \qquad [1-\mu(k)]L(k)$$

$$\sum_{k=1}^{NT} \mu(k)L(k) = 0$$

METHODS

Load Profile Management Integrated <u>Economic</u> Dispatch:

$$\underset{P_{G},\mu}{Min}\ F_C \quad \textit{Subject to the constraints}$$

Constraints:

$$\sum_{i=1}^{NG} P_{G,i}(k) = [1-\mu(k)]L(k) + \sum_{i=1}^{NG} B_i P_{G,i}^2(k)$$

$$P_{G,i,min} \le P_{G,i}(k) \le P_{G,i,max} \qquad -\mu_{max} \le \mu(k) \le \mu_{max}$$

$$0 \le \mu_{max} \le 1$$

Load Profile Management Integrated <u>Emission</u> Dispatch:

$$\underset{P_{G},\mu}{Min}\ F_E \quad \textit{Subject to the constraints}$$

Load Profile Management Integrated <u>Eco/Emi</u> Dispatch:

$$\underset{P_{G},\mu}{Min}\ \{F = \lambda F_C + (1-\lambda) W F_E\} \quad \textit{Subject to the constraints}$$

λ is the weighting factor and W is the scaling factor

Load management integrated power dispatch algorithms have been implemented using the Optimization Toolbox in Matlab. The algorithms were tested in a 5-bus system with 3 generators [2]. (Fig. 1)

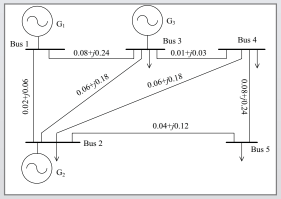

Fig. 1. Diagram of the test system.

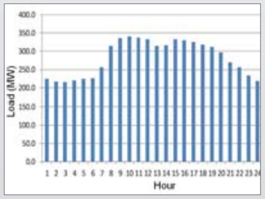

Fig. 2. Hourly demand pattern

Unit No.	Cost Model				
	$P_{G,max}$	$P_{G,min}$	a_i	b_i	c_i
1	150	40	70.81	4.88	0.00135
2	130	35	96.13	4.56	0.00522
3	120	35	225.95	6.25	0.00335
	Emission Model Parameters				
	α_i	β_i	γ_i	δ_i	ϑ_i
1	4.073	-5.112	5.534	2.1×10^{-3}	3.875
2	3.216	-5.542	6.123	5.2×10^{-4}	4.223
3	3.775	-4.521	5.785	6.5×10^{-3}	4.756

Table I. Cost & Emission Model Parameters

RESULTS

Load Management Integrated <u>Economic</u> Dispatch: Fig. 3 shows the overall generation cost of the system at different levels of load management in the 24-hour simulation period. The generation cost is reduced as a greater portion of the load is controllable.

The results also show that when the controllable load reaches approximately 30%, the generation cost saving is maximized (μ_{max} = 0.30). Thus, for this simulation, the controllable load saturation level is 30%. Even if more loads were controllable, no additional cost savings will result.

Based on the cost model given in Table I, the load management can reduce generation cost by around 0.7%. The emission versus load management is also given in the Fig. 2. It can be seen that emissions can rise while the objective is only targeted for cost reduction.

Fig. 4 shows the total generation profiles over the 24 hour simulation period for the case of no load management (μ_{max} = 0) and the scenario when μmax = 0.20.

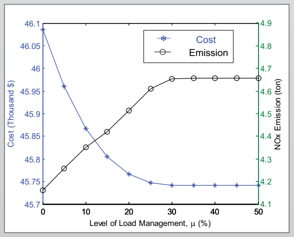

Fig. 3. Cost and Emissions result for economic dispatch

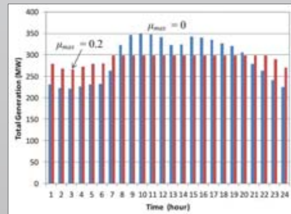

Fig. 4. Hourly generation for the two scenarios of μ_{max} = 0, and μ_{max} = 0.2.

Load Management Integrated <u>Emission</u> Dispatch: Fig. 5 shows the overall NOx emission of the system at different levels of load management in the 24-hour simulation period. It can be seen from the figure that the load management helps further reduce emissions about 4.4%,

Similar to the economic dispatch, when the level of controllable load exceeds 25% (μ_{max} = 0.25), the emission reduction reaches its saturation point.

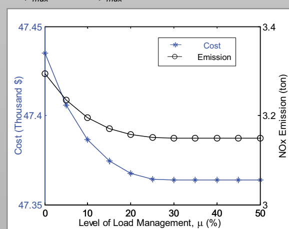

Fig. 5. Cost and Emissions result for emission dispatch

RESULTS (CONTINUED)

Load Management <u>Integrated Economic/ Environmental</u> Dispatch: The independent goals of cost minimization and emission minimization may not yield a singular, optimal point of operation. The EED can provide a Pareto *front*, which can be used to find a range of operating conditions that lead to varying levels of both cost and emission minimization.

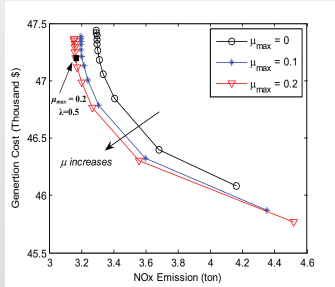

Fig. 6. Pareto front curves of the system under different levels of load management.

CONCLUSIONS

Load management integrated economic, emission, and economic/environmental dispatch algorithms were formulated in this paper. The algorithms were implemented using Matlab optimization toolbox and tested on a 5-bus, 3-generator system. The simulation results show that the load management can further reduce system generation costs and emissions. For all the three cases of economic, emission, and economic/ environmental dispatch, the results show that the effect of load management reaches capacity when the level of load management is 25%.

In the future this work will be extended to include the optimal water pumping schemes responsible for the energy demand. Accordingly, one of our initial tasks is to integrate the hydraulic models of water delivery system into the EED of electric power. The pumping load of DWSD will be investigated as an example to further explore and verify the proposed LMIEED algorithms for emission and cost reduction due to electric power generation.

REFERENCES

1. Timothy H Carter, C. Wang, Stephen S. Miller, Shawn P. McElmurry, Carol J. Miller, and Ian A. Hutt, "Modeling of Power Generation Pollutant Emissions Based on Locational Marginal Prices for Sustainable Water Delivery," *2011 EnergyTech*, May 2011, Cleveland, OH.
2. Hadi Saadat, Chapter 7, *Power System Analysis*, McGraw Hill, (ISBN: 0-07-284869-3), 2nd edition, July 15, 2002.
3. J.H. Talaq, F. El-Hawary, and M.E. El-Hawary, "A summary of environmental/economic dispatch algorithms," *IEEE Transactions on Power Systems*, vol. 9, no. 3, pp. 1508-16, Aug. 1994.
4. Chao-Lung Chiang, "Optimal economic emission dispatch of hydrothermal power systems," *International Journal of Electrical Power & Energy Systems*, vol. 29, no. 6, pp. 462-9, July 2007.
5. A.A. Abou El Ela, M.A. Abido and S.R. Spea, "Differential evolution algorithm for emission constrained economic power dispatch problem," *Electric Power Systems Research*, vol. 80, no. 10, pp. 1286-92, Oct. 2010.

ACKNOWLEDGEMENT

This work was made possible through funding (Grant #881) from the Great Lakes Protection Fund (GLPF). In addition to GLPF, we would like to thank DTE Energy and the Detroit Water and Sewerage Department (DWSD) for their cooperation throughout the course of this study.