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1993 – A DISTRIBUTION SYSTEM EXPANSION PLANNING METHOD CONSIDERING IESP's REVENUE ON ENERGY STORAGE INVESTMENT

Yuquan LIU
China Southern Power Grid Corp. Limited, China

Xinyi ZHAO, Xinwei SHEN
Tsinghua-Berkeley Shenzhen Institute, China

Wen XIONG, Li WANG,
China Southern Power Grid Corp. Limited, China

Introduction

The increasing load which require power supply in a short period is enlarging the gap between the peak and valley value in power system. **Energy storage system** (ESS) will help address the problem as a flexible distributed power sources. Some companies named as **integrated energy service provider (IESP)** are interested in investing on ESS because there is potential revenue coming from energy arbitrage.

Figure 1 – Energy Storage System invested by IESP and Guangzhou Power Grid Corp. (8MW/40MWh)

Model formulations

The DSEP method is established as a **mixed integer linear programming model (MILP)** [2], with constraints denoting the reasonable revenue for IESP and modelling the operation conditions of ESS.

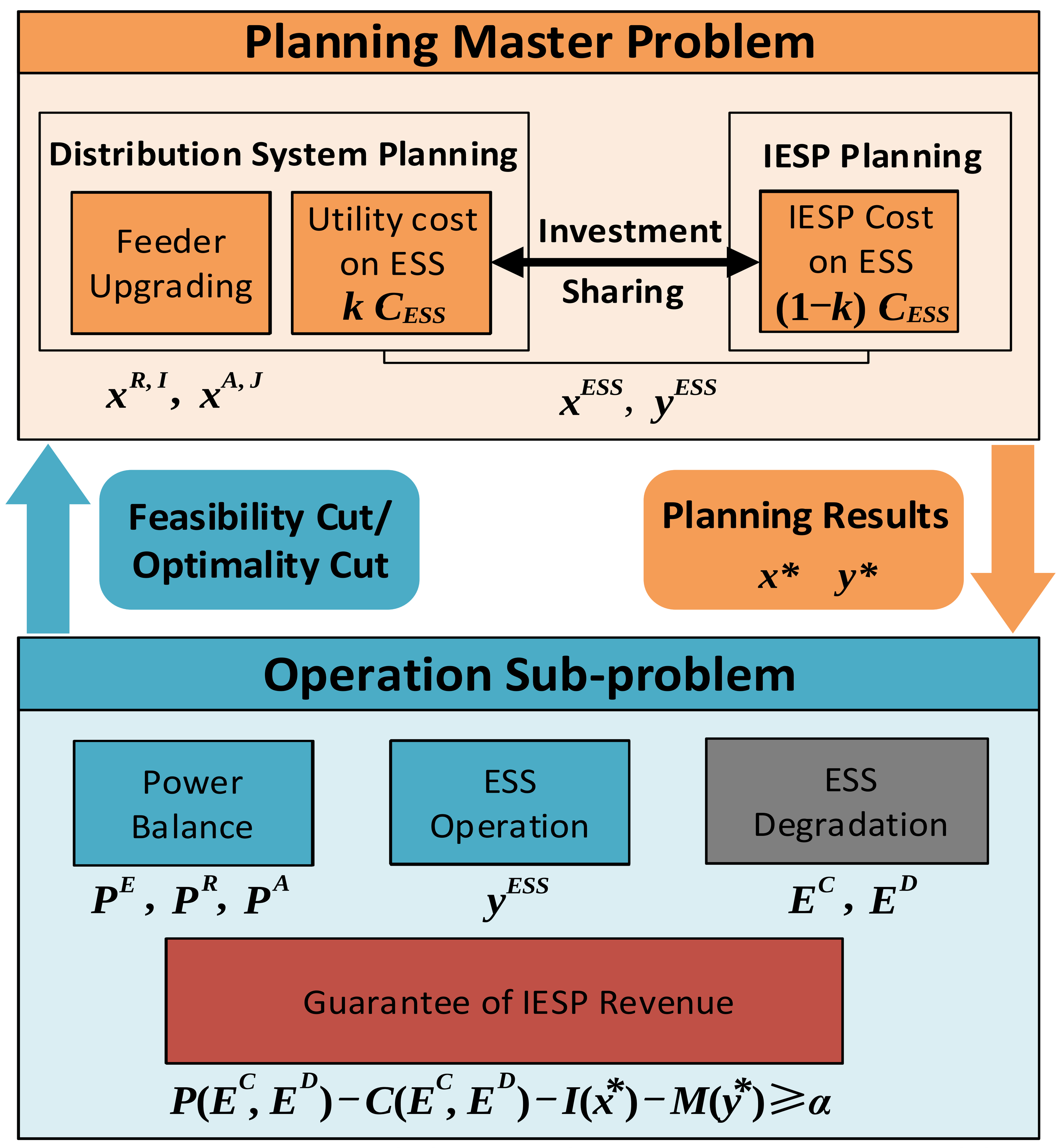


Figure 2 – MILP model considering operation problem

- **Degradation cost**

The utility cover part degradation cost of ESS as below.

$$C_{CDC}=k\sum_s \rho_s \sum_h C_h^{cdc}\left(\sum_{n\in\Pi^{EN}} \left|E^D_{n,h,s}\right|+\left|E^C_{n,h,s}\right|\right)$$

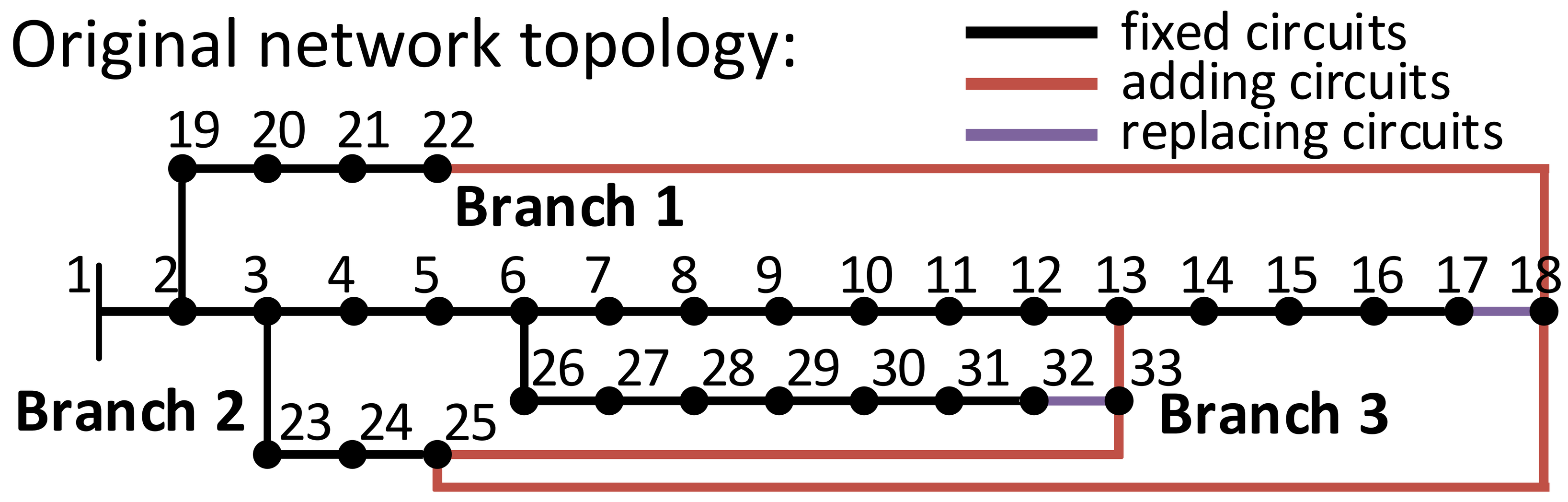
- **IESP's revenue**

IESP's revenue is set as a constraint in order to guarantee their benefit during the DSEP.

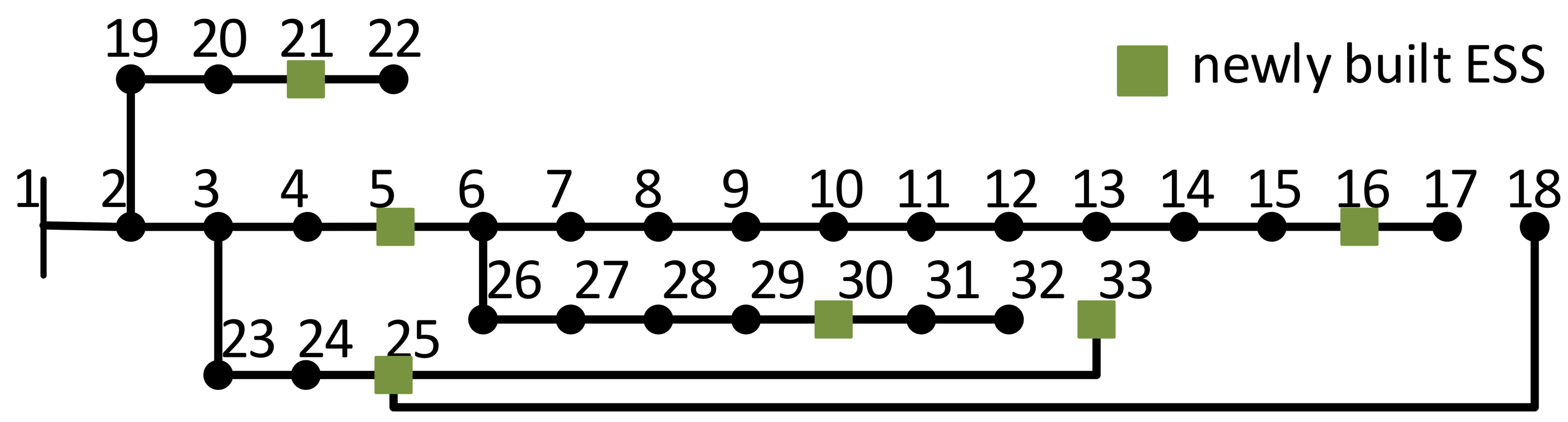
$$\sum_T \frac{1-k}{(1+i)^{T-1}}\left(T\left(C_{PES}-C_{ME}-C_{CDC}\right)-C_{IE}\right)\geq\alpha$$

Result analysis

☐ Original network topology:



☐ Topology after the DSEP:



Adjusting the investment proportion k in case2:

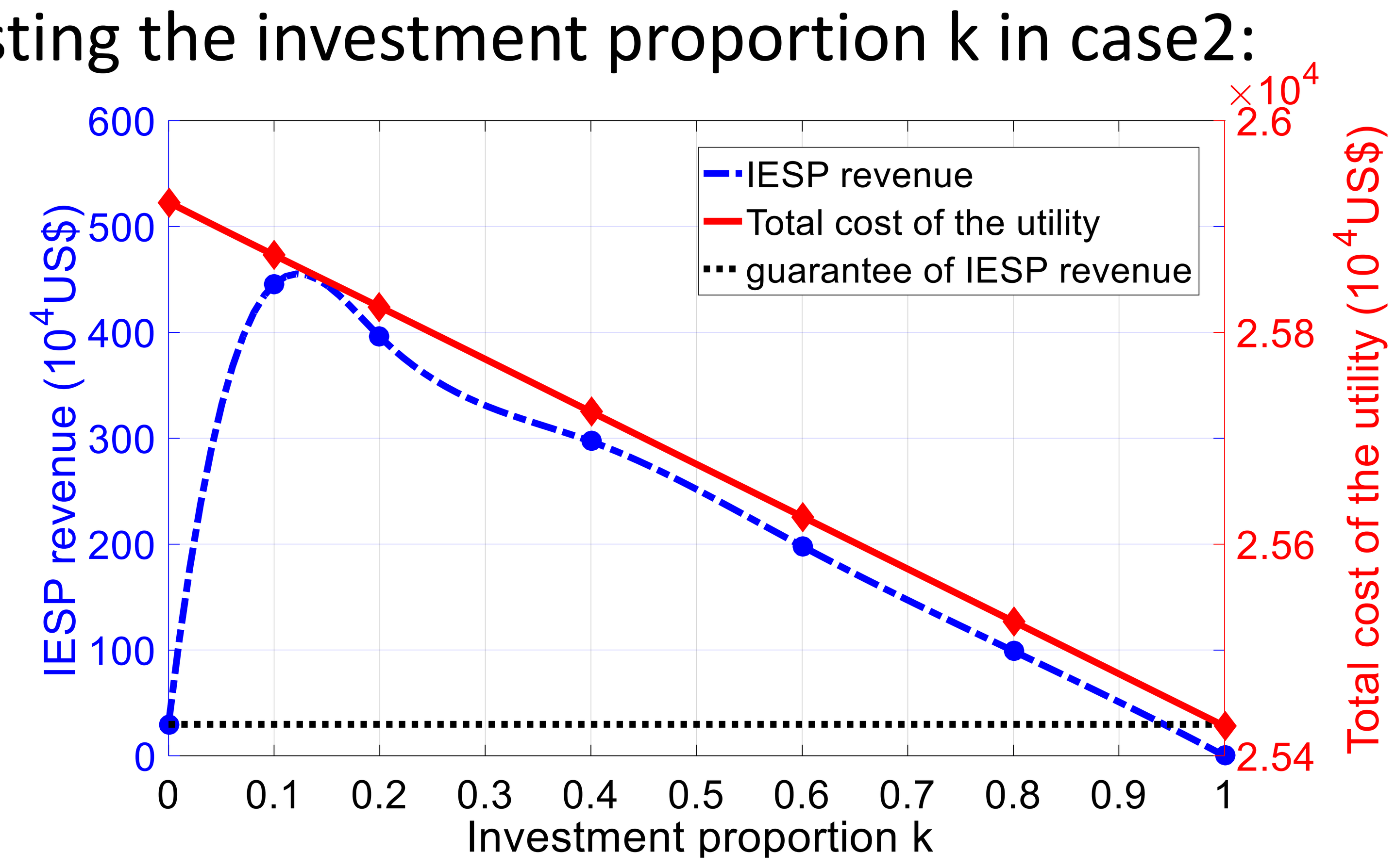


Figure 3 –IESP's revenue and the utility's cost considering investment sharing

Conclusion

A DSEP method considering IESP's revenue on ESS is proposed here and solved by Benders decomposition. Results show that by sharing the investment cost on ESS, the utility will effectively cut expenses as well as obtaining a possible higher revenue to attract IESP investing on ESS.

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Objective functions

The model is aimed at minimizing the comprehensive cost of construction and operation for the distribution network expansion in typical scenarios, from the perspective of the utility.

$$\min\left(C_{INV}+T\left(C_M+C_{CDC}+C_{PT}+V_{OLL}\sum r\right)\right)$$

Constraints

The DSEP model proposed in [2], which considers conventional planning constraints based on **Kirchhoff's current law, node voltage limits, feeders' capacity, construction logic, load shedding** etc., will not be discussed here. Furthermore, there are some expansion constraints illustrated below.

- **Planning & operation constraints for ESS:**

$$E^E_{n,h+1,s}=E^E_{n,h,s}+\left(\eta^C_n E^C_{n,h,s}-\frac{1}{\eta^D_n}E^D_{n,h,s}\right)\quad h=1,2,\cdots,23$$

$$\sum_{N\in\Omega^{CES}_n} y^{ESS,N}_n E^{E,N}_{n,\min}\le E^E_{n,h,s}\le \sum_{N\in\Omega^{CES}_n} y^{ESS,N}_n E^{E,N}_{n,\max}$$

$$E^E_{n,h,s}=E^E_{n,0}\qquad h=1,24$$

$$E^D_{n,h,s}\le \sum_{N\in\Omega^{CES}_n} y^{ESS,N}_n E^{D,N}_{n,\max}$$

$$E^C_{n,h,s}\le \sum_{N\in\Omega^{CES}_n} y^{ESS,N}_n E^{C,N}_{n,\max}$$

- **IESP revenue constraints:**

$$\sum_T \frac{1-k}{(1+i)^{T-1}}\left(T\left(C_{PES}-C_{ME}-C_{CDC}\right)-C_{IE}\right)\ge\alpha$$

$$C_{PES}=\sum_s \rho_s\left(\sum_h P^{ESS}_{R,h}\sum_{n\in\Pi^{EN}}E^D_{n,h,s}-\sum_h P^{BUY}_{R,h}\sum_{n\in\Pi^{EN}}E^C_{n,h,s}\right)$$

$$C_{IE}=\sum_{n\in\Pi^{EN}}\sum_{N\in\Omega^{CES}_n} C^N_{ESS,n}x^{ESS,N}_n$$

$$C_{ME}=\sum_{n\in\Pi^{EN}}\sum_{N\in\Omega^{CES}_n} O^N_{ESS,n}y^{ESS,N}_n$$

Case study

- ☐ Case1: replacing/adding new circuits in the original distribution system with no ESS to be built.
- ☐ Case2: considering IESP's building ESS on the basis of Case1 under constraints of IESP revenue guarantee (investment proportion k can be set from 1 to 0).

TABLE I. Calculation results of two cases

Case		Case1	Case2
The utility	Total cost (10^4US$)	29527	25824
	Construction cost of lines (10^4US$)	689	555
	Construction cost of ESS (10^4US$)	0	240
	Operation cost of ESS (10^4US$)	0	25
	Charge- discharge cost (10^4US$)	0	167
	Purchase fee from MG (10^4US$)	28621	22495
	Purchase fee from ESS (10^4US$)	0	2125
IESP	Total cost (10^4US$)	—	1729
	Construction fare of ESS (10^4US$)	—	960
	Operation fare of ESS (10^4US$)	—	101
	Charge- discharge cost (10^4US$)	—	668
	Revenue (10^4US$)	—	396

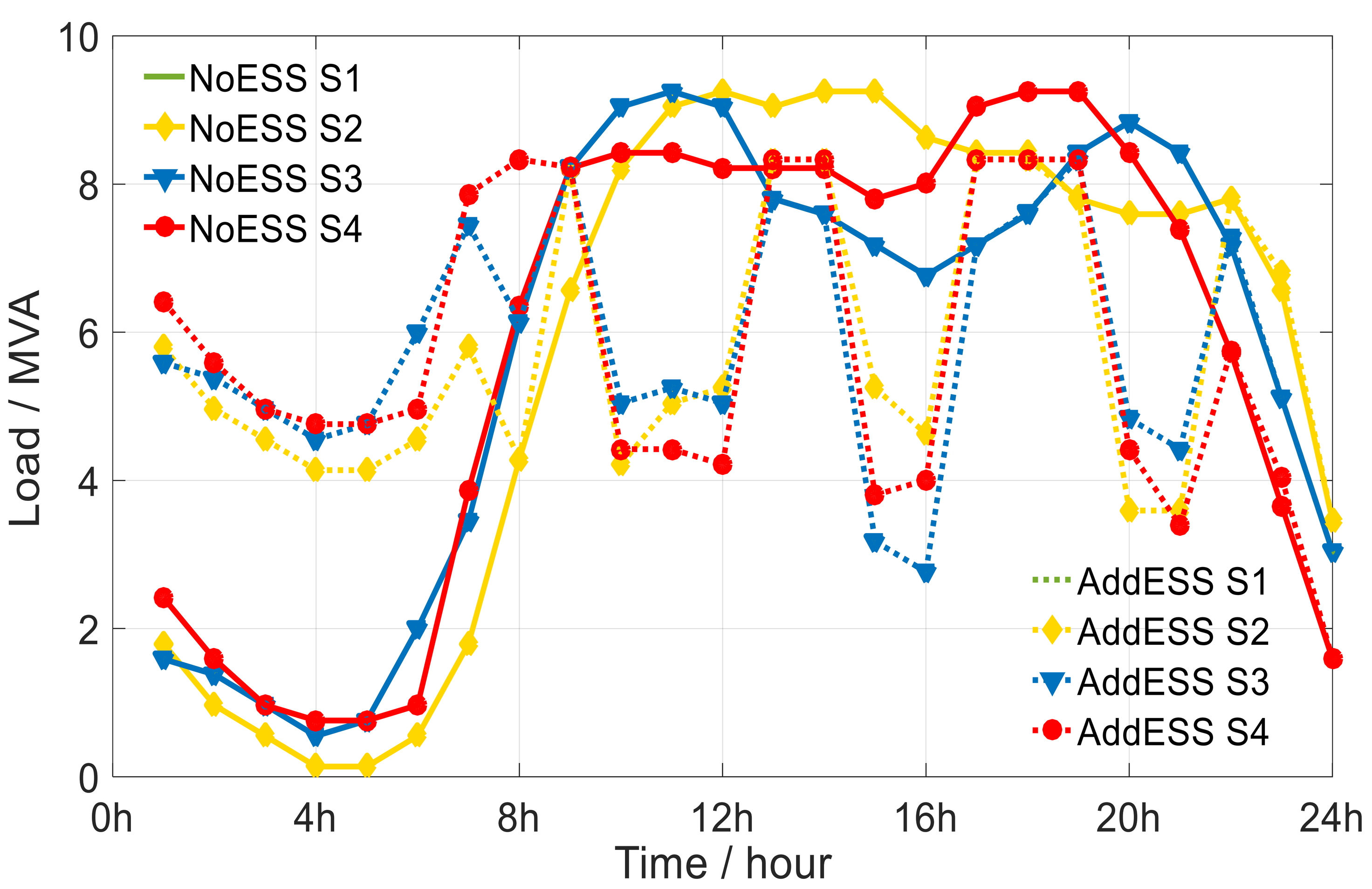

Figure 4 –Daily load curve in case2

References

[1] P. F. Ribeiro, B. K. Johnson, M. L. Crow, et al, 2001, "Energy storage systems for advanced power applications", Proceedings of the IEEE, vol. 89, 1744–1756.

[2] **X. Shen**, M. Shahidehpour, Y. Han, et al, 2017, "Expansion planning of active distribution networks with centralized and distributed energy storage systems", IEEE Trans on Sustainable Energy, vol. 8, 126-134.