Simulation of the Appropriate Capacity and Mouthing Position of Distributed Battery Storage Systems for Maintaining the Power Quality in Maesariang Microgrid System, Thailand

Chaiyaporn Kaewvata, Chatchai Sirisamphanwong*, and Tawat Suriwong

Abstract— *This article presents the simulation of appropriate battery capacity and mouthing position in a large scale Maesariang Microgrid system (MMGs) as well as to realize the relationship between load power demand and the Li-on battery capacity. The MMGs are located in Maesariang District, Maehongson province, Thailand. At present, the electricity network in this area has many problems due to the long distribution line causing high-energy loss (19% or 6.7 GWh/year), which sometimes creates power outages and grid voltage fluctuations which is caused by unstable RE power production. The energy storage system is the key to maintaining power quality and stability by balancing supply and demand. Therefore, the centralized battery storage system will be installed at the Masariang substation as the energy buffer. This research aims to study the technical parameters of MMGs in the case of a centralized and decentralized battery storage system for maintaining the grid voltage. The parameters which are concerned with the performance of an MMGs such as voltage, frequency of the grid network, PV, battery, load, and diesel generator power will be simulated by DigSILENT Power Factory Software (Research license of Naresuan University). The simulations consist of three cases; the first is the original Maesariang system without a battery storage system, the second is the Maesariang system with a centralized energy storage system, and the Maesariang system with a decentralized energy storage system. The result of the research showed that the battery storage system could stabilize the grid voltage into the acceptable range by balancing supply and demand power. The grid voltage of original, centralized, and decentralized systems fluctuated between 0.90 p.u. – 1.102 p.u., 0.94 p.u. - 0.98 p.u. and 0.94 p.u – 0.96 p.u, respectively. The decentralized battery storage system can maintain the grid voltage better than a centralized storage system because the decentralized storage system can supply electricity to load with low loss in the distribution feeder.*

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Keywords— **Microgrid, battery storage system, centralized BSS, decentralized BSS, battery power management.**

1. INTRODUCTION

At present, the energy crisis has become more intense because of the increase in energy demand and limitation of the fossil power plant. Environmental problems are of particular concern from the rising of greenhouse gases, which have been generated from the use of fossil fuels. Many countries promote the use of renewable energy, such as solar, wind, etc. However, the increase of renewable energy without a suitable plan will result in problems with the power quality of electricity in the distribution system. According to the issues above, many advantages technologies have applied to the power system. The Microgrid or Smart Grid is to realize the unstable and unbalance between the supply and the load demand [1]-[5]. Hossein and etc, summarized that energy management approaches for the microgrid system from a new classified into four categories, namely, non-renewable, ESS, DSM, and hybrid-based EMS and all of them may be widely used in future [6]. Many researchers reported that modern power systems and RE distributed generations, the combination of them with energy storage systems, was contributed to the microgrid systems, and it enables them to maintain the power quality in the network [7]-[15]. The Microgrid system (MGs) is adaptable, flexible, affordable technology and can increase system stability by the management of distributed energy resources (DER) and intelligent grid devices [16]-[21]. A microgrid system is a group of interconnected loads and distributed energy resources (DER) within clearly defined electrical boundaries that act as a single controllable entity concerning the grid.

PEA is developing the Maesariang Microgrid system (MMGs) in Maehongsorn province [22], Thailand, which has faced many problems, such as energy loss from the110 kilometer-long 22 kV distribution line that also has to pass through a forest from the Hot substation. Therefore, the power loss in the distribution line (19 % or 6.7 GWh/year), and the voltage fluctuation causes interruption problems creating power outages more than 20 times per year. Moreover, in case of low load consumption and high solar irradiation, PV power plants cannot connect to the grid because of voltage increase over the maximum upper limit of the PEA requirement [23]. According to the reasons above, Maesariang District is a suitable area to study the large scale Microgrid system. Therefore, MMGs will be

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implemented in the Maesariang district and will be finished by the end of 2019. The Maesariang Microgrid system (MMGs) is the large-scale substation microgrid systems, covering the area of one district in Maehongsorn province, Thailand. The components of the MMGs are shown in Fig 1.

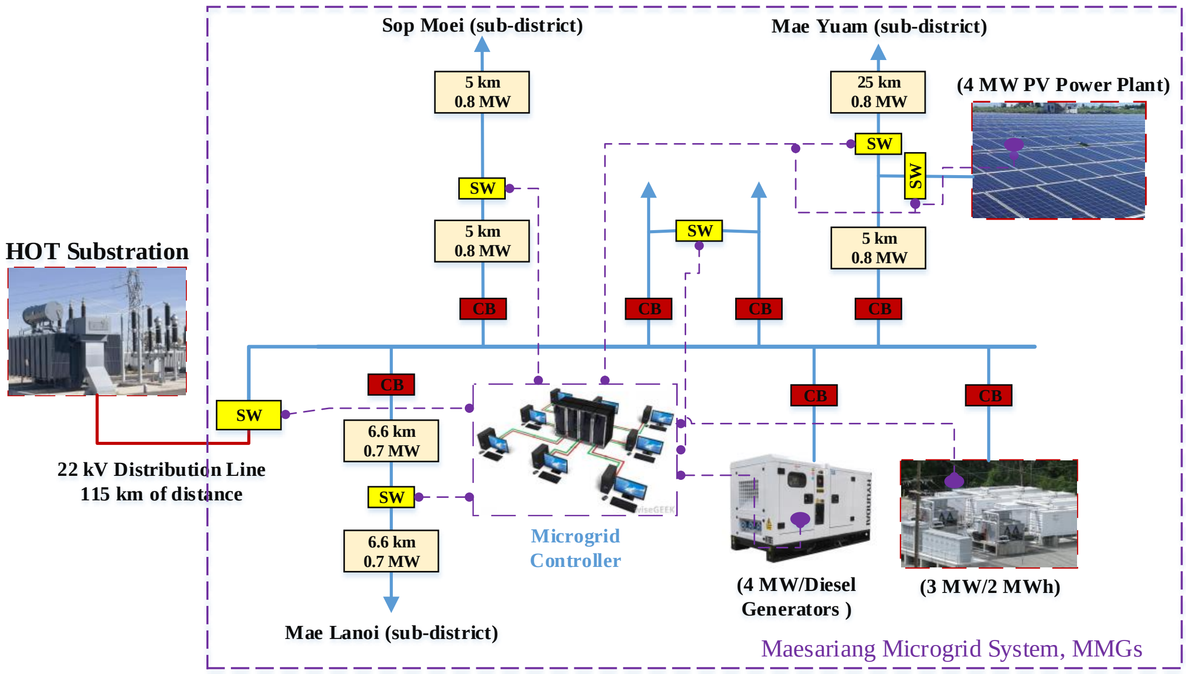

Fig. 1. Maesariang Microgrid System, (MMGs).

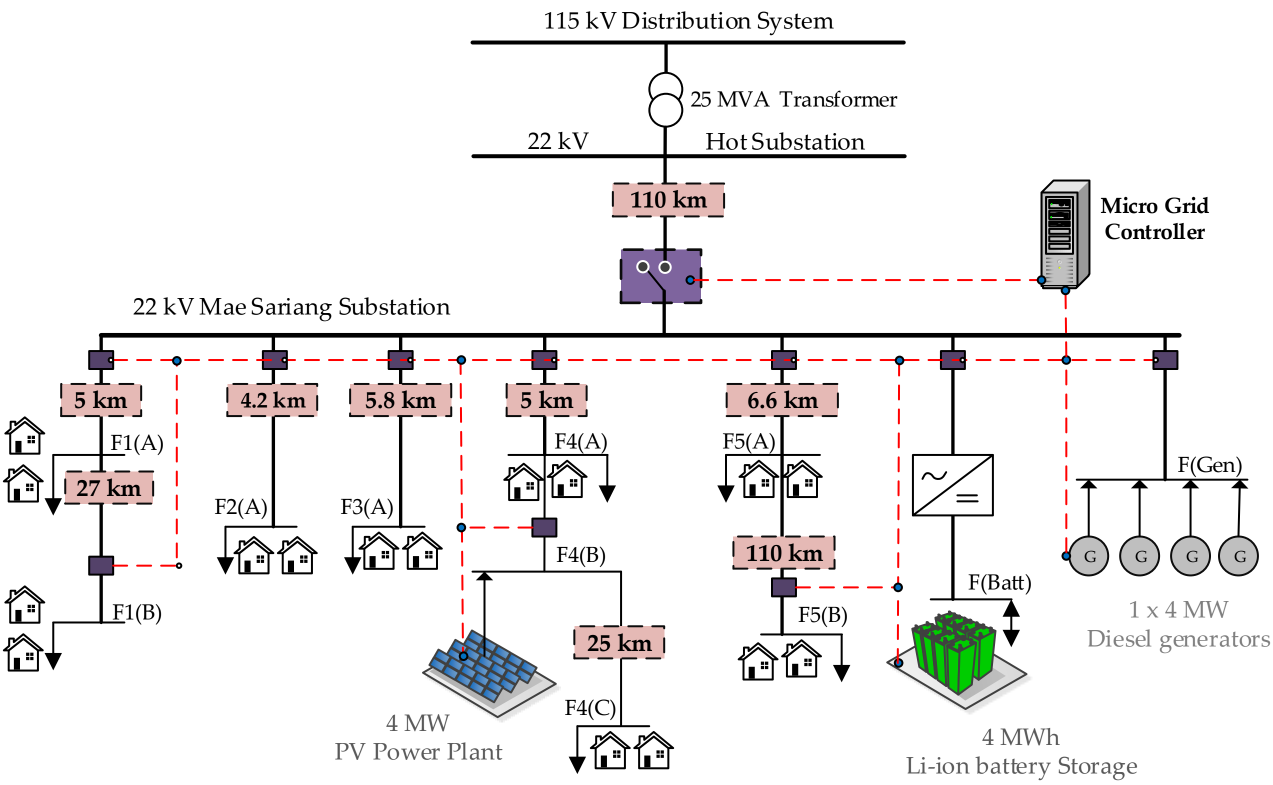

Fig. 2. The Maesariang Microgrid System.

Usually, the 2 MW/4 MWh of the Li-on battery storage system is connected to the Maesariang substation, which is the location too far from the load, for example, F5(B) is far from substation about 117 km. This distance is difficult to maintain the power quality in the distribution system. According to the problem above, the battery storage system can be divided into a centralized system and a decentralized system, and it can spread into the MMGs feeders. This concept may appropriate method for maintaining the power quality in the MMGs, which is covering the wide-area [24] – [27]. Therefore, this research aims to study the technical impact of a centralized and distributed battery storage systems in the MMGs. The dynamic load flow was simulated for a whole day (24 hours) by using the DigsiLent Power Factory software. The simulation results showed the voltage level in the studied busbars and the active/reactive power of the PV power plant, BESS and a diesel generator that depends on the load and power generation profiles during a whole day. Daily parameters during any situation on the distribution network are simulated in this part.

2. THE MAESARIANG MICROGRID SYSTEM

The Maesariang Microgrid System (MMGs) is located in Maesariang District, Maehongson province, Thailand. At present, the electricity network in this area has many problems, due to the long distribution line causing high-energy loss (19%), two generating sources (Diesel generators, and PV systems). That sometimes creates power outages and grid voltage fluctuations, which is caused by unstable RE power production, approximately 20 times per year. According to the reasons above, Maesariang District is a suitable area to study the Microgrid system. Therefore, MMGs has implemented in the Maesariang district and finished by the end of 2019. This project aims to improve system power quality, stability, and reliability. The MMGs operation mode consists of a grid-connected mode and an islanded mode. The MMGs must operate to manage all the components for energy efficiency, but in the case of an emergency, it can control the coverage area, which is very secure. All the advantages components have installed in the Maesariang district and have worked together for system efficiency and stability. The Microgrid controller can manage the distributed generation in MMGs and enables it to connect/disconnect the DER. Not only can the generation size be controlled, but also load size for balancing the supply and demand. The energy storage system is significant for energy management in the MMGs because, in case of an imbalance between supply and demand, energy storage (battery system) can be the medium buffer and support the power stability and quality [28]-[29]. The schematic diagram of the MMGs controller is shown in Fig. 2, and the main components of the MMGs details are presented in Table 1.

Table 1. Components of the MMGs

No.	Distributed Energy Resources	Size
1	PV Power Plant	4 MW
2	Diesel Generators	1*4 MW
3	Li-ion Battery Storage	4 MWh
4	Peak load in five feeders	6.8 MW
5	Microgrid Controller	1 Set
6	Switching Devices	1 Set
7	FLISR	1 Set

3. OPTIMIZE LOCATION

The optimal mounting area for the battery storage system in the MMGs has performed the power quality and

power loss analyses. The objective function to find the optimal mounting location as described as follow. The optimal mounting location is the position for battery storage system installation, which gave the power quality in the desired range. The grid voltage at every busbar in the test system is shown as equation 1.

$$F_{place} = \sum_{\tau=1}^{n} place_{\tau}^{lessloss} \quad (1)$$

$$V_{mindesire} < V_n < V_{maxdesire} \quad (2)$$

The $V_{mindesire}$ is the minimum voltage of the desired range, V_n is nominal voltage, and $V_{maxdesire}$ is the maximum voltage of the desired range.

4. THE OPTIMAL SIZE OF BESS

The optimal capacity of BESS can be chosen from the lack of load demand. The optimal size is used to determine the optimal maximum and minimum capacity, as presented in equation 3 and equation 4.

$$E_{min}^{BESS\_Size} = \sum_{n\tau=1}^{n} (P_{n\tau}^{Load} + P_{n\tau}^{Loss} - P_{n\tau}^{PV} - P_{n\tau}^{WT})\Delta t \quad (3)$$

$$\text{OptimalSize} = \rho E_{min}^{BSS\_Size} \quad (4)$$

5. SIMULATION AND CASE STUDY

The electrical parameters which are concerned with the performance of the MMGs such as grid voltage, frequency, PV, battery, generation, and load power were simulated by DigSILENT Power Factory Software (Licensed to Naresuan University). The simulation consists of two parts, which are power flow dynamic and transient simulations. The purpose of the study is to maintain the grid voltage and frequency in the desired range (grid voltage is 0.94 p.u. – 1.06 p.u. and the frequency is 47 – 52 Hz.). The MMGs was modified to the Measariang Microgrid with the decentralized battery storage system (MMGs-Dbss).

5.1 Case Studies

The case studies in this research can be divided into three cases. The first is the original Measariang system without a battery storage system, and the second is the Maesariang system with a centralized battery storage system; finally, the third is the Maesariang system with a decentralized battery storage system, as detail below.

Case Study 1: The dynamic load flow simulation of the voltage profile depends on the load profile, PV power output profile, and operating with diesel generators. This Case Study is the original Measariang distribution system without a battery storage system, as shown in Fig. 3.

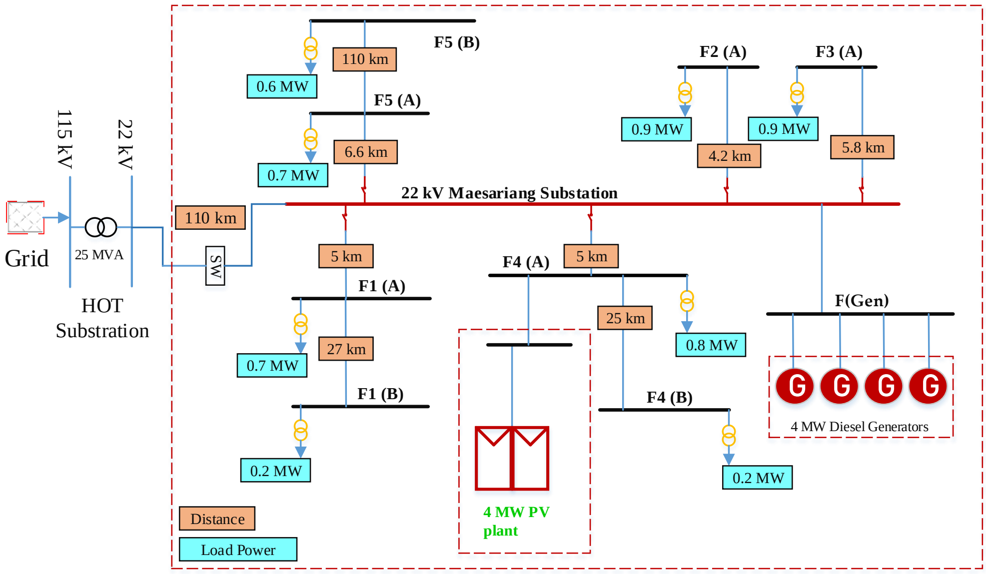

Fig. 3. The original Maesariang system without a battery storage system for Case Study 1.

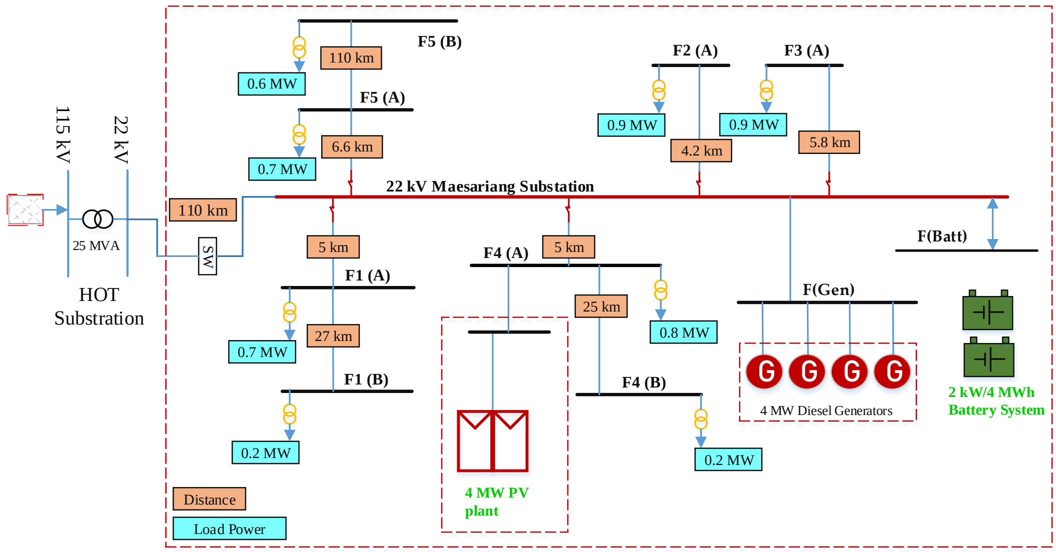

Fig. 4. The Maesariang system with a centralized battery storage system for Case Study 2.

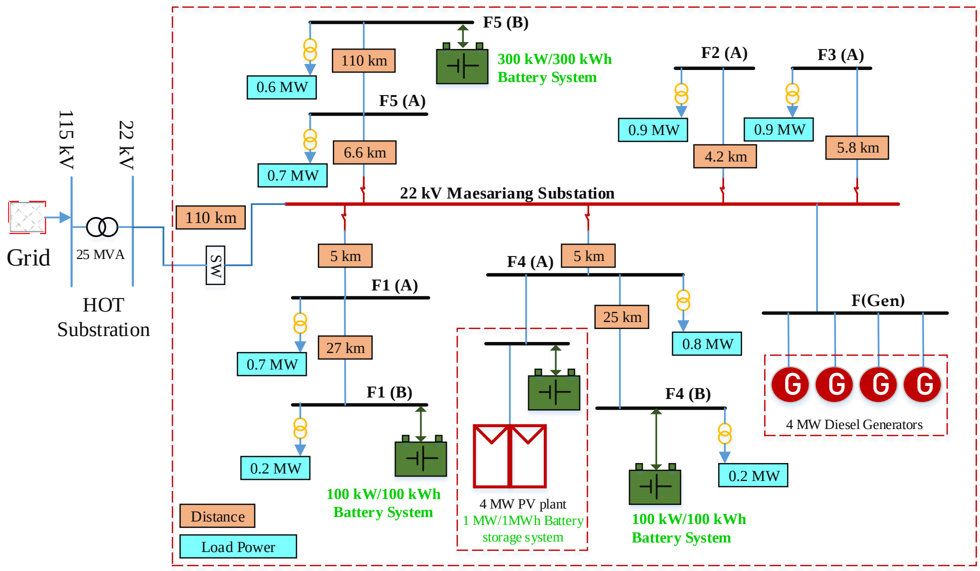

Fig. 5. The Maesariang system with the decentralized battery storage system for Case Study 3.

Case Study 2: The dynamic load flow simulation of the voltage profile depends on the load profile, PV power output profile, and operating with diesel generators. This Case Study is the MMGs working with a centralized energy storage system, as shown in Fig. 4.

Case Study 3: The dynamic load flow simulation of the voltage profile depends on the load profile, PV power output profile, and operating with diesel generators. This Case Study is the MMGs working with the decentralized battery storage system, as shown in Fig. 5.

For Case Study 3, the battery storage systems are small capacity than the centralized battery system in Case Study 2, and it is assumed to install in the Maesariang feeder near the load demand spreading in the distribution system, as presented in Table 2.

Table 2. The mounting location and capacity of the decentralized storage systems

Case Study 2. Centralized Energy Storage Systems		
Location (Busbars)	Power (PCS)	Capacity (kWh)
Maesariang Substation	2 MW	3000
Case Study 3. Decentralized Energy Storage Systems		
Location (Busbars)	Power (PCS,kW)	Capacity (kWh)
F4(B)	100	100
F4(A)	1000	1000
F1(B)	100	100
F5(B)	300	300

6. THE RESULTS

The results of this research can be classified following the case studies as described above. After that, technical parameters were compared between Case Study 2 and Case Study 3.

6.1 The simulated result of Case Study 1

This study is the simulation of the original Maesariang distribution system without a battery storage system as the same as the present situation. The daily profiles of the load, PV power, and generators are shown in Fig.4. The 4 MW PV power plant, generated and injected electricity into the grid during the grid has a light load. This time people in this area are going out to work. The peak load in Maesariang district is about 5 MW, and it occurs from 8.00 AM - 9.00 PM. During this time, the diesel generators are operated for supporting the load demand and maintaining the power quality in Maesariang distribution. The daily profile of load, PV power plant, and the diesel generators are presented in Fig. 6.

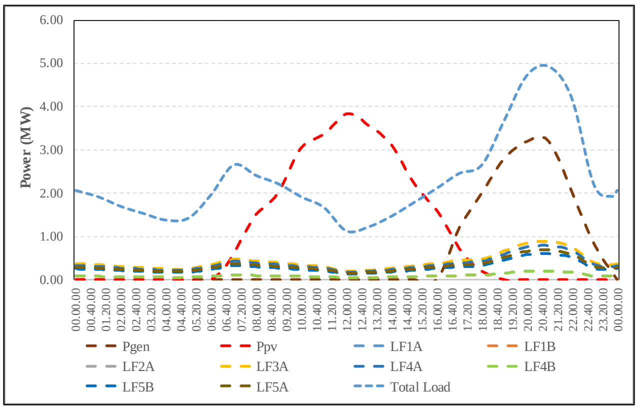

Fig. 6. The profile of the load, PV power production, and diesel generators

According to the load profile, PV and generator power production showed that the grid voltage was fluctuation. Sometimes, it may fluctuate out of the acceptable range of PEA because of the unbalance between supply and demand. The grid voltage profiles at the study busbars in the Maesariang distribution system is shown in Fig. 7.

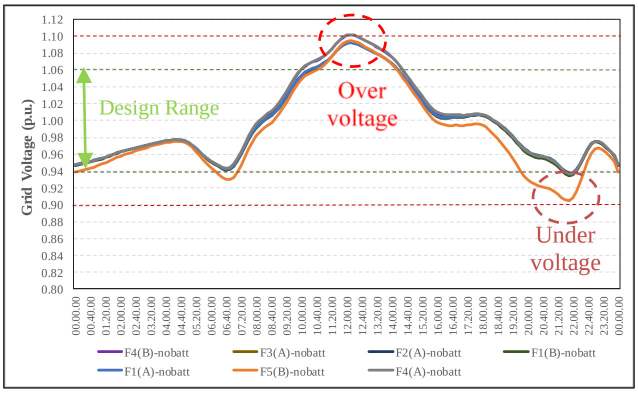

Fig. 7. Grid voltage profiles in Maesariang network in the Case Study of no battery storage system.

The grid voltage profiles at the study busbars were unstable, depending on the unbalancing of the load demand and power supply (4 MW PV Power plant). Considering at the daytime when high power production from 4 MW PV power plant injected to the grid, affected the grid voltage was rising over the limitation of PEA, this case may power outage because distribution switch (SW.) may disconnect. The grid voltage at the point of common coupling (PCC) at the PV power plant (busbar F4(A)), the voltage was about 1.103 p.u., which over 1.10 p.u. (this value is a limitation of Thailand) On the other hand, during the evening time from 6.30 PM to 10.30 PM, high load demand, then the diesel generators have to operate for supporting the load and maintaining the grid power quality. During the evening time, the under-voltage often causes power outages, which are due to the safety switches operating.

6.2 The simulated result of the Case Study 2

As mention in Case Study 1, the grid voltage is unstable because of unbalancing demand and supply. Therefore, the battery storage system will be installed for balancing supply and demand. It results in maintaining the power quality in the grid network. This Case Study performed the simulation of a 2 MW/3 MWh of a centralized battery storage system that is installed at the Maesariang substation. The simulation results were presented in Fig. 8.

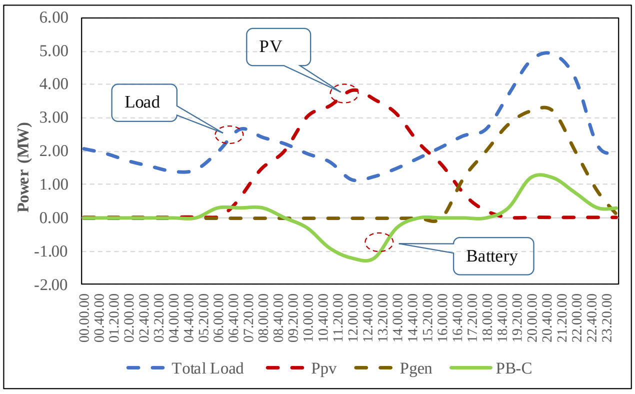

Fig. 8. The relationship of PB-C, Pgen, Ppv and Total load

This Case Study presented a dynamic load flow simulation for the Maesariang distribution system operated with a central battery storage system at the substation. The grid voltage at all busbars is better than Case Study 1, which is operated without a battery storage system. During the day time, active power has injected into the grid from the PV system, which affected to voltage rise. Still, this case has a battery storage system, which can increase the load demand by charging power from the grid to battery. As shown in Fig. 8, a centralized battery storage system has charged the electric power to the battery at the same time as the PV power plant generates electrical energy. So, the excess energy is charged into the battery storage system. On the other hand, during peak load demand between 07.00 PM - 10.00 PM, the electric power has discharged from the battery into the grid for supporting the peak demand and also maintaining the power quality, as shown in Fig. 9.

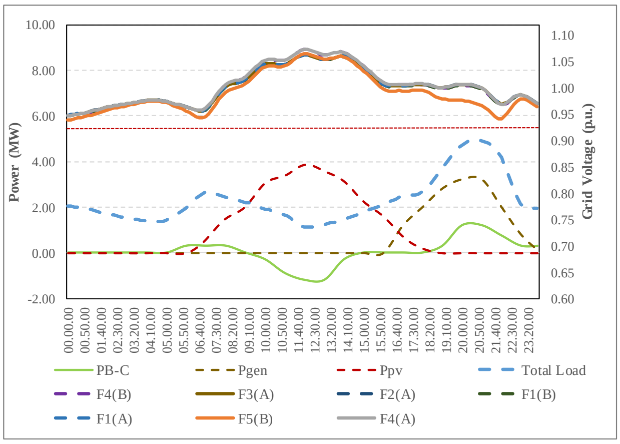

Fig. 9. The voltage profiles in case of a central battery storage system

The grid voltage profiles, in this case, fluctuated between 0.94 p.u. to 1.07 p.u, which is in the acceptable range of Thailand grid code 2016. During the daytime, when high power production from the PV system, the grid voltage at F4(A)-nobatt decreased from 1.102 p.u. to 1.08 p.u., which is in the acceptable range. On the other hand, during the evening time, the grid voltage was increased from 0.90 p.u. to 0.94 p.u. by discharging electrical power from the battery to the grid for supporting the peak load demand. The central battery storage system at the Maesariang substation can maintain the power quality into the acceptable range of Thailand grid code.

6.3 The result of the Case Study 3

According to the power quality problems indicate in Case Study 1 and the limitation in Case Study 2, so, this Case Study is performed the dynamic load flow simulation of the distributed battery storage systems which spread around the Maesariang distribution system. The mounting location of the decentralized battery storage is located at the feeders; F1(B), F4(B), F4(A), and F5(B), all of them working as the same algorithm. The dynamic load flow simulation of Case Study 3, which consists of the relationship between load, PV, generators, and battery power profiles, as shown in Fig. 10.

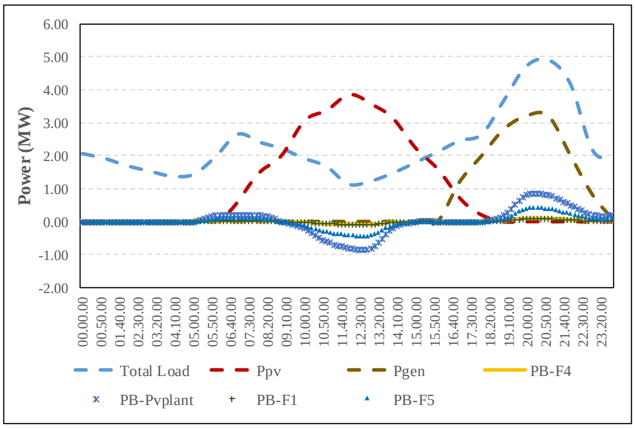

Fig. 10. The relationship between Total load, P_{pv}, P_{gen} and battery power

Fig. 10. presented the dynamic load flow simulation in case of implementing the distributed battery storage systems spreading in the Maesariang network for maintaining the grid voltage. All the battery storage systems are working as the same algorithm, during the daytime charging electricity from the grid into the battery storage system because the PV system generated electricity higher than the load demand. In the evening time, electricity was discharged from the battery storage system into the grid for maintaining the grid voltage in the desired range, as shown in Fig. 11.

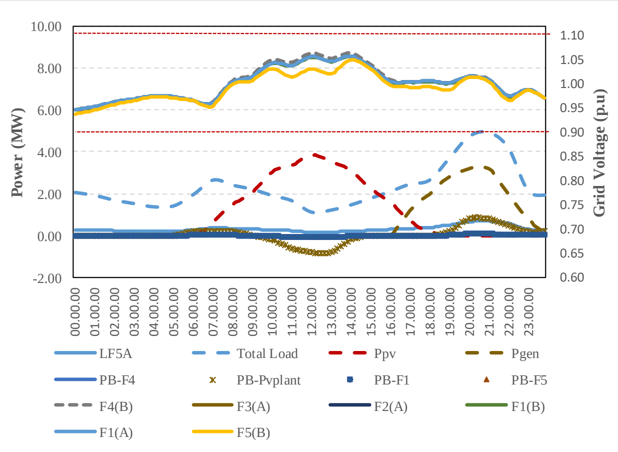

Fig. 11. The voltage profiles in the case of the decentralized battery storage system.

The grid voltage profiles fluctuated between 0.94 p.u. to 1.06 p.u, which was in the desired range. During the daytime, when high power production from the PV system, the grid voltage at F4(A)-nobatt decreased from 1.102 p.u. to 1.05 p.u., which is in the desired range. On the other hand, during the evening time, the grid voltage was increased from 0.90 p.u. to 0.94 p.u. by discharging electrical power from the battery storage system to the grid for supporting the load demand. The decentralized battery storage system can maintain the grid voltage into the desired range.

6.4 The technical comparison between Case Study 2 and Case Study 3

Case studies 2 and 3 are the simulations of the Maesariang distribution system with a battery storage system, which is classified into two systems, centralized and decentralized battery storage systems, as already mentioned above. The result of the simulation found that Case Study 3 (decentralized system) was able to maintain the grid voltage into the desired range. The grid voltage levels in the Maesariang distribution system of Case Study 2 and Case Study 3 were at the level of 0.94 p.u. - 1.08 p.u. and 0.94 – 1.06 p.u., respectively. The grid voltage at F1(A), F2(A), F3(A), F4(A), F5(B) can be shown in Fig. 12.

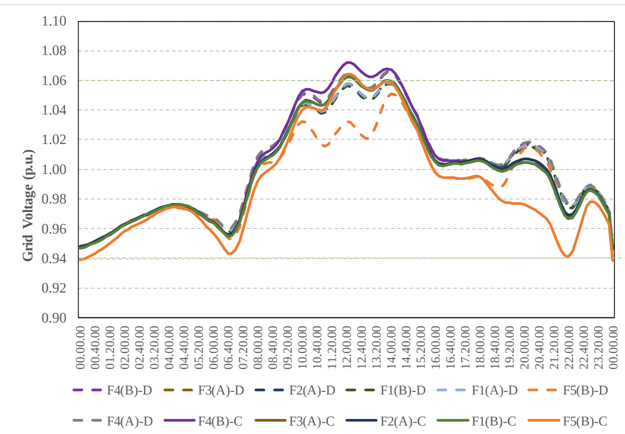

Fig. 12. The grid voltage comparison between the centralized and decentralized battery storage system.

Considering the grid voltage at F5(B), this is the Case Study of a decentralized system. Found that the grid voltage is stable than a centralized system because the battery storage system was located near the load demand. Therefore, the decentralized battery storage system can supply electricity to the load with low loss in the distribution system. During the daytime, when high PV power production, the grid voltage at the F5(B) was decreased to 1.03 p.u.. But on the other hand, in the case of the decentralized battery storage system, the active power was not injected into the grid, but the excess energy was charged to the battery system. So, from this process, the battery storage system can maintain the grid voltage into the desired range by balancing supply and demand. During the evening time when peak load occurred, the decentralized system can maintain the grid voltage better than a centralized system because the decentralized system can supply electricity to load demand directly, Still, a centralized system has to supply electricity from the substation through the 22 kV distribution line, then to supply the load. Considering the F5(B)-C, the grid voltage increased from 0.94 p.u. to 0.96 p.u. in the case of the decentralized system. Finally, the technical results of the simulation showed that the decentralized could maintain the grid voltage better than a centralized system, as shown in Fig. 13.

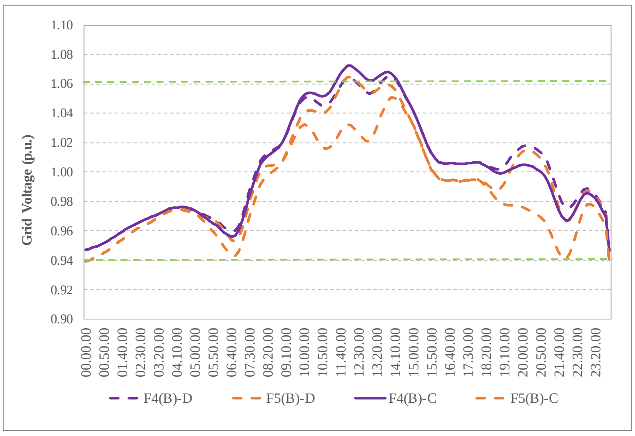

Fig. 13. The grid voltage comparison at F5(B)-C and F4(A)-C between the centralized and decentralized system

7. CONCLUSION

Maesariang District, Maehongson province, Thailand, the electricity network in this area has many problems. Due to the long distribution line is causing high-energy loss (19% or 6.7 GWh/year), that sometimes create power outages and grid voltage fluctuations which is caused by unstable RE power production, approximately 20 times per year. So, this research aims to use the battery storage system as the energy buffer for maintaining the grid voltage in the distribution system. The results of the study indicated that the battery storage system could stabilize the grid voltage into the acceptable range by balancing supply and demand power. The decentralized battery storage systems can maintain the grid voltage better than a centralized storage system because the decentralized storage system can supply electricity to load with low loss in the distribution feeder. Although the decentralized storage system is better than a centralized system for maintaining power quality, it may difficult for controlling and operating. Future research should focus on the techniques for control, operating, and maintaining the decentralized battery storage systems.

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NOMENCLATURE

Symbol	Meaning	Unit
Ppv	PV power Production	MW
Pgen	Generator power production	MW
PB-F4	Power of battery storage system at F4	MW
PB-F1	Power of battery storage system at F1	MW
PB-F5	Power of battery storage system at F5	MW
PB-PVplant	Power of battery storage system at busbar PV power plant	MW
Total Load	A total load of the distribution system	MW
F1(A)	Grid voltage at the feeder 1 busbar A	p.u.
F1(B)	Grid voltage at the feeder 1 busbar B	p.u.
F5(B)-nobatt	Grid voltage at feeder 5 busbar B case No battery storage system	p.u.
F4(A)-nobatt	Grid voltage at feeder 4 busbar A Case Study No battery storage system	MW
PB-C	Power of battery storage in case of the centralized battery system	MW
F4(A)-D	Grid voltage at feeder 4 busbar A Case Study decentralized battery storage system	p.u.
F4(A)-C	Grid voltage at feeder 4 busbar A Case Study centralized battery storage system	p.u.

REFERENCES

[1] Ronayut. 2016. Small power plants and renewable energy policy under fluctuation of energy price and economic growth in Thailand. *International Conference on Cogeneration, Small Power Plants and District Energy (ICUE)*, 14-16 September.

[2] D. Cheng, B.A. Mather, R. Seguin, J. Hambrick and R.P. Broadwater. 2016. Photovoltaic (PV) Impact Assessment for Very High Penetration Levels, *IEEE Journal of Photovoltaics* vol 6: 295-300.

[3] Tariq and Nipon. 2017. Enhancing PV Penetration in LV Networks Using Reactive Power Control and On Load Tap Changer With Existing Transformers. *IEEE Access* vol 6: 2683-2691.

[4] Shutang Y., Gefei K., Yong L., Xuemeng Z., Yi C., Micah J.T., Wenxuan Y., and Yilu L. 2017. Impact of High PV Penetration on the Inter-Area Oscillations in the U.S. Eastern Interconnection, *IEEE Access* vol 5: 4361-4369.

[5] H. Pezeshki. 2013. Impact of High PV Penetration on Distribution Transformer Insulation Life, *IEEE Transactions on Power Delivery*, vol 29:1212-1220.

[6] H. Shayeghi., E. Shahryari., M. Moradzadeh., and P. Siano. 2019. A Survey on Microgrid Energy Management Considering Flexible Energy Sources. *Energy*, Vol 12: 2156.

[7] S.Hashemil and J. Stergaard. 2016. Methods and strategies for overvoltage prevention in low voltage distribution systems with PV. *IET Renewable Power Generation* Vol. 11: 205-214.

[8] S. Pukhrem, M. Basu, M. F. Conlon, and K. Sunderland. 2017. Enhanced Network Voltage Management Techniques Under the Proliferation of Rooftop Solar PV Installation in Low-Voltage Distribution Network. *IEEE Journal of Emerging and Selected Topics in Power Electronics* vol. 5, No. 2: 681-694.

[9] B. Zhao, X. Wang, D. Lin, M.M. Calvin, J.C. Morgan, R. Qin and C. Wang. 2018. Energy Management of Multiple Microgrids Based on a System of Systems Architecture, *IEEE Transactions on Power Systems*, vol 33: 6410-6421.

[10] E. Harmon, U. Ozgur, M.H. Cintuglu, R. de Azevedo, K. Akkaya and O.A. Mohammed. 2017. The Internet of Microgrids: A Cloud-Based Framework for Wide Area Networked Microgrids. *IEEE Transactions on Industrial Informatics* vol 14: 1262-1274.

[11] Tushar and Mahmud. 2018. Dynamic Stability Analysis of Hybrid Islanded DC Microgrids Using a Nonlinear Backstepping Approach. *IEEE Systems Journal* vol 12: 3120-3130.

[12] L. Che, M. Shahidehpour, A. Alabdulwahab and Y. Al-Turki. 2015. Hierarchical Coordination of a Community Microgrid With AC and DC Microgrids. *IEEE Transactions on Smart Grid* vol 6: pp. 3042-3051.

[13] N. Namdi and X. Xia. 2017. Optimal dispatch for a microgrid incorporating renewables and demand response. *Renewable Energy* Vol. 101: pp 16 – 28.

[14] A. Hirsch, Y. Parag and J. Guerrero. 2018. Microgrids: A review of technologies, key drivers, and outstanding issues. *Renewable and Sustainable Energy Reviews* vol. 90: pp 402-411.

[15] Z. Li, M. Shahidehpour, F. Aminifar, A. Alabdulwahab and Y. Al-Turki. 2017. Networked Microgrids for Enhancing the Power System Resilience. *IEEE Journals & Magazines* vol. 105: pp 1289-1310.

[16] A.R. Millner, C.L. Smith, R. Jaddivada and M.D. Ilić. 2019. Component Standards for Stable

Microgrids. *IEEE Transactions on Power Systems* vol. 34: pp 852-863.

[17] M. Pulcherio, M.S. Illindala, J. Choi and R.K. Yedavalli. 2018. Robust Microgrid Clustering in a Distribution System With Inverter-Based DERs. *IEEE Transactions on Industry Applications* vol. 54: pp 5152-5162.

[18] T. Zhao and Z. Ding. 2018. Cooperative Optimal Control of Battery Energy Storage System Under Wind Uncertainties in a Microgrid. *IEEE Transactions on Power Systems* vol. 33: pp 2292-2300.

[19] A. Hussain, H.M. Kim and V.H. Bui. 2019. Microgrids as a resilience resource and strategies used by microgrids for enhancing resilience. *Applied Energy* vol. 240: pp 56-57.

[20] P. Wei and W. Chen. 2019. Microgrid in China: A review in the perspective of application. *Energy Procedia* vol. 158: pp 6601-6606.

[21] R. Sriwatcharin. 2014. *A study of overcurrent protection for mae sariang micro-grid system. faculty of graduate studies*, Mahidol University.

[22] J. Kantiyawong and S. Premrudeepreechacharn. 2017. Power losses reduction analysis in Mae sariang microgrid system. *14th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON)*. 27-30 Jun 2017. Phuket Thailand.

[23] W. Srithiam, S. Asadamonkol and T. Sumranwanich. 2015. Smart Grid National Pilot Project in Mae Hong Son Province, Thailand. *Energy & Environment* vol. 26: pp, Issue 1-2.

[24] K. Mansiri, S. Sukchai and C. Sirisamphanwong. 2018. Fuzzy Control Algorithm for Battery Storage and Demand Side Power Management for Economic Operation of the Smart Grid System at Naresuan University, Thailand. *IEEE Access* vol. 6: pp 32440-32449.

[25] K. mansiri et al, “Fuzzy Control for Smart PV-Battery System Management to Stabilize Grid Voltage of 22 kV Distribution System in Thailand,” Energies, vol. 11, pp 1730, 2018.

[26] A. Samadi, L. Söder, E. Shayesteh and R. Eriksson. 2015. Static Equivalent of Distribution Grids With High Penetration of PV Systems. *IEEE Transactions on Smart Grid* vol. 6: pp 1763-1774.

[27] R. Torquato, D. Salles, C.O. Pereira, P. Cesar, M. Meira and W. Freitas. 2018. A Comprehensive Assessment of PV Hosting Capacity on Low-Voltage Distribution Systems. *IEEE Transactions on Power Delivery* vol. 33: pp 1002-1012.

[28] M. Mosadeghy. 2016. Impact of PV penetration level on the capacity value of South Australian wind farms. *Renew. Energy* vol. 85: pp. 1135-1142.

[29] S. Hashemi and J. Stergaard. 2016. Methods and strategies for overvoltage prevention in low voltage distribution systems with PV. *IET Renewable. Power Generation* vol. 11: pp 205–214.