

Energy Storage System Application in MEA Building

A. Phayomhom¹, K. Methapatara², T. Limlek³

¹Department of Power System Planning, Metropolitan Electricity Authority (MEA), Bangkok, Thailand
¹attp@mea.or.th, ²kanokpol.me@mea.or.th, ³thanaphat.li@mea.or.th

Abstract – Thailand Power Development Plan (PDP) 2015; a long-term power procurement plan that its demand forecasting is adjusted to correspond to directions of economic growth, the Energy Efficiency plan, and the Alternative Energy Development plan. PDP 2015's subject matters is to increase generation from renewable energy. Additionally, MEA is well aware that greenhouse gas emission is caused by uses of electricity. Therefore, MEA initiates technology experiment project, which is called Smart Metro Grid. Smart Metro Grid is viewed as electric power distribution system with integration of both electrical system infrastructure and ICT leads to higher reliability and stability, and accommodating renewable energy source, as well as enhancing quality service for greatest public benefits and sustainable development. In addition, the initiation of energy management pilot project is addressed. The pilot project will apply Smart Grid technology using Solar PV, Energy Storage System by Energy Management System to control electric power in the system.

Keywords - Energy Management System, Energy Storage System, Microgrid, Solar

I. INTRODUCTION

Metropolitan Electricity Authority (MEA) is an electric utility that is responsible for power distribution covering an area of 3,192 square kilometers in Bangkok, Nonthaburi, and Samutprakarn provinces of Thailand as shown in Fig. 1.

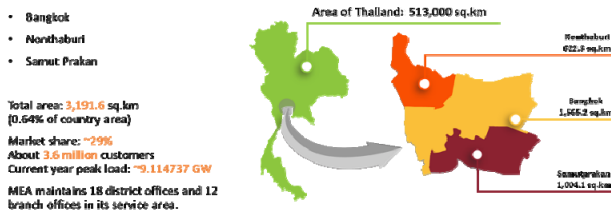


Fig. 1. MEA power's distribution service area

Undoubtedly, today electricity is modern society's most convenient and useful form of energy. The increasing per capita consumption of electricity throughout various countries in the world reflects the national growing standard of living of people. However, the optimal utilization of electricity by society can be ensured by an effective distribution system. The smart grid is a kind of modern electric power grid infrastructure for improving efficiency, reliability and safety of the conventional power system, with smooth integration of renewable and alternative energy sources, through

automated control and modern communications technologies. Today renewable energy sources seem to be a promising technology to reduce fossil fuel consumption and greenhouse gas emissions. Most importantly, it enables new network management strategies by providing the effective grid integrations of renewable energy sources for Demand Side Management and energy storage for load balancing, etc.

II. SMART DISTRICT PHASE I OVERVIEW

To strengthen and stabilize power system in the country which will lead to benefits and economic advantages in the future; therefore, one of the Thailand Power Development Plan (PDP) 2015's subject matters is to reduce natural gas dependency from 65% currently to be not over than 40% in 2036. To accomplish accordingly, proportion of electrical generation from renewable energy and power purchase from neighbour countries will be increased while reserved electrical generation in the country will not lower than 15% of the its highest demand.

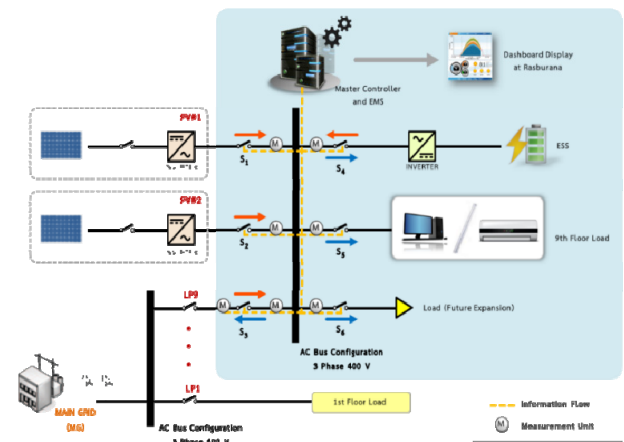


Fig. 2. Smart district office building system overview.

As the agency in charge for electrical distribution of the country, MEA is well aware that greenhouse gas emission is caused by uses of electricity and resulted in global warming. Therefore, MEA initiates technology experimental project according to the third pillar: Excellent Energy. The renewable energy (solar energy) would be integrated to MEA's main grid whereby Energy Storage System (ESS) would help to reduce impact from unstableness of the renewable energy productivity in order to efficiently control quality of electric power that supplied to equipment in the building. The project is

called “Smart District Phase I”, which has been installed and currently in use since 2017. The overall structure of the Smart District Phase I at MEA Rat Burana district is shown in Figure 2. The PV supply electric power to the electrical loads including charging the ESS. In case electric power from the PV is oversupply, it would be distributed to the grid. However, if electric power from the PV is undersupply, the Master Controller + Energy Management system would intelligently draw electric power from the grid to supply electric power to the electrical loads. Additionally, in case the grid experiences some problems; the systems will continually supply electric power by retrieving it from the PV and the ESS. To study and develop efficient electrical generation and distribution model in the building as well as electric power stability and quality from renewable energy, the electrical loads on the 9th floor is separated from MEA Rat Burana district building’s load centre as shown in Fig. 2. Moreover, its dashboard display is presented on the 1st floor to provide knowledge regarding renewable energy to people and promote MEA’s organizational image as well.

A. Objectives

- To promote the national energy policy that motivates the extensive use of renewable energy.
- To realize a demonstration site of MEA that mainly depends on renewable energy.
- To serve as a smart grid model of MEA distribution system the efficient way of a building that used solar energy as primary power source.
- To serve as a CO₂ reduction building model and raise people awareness.
- To study the islanding capability of this model.

TABLE I
EQUIPMENT RATING OF SMART DISTRICT PHASE I

Device	Specification
Energy Storage System (ESS)	Type : LiFePO ₄ Voltage : 512 V Capacity : 60 Ah Energy : 30.72 kWh Maximum charging current : 180 A Maximum discharging current : 260 A
Power Conditioning System (PCS)	Rated power : 125 kW Line voltage : 380 V DC voltage : 512 V Transition time : ≤ 20 ms
Photovoltaic (PV) array 1	Rated power : 62.2 kWp
Photovoltaic (PV) array 2 (Will be moved to be installed in Smart District Phase II)	Rated power : 50.0 kWp

III. THE WORKING PRINCIPLE AND THE EMS ALGORITHM OF SMART DISTRICT PHASE I

Smart District Phase I has 2 modes of operation.

1. Grid-connected

2. Islanded - Normally, Smart District Phase I always operate on grid-connected mode, Islanded mode will be activated in case the grid failed. To operate on islanded mode, the battery inverter software must be modified to archive an islanding capability in order to maintain the voltage and frequency of Smart District Phase I when disconnected from the grid and grid-connected/islanded transition time must be less than 20 milliseconds.

This section will discuss about an algorithm for the energy management system [1]. The principle of the energy management is to maximize the efficiency of the renewable energy used by the Smart District Phase I and minimize the energy used from the grid. In this case, the total energy used from the grid is near zero.

A. Grid-Connected Mode:

- During off-peak period, the ESS is charged by the grid. Increase power consumption during off-peak. (Put energy into the ESS) and supply electric power to the grid during on-peak or reduce peak power consumption allows the higher load factor.

- During on-peak period, the system will draw electric power from the PV, if electric power from the PV cannot meet the demand, the ESS will helps the PV supply electric power to the electrical loads. If electric power from the PV exceed the demand, ESS will be charged by the excess electric power, but if the ESS is fully charged, the system will feed the excess electric power to the grid. In case electric power from the PV and the ESS cannot meet the demand. The system will draw electric power from the grid. By the way, the ESS only discharge to support the electrical loads, not for feeding to the grid.

B. Islanded Mode:

Most of functions on islanded mode are as same as grid-connected mode except the system cannot draw electric power from/feed electric power to the grid. So, if electric power from the PV and the ESS cannot meet the demand, the EMS must disconnect the electrical loads to protect itself from overloading. However, if the demand is less than electric power generated by the PV, and the ESS cannot be charged anymore, the EMS must disconnect the PV and let the ESS supply electric power to the electrical loads

Considering Fig. 3. The 1st and 2nd path work on off-peak and the 3rd to 6th path work on on-peak.

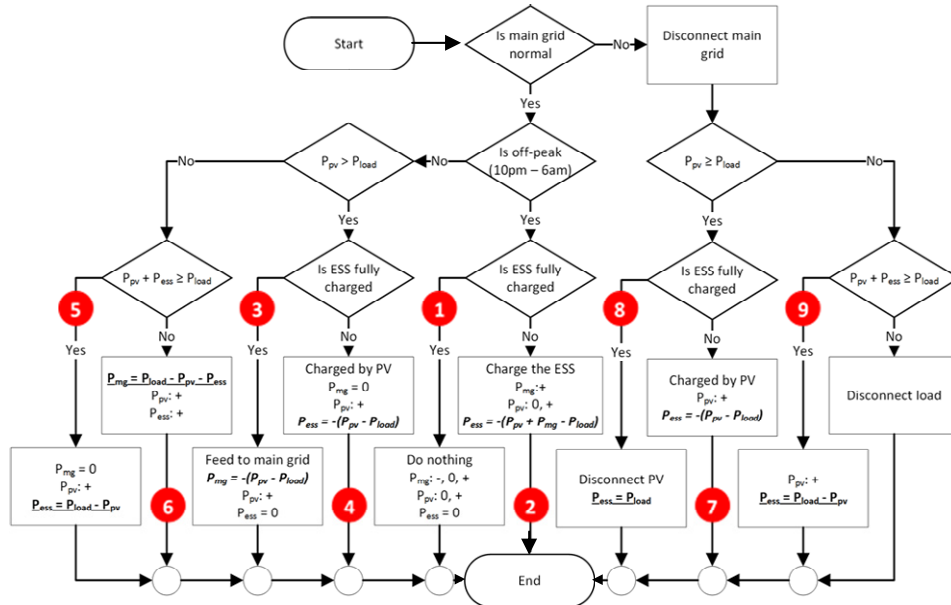


Fig. 3. The EMS flowchart. The “underlined bolded” equation means electric power flow from the ESS or the grid to bus. The “underlined italic” equation means electric power flow from bus to the ESS or the grid

IV. DEMONSTRATION RESULTS

The tests demonstrated that the system can function properly. Considering Fig. 4, this chart can be divided into 5 sections. Each section can be described as follows:

1. $P_{pv} + P_{ess} < P_{load}$, Smart District Phase I must draw electric power from the grid.
2. $P_{pv} < P_{load}$ but $P_{pv} + P_{ess} \geq P_{load}$, Smart District Phase I only draw electric power from the PV and the ESS.
3. $P_{pv} > P_{load}$, the EMS command the ESS to be charged by the PV.
4. $P_{pv} > P_{load}$ and the ESS is fully charged, so any excess electricity is fed back into the grid.
5. During off peak, the EMS command the ESS to be charged by the grid or do nothing if the ESS is fully charged.

When the grid failed, the inverter will switch from grid-connected mode to islanded mode immediately. Transition time is less than 20 milliseconds as shown in Fig. 5.

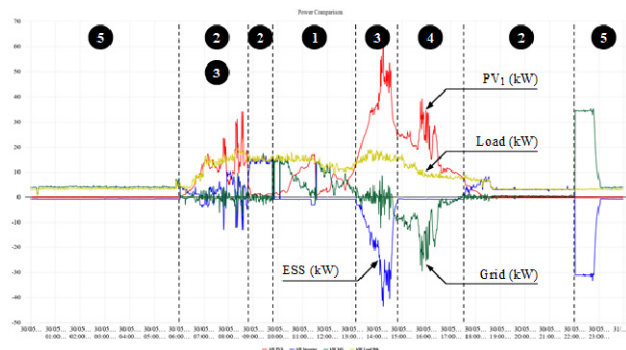


Fig. 4. Relation between electric power of the electrical loads, the ESS, the grid and the PV.

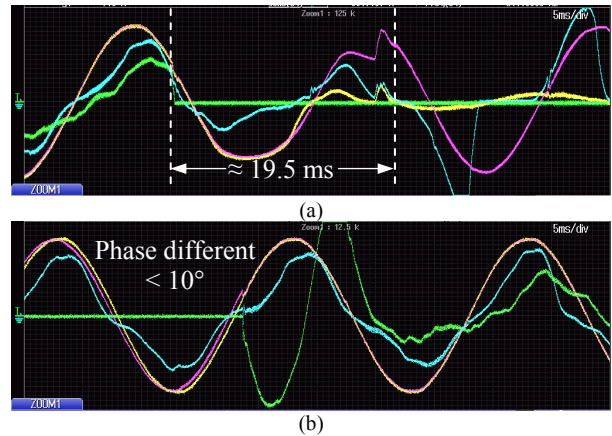


Fig. 5. Voltage and current of the grid and the electrical loads while the PCS is switching the operation mode. The yellow, green, magenta, and cyan line represent the grid voltage, grid current, load voltage (or the PCS output voltage), and load current, respectively.

- (a) The switching time from grid-connected mode to islanded mode.
- (b) The different phase angle between grid voltage and voltage from the PCS before switching from islanded mode to grid-connected mode.

Also, the above system result can be remotely accessed via Virtual Private Network/Secure Sockets Layer (VPN/SSL) connection for system monitoring and maintenance.

V. LESSONS LEARNED

- Standard inverter software has anti-islanding features built in. As a result, software modification was required for islanding operation.
- Quickly discharges the battery cause the battery terminal voltage lower than it should be. So, when the battery stops discharging (the battery terminal voltage hits

the End of Discharge point (EOD)), the voltage will jump up for a little, making the battery starts discharging again.

VI. NEXT STEPS

The next steps are to create a new system (known as Smart District Phase II) which can supply electric power for the whole building, add new energy management and power management function, reconfigure electric system in the building by integrating Smart District Phase I with Smart District Phase II.

A. Equipment Rating of Smart District Phase II

Equipment rating of Smart District Phase II is shown as Table II.

B. Overall System Circuit Diagram and Communication Diagram

Smart District Phase II circuit diagram is shown on left side in Fig. 6. (A). Smart District Phase I and Smart District Phase II use same electrical network topology but different device scale and rating.

TABLE II
EQUIPMENT RATING OF SMART DISTRICT PHASE II

Device	Specification
Energy Storage System (ESS)	Type : Li-ion
	Voltage : 400 - 1000 V
	Energy : 500 kWh
Power Conditioning System (PCS)	Rated power : 250 kW
	Line voltage : 380 V
	DC voltage : 400 - 1000 V
	Transition time : ≤ 20 ms
Photovoltaic (PV) array 2	Rated power : 50.0 kWp

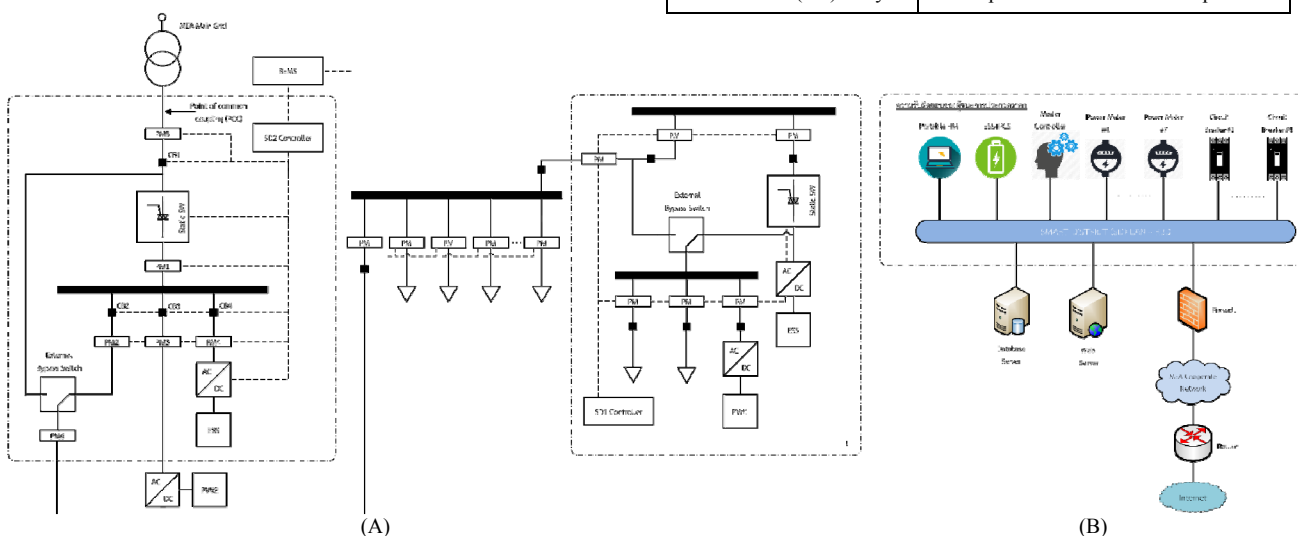


Fig. 6. Smart District Phase II conceptual design. (A) Circuit diagram. (B) Communication diagram.

Smart District Phase II electrical measured and devices status data will be sent to database server which is locate at MEA engineering cloud (internal access) through MEA LAN. Application server is separated from database server and locate at MEA cloud which can be accessed from internet through firewall as shown in Fig. 6. (B).

C. Enhanced Functionality of Smart District Phase II

Smart District Phase II has been designed to work with Smart District Phase I on Multilevel Microgrid topology follows IEC TS 62898-1:2017 standard as Smart District Phase I is subsystem of Smart District Phase II (Fig. 6. (A)).

Smart District Phase II algorithms have been enhanced to support more applications as follows:

C. 1. Main grid power minimizing.

Minimize electric power feed into/consume from main grid, not just consumption minimizing (reduce electrical energy from grid).

This function will keep both electric power feed into main grid and consume from grid to nearest zero. This make the grid more stable due to the smoothing electric power flow. Second benefit is to reduce electricity bill charge. This function will force the PCS to charge the battery on setting period which normally off-peak period due to low tariff.

C. 2. Peak load shaving.

Cut peak demand which exceed criteria and increase demand when it below the criteria.

Electric power consumed from main grid will be regulated within setting range. If electric power demand exceeds the upper bound, then the battery will be discharged to supply the demand for the exceeding. If the demand lower than the lower bound, then the battery will be charged to make the total demand equal to the lower bound.

C. 3. Load leveling (Curve matching).

Match electric power demand to setting curve.

Electric power demand will be controlled to match the setting curve which is input by user. For main grid point of view, electric power feed to Smart District Phase II will be looked as electric power demand no matter where is that power go to (to charge the battery or to supply loads), so the battery must be charged when the demand is lower than the setting curve and discharged when the demand is higher than the setting curve.

C. 4. Power smoothing.

Smooth the electric power feed to main grid (at PCC) by using smoothing algorithm such as Moving Average.

Electric power generated from solar PV is unreliable and can impact grid stability [2] and connected synchronous generator stability (It is possible that diesel generator will be installed in Smart District to increase backup time while main grid failed.) due to high fluctuation power flow. So, system stability has been studied as follows and the result will be used for determining acceptable electric power ramp rate.

Equation (1) shows relation between angular displacement of rotor of machine from synchronously rotating reference axis ($\delta(t)$) in term of angular acceleration and balancing of mechanical and electrical power of the machine. H is constant ω_s (synchronous speed) and $\delta(t)$ must have same kind of angular unit such as mechanical radians or electrical degrees. If input power (as generator is P_m) equal output power (P_e : electric power), then the displacement is constant, and the machine is operated at steady state.

$$\frac{2H}{\omega_s} \frac{d^2\delta(t)}{dt^2} = P_m - P_e \text{ per unit} \quad (1)$$

Now we know that unequal P_m and P_e leads to changing of $\delta(t)$ and make the machine unstable. Next, we need to determine how P_e is changing.

Equation (2) shown how to determine P_e and factors that can cause P_e changing.

$$P_e = P_{max} \sin \delta \text{ per unit}; P_{max} = V_1 V_2 / X_{12} \quad (2)$$

Considering Fig. 7. Loads is modeled in Thévenin equivalent form. If loads are composed of generations and ordinary loads, changing of consumption and/or generated power cause changing of Z_{th} and V_{th} which leads to changing of power-angle curve expressed by (2).

Consider Fig. 8. The generator currently generate power at 0.6 per unit. PV power fluctuation cause changing on power-angle curve at any time t_x . These situations are happened repeatedly. Sometimes, the generator cannot handle the transient and lose synchronism at time after t_6 .

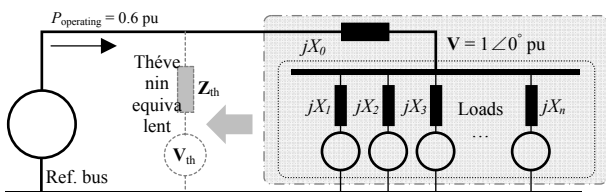


Fig. 7. Circuit diagram for simple stability analysis.

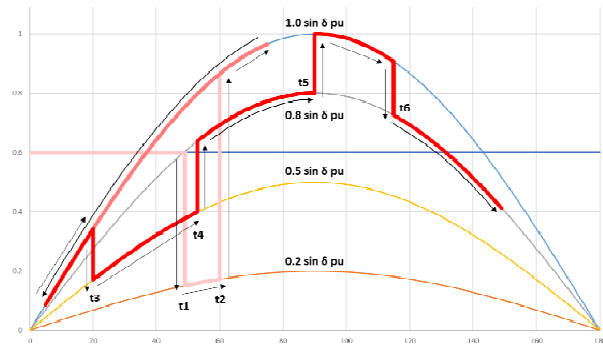


Fig. 8. Power-angle curves for stability analysis example.

By applying smoothing algorithm at PCC, electric power feeding to main grid will be predicted with more accuracy over a large timeframe and increase grid stability.

C. 5. Grid backup.

Backing up power in the building while main grid has been being loses electric power. While Smart District Phase II switch to/switch from this mode, electric power in the building should not be loose longer than 20 milliseconds as in Smart District Phase I.

C. 6. Voltage regulation [3].

Provide voltage regulation service by using Fixed Power Factor, Q(U), pf(P), and P(U) function.

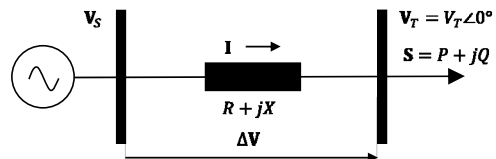


Fig. 9. Model for voltage regulation analysis.

$$\begin{aligned} V_s &= \Delta V + V_T = I(R + jX) + V_T = \left(\frac{S}{V_T}\right)^* (R + jX) + V_T \\ V_s &= \frac{(P - jQ)(R + jX)}{V_T^*} + V_T = V_T + \frac{(PR + QX)}{V_T} + j \frac{(PX - QR)}{V_T} \end{aligned} \quad (3)$$

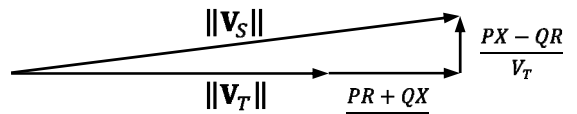


Fig. 10. Phasor diagram to visualize the result from (3).

Distribution system has been modeled as shown in Fig. 9. Equation (3) and Fig. 10. show that changing of $PR + QX$ term cause $\|\Delta V\|$ significantly changed. Since X/R for distribution system (Medium voltage) is high, PR term can be neglected, and the result can be estimated to QX/V_T .

Q(U) (Volt-var function): Voltage controlling by using reactive power. This function monitor system voltage and calculate reactive power to be injected to/take from the system to control the voltage, control characteristic is shown in Fig. 11. (right).

pf(P) (Watt-power factor function): Voltage controlling by using power factor. This function monitors injected active

power and calculate power factor to be changed to control the voltage, control characteristic is shown in Fig. 11. (left).

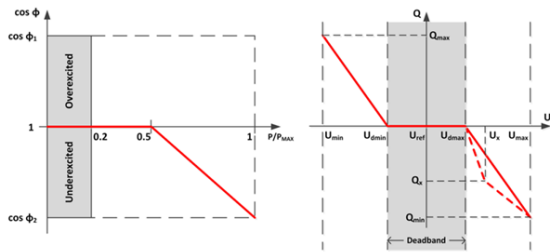


Fig. 11. pf(P) (left) and Q(U) (right) control characteristic.

P(U) (Voltage-watt function): Voltage controlling by using active power. This function monitor system voltage and calculate active power to be injected to/take from the system to control the voltage. (Active power controlled has better performance for LV than MV system due to the lower X/R.)

C. 7. On demand charging/discharging.

Control electric power from the battery by sending command to the controller via RESTful API.

Smart District Phase II can be basically controlled via RESTful API such as charge the battery, discharging start time with duration and discharging power. This function enables Smart District Phase II to communicate with other system such as BEMS and DR.

For example, BEMS received DR command to reduce load for 100 kW. Unfortunately, electrical loads can only be reduced power consumption by 10 kW. Then the remaining of 90 kW shall be commanded from BEMS to be supplied from the battery installed at Smart District Phase II.

E. Difference between Main Grid Power Minimizing and Power Smoothing

Main Grid Power Minimizing focus on reduce energy consumed from grid and reduce electricity bill charge, to operate this function, large battery is required because electrical energy must be stored during one period to be discharged during another period.

Power Smoothing focus on smooth electric power, large battery is not necessary while large battery capacity is more important because the battery must be charged and discharged frequently and handle high electric power as showing in Fig. 12.

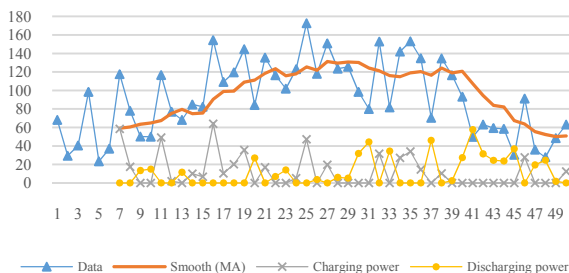


Fig. 12. Moving average smoothing algorithm

F. Smart District Phase I and Smart District Phase II Electrical Network Connection Topology and Its Benefits.

Normally, Smart District Phase II is operated on Grid-connected mode. By applying multi-level microgrid topology, Smart District Phase I will be able to achieve N-3 contingency and N-2 for Smart District Phase II (MEA distribution system has been designed based on N-1 contingency).

Smart District Phase I and Smart District Phase II work independently (No communication). When main grid failed, Smart District Phase II will switch to islanded mode while Smart District Phase I will not notice any interruption. If Smart District Phase II transition time is slower than Smart District Phase I transition time, then Smart District Phase I will notice the interruption and it will switch to and working on islanded mode until electricity supplied by Smart District Phase II back to normal, it will switch to grid-connected mode by using synchronization.

VII. CONCLUSION

Smart District Phase I pilot project of MEA is served as building smart energy management model via smart grid technology to create better quality, reliability yet economical and conserve the environment. This, perhaps, the secure way to power the office building, support the use of renewable energy and, at the same time, conserve the environment in accordance with the national energy policy, to reduce the emission of greenhouse gas which is the cause of global warming. For 549 days, the amount of CO₂ reduced by the Smart District Phase I is around 71,873 kg.

Last but not the least, MEA is envisioned as the master prototype achievement in energy management.

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