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Optimal Energy Storage Sizing in Photovoltaic and Wind Hybrid Power System Meeting Demand-Side Management Program in Viet Nam

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ORIGINAL ARTICLE

Abstract - This paper proposes a new method to determine optimal energy storage sizing in photovoltaic and wind hybrid power generation systems. These generations are placed in a scheme of three blocks to forecast, measure, and dispatch/control and distribute power flows in whole system to meet requirements of the demand-side management program in Viet Nam. Data about electric load power, power of solar irradiance, ambient temperature, wind speed and other weather conditions must be forecasted in a high accuracy. An algorithm to determine the optimal sizing is designed basing on forecasting data, constraints, the relation of quantities in whole system and the capability to charge/discharge energy of energy storage. The optimal sizing in this research helps to rearrange load diagrams that compensate deficient energy completely in stages having high and medium price levels. It can be applied at each bus to reduce cost for buying electricity from electric power system. The new proposal is illustrated by simulation results in a case study carried out by MATLAB 2017a.

Index Terms*: *Demand-side management, energy storage, optimal sizing, renewable energy, hybrid power generation system, photovoltaic power generation, wind power generation.

I. INTRODUCTION

Large electric power system (EPS) can be divided into many islands and these islands are operated in isolated or half-isolated modes to actively dispatch and change the way to mobilize power from traditional generations. With the support of communicating and forecasting technology and intelligent devices, each island can be considered a smart grid with the participation of renewable sources and operated by the demand-side management (DSM) program. This strategy is to create small systems in a large system, develop EPS in the direction of intelligence and meet economics requirements [1-6].

In Viet Nam, politicians and administrators are promoting the development of photovoltaic power generation (PVG) and wind power generation (WG). They can be used in a hybrid power generation system at each bus due to the high potentiality of solar energy and long coasts. Moreover, they are scaling electricity in three price levels, where stages having high and medium price are continuous from 4.5 o'clock am to 10 o'clock pm every day [7], [8]. A price for electricity from renewable energy is also higher than the medium price level of scaling. It means that the DSM program can be applied to establish economic problem and make operating schedules for whole system.

Problem of power distribution to meet requirements of the DSM program can be solved by using a power balance unit, called energy storage (ES). There are some types of ES such as battery, fuel cell, super-capacitor, they can be combined both of them in a system and have enough capacity to meet the amount of energy and the speed of charging/discharging process in the considered cycle and speed. Optimal sizing of ES is an important value which is possible to minimize the cost of energy. This value depends on objectives of each problem and applied locations, approaching methods such as ratio of lack of power (RLP), loss of power supply probability (LSLP),... [9-14].

RLP is a famous approach to determine the optimal sizing of ES in meeting deficient power by evaluating the difference of total load power and power from generations in the considered cycle. Each required RLP can be reached bu using data in the past or future about diagrams of load and generations. When RLP reduces to zero, the deficiency of load power is completely met by ES. The disadvantage of this method is that does not have any evaluation of electric price levels and time range for nay value of power [9].

LSLP is also a popular approach to determine the optimal sizing by using the concept of probability at any time in the considered cycle. Value of LSLP can be applied to have the minimum cost for losing electricity or reaching required LSLP. It is easy to realize that this approach only evaluates the power supply probability and does not evaluate the effect of electric price level to the sizing of ES [10-14].

Another approach uses the value of adding rated load power or total rated power of generations and backup capacity. Sizing of ES ensures the possibility of supplying energy for load or storing all energy from generations in whole considered cycle. This method often provides a large value of sizing and is not interested in the variation of power and effect of electric price or the interaction of generation side and EPS [15].

This paper proposes a new method to determine the optimal sizing of ES to meet requirements of the DSM program in Viet Nam. The optimal capacity can completely compensate deficient energy in the stages having high and medium price levels. The next section will introduce the system scheme and energy conversion. The third section will represent the objective of the DSM program in Viet Nam, constraints and the proposed algorithm to determine the optimal sizing of ES. The fourth section will illustrate some simulation results corresponding to a supposed case study. The last section will show contributions of this paper and next research problems.

• Block 1 provides diagrams about forecasting values of working parameters at any time in the considered cycle (time length is τ). They include G, T, wind speed, cloud... and the variation of electric load. This block must use programs basing on their values in the past, mathematical models, intelligent algorithms and forecasting devices to show values that will receive in the future [16-20].

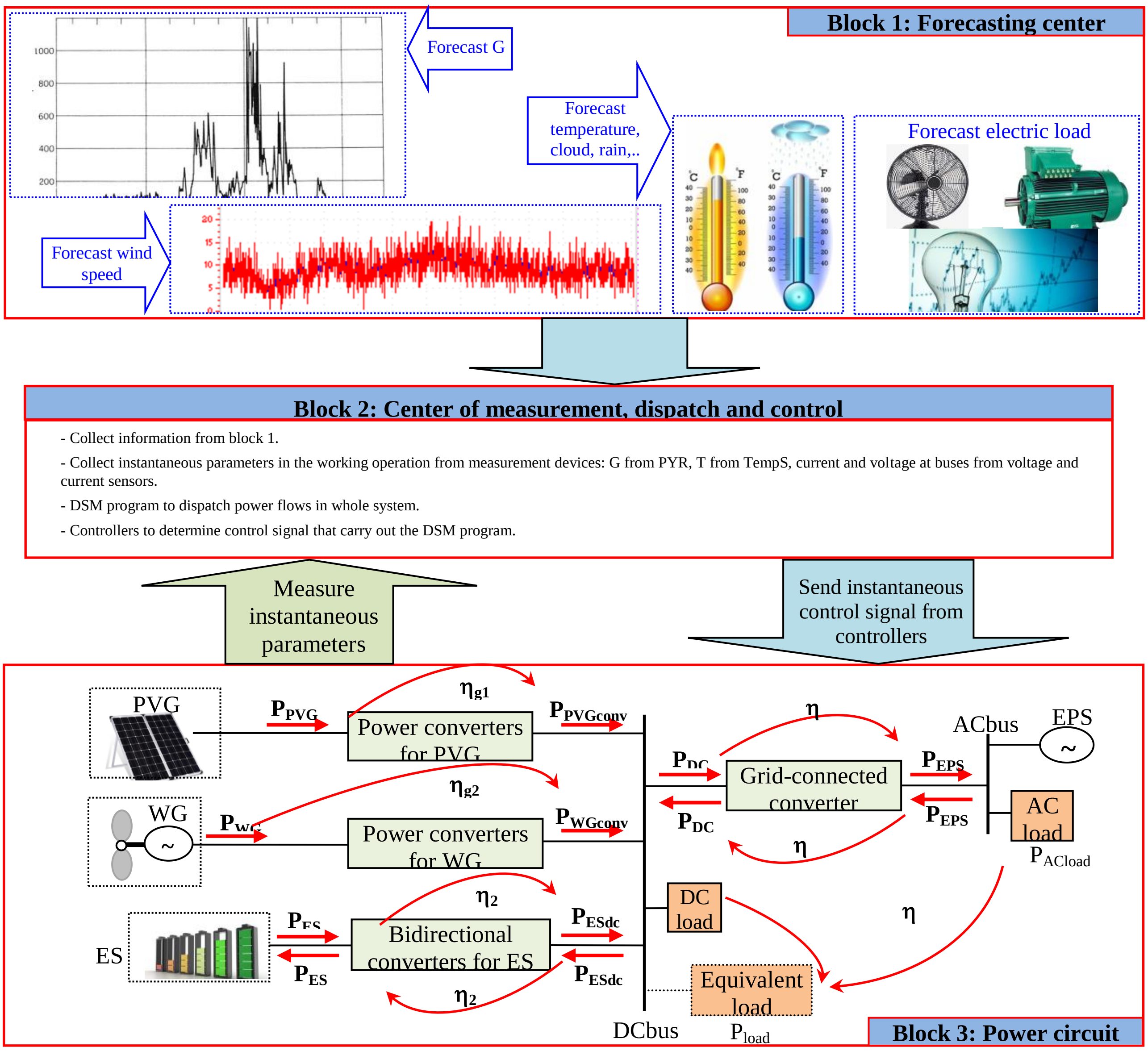


Fig. 1 System scheme

• Block 2 collects all instantaneous information about operating states of whole system from sensors such as current through each branch, voltage at buses to regulate control signals. These signals are sent to controllable switches placed in power converters to execute all requirements of the DSM program: harnessing maximum power from hybrid power generation, supplying electricity for load, holding voltage at DCbus as a constant value, synchronizing to the grid.

• Block 3 has power converters to regulate power for PVG and WG, bidirectional power converter for ES to regulate power for charging/discharging ES and bidirectional power converter to interact power with the grid. These converters must be co-ordinated closely to meet all operating requirements

The DSM program is placed in the second block to make a schedule of power flows in all cycle at any time for all units in the system. The redundant energy of hybrid power generation system or ES will be generated to EPS or the deficient power will be bought from EPS.

II. SYSTEM SCHEME AND POWER CONVERSION

2.1 System scheme

The structure of the hybrid power generation system is represented in Fig. 1. It has DC coupled structure with three main blocks for power circuit, forecasting, measurement, dispatch and control with [1-6].

2.2 Energy conversion

When currents go through power circuits, they always cause power losses in conductive units and switching power loss. They can be characterized by the following quantities:

• η_{g1} and η_{g2} for the efficiency of energy conversion in the process of harnessing PVG and WG,

• η for for the efficiency of energy conversion in the process of interacting power between DCside and ACside (same value in both two directions).

• η_2 for the efficiency of energy conversion in the process of interacting power between DCbus and ES (same value in both two directions).

Quantities have subsymbol "conv" to depict the power received after doing the conversion. The relations of these quantities are represented by (1):

$$\begin{cases} P_{PVGconv} = P_{PVG}\eta_{1g} \\ P_{WGconv} = P_{WG}\eta_{2g} \\ P_{ESdc} = P_{ES}\eta_2 \text{ (Power from ES to DCbus)} \\ \text{or } P_{ESconv} = P'_{ES}\,\eta_2 \text{ (Power from DCbus to ES)} \\ P_{load} = P_{DCload} + \dfrac{P_{ACload}}{\eta} \\ P_{EPSconv} = P_{DC}\eta \text{ (Power from DC to AC)} \\ \text{or } P_{DC} = P_{EPS}\eta \text{ (Power from AC to DC)} \end{cases} \quad (1)$$

III. OPTIMAL SIZING OF ES MEETING THE DSM PROGRAM IN VIET NAM

3.1 Objective of the DSM program in Viet Nam

Although the general role of the DSM program is to make an operating schedule for all units, it has some different problems when applied in Viet Nam and hybrid power generation system. They are the electric price levels and the minimum cost for buying electricity. The DSM program must help to reduce electricity from EPS in stages having high and medium price levels by using an ES that has enough capacity to balance power. It means that the power that interacts between EPS and DCside is limited in the stages having high and medium price levels.

3.2 Constraints

• Power from generations often varies in accordance with the variation of input parameters (G, T, v_{wind},...). Although these parameters change very fast and random in real working process, they can be forecasted and their instantaneous diagrams can be rearranged to rectangular diagrams in each $\Delta\tau_i$ by using the technique of area approximation. So, the forecasting center will provide approximately rectangular diagrams in whole cycle (24 hours) use to redistribute these diagrams in to rectangular diagrams. This technique will provide new rectangular diagrams (S1, S2, S3,…) having the same area with original diagrams as described in Fig. 2.

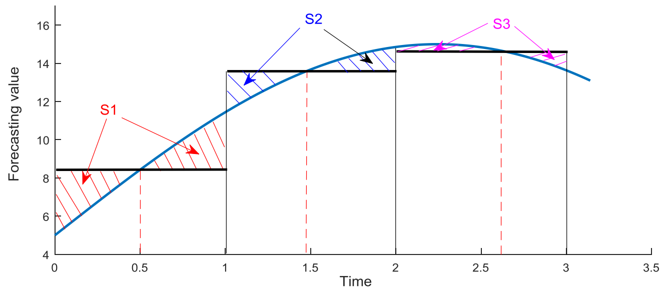


Fig. 2 Technique of area approximation to create rectangular diagrams

• Capacity of ES is specilized by rated value C_r (the highest value that can be stored), minimum value C_{min} to ensure the ability to restore or rework at the next time and instantaneous value C_{ins} at any time. Constraints for above quantities are shown by (2):

$$\begin{cases} C_{min} = 0.2C_r \\ C_{min} \le C_{ins} \le C_r \end{cases} \quad (2)$$

In working process, value of C_{ins} can change continuously (increase, decrease or constant) depending on the the relation of load power and hybrid generations. In this research, the variation of capacity is considered as a linear function.

• Power received at DCbus is always smaller than power generating from generations due to the conversion process. Constraints for power from generations are represented by (3):

$$\begin{cases} 0 \le P_{PVG} \le P_{PVGr} \\ 0 \le P_{WG} \le P_{WGr} \\ 0 \le P_{PVGconv} \le P_{PVG} \\ 0 \le P_{WGconv} \le P_{WG} \end{cases} \quad (3)$$

• ES plays a role of a power balance device so the constraint for power balance at DCbus is represented by (4):

$$P_{PVGconv} + P_{WGconv} + P_{DC} = P_{ES} \quad (4)$$

Due to the power balance, power flows in whole system can be depicted by some case as shown in Fig. 3.

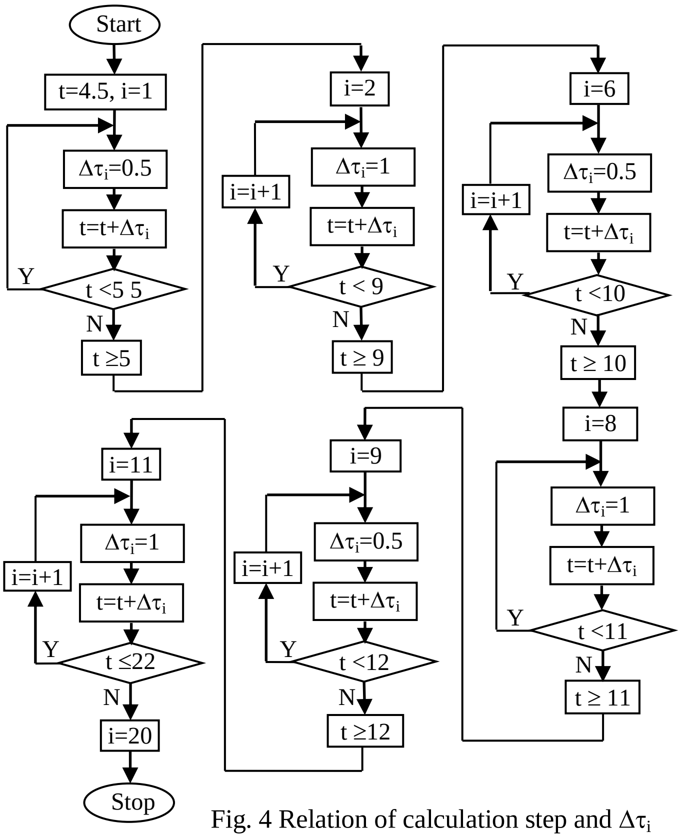


Fig. 4 Relation of calculation step and $\Delta\tau_i$

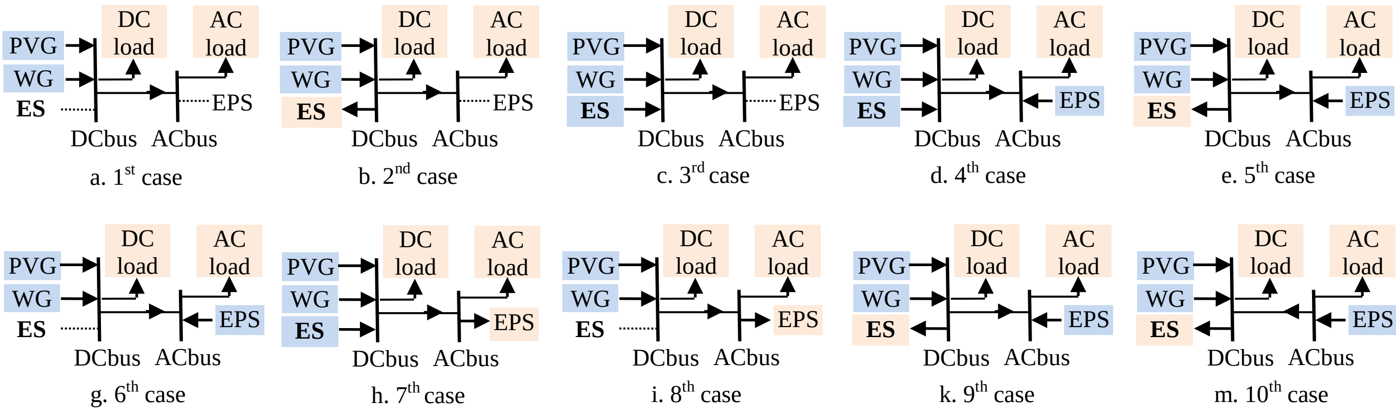


Fig. 3 Power-flow cases

3.3 Alogrithm to determine optimal sizing

Although there are many forecasting diagrams, only the maximum values for load power and minimum values of power from generations at each time are used to determine optimal sizing of ES. For the DSM program in Viet Nam, ES must be met deficient energy adequately in the stages having high and medium price levels (from 4.5 o'clock am to 10 o'clock pm every day). The relation of calculation step and $\Delta\tau_i$ is represented in Fig. 4.

Due to neglecting cost for investment, optimal sizing of ES will be chosen by adding (5 ÷ 10)% rated value as represented in Fig. 5 to have a backup value when having a deviation of forecasting data.

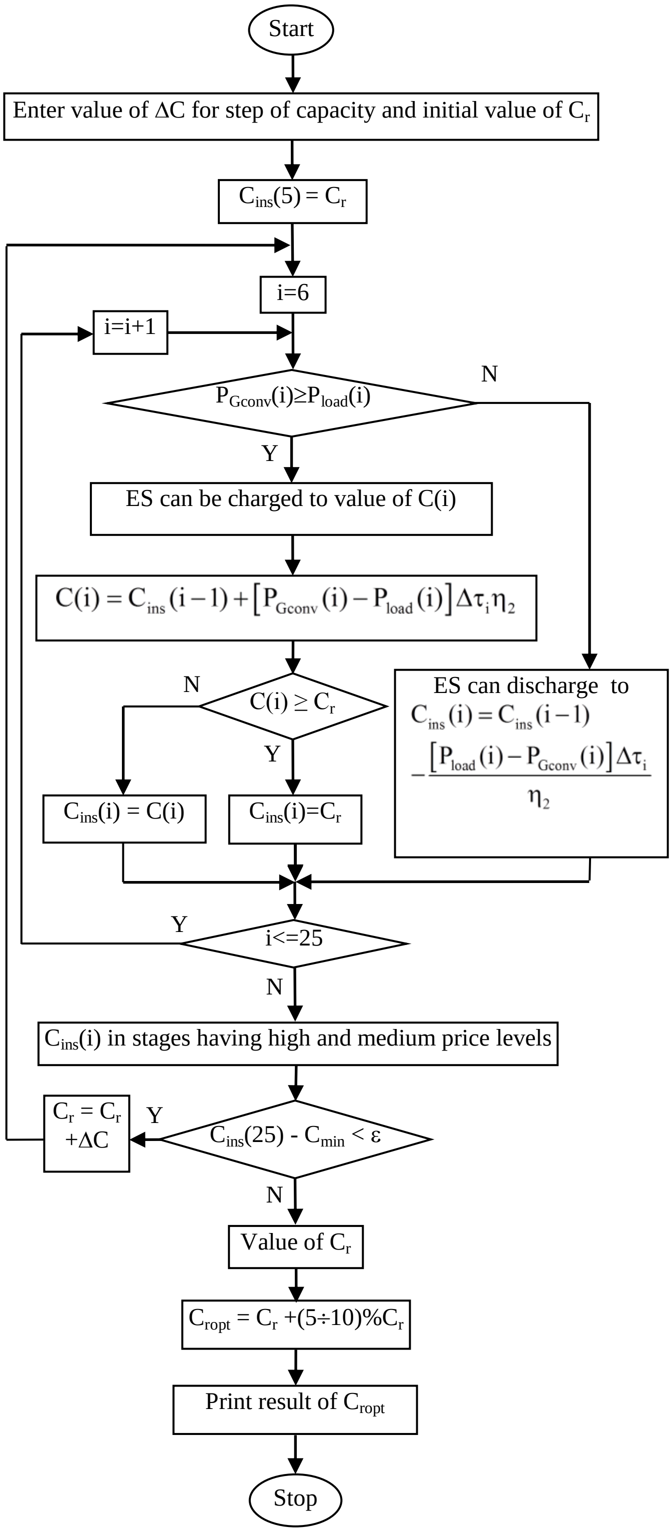


Fig. 5 Algorithm to determine optimal sizing of ES

Using the result in Fig. 5, value of C_{ins} at any time is calculated by algorithm as depicted in Fig. 6, where C(i) is the temporary variable of capacity before setting up the value of C_{ins} at the i^{th} step.

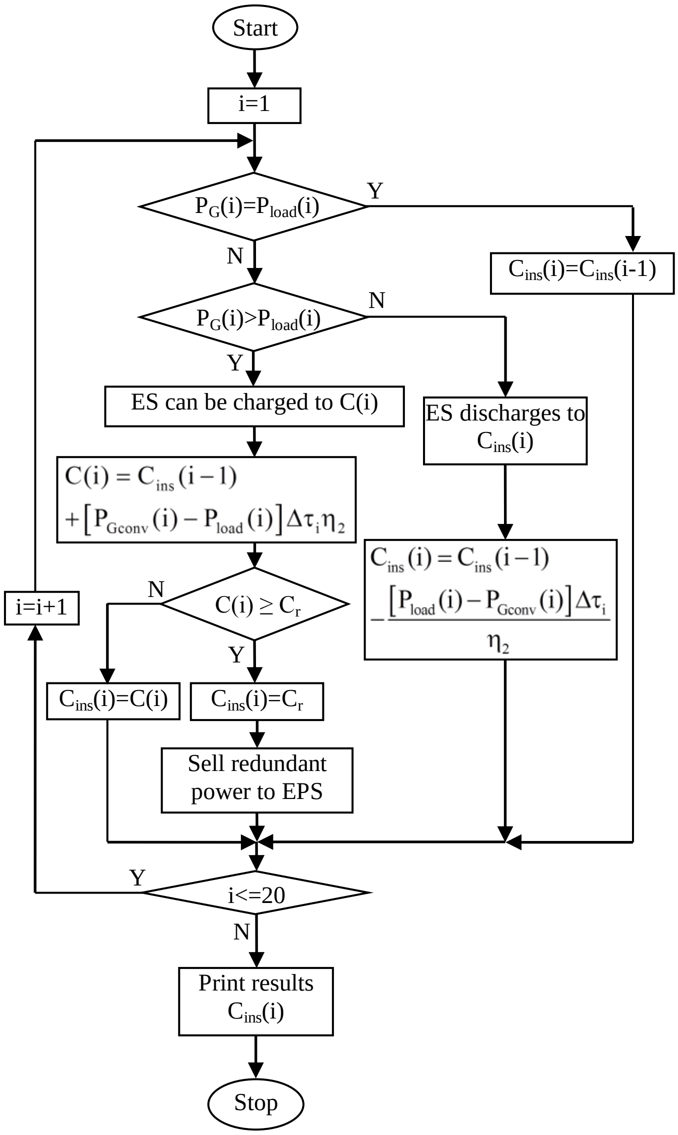


Fig. 6 Determine $C_{ins}(i)$ in stages having high and medium price levels

IV. SIMULATION

4.1 Simulation parameters

Hybrid generations: rated power for PVG is 6.6 kW at standard test condition and rated power for WG is 8.5 kW.

Power received at DCbus from hybrid generations ($P_{PVGconv}$ and P_{WGconv}) is represented in Fig. 7. Diagrams of total power received at DCbus from generations and load power are represented in Fig. 8.

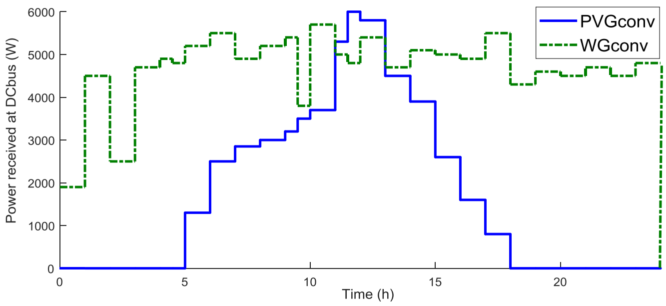


Fig. 7 Power received at DCbus from generations

Values of energy received at DCbus from generations and load in stages are represented in Table. 1.

We can see that total energy for load is larger than total energy received at DCbus from generations in stages having high and medium price levels.

Value of efficiency: $\eta_2 = \eta = 0.95$.

Initial value of rated capacity is 30 kW.

Step for capacity is $\Delta C = 5$ kWh.

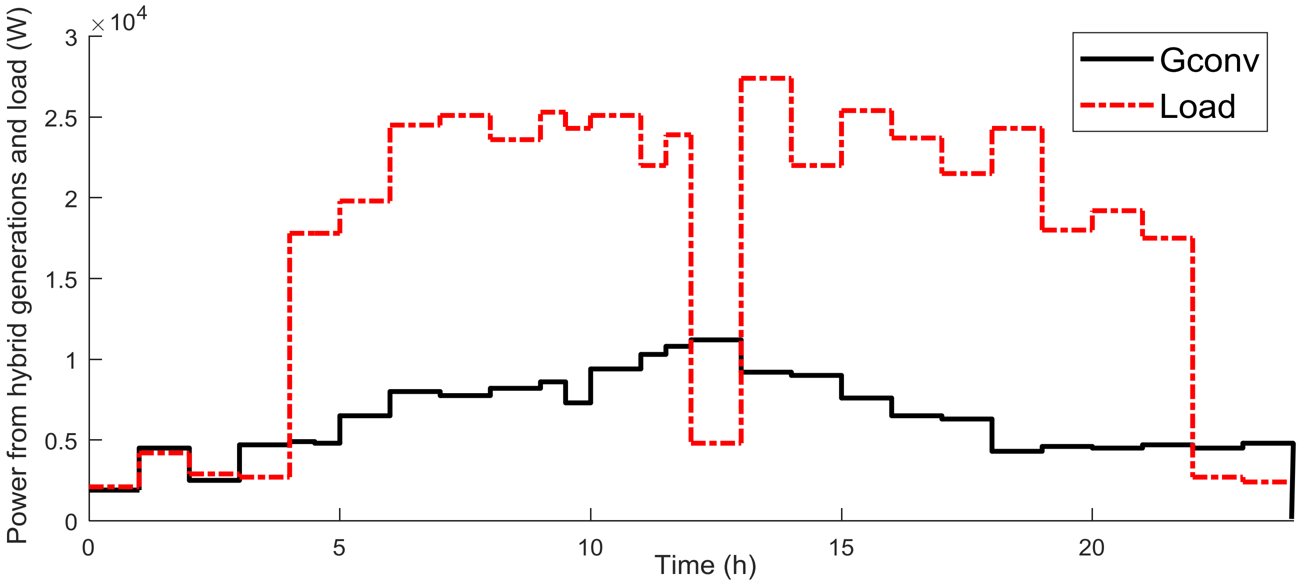


Fig. 8 Power received at DCbus from generations and load

Table. 1 Values of energy in stages

Energy	E_{Gconv} in stages having high and medium price levels (kWh)	E_{load} in stages of high and medium (kWh)
Value	128.6	378.6

Table. 2 The relation between C_r and $C_{ins}(25)$

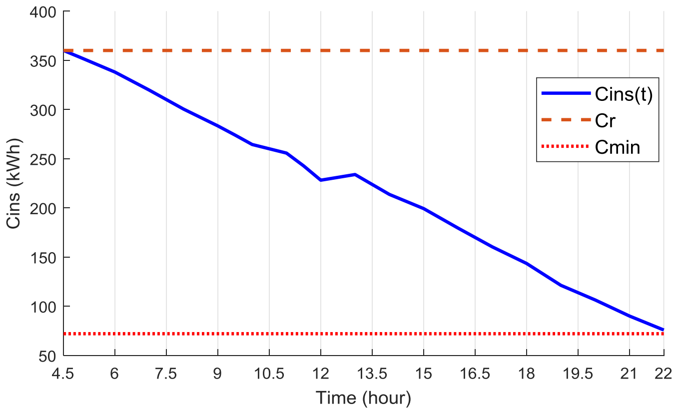
Value of C_r (kW)	360	365	370
Value of $C_{ins}(25)$ (kWh)	66.48	71.48	76.48
Value of C_{min} (kWh)	72	73	74

4.2 Simulation results

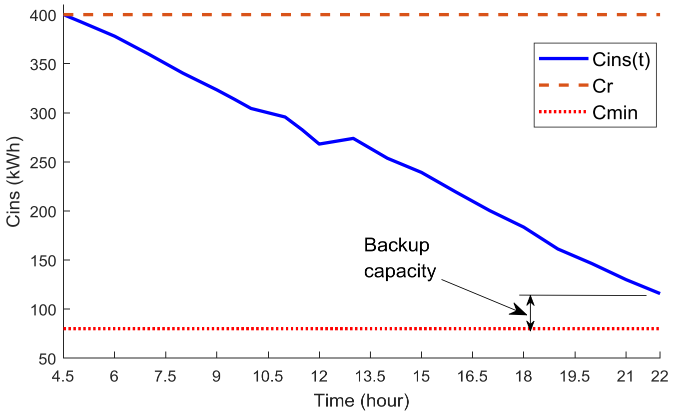
Simulation results about the relation between C_r and instantaneous capacity at the end of the last medium stage $C_{ins}(25)$.

Results in Table. 2 showed that the suitable sizing of ES must be from 365 kWh to 370 kWh. To have a backup capactiy, optimal sizing should be chosen as C_{ropt}= 400 kWh.

Values of C_{ins} at any time in stages having high and medium price levels corresponding to two case studies of C_r (360 kWh and 400 kWh) are represented in Fig. 9.



a. Cr=360 kWh



b. Cr=400 kWh

Fig. 9 Values of C_{ins} in two case studies of C_r

We can see that if value of C_r is 360 kWh, we will not have any backup capacity. In this case, it is easy to fall into deficient energy when there is a deviation of the forecasting parameters in real working condition. The value of 400 kWh can help to have a backup capacity after finishing stages having high and medium price levels (10 o'clock pm) so it is the best choice for sizing of ES.

V. CONCLUSION

For the hybrid system harnessing photovoltaic and wind generations, this paper proposes a new method to determine optimal sizing of ES to meet the DSM program in Viet Nam. The sizing satisfies constraints, power balance at DCbus and ability to charge/discharge energy from ES. The optimal sizing ensures to adequately meet deficient energy in stages having high price and medium price levels and and be added a backup capacity.

The forecasting center is used to provide available power diagrams including demand of load and generations in a considered cycle. The maximum values of load power and minimum values of power from generations are used and combined with the approximation method to rearrange instantaneous diagrams to rectangular form. Because of this method, the optimal sizing can completely supply energy for load in any other case of diagrams. Using the optimal sizing of ES, an algorithm is also designed in this paper to analyze power flows in whole system that considers power loss in power converters.

Simulations results showed the feasibility and the accuracy of the proposed method in a deficient case study. Corresponding to the example diagrams, calculation results provide the value of optimal sizing and verify the new contribution of this paper in hybrid systems harnessing photovoltaic and wind generations and operated in the DSM program. The contribution of this paper can be applied to determine the optimal sizing of ES in other countries by using their diagrams of electric price levels. For the next research, we will continue to study in other cases that have redundant energy relations in stages having high and medium price levels.

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DECLARATION

All authors have disclosed no conflicts of interest.

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