Demand-Side Management Program with A New Energy Strategy for Photovoltaic and Wind Power Generation System in Viet Nam

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***Abstract*— This paper proposes a new energy strategy to distribute energy at each bus in Viet Nam electric power system with the participation of photovoltaic and wind power generations. A structure for this system is also constructed including some main blocks: power circuit, forecasting center and center of measurement, dispatch and control. Each block closely works together with others and energy storage to have a balance power at any time in whole considered cycle. A demand-side management algorithm is designed corresponding to a case study that has energy from the generations smaller than consumed energy of electric load in whole time stages. In this algorithm, the deficient energy in stages having high and medium electric price levels can be bought from the electric power system to charge to the energy storage in the stage having low electric price level to reduce the economic function. Simulation results were carried out by the MATLAB 2017a software to show the feasibility of the demand-side management program to re-dispatch power flows in whole system and bring out high economic effectiveness.**

***Index Terms*— Demand-dide management, dispatch power flow, photovoltaic power generation, wind power generation, hybrid system.**

I. INTRODUCTION

Renewable energy is considered as a effective solution to prolong life on earth when traditional energy sources become to exhaust. Although there are many types of renewable sources, photovoltaic power generation (PVG) and wind power generation (WG) are the most potential sources because they can be installed anywhere in the world and are constantly present during the day. They can be combined together into a hybrid generation system to support each other and enhance the ability to supply electricity because WG can generate electricity at any time while PVG can only generate it when daylight is present. With the combination of power converters, control and communication techniques and energy storage (ES), power flows in whole system can be dispatched and operated by using the model of smart grid via a demand-side management (DSM) program.

Unlike traditional electric power system (EPS), smart grids uses the DSM program and forecasting data to determine values of power that will receive from generations or be consumed by electric load before entering the working cycle. There are much forecasting data in this structure such as power of solar irradiance, ambient temperature, wind speed and other factors of weather condition. All data must be forecasted in a high accuracy to make a schedule for control and energy management. One of the most important device in this structure is ES and the its sizing must be enough large to completely compensate for the deficient energy of load as required. Because of having the support from ES, power directions between DCbus and ES, DCbus and ACbus are calculated and controlled by the DSM program as required [1-6].

In Viet Nam, there are three electric price levels for customers. To buy electricity, they must be one of the following objects: provided by transformers having rated power more than 25 kVA, having average electric consumption in three continuous months more than 2000 kWh per month, saling electricity at industrial zones, buying electricity to sale for other purposes at commercial, service and living complex. Three levels can help to promote the electric consumption in the stage having low price level and limiting it in stages having medium and high price levels [7], [8].

Recently, forcasting centers can provide quite accurate values of forecasting data due to using many modern measurement devices, history of data in many years and mathematical tools. They can help to completely optimize power flows in whole system and make minimum cost for buying electricity and maximum profit from saling it [9], [10], [11], [12], [13]. Although there are many reseaches about applying the DSM program in hybrid systems harnessing PVG and WG but it must be met requirements of each country. Until now, it hasn't had any complete research about this problem in Viet Nam.

In this paper, a new DSM program is proposed for hybrid generation systems at any bus applied in Viet Nam EPS. The purpose of this program is to ensure the ability to meet requirements of energy supply for electric load. The next section will introduce the system scheme and the relation of power quantities in the process of power conversion. The section III will represent a new strategy to distribute power flows in whole system applied in Viet Nam in accordance with a case study of deficient energy in all stages. This section will also construct a method to evaluate economic effectiveness of the DSM program. Section IV will demonstrate some simulation results. The last section will show some conclusions and propose the problem for next researches.

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].

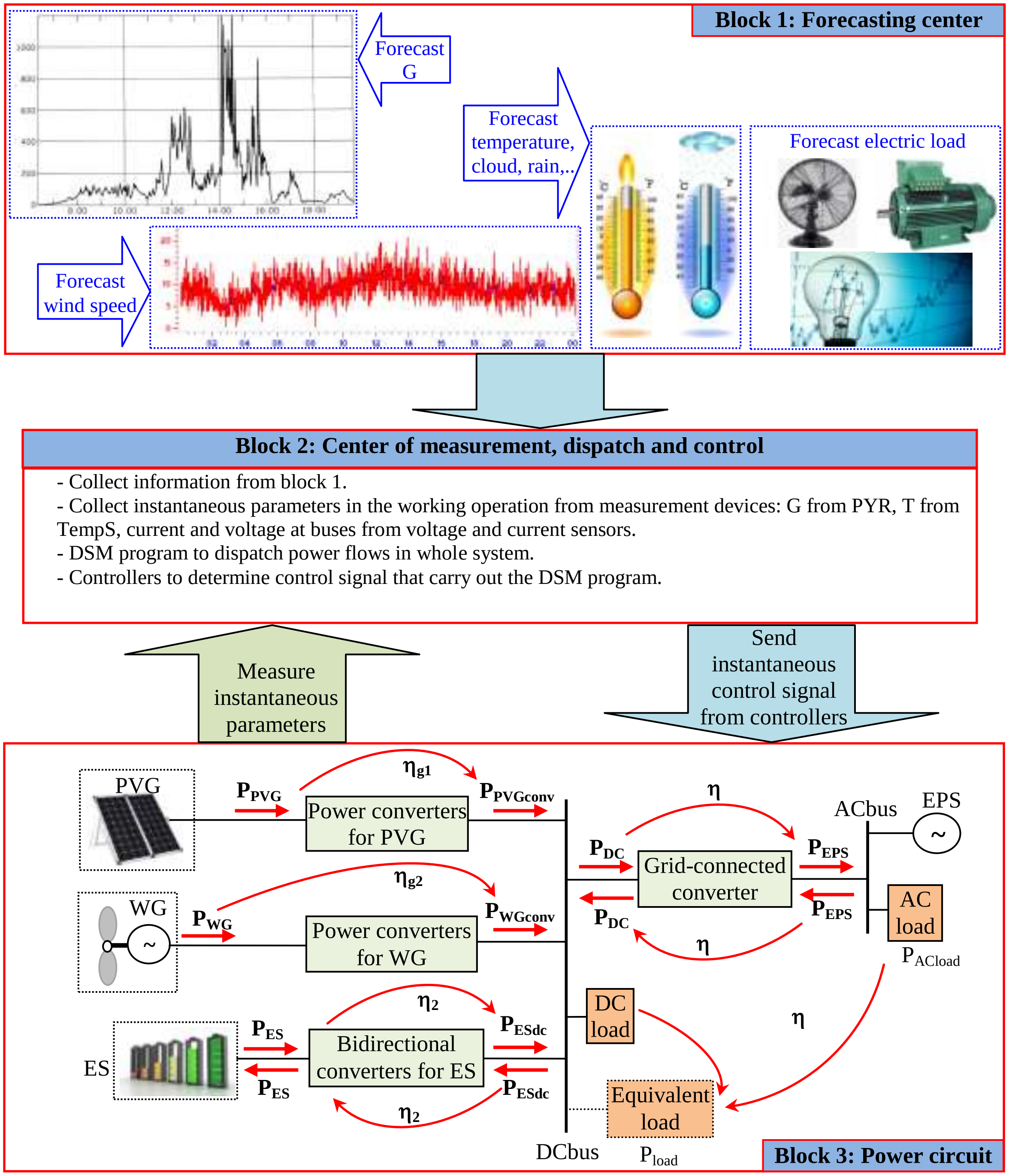


Fig. 1 System scheme

- 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 [9-13].

- 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 controlable 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.

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. DSM STRATEGY WITH APPLICATION IN VIET NAM

3.1 Diagram of electric price in Viet Nam

Viet Nam EPS is using a diagram with three price levels corresponding to the following stages [7], [8]:

- High price stage (H-stage) including H1-stage and H2-stages,
- Medium price stage (M-stage) including M1-stage, M2-stage and M3-stage,
- Low price stage (L-stage) including L1-stage and L2-stage.

The relation of above stages and electric price is represented in Fig. 2.

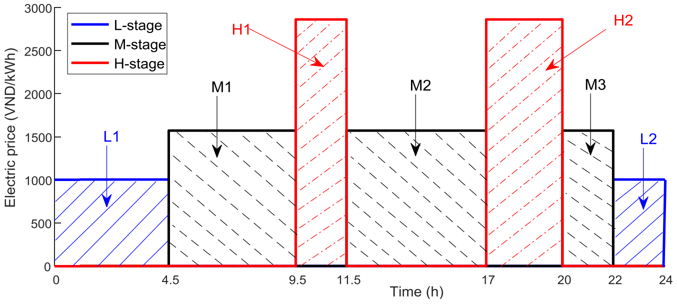


Fig. 2 The relation of stages and electric price in Viet Nam

We can see the electric price in the H-stage (β_3=2862 VND/kWh) is nearly three times it at the L-stage (β_1=1004 VND/kWh) and nearly twice it at the M-stage (β_2=1572 VND/kWh).

Due to the development of electric market and renewable sources, EPS in Viet Nam also sets values of buying electric from renewable energy. This paper considers that they are same for PVG and WG to have a target to evaluate benefit received from generations.

3.2 DSM strategy for the case study of deficient energy in H-stage and M-stage

DSM strategy is proposed to evaluate deficient energy and working capacity of each unit as the following descriptions:

- Deficient energy (power from hybrid is smaller than load power) is only bought from EPS in L1-stage and L2-stage. Specially, it needs to buy energy to charge ES to rated capacity (C_r) and provide energy for load before working in the H-stage and M-stage. It means that the DSM program helps to reduce cost for buying electricity from EPS because deficient energy in H-stage and M-stage can be provided by ES.
- In the H-stage and M-stage, redundant energy (load power is smaller than power from hybrid generations) will be generated to EPS if ES can not absorb. Capacity of ES will be discharged to minimum capacity (C_{min}) before finishing the M3-stage.
- Beside C_r and C_{min}, value of instantaneous capacity (C_{ins}) represents the ability to meet electricity demand at the current time. Unit for all of these quantities is kWh. The constraint for above quantities is shown in (2)

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

In the working process, value of C_{ins} can continuously change corresponding to charging or discharing energy caused by the changing of power of hybrid generations and load. In this paper, the increase or decrease of C_{ins} is a linear in each considered time range.

3.3 Algorithm for the DSM strategy

Time step ($\Delta\tau_i$) at the i^{th} step is depicted in Fig. 3.

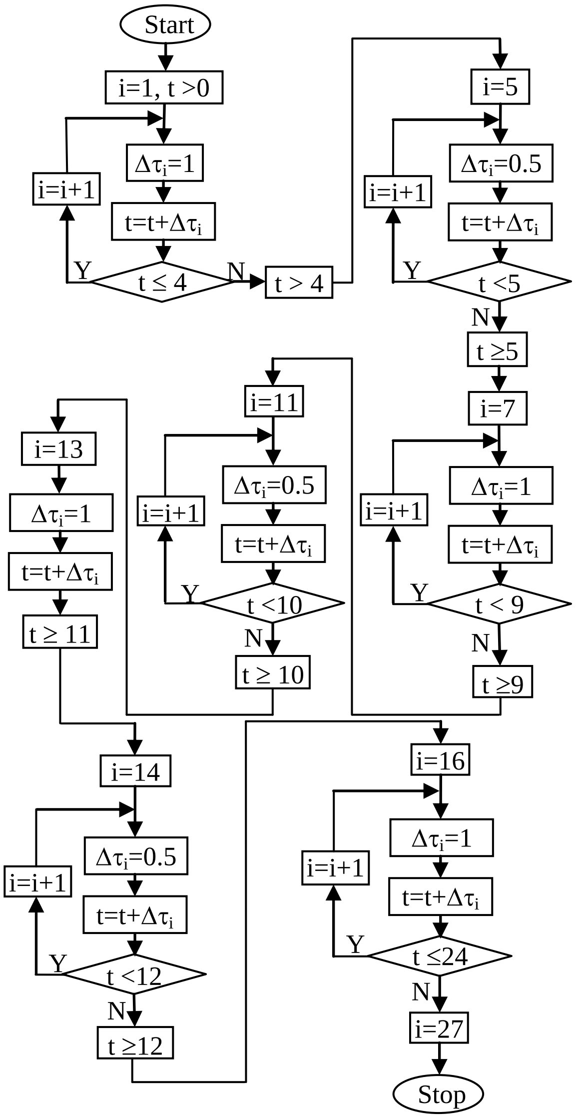


Fig. 3 Time step and step counter

Total predictive power received at DCbus at the i^{th} step is calculated by (3):

$$P_{Gconv}(i) = P_{PVGconv}(i) + P_{WGconv}(i) \qquad (3)$$

where, $P_{PVGconv}(i)$ and $P_{WGconv}(i)$ are quantities of power delivered to DCbus at the i^{th} step of PVG and WG.

Total energy from hybrid generations received at DCbus in H-stage, M-stage and L-stage is calculated by (4), (5), (6). Total demand of load in DCbus in H-stage, M-stage and L-stage is calculated by (7), (8), (9).

$$E_{GconvH} = \underbrace{\sum_{i=12}^{14}\left[P_{Gconv}(i)\times\Delta\tau_i\right]}_{E_{GconvH1}} + \underbrace{\sum_{i=21}^{23}\left[P_{Gconv}(i)\times\Delta\tau_i\right]}_{E_{GconvH2}} \qquad (4)$$

$$E_{GconvM} = \underbrace{\sum_{i=6}^{11}\left[P_{Gconv}(i)\times\Delta\tau_i\right]}_{E_{GconvM1}} \qquad (5)$$
$$+\underbrace{\sum_{i=15}^{20}\left[P_{Gconv}(i)\times\Delta\tau_i\right]}_{E_{GconvM2}} + \underbrace{\sum_{i=24}^{25}\left[P_{Gconv}(i)\times\Delta\tau_i\right]}_{E_{GconvM3}}$$

$$E_{GconvL} = \underbrace{\sum_{i=1}^{5}\left[P_{Gconv}(i)\times\Delta\tau_i\right]}_{E_{GconvL1}} + \underbrace{\sum_{i=26}^{27}\left[P_{Gconv}(i)\times\Delta\tau_i\right]}_{E_{GconvL2}} \qquad (6)$$

$$E_{loadH} = \underbrace{\sum_{i=12}^{14}\left[P_{load}(i)\times\Delta\tau_i\right]}_{E_{loadH1}} + \underbrace{\sum_{i=21}^{23}\left[P_{load}(i)\times\Delta\tau_i\right]}_{E_{GH2}} \qquad (7)$$

$$E_{loadM} = \underbrace{\sum_{i=6}^{11}\left[P_{load}(i)\times\Delta\tau_i\right]}_{E_{loadM1}} \qquad (8)$$
$$+\underbrace{\sum_{i=15}^{20}\left[P_{load}(i)\times\Delta\tau_i\right]}_{E_{loadM2}} + \underbrace{\sum_{i=24}^{25}\left[P_{load}(i)\times\Delta\tau_i\right]}_{E_{loadM3}}$$

$$E_{loadL} = \underbrace{\sum_{i=1}^{5}\left[P_{load}(i)\times\Delta\tau_i\right]}_{E_{loadL1}} + \underbrace{\sum_{i=26}^{27}\left[P_{load}(i)\times\Delta\tau_i\right]}_{E_{loadL2}} \qquad (9)$$

To meet requirements of the DSM program, capacity of ES must be enough large to ensure the ability to completely supply energy for load in H-stage and M-stage and be suitable to the constraint (2). The DSM strategy is proposed basing on the principle: buying the amount of deficient energy of H-stage and M-stage to charge ES in L1-stage, discharging ES to balance power in H-stage and M-stage, load demand in the L2-stage can be met by EPS if power from ES and generations is smaller than load power.

A new strategy for the DSM program applied in a case of deficient energy (generating energy is smaller than load energy in both L1-stage, H-stage and M-stage) is represented in Fig. 4. It will show the values of charging or discharging energy of ES, interacting energy between the hybrid system and EPS (saling or buying) at any step. Results of this algorithm including E_{rb} (energy required to buy), E_{as} (available energy to sale) can be used to determine cost for buying electricity or benefit for saling electricity. Method to distribute power flows in L1-stage is depicted in Fig. 5.

Basing on diagram of electric price in Fig. 2 for buying from EPS and electric price for saling electricity from renewable sources, values of E_{rb} and E_{as} when using or not using the DSM program are used to determine cost for buying electricity (Z_{rb}) and profit for saling electricity (Z_{as}). They can be used to calculate the economic function (Z) and evaluate the effect of the DSM program.

$$\begin{aligned} Z_{rb} &= \beta_1\left[\sum_{i=1}^{5} E_{rb}(i) + \sum_{i=26}^{27} E_{rb}(i)\right] + \\ &+ \beta_2\left[\sum_{i=6}^{11} E_{rb}(i) + \sum_{i=15}^{20} E_{rb}(i) + \sum_{i=24}^{25} E_{rb}(i)\right] \\ &+ \beta_3\left[\sum_{i=12}^{14} E_{rb}(i) + \sum_{i=20}^{22} E_{rb}(i)\right] \end{aligned} \tag{10}$$

$$Z_{as} = \beta \sum_{i=1}^{27} E_{as}(i) \tag{11}$$

$$Z = Z_{rb} - Z_{as} \tag{12}$$

In this system, the role of the DSM program is to make value of Z receive the smallest value (minimum value).

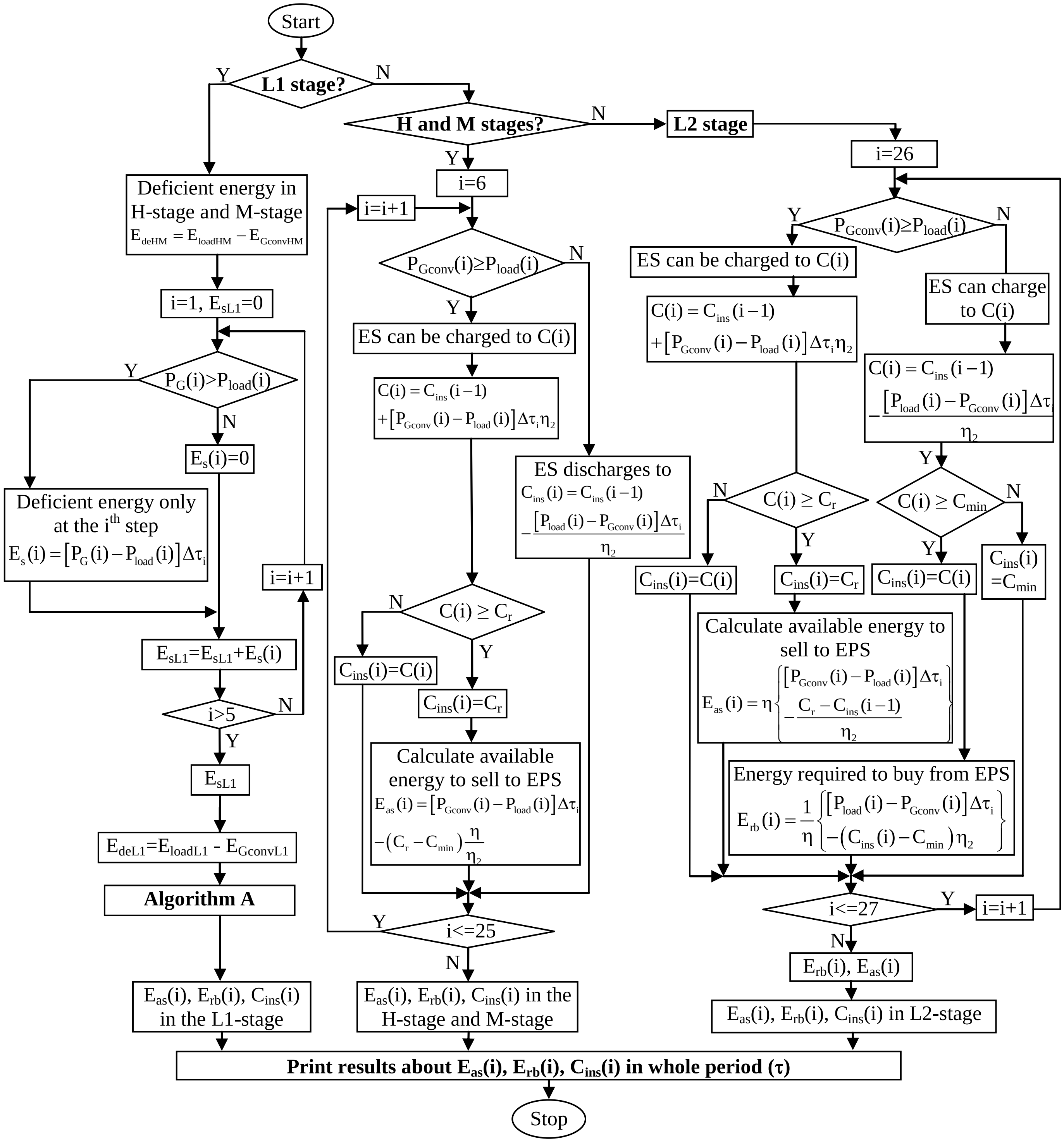


Fig. 4 Propose a new strategy for the DSM program in the case of deficient energy

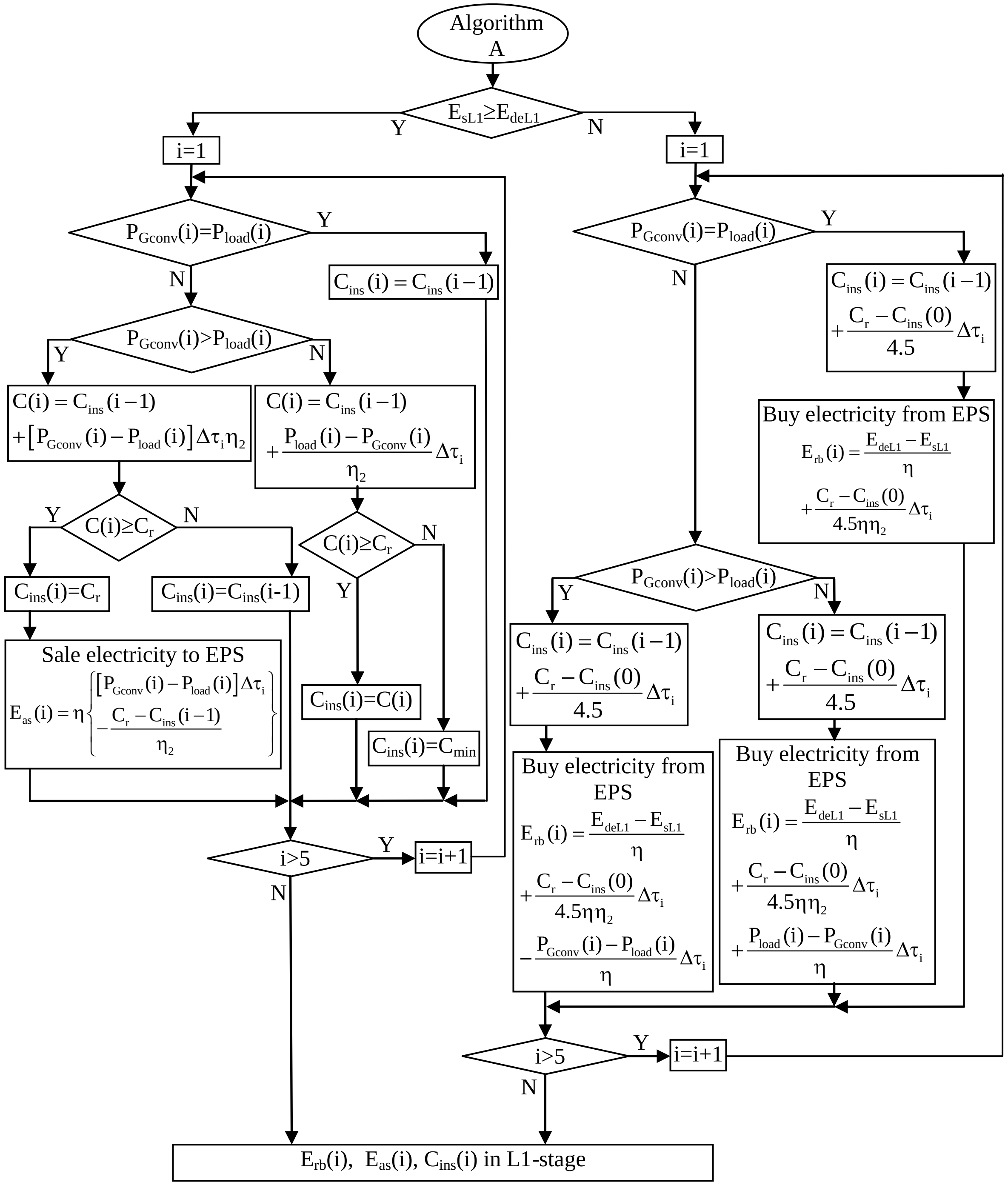


Fig. 5 Algorithm A to distribute power flows in L1-stage

Where:

C(i) is the temporary variable for instantaneous capacity at the end of ,

E_{sL1} is value of redundant energy in the L1-stage,

$E_s(i)$ is value of instantaneously redundant energy at the i^{th} step.

IV. SIMULATION

4.1 Simulation parameters

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 generations ($P_{PVGconv}$ and P_{WGconv}) is represented in Fig. 6. Total power received at DCbus from generations (combining data in Fig. 6) and load power are represented in Fig. 7.

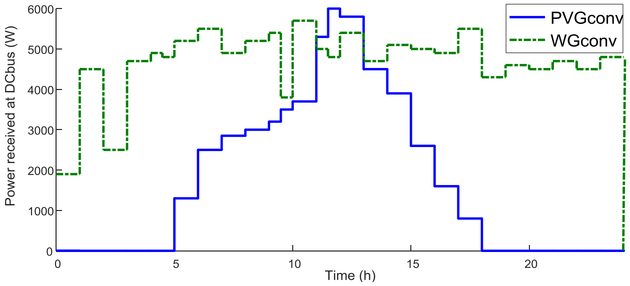


Fig. 6 Power received at DCbus from generations

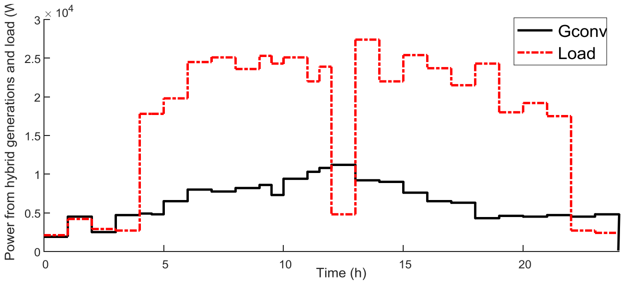


Fig. 7 Power received at DCbus from generations and load

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

Table 1. Values of energy for generations and load

Energy	E_{Gconv} (kWh)	E_{load} (kWh)	$E_{GconvHM}$ (kWh)	E_{loadHM} (kWh)	$E_{GconvL1}$ (kWh)	E_{loadL1} (kWh)
Value	154	404.4	128.6	378.6	16.1	20.8

We can see that total energy for load demand is larger than total energy received at DCbus from generations in L1-stage, H-stage, M-stage and whole considered cycle.

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

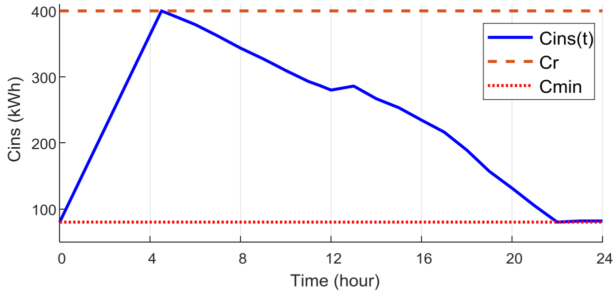
Rated capacity for ES is 400 kWh.

4.2 Simulation results

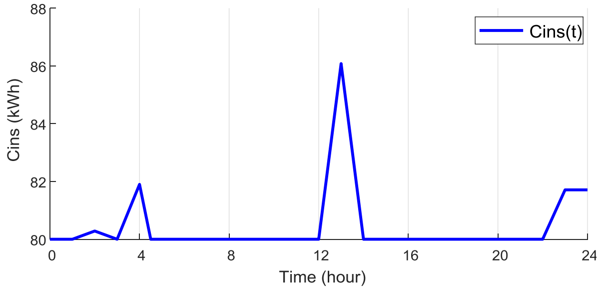
Simulation process was carried out by using MATLAB 2017a to compare the effectiveness in two cases: using the DSM program and not using the DSM program.

Simulation results about C_{ins} characteristic in above case are shown in Fig. 8. In Fig. 8a, value of C_{ins} reached to C_r before finishing L1-stage and discharging to C_{min} before finishing M3-stage as requirements of the DSM program. In Fig. 8b, ES only charges when P_{Gconv} is larger than P_{load} and discharges in its available capacity when P_{Gconv} is smaller than P_{load}.

Diagrams representing E_{rb} and E_{as} in two cases are shown in Fig. 9. In Fig. 9a, the DSM program helped to buy electricity from EPS in L1-stage to meet the load demand and charge ES. Moreover, it was not bought electricity from EPS in H-stage and M-stage as the requirement of the DSM program. In Fig. 9b, electricity can be bought from EPS at any stage to meet load demand.

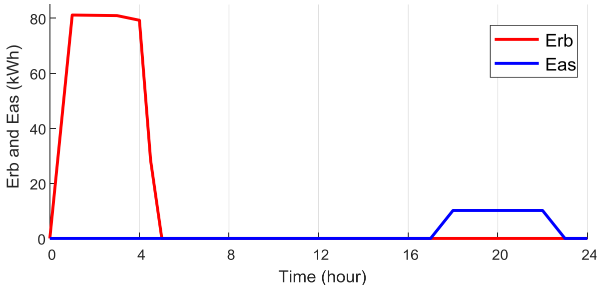


a. Using the DSM program

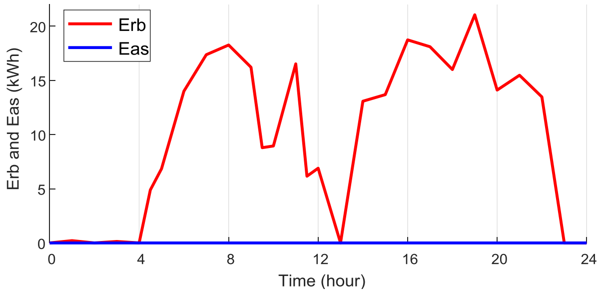


b. Not using the DSM program

Fig. 8 C_{ins} diagrams



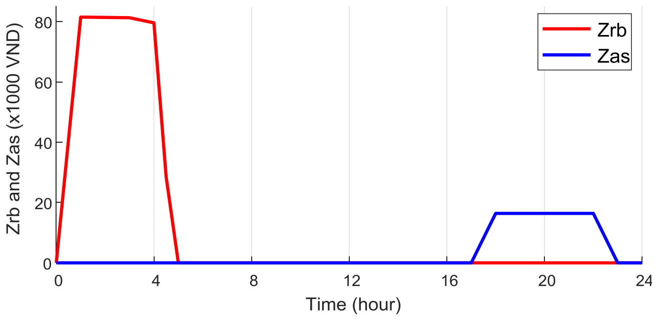
a. Using the DSM program



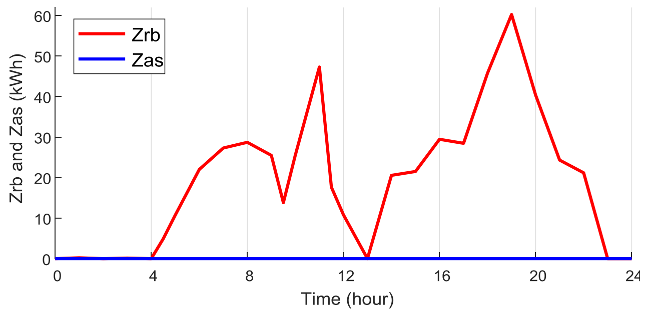
b. Not using the DSM program

Fig. 9 E_{rb} and E_{as} diagrams

Diagrams representing value of Z_{rb} and Z_{as} in two cases are shown in Fig. 10. Fig. 10a showed that the DSM program worked very well to reduce cost function due to buying electricity in L1-stage to meet the load demand. Fig. 10b showed that it took some money to buy electricity and did not have any profit from saling electricity. These results depict the advantage of the DSM program in the operating process for hybrid generation in half-isolation mode. The effectiveness of the DSM can be evaluated by the difference between cost for buying electricity and profit from saling electricity. Moreover, value of ΔZ is an important factor to compare the economic meaning corresponding to using the DSM program and not using the DSM program. Simulation values of economic functions are represented in Table. 2.



a. Using the DSM program



b. Not using the DSM program

Fig.10 Z_{rb} and Z_{as} diagrams

Table. 2 Economic factors in two cases

Case study	E_{rb} (kWh)	E_{as} (kWh)	Z_{rb} (x10^3 VNĐ)	Z_{as} (x10^3 VNĐ)	Z (x10^3 VNĐ)	ΔZ (x10^3 VNĐ)
DSM	350.8	50.8	352.2	82	270.2	256
No DSM	269	0	526.6	0	526.6	

Results in Table. 2 showed that the DSM program helped to make a profit from saling electricity and reduced cost for buying electricity very much (approximately 50%). It makes more clear about the meaning the DSM program to distribute power flows in whole system.

V. CONCLUSION

This paper proposed a new strategy to distribute power flows in systems harnessing photovoltaic and wind power generations at any bus in power system using the DSM program. It can be applied in a case study of deficient energy (generating energy is not enough to meet the load demand in both L1-stage, H-stage and M-stage when combined with forecasting center of weather and load.

The DSM program was proposed basing on the requirement of buying all deficient energy to charge ES in L1-stage to meet load demand in H-stage and M-stage. It made power flows in whole system change. In this system, ES plays an important role in balancing energy at any time while power going through the grid-connected converter is limited. It is also the difference of this operating method in this system and the traditional operating method.

The contribution of this paper was illustrated by simulation results for a case study of input parameters. They made very clear the meaning of the DSM program in the hybrid system harnessing renewable sources when compared with not using the DSM program. Beside helping to redistribute power flows in whole system, the DSM program can help to make a economic profit by evaluating cost for buying and saling electricity. It showed the feasibility of the DSM program in making an operating schedule and receiving economic profit when applying it into a real system. In the future, the DSM program can be continued to develop for other case studies of energy relation in stages and design experimental models to verify the proposed strategy.

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