Determine Battery Capacity Basing on the Distribution of Power Flows in Hybrid Photovoltaic and Wind Generations Operating in Half-Isolation Mode

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***Abstract*—Hybrid models exploiting photovoltaic and wind generations are combined with energy storage to overcome disadvantages of each other. This paper mentions the distribution of power flows through power converters to make operating plans for each element. It can be done by using known data collected or predicted and applied in half-isolation mode for whole system. This paper also proposes a new program to determine the optimal capacity for DC storage using battery. The operation of whole system is simulated in Matlab software accounting for random characteristic of input data. Experimental results represented the ability of controlling power flows in a photovoltaic system.**

***Keywords*—Battery, distribution of power flows, energy management system, optimal battery capacity, photovoltaic generation, power converter, smart grid, wind generation.**

I. INTRODUCTION

Photovoltaic generation (PVg) and wind generation (Wg) are potential energy types to replace traditional sources. Because of advance in producing, PVg has enhanced its efficiency and reduced cost price whereas Wg has some silent types to install at any place in residental zone and used as distributed source.

In smart grid, power converters can help us operate hybrid generations flexibly in isolation or half-isolation mode to have some support from grid. One case of operating in half-isolation mode, Fort Collins - Colorado State (America) is executing a special energy policy – consume energy less than generate by using the following ways: photovoltaic systems are located on roofs and gardens, wind turbine, thermal and electrical energy storage, etc, and saving energy programs. Separating the grid into many small islands represented in Fig. 1 will become a good growth trend to keep our existence on the earth [1]. In this system, battery storage is used to overcome random characteristic of input data (solar irradiance, wind speed, etc). Two criterions, enough capacity to absorb all energy from source or enough to provide for load power, can be often applied to determine battery capacity C for an individual generation but can't be applied for hybrid generations [2]. References [3-6] are introduced an approximative method to calculate the distribution of power flows in hybrid systems for all periodic time T (day, month, year) and execute an economic problem to compare cost price between purchasing and selling electricity but it only can be applied in completely connected grid problem and the available value for lack of power P_{lp} is not limited.

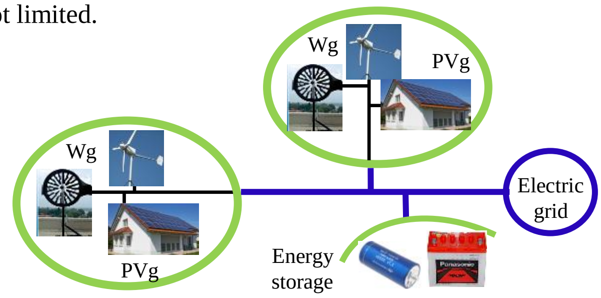

Fig. 1. Connect islands in the smart grid.

This paper proposes a new algorithm to determine C basing on collected or predicted input data (solar irradiance, wind speed), load diagram in periodic time T and execute the distribution of power flows at each time for all elements in the system operated in half-isolation mode and limited P_{lp}.

II. SYSTEM STRUCTURE AND DISTRIBUTE POWER FLOWS IN WHOLE SYSTEM

A. System structure

A system operates in half-isolation mode often has DC parallel structure as Fig. 2 [7-9].

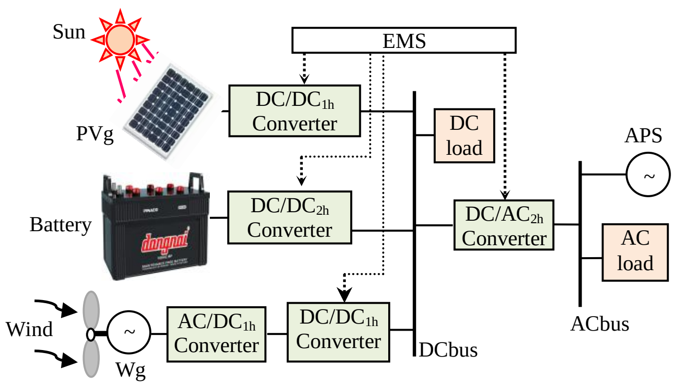

Fig. 2. System structure.

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Where:

APS (Auxiliary Power Source), such as grid, diesel generators, etc, provides power in a limited range because of the ability of grid, other systems or rated power of generators.

DC/DC_{1h} and AC/DC_{1h} converters are used to control the operation point for PVg and Wg.

DC/DC_{2h} and DC/AC_{2h} are are bidirectional converters used to control charging or discharging mode for battery and generate power to ACbus and connect to APS.

EMS (Energy Management System) collects all information about load diagram, solar irradiance, wind speed and instant battery capacity to calculate power flows having to operate for all elements in periodic time T [10-12].

To limit power from APS, battery has to have enough large capacity to adapt technical requirements but not allow abundance because of high price and low working life.

B. Distribute power flows in whole system

Power flows in whole system are executed by the following criterions [3-6]:

- Power from generations is prior to provide load.
- Battery operates in discharging mode when generations don't provide enough power for load or in charging mode when load can't absorb power from generations whereas instant capacity C_{ins} is at admittable limitation (C_{min}=0.2C≤ C_{ins} ≤ C).
- APS isn't used to charge battery or aborb power from battery. The value of lack of power from APS is always less than admittable value P_{lpcp} (P_{lp}≤P_{lpcp}).

Because of above criterions, power flows in whole system can be clasified into the following scenarios:

Scenarios 1: generations provide enough power for load by themselves. In this case, load doesn't use power from battery and APS

Scenarios 2: Abundunt power from generations after providing for load power is used to charge battery

Scenarios 3: Generations don't provide enough power for load. Battery operates in discharging mode.

Scenarios 4 and 5: Generations don't provide enough power for load. Load consumes power from both battery and APS.

Scenarios 6 and 7: Generations don't provide enough power for load. Load consumes power from only APS.

Power flows in whole system are represented clearly in Fig. 3. Where, $\eta_{DC/DC1h}$, $\eta_{DC/DC2h}$, $\eta_{AC/DC1h}$, $\eta_{DC/AC2h}$ are efficiencies for converters.

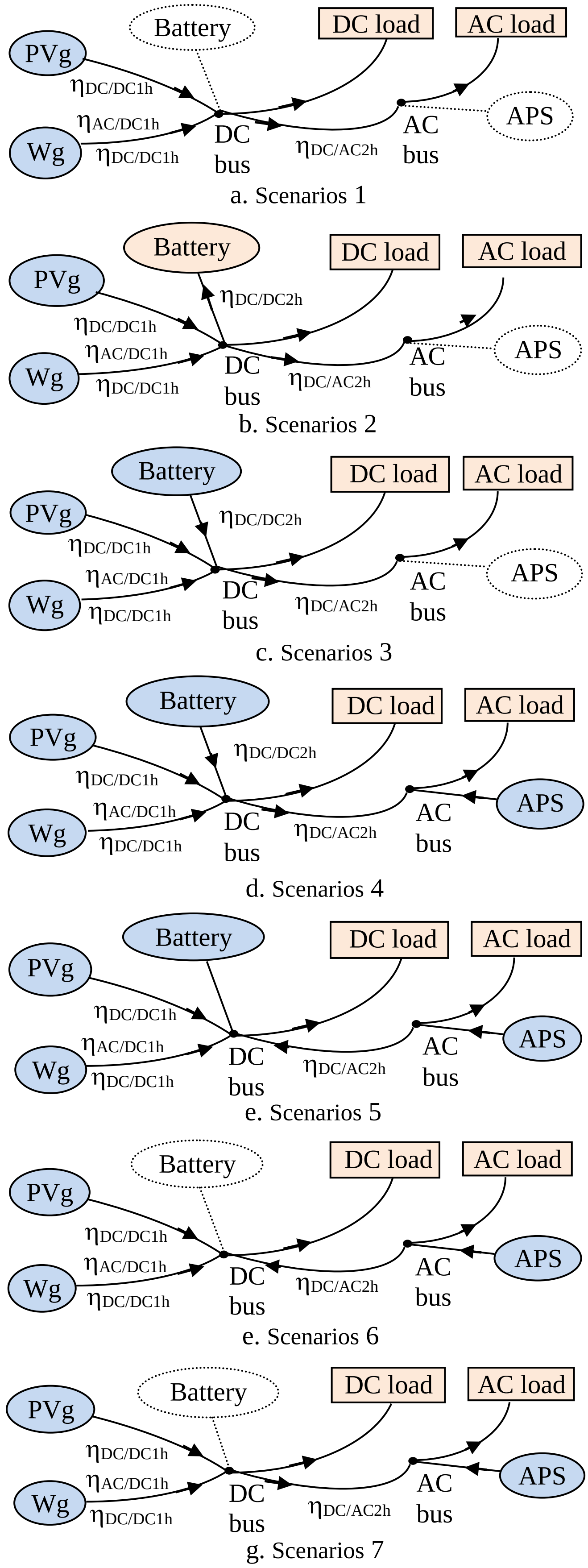

Fig. 3. Power flows in whole system.

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III. DETERMINE BATTERY CAPACITY

A. Proposed algorithm

In preliminary calculation, the value of power from generations can be received by a simple model basing on solar irradiance S, start-up wind speed $v_{cut\text{-}in}$, cut-out speed $v_{cut\text{-}out}$, rated speed v_r, rated power P_{rPVg} and P_{rW} at standard conditions.

- For PVg

Using half-fold diagram to calculate exact power at each instant time [13] or estimate power approximately [14], [15]:

$$P_{PVg} = P_{rPVg} \cdot \frac{S}{1000} \qquad (1)$$

- For Wg [3], [4]

$$P_{Wg} = \begin{cases} 0 & \text{when } v < v_{cut-in} \text{ or } v > v_{cut-out} \\ P_{rW} \cdot \left(\dfrac{v - v_{cut-in}}{v_r - v_{cut-in}} \right)^3 & \text{when } v_{cut-in} \le v \le v_r \\ P_{rWg} & \text{when } v_r \le v \le v_{cut-out} \end{cases} \qquad (2)$$

At i[th] time, total power $P_G(i)$ generates from generations:

$$P_G(i) = P_{PVg}(i) + P_{Wg}(i) \qquad (3)$$

Basing on data about DC and AC load, total equivalent load at i[th] time:

$$P_{load}(i) = P_{loadDC}(i) + \frac{P_{loadAC}(i)}{\eta_{DC/AC2h}} \qquad (4)$$

For battery, battery capacity can charge to $C_n(i)$ or discharge to $C_p(i)$ at i[th] time can be determined by time step Δt [3-6], [16]:

$$C_p(i) = C_{ins}(i-1).(1-\sigma) - \frac{(P_{load} - P_G(i)).\Delta t}{\eta_{DCDC2h} V_{DCbus}} \qquad (5)$$

$$C_n(i) = C_{ins}(i-1).(1-\sigma) + \frac{(P_{load} - P_G(i)).\Delta t}{V_{DCbus}}.\eta_{DCDC2h} \qquad (6)$$

Where:

$C_{ins}(i\text{-}1)$ is instant battery capacity at (i-1)[th] time.

Value of lack of power consuming from APS in scenarios 4 and 5 can be determined by Kirhoff law 1:

$$P_{lp}(i) = P_{load}(i) - P_G(i) - P_b(i) \qquad (7)$$

Discharging capacity from battery to DCbus can be determined by:

$$P_b(i) = (C_{ins}(i) - C_{ins}(i-1)).V_{DCbus} \qquad (8)$$

Value of lack of power in scenarios 6 and 7 can be determined by Kirhoff law 1:

$$P_{lp}(i) = P_{load}(i) - P_G(i) \qquad (9)$$

Basing on preliminary calculation, battery capacity C can be determined by a proposed algorithm in Fig. 4. New ideals for this algorithm is that only applies in half-isolation mode limiting received power from the grid and battery capacity step ΔC will be increased immediately if current capacity doesn't adapt to requirements.

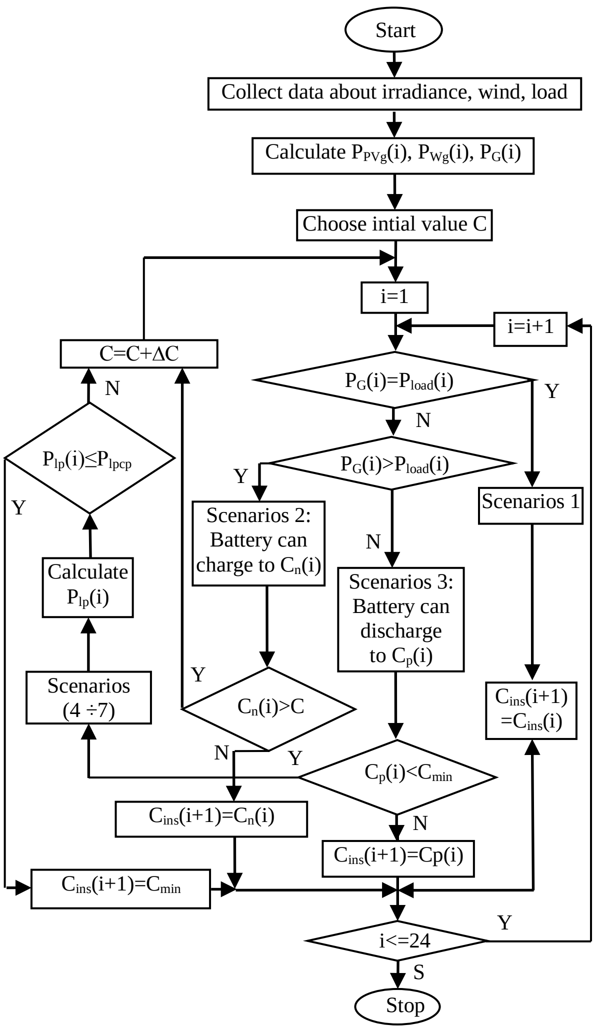

Fig. 4. Proposed algorithm to determine battery capacity.

B. Simulate the problem determining battery capacity and distributing power flows

Periodic time T=24 [h], time step Δt=1 [h], battery capacity step ΔC=10 [Ah], admittable value of power P_{lpcp} = 1600 [W].

Generations: Rated power of Wg is 5000W and PVg is 1360W. Generating diagrams of PVg and Wg are represented in Fig. 5.

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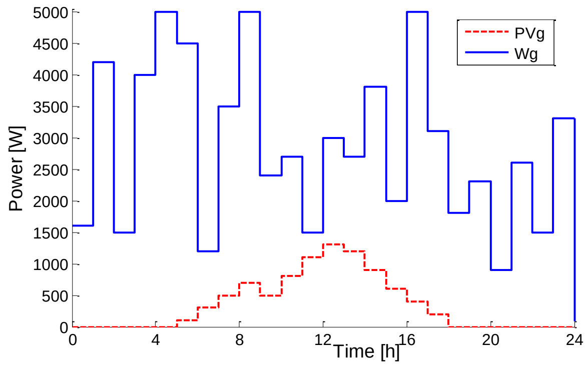

Fig. 5. Generating diagrams of PVg and Wg.

DC and AC load diagrams are represented in Fig. 6.

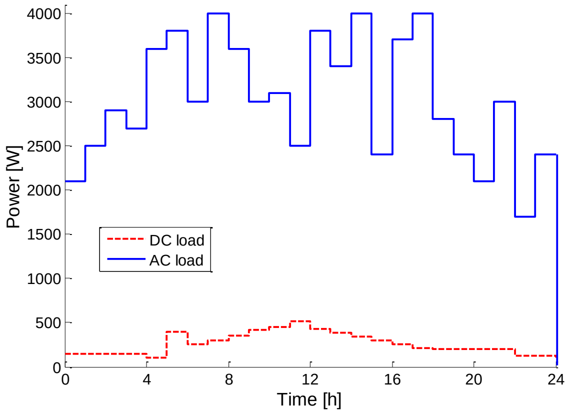

Fig. 6. DC and AC load diagrams.

Apply proposed algorithm in Fig. 4 for above data, suitable battery capacity resulting from program is 200 [Ah]. Use some local values of above suitable battery capacity to recalculate maximum value of P_{lp} and abundant power $P_{abundant}$ of generations. Results in TABLE. I show that 200 Ah is the most value for above input data.

TABLE I. RECALCULATE P_{LPMAX} AND $P_{ABUNDANT}$ FOR SOME LOCAL VALUES OF SUITABLE BATTERY CAPACITY

C [Ah]	180	190	200	210
P_{lpmax}[W]	1582.6			
$P_{abundant}$ [W]	117,1	67,5	0	0

Power generating from generations and battery, load power, lack of power P_{lp} diagrams corresponding C=200Ah are represented in Fig. 7.

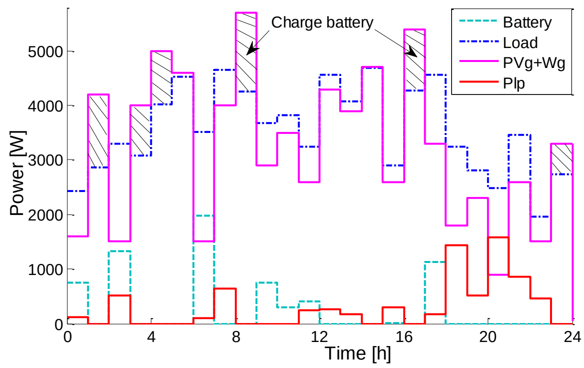

Fig. 7. Power generating from generations and battery, load power, lack of power diagrams.

Fig. 8 represents time ranges for charging and discharging battery, where positive power presents charging power and negative power presents discharging power.

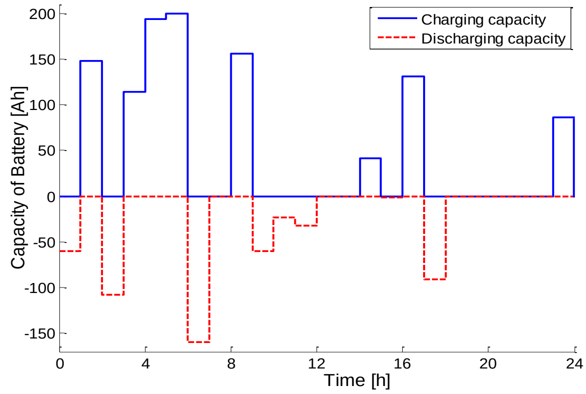

Fig. 8. Charging and discharging battery.

In Fig. 8, the battery operates in discharging mode in time range (0÷1), (2÷3), (6÷7), (9÷12), (17÷18)h and charging mode in time range (1÷2), (3÷6), (9÷10), (14÷15), (16÷17), (23÷24).

IV. EXPERIMENTAL DISTRIBUTION OF POWER FLOWS

A. *Experimental model*

Modules of PVg located in Thai Nguyen university of technology by Phoenix Solar Pte, Singapore are parameters shown in TABLE II. Parameters of battery are shown in TABLE III.

TABLE II. PARAMETERS OF PVg

Type	Kyocera KC85/Japan
Rated power [Wp]	1360 Wp

TABLE III. PARAMETERS OF BATTERY

Type	Lead-acid, Dong Nai N200
Nominal voltage	12 V
Capacity	200Ah

Structure model for PVg is represented in Fig. 9, where DC/DC converter is flyback type.

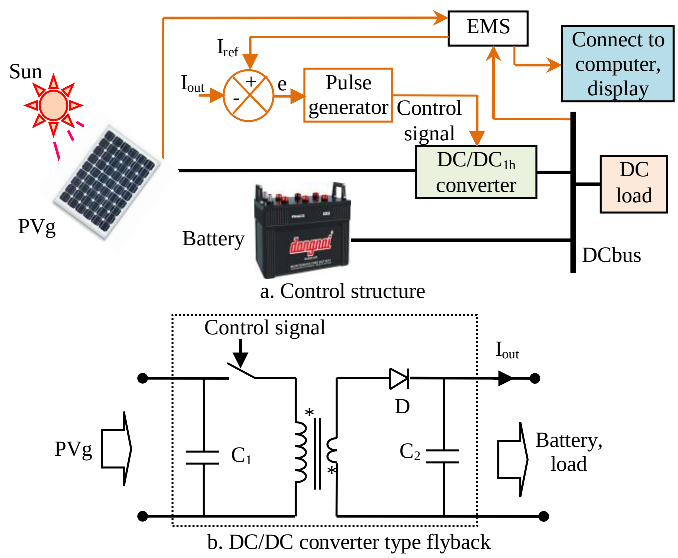

Fig. 9. Structure model for PVg.

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Experimental model for PVg is represented in Fig. 10. Where, load block has 4 compact lights (4x33W) and each light can be switch on or off invidually.

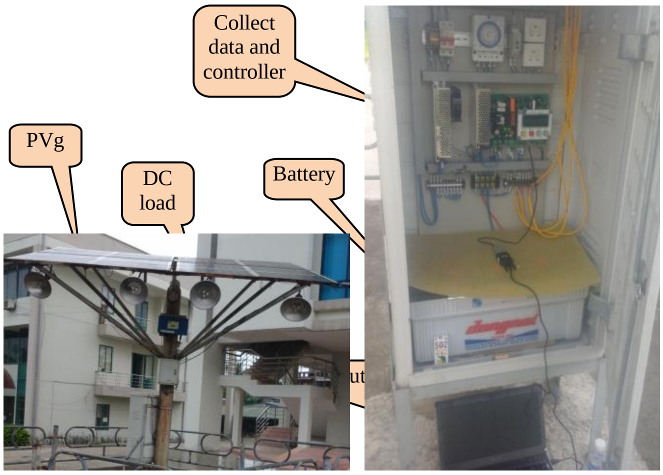


Fig. 10. Experimental model.

B. Experimental results

Reference current I_{ref} is installed to controller by buttons on board or computer. Maximum power point tracking in control program is only actived when output current of converter Iout is less than I_{ref}. Operation parameters can be observed online on display panel of control board and program "TRACKING PV SYSTEM PROGRAM" in computer using Visual Studio software version 10. At the end of observation process, the program will create a file collected data about the operation process.

Experimental time: from 8h15' to 8h43' on 11 September 2014, battery voltage is 12,8V. Operation scenarios are shown in TABLE IV.

TABLE IV. EXPERIMENTAL SCENARIOS

Operation time	Operation scenarios
From 8h15' to 8h21'	I_{ref} =16A, P_{loadDC}=0
From 8h21' to 8h27'	I_{ref} =10A, P_{loadDC}=0
From 8h27' to 8h33'	I_{ref} =10A, P_{loadDC}=33W
From 8h33' to 8h37'	I_{ref} =10A, P_{loadDC}=0
From 8h37' to 8h43'	I_{ref} =17A, P_{loadDC}=0

I_{ref}, current and voltage output converter diagrams are represented in Fig. 11.

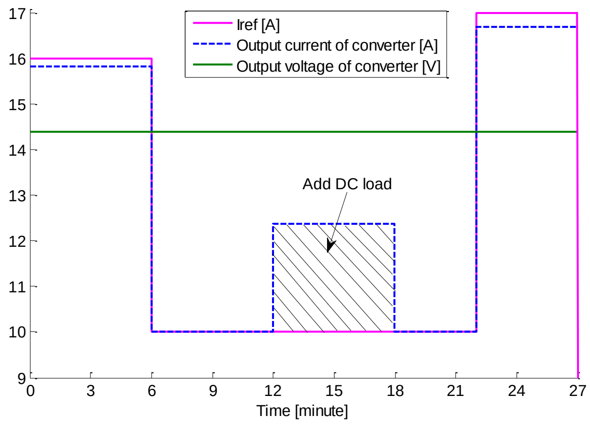


Fig. 11. I_{ref}, current and voltage output converter diagrams corresponding scenarios.

Results of "TRACKING PV SYSTEM PROGRAM" in 27 minutes are represented in Fig. 12. Where, the red curve represents input power and the green curve represents output power of the converter.

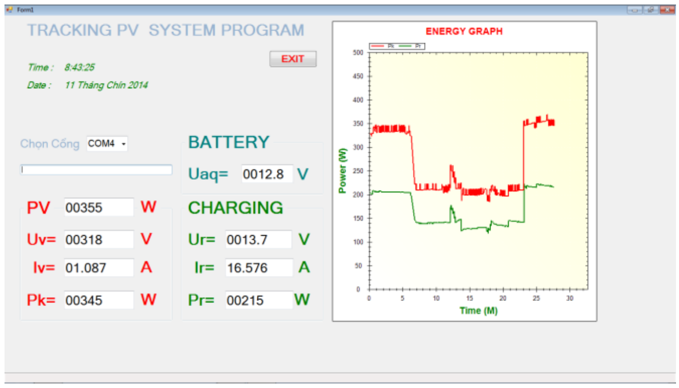
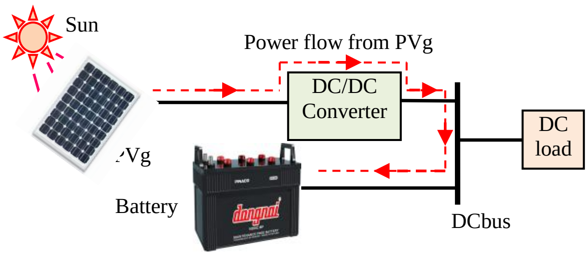


Fig. 12. Results of observation program.

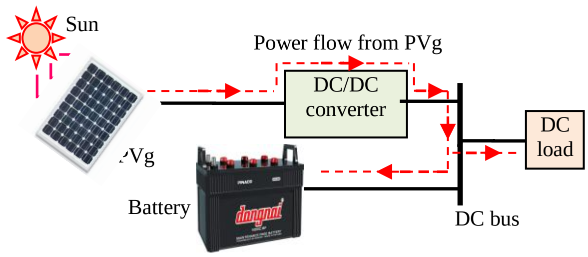
Results from control program are shown:

- Converter only exploited power from PVg in time ranges (8h15'÷8h21'), (8h21'÷8h27'), (8h33'÷8h37') and (8h37'÷8h43') to charge battery. After changing Iref, input and output power curves of the converter changed pulse to track energy requiments.
- From 8h27' to 8h33', Iref was hold in constant by 10A whereas added a 33W light load at 8h27'. Immediately after adding load, EMS hadn't changed pulse so input and output power curve of PVg was built-up corresponding 33W. After transient time, EMS changed pulse control to take output current converter to Iref and power charging battery curve dropped corresponding 33W. It showed that it has amount of power from PVg shared partial power into light, partial power into battery.

Power flows controlled in all operation modes of experimental model are represented in Fig. 13.



a. Charging battery and not adding load



b. Both charging battery and adding load

Fig. 13. Distribution of power flows in experimental model corresponding to scenarios.

V. CONCLUSION

Operating hybrid generations in half-isolation mode to receive support from grid but not depending much on the grid can provide power for load in site and take some benefits such as reducing transmition power loss and pressure on the national power system. This is also the future model for all power systems.

Experimental model showed that converters can help us control power flows between all elements flexibly and adapt to many different requirements.

Proposed algorithm determining battery capacity basing on distribution of power flows in hybrid generations in half-isolation mode can help system adapt to load more actively. The program basing on proposed algorithm collects multiple sets of data to evaluate the best value for battery or optimal battery capacity.

When input data (wind speed, solar irradiance) can be predicted, above program will help operator calculate distribution of power flows for each element or make operation plan for whole system.

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