# Decentralized Battery Energy Management for Stand-Alone PV-Battery Systems

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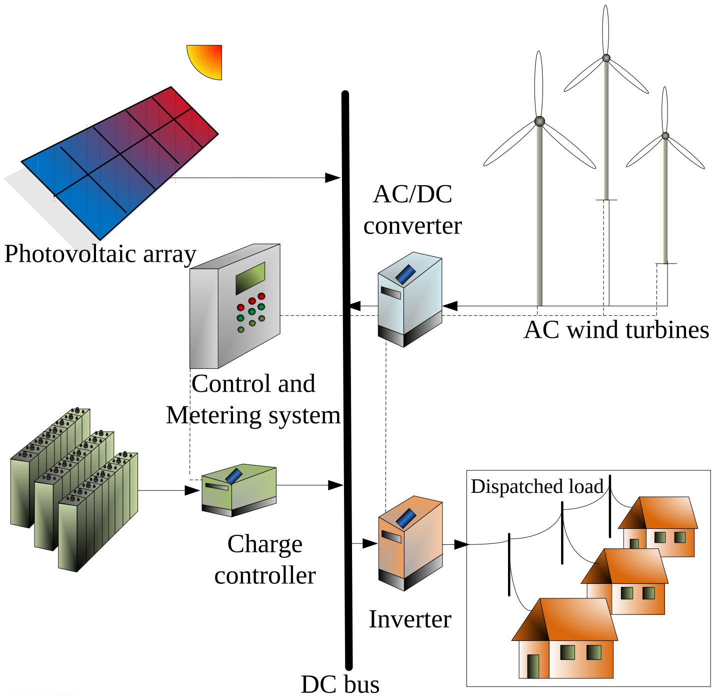
# Outline

- A key of stand-alone renewable energy systems… "Battery management"
  - A traditional battery control method
  - Decentralized battery storage control methods
  - Decentralized Battery Energy Management (DBEM) method
- Optimization of a stand-alone PV-Battery system with the DBEM method
- Case study
  - Results and Discussions
- Conclusions
- Prototype
- Publication

# A key of stand-alone renewable energy systems…

# "Battery management"

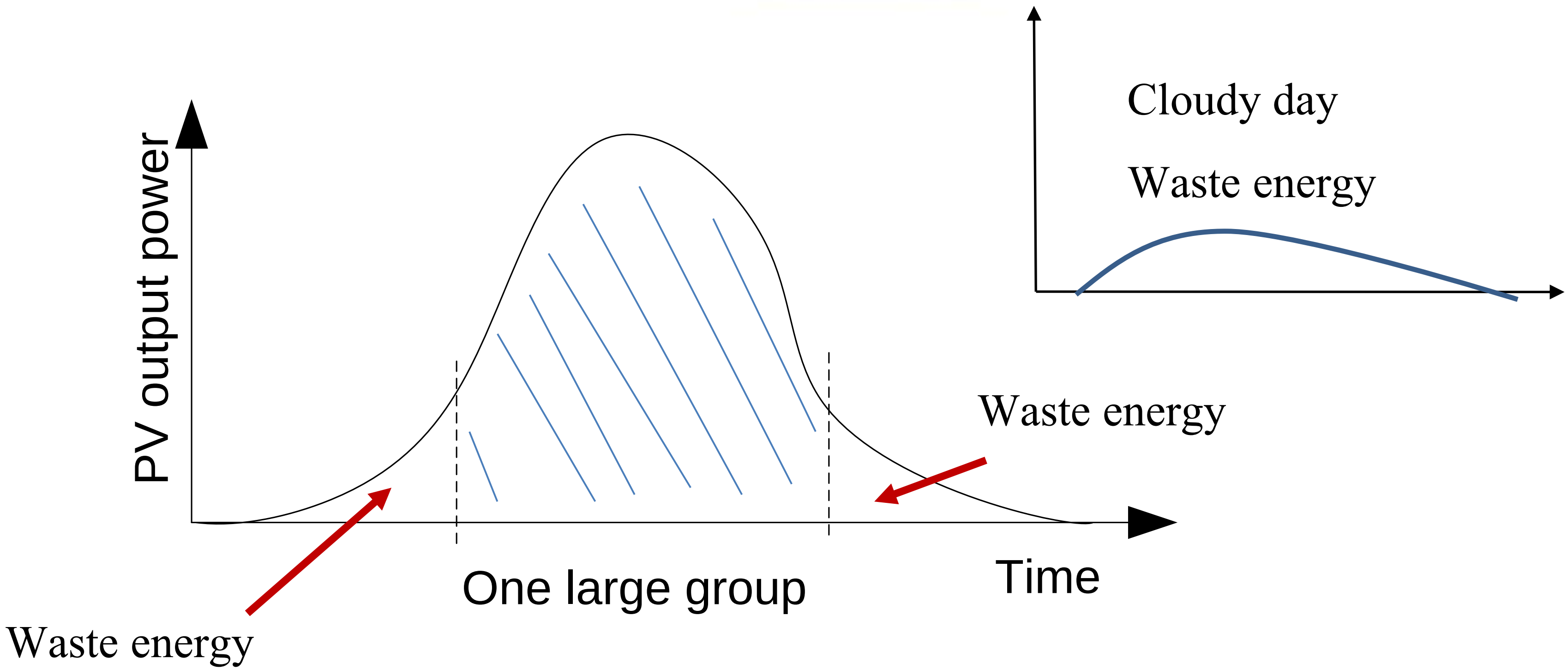
A traditional battery control method is a single charge controller by grouping all batteries into parallel strings.




**Drawbacks:**

- Batteries in the same string must have the same capacity and initial State of Charge (SOC) .
    - If a battery has a higher initial SOC, it would be charged faster and have gassing while other batteries in the string are still undercharged, leading to the reduction of battery lifetime.
- Due to limitation of charging power levels, therefore, the energy produced will be wasted **and the wasted energy will increase in larger battery energy storage systems**.

# Charging process situation




Minimum current limit of batteries

# A key of stand-alone renewable energy systems…

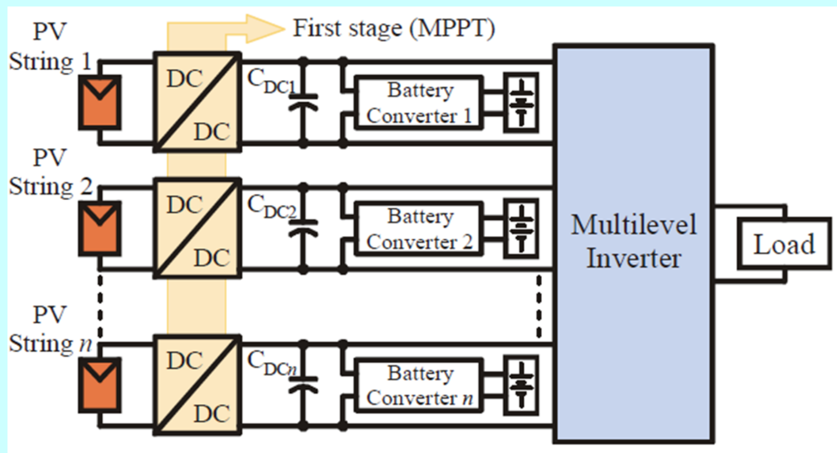
# "Battery management"

Decentralized Photovoltaic (PV) and battery system with multilevel inverter

-Better performance

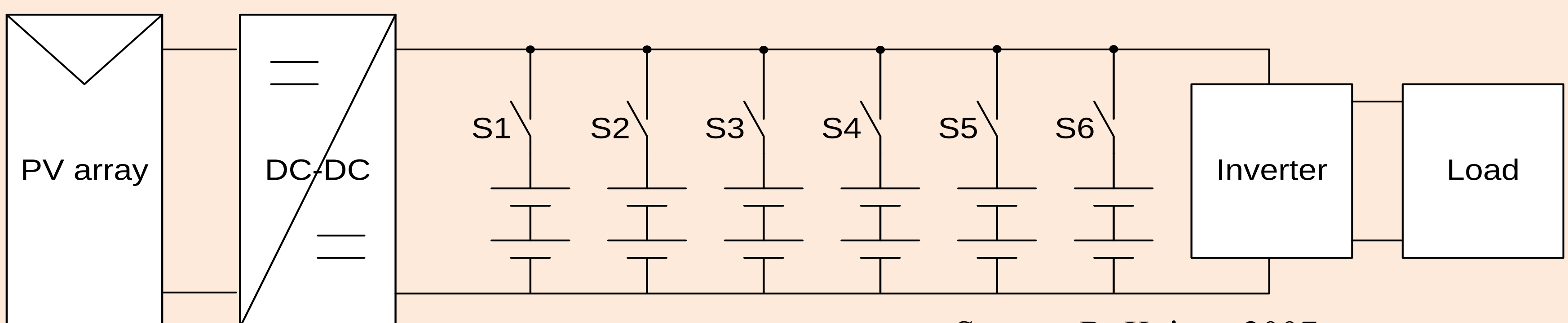
-Longer lifetime of battery storage systems

**However, larger systems will be more expensive.**



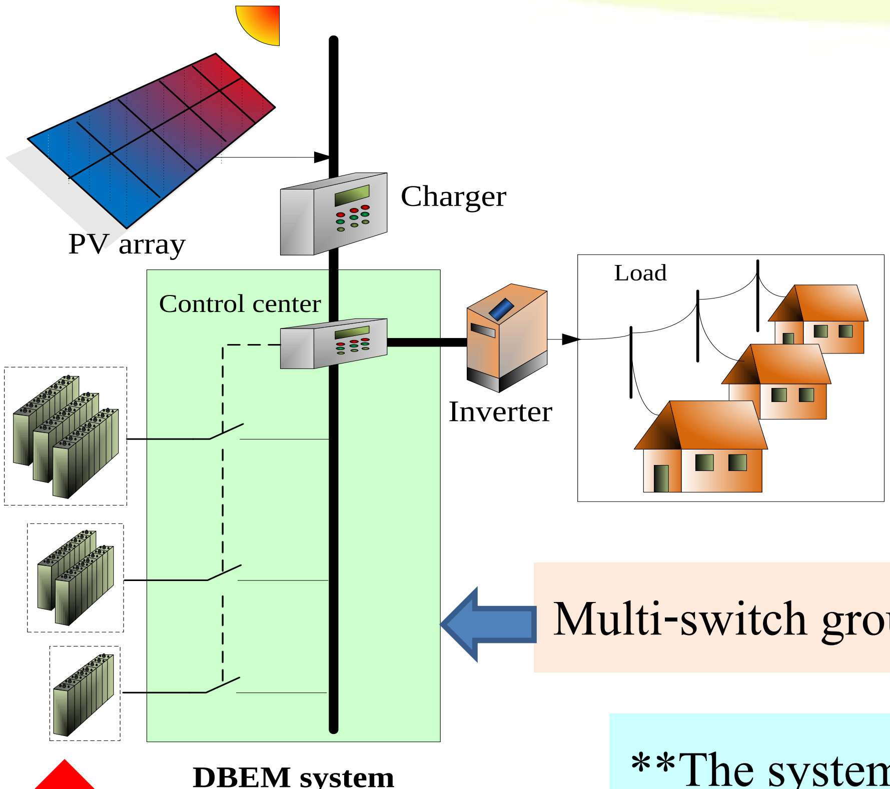

Source : M. I. Desconzi etc., 2010

Decentralized battery storage control system




Source: R. Kaiser, 2007

# Decentralized Battery Energy Management (DBEM) method




Multi-switch groups

Different group sizes

**Objectives:**

- To minimize ….
  - loss of power supply
  - cost of energy
  - wasted electrical energy
- To prolong battery life

**The system should be practical and economical for operation.***

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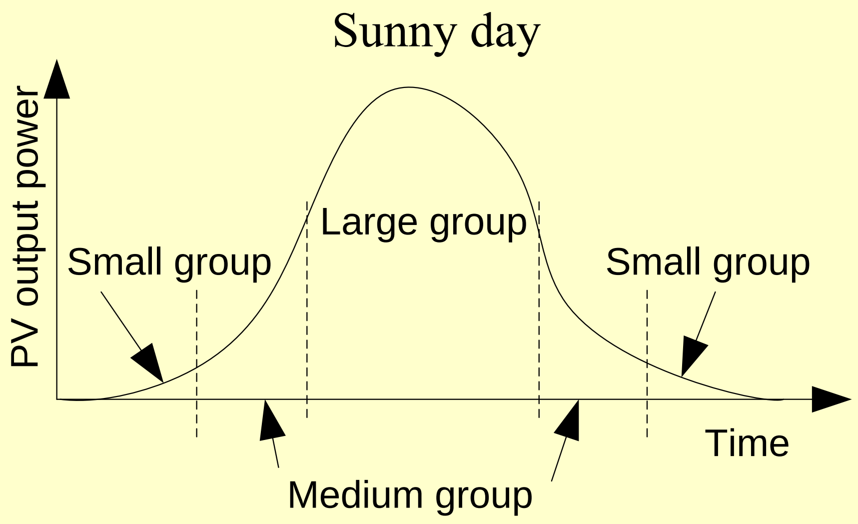
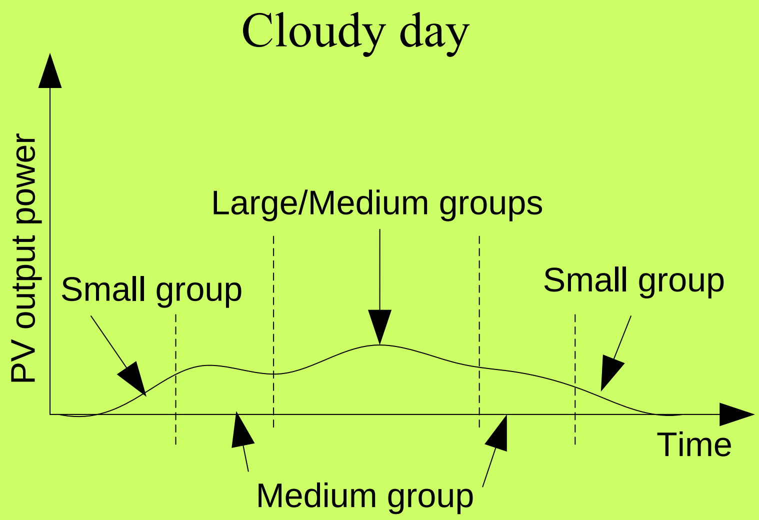
# Charging process situations

**Decentralized Battery Energy Management (DBEM) method**

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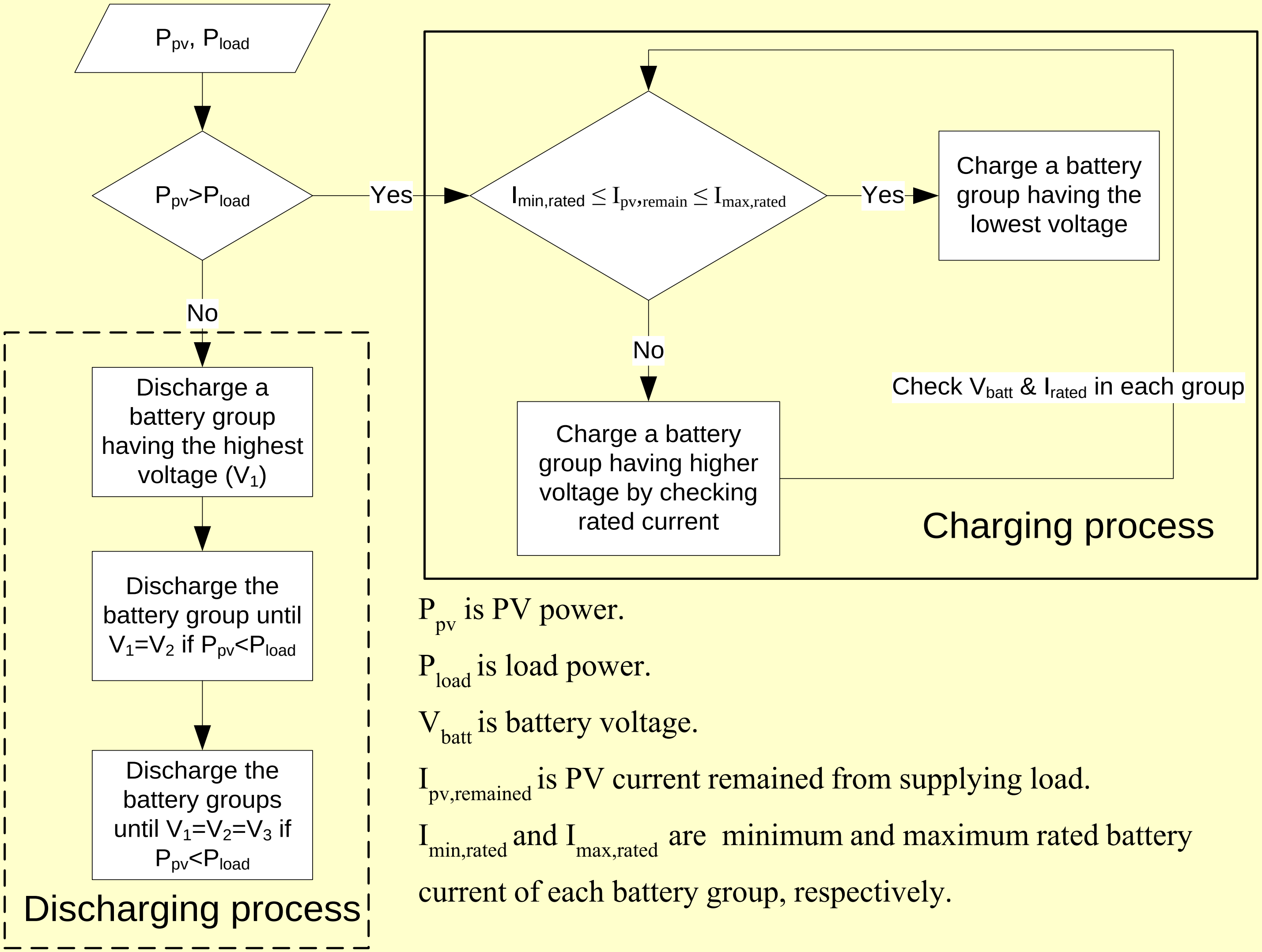
# Charging and discharging processes of the DBEM method




$P_{pv}$ is PV power.

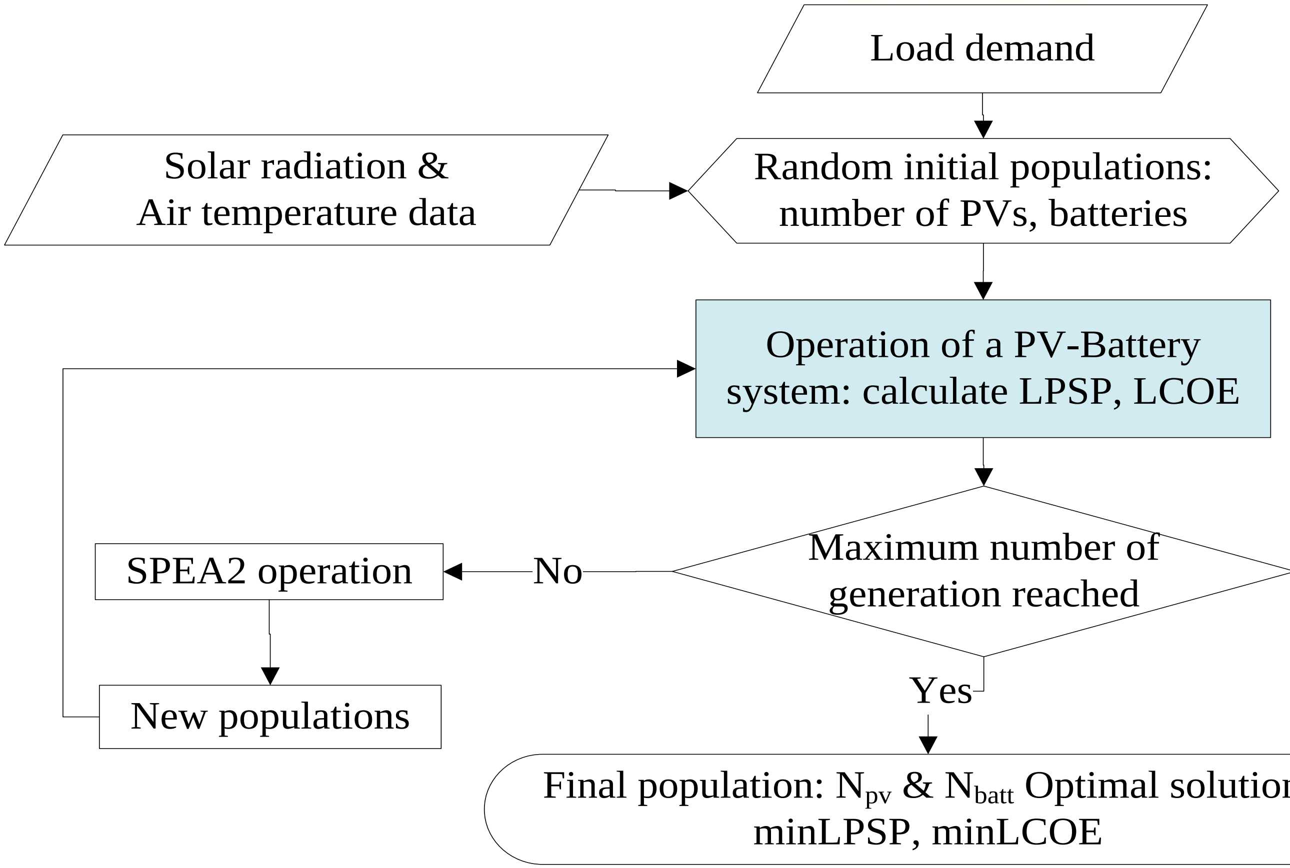
$P_{load}$ is load power.

$V_{batt}$ is battery voltage.

$I_{pv,remained}$ is PV current remained from supplying load.

$I_{min,rated}$ and $I_{max,rated}$ are minimum and maximum rated battery current of each battery group, respectively.

# Optimization of a stand-alone PV-Battery system with the DBEM method




**Objectives:**

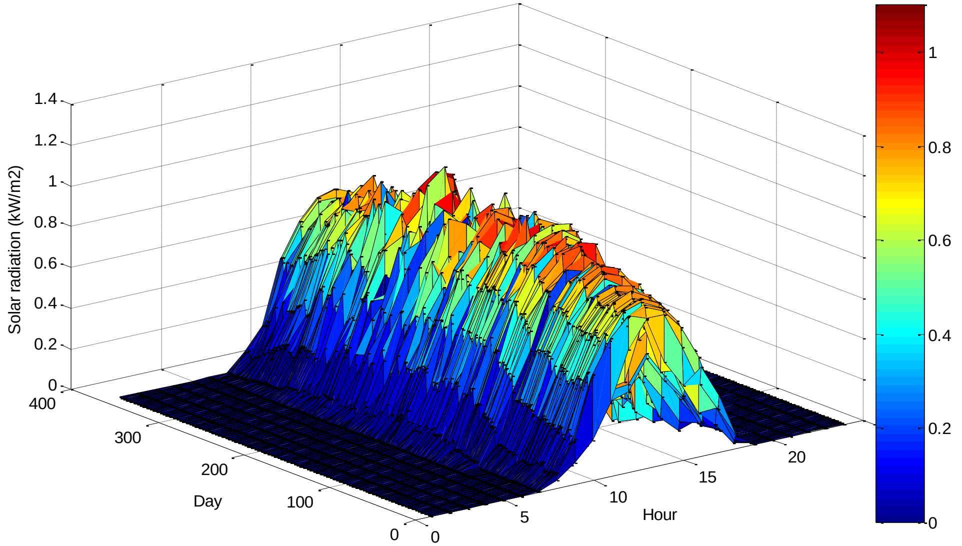
✓ To minimize Levelized Cost of Energy (LCOE)

✓ To minimize Loss of Power Supply Probability (LPSP), $0 \leq LPSP \leq 1$.

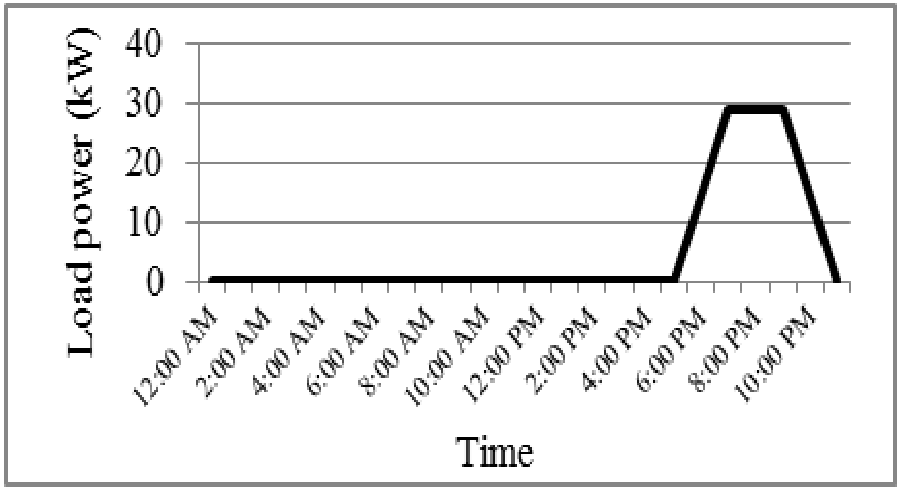
Optimization method: Strength Pareto Evolutionary Algorithm 2 (SPEA2)

# Case study

Average hourly solar radiation in Thailand




A load profile in a Thai rural area




Estimated costs and lifetime of system components

| Components | Initial capital cost | Replacement cost | O&M cost | Lifetime |
|---|---|---|---|---|
| PV module including Tax<br>- Installation cost and other components | 15,000 Baht per module<br>20% of total PV system cost | 15,000 Baht per module | 0.5% of ICC | 25 years |
| Battery, 550 Ah | 12,500 Baht per cell | 12,500 Baht per cell | 3% of ICC | 1000 cycles |
| Bi-directional converter and system control | 22,550 Baht per kW | 22,550 Baht per kW | 3% of ICC | 15 years |
| Charge controller | 190 Baht per Ampere | 190 Baht per Ampere | 3% of ICC | 15 years |

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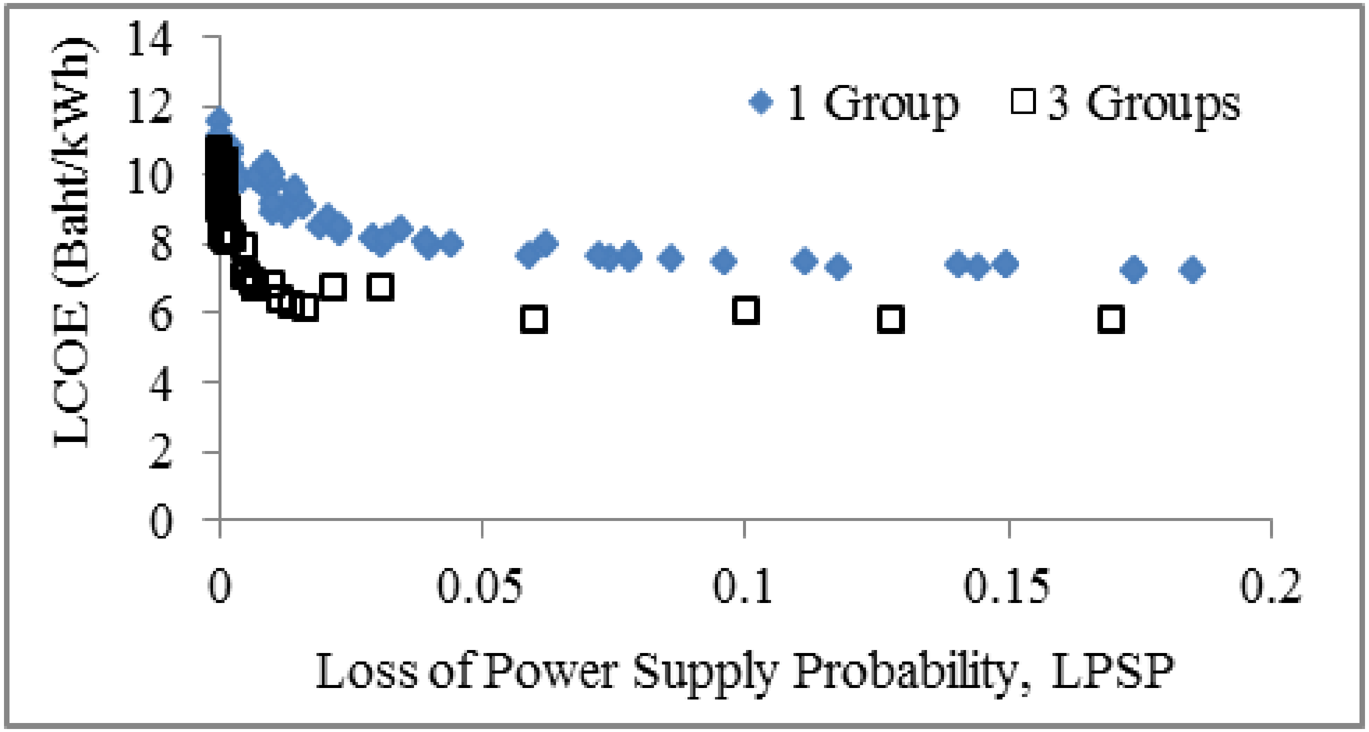
# Results and Discussions

LPSP and LCOE of stand-alone PV-Battery systems




The fractions of the three groups were set as 1/6, 1/3 and 1/2 to be small, medium and large groups, respectively.

# Results and Discussions

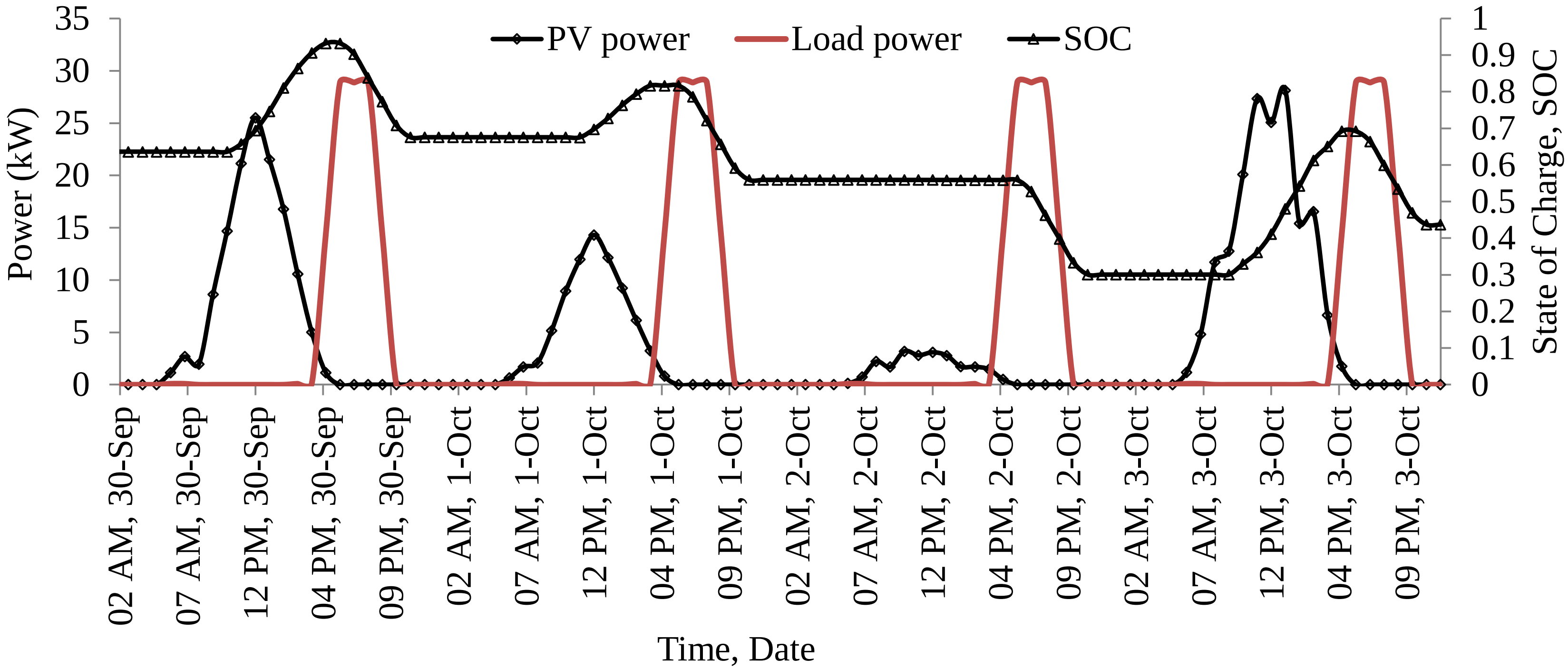
## Comparisons between one and three battery groups

| Particular | Battery groups | | | | |
|---|---|---|---|---|---|
| | *1 group* | | | *3 groups* | |
| Loss of power supply probability, LPSP | **0%** | 1% (≈ 87 hrs) | 32.11% (2,813 hrs) | **0%** | 1% (≈ 87 hrs) |
| PV capacities (kWp) | 35 | 31 | 20.5 | 20.5 | 13 |
| Battery capacities (kWh) | 356.4 | 237.6 | 316.8 | 316.8 | 237.6 |
| Annual PV energy (MWh/year) | 67.62 | 59.89 | 43.5 | 43.5 | 25.12 |
| Annual total waste energy (MWh/year) | 25.33 | 17.6 | 1.40 | 1.21 | 0.32 |
| Annual overall energy efficiency of systems | 62.5% | - | - | 97.22% | - |
| LCOE (Baht/kWh) | 10.86 | 9.80 | 9.64 | 9.35 | 6.81 |

- The 3-groups system has lower PV and battery capacities and lower annual total wasted energy, leading to higher overall energy efficiency and lower LCOE.
- The 3-groups system has higher reliability than the 1-group system.

# Results and Discussions

The SOC and PV power supply for load demand, of the system using one battery group




Cloudy days in rainy season

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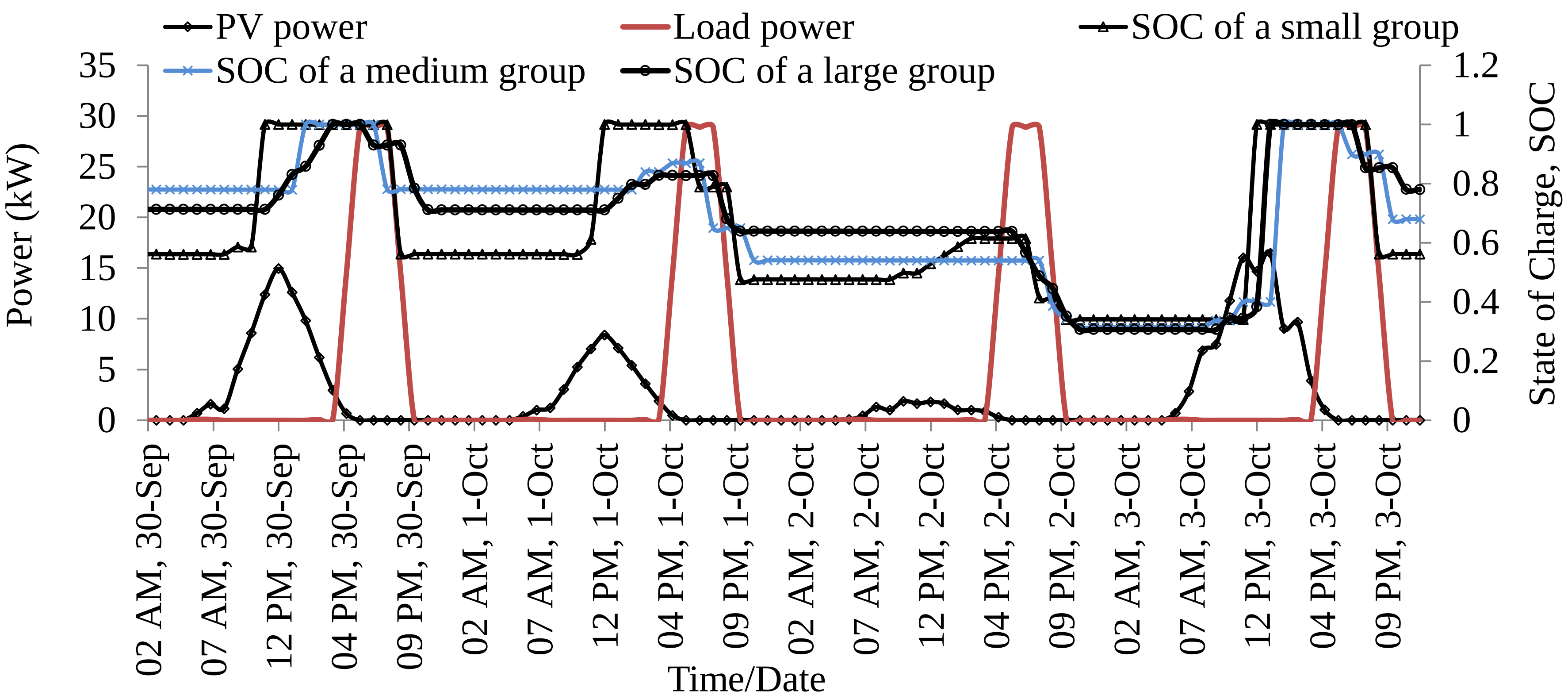
# Results and Discussions

The SOC and PV power supply for load demand, of the system using three battery groups




Cloudy days in rainy season

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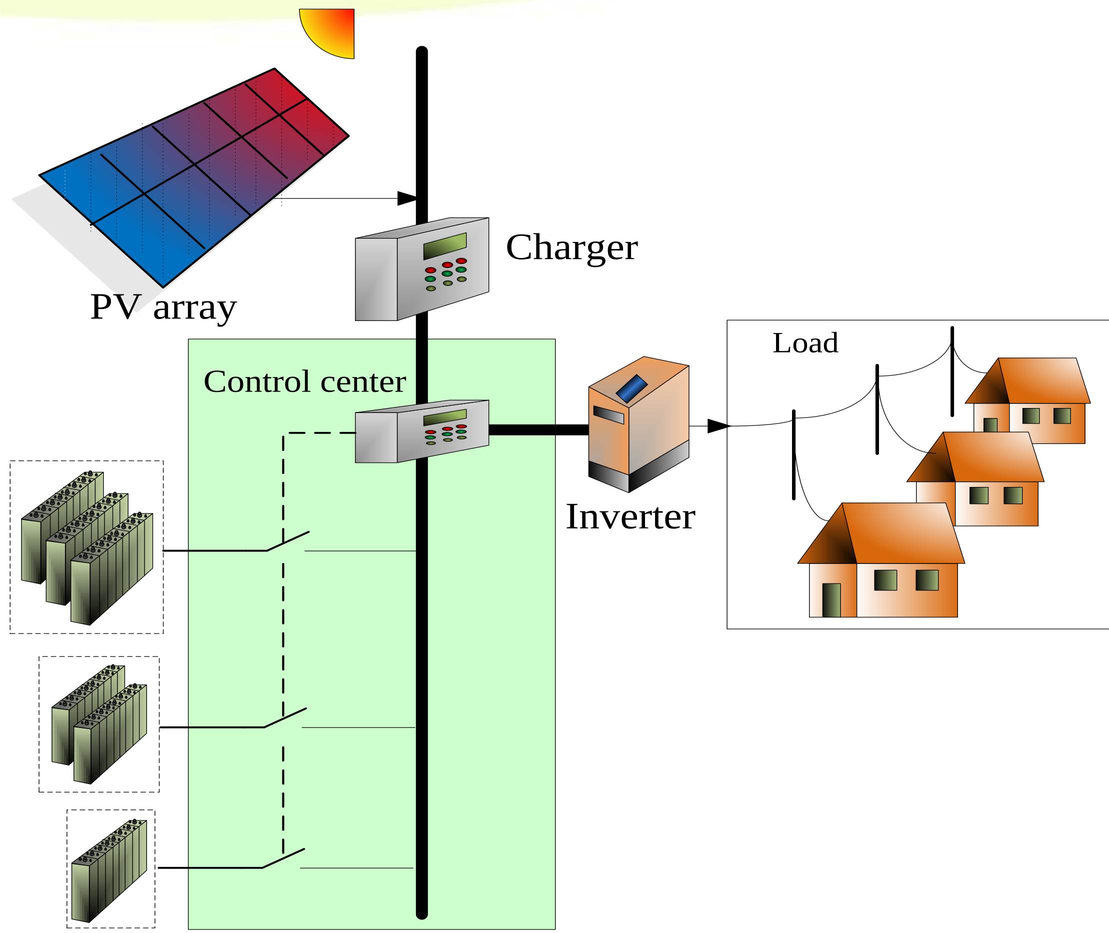
# Conclusions

- The DBEM method is proposed for minimizing loss of power supply, cost of energy and wasted electrical energy.
- From SPEA2 optimization and energy simulation,
  - the PV system using the DBEM method has **higher reliability and energy efficiency** than the system using one battery group,
  - while decreasing the number of PV and battery modules leading to **lower LCOE and waste energy**.
- The DBEM method can be applied for renewable energy systems such as wind turbines.
- A DBEM prototype, of which controller and circuit are uncomplicated, has being designed and built.

# Prototype System

**Specification:**

- For a PV system of 3 kWp
- Using a micro processor to be a center controller between a charger and an inverter
- Data monitoring via Ethernet
- Upload data via USB
- Sleep mode for saving energy

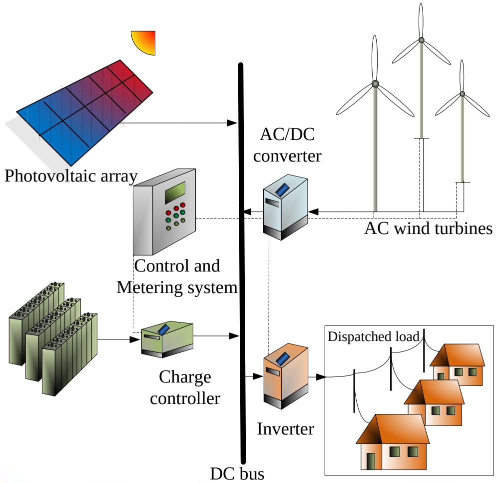


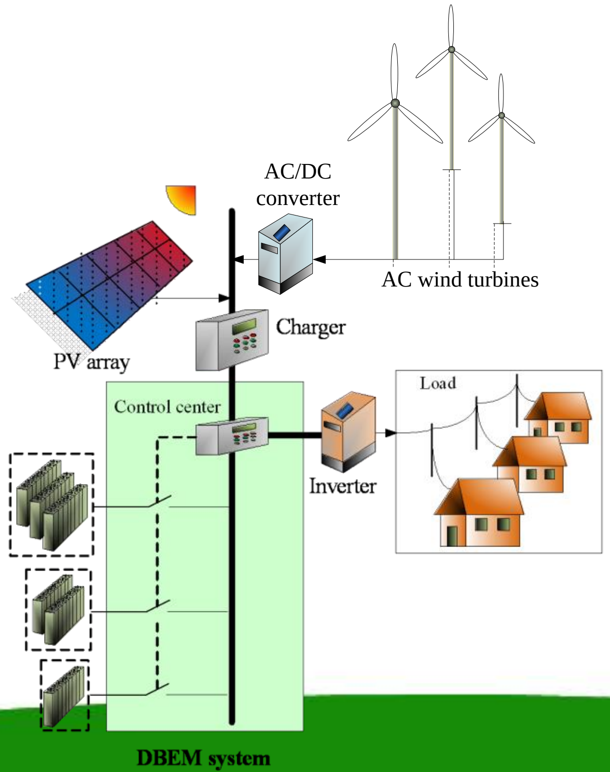

**DBEM system**

# Publications

- **U. Sangpanich**, “Optimization of Photovoltaic Systems Using Batteries for Peak Demand to Improve Rural Electrification, CIGRÉ Canada Conference 2015 Proceeding, Canada, August 31-September 2, 2015
- **U. Sangpanich**, “A Novel Method of Decentralized Battery Energy Management for Stand-Alone PV-Battery Systems,” in The 6$^{th}$ IEEE PES Asia-Pacific Power and Energy Engineering Conference (IEEE PES APPEEC 2014), 2014.

# Thank you very much for your attention.

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