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CONCEPT OF TWO-LEVEL OPTIMIZATION OF A HYBRID ENERGY SUPPLY SYSTEM

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Abstract
The paper deals with the problems of selection, sizing and obtaining energy management strategy in a hybrid energy supply system. The system consists of a number of energy storages and generators. The two-level optimization using genetic algorithm is presented. The algorithm work was considered in two states: static – while optimizing a HESS configuration with energy management strategy and dynamic while optimizing the strategy in real time. The aim of these research is to develop a method for selecting the optimum configuration of devices in a HESS and to optimize energy management strategy in real time, allowing for interference in the system configuration.

Introduction

Energy storage systems (ESS) are becoming one of the most important components that change overall system performance in various applications, ranging from the power grid infrastructure, electric traction system [1], to electric vehicles [2] and portable electronics. Yet, a homogeneous ESS has limited characteristics in terms of cost, energy and power density, lifetime, etc., by the energy storage technology that comprises the ESS. That issue can be solved by creating hybrid energy supply system (HESS) that contains not only different kinds of energy storages but also generators. That creates problems of selecting and sizing the devices and obtaining the energy management strategy, with which the paper deals.

The optimization of the HESS, consisting of several energy storage and power generation devices which have different dynamic models, can be inefficient without simultaneous optimization of energy management strategy. HESS sizing optimization was carried out in [3-5]. The interdependence between sizing and power split optimization of hybrid energy storage systems was described in [5]. To solve that problem, the two-level optimization algorithm was developed. The scheme of the DC line system considered in the research is shown in Fig. 1. On the first level of algorithm the optimization of the system configuration is carried out. In this calculation the initial energy management strategy is used. The result of the first level of calculations is power vector in which every value represents the power of each device in the system. On the second level, the energy management strategy is optimized. After selecting the best strategy for particular setup, it is given back to first level and the process is repeated.

Such an approach to the problem of selection and power control allows not only the selection of the optimal devices power and minimize system cost, but also optimal utilization of individual components even after making changes to the system configuration. This allows disconnecting and adding devices to the system without interference in energy management strategy. Different, fixed energy management strategies for HESS were described in [6-7]

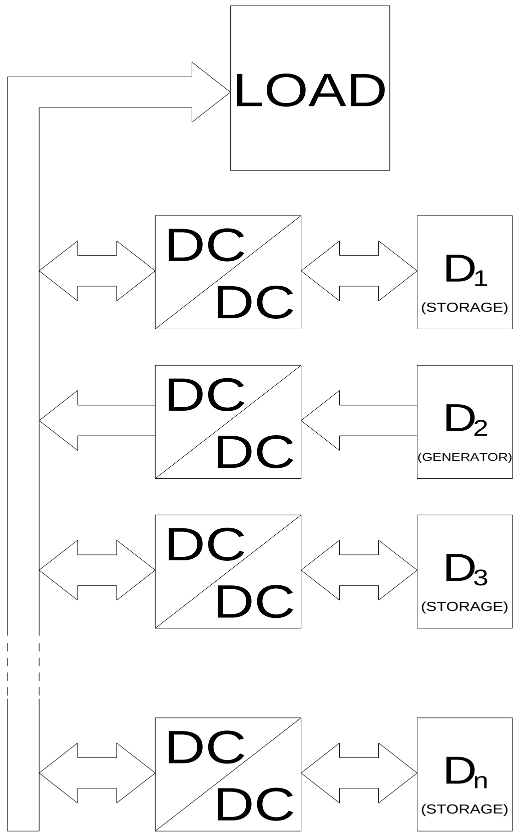

Fig. 1. Scheme of the HESS.

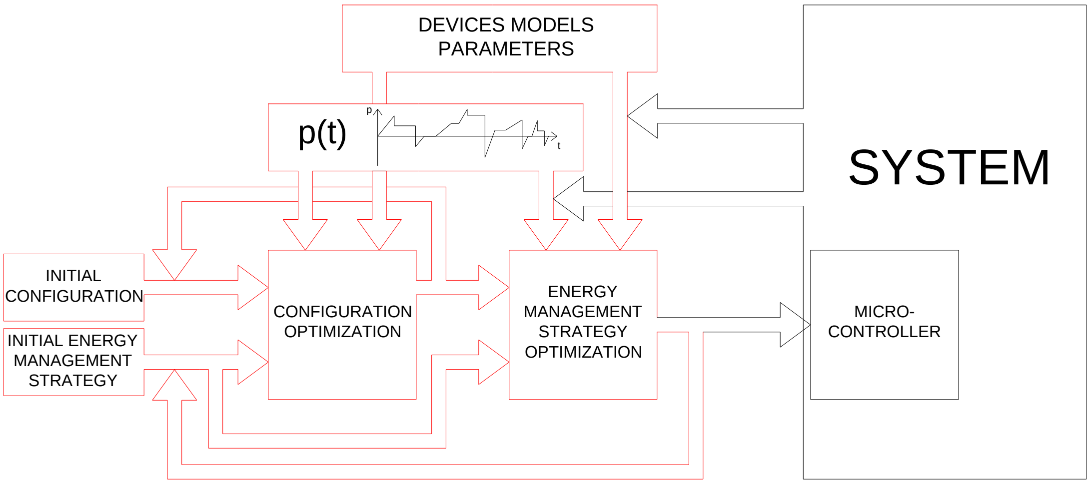

Fig. 2. Block diagram of the optimization system with an indication of elements working in the static state.

Static state work

The configuration selection is carried out during offline algorithm work, before connecting the strategy optimization segment to microcontroller (Fig. 2). The algorithm requires theoretical power graph and parameters of devices taken into account in the optimization process.

The following mathematical notation of optimized values was accepted:

In the segment defining the HESS configuration, the rated power of each device is optimized, regardless of whether they are energy storages or generators. The output from that segment is the power vector $\boldsymbol{P}$ containing the powers of individual devices in the system.

$$\boldsymbol{P} = [P_1\ P_2\ P_3\ \dots\ P_n] \tag{1}$$

The output of the energy management optimization segment is a set of functions of power distribution coefficients γ_i for each device. Subsequently they are given as an input to the microcontroller which executes the real time power control. The power control algorithm was described in [8,9].

$$\gamma_i = f\left(P_{0max}, \frac{dP_0}{dt}_{max}, SOC_1, SOC_2, SOC_3, \dots, SOC_n\right) \tag{2}$$

Where P_{0max}, $dP_0/dt_{\ max}$, are respectively maximum load power and maximum load power growth in time. $SOC_{1,2,..n}$ is state of charge of each energy storage. The optimization algorithms require typical load power use $p(t)$ and parameters of devices taken into account in system configuration. For the configuration optimization segment the following input parameters were accepted.

Energy storages

- Maximum power P_{imax};
- Maximum power growth in time $(dP_i/dt)_{\ max}$;
- Specific power $s_{Pi}=(P/m)_i$;
- Specific energy $s_{Ei}=(E/m)_i$;
- Power density $d_{Pi} = (P/V)_i$ or energy density $d_{Ei}=(E/V)_i$;
- Cost per mass $c_{mi}=(cost/m)_i$, power $c_{Pi}=(cost/P)_i$ or energy $c_{Ei}=(cost/E)_i$;
- Initial state of charge SOC_{0i}.

Generators

- Maximum power as a function in time $P_{imax}\ (t)$;
- Maximum power growth in time $dP_i/dt_{\ max}$;
- Specific power $s_{Pi}=(P/m)_i$;
- Power density $d_{Pi} = (P/V)_i$;
- Cost per mass $c_{mi}=(cost/m)_i$, or power $c_{Pi}=(cost/P)_i$
- Energy cost $c_{Egi}=(cost/E)_i$.

Using listed values and genetic algorithm the best configuration in terms of cost, mass and volume is established. The necessary condition to fulfill by devices setup is providing power to the load according to $p(t)$.

The energy management optimization segment requires the following input parameters:

Energy storages

- Maximum power P_{imax};
- Maximum power growth in time $dP_i/dt_{\ max}$;
- Specific power $s_{Pi}=(P/m)_i$;
- Specific as a function of load power $\eta(Po)$;energy $s_{Ei}=(E/m)_i$;
- Efficiency characteristic
- Initial state of charge SOC_{0i}.

Generators

- Maximum power as a function in time $P_{imax}\ (t)$;
- Maximum power growth in time $dP_i/dt_{\ max}$;
- Energy cost $c_{Egi}=(cost/E)_i$;
- Efficiency characteristic as a function of load power $\eta\ (Po)$.

The optimization is subject to efficiency and costs of energy consumed during a single cycle. It is based on the genetic algorithm, as in the previous case.

Dynamic state work

During online system work for chosen configuration (Fig.3) the energy management strategy continues to be

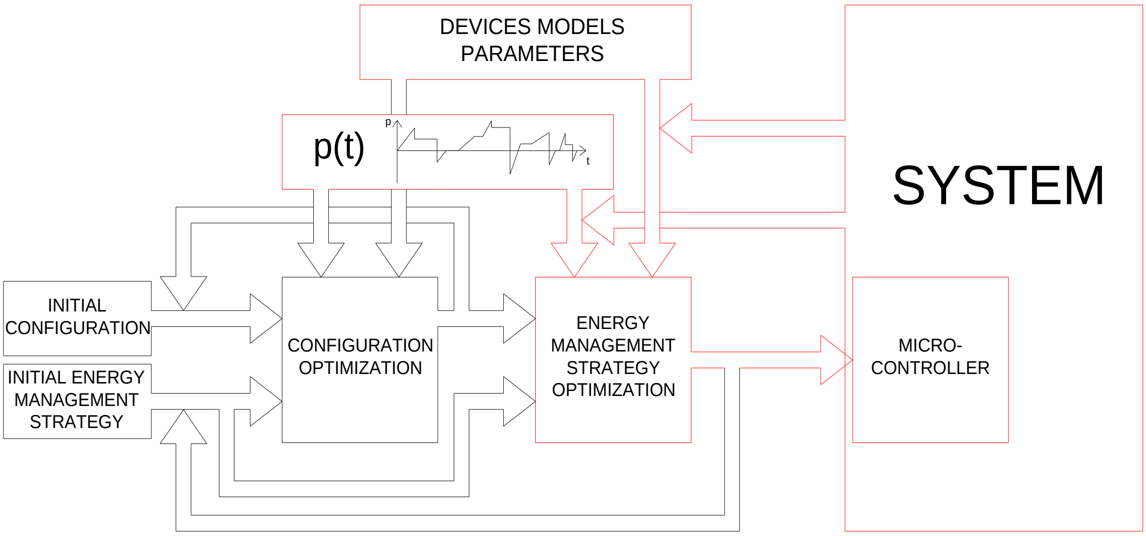

Fig. 3. Block diagram of the optimization system with an indication of elements working in the dynamic state.

optimized, but the parameters of the device and load power graph are based on measurements.

Designated values of γ_i are given as an input to the micro-controller which executes the real time power control. Basing on the power graph, for accepted time interval, the algorithm plan the energy management strategy for future. Due to that, in the case of changes in the system configuration, there no need to change the strategy because it is not fixed but planned in real time.

All values required to optimize the energy management strategy can be established by measurements.

Conclusions

The aim of the research is to develop a method for selecting the optimum configuration of devices in a HESS consisting of energy storages and generators. Another element of the is to optimize energy management strategy in real time, allowing for interference in the system configuration. This work is a theoretical description of the solution of these problems. The use of two-level genetic algorithm optimization and the distribution system operation on static and dynamic states was accepted. The next stages of work will be simulation and computational research for adopted algorithms. The laboratory stand implementation of the dynamic power control system is being carried out.

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