CLASSIFICATION OF ENERGY MANAGEMENT SYSTEMS FOR RENEWABLE ENERGY HYBRID SYSTEMS

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ABSTRACT: This paper presents a classification of energy management systems (EMS), in order to work out differentiated realization possibilities with detailed characteristics for further discussions and development strategies. A short overview of the state of the art is used to point out the pro and cons of methods used for control and management systems, especially for PV energy supply systems [1, 3, 4] with a high portion of renewable energy converter. This comparison allows working out the essential characteristics with a focus on their capabilities for a usage in renewable PV energy hybrid systems, especially with respect to the stochastical behaviour of some converter as well as consumer load. Basing on this, the authors present a worked out proposal for a generalized formulation of the structure of such energy management systems, followed by detailed explanations and discussions. This structure could be a helpful tool for future developments and perhaps give the chance for common discussion standards. The basic structure of the presented EMS consists of three important modules, the forecast-module, the optimization-module and the demand-side management-module, which are also classified in detail.
Keywords: Plant Control, Stand-alone PV Systems, Energy Management, Hybrid System, Classification

1 INTRODUCTION

In conventional system management strategies for hybrid energy systems a present optimization is realized by measurement of relevant values. The operation of controllable energy generators, the charge of the battery as well as the connection of renewable generators are effected by ideal values, by rules of thumb or by a limit value regulation considering interior factors. The points of connecting and disconnecting the consumer load are set at a certain percentage system load against battery state of charge, battery voltage, line frequency, capacity-frequency-characteristic curves, and load of the diesel generator or periodic specified point of time. [1]

At the simple management strategies usually consumers are not included in EMS. Information about future energy flows are not included in easy control strategies.

This deficit makes it understandable that a new kind of EMS has to accomplish further requirements in comparison to conventional system management strategies. [2]

2 BASIC STRUCTURE OF AN EMS FOR RENEWABLE ENERGY SYSTEMS

The basic structure of the presented EMS consists of three important modules, the forecast-module (FM), the optimization-module (OM) and the demand-side management-module (DSM), which are also classified in detail. All three modules can be considered and classified in different detailed levels. The forecast-module generates the future schedule of potential energy production of the renewable energy generators (solar and wind energy). The forecast-module can be built on in different ways. Three basic types are differentiated and presented precisely. The main task of the EMS is to improve the operation of the energy system. The classification of different EMS depends substantially on the functionality of the optimization-module. According to this the objective function and side conditions of the optimization task (OT), the optimization process, the length of the optimization interval and the structure of the optimization process can be distinguished. In off-grid PV energy systems with a high portion of renewable energies the task of DSM is an adequate adjustment of the power consumption to the power production. Three different types can be differentiated and are presented in detail: directional, automatical bidirectional and interactive bidirectional demand-side management.

3. FORECAST-MODULE

The forecast-module generates the future schedule of potential energy production of renewable energy generators (solar and wind energy). But these forecasts are afflicted with inaccuracies, which depend on different boundary conditions and can be changed in the course of time (behaviour of solar radiation or wind speed). Controlling the system components of the hybrid system, it is necessary to know these inaccuracies. The FM can be built on in different ways. Data origin plays a decisive role for determining the required forecast method, the length of the forecast interval, the achievable forecast horizon, the required hardware, costs and the forecast accuracy. Three basic types can be differentiated according to data origin: the first type is based on measured data of produced power, the second type is based on internal and external weather forecasts and the third type describes a combination of the both mentioned types. Table 1 shows the basic differences between the three optional forecast methods and their combinations.

Table I: Forecast methods s = short-term (<15min), m = middle-term (>15min - 1h), l = long-term (>1h - 24 h)

power measurement	int. weather forcast	ext. weather forecast	forecast horizon	generator model	gardware	isolated operation	forecast accuracy	data adjustment	forcast analysis	functional analysis
•			s			x	x			
	•		s/m	x	x	x	x			
		•	s/m/l	x	x		xx			
•	•		s/m	x	x	x	x	x	x	x
•		•	s/l	x	x		xx	x	x	x
	•	•	s/m/l	x	xx		xx	x	xx	
•	•	•	s/m/l	x	xx		xxx	xxx	xx	xx

The second line in table 1 represents version 1 and the last line represents version 7.

3.1 Power measurement

By means of measured data of produced renewable power and statistical forecast methods the future renewable energy production for the short-term forecast horizon can be generated. The forecast accuracy depends on an exact power measurement, the measurement interval and the selected statistic forecast method.

3.2 Weather Forecast

The forecast of the renewable power production is realized on meteorological data. Therefore, data like solar radiation, wind speed and temperature should be selected and measured. These data are used as input data for the physical generator models. By simulation the particular power production of wind generator and PV generator is calculated in the course of time.

3.2.1 Internal weather forecast

A meteorological station generates the input data for the generator models. The internal weather forecast is suited especially for the short- and middle-term forecast horizon.

The forecast accuracy depends on an exact power measurement, the measurement interval the selected statistical forecast method and the accuracy of the physical generator model.

3.2.2 External weather forecast

The meteorological data are not generated locally, but transferred via internet and gateway. In Germany data offered by the DWD (German Meteorological Service) can be used. Therefore, adequate services on the part of the data supplier have to be realized. The external weather forecast is suited especially for the long-term forecast horizon. The important factors affecting the forecast accuracy are the measurement interval and the accuracy of the generator models.

3.3 Combinations

Additional functionality results from the combination of the power measurement and the internal and external weather forecast. A detailed description is given in section 4.4.

3.3.1 Internal weather forecast and power measurement

A comparison of different generated power data can be done, whereby a monitoring of the PV- and wind generator and the meteorological station gets possible at regular intervals.

In case of inadequate variation of predicted power production there is a breakdown of the renewable generators, clouding or dysfunction of the meteorological station. An acoustic or visual signal informs the user about dysfunction.

3.3.2 External weather forecast and power measurement

Dysfunction of the PV- and wind-generators can be identified quickly. Inaccuracies in short-term forecast horizon of the external weather forecast can be compensated in parts. With that, a higher accuracy in short-term forecast horizon in areas with only few official meteorological stations becomes possible.

3.3.3 Internal and external weather forecast

The forecast results can be unified in the short-term forecast horizon and they can be changed or improved if necessary. Also disturbances of the meteorological stations can be recognized. With this a further increase of short-term forecast accuracy is possible. Dysfunctions of the PV- and wind-generators remain unrecognized.

3.3.4 Internal and external weather forecast and measuring

There are data for the short-, middle- and long-term forecast horizon available. In the short- and middle-term forecast horizon the forecast results can be unified. Inaccuracies on internal and external weather forecast, generator models for PV- and wind generators and measurement can be recognized and improved if necessary. An additional advancement of the forecast accuracy in areas with only a few measuring stations is possible. Dysfunctions of the PV- gerators, the wind generators and the weather station can be identified quickly. Figures 1 and 2 show the forecast methods in comparison.

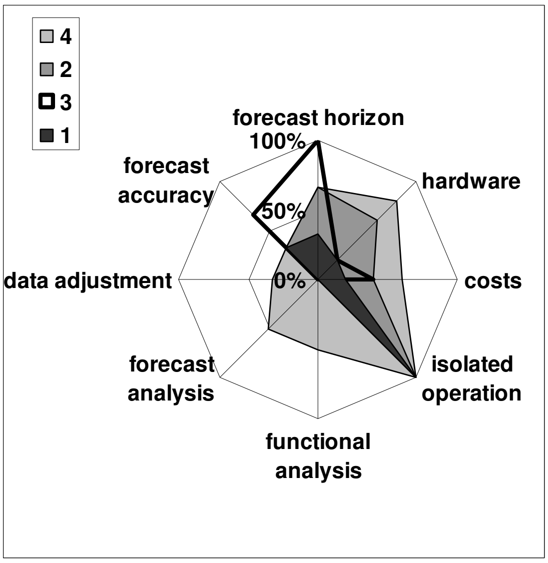

Figure 1: Comparison of forecast methods (1-4)

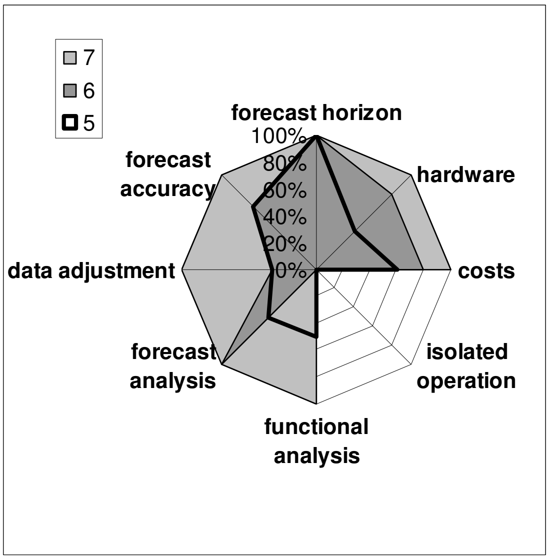

Figure 2: Comparison of forecast methods (5-7)

4 OPTIMIZATION-MODULE

The main task of the EMS is to improve the operation of the energy system. The classification of different EMS depends substantially on the functionality of the optimization-module. According to this the objective function and side conditions of the optimization task (OT), the optimization procedure, the length of the optimization interval and the structure of the optimization process can be distinguished.

4.1 Objective function and side conditions

Generally the optimization task can have different objective functions and side conditions. As objective functions can be seen the security of supply, the total costs, the total efficiency or the emissions. Side conditions can be avoidance of unnecessary operation hours, nominal system operation, minimization of battery load, operating the system with maximal efficiency, maximal use of renewable energies, minimal use of controllable power generators and avoidance of losses through unnecessary energy flow through the battery or minimization of output surpluses. [5]

4.2 Optimization procedure

The selection of the optimization procedure depends on the selected objective function, the side conditions and the variables.

4.3 Optimization interval

The optimization interval complies with the available data from the forecast-module and the demand site management-module. Regarding the time horizon the present optimization and future-oriented optimization can be differed.

The present optimization mainly based on performance data is used in conventional system management strategies - as described in the introduction.

The optimization module produces an optimal schedule suggestion based on data from FM, the DSM and the knowledge of different technical, economical and ecological marginal conditions of the energy system. For that, the optimization period is divided in different intervals. Schedule suggestion means, that the optimal operating point of each system component (producer, storage, consumer) of the energy system, controlled by the EMS is calculated for each interval. Calculating the operation points physical modeling of each system component is necessary. Depending on time horizon of data from FM and DSM it is possible to calculate short-, middle- or long-term events.

4.4 Optimization layout

To classify the optimization process, several layers have been developed, interacting with the three modules and the systems components. Some layers are essential for each kind of EMS like measuring layer and control layer. To enlarge the functionality of EMS and integrating future events of producer and consumer a model layer and a recording layer are added. In case of self-learning and self-diagnostic features, the EMS is equipped with an anlysis layer and a strategy layer.

The different layers are described in the following.

Measuring layer:

Performance parameters are measured, which are needed for control and simulation.

Model layer:

For each producer, storage and consumer a physical model is saved on a database. Further models describe economic and ecological aspects. The models establish a basis for calculating optimal operation points for future events.

Recording Layer:

Performance data, meteorological data and data from FM and DSM are saved on a database. Furthermore, results from simulation and the optimization-module are recorded. All data could be readout.

Analysis Layer:

Functional check for meteorological station, producer storage and consumer is possible. Maintenance can be predicted.

Time series of meteorological data, producer data and consumer data are analysed and compared with the predicted data.

Performance data are compared with results from simulation. Ageing effects, start-up, turn off and partial load behaviour are adjusted during system operation.

Strategy Layer:

The strategy layer sets rules for each system component that are considered in the control layer, e.g. the planning of maintenance.

Results from analysis layer are factored into FM and DSM and update forecast methods. Thus, the forecast accuracy rises.

The models are updated by analysis results, also.

Control layer:

Algorithms for control are saved on a database. Performance data are needed for present optimzation of producer, storage and consumer. To consider future events the control layer gets optimized schedules that are translated into superior control algorithms. The strategy layer can intervent the control layer considering maintenance, also.

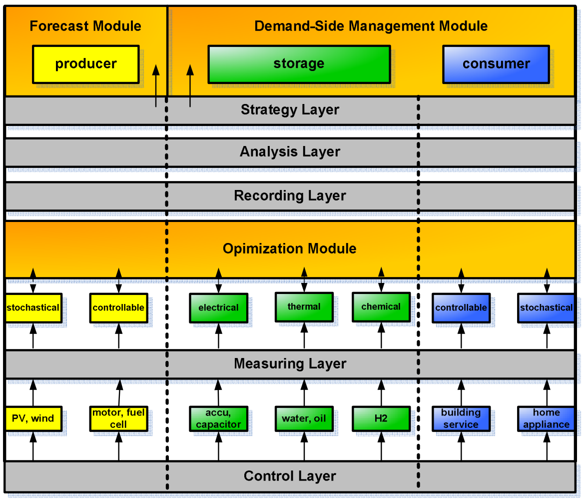

Figure 3: Layout of EMS

4.5 Process optimization

Process optimization improves the process efficiency in every optimization interval for the entire process. The optimum way of operating the entire process is determined. At the same time the minimum and maximum of the objective function are calculated. As a result of the calculation there are set points of performance of energy producer, storage and consumer, which are passed to the functional optimization. Within this the objective function connects the component combinations considering a special OT. E.g. the energy produced by a PV-generator is directly passed on to the consumer instead using a battery including energy losses.

With regard of connecting the DSM with the process optimization the direct and the bidirect demand-side management can be distinguished.

The directional demand-side management does not include a feedback of energy demand to the optimization-module. To cover the energy demand at any time, the storage has to provide a minimum load. By checking the present energy production, the forecast of energy production (PV-, wind generators) and the storage capacity the optimization-module determines the necessity of adding a controllable producer. If the storage is sufficiently dimensioned, the frequency of connecting or disconnecting a controllable producer can be decreased. The charging time is longer, but less often. With a suitable planning the charging can happen at night. Through missing information about the required power by consumers, the optimization is limited and suboptimal, because only a part of the side conditions can be fulfilled. The connection and disconnection of the controllable energy producer has a high frequency, which leads to accelerated ageing and a shortened lifetime. If the consumer behaviour is changed no adjustment of the process optimization is done. Through this a focused middle- and long-term controlling of additional energy producer is not possible.

The bidirectional demand-side management includes consumer forecasts to optimization-module. After checking the forecast of energy production and the storage capacity, the consumer load generated by the DSM is integrated into the process optimization. Depending on the forecast horizon, the optimization can provide with the help of the FM optimal schedules for the near future and with this the present optimization is able to adjust on the consumption. By integrating the demand-side management a focused control of additional energy producer is possible. Changes in the consumer behaviour can be added into the optimization. According to the type of DSM the optimization task can get very complex. The calculations and the required time increase correspondingly.

4.6 Functional Optimization

Functional optimization maximizes the efficiency of each system component for every optimization interval. Each component of the energy system that can be controlled by the EMS is simulated with a specific physical model. The process optimization transfers the set points of performance to the functional optimization. Firstly, the set points get checked on reliability. Secondly, the optimal calibration of each system component gets identified for the specific set points. Thus, the minima and maxima of the objective function are calculated. E.g. the PV-generator operates in maximum power point (MMP).

5 DEMAND-SIDE MANAGEMENT-MODULE

In local energy systems with a high portion of renewable energies the target of the DSM is an adequate adjustment of power consumption to the power production. With an increase in stochastical power generators (PV and wind energy) the power production becomes more fluctuant.

However, to reach a well adjustment and to guarantee security of supply, there are different options to build on the DSM.

Three different types can be differentiated: directional, automatical bidirectional and interactive bidirectional demand-side management. Table 2 and figure 4 show this basic classification.

Table II: Demand-side management methods

directional	bidirect., automatical	bidirect., interactive	forecast of p. c.	forecast horizon	user specific wishes	hardware	flexibility	consumptions groups	integration to OM
•				x		x	x	x	
	•		x	xx	x	xx	xx	x	x
		•	xx	xxx	xx	xxx	xxx	x	xx

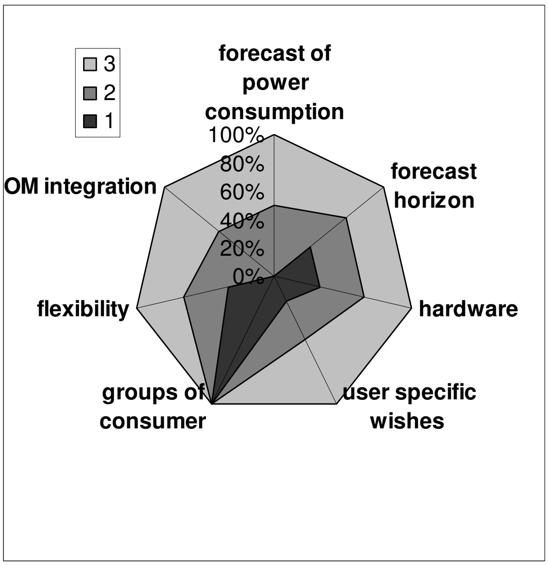

Figure 4: Comparison of demand-side management methods

5.1 Directional demand-side management

The available energy is distributed to the consumer without sending a demand feedback signal to the OM. That means there is no forecast of energy consumption (compare section 4.5). The following methods are used in general: influence of the power consumption (brightness), sensor controlled circuit switching of consumers (brightness, temperature) and priority controlled circuit switching of consumers for prevention of simultaneous consumption. This takes up the notice of the exact consumer data over time. During system planning, generators and accumulators have to be rated accordingly big. This kind of demand-side management is very inflexible because changes in consumer behaviour or additional installed consumers the limit of security of supply is reached very quickly. Specific wishes of users can be included during the system planning but not during system operation.

5.2 Bidirectional demand-side management

Predictions of energy consumption get established. The results of this prediction are embedded in the optimisation process. So there is a feedback of the DSM to the optimisation-module.

5.2.1 Automatical demand-side management

The demand-side management identifies for every optimization interval the required energy demand according to the characteristic of different consumer groups. To realize a forecast of power consumption all consumers have to be classified in specific consumer groups with similar temporary characteristics. Furthermore, the time constants of each group have to be estimated because the EMS makes temporally offsets of power demand and power supply possible. The forecast of energy consumption has the same time interval required by the optimization-module. Variations in energy consumption are collected automatically with a measuring system.

5.2.2 Interactive demand-side management

User-spezific wishes can be integrated during system operation. A display is used to inform the user about the current operating status. In form of a days' or weeks' schedule the user determines his individual consumption e.g. for the home appliances. The individual wishes get checked on reliability with data of the forecast-module, the capacities of storages and the data of other consumer groups. After that, the EMS informs the user about the efforts to realize his wishes. E.g. start of a motor and thus higher cost of operation. This result can be confirmed by the user or another schedule is created.

The advantage of this type of demand-side management is that a high degree of user specific wishes are integrable. The demand-side management achieves the highest degree of flexibility but also the highest investment costs. The average calculation time and the energy consumption are high. Without user readiness to change his energy consumption behaviour in aid of the energy production of the renewable energies no additional advantages arises for the user by electing the bidirectional demand-side management

6 CONCLUSION

This paper presents a classification of energy management systems (EMS), in order to work out differentiated realization possibilities with detailed characteristics for further discussions and development strategies.

The presented generalized structure of EMS could be a helpful tool for future developments and perhaps gives the chance for common discussion standards.

Further research and development in following areas is essential: simple mathematical methods to realize forecasting of energy production of PV-generators and wind generators and energy consumption, adequate modelling of producer, storage and consumer with different aspects (physical, economical and ecological) and flexible integration structure to optimization-module, efficient methods for optimization with stochastical variables and varying objective functions and communication interfaces to superoir energy systems.

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