CONTROL METHOD AND STORAGE SYSTEM SIZING FOR PV-DIESEL MICROGRID: FROM SIMULATION TO EXPERIMENTAL ANALYSIS

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ABSTRACT

Photovoltaic (PV)-Diesel microgrid system is considered as an efficient solution to help reducing operation cost and pollution emission on islanded sites, which are initially supplied by diesel generator plant. In order to ensure system's stability face to PV production intermittency, technical solutions such as designing advanced control strategy or adding energy storage can be considered. To evaluate the benefits of those solutions simulation and experimental test are carried out.

Two study cases are considered in simulation. The first system is a 100kW-scale and the second system is 10MW-scale. Each case represents a multi-gensets system combined with a PV production. Simulations are handled with respectively rule-based and advanced control for a period of 43 days with different daily PV profiles. Indicators such as undistributed energy (UNE), fuel consumption and operating time are computed for each simulation. Sensibility analysis is performed for different PV installation rates. Experimental testing has been carried out on the smaller system. From these studies, benefit values of advanced control and storage system in terms of system operation cost and stability warranty for PV-Diesel system are demonstrated as well as storage system sizing dependence on system design and storage management strategy.

INTRODUCTION

In a previous work, it has been shown that using advanced control strategy with PV short term forecast allows to have operation cost gain compared to rule-based control strategy in a hybrid system without storage [1]. Simulations of typical PV day profiles also highlighted that in case of rule-based control, adding storage helps to improve PV production penetration rate, reduce system operation cost and better warrant system stability. As storage system is expensive, minimizing storage size can offer an interesting economic benefits for the total system cost. Storage system sizing have to take into account system's configuration, such as gensets rated power, PV penetration rate and also system control strategies.

In this work, in order to evaluate and compare the gain obtained by storage system and advanced control to a PV-Diesel system, additional simulations are carried out with more PV profiles and study cases. The study cases represent two system size levels in which technical requirements are different.

SYSTEM DESCRIPTION

The architectures of two studied system are similar, as described in the Fig.1. Each system is composed of three diesel generator, one PV system, one storage system and loads. The systems are managed by a centralized Energy Management System (EMS). The sizing of different elements such as maximum load power, PV peak power and genset nominal power in the system in case 1 and case 2 are given in Table 1. Gensets main characteristics of each case are provided in Table 2.

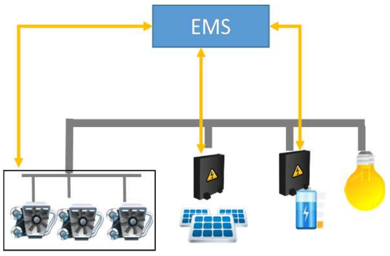

Figure 1 PV-Diesel systems architecture

As described in Table 1, system case 1 represents a small scale power system, which can be found in a specific electrical installations such as farm, military, telecommunication or community sites. In such system, power supply quality requirement can be considered as of a medium level which means that power supply must be continuous for most of time, but short and bare interruptions are allowed. On the contrary, a system represented by case 2 with much higher power scale (more than 10 MW) are usually installed for big industrial sites. In function of industrial process, power supply continuity can be highly critical and no interruption tolerance. In this case, the power has to be ensured at any moment.

	PmaxLoad	*PVPeak*	*PmaxPRP Genset*
System case 1	100 kW	50 kWp; 100 kWp; 150 KWp	3 X 32 kW
System case 2	25 MW	12.5MW; 25MW;37.5MW	3 X 8.9MW

Table 1 Power sizing of two system cases

	PmaxESP Genset	*PminPRP Genset*	*Tstart_ cold*	*Tstart_ hot*	*T_min_ ON*
System case 1	3 X 35 kW	3 X 9.6 kW	10 s	10 s	0
System case 2	3 X 9.8 MW	3 X 2.7 MW	6 mn	6 mn	60 mn

Table 2 Main characteristics of gensets in two system cases

In Table 2, several of the main characteristics of the diesel generators used in two system cases are listed, where:
- *PmaxESP Genset* is Emergency Standby Power (ESP) - the maximal power which can be provided by genset, during a limited duration per year;
- *PmaxPRP Genset* is Prime Power – nominal power which can be provided by genset during unlimited running hours;
- *PminPRP Genset* is minimal recommended running power of genset, which is usually fixed as 30% of the nominal power;
- *Tstart_cold* and *Tstart_hot* are respectivly starting delay from a “cold” state and “hot” state*;*
- *T_min_ON* is the minimal operation duration of genset for each starting. This constraint limits the number of gensets state change during a period, which is better for their maintenance.

Beside those parameters which are important for PV-Diesel system simulation, genset modelling in the plateforme SPIDER, developed in CEA-INES [3] takes into account genset fuel consumption data. This latter is normally provided by manufacture datasheet under a table format with several measured points. Interpolation between those points is done in order to compute genset consumption at any situation.

Storage system is Li-Ion technology electrochemical battery, modelled such a way that it can be scalable according to the battery nominal power and energy capacity.

Control methods

PV-System EMS contains two-levels control structure as described in the Figure 2, with:

- High level control using forecast data such as PV production forecast and load forecast to compute genset dispatching planning;
- Operational control level with power sharing between production units such as PV production, gensets and storage.

Similar as our previous works, 2 modes of system control were implemented and tested for each study case:

- S1 – rule-based strategy which only operational control level implemented. In this mode, gensets power sharing is carried out simply based on net load power, which is the difference between the initial load and PV production. Results in [1] showed that with this method, fuel consumption is optimal. However, in case of high PV integration rate, system power unbalanced situation may happen.
- S2 – advanced strategy with two levels fully implemented. In the planning level, optimisation is carried out using PV-short terms forecast data in order to compute gensets dispatching. In a base of operational control time step of 10s, planning computation is launched every 2mn for upcoming hour, or whenever an event happens.

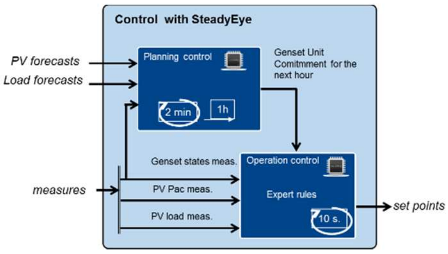

Figure 2 2-leves control system

PV data

43 days of PV profiles are tested. Those profiles represent various weather conditions during a year: clear sunny days, days with mixed condition and very cloudy weathers. Some examples are illustrated in Figure 3.

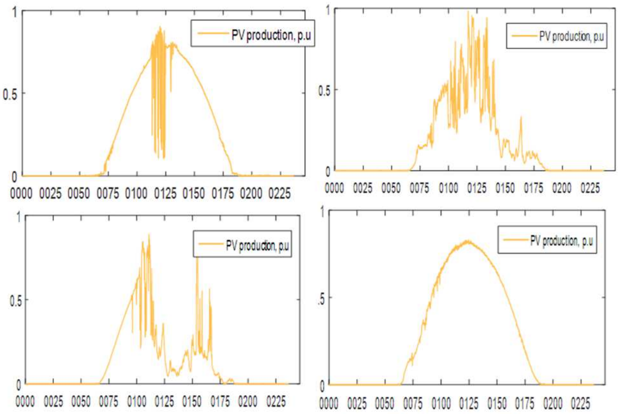

Figure 3 Different PV daily profiles

Absolute values of PV production are scaled with PVPeak values in Table I.

PV production forecast [4] is obtained using a sky-imager installed on site. The camera takes hemispheric photos of the sky every minute. These images are then automatically sent to a server or a local PC via a built-in Power over Ethernet connection. Using image processing algorithms in conjunction with a cloud mass movement forecast and physical models, the state of the cloud cover is forecasted for a very short term along with the plant’s production.

The percentiles from 10% to 90% (cf.Figure 4) are provided in addition to the mean expected power P50 (and/or irradiation level – GHI) as confidence indicators. Calculation of percentiles are mainly based on cloud movement uncertainty. The use of the confidence interval (for instance: P20-P80) allows to anticipate risk of irradiation/production drops. The proposed control relies on the percentile P20.

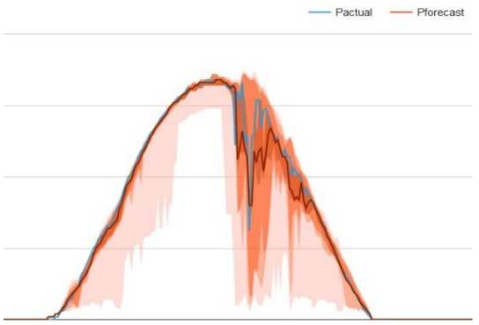

Figure 4 PV forecast percentiles

STORAGE SYSTEM SIZING

Simulations are firstly carried out on systems without storage in order to analyse and compare control strategy influence according to PV integration rate in each of the two systems. The study performs simulations with 43 PV daily profiles containing various typical days. Comparisons between S2- advanced control strategy and S1- rule-based control strategy are carried out based on the following main indicators:

- Undistributed energy (UNE): this indicator point out systems' continuity of service and their stability. UNE is expressed on energy quantity and period.
- Fuel consumption and genset operation period: those indicators represent the main part of energy cost in islanded PV-Diesel system.

Secondly, storage is added with various size to each simulation. The purpose of adding storage is to provide a complementary service to the strategy S1 such a manner that this combination can offer the same performance as the strategy S2.

SIMULATION ANALYSIS

Some examples of daily simulation are show in **Erreur ! Source du renvoi introuvable.**.

Indicators computations from simulations reconfirm conclusions of previous works:

- Strategy S2 based on planning optimization using PV short-term forecast data offer a good technical-economical compromising with reduced UNE indicators compared to strategy S1;
- In terms of fuel consumption and gensets operation time, the two strategies are almost equivalent;

The benefits of strategy S2 are increased as well as with high PV integration rates and with big size power system.

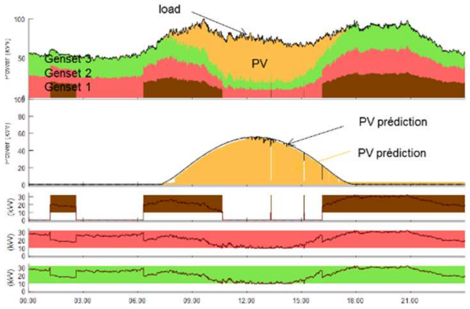

Figure 5 day simulation with S2 control

Figure 6 illustrates some results on system of case 2, with a PV peak power of 100% and 150% of the maximal load power (*PV_rate* = 1 or 1.5). In those graphs, system stability UNE indicator is computed for different cases: S2 and S1- rule-based control strategy without storage and then S1 control strategy with storage system of various sizing, from 20% to 100% of PV peak power.

It can be observed that, in such case of high PV rate integration, using S1 strategy bring to high UNE period, around 2% of total operation duration which is considered as highly critical constraint for such a system. This UNE period is essentially due to gensets start delay while PV production rapid decreasing or load increasing periods. Using S2 strategy with PV forecast helps to predict PV variation events, adapt gensets dispatching so that UNE is avoided. Hence, with this strategy UNE period is strongly reduced, down to 0.1% of total operation duration. Adding storage during genset start transition period in case of S1 strategy is also an efficient option, as showed by the same figure. For all cases with storage, storage energy capacity is sized in order to provide its maximal power during three successive genset starts. One can see that UNE is reduced while storage maximal power increases. For *PV-rate* of 1 or 1.5, a storage with a maximal power of 40% of *PV Peak Power*, i.e. 10MW and 15MW respectively, can help the system controlled by S1 strategy to get the same UNE of S2 strategy. Storage nominal capacity values corresponding for those cases are 3MWh and 4.5MWh respectively.

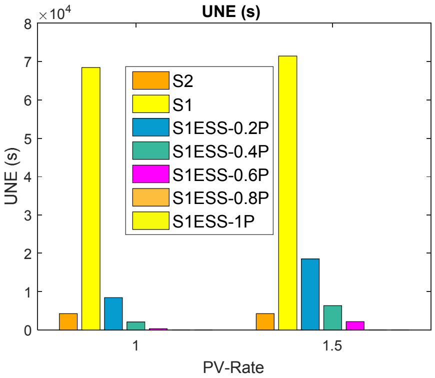

Figure 6 Comparison in terms of undistributed energy period

EXPERIMENTAL TESTS

In the second step, experimental test in laboratory is carried out to validate control algorithms implementation on study case 1, i.e. 100kW-scale system. Test system diagram is showed in and some test results in Figure 7.

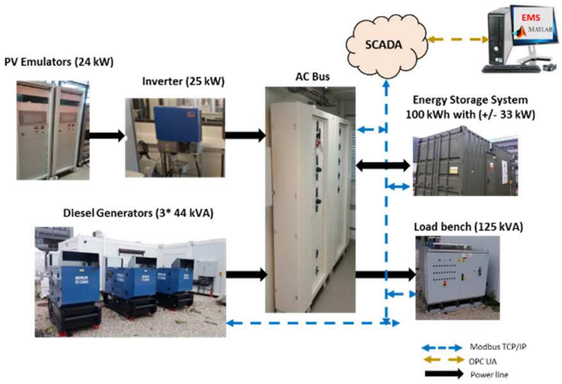

Figure 7 Test system configuration

PV emulators have been used to perform similar conditions as simulation studies. UNE situation driving to a black out with S1 strategy is reproduced as showed in Figure 8. Event at 360 s combining a load increasing and PV drop has strongly increased the net load value. Genset 2 is called for start at this moment but during its state transition, power balancing is lost, driving to genset 1 shut down and to stop all the system. Test using S2 strategy then storage addition to the system at the same condition show the advantages of these solutions to go through high variation events, as showed in Figure 9. Indeed, during genset 2 start transition period, storage discharges to help genset 1 keeping system production-load balance (from 360s to 390s). After this period, once genset 2 is ON, storage power discharge is stopped and the system continue to operate with the two gensets production.

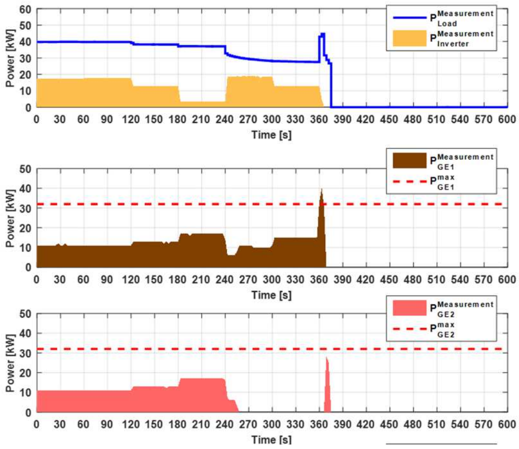

Figure 8 Test with S1 strategy, UNE apparition

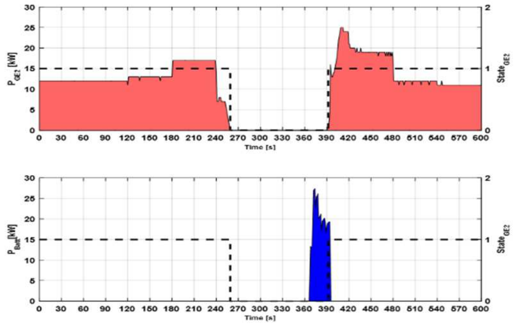

Figure 9 Test with S1 strategy and storage

CONCLUSIONS

In this work, the stability challenge of hybrid PV-Diesel system is studied through simulations and experimental tests. Advanced control and storage system integration solutions are successively considered which show benefits in terms of system stability face to PV and load high variations. Sensibility analysis are carried out by simulation with variation on system sizing, PV integration rate and PV production profiles. Storage sizing with stability criteria is studied in order to compare the combination of storage and rule-based control versus the use of advanced control with PV forecast data. Although more complete studies with better stochastic analysis of PV production and PV forecast reliability are needed, those results allow to have good indicators on values that storage or advanced control can bring to hybrid system operation.

For the next step, combination between advanced control and storage will be studied and further investigation on economic benefits of these options will be discussed.

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