Integration of Short-term PV Forecasts in Control Strategies of PV-Diesel Systems

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***Abstract*—Photovoltaic systems are becoming a cost-effective solution for power systems traditionally based on diesel generator, such as islanded sites or microgrids. Indeed, hybrid systems which combine solar energy and fossil fuel power supply, allow both limiting atmospheric pollution and reducing operational cost. Nevertheless, in order to have a significant contribution of photovoltaic into such power systems, adapted control systems need to be developed. In this work, we present through simulation how the integration of short-term PV forecast into control strategies is an efficient way of lowering fossil fuel consumption and increasing PV-rate integration in the system. We first present our modeling approach, based on an innovative modeling platform developed at the CEA-INES called SPIDER. The system behavior is analyzed for different control strategies, and different PV system sizes.**

I. Introduction

PV generation has become an attractive source of energy, due to its competitive cost and its low environmental impact. However, due to its intermittent characteristic, high penetration of PV generation in a local distribution system causes different issues linked to grid stability, such as demand supply management and frequency or voltage fluctuations. This is especially true for systems where PV energy is mixed with diesel generator (genset) plant, where starting a new group for example requires a certain lapse of time.

In order to address this issue, industrial approaches propose to limit the PV production through a control of the PV inverters [1]. This curtailment strategy offers advantages in terms of system stability but do not optimize the use of PV power. Alternative strategies, based on PV forecasts, can counterbalance this limitation, and helps optimizing the use of photovoltaic resource through a better dispatch of the diesel generators. Previous work has shown that such advanced control strategy can effectively decrease operational cost when compared to rule-based strategy control [2], [3]). The purpose of this work is to better quantify this gain, by evaluating and comparing the simulation results of a hybrid system control based on the 2 mentioned approaches: 1) using a curtailment strategy; 2) using short-term PV forecasts.

For this comparison, relevant indicators are studied, such as fuel consumption, rate of photovoltaic energy used, undistributed energy and operating time of the gensets.

II. Modeling approach

A. Simulation platform

In this context, the CEA developed an advanced simulation platform, which addresses various PV applications such as self-consumption systems, microgrids or utility scaled PV systems [4]. The software is called SPIDER as Simulation Platform for the Integration of Distribution Energy Resources. SPIDER is a standardized platform based on a generic open-source modeling environment (Papyrus) [5]. SPIDER relies on the model based designed approach where models representing the physical system are associated to models representing the system control. Regarding the control concept, a generic multi-level architecture for Energy Management System (EMS) has been developped. Such architecture defines the EMS as a combination between planning controls and one operation control. The planning control aims at computing system set points for a given horizon. It is based on generation or consumption power forecasts, and includes optimization methods and associated models. The approach used in our simulation is further detailed, in section II.D.

B. System components

The system studied represent a large scale system, with a peak power load of 25 MW, and a daily energy consumption of 430 MWh. This is comparable to the consumption of an island, such as Granada in the Caribbean, where approximately a 100 000 people live [6]. The load profile is a typical city load profile, with low consumption during night time, one peak demand in the morning and one in the evening (see section III).

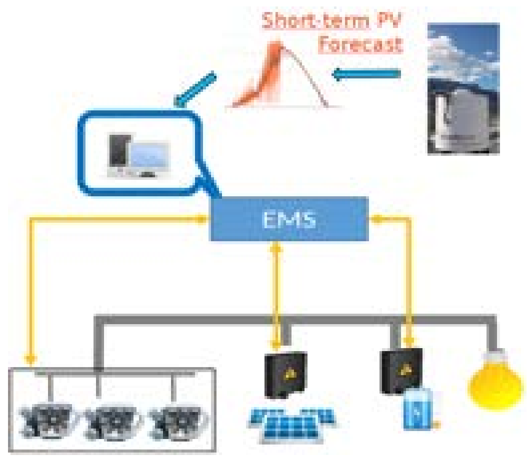

Fig. 1. Hybrid system architecture containing 3 gensets, a PV system, an ESS and a load. Short-term PV forecast can be used as an additional input of the EMS, in order to optimize the control of the system

To produce the electricity, the system is composed of three diesel generators and one PV system (see figure 1). Optionally, there is the possibility to add a storage system (ESS) in the model. The sizing of the three generators is fixed, whereas the system is simulated for different PV peak power ranging from 30% to 150 % of the maximum load power (namely 7.5 MW to 37.5 MW). A base case without PV system is also simulated.

The genset modeling in the SPIDER platform takes into account several main characteristics, in order to be representative of a real system:

- P_{max} ESP is Emergency Standby Power (ESP) - the maximal power which can be provided by genset, during a limited duration per year;

-P_{max} PRP is Prime Power nominal power which can be provided by genset during unlimited running hours;

- P_{min} PRP is minimal recommended running power of genset, which is usually fixed as 30% of the nominal power;

- $T_{start,cold}$ and $T_{start,hot}$ 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.

The set parameters for the genset model are detailed in table I.

TABLE I
GENSET MAIN CHARACTERISTICS

P_{max} ESP	P_{max} PRP	P_{min} PRP	$T_{start,cold}$	$T_{start,hot}$	$T_{min,ON}$
3 X 9.8 MW	3 x 8.9 MW	3 x 2.7 MW	6 min	6 min	60 min

Fuel consumption is also calculated, thanks to manufacturer data. As data are generally provided for few operating points, interpolation is performed between those points to obtain the fuel consumption for the whole genset power range.

C. PV data and short-term forecasts

PV data used for this work are based on measurement performed at SteadySun test site, in Le Bourget-Du-Lac, France (Latitude: 45.65; Longitude: 5.85). A thirty degrees tilted surface towards the South is considered, and PV production is scaled according to the PV power capacity defined in the simulation. 30 days are simulated, corresponding to the month of April 2018, where different weather conditions were observed (sunny days, partly cloudy or completely cloudy).

Short-term PV forecast is made using sky images processing techniques. The "steadyEye" solution studied in this work [7], allows the sky to be observed from the plants site using a camera pointing upwards that takes hemispherical photos. Used in conjunction with image processing algorithms, a cloud mass movement forecast and physical models, the state of the cloud cover is forecast for the very short term (up to 60 mins) along with the plant production.

The delivered forecasted values rely on a probabilistic approach, where confidence interval are calculated instead of single-point values. Indeed, for the deterministic approach, point forecasts don't give a full picture of all potential future outcomes, and therefore are not adapted to situations where uncertainties or risks are involved. Therefore, probabilistic predictions are more adapted to control strategies of systems; where decisions can be taken under a chosen level of risks. Calculation of percentiles relies on a combined approach of statistical data analysis and cloud movement uncertainties. An example of forecasts at a 15 minutes horizon for two consecutive days is shown on figure 2, where different levels of confidence are represented. For our study, the percentile 'P20' is considered, which corresponds to 80% chances that real power exceeds this value.

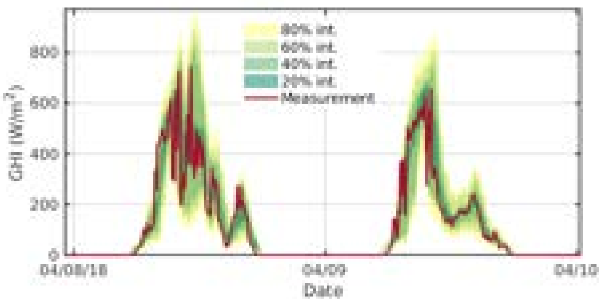

Fig. 2. Example of 2 days of GHI measurement at SteadySun test site, associated with their probabilistic short-term PV forecasts (horizon = 15 min)

D. Control strategies

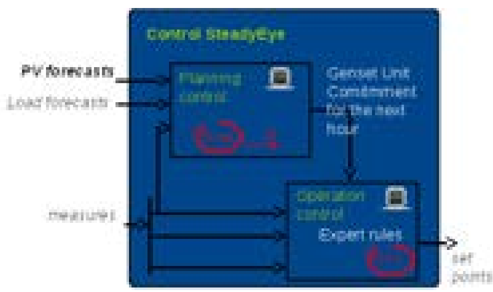

Fig. 3. Architecture of the advanced control strategy, with two levels of control

The PV-Diesel system is managed thanks to the EMS, which can be configured depending on the chosen control strategy. Two strategies are simulated in this work:

1) A "curtailment strategy", called S1: This is a rule-based control, where PV power can be limited in order to respect genset power restrictions and always have sufficient spinning reserve to compensate a sudden drop of PV power. This strategy is considered as a reference strategy, since it is widely used in hybrid system controlers. This type of control is defined as an 'operational control', since it behaves in real-time depending on the energy balance in the system.
2) A 'steadyEye strategy', called S2: The operation of the gensets is anticipated, based on short-term PV forecast. This type of control is defined as an 'anticipative strategy' where we observe two steps in the control process: first, a planning level, where the dispatch of the gensets is optimized using the short-term PV

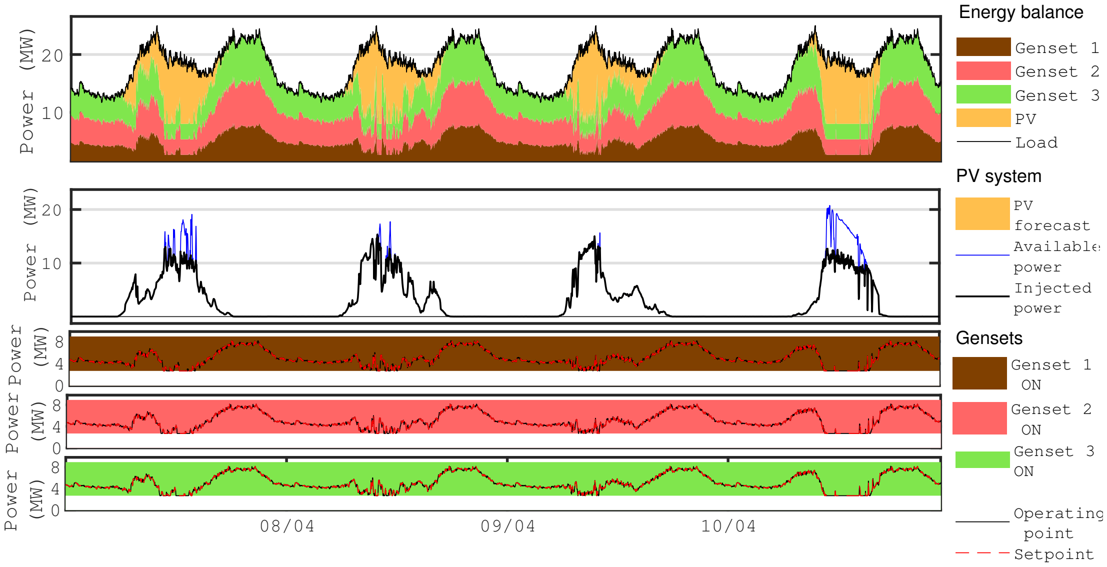

Fig. 4. Example of results for 4 days of simulation for strategy S1. From top to bootom: Energy balance in the system is represented, then available and injected PV energy, and below the operation the three gensets.

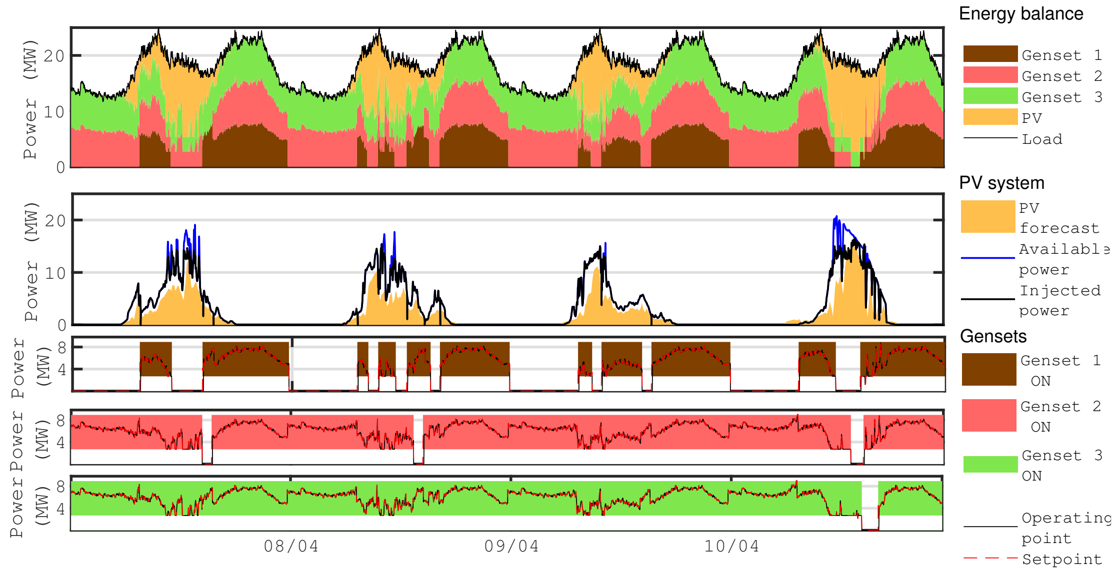

Fig. 5. Example of results for 4 days of simulation for strategy S2. From top to bootom: Energy balance in the system is represented, then available and injected PV energy, and below the operation the three gensets.

forecast. During this phase, the set point of each genset is also calculated. Then there is the operational level, where the EMS will take into account the calculated set points and the real time behaviour of the system in order to operate the system efficiently. This two-phases control is illustrated on the figure 3. We observe that the frequancy of each control is independent: for our simulation, the planing control is launched every 2 minutes, whereas the operational control is launched at each simulation time-step which coorresponds to 10 seconds.

III. Simulation Results

A. *Energy balance and gensets operation*

An example of 4 days of simulation for a PV system of 25 MW, corresponding to 100% of the load peak power, is illustrated on the figures 4 and 5. The figures correspond to results obtained with respectively strategies S1 and S2.

Different observations can be made, based on the comparison between strategy S1 and strategy S2: first, we do observe that for strategy S1, the gensets are always operating in order to have sufficient power margin, in case a sudden increase or decrease of required power occurs. The power to be delivered is equally shared between the three gensets, meaning that they have the same operating point. For strategy S2, the gensets are regularly turned on or off depending on the planning calculated. The different gensets don't provide the same amount of energy and we observe that genset 1 has more interruptions than genset 3, which can be considered as a baseline power source.

Then, if we look at the share of the available PV energy injected in the system, strategy S2 shows a more efficient behaviour. Indeed, for day 1 and day 4, the amount of energy curtailed is higher for strategy S1 than strategy S2. This is very obvious for day 4, where during a specific period (around noon) only 1 genset is operating, and the PV system provides a high part of the demanded power.

Days 2 and 3 are also interesting, as they underline another advantage of planning the gensets' dispatch. For strategy S1, the 3 gensets are always on and operate at a relatively low power, when compared to strategy S2. Indeed, as not all the gensets are operating, the demanded power is higher, and the gensets operate at conditions closer to their nominal power. The generators are generally more efficient under those conditions, meaning that fuel consumption is lower.

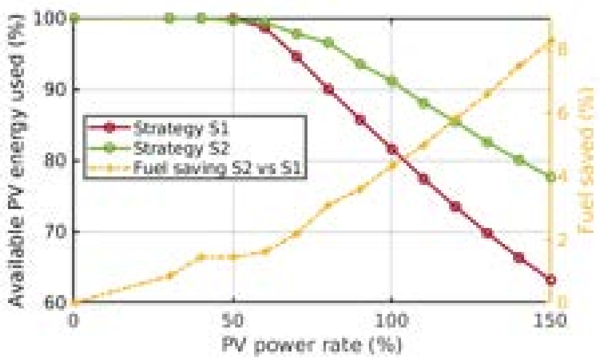

Fig. 6. Available PV energy injected (in percent) for different sizes of PV system (in percentage of the maximum load power). Fuel saving between strategy S2 and S1 is also represented (right axis). Results are obtained for 30 days of simulation.

Results presented in the figure 6 show the behaviour of the system for the whole period of simulation (30 days). The curtailed PV energy increases logically with the size of the PV system. But the decrease is less important for strategy S2 than for strategy S1, meaning that the available PV energy presents a higher injected rate. For a PV system of 25 MW (100%), 91% of the available PV energy is used in the case of strategy S2, where this rate is only 81% for strategy S1. This corresponds to an economy of fuel of roughly 4%. It is important to underline that this result can be considered as a lower bound. Indeed, the short-term PV forecast used are conservative (see figure 5), and underestimate the PV power produced. Therefore, the dispatch planning can sometimes not be optimal. Improving the accuracy of the forecasts, by narrowing the confidence interval, will lead in a more optimal planning, hence a higher level of fuel saving.

The figure 7 represents the relative operating time of the gensets and their averaged load factor, corresponding to the ratio of their operating power over the nominal power. In the case of strategy S2, all the genets operate 100% of the time, in order to have sufficient reserve in case the demand increases suddenly. Therefore, the energy to deliver is shared between the three gensets and they run at a low load factor. For example at a PV rate of 100%,

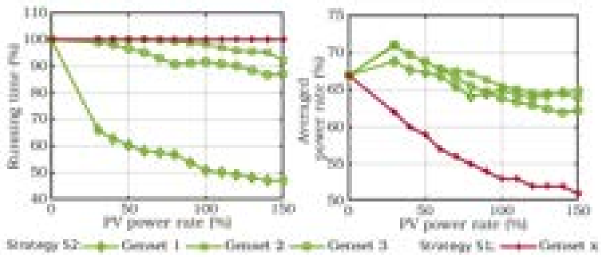

Fig. 7. Left: Operating time of the different gensets (in percentage of the total time). Right: Averaged operating rate of the genset nominal power. For both graphs, only one genset (genset x) is represented for strategy S1, as the three gensets have the same operating points

the averaged laod factor is around 53%. This phenomenon increases with the size of the PV system. For strategy S2, generators are not always running. Therefore, the provided power by the running genesets is higher, meaning load factor is higher. We observe values of load factor between 63 % and 70% depending on the PV system size. This results has two main consequences: first, the maintenance of the diesel generators depends on their running time, and therefore a lower operating will lead to a reduction in term of operating cost. Secondly, the gensets run at a better efficiency when their operating power is close to their rated power (typically 80% of this value). Consequently strategy S2 allows limiting fuel consumption, and therefore operating cost will also be reduced.

B. *Grid stability*

Despite its non-optimized gensets dispatch, strategy S1 has one main advantage: energy balance on the grid is respected, and therefore grid stability is ensured. For strategy S2, the grid stability is not guaranteed. To better understand this issue, we have calculated the unmet load, in term of energy and duration. For a PV system of 25 MW, and the 30 days of simulation, the percentage of undelivered energy corresponds to 0.0005 %. In term of duration, this corresponds to 0.011 % of the total time, that is to say 300 seconds. Extending those results to longer period of time might not be relevant: indeed, in our case, the load was unmet only at one specific event, where a genset was started too late to compensate a decrease of PV energy. The order of magnitude of the duration of unmet load corresponds to the starting time of the genset. Assessing global trend and extending those observations to longer period is therefore not possible. Further analysis, with simulation over longer period and shorter time time step, would be necessary to quantify grid stability of strategy S2. Moreover, since the unmet load appears to be relatively small for the considered period, integrating a small ESS could be sufficient. Further investigations will be carried in order to study such topic.

IV. Conclusion

In this work, the energy balance of a hybrid PV-Diesel system is studied through simulations. Advanced control strategy based on short-term PV forecasts, when compared to curtailment strategy, show benefits in terms of genset fuel consumption, integration of PV energy in the system and genset operation time. Different PV system sizes were simulated, and the gain observed increase with the PV system size. Although, on-going investigation in grid stability is expected to better quantify the impact of the anticipative control strategy, this is definitely an interesting approach for controlling hybrid system.

REFERENCES

[1] R. Tonkoski, L. Lopes, and D. Turcotte, “Active power curtailment of pv inverters in diesel hybrid mini-grids,” in *IEEE Electrical Power and Energy Conference (EPEC)*, 2009.

[2] T. P. Do, G. A. Koucoi, F. Bourry, and X. L. Pivert, “Control method and storage system sizing for pv-diesel microgrid: from simulation to experimental analysis,” 2018.

[3] ——, “Assessment of control strategies performance in stand-alone pv-diesel system: Simulation and experimental test,” in *Proceedings of the 3rd international hybrid power systems workshop*, 2018.

[4] F. Bourry, “Advanced simulation platform for the integration of photovoltaics into power systems: Spider,” in *32nd PVSEC Conference*, 2016.

[5] “Papyrus : an industrial-grade open source model-based engineering tool.” [Online]. Available: https://www.eclipse.org/papyrus/index.php

[6] E. transition initiative, “Energy snapshot of granada,” NREL, Tech. Rep., 2015. [Online]. Available: https://www.nrel.gov/docs/fy15osti/62699.pdf

[7] “Steadyeye solution: product sheet,” SteadySun, Tech. Rep., 2018. [Online]. Available: http://www.steady-sun.com