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The role of residential load-management in the support of RES-based power generation in remote electricity grids

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Abstract

Increased interest is recently demonstrated in the promotion of distributed generation based on renewable energy sources (RES). Contrariwise, owed to RES intermittency, most remote areas rely on oil-fired power generation. To facilitate further penetration of RES, the concept of demand side management (DSM) has lately emerged. To this end, a new DSM algorithm is currently developed. Peak shaving and load shifting are applied, considering implementation levels that the residential sector may comply with. Finally, a small-medium scale island grid is used as case study, with our results indicating that the appropriate level of DSM application may yield considerable benefits.

Keywords: demand side management; peak shaving; load shifting; hybrid RES systems; island grid

1. Introduction

Increased interest is recently demonstrated in the promotion of distributed generation (DG) patterns, often employing power systems that rely on the combined operation of renewable energy sources (RES) and energy storage technologies [1]. On the other hand, owed to the variable generation characteristics determining RES -that also imply the need for oversizing such configurations so as to effectively cover the load demand of a remote area- local power supply of remote areas is mainly based on the operation of oil-fired power stations, responsible for increased electricity production costs [2]. To this end, although up till now emphasis has been given on the optimum

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sizing of RES-based configurations from the supply point of view [3], the concept of demand side management (DSM) that lately emerged has also attracted the attention of several researchers [4,5].

DSM refers to the use of a wide range of techniques (Figure 1), aiming to achieve a balance between electricity supply and demand. In fact, DSM mechanisms [6] vary from direct-load control (DLC) and load limiters, to time-of-use pricing and demand bidding programs. Furthermore, as Rae and Bradley point out in [7], the greatest benefit of DSM concerns its ability to support improved performance and greater flexibility of renewable energy systems, which in the absence of support provided by energy storage and DSM introduce highly disruptive temporal mismatches between supply and demand.

Acknowledging the above, an effort is undertaken in the current study so as to develop a new DSM algorithm based on the application of load-management techniques that will also emphasize on the potential for downsizing of RES-based energy storage configurations. More precisely, combination of peak shaving (clipping) and load shifting is currently applied at the system level, considering however levels of implementation that the residential sector may comply with. The developed methodology is accordingly applied to a small-medium scale island grid of medium-high quality RES potential, with our results indicating that the appropriate level of DSM application may yield considerable benefits in terms of energy autonomy and system size for both wind-storage and hybrid wind-PV-storage configurations.

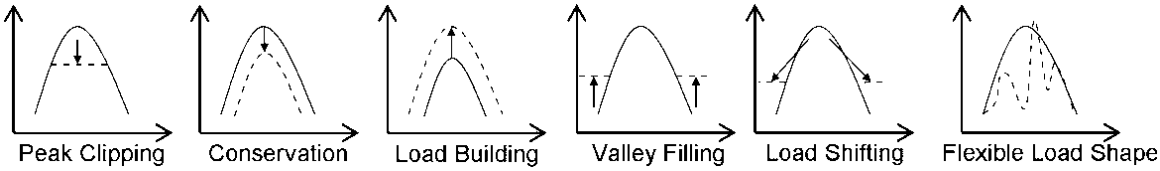

Fig. 1. Different aspects of DSM.

2. Methodology – proposed strategies

As already mentioned, DSM techniques currently applied concern peak clipping / shaving and load shifting during hours of lower load demand. More precisely, by determining the monthly peak load demand, a peak limit signal is used in order to cut load from the peaks and shift it in subsequent periods of lower load demand. The maximum peak limit signal is determined as a percentage of the maximum monthly peak demand, while load shifting occurs under the precondition that subsequent loads can only be increased up to the maximum peak level selected, otherwise load cuts are accumulated. In case that load cuts cannot be shifted entirely, which in essence means that the revised load demand is lower than the respective original one, the peak limit signal has to be reduced, up to the point that the current condition is satisfied.

Evaluation of DSM is accordingly undertaken using as criterion the system size of different RES-based energy storage configurations. Extending an already developed algorithm used for the sizing of hybrid wind-PV-storage configurations [8], DSM is added in order to measure the impact of the latter in system sizing. At the same time, energy autonomy levels achieved for each of the examined configurations are also recorded through the estimation of hours of load rejection per year. In this context, a parametrical analysis is undertaken, using as parameters the size of main system components (i.e. installed capacity of wind and/or solar power along with energy storage capacity) as well as the maximum peak shaving limit signal.

3. Case study characteristics

The developed methodology is accordingly applied to a typical small-medium scale island grid of the Aegean Archipelago Sea. At this point it should be noted that the entire area of the Aegean Sea appreciates medium to high quality solar potential (1300-1800kWh/m^2.a) while in many locations one may also encounter medium to high quality wind potential [9,10].

To this end, Figure 2a presents the RES potential of the entire Greek territory while in Figure 2b the load demand of the area under investigation is given. The annual energy consumption reaches approximately 11.2GWh with the respective annual peak load demand being equal to 3MW. Furthermore, hourly wind speed data used are provided in Figure 3a with the annual average wind speed approaching 9m/sec, while Figure 3b gives the respective solar irradiance measurements, with the total annual available solar energy at the horizontal plane being equal to ~1570kWh/m^2.a.

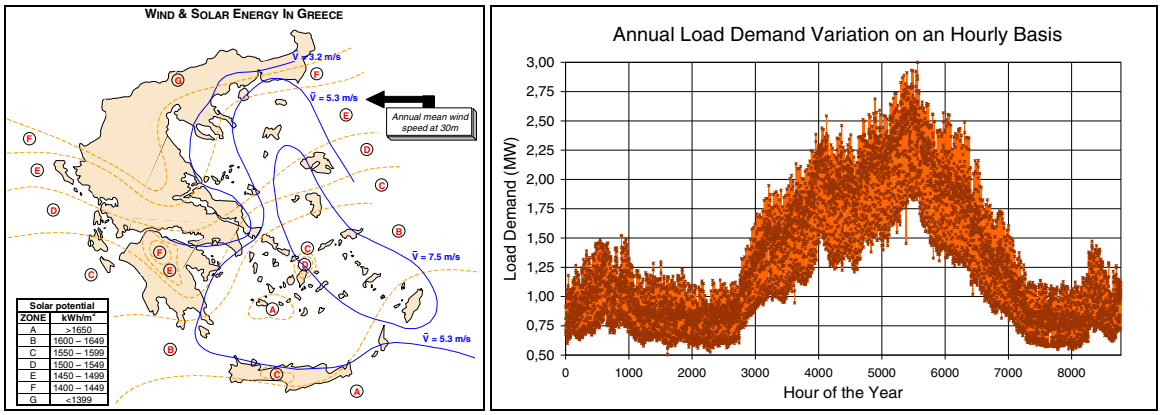

Fig. 2. (a) RES potential of the entire Greek territory; (b) annual load demand variation of a typical small-medium Aegean island grid.

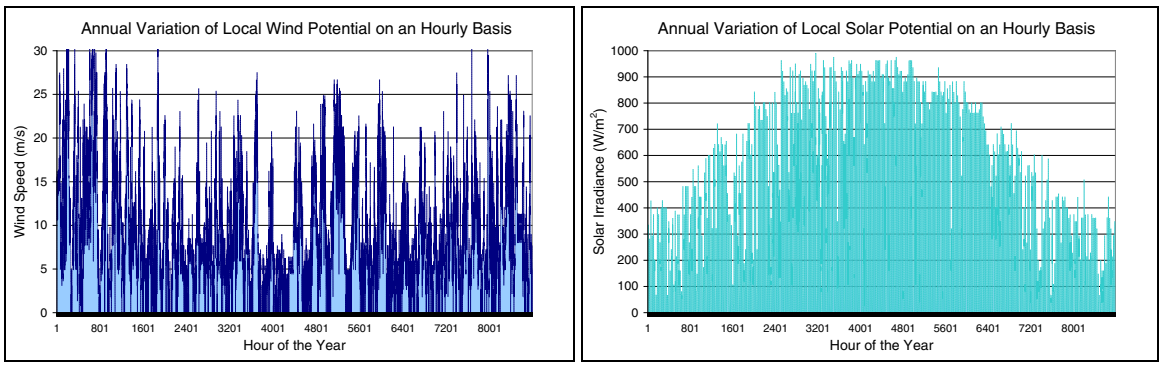

Fig. 3. (a) Annual variation of wind potential; (b) and solar potential, for the typical area of investigation on an hourly basis.

4. Application results

Application of the developed methodology is first undertaken with regards to the examination of wind-energy storage configurations, employing battery storage of round-trip efficiency in the order of 65% and a maximum depth of discharge of 60%. Levels of complementarity between the annual average 24 hour wind speed and load demand for the area of investigation are illustrated in Figure 4, where as one may note, there is an inverse behaviour between the two patterns, with higher, night-time load demand coinciding with comparatively lower-wind speed periods.

In this context, application of DSM could have significant impact on the dimensions of wind-battery configurations and energy storage capacity, otherwise stressed to cover calm spell periods during which wind energy production is insufficient to cover load demand.

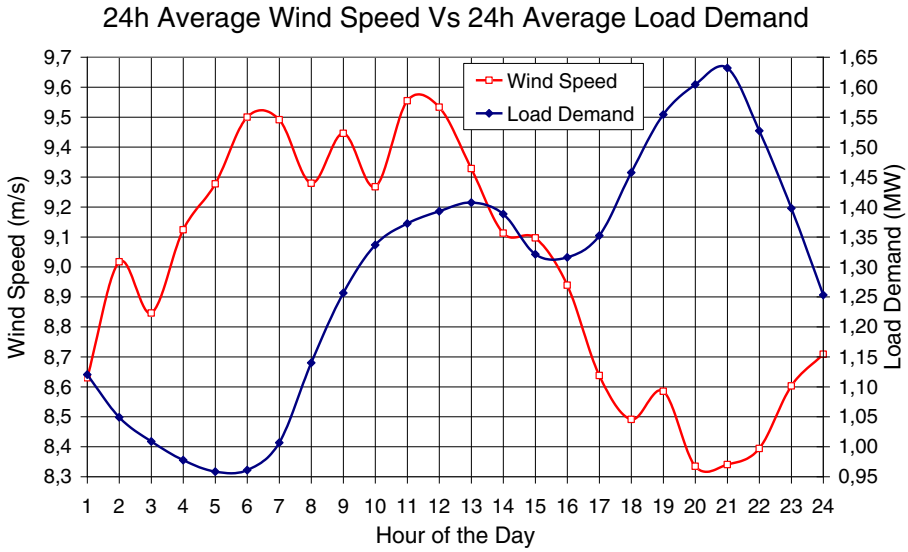

Fig. 4. 24h average load demand vs 24h average wind speed.

Furthermore, on top of the peak limit signal application, a wind speed signal is also investigated in order to avoid implementation of DSM during hours of high wind speed. Illustration of the two DSM strategies, i.e. with (revised load-2) and without (revised load-1) the use of a wind speed signal (currently set at the wind speed of 12m/s, corresponding also to the rated wind speed of the wind turbine curve used, with the respective cut-in and cut-out speeds being 4m/s and 25m/s) is given in Figure 5 for a 30% peak limit signal.

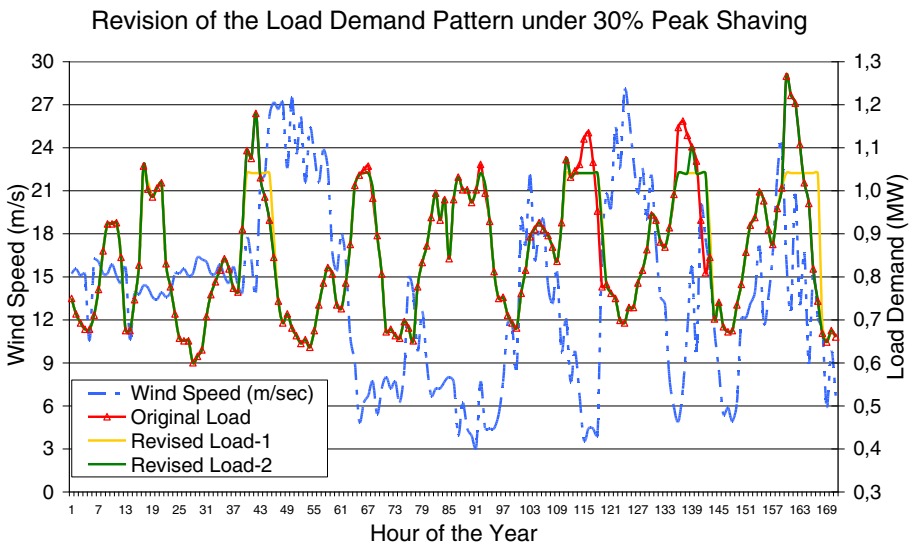

Fig. 5. Revision of the load demand pattern vs wind speed variation.

According to the figure results, whenever load demand exceeds 70% of the respective monthly peak demand, DSM is applied in order to reduce load demand to the desirable maximum load (i.e. 70% of the corresponding monthly load demand), while in case that the wind speed signal is also activated, DSM (peak shaving) is permitted only when wind speed drops below 12m/s (see for example hours 37-45 and 160 to 167).

Following, by considering a range of variation for the system main parameters, i.e. wind power capacity between 10 and 24MW and energy storage capacity between 150 and 350MWh, in Figure 6a we present the energy autonomy levels achieved by each of the examined combinations with and without the application of DSM.

In fact, instead of energy autonomy levels achieved, the complementary hours of load rejection are estimated, these expressing the hours of the year that the load cannot be fully covered owed to the weakness of the combined wind-storage solution to satisfy the appearing demand (insufficient wind energy production and low levels of energy stores).

According to the figure results, peak shaving limit of 30% (which is rather considerable) is found to have significant impact on the hours of load rejection per year, even reducing them by 15%.

On top of that, owed to the application of DSM, configurations of wind park capacity such as the ones exceeding 22MW and also employing storage capacity of 350MWh could even become energy autonomous, i.e. achieve zero load rejection per year.

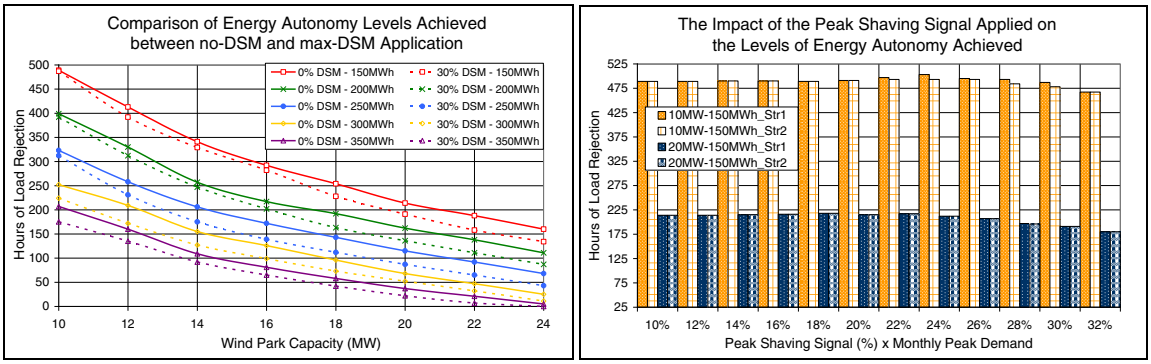

Fig. 6. (a) Energy autonomy levels achieved from a wind-battery system; (b) the impact of increasing the DSM peak limit.

In the same context, in Figure 6b the impact of peak limit increase is provided for two distinct configurations, i.e. a wind park of 10MW and 20MW respectively, combined with a fixed storage capacity of 150MWh. At the same time, both of the strategies, i.e. with (Str2) and without (Str1) the consideration of the wind speed signal, are included. According to the figure results, the peak limit is found to reduce hours of load rejection (note that up to 10% rejection hours values are constant) only if increased to exceed 26%.

On the other hand, in certain cases, the opposite result is noted, i.e. DSM has an adverse effect on energy autonomy levels since hours of load rejection appear to increase. Finally, as far as the impact of the wind speed signal is concerned (Str2), difference induced by its application is found to be negligible, although having a positive effect on the reduction of hours of load rejection.

In addition, in the final Figure 7 of the current study, DSM is again applied, this time for representative hybrid RES configurations, employing both wind and solar power. More precisely, a fixed 10MW wind power capacity is currently combined with 1MW and 2MW PV power respectively, under the variation of energy storage capacity from 150MWh to 350MWh.

Again, the extreme scenarios of 0% and 30% DSM application are considered, while for comparison purposes, the wind-only case (i.e. 0MW of PV power) is also included. According to the figure results, despite the fact that addition of solar power reduces -in comparison to the wind-only case- hours of load rejection considerably, the role of DSM still remains important, especially for the medium scale storage capacity where DSM may even yield reduction of load rejection hours by 20%.

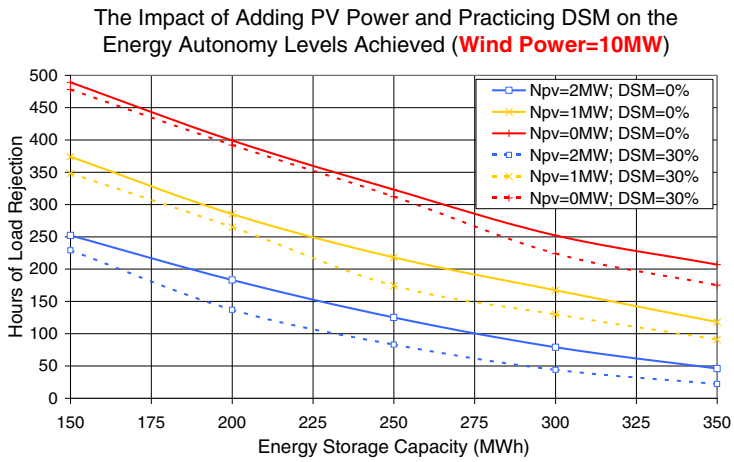

Fig. 7. The impact of DSM on the energy autonomy achieved by hybrid wind-PV systems.

5. Conclusions

By applying peak shaving and load shifting techniques, we currently study the impact of DSM on the sizing of RES-based energy storage configurations. For this purpose, we extend an already developed sizing algorithm for hybrid RES configurations, through the addition of DSM attributes. The revised algorithm is accordingly applied to a typical remote island grid area of medium-high RES potential in order to measure the impact of DSM on system size and energy autonomy levels achieved. According to our results, the appropriate level of DSM application may produce considerable benefits in terms of energy autonomy that yield even 15% reduction of hours of load rejection per year for wind-battery configurations. At the same time, despite the fact that addition of solar power increases the levels of energy autonomy considerably on its own, the role of DSM in the performance of hybrid wind-PV systems still remains important. To this end, further work is required in order for the effectiveness of prognostic tools to also be counted in, in comparison with the current ex-post approach considering perfect prognosis of both load demand and RES potential information, i.e. problem parameters necessary to produce the appropriate DSM rules. On top of that, the specific methodology may be further improved by also considering specific time rules as well as the stochastic behaviour of electricity consumers if given the opportunity to adopt certain DSM attributes.

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