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# Effects of Ramp Rate Limit on Sizing of Energy Storage System for PV-Wind Power System

**Abstract:** The power produced by variable renewable energy power plants (VREPP) can fluctuate heavily and cause issues in the power grid. To prevent the power quality issues in the grid, some countries have set a ramp-rate limit (RR) that the generated output power of power plants may not exceed. The power fluctuations of VREPPs are often mitigated by an energy storage system (ESS) and a power smoothing method. This paper presents how the RR limit value affects the size of an ESS needed for a photovoltaic (PV)-wind power system. Also, the size of the power plant is considered, and how it affects the size of the ESS. The generated power of the PV-wind power system was simulated using measured irradiance, temperature and wind speed. An RR-based control algorithm was used to operate the virtual ESS. It was found that the increase in the RR limit greatly decreases the size of the ESS. The size of the power plant also significantly affects the size of the ESS.

**Keywords:** photovoltaic power, wind power, power ramp rate, energy storage, power smoothing

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## 1 Background and Aims

As the amount of grid-connected variable renewable energy power plants (VREPP) increases, the stability of the grid is endangered as the output power fluctuations of these power plants are likely to cause issues with the power quality. Some countries have set limitations in their grid codes to prevent issues caused by highly fluctuating power. For example, Puerto Rico has set a ramp rate (RR) limit of 10 %/min of the rated power of the power plant [1]. The RR limit is the power ramp level below which the power fluctuations of power plants should not cause issues in the grid. The applied RR limits vary by country, and the RR limit of a country can change in the future.

The power output fluctuations of VREPPs are often mitigated by an energy storage system (ESS) and a power smoothing method. The smoothed power acts as the reference power for the ESS. One power smoothing method type is an RR-based control algorithm. An RR-based control algorithm was used in [2, 3] to mitigate the power fluctuations of a photovoltaic (PV) power system. In both studies, it was found that the RR limit value affects the size of an ESS required for the PV power system. There are not that many studies that have investigated sizing of an ESS for a PV-wind power system.

This paper will study the effects of different RR limits on the size of an ESS coupled with a PV-wind power system. Also, it will be covered how the size of the power plant affects the size of an ESS when different RR limits are used.

## 2 Materials and Methods

Simulations for the generated power of the PV-wind power system were carried out with the irradiance, temperature and wind speed measurements from Tampere University Solar PV Power Station Research Plant [4]. All measurements were done for a period of 5 months with a sampling frequency of 10 Hz. The PV and wind power (WP) was simulated with MATLAB. A virtual ESS was used to mitigate the power fluctuations of the simulated sum power of the PV-wind power system.

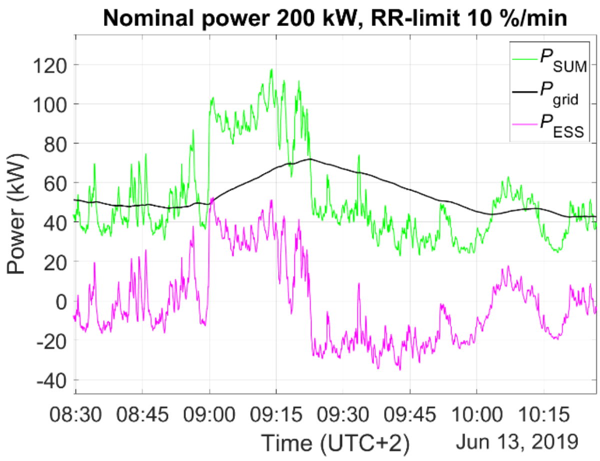


**Figure 1:** ESS mitigating the fluctuating sum power of the PV-wind power system**.**

The control algorithm used for the ESS was an RR-based algorithm that also takes into account that at every moment the ESS has enough energy for a sudden shutdown of the power plant. In other words, the output power of the power plant follows the RR limit also during a possible shutdown. Fig. 1 shows how the ESS operates to mitigate the fluctuating sum power $P_{\mathrm{SUM}}$ of the PV-wind power system. The grid input power of the PV-wind power system $P_{\mathrm{grid}}$ does not exceed the RR limit of 10 %/min, as the ESS is either charged or discharged with the power $P_{\mathrm{ESS}}$ of the ESS.

The simulations were done for 3 different power plant sizes whose total nominal powers $P_{\mathrm{NOM}}$ were 20 kW, 200 kW and 2 MW. With all the power plant sizes, 50% of the $P_{\mathrm{NOM}}$ consisted of PV power and 50% of WP. The nominal power of the PV system was scaled using different numbers of PV modules. The nominal power of a single PV module was 190 W. The nominal power of the WP system was scaled using 3 different wind turbine (WT) models whose nominal powers were 10 kW, 100 kW and 1 MW. The hub heights of the WT models were 16.5 m, 19.4 m and 70.5 m, respectively. The measured wind speeds at the height of 16.13 m were extrapolated to the hub heights of the WT models. The applied RR limit values were 1, 2, 5, 10 and 20 %/min with respect to $P_{\mathrm{NOM}}$.

## 3 Results and Conclusions

The main results of this study are the relative energy capacity $\frac{C_{\mathrm{ESS}}}{P_{\mathrm{NOM}}}$ (Fig. 2) and the relative power $\frac{P_{\mathrm{ESS}}}{P_{\mathrm{NOM}}}$ (Fig. 3) required for the ESS to smooth the power fed to the grid to comply with the applied RR limit all the time. The highest value for the $C_{\mathrm{ESS}}$ is mainly determined by the highest value of the $P_{\mathrm{grid}}$ as the ESS needs to have enough energy for a possible shut down at the $P_{\mathrm{grid}}$.

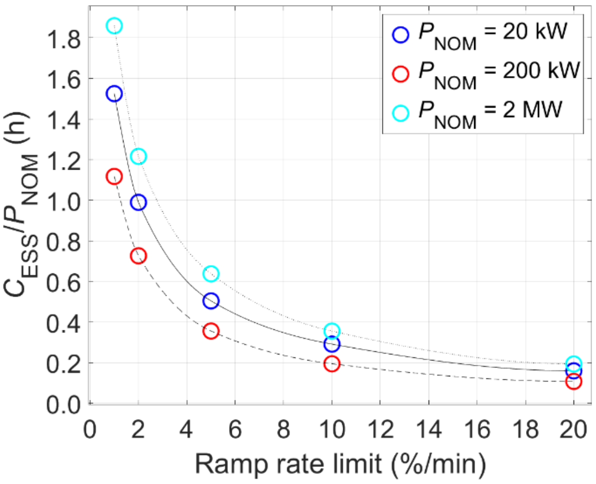


**Figure 2**: Relation between the ramp rate limit and the required energy capacity of the ESS with different power plant sizes.

In Fig. 2, it can be seen clearly that as the value of the RR limit increases, the value of the $\frac{C_{\mathrm{ESS}}}{P_{\mathrm{NOM}}}$ decreases for all the power plants. As the hub height of the 1 MW WT is roughly 50 meters higher than the hub heights of the 10 kW and 100 kW WTs, the incoming wind speed is higher, and the wind has greatly higher power density at the hub height of the 1 MW WT. This means that there is relatively more power available to be extracted for the 1 MW WT, and thus, the $P_{\mathrm{grid}}$ is also relatively higher for the 2 MW power plant. Therefore the $\frac{C_{\mathrm{ESS}}}{P_{\mathrm{NOM}}}$ values are higher for the 2 MW power plant. With the relatively higher generated WP, the power fluctuations of the 2 MW power plant are relatively greater compared to the 200 kW power plant. This explains the higher $\frac{P_{\mathrm{ESS}}}{P_{\mathrm{NOM}}}$ values for the 2 MW power plant compared to the 200 kW in Fig. 3.

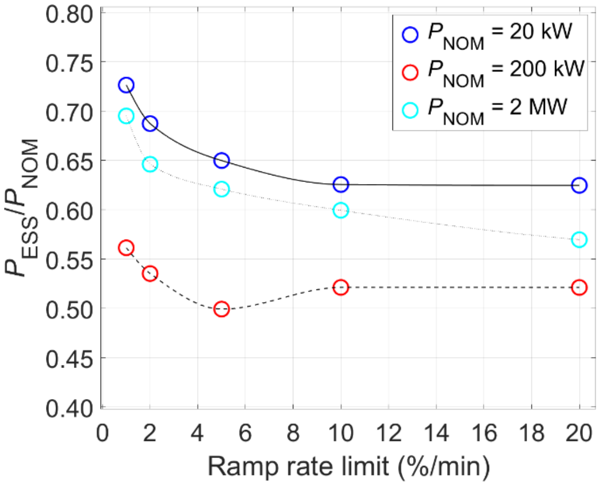


**Figure 3:** Relation between the RR limit and the power requirement of the ESS with different power plant sizes.

In Fig. 3, it can be seen that as the value of the RR limit increases, the value of the $\frac{P_{\mathrm{ESS}}}{P_{\mathrm{NOM}}}$ decreases for all the power plants. The highest value for the $P_{\mathrm{ESS}}$ is determined by the fastest power fluctuation.

As the hub height difference between the 10 kW and the 100 kW WTs is small, the difference between the relative maximum value of $P_{\mathrm{grid}}$ is small also. As the size of the PV power plant increases, the output power fluctuations decrease [5]. As the PV power fluctuations decrease, the requirements for the ESS decrease also. In Fig. 2, the $\frac{C_{\mathrm{ESS}}}{P_{\mathrm{NOM}}}$ values of the 200 kW power plant are lower than the values of the 20 kW power plant because the power smoothing effect of the larger PV power plant has a greater impact on the $\frac{C_{\mathrm{ESS}}}{P_{\mathrm{NOM}}}$ values than the increased WP production of the slightly higher WT. This effect also explains why the $\frac{P_{\mathrm{ESS}}}{P_{\mathrm{NOM}}}$ values of the 200 kW power plant are lower than the values of the 20 kW power plant in Fig. 3.

Table 1 shows the highest and median daily requirements for the ESS of the 200 kW PV-wind power system for several RR limits. From the energy shares cycled through the ESS, it can be clearly seen that the ESS operates a lot more during a highly fluctuating day than on an average day. The required size of the ESS is clearly smaller for an average day also.

**Table 1.** Requirements for the ESS of the 200 kW PV-wind power system for RR limits of 1, 10 and 20 %/min.

| | Highest daily value | | | Median daily value | | |
|---|---|---|---|---|---|---|
| RR limit (%/min) | 1 | 10 | 20 | 1 | 10 | 20 |
| Capacity (kWh) | 223 | 38.9 | 21.5 | 107 | 23.4 | 13.3 |
| Charging power (kW) | 112 | 104 | 104 | 62.7 | 49.6 | 49.7 |
| Discharging power (kW) | 57.8 | 75.5 | 79.7 | 34.5 | 43.4 | 44.5 |
| Energy cycled (%) | 35.2 | 20.2 | 18.4 | 25.2 | 12.0 | 10.0 |

The results show that the RR limit greatly affects the size required for the ESS of the PV-wind power system. The size of the power plant has also a notable effect on the size of the ESS.

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