Investigating the Voltage Fluctuation Caused by Solar PV Generation Variability in Distribution Grids

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Introduction

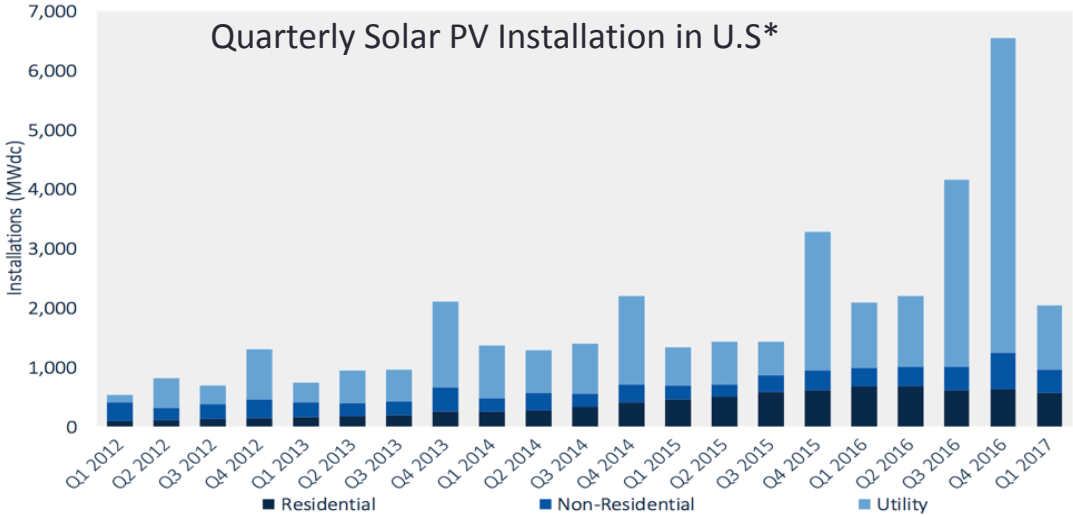
- The Renewable energy resources, particularly solar generation, are experiencing a rapid proliferation in power systems
- This proliferation, however, poses a set of new challenges in power grid operation and planning, mainly due to the inherent variability and uncertainty characteristics associated with these resources
- The generation variability of solar photovoltaic (PV) is caused by changing cloud cover and is mainly seen as large ramp rates, i.e., the rate at which a generation output of a unit changes.

Objective

- This presentation investigates the impact of solar ramp rate on the distribution system voltage by integrating a 1.04 MW solar PV
- The study exhibits the changes in the voltage when the ramp rate limitation has been applied to solar output.
- The ramp rate limitation is 10%/minute of the installed capacity. The system is studied for one selected hour, representing the highest ramps

Solar Installation

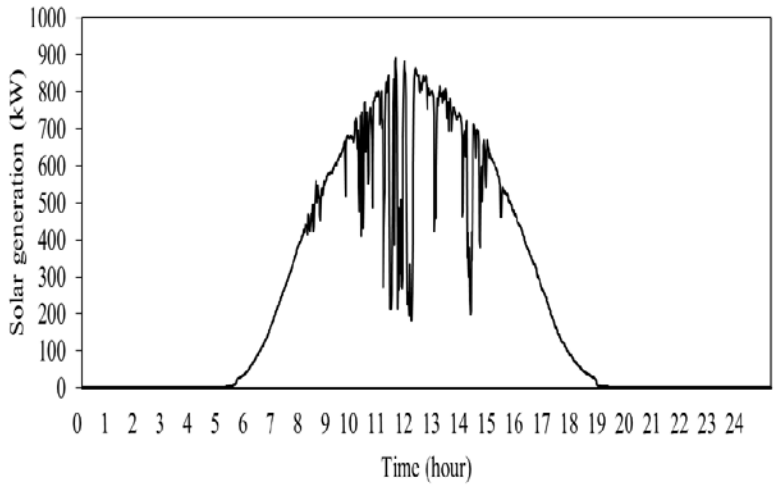
- In the first quarter of 2017, a total of 2 GW of solar PV was installed in the U.S., following exceptional capacity growth of more than 15 GW in 2016. .
- In 2016, solar generation was ranked as number one newly-added generation, representing 39% of the new capacity.
- It is further estimated that solar energy will provide 28% of all global energy used in 2040, making it the most significant energy resource by then



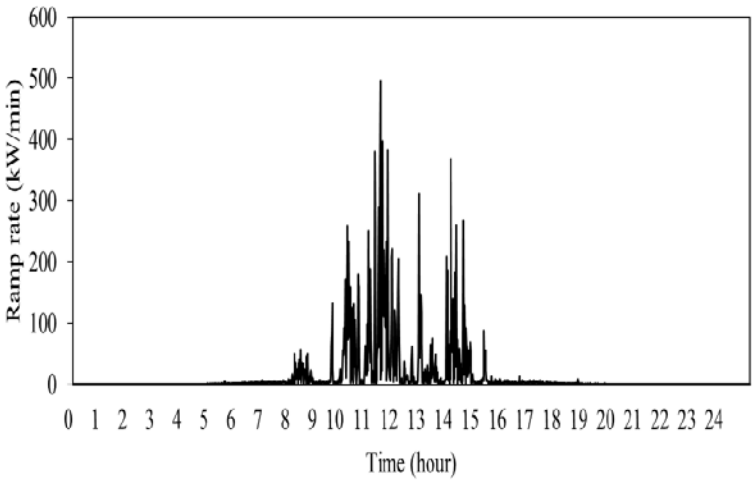
*Solar Energy Industries Association, "US Solar Market Insight:Q2 2017 ".

Solar Ramp Rate

- The solar generation with one-minute resolution for a sample day is shown below.
- It is clear that ramps are small in morning and evening hours due to clear weather conditions.
- Passing clouds can cause ramp rates to reach up to 500 kW/min.



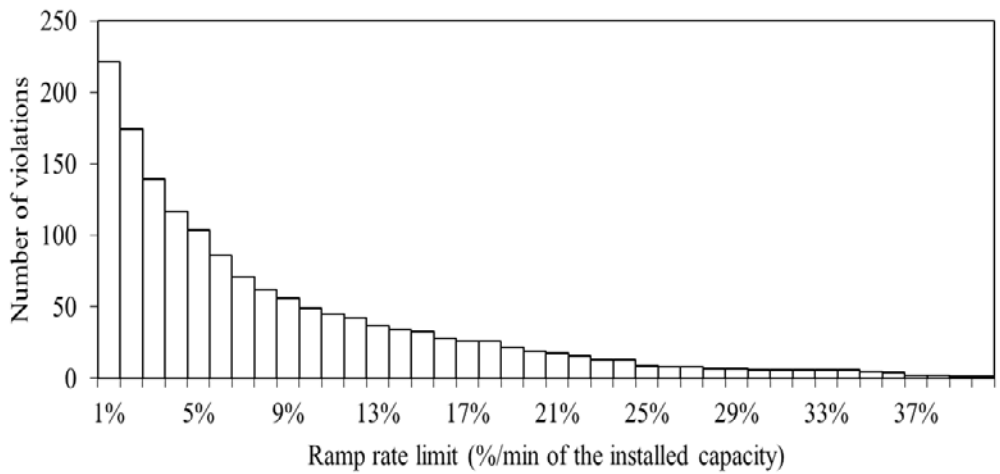
One-minute resolution solar generation.



One-minute resolution solar generation ramp rate

Case Study

- A total of 49 ramps is experienced when the ramp rate limit is set to 10%/min of the installed capacity where 37% of these ramps have occurred between 11:30 AM and 12:30 PM.
- If the ramp rate limit is set to 20%/min of the total installed capacity, the total number of ramps is reduced to 20.
- After 40%/min ramp rate limit, the number of violations is zero



The number of ramp rate volitions as ramp rate limit increases.

Case Study

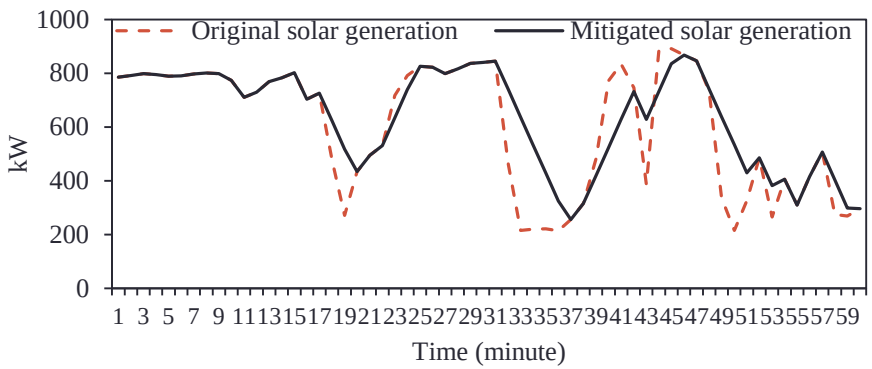
- In order to investigate the impact of solar power ramp rate mitigation, the IEEE 33-bus test system is used to run the power flow for a selected hour (11:30am to 12:30pm) and calculate the voltage changes at each bus.
- A 1.04 MW solar PV is connected to bus 18.
- The load is considered to be constant at this hour, with a value of 5.6 MW.
- It is assumed that solar has no voltage control.

The following cases are studied:

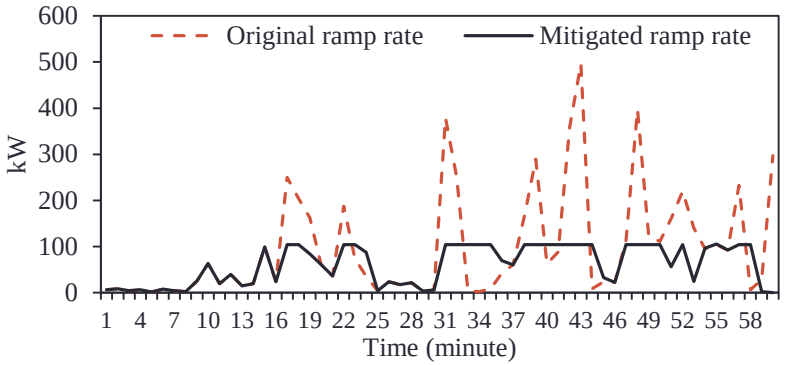
- Case 1: Voltage deviation at each bus without solar generation ramp rate mitigation.
- Case 2: Voltage deviation at each bus with solar generation ramp rate mitigation.

Case Study

- The solar generation is adjusted to mitigate the solar generation ramp rate.
- It is assumed that ramp rate, with negative and positive slopes, is corrected by charging and discharging the energy storage to reduce the ramp rate to a maximum of 104 kW/min.
- The energy storage sizing requirement is ignored in this study assuming that the existing energy storage is optimally sized and placed to limit and capture the solar ramp rate of larger than 104 kW/min.



Original solar generation vs. mitigated solar generation



Ramp rate vs. mitigated ramp rate

Case Study-Case1

- The highest ramp rate occurs between 11:30am and 12:30pm where the ramp rate has reached 496 kW/min.
- The solar generation data for the hour (11:30am to 12:30pm) is selected as solar generation connected to bus 18.
- The solar generation is considered in this study with unity power factor so no reactive power is generated by the solar PV.
- In this hour, 18 violations to ramp rate limit, which is 104 kW/min, have been recorded.
- The power flow is simulated under this case without mitigating the ramp rate.

Case Study-Case1

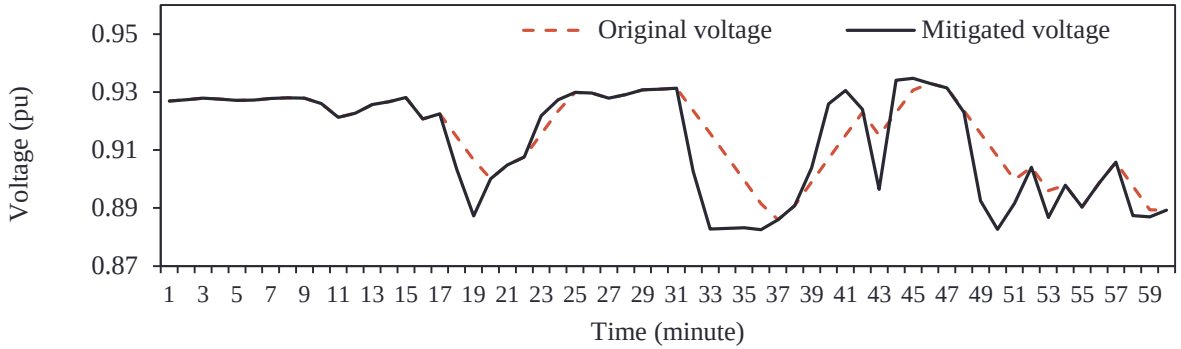
- Table below depicts the standard deviation for each bus over the hour and the highest deviation is on bus 18 where the PV is connected.
- In the simulation, bus one is considered an infinite bus with the bus voltage fixed to 1 pu.
- All the buses are still within the voltage limits used in the power flow.

Bus#	Standard deviation	Bus#	Standard deviation	Bus#	Standard deviation	Bus#	Standard deviation
2	0.000159	10	0.008644	18	0.018148	26	0.003724
3	0.001008	11	0.008964	19	0.000159	27	0.003738
4	0.001635	12	0.009573	20	0.000160	28	0.003800
5	0.002286	13	0.011965	21	0.000160	29	0.003846
6	0.003713	14	0.012846	22	0.000160	30	0.003865
7	0.004048	15	0.013790	23	0.001013	31	0.003888
8	0.005222	16	0.014973	24	0.001023	32	0.003893
9	0.006924	17	0.017006	25	0.001027	33	0.003895

Standard Deviation for the voltage at each bus – Case 1

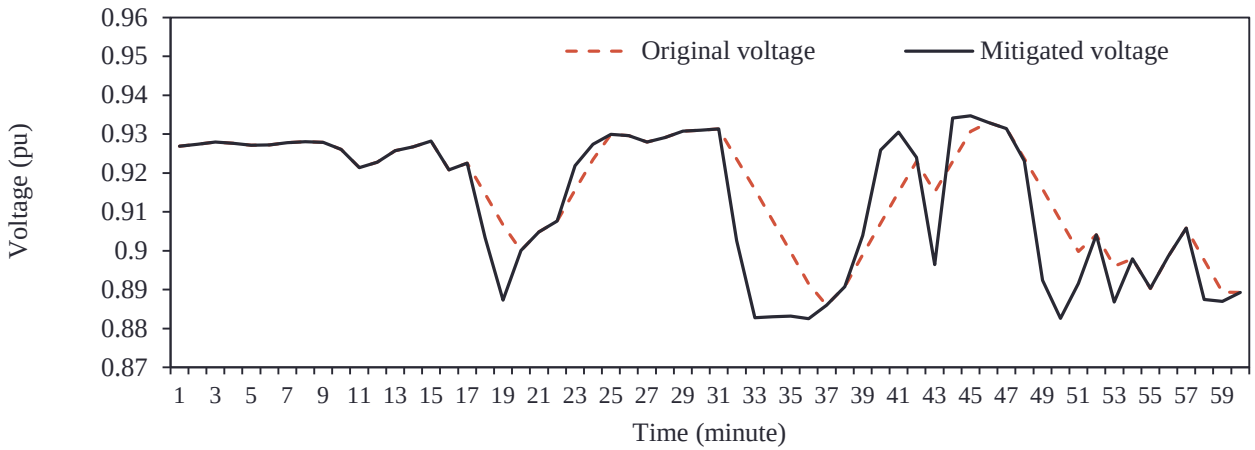
Case Study-Case2

- Under this case, the solar generation ramp rate is mitigated and limited to 104 kW/min.
- The ramp rate mitigation reduces the standard deviation in the voltage at each bus compared to case 1.
- Bus 18 still has the highest standard deviation, but it is reduced by almost 23% compared to Case 1.
- The buses closest to PV site have experienced a bigger reduction in the standard deviation compared to the other ones.
- Results further indicate that standard deviation increases gradually as buses get closer to bus 18.

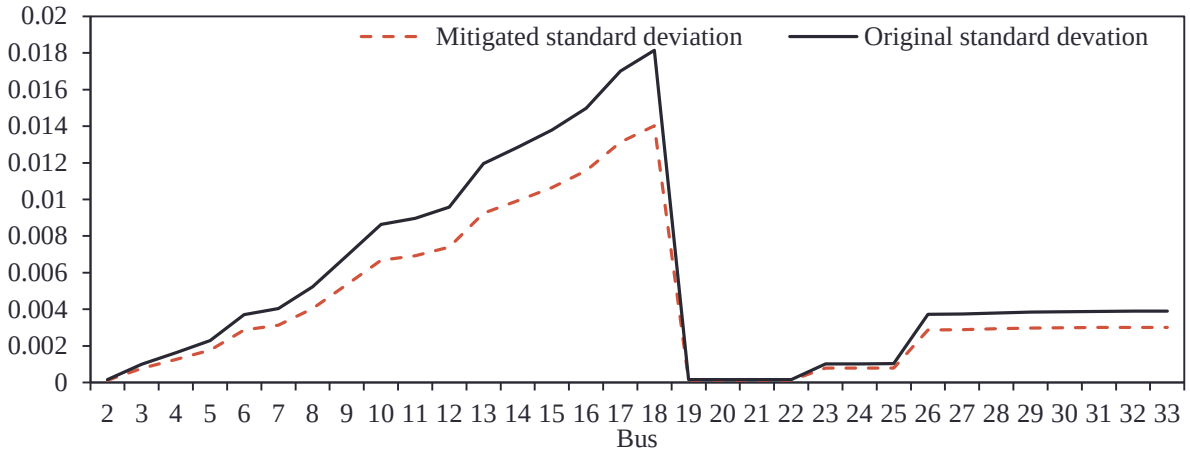


Voltage at bus 18 with/without ramp rate mitigation.

Case Study-Results



Voltage at bus 18 with/without ramp rate mitigation.



Standard deviation for the voltage at each bus.

Conclusion

- The effect of the solar generation ramp rate was investigated on a distribution system voltage.
- The power flow was simulated under two different cases.
- The first case where the solar ramp rate was not mitigated while the second case the solar generation ramp rate was mitigated to limit the ramp rate to 10%/min of the installed capacity.
- The Solar generation between 11:30am and 12:30pm had the highest ramp rate.
- A total of 18 violations to ramp rate limit have occurred at this hour. The ramp rate mitigation reduced the standard deviation for bus 18 where the PV is connected by almost 23%.
- In case of higher solar penetration, the solar ramp rate may cause a negative impact on the system voltage.

Thank you

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