Grid Stability Analysis for High Penetration Solar Photovoltaics

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Introduction

- The ever growing global energy needs and the immediate need for an environment friendly sustainable growth has made us focus on renewable energy sources, especially wind and solar.
- But these renewable energy resources when implemented in large scale without any specialized controls is found to impact the integrity, reliability and stability of the grid.
- Solar PV forms a major portion among the utility level renewable energy power plants.
- Solar PV power penetration into the grid is on continuous rise and plants of order of hundreds of MW are coming up in India and at global level.
- The large upcoming utility scale solar plants are expected to behave similar to the conventional plants when it comes to handing grid stability.
- Hence it is important to study and analyze the impact of the large scale penetration of solar PV power into the grid.

Problem Statement

- Till now, the solar PV installations were small in size and quantity and were connected only at distribution level. But large solar parks of order of hundreds of MW are coming up and will be connected at transmission level.
- Solar PV unlike thermal power plant is asynchronously integrated into the grid through inverter. Hence they do not contribute for grid inertia. It is a significant aspect of conventional synchronous generators that helps in the inertial response during frequency control.
- At present the solar PV plant's anti-islanding protection immediately trips the plant when there is a grid fault. When the capacity of the plant is large, it will cause generation-load imbalance.
- If the plant capacity is large, the seasonal and weather variations like clouding will heavily impact the grid.
- There are several such impacts caused by the increased penetration of solar PV into the power system.

Project Objectives and Scope

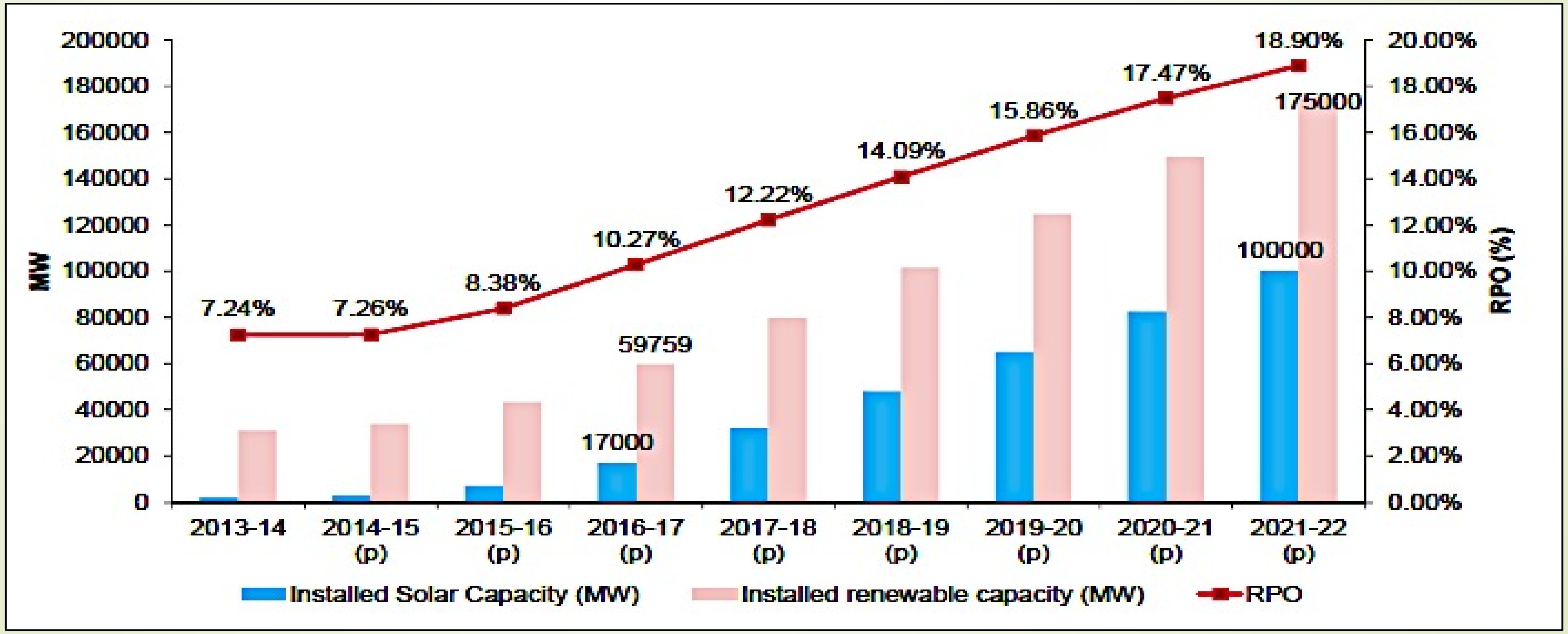
- To understand the need and requirement in analyzing the impact of high penetration PV into the grid,
  - The basics of grid stability has been studied.
  - A brief study has been done on the present scenario of Indian power sector to understand the current and future solar PV penetration levels and the policy framework in India to promote solar power.
- To understand the performance requirements of large and upcoming solar PV plants,
  - Study on the controls existing in a conventional power plant to manage the grid stability has been done
- In order to identify the drawbacks and impact of high penetration PV on the power system, literature survey has been done.

Project Objectives and Scope (Contd.)

- A standard bus system has been identified and modelled in ETAP software. Solar PV plant is integrated into the standard bus system. This system has been used for further analyses.
- The impact of increased solar PV penetration on the ***steady state performance*** of the system has been studied.
- The impact of large solar PV penetration on the ***transient stability*** of the grid has been studied.

Study on Indian power sector scenario

- Based on CEA and MNRE data, the present solar penetration is about 2.23% (6,762.85 MW of solar among 3,02,833.2 MW in total as on April 2016).
- Renewable energy installments being order of the day and government's thrust in promoting renewable energy throughout the country the total penetration of solar is set to increase at a rapid pace.
- As per CEA projection and MNRE's JNNSM-2015 target, the penetration would be around 23% by 2022 (100 GW of solar among 434900 MW in total).



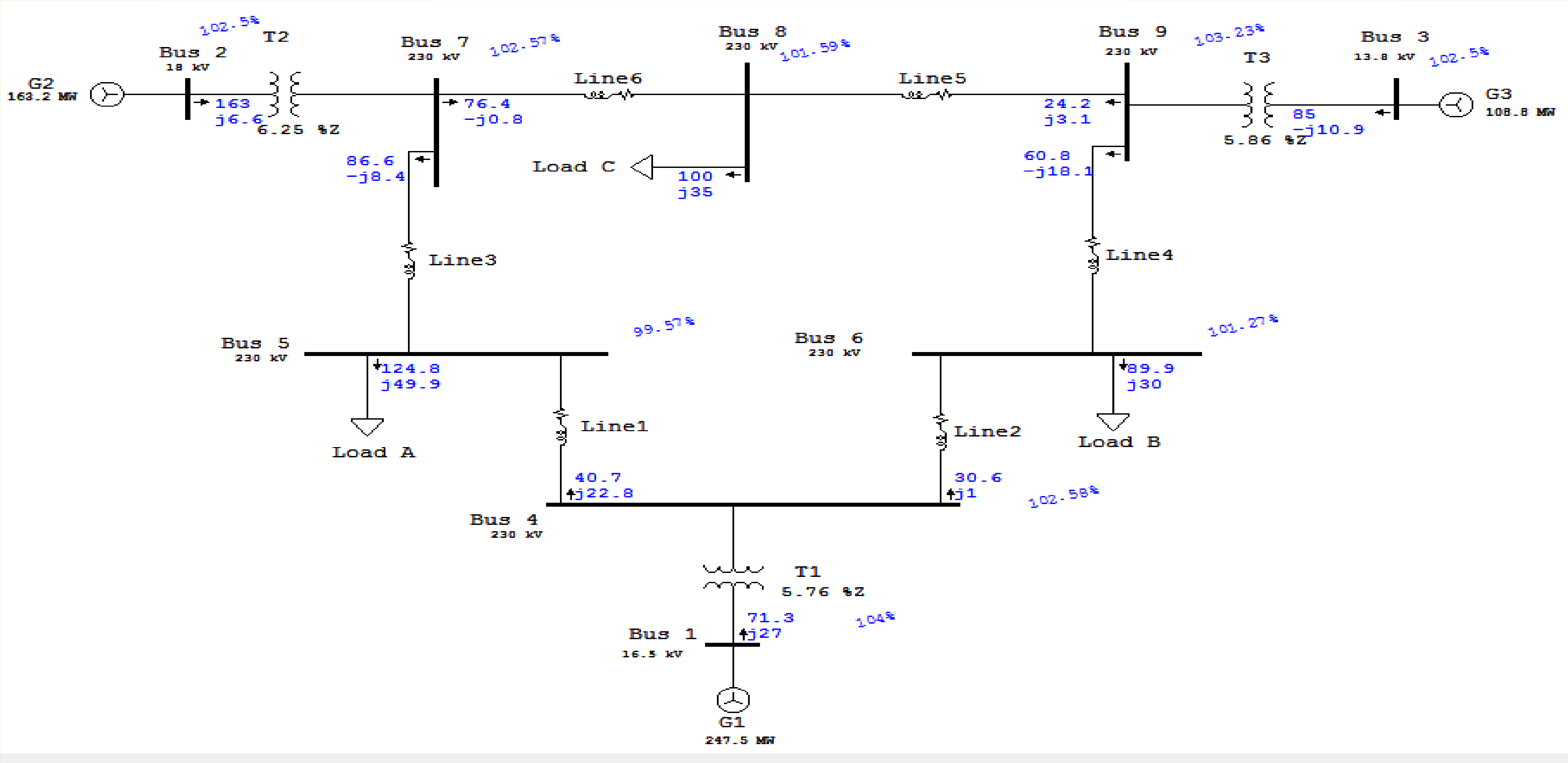
Controls existing in a conventional power plant

- **Generation side controls existing in a conventional power plant (Based on the Industrial Visit done at MTPS, Tamil Nadu)**
  - **Frequency stability and active power control**
    - Initial phase – Grid inertial response
    - Control phase – Primary control (Turbine speed governor system – ALFC & RGMO with speed droop), Secondary control – AGC, Tertiary control, Overall plant control.
  - **Voltage stability and reactive power control**
    - Steady state voltage regulation – AVR in Excitation system with voltage control mode
    - VAR compensation and support – AVR in Excitation system with VAR mode (Under or over excitation)
    - Voltage profile improvement by on-load or off-load tap changing transformer
  - **Angle stability**
    - PSS in excitation system to improve small signal angle stability
    - Transient stability improvement – High speed excitation along with PSS and several other controls.

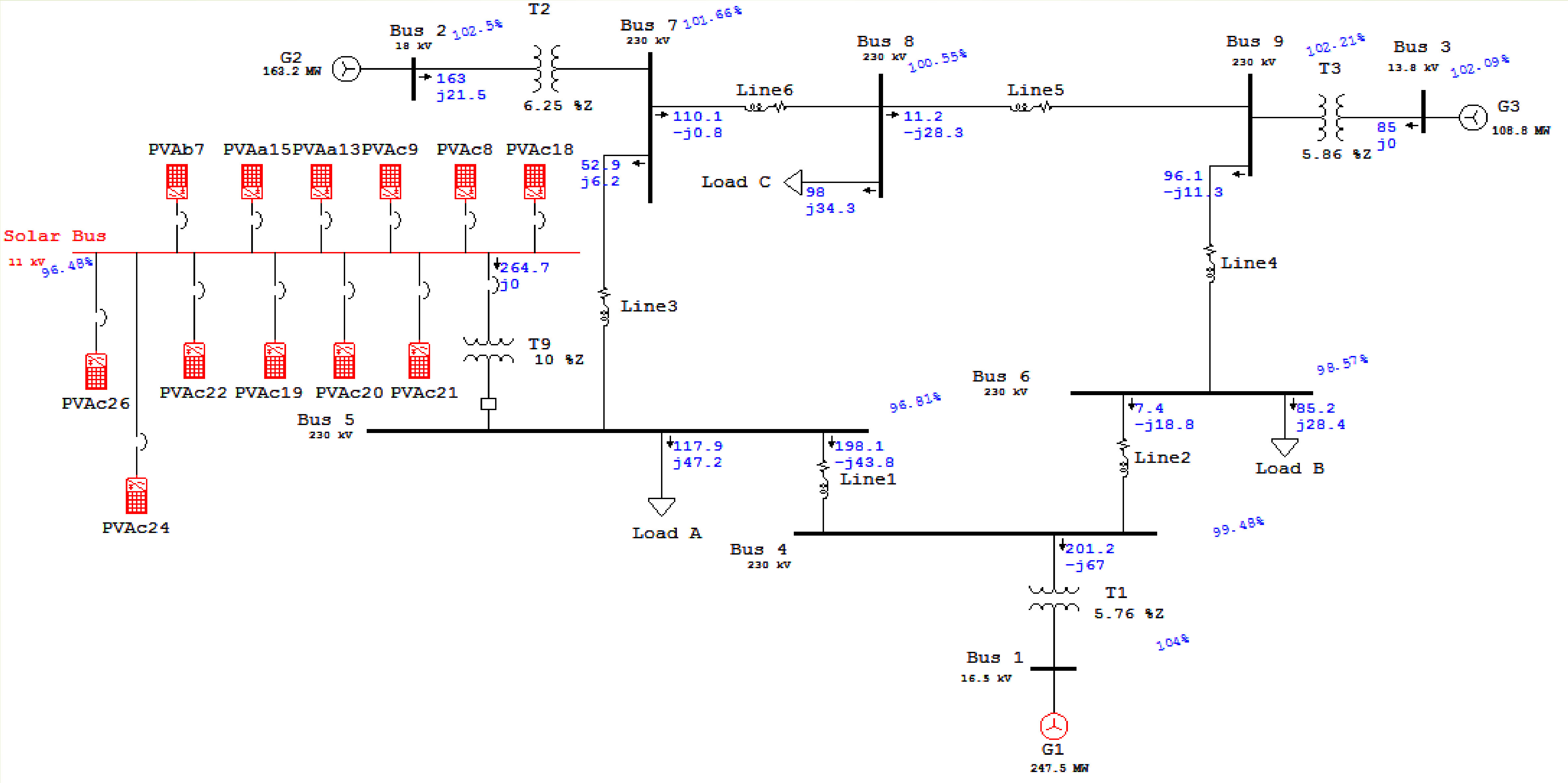
Methodology for analysis

- **Steady state analysis**
  - A standard bus test system integrated with a large solar PV plant has been considered. Through 'Load Flow Analysis module' in ETAP software, the impact of large scale penetration of Solar PV on the steady state performance of the grid is assessed with a specific focus on,
    - Voltage Variation in all buses
    - Slack bus power
    - Line loading effect and system losses
- **Transient analysis**
  - A standard bus test system integrated with a large solar PV plant has been considered. Through 'Transient Stability Analysis' module in ETAP software, the impact on the transient stability performance of the grid is studied for the following transient events,
    - Effect due to a Bus Fault
    - Effect due to Loss of a Transmission Line
    - Effect on Critical Clearing Time
    - Effect due to Load Rejection

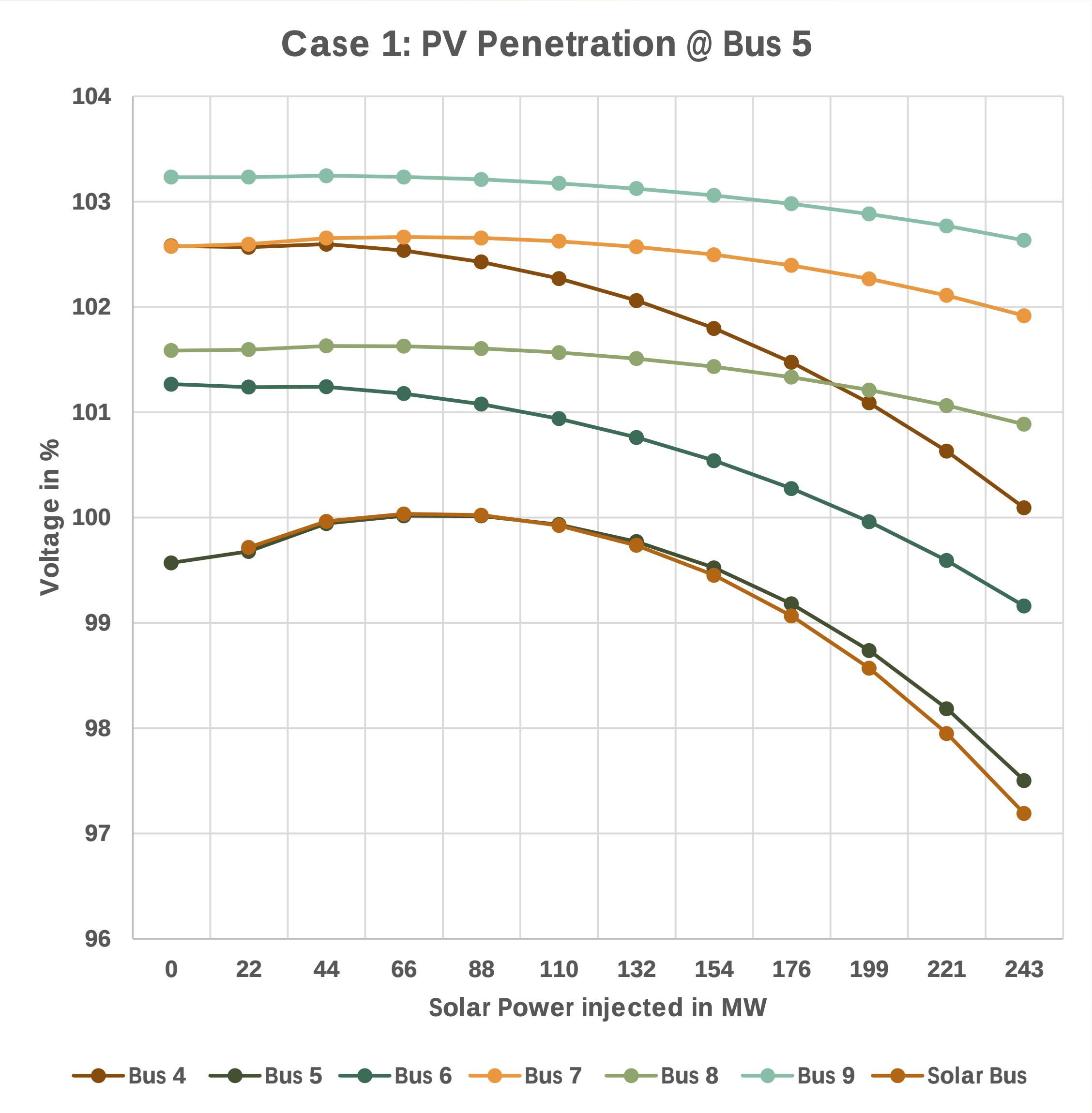
Modelling in ETAP – IEEE 9-bus system

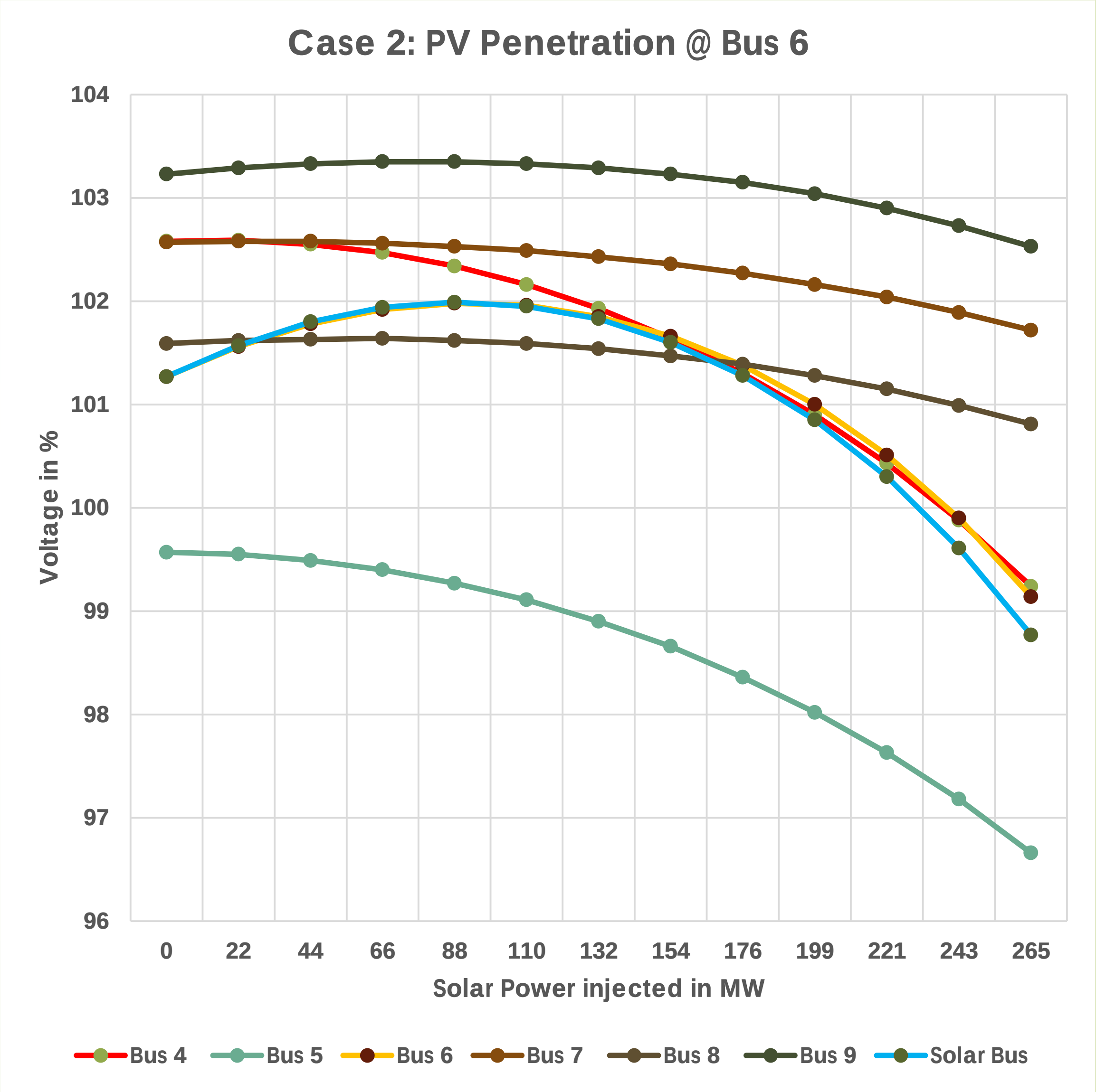


Modelling in ETAP: IEEE 9-bus system integrated with solar PV plant

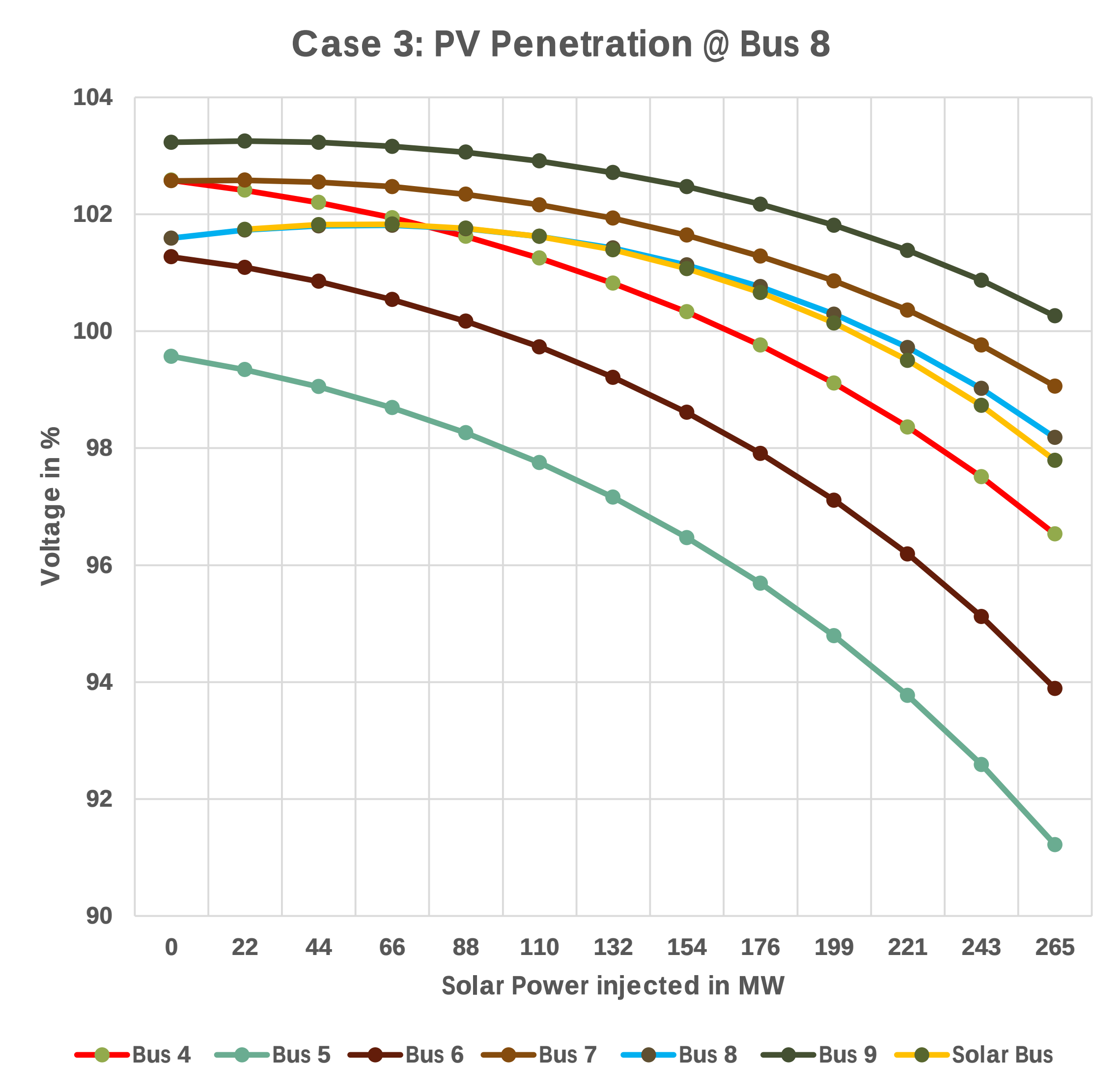


Steady state analysis: Effect on steady state bus voltages



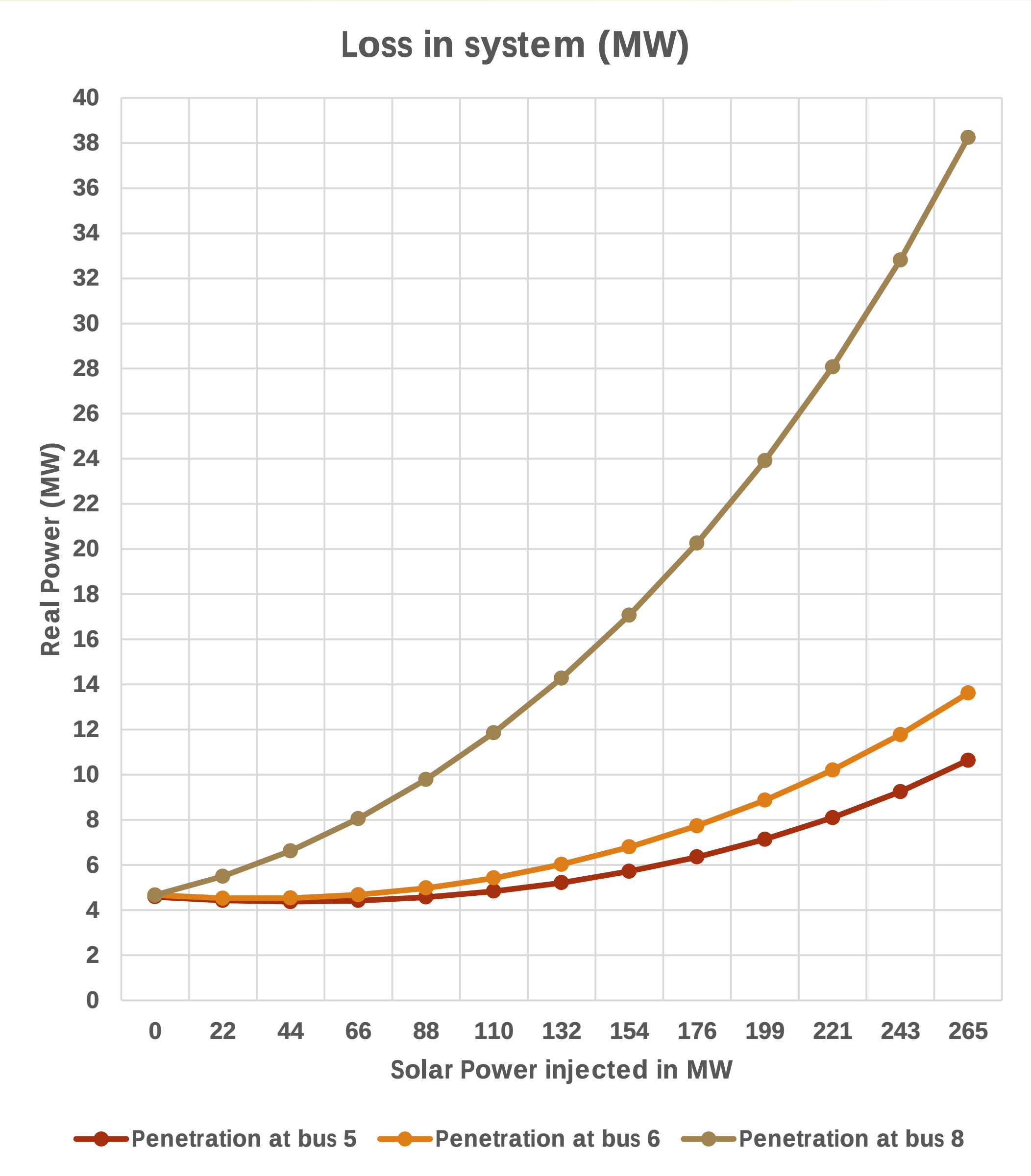


Steady state analysis: Effect on steady state bus voltages

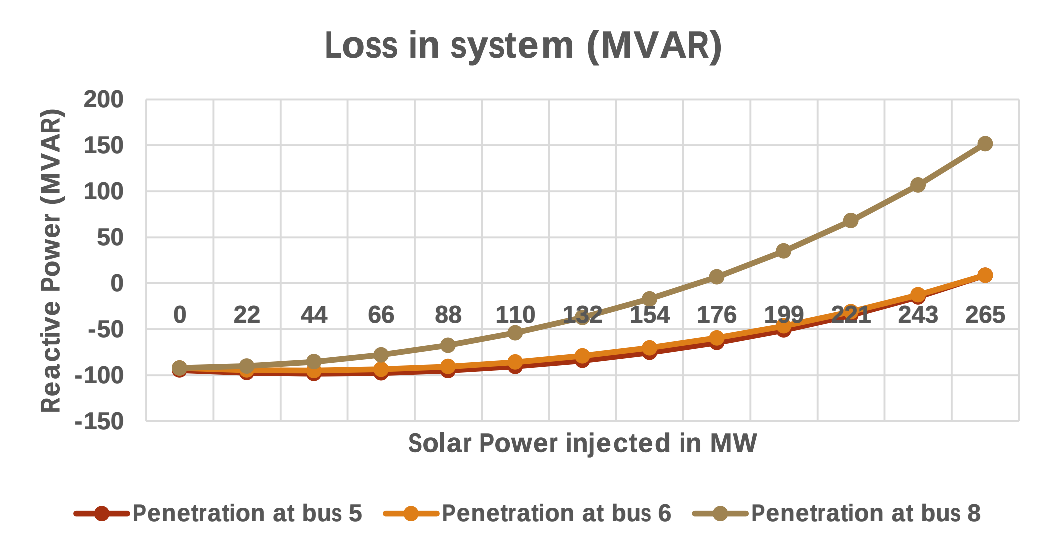


- Similar trend of voltage variation is observed in all three cases as shown in the plot – Bus voltages (except for generator buses) improved with increase in solar penetration till a point and then it started dropping because of increased line drop.
- The intensity of variation in voltages varied with the location of penetration. The maximum of the variation in bus voltages observed in all three cases is listed below,
  - Case 1: 2.5% variation @Bus 5; Case 2: 3.35% @Bus 4; Case 3: 8.35% @Bus 5;
- The peak point of the curve also varies with the location of penetration.
- it is seen from the study that among the three cases, PV injection at bus 5 was better as it allowed for more penetration with less severe variation in voltages.

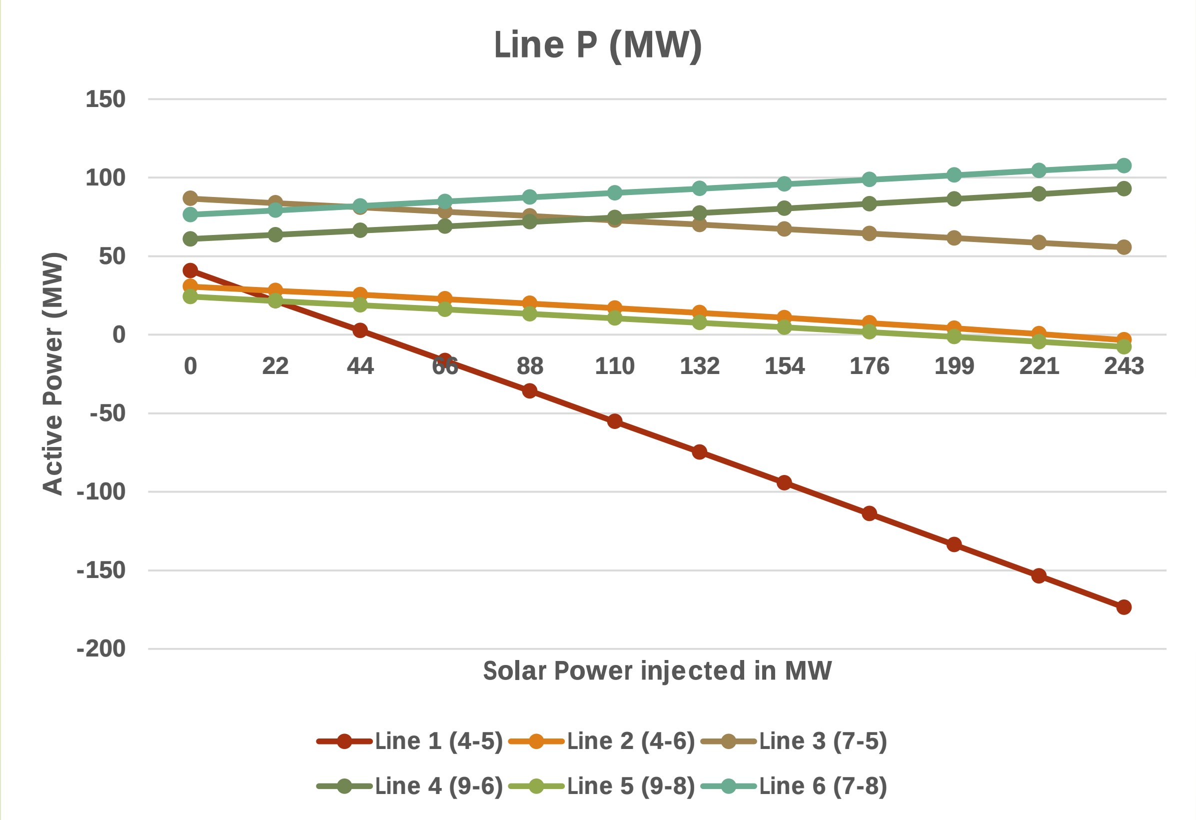
Steady state analysis: Effect on System loss

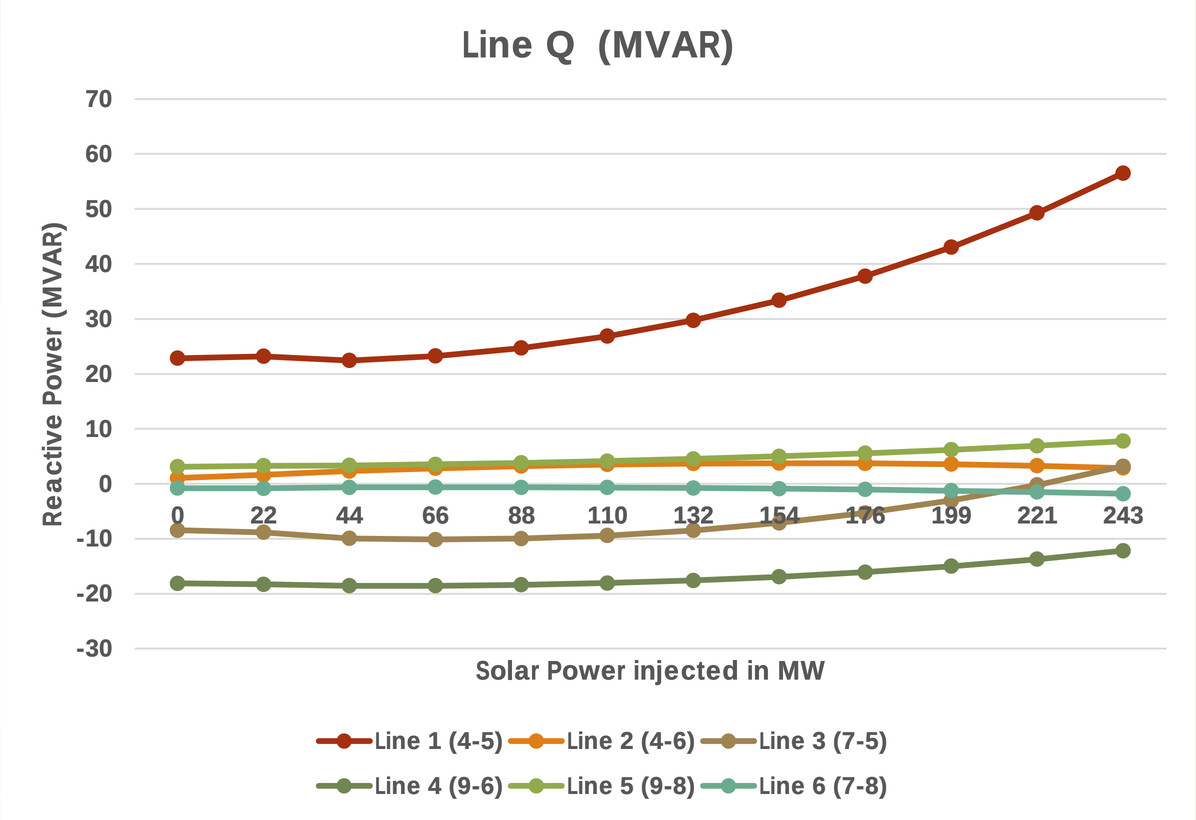


- Total system loss (both MW and MVAR) was decreasing initially as the level of penetration was increasing and beyond a point the losses started increasing. Case 3 was severe where the losses started increasing from the beginning.
- Optimal penetration level with respect to the system losses can be identified from the system loss profile and also the best location for penetration can also be identified from this analysis.



Steady state analysis: Effect on Transmission Line Power Flow





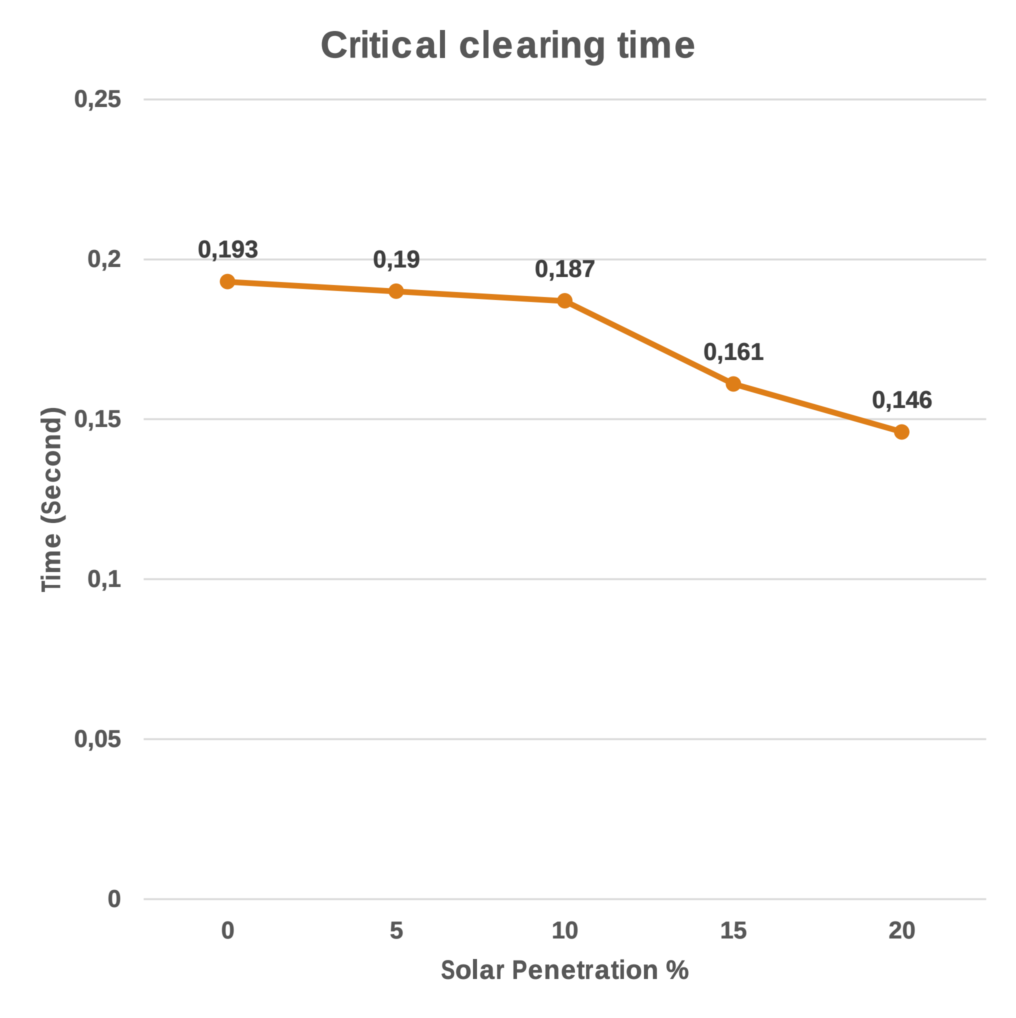
- The variation in loading of the transmission lines was mixed with few lines experiencing increase in power and few lines experiencing decrease in power, as the % penetration increases. Few of the lines experienced power reversal beyond a point. The changes in loading of line 1 is severe of all.
- It is very important to consider the impact of solar penetration on transmission line loading parameters while planning the network.

Steady state analysis: Summary

	Appropriate location	Maximum possible penetration
Based on bus voltage	Bus 5	66 MW
Based on system loss	Bus 5	44 MW

- Increase in PV penetration can bring about variation in steady state bus voltage levels and can be really critical and could even contribute to affecting the voltage stability of grid.
- It might bring about severe changes into other parameters like steady state real power and reactive power loading of transmission lines and other equipment in the system and also affect the system losses.
- It is important in performing such a study, which will help engineers in planning the system with high penetration levels of solar PV power and in identifying the critical PV penetration levels and appropriate location for penetration in a given network.

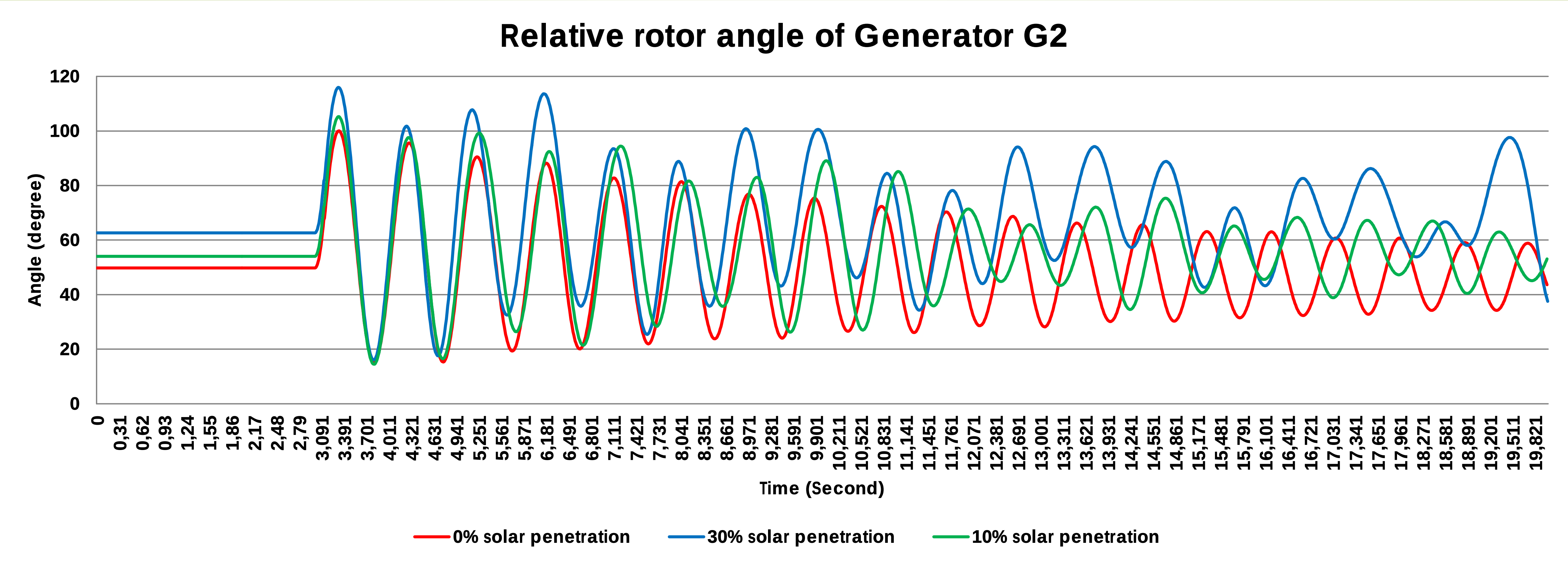
Transient Stability Analysis: Effect on Critical Clearing Time



- The critical clearing time of the system continuously decreases as the the solar PV penetration increases.
- For the penetration beyond 20%, the system is unstable for any clearing time.

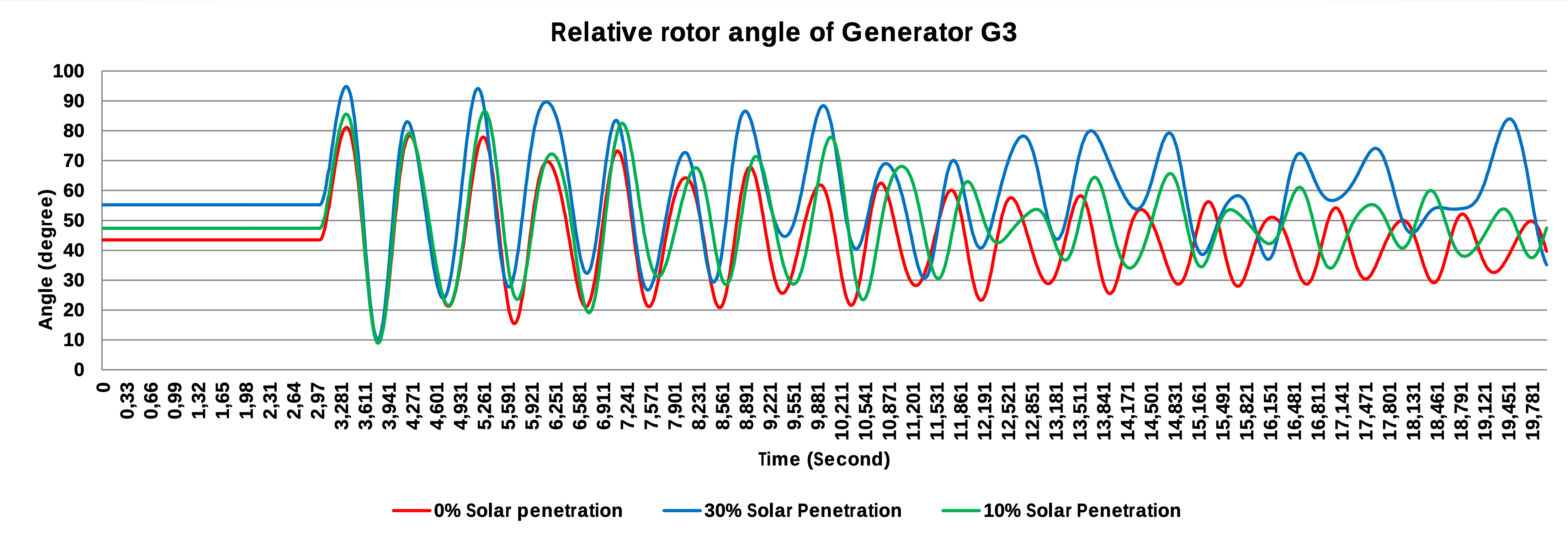
Solar penetration (%)	Critical clearing time (second)
0	0.193
5	0.19
10	0.187
15	0.161
20	0.146
> 20	Unstable for any clearing time

Transient Stability Analysis: Effect due to a bus fault



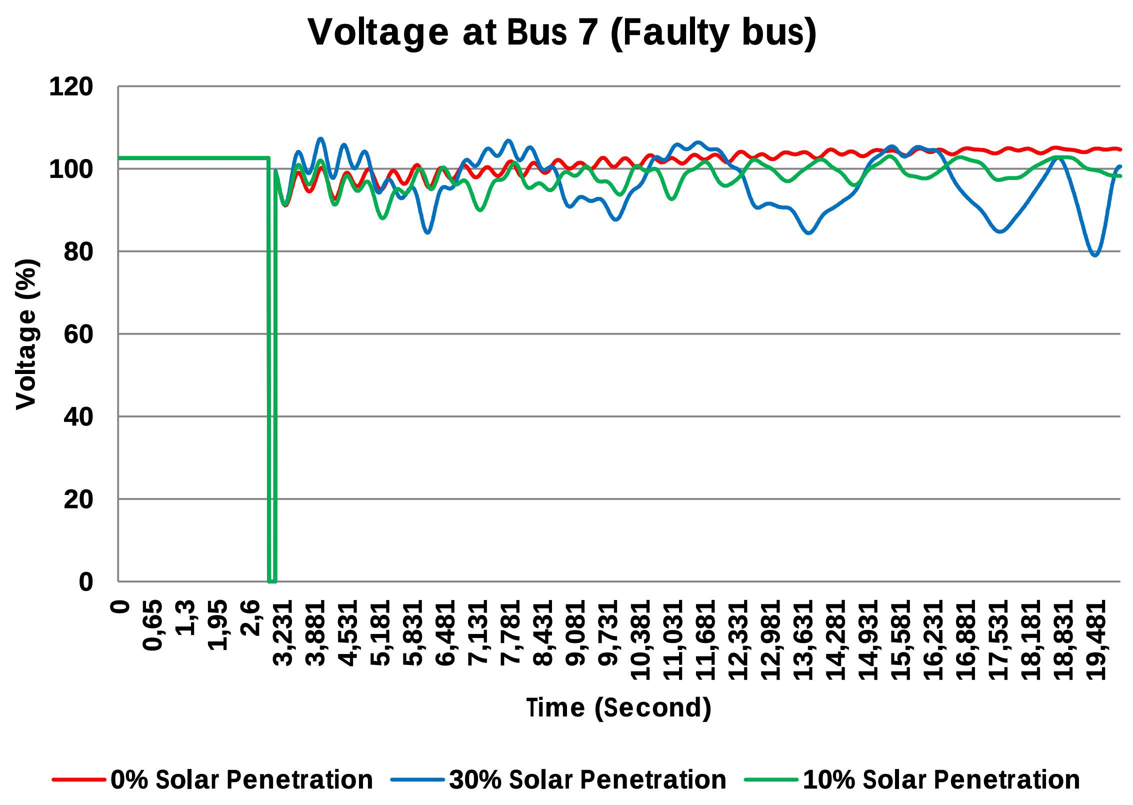
- The oscillations following the disturbance for the base case with 0% solar PV penetration is smooth and is converging towards a stable value. For the case with 10% solar penetration, the amplitude of oscillations is a bit more and is getting little irregular. Yet it was converging and the system was stable. For 30 % penetration case, the oscillations have been completely irregular and don't converge to a stable value.

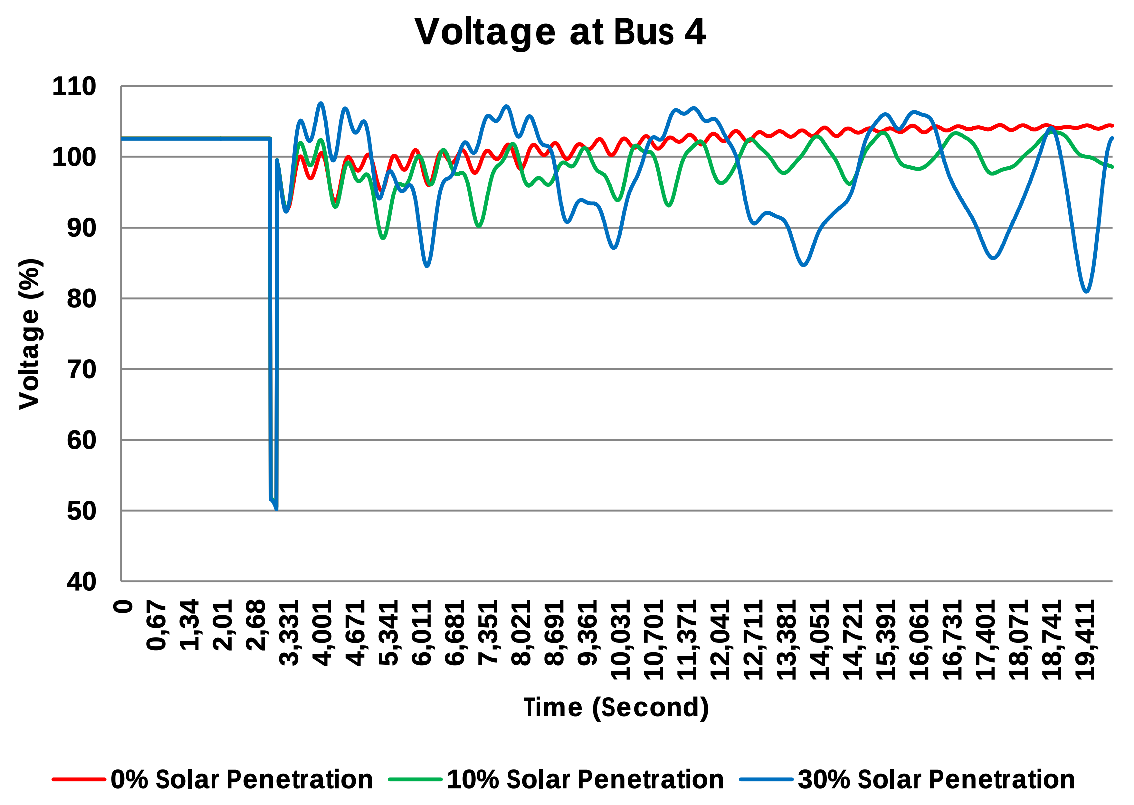
Transient Stability Analysis: Effect due to a bus fault



- Similar trend has been observed for Generator G3.
- The system is unstable beyond 20% penetration

Transient Stability Analysis: Effect due to a bus fault

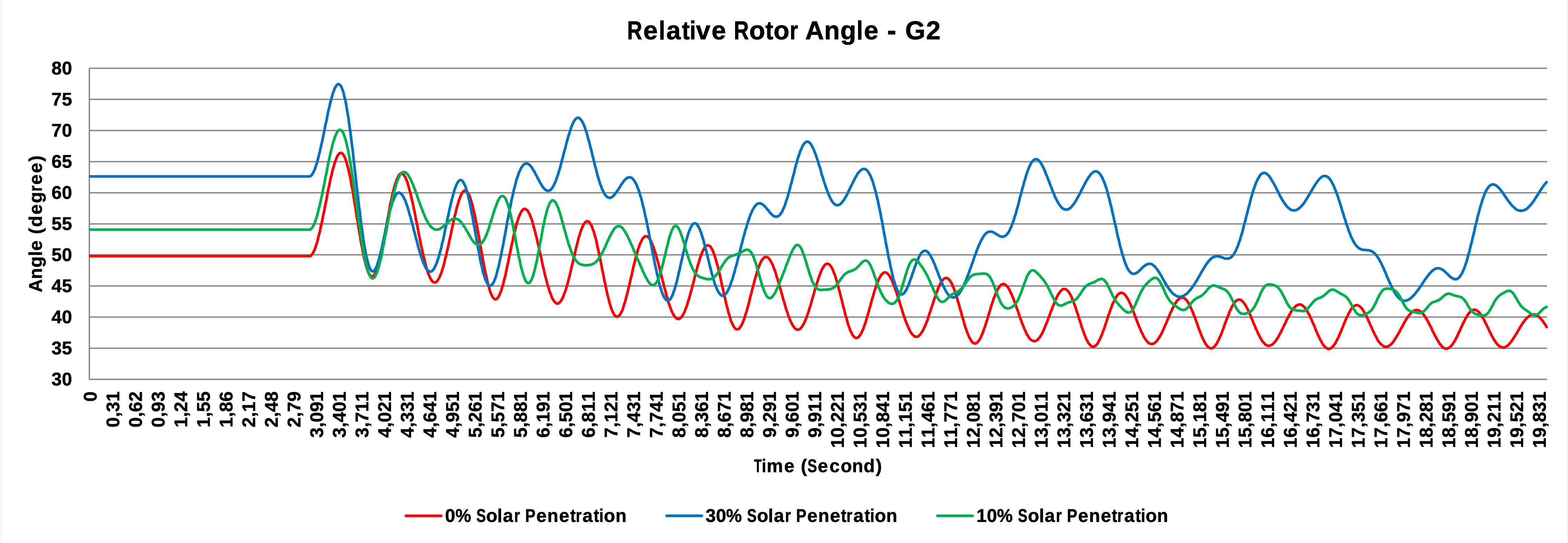




- The oscillations after the fault for the base case are minute and converging to a stable value. The oscillations for 10% penetration case was with higher amplitude and was getting irregular. The voltage dips are quite high. But it was getting stabilized after a while. Whereas for the 30% penetration case the oscillations and voltage dips have been very severe and was not stabilizing.

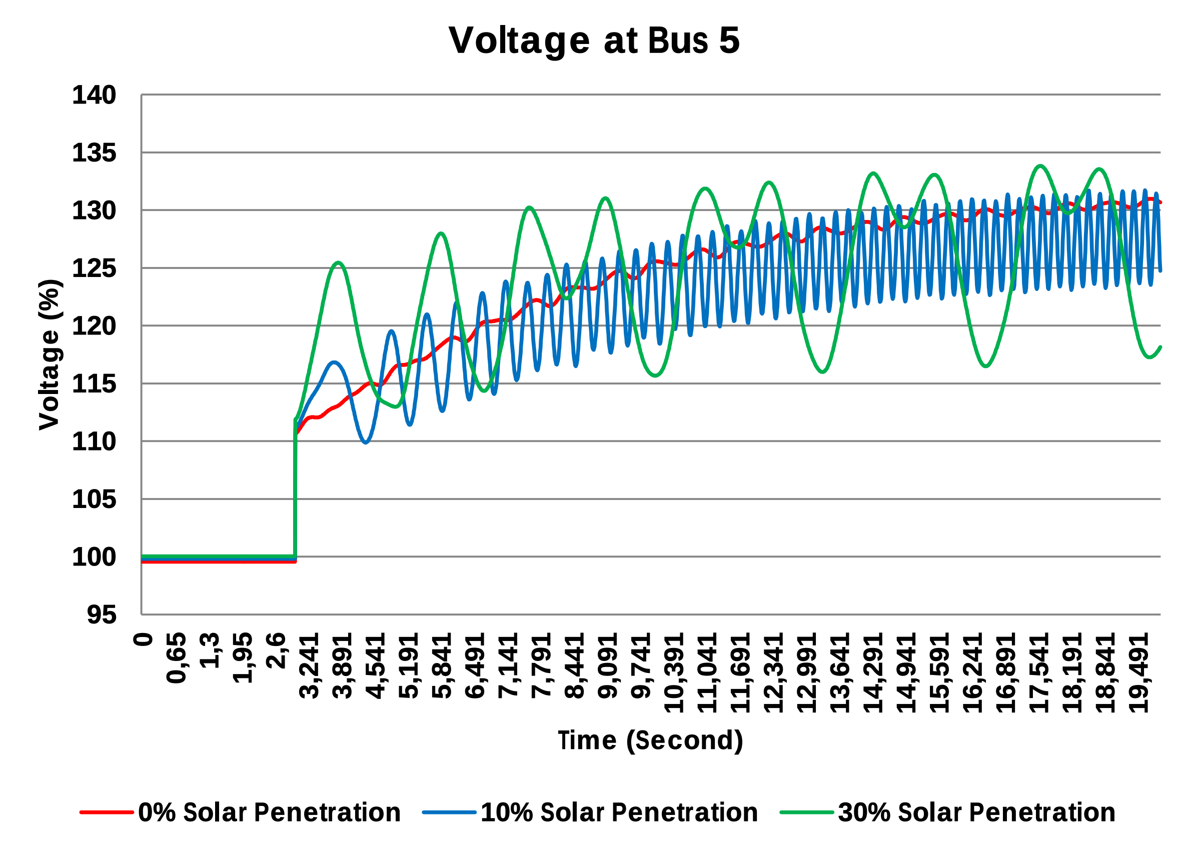
- As the level penetration increases the system becomes unstable and goes out of synchronism beyond a point.

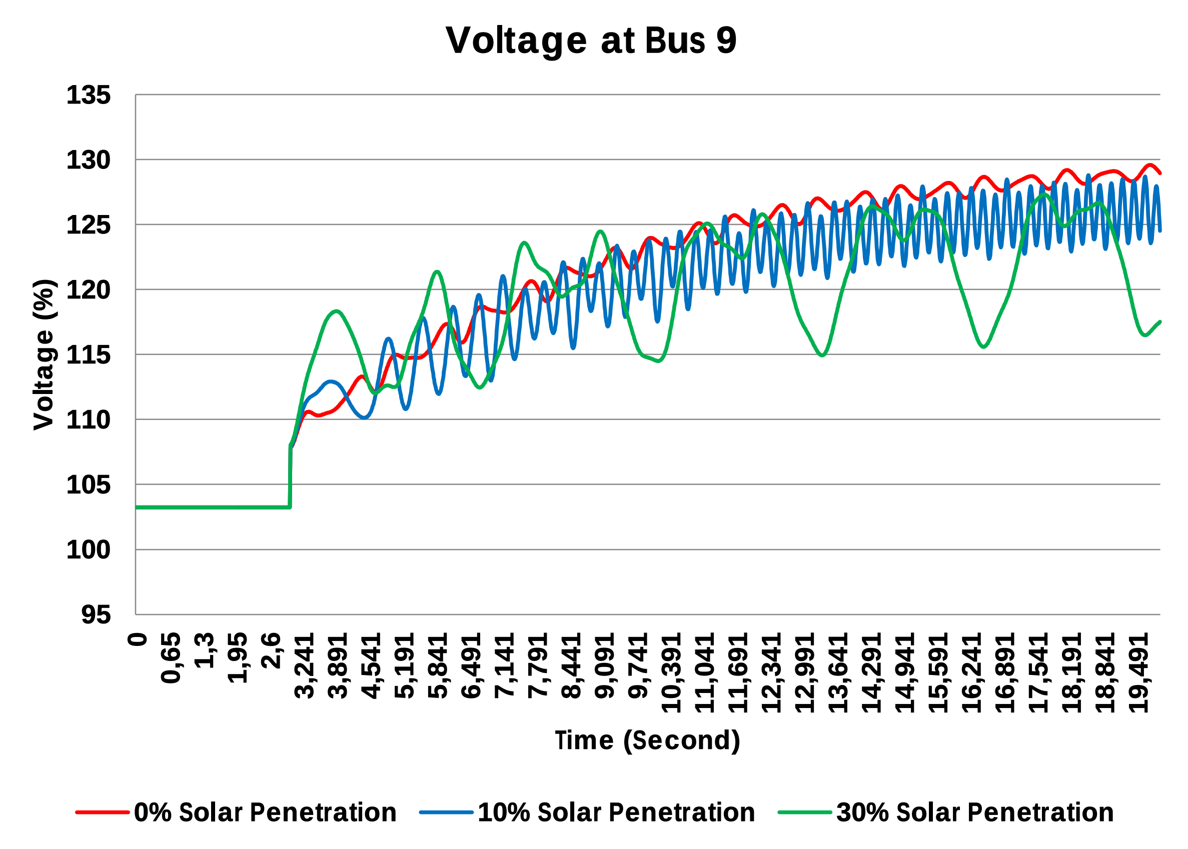
Transient Stability Analysis: Effect due to Load Rejection



- The oscillations for the base case have been uniform is was converging and settling to a new value. The oscillations for the 10 % case is less in amplitude but little irregular compared to the base case. Yet it is converging to a finite one. Beyond 20% penetration the system is unstable. The oscillations for the 30% penetration case are severe and completely irregular from the base case. It is not converging and going out of step.

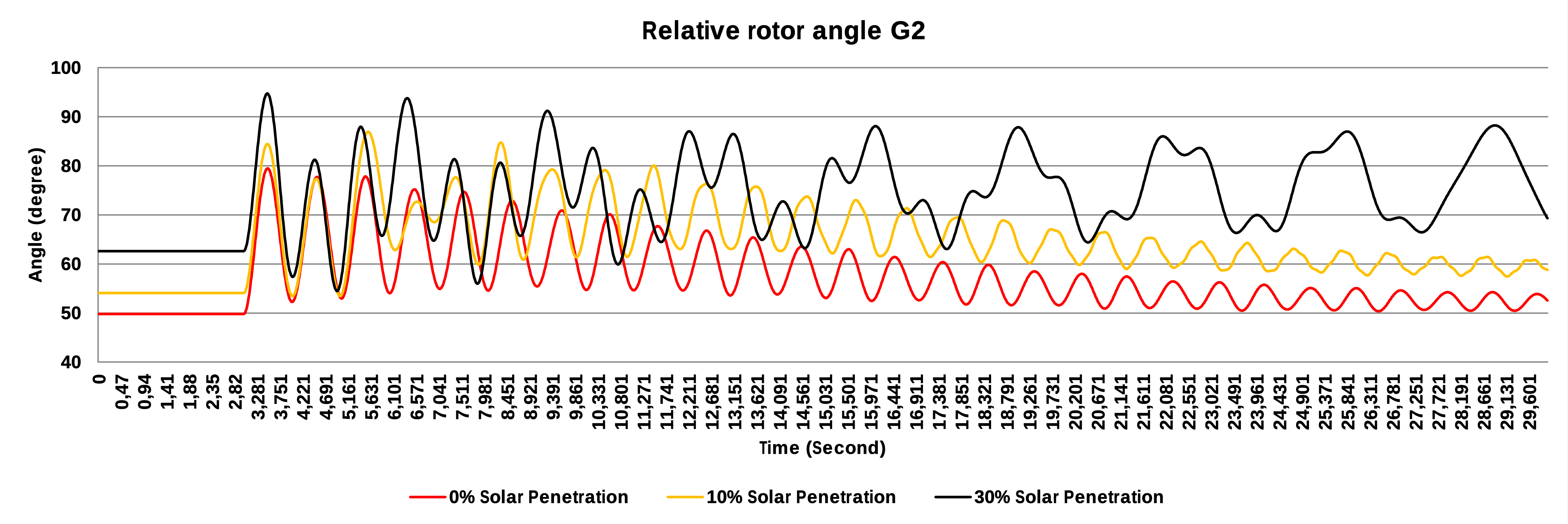
Transient Stability Analysis: Effect due to Load Rejection





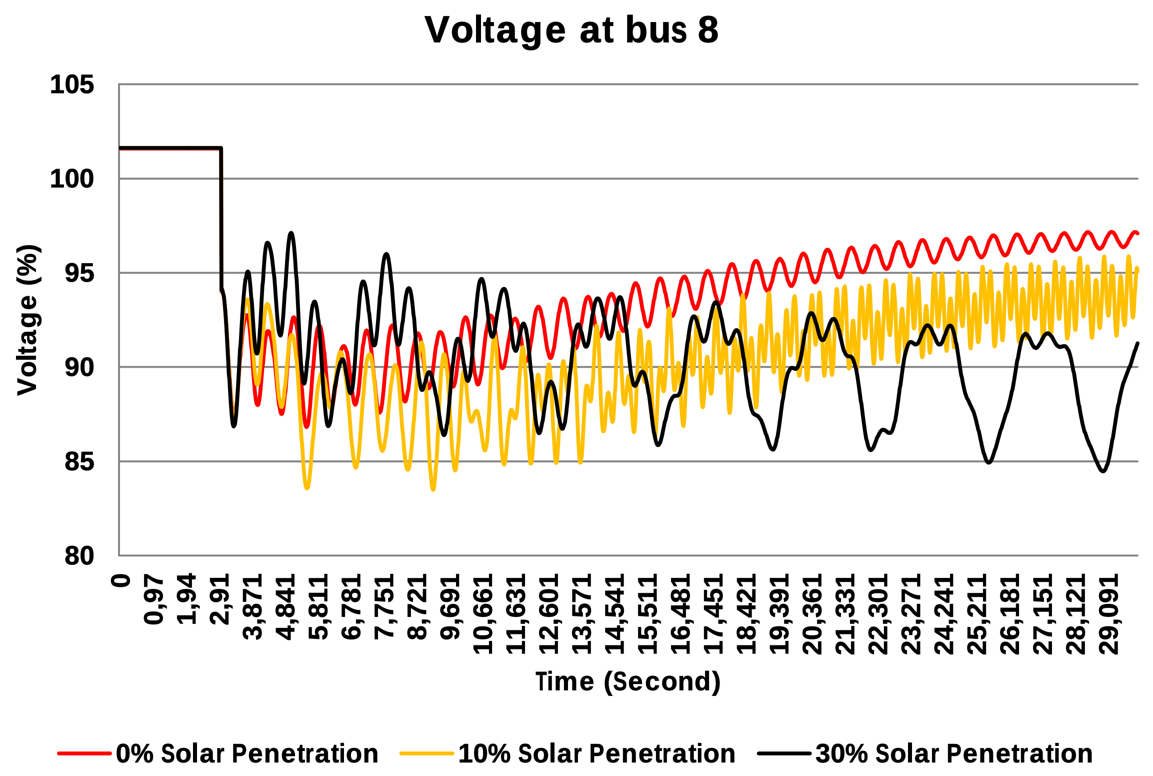
- In the base case voltage undergoes minor disturbance after the disconnection and smoothly settles towards the new value. The oscillation frequency is quite high for the 10% penetration case but is converging towards the new value. For 30% penetration case the oscillations are severe and irregular. The frequency is also less and is not converging.
- In this case too, the system gets unstable as the level of solar penetration increases.

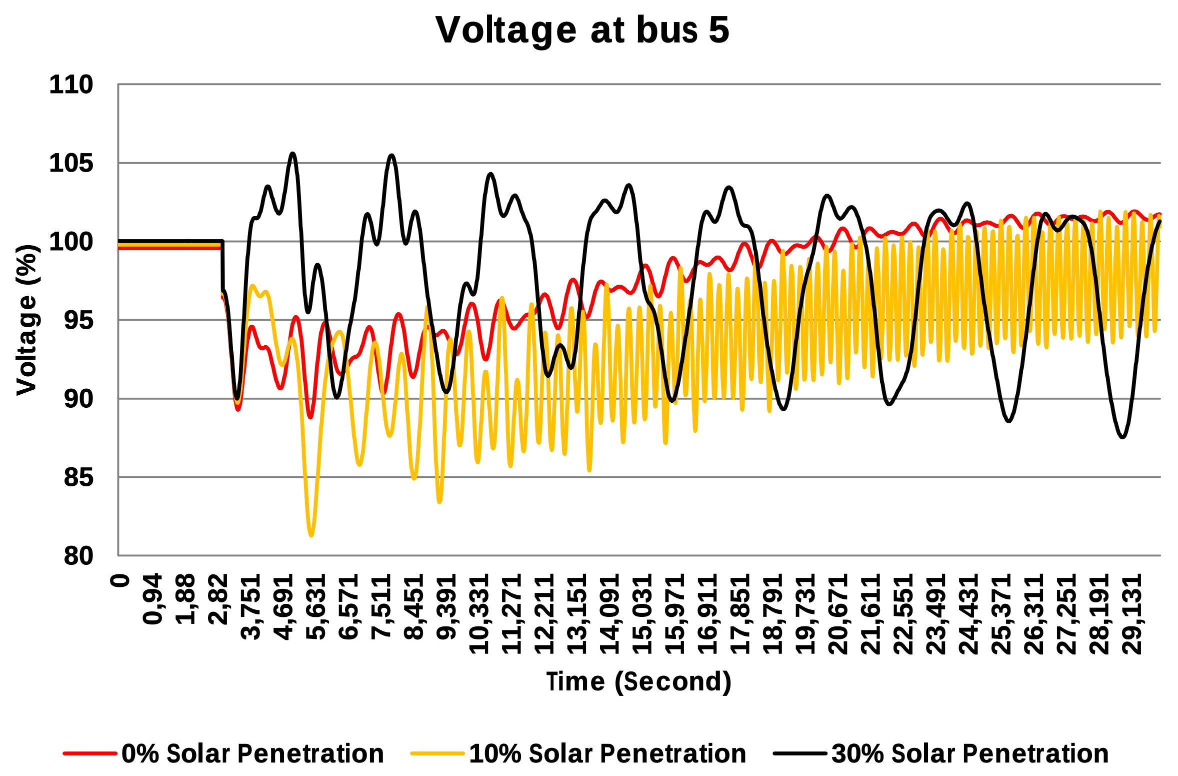
Transient Stability Analysis: Effect due to Loss of a Transmission Line



- The oscillations for the base case is uniform and is converging and settling to a new value. The oscillations for the 10 % case is very similar compared to the base case and is converging to a finite value. Beyond 20% penetration the system is unstable in this case too.
- The oscillations for the 30% penetration are severe and completely irregular from the base case. It is not converging and is going out of step.

Transient Stability Analysis: Effect due to Loss of a Transmission Line





- Severe drop in voltage occurs for bus 8 as the line 6 is disconnected from that bus. In the base case, the voltage slowly recovers and settles to the new value. Heavy high frequency oscillations occur in case of 10% penetration but moves towards the new value. In case of 30% penetration, irregular low frequency oscillations occur and doesn't converge to a stable value.
- The system is getting unstable for the loss of a transmission line as the level of penetration increases.

Transient Stability Analysis - Summary

- Thus in all the case studies done, the system was getting unstable for a transient disturbance as the level of PV penetration is increased.
- The bus voltage magnitudes and relative rotor angle and hence synchronism are the most adversely affected system parameters during the transients in the system with high penetration of PV.
- It is very important in taking into account the transient performance of the system with high penetration levels of the PV to maintain the stability and integrity of the system following faults.
- The total system inertia is very less in systems with high PV penetration leading to severe issue following various system disturbances.

Conclusion

- The preliminary study helped in understanding the drawbacks of high penetration solar PV into the power system. Further studies revealed the control requirements of upcoming large PV plants. The need and importance in analyzing the impact of the high penetration photovoltaics into the grid has been understood.
- The increased penetration of solar PV into the grid without any specialized controls has been proved to affect both the steady state performance and the transient stability of the grid, through the analysis done in ETAP.
- Thus suitable control mechanisms are required from the upcoming large solar plants to address such issues and to mitigate the stability issues arising out of increased solar PV penetration.
- It is important in performing such a study, which will help in planning the system with high penetration levels of solar PV power and in identifying the critical PV penetration levels for a given network.

Future work

- The impact on the grid due to sudden loss of the solar PV generation due to problems from plant side like sudden variation of irradiance due to clouding, etc. can be studied and analyzed.
- Control systems and mechanisms can be designed for large solar PV plants like active power and reactive power controls similar to that of conventional plants, LVRT capability, etc. and their effectiveness in mitigation of the impact on grid performance can be analyzed.

Thank you ☺