“The challenges faced while integrating large PV plants into the electrical grid .”

Shivananda Pukhrem

PhD Student

Prof. Michael Conlon & Dr. Malabika Basu

School of Electrical & Electronics Engineering

Date: 24th February 2015

Motivation

- Understanding the challenges faced while integrating large PV plants into the grid and ***resolve*** them in order to maintain ***secure***, ***reliable*** and ***robust*** electrical power system network ***without*** any ***grid reinforcement***.
- ***These*** are the primary roles of the distribution grid and of the Distribution System Operator, DSO (*Electricity Supply Board,* ***ESB***).
- And the most important aspect of ***DSO*** is to maintain the ***voltage level*** throughout the distribution network.
- The **frequency control** is maintain primarily by Transmission System Operator, TSO (***EirGrid***)

Outline

1. Overview of PV system

- Cumulative capacity forecast compared to EPIA's new 2030 scenarios
- Real 10 MW PV power output measured every 5 seconds on 31/10/2010

2. Voltage profile

- Voltage profile with and without PV

3. The Grid integration Challenges

- Voltage rise and fluctuation
- Reverse power flow
- Increase in power losses

4. Current Research

- Voltage rise and fluctuation

Future Work

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Cumulative capacity forecast compared to EPIA's new 2030 scenarios. [1]

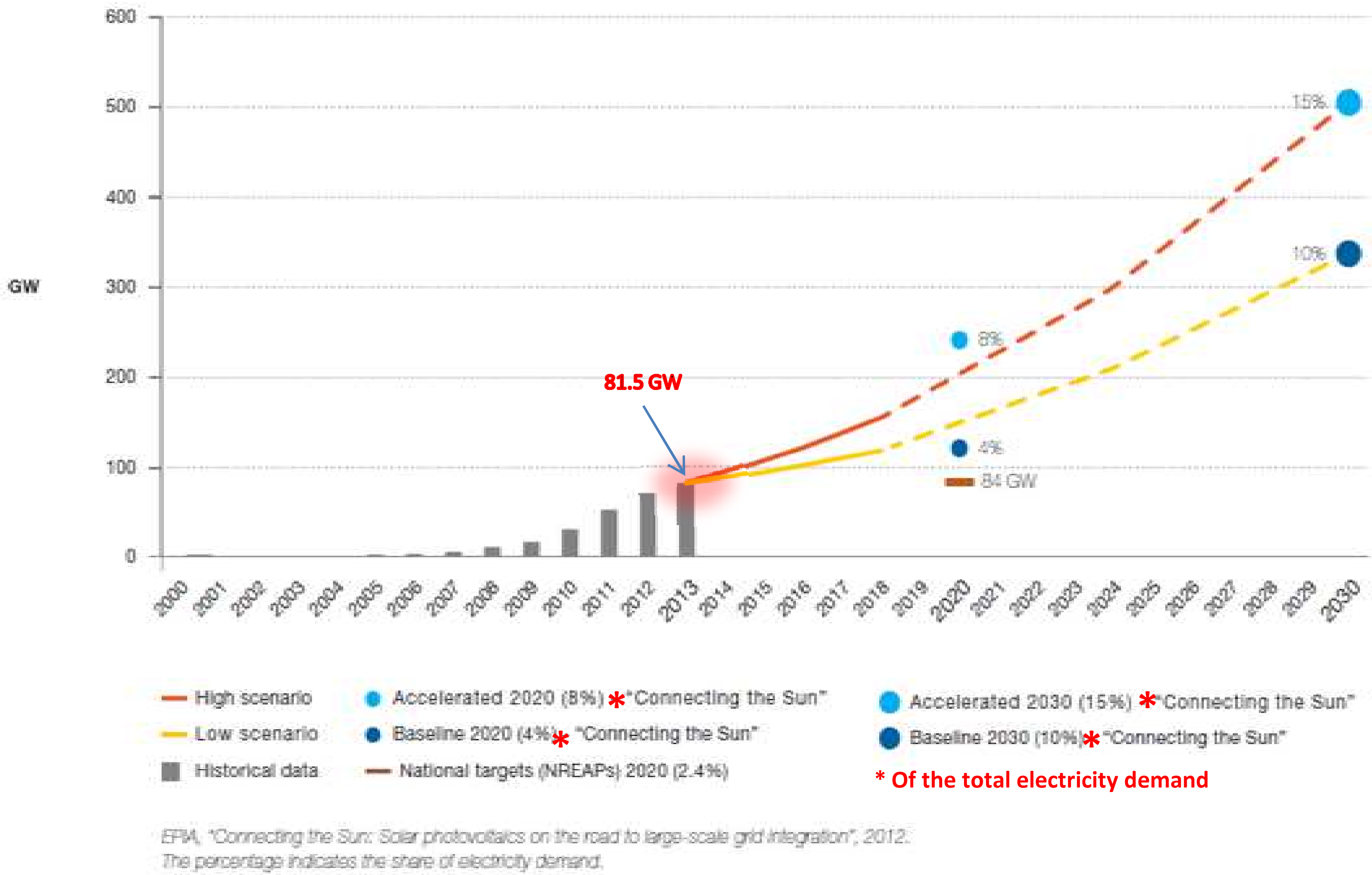

Fig: 1 Cumulative capacity forecast

Real 10 MW PV power output measured every 5 seconds on 31/10/2010 [2]

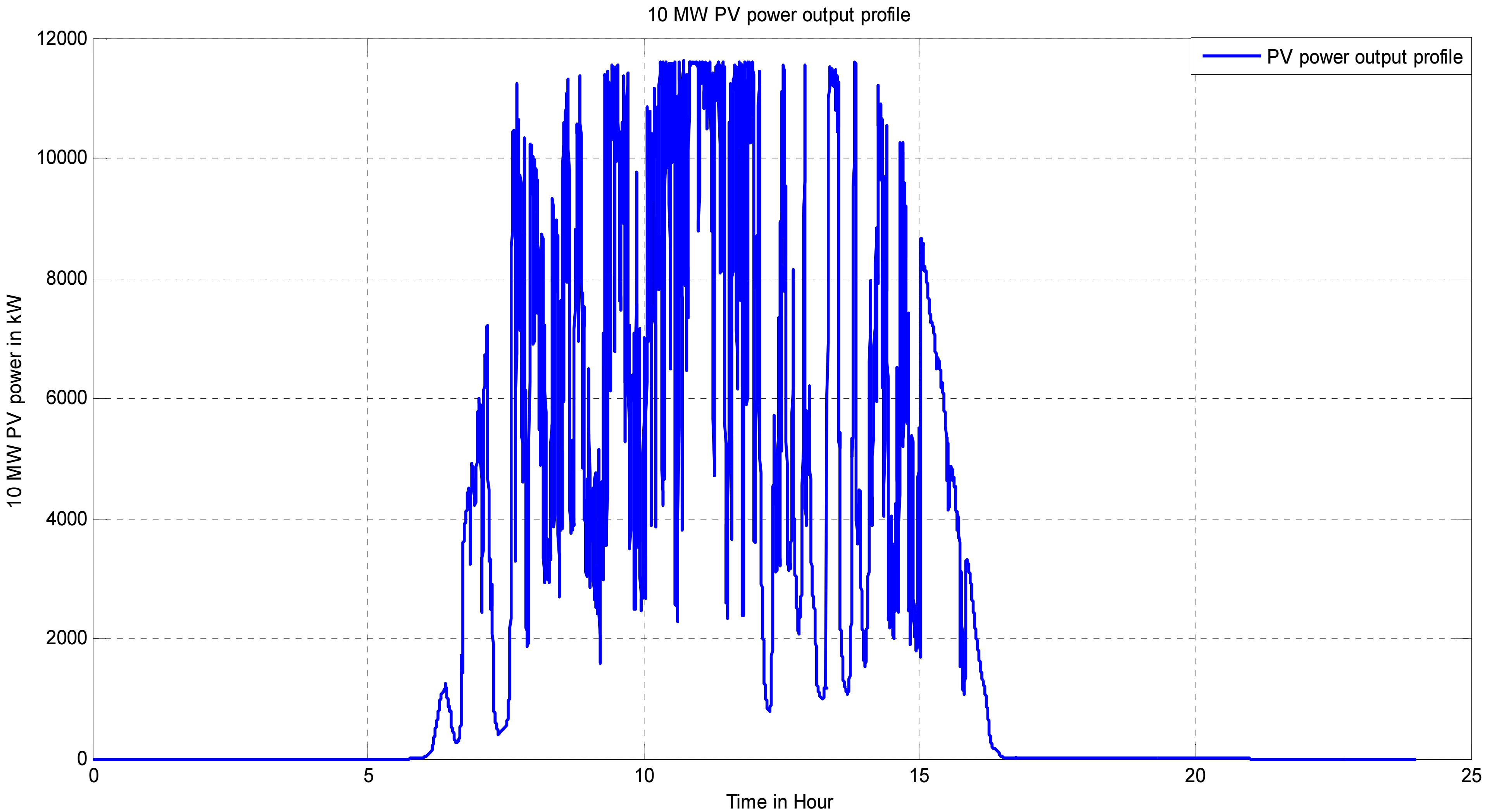

Fig: 2 Real 10 MW PV output

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Voltage profile when large PV is Integrated[3]

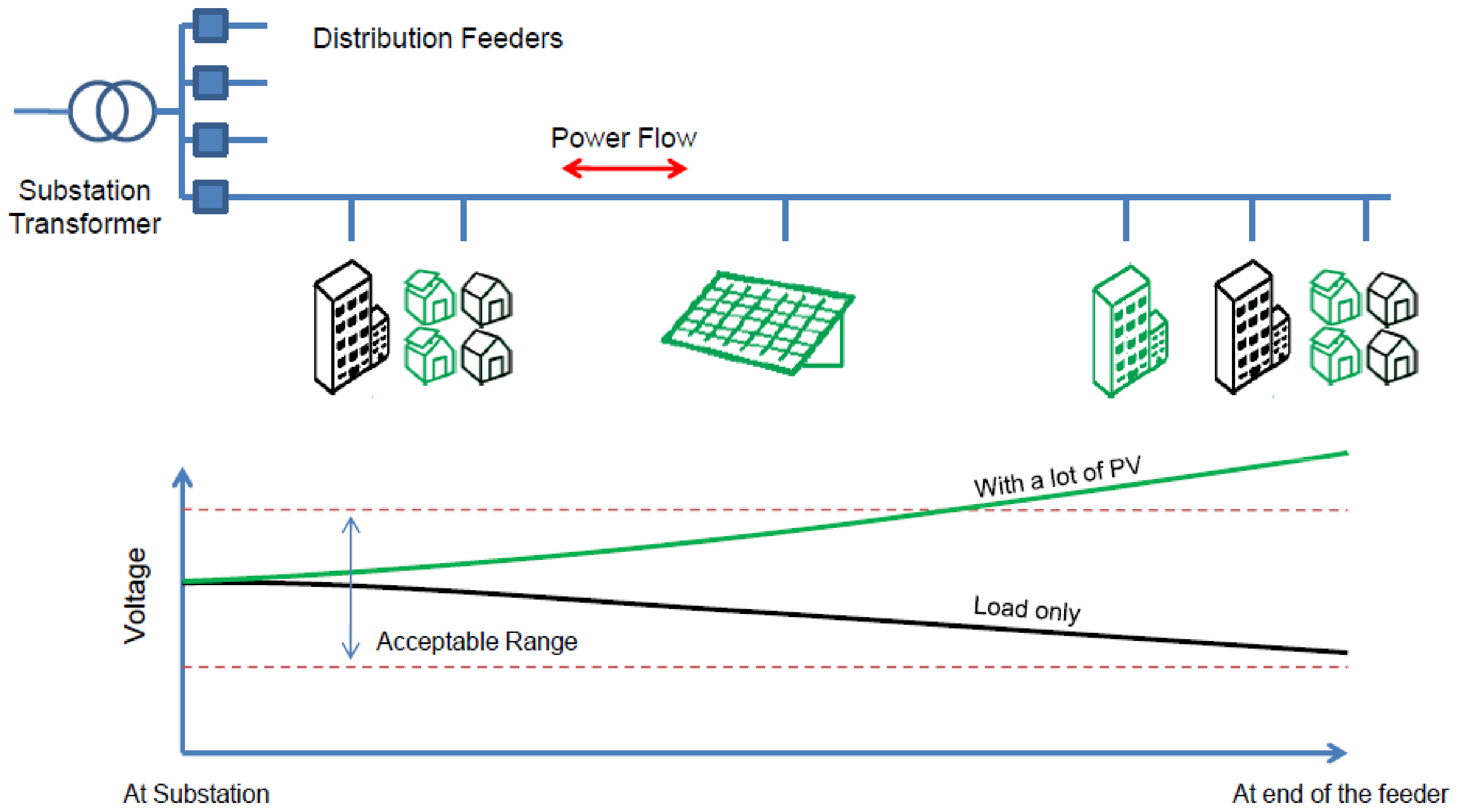

Fig: 3 Voltage profile when PV is connected

Voltage Profile with & without PV [4]

Without PV

With PV

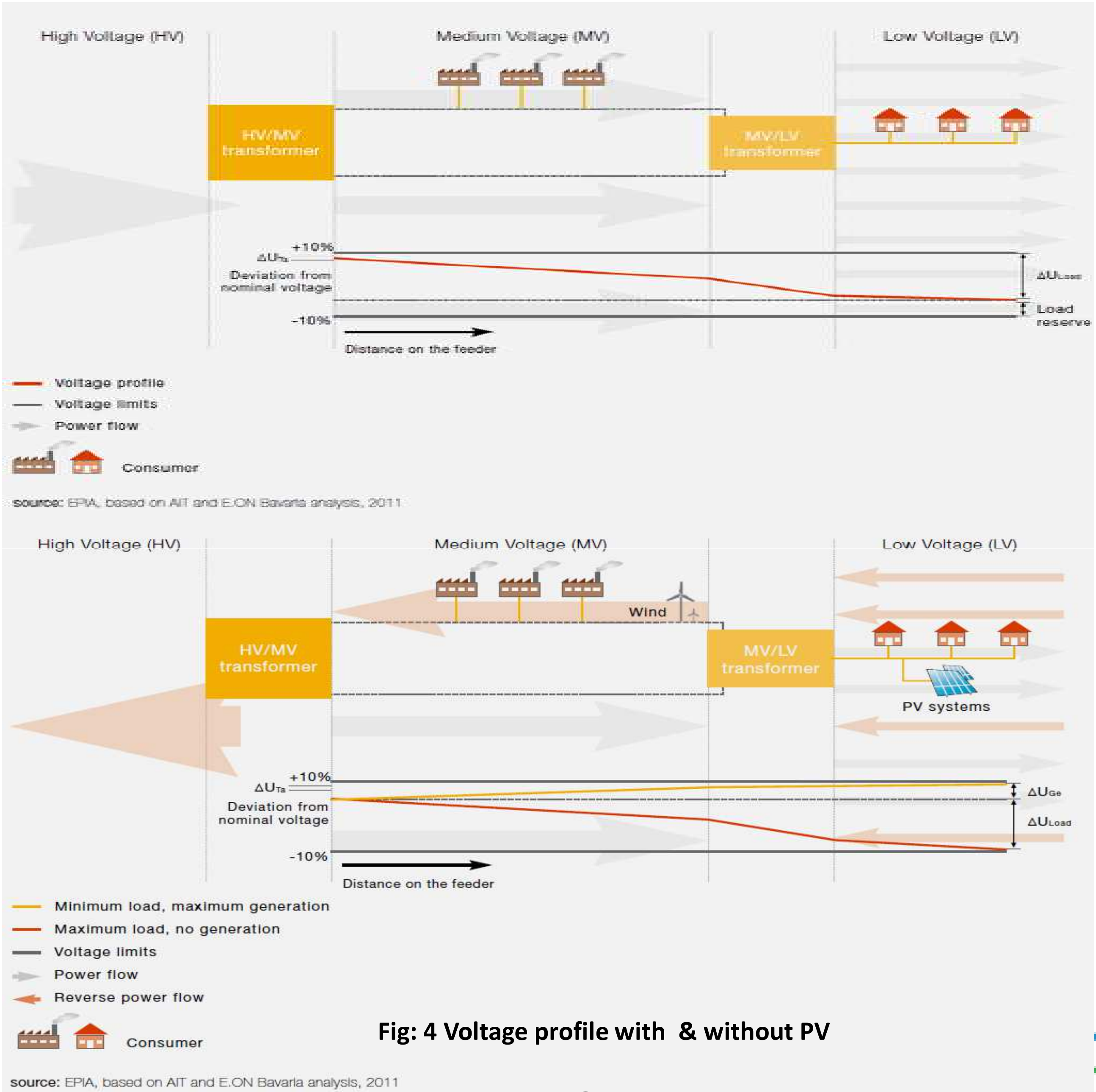

Fig: 4 Voltage profile with & without PV

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Voltage rise and fluctuation [5]

- Voltage rise is one of the ***major*** and ***notorious*** impact in the distribution network.
- Mostly occur :

  a) in a ***weak or/long network*** where there is ***low consumption/ less load*** and ***high feed*** in power from PV.

  b) as the ***number of PV plants*** connection in the distribution network ***increases.***

  c) due to the ***power output intermittency*** from PV plants.
- Due to ***increase in voltage*** **,**power flow can be ***reversed*** e.g. flowing towards the transformer.
- Consequently it can affect the whole distribution network including the ***sensitive consumers*** and ***other generators*** connected in the network.

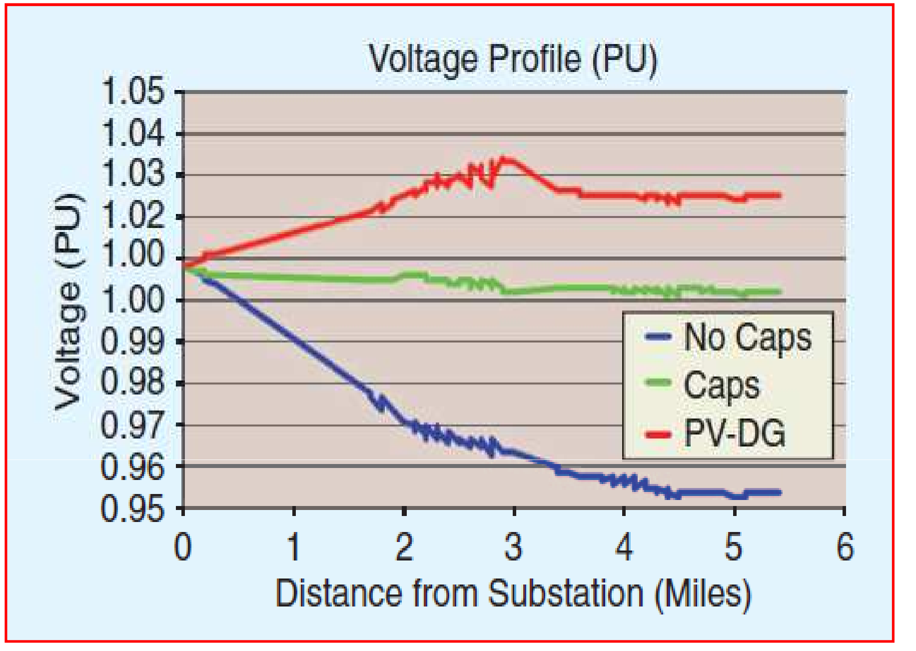

Fig: 5 Voltage profile in p.u

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Reverse power flow [5]

- ***Proliferation*** of large scale ***PV plant*** can lead to ***reverse power flow*** conditions at ***section***, ***feeder***, and ***substation level***.
- Due to ***reversed power flow***, the feeder will start ***exporting power*** to neighbouring feeders or to the transmission system.
- Thus it can negatively affect ***protection coordination*** and operation of ***line voltage regulators***.
- Under high penetration cases, the total PV output will likely ***offset the feeder load***.

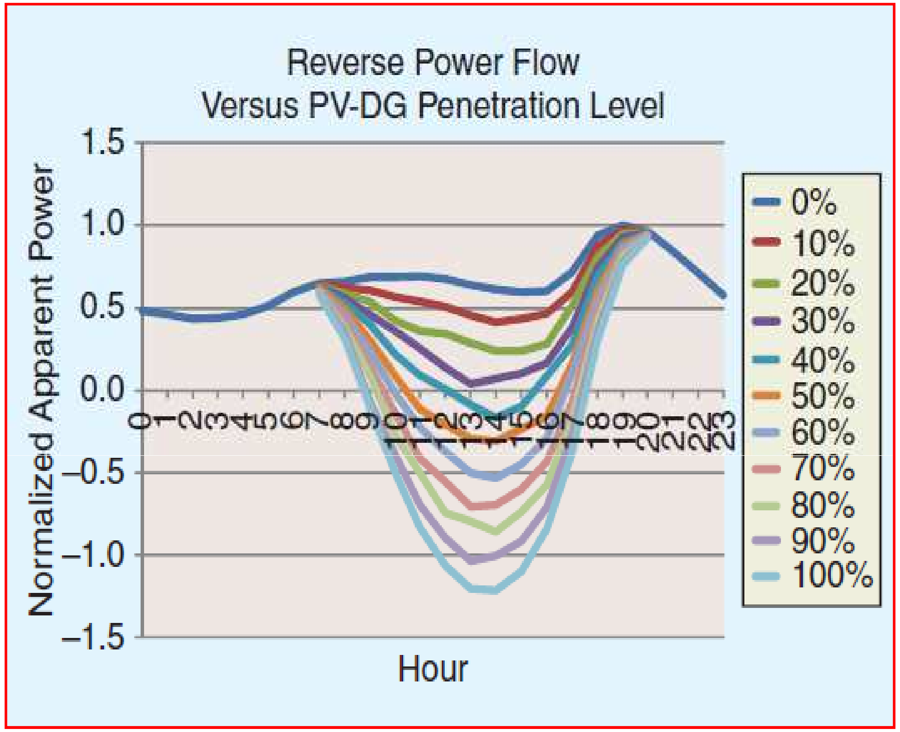

Fig: 6 Reverse power flow vs PV penetration level

Increase in power losses [5]

- For ***low*** to ***moderate*** penetration levels, ***line losses*** tend to ***decrease*** until they reach a ***minimum***;
- For ***high PV*** penetration levels, line losses tend to ***increase*** for several reasons;

a) The loading of distribution lines under **high solar PV** penetration may be ***greater*** than the normal ***feeder loading*** conditions;

b) The ***lack*** of local reactive power supply via ***capacitor banks***;

c) The nodal voltage increase caused by high solar PV penetration will ***increase*** the ***no-load losses*** of ***distribution transformers***.

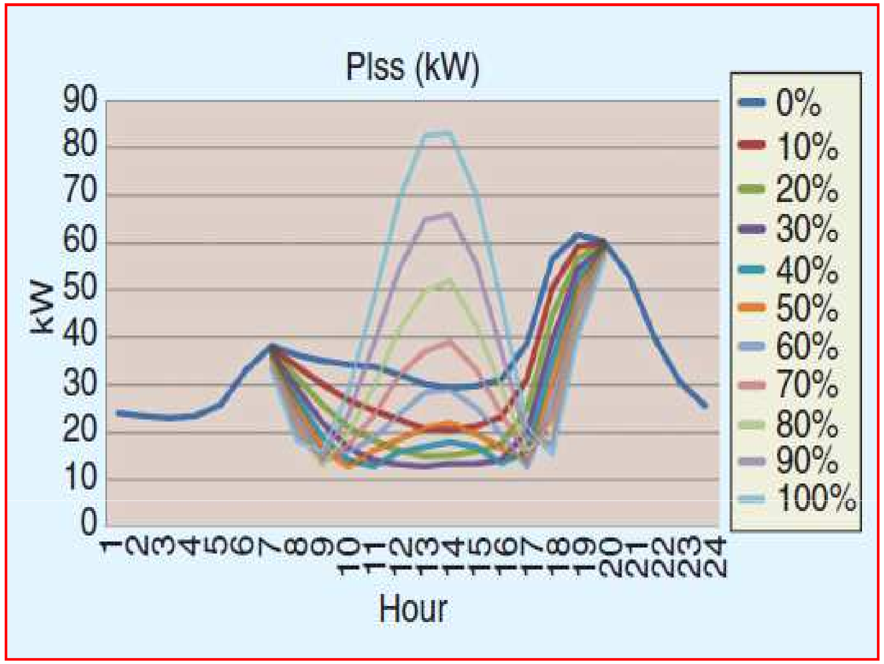

Fig: 7 Power losses

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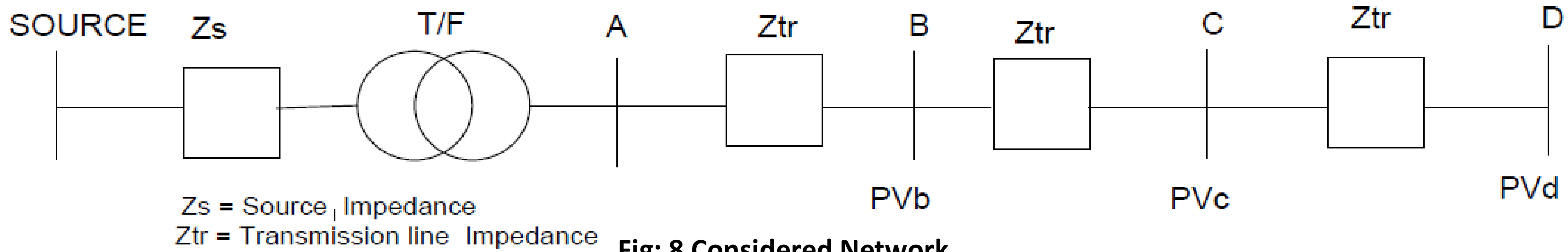


Fig: 8 Considered Network

Table: 1 Network Parameter

Parameter	Value
Source	base kV=220 kV/sqrt3 = 127.01 (p.u= 1 ∠ 0), base frequency = 50 hz, 3 phase system
Transformer, T/F	3 phases 2 windings: source bus and bus A (wye, wye) star/star connection. 220kV/66kV MVA= (100/100), % loadloss = 0, xhl (reactance loss from high to low)=10%
Line AB	Length = 20 km, R1= 0.2113 ohm/km, X1= 0.4865 ohm/ km, R0 = 0.7581 ohm/km , X0= 1.47265 ohm/km,3 phases line
Line BC, Line CD	Similar to **Line AB**
PVb, PVc	50MW
PVd	30MW

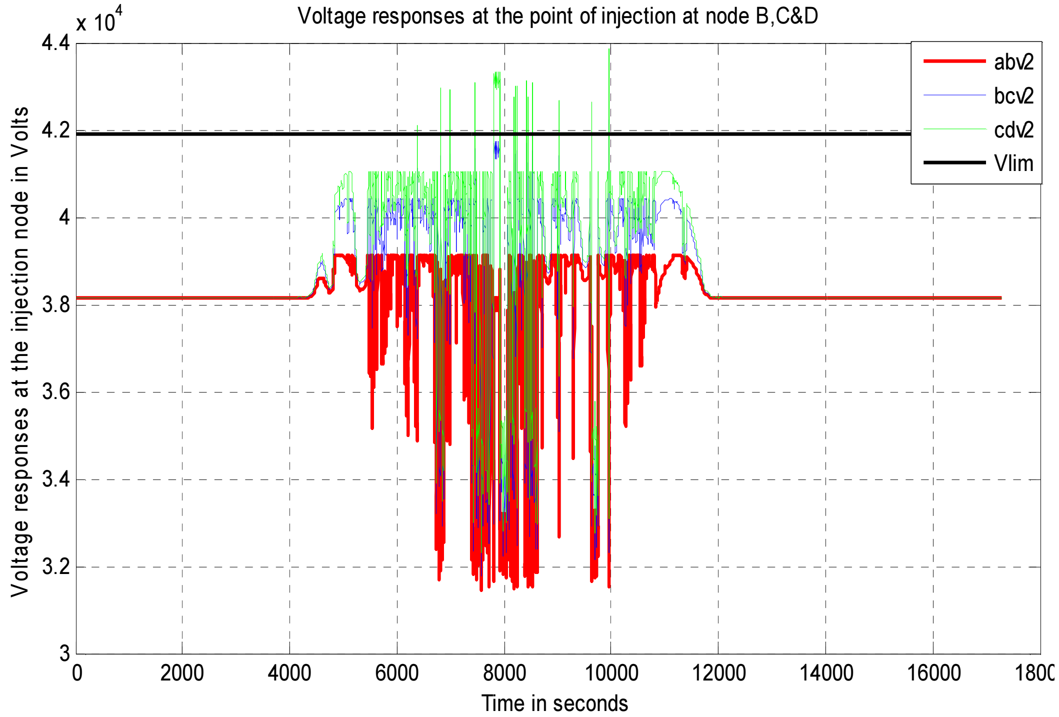


Fig: 9 Voltage responses at each nodes

According to **IEC 60364-4-443**, **±10%** of the nominal voltage, i.e., **41915.62954 Volts**

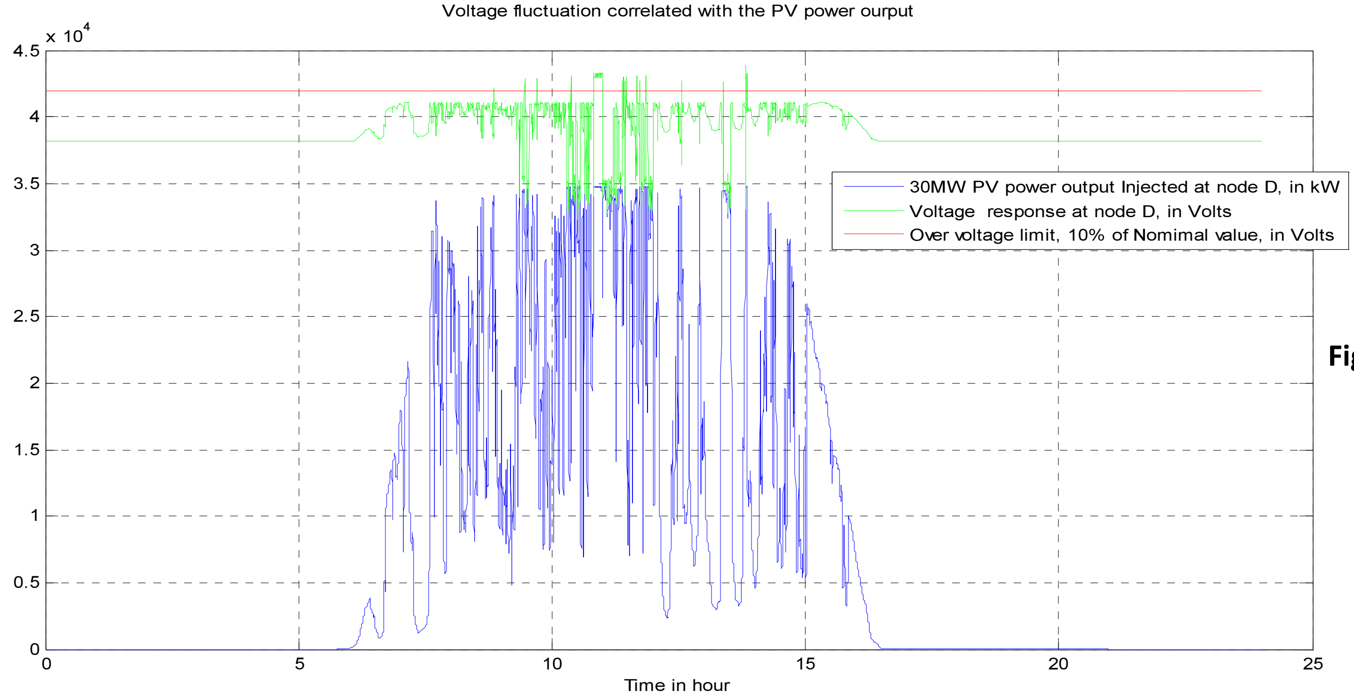


Fig: 10 Voltage fluctuation correlated to PV power

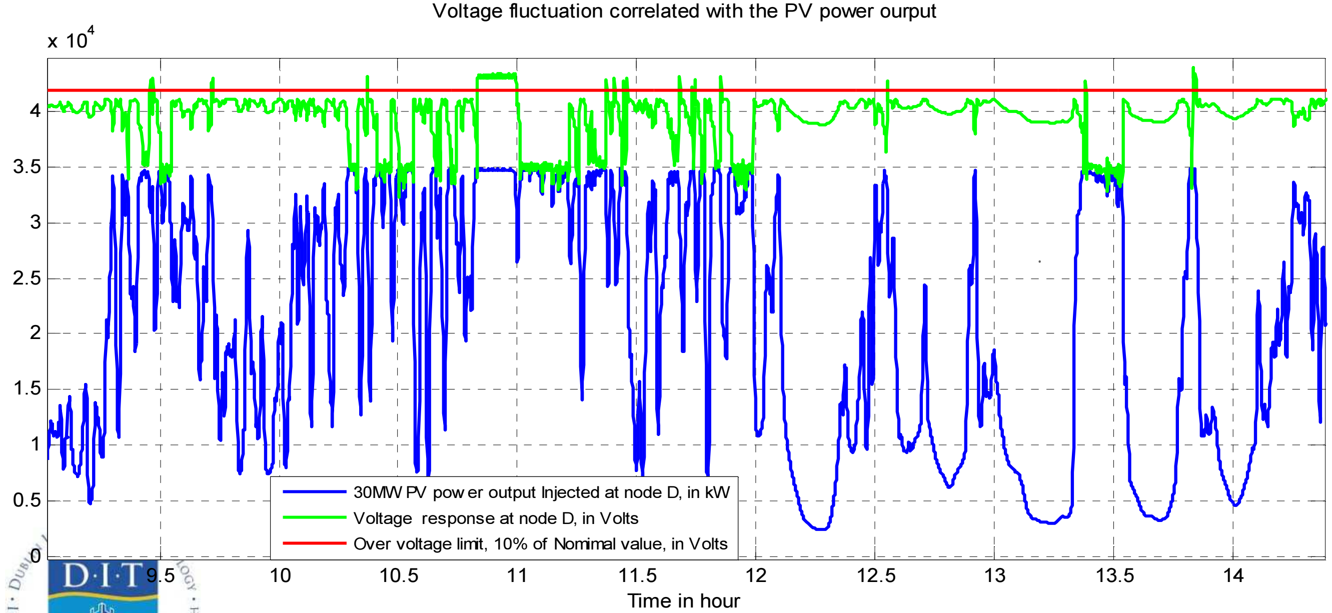
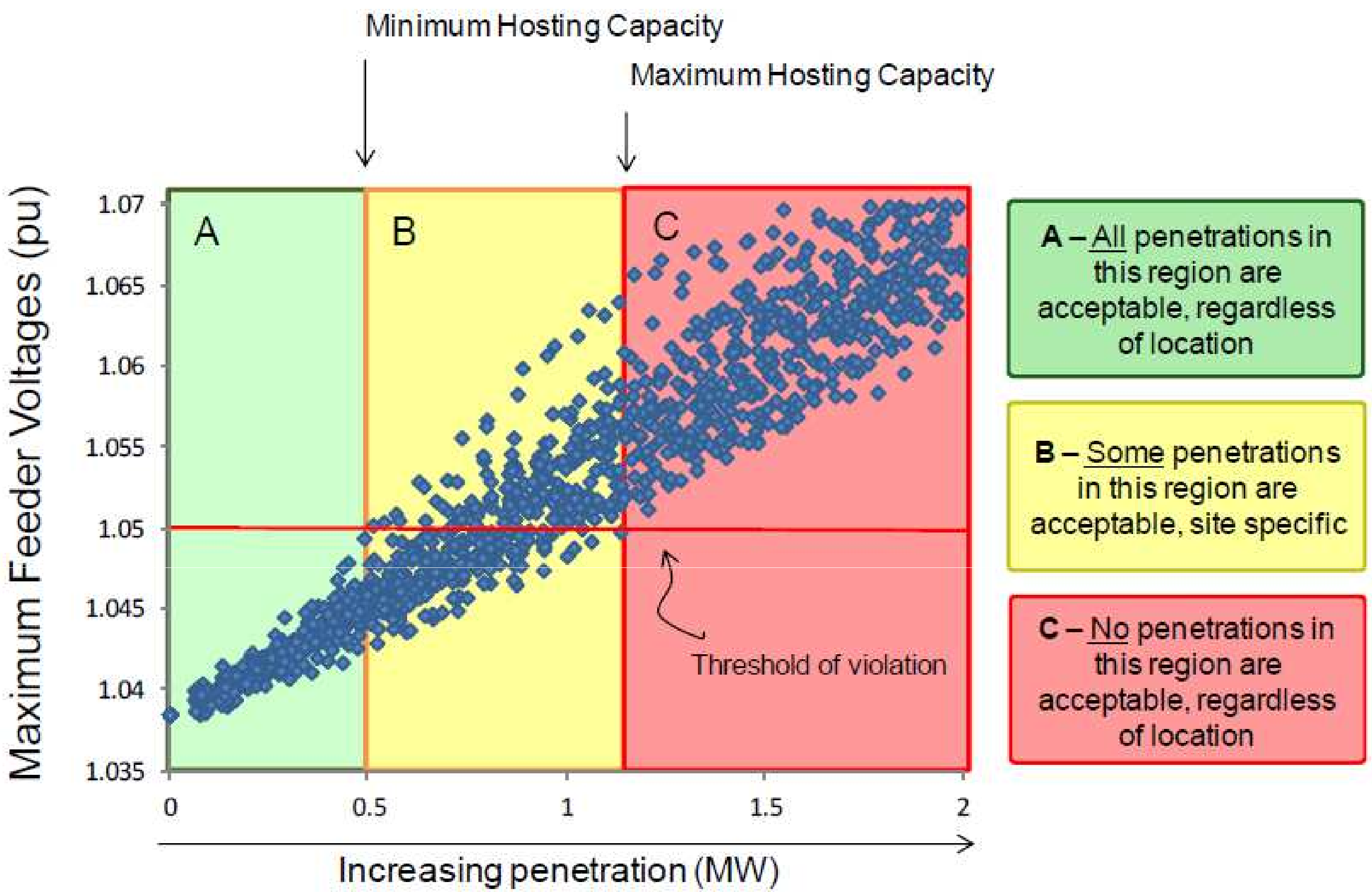


Fig: 11 Voltage fluctuation correlated to PV power

PV impact analysis [6]



Stochastic analysis to determine feeder hosting capacity fro Distributed Solar PV, EPRI, Palo Alto, CA:2012

Fig: 12 PV Impact Analysis

How to resolve??

General idea : Through reactive power control and active power curtailment

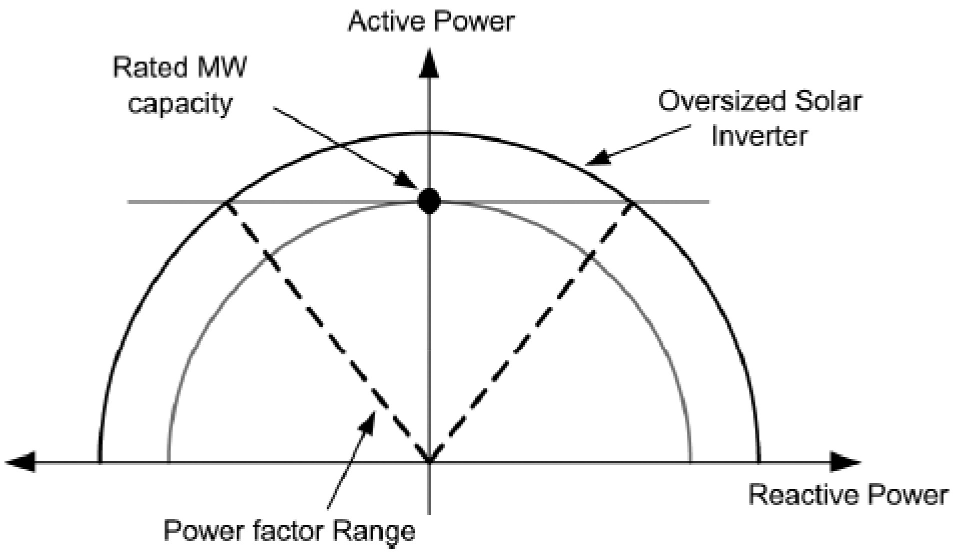


Fig : 13 Solar generation capacity curve[7]

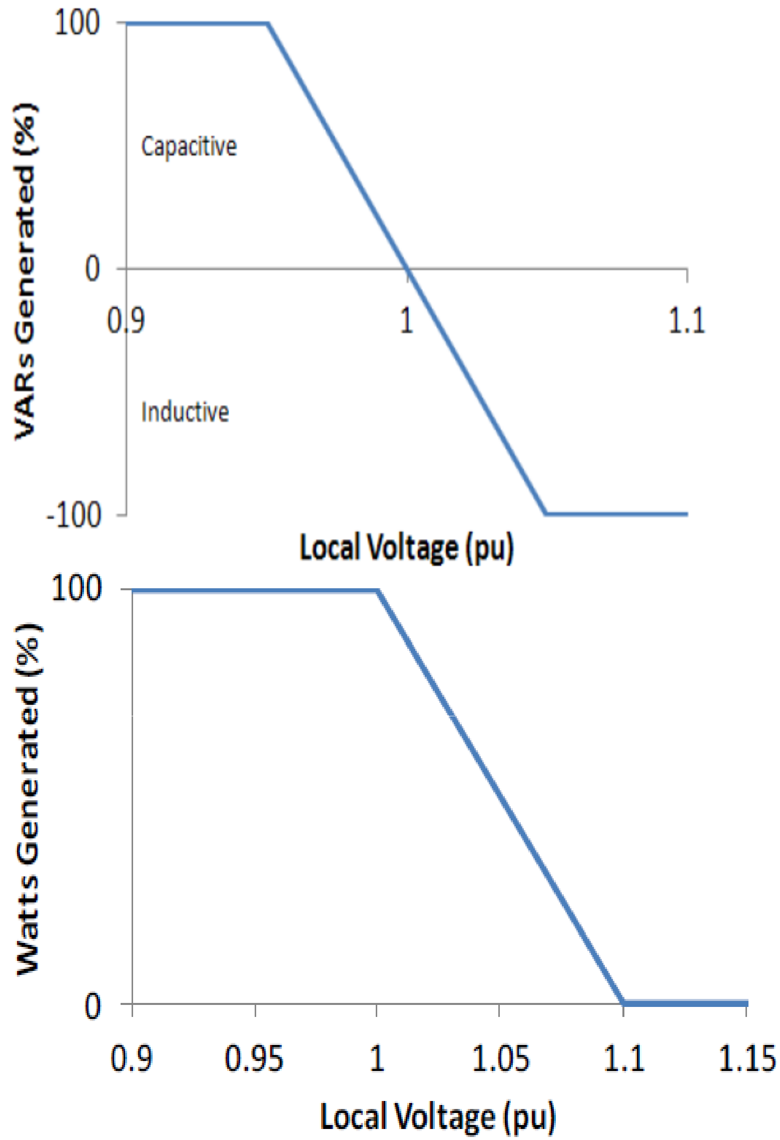


Fig: 14 Reactive power control and active power curtailment [6]

Methodology to solve over voltage during high penetration of PV

To be reviewed :

1. [8] Local control method: Q(V), Q(V) & P(V) and $Q(P_{PV})$

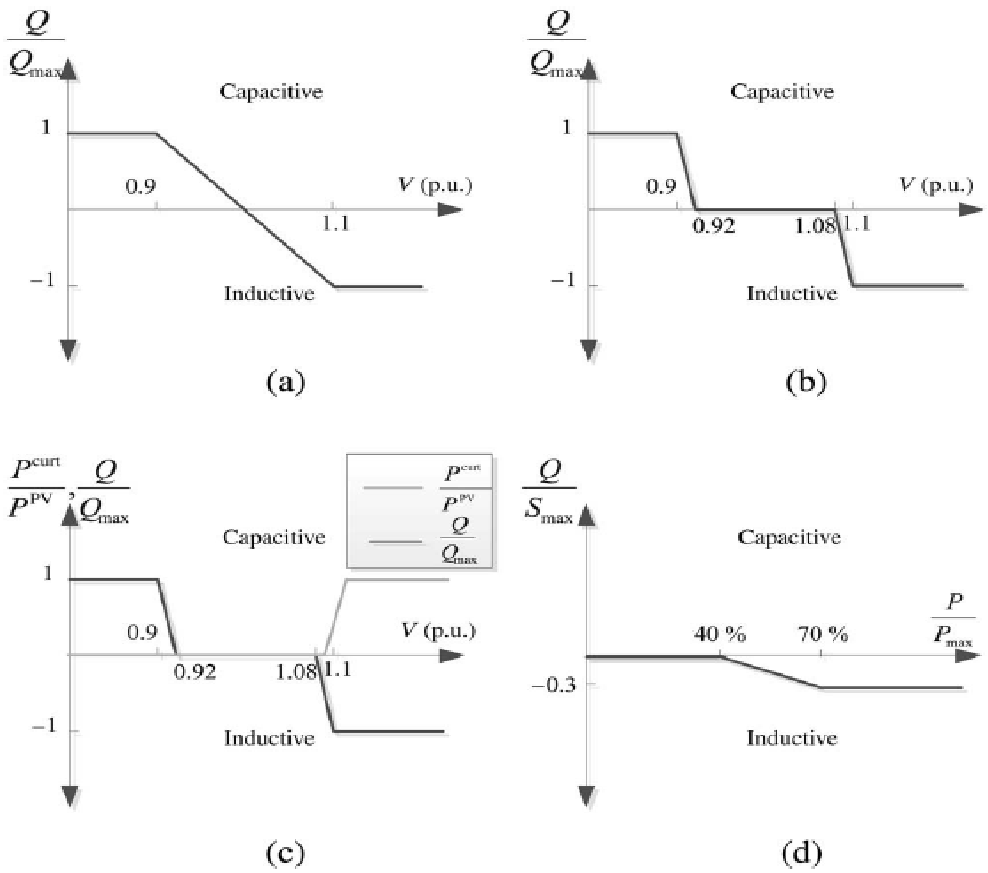


Fig: 15 Four different local control methods:
(a) local control method 1 Q(V);
(b) local control method 2 Q(V);
(c) local control method 3 Q(V), P(V); and
(d) local control method 4 $Q(P_{PV})$.

2. [9] Local control Method: P.F(P), Q(V) and P.F(P,V)

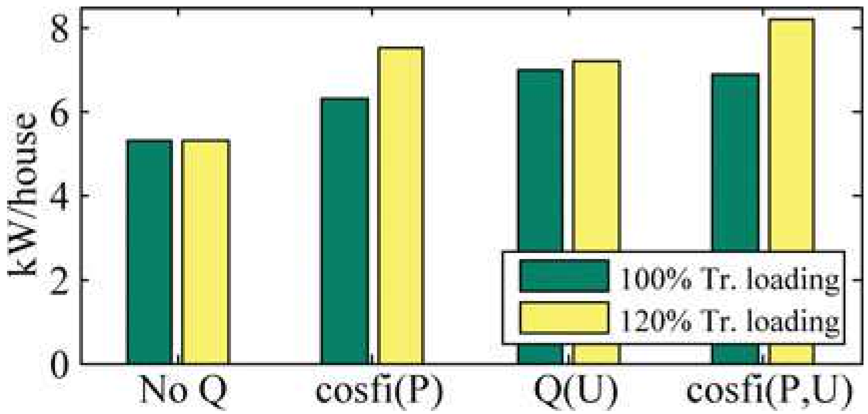


Fig: 16 PV capacity of the grid with different reactive power methods.

Table: 2. MONTHLY ANALYSIS

	Max. voltage at critical bus (p.u.)	Max. trafo loading (%)	Network active power losses (MWh/month)	Total absorbed reactive energy by inverters (MVArh)
cosφ=1.0	1.106	80.2	2.187	0
fixed cosφ=0.9	1.07	92	2.599	25.294
cosφ(P)	1.072	90.8	2.332	8.342
Q(U)	1.092	81.6	2.223	2.489
cosφ(P,U)	1.083	83.2	2.251	3.618

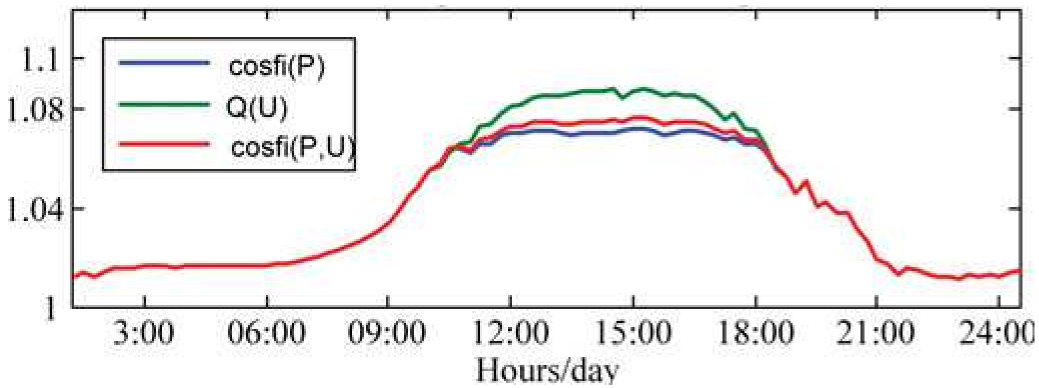


Fig: 17 Voltage variation performance of the proposed method

Future work

- To **investigate** the **proposed** methodology and **review** them in the **existing/new network**.
- Perform **comparative studies** of the result obtained.
- **Continue investigating** other methodology under **different network** consideration.

References

[1] ***Global market outlook for PV***, 2014-2018, EPIA

[2] Pvcrops partner, http://www.pvcrops.eu/.

[3] Abraham Ellis, Solar webinar, ***"Expanding Grid Integration of Renewable Energy in South Africa***", September 12 ,2013.

[4] ***Connecting the Sun, Solar PV on the road to large scale grid integration, EPIA***, September 2012

[5] Farid Katiraei and Julio Romero Aguero,"***Solar PV integration challenges***", May-June 2011

[6] Matthew Rylander, "***Increasing Hosting capacity with advanced inverter functions***", PV distribution system modeling workshop, May 6, 2014

[7] Yashodhan P. Agalgaonkar, *Student Member, IEEE, Bikash C. Pal, Fellow, IEEE, and* Rabih A. Jabr, *Senior Member, IEEE, "**Distribution Voltage Control Considering the Impact of PV Generation on Tap Changers and Autonomous Regulators**",* IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 29, NO. 1, JANUARY 2014

[8] Sam Weckx, Student Member, IEEE, Carlos Gonzalez, and Johan Driesen, Senior Member, IEEE, "***Combined Central and Local Active and Reactive Power Control of PV Inverters***", IEEE TRANSACTIONS ON SUSTAINABLE ENERGY, VOL. 5, NO. 3, JULY 2014

[9] Erhan Demirok*, Student Member, IEEE, Pablo Casado Gonz´alez, Student Member, IEEE, Kenn H. B. Frederiksen,* Dezso Sera*, Member, IEEE, Pedro Rodriguez, Senior Member, IEEE, and Remus Teodorescu, Fellow, IEEE, **"Local Reactive Power Control Methods for Overvoltage Prevention of Distributed Solar Inverters in Low-Voltage Grids**",* IEEE JOURNAL OF PHOTOVOLTAICS, VOL. 1, NO. 2, DECEMBER 2011.

Any Questions ???

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Thank you for your time!