Optimal Control of Wind Turbines in Active Distribution Networks

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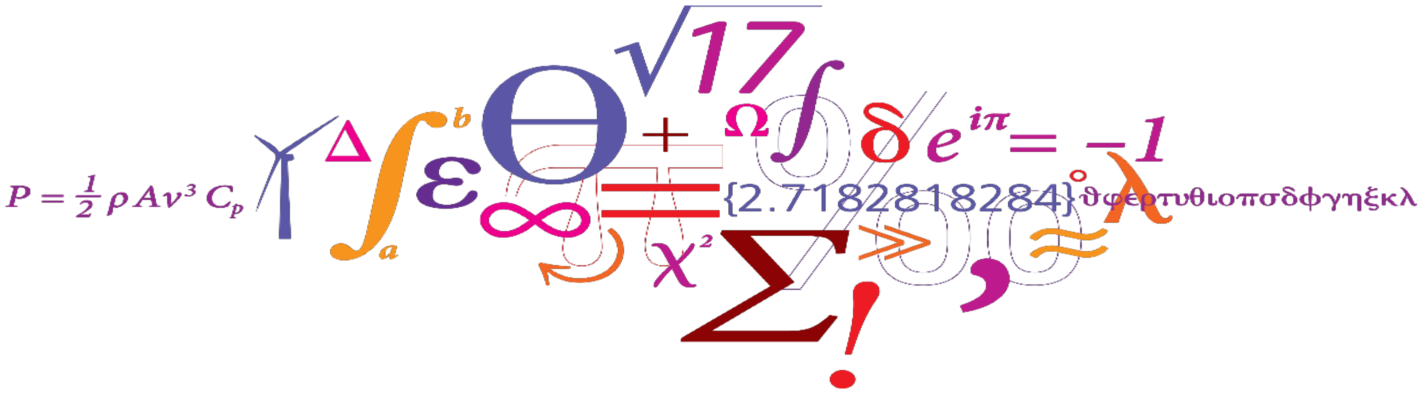
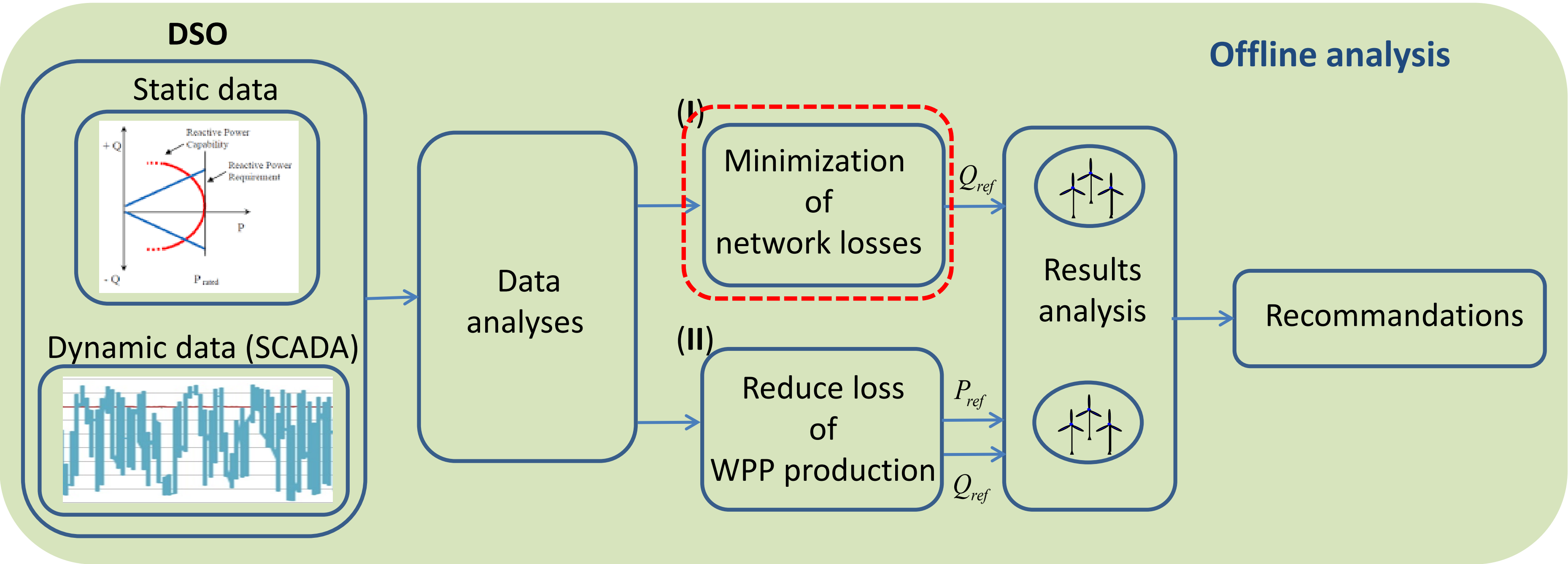


Research in NetVind

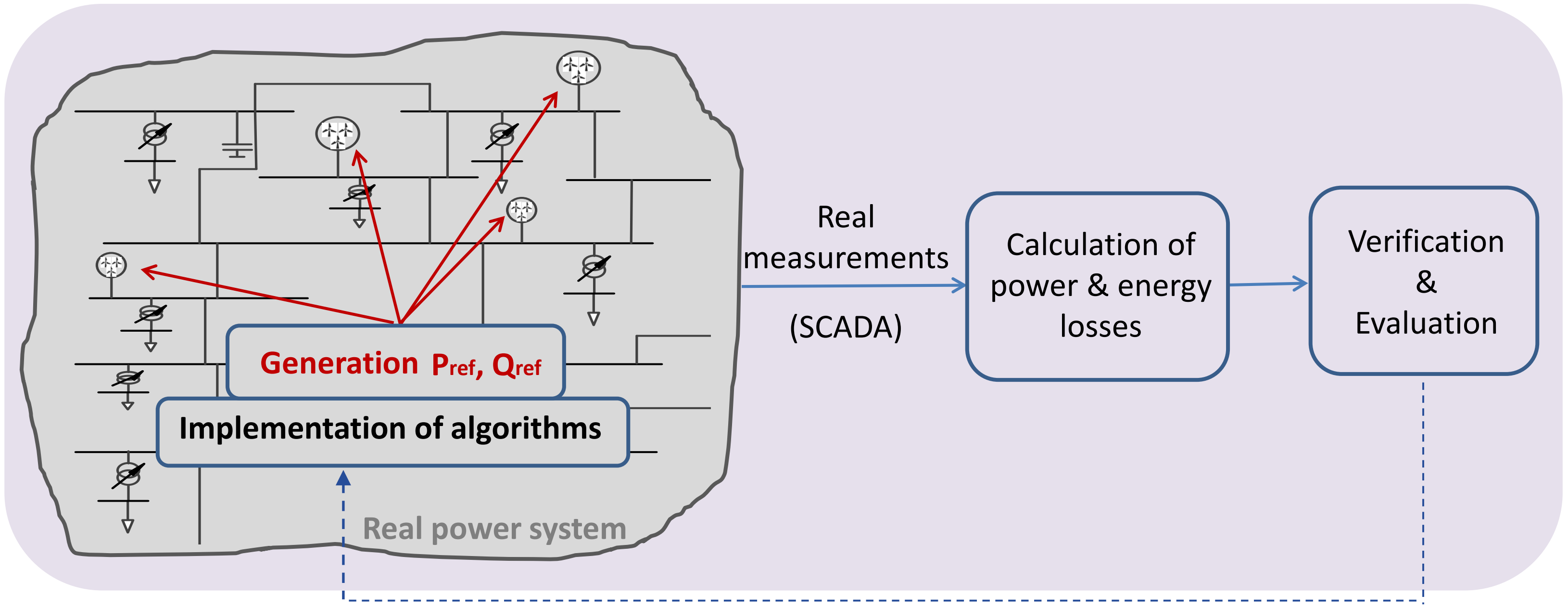


Main Focus:

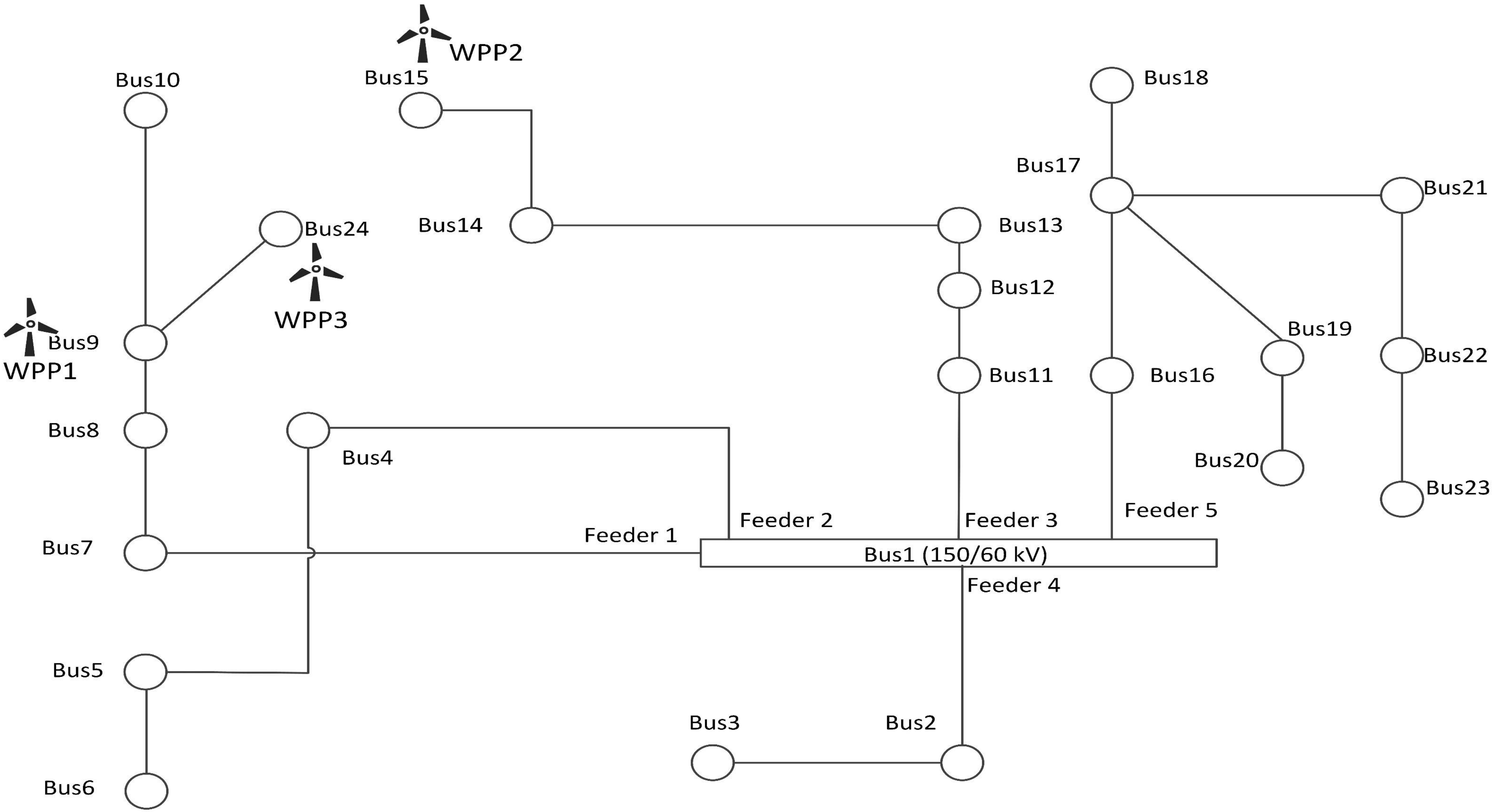
- Reduce active power losses in 60 kV network
- Keep MVAR balance within design limit
- Control reactive power output of the wind power plants

Output of the optimization algorithm is Q set points for WPPs

Online operation



Topology

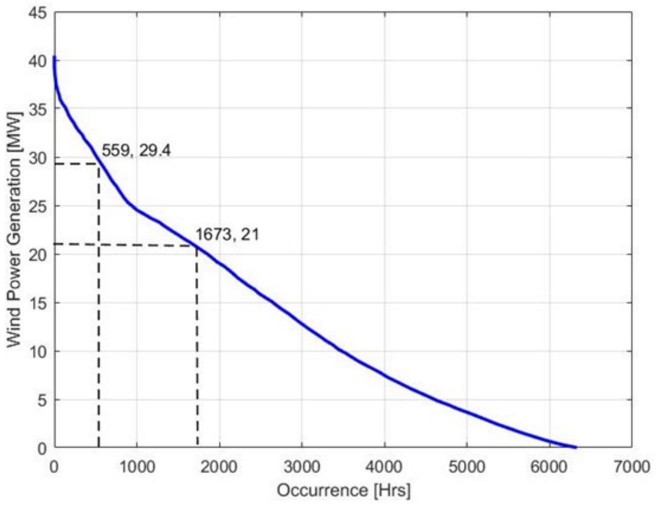

WPP2
Bus10
Bus15
Bus18
Bus17
Bus21
Bus24
Bus14
Bus13
WPP3
Bus12
Bus9
WPP1
Bus19
Bus22
Bus11
Bus16
Bus8
Bus4
Bus20
Bus23
Feeder 2
Feeder 3
Feeder 5
Feeder 1
Bus7
Bus1 (150/60 kV)
Feeder 4
Bus5
Bus3
Bus2
Bus6

NetVind - Project Assumptions/ Considerations/ Constraints

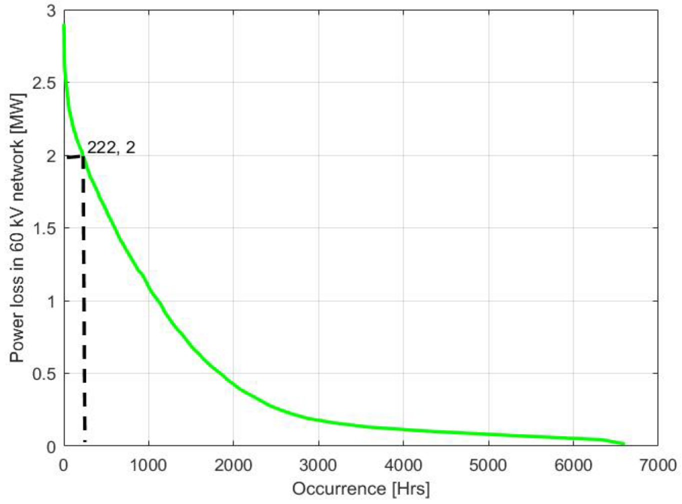
- Topology assumed unchanged for the whole period of study
- Only control variables are Q set points of WPP
- 60/10 kV tap changers are not controlled by the optimization
- Using only healthy data from the complete data set
- Measurement accuracy not considered in this study

Input Data Analysis

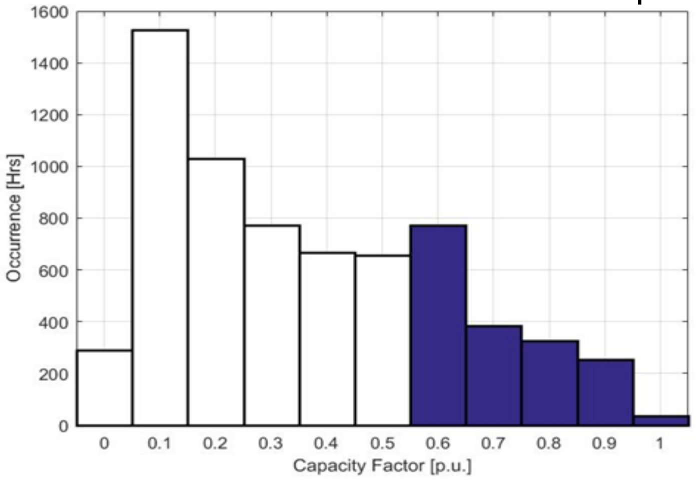
Duration curve for Wind Power Generation



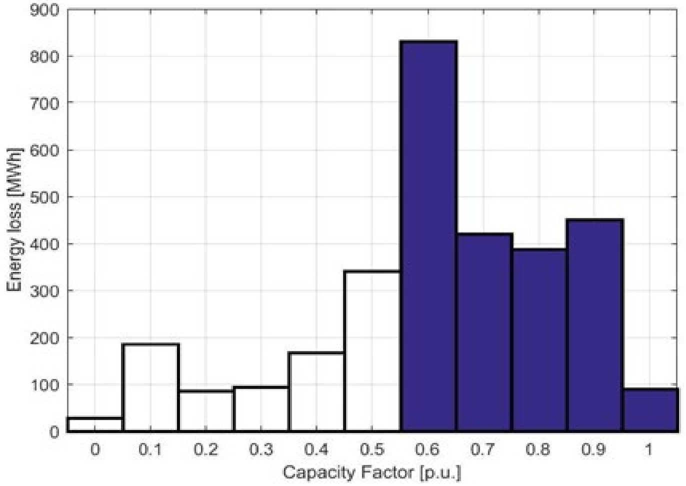
Duration curve for power loss in 60 kV network



Operational hours for WPPs at different capacity factors



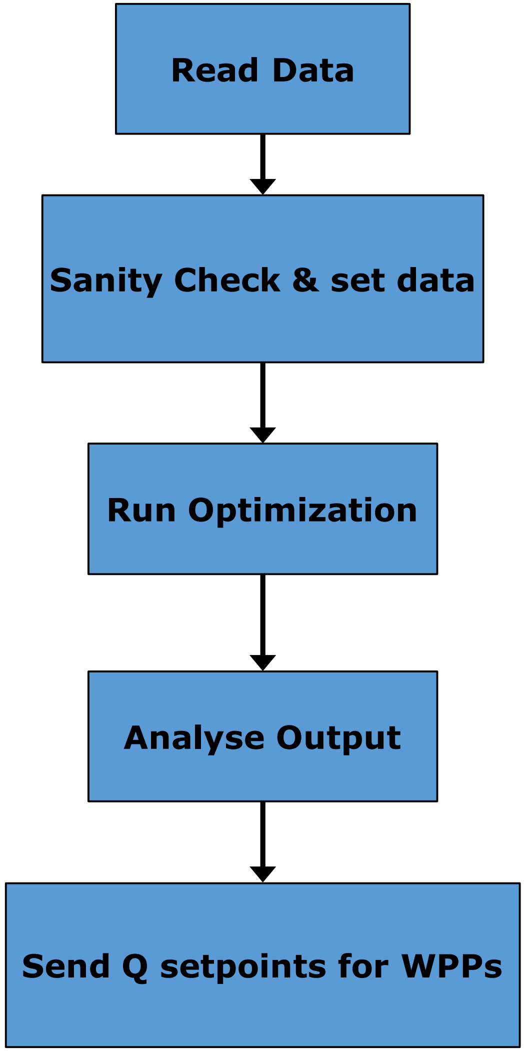
Energy loss in the 60 kV network for different WPP capacity factors



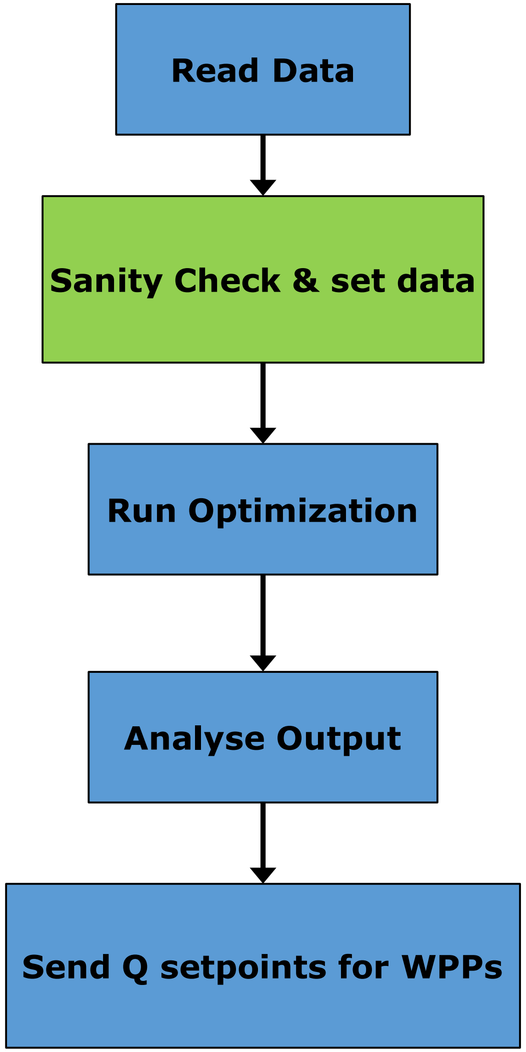
Higher is wind power generation, higher is network loss

Although high wind power generation occurs for small duration, it contributes for major proportion of energy loss

Flowchart – Minimization of network losses

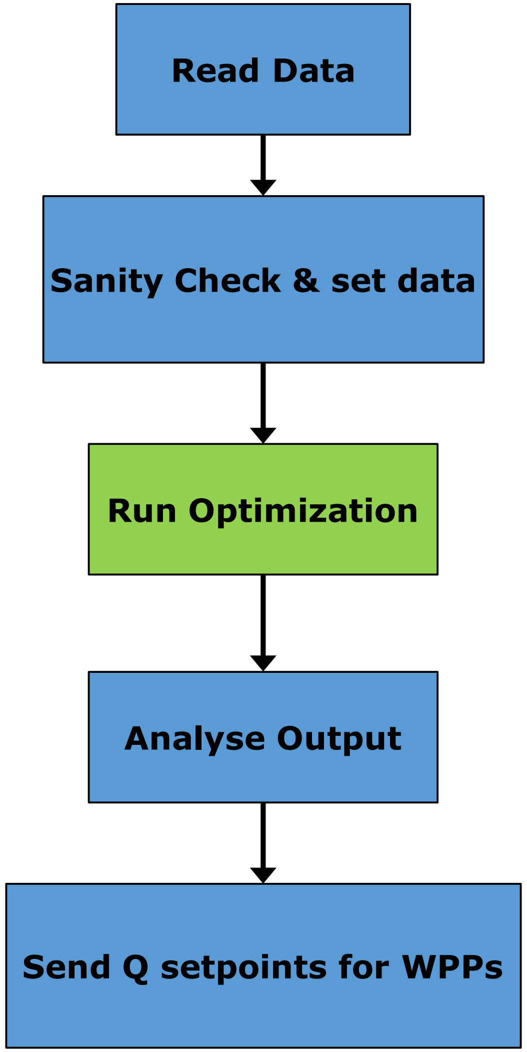


Sanity Check & set data



- Check if all required data (load and generation) are available
- Check if there is any overloading in the lines/transformers, then discard that data point
- State Estimation for more accurate filtering (ongoing research)
  - State estimation may also incorporate automated meter-reading (AMR) data

Optimization



- Control variables:
  - Reactive power set point of 3 WPPs
- Objective:
  - Minimize active power loss in 60 kV feeders
- Constraints

Network constraints

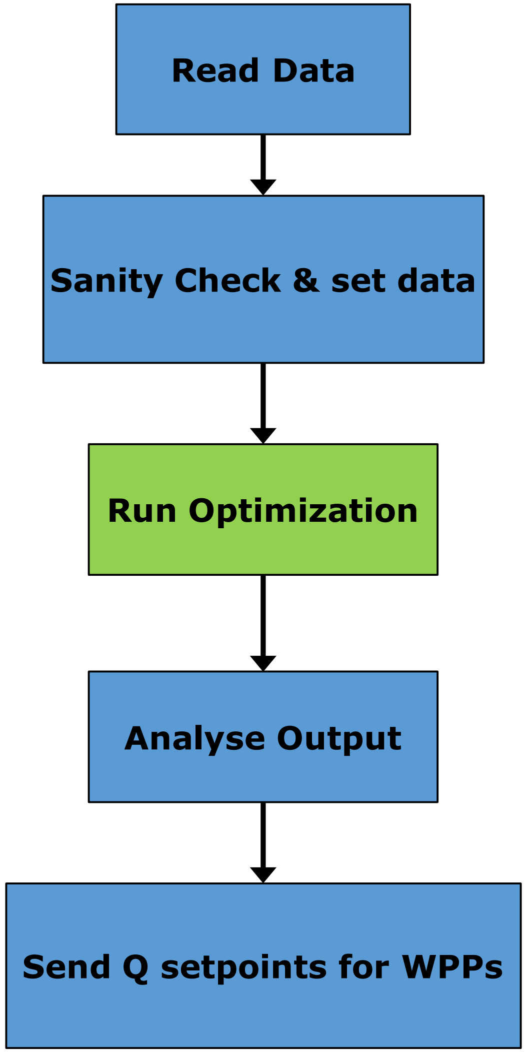
- MVAR flow ≤ 0.48 * Capacity in 150/60 kV transformer
- Loading of 60 kV feeders < 100%
- Loading of 60kV/10kV transformers < 100%

  (can be allowed up to 120% for small amount time)
- 59kV < Voltage at 60 kV busbars < 66kV

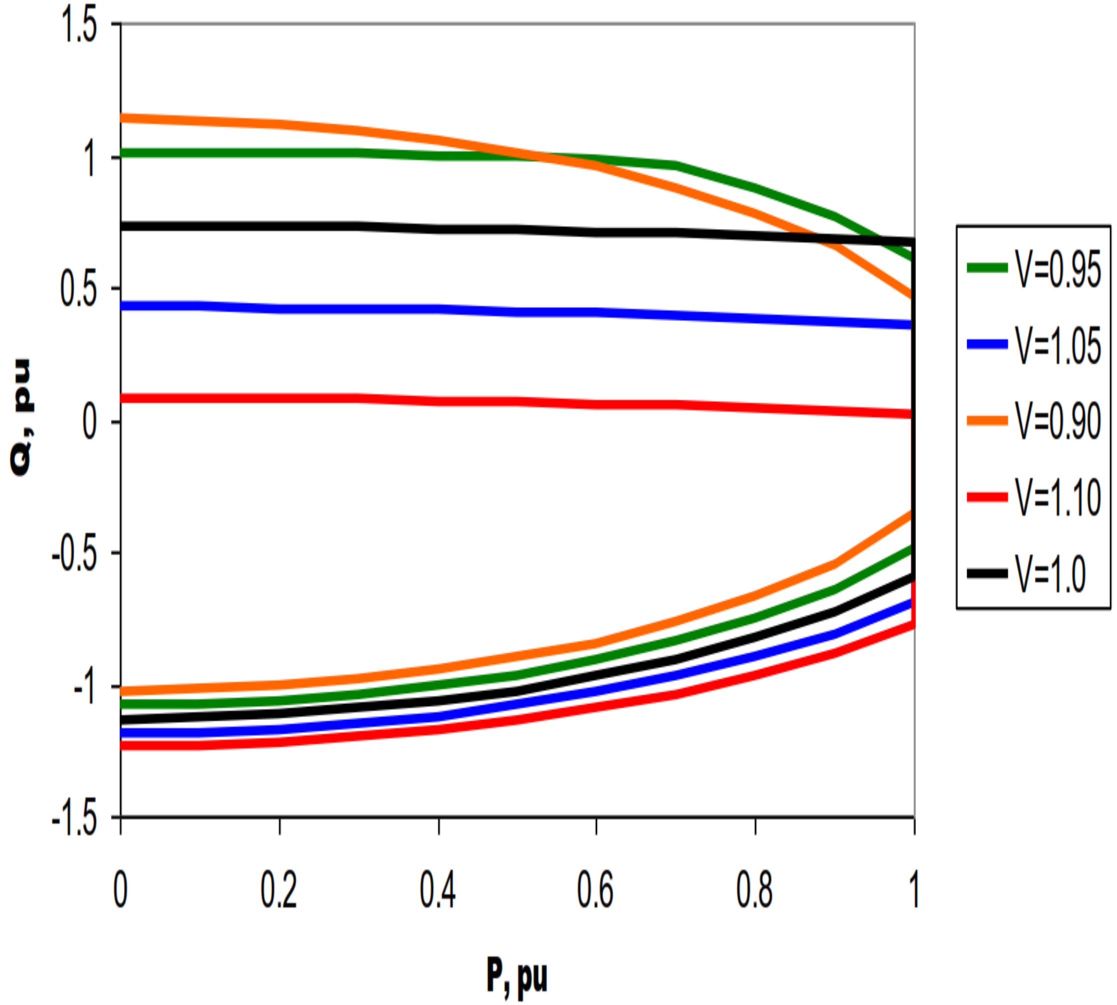
WPP constraint

- Q lower capability< Q set points < Q upper capability

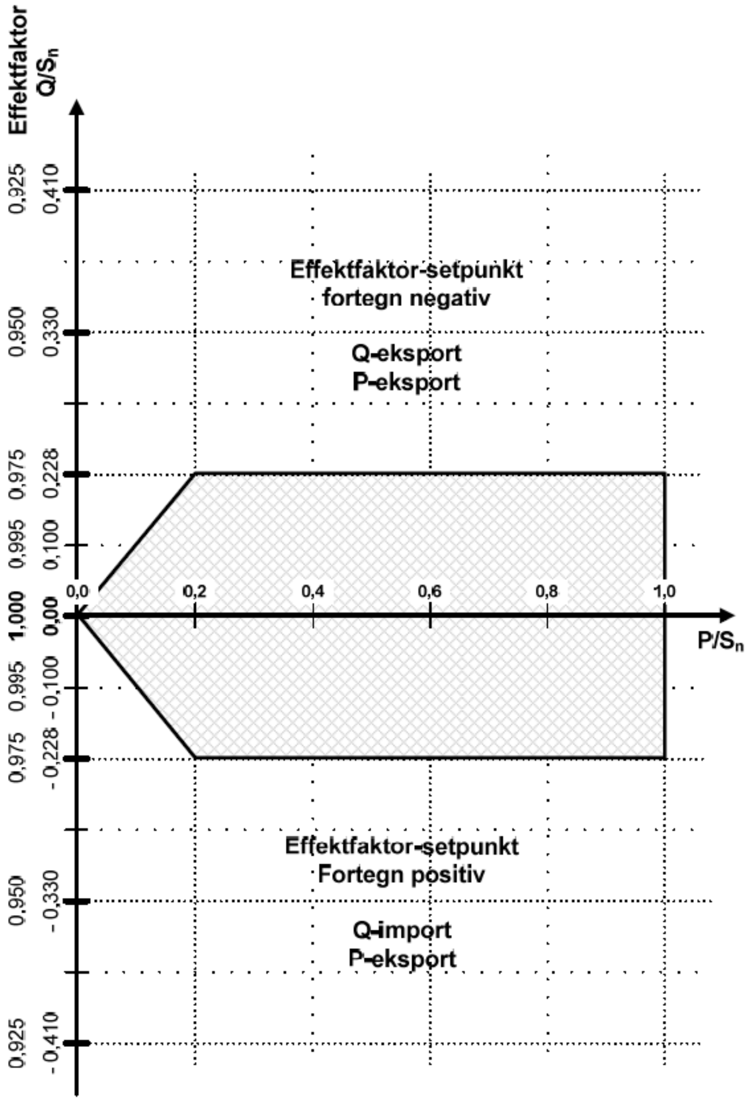
Optimization

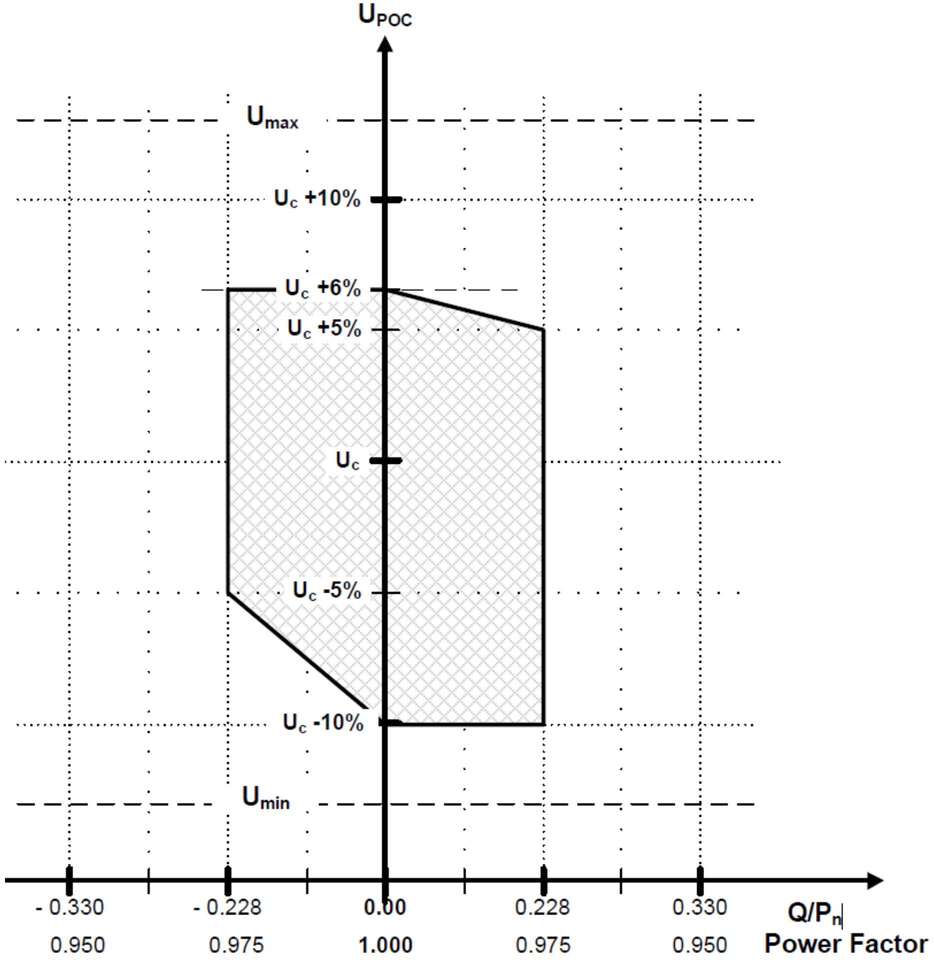


Q lower capability< Q set points < Q upper capability

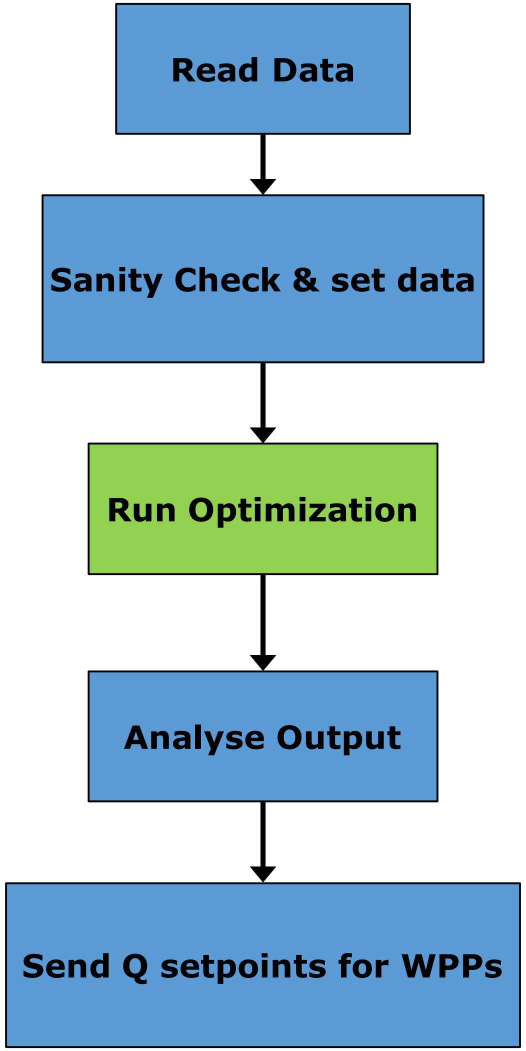


Grid Code Requirements





Optimization: Method



Meta-heuristic Algorithms

- Advantages:
  - Non-linear method – linearization is not required
  - Jacobian/Sensitivity matrix is not required
    - Less mathematical computation
    - Less prone to human error
  - Finding global optimum is possible
  - Easy to add new objectives / constraints
  - Adaptable for other distribution topologies

- Challenges:
  - Time Consuming

Results: Scenarios of Loss Minimization

S1: High Wind Low Loading
S2: Moderate Wind Low Loading
S3: Low Wind Low Loading

S4: High Wind High Loading
S5: Moderate Wind High Loading
S6: Low Wind High Loading

	S1	S2	S3	S4	S5	S6
Date/Time	10-12-14 21:00	10-12-14 17:00	10-01-15 19:00	09-01-15 23:00	03-01-15 01:00	30-01-15 08:00
P Load [MW]	-3.48	7.28	12.28	-31.79	-45.52	56.93
Q Load [MVAR]	14.25	17.31	10.87	27.59	19.86	3.43
WP Gen. [MW]	31.31	23.53	7.53	37.82	22	1.94
P loss without optimization [MW]	0.758	0.512	0.271	1.665	1.106	0.265
P loss with optimization [MW]	0.716	0.485	0.217	1.572	1.05	0.265
Loss Improvement [%]	5.4	5.27	0	5.58	5	0

Output Analysis

Case: 6721 hours

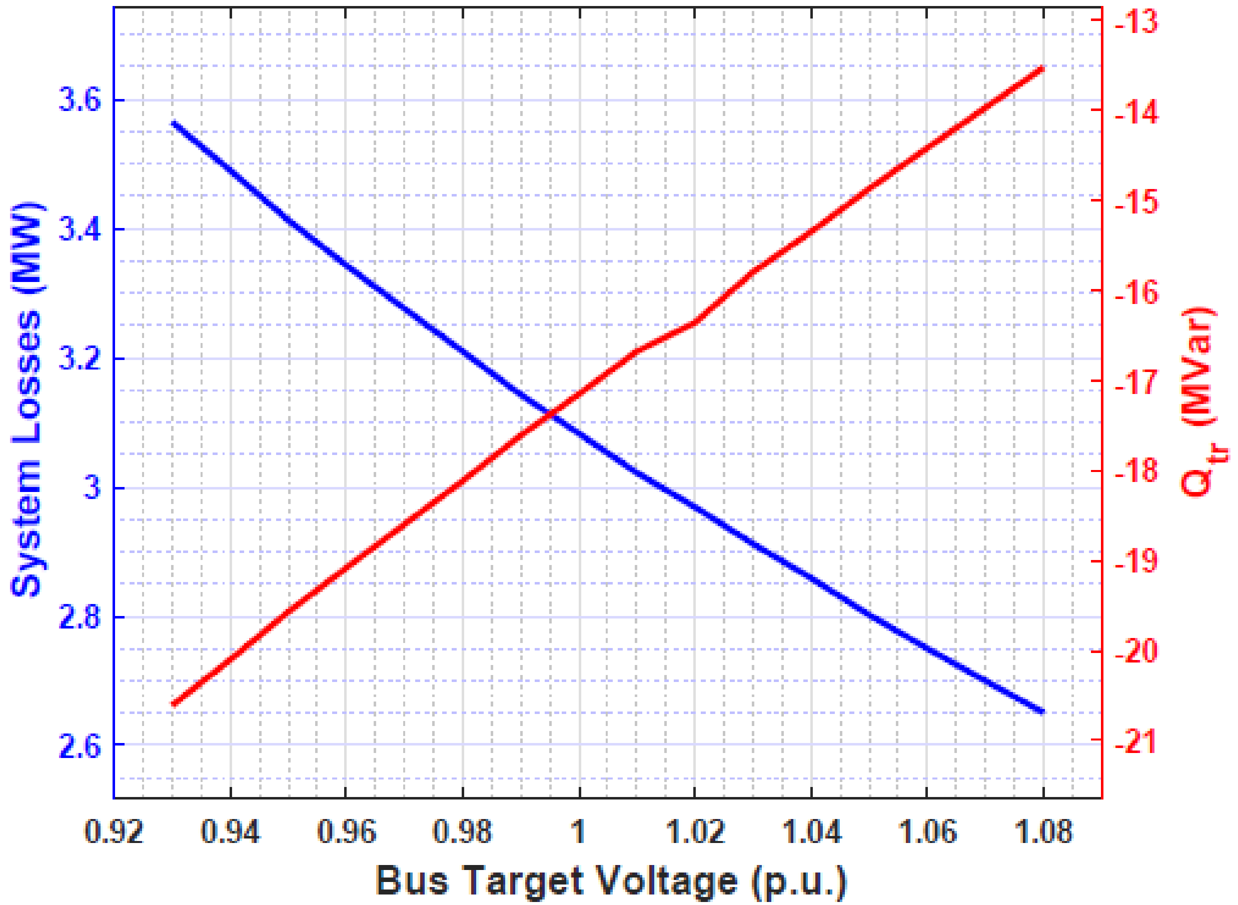
Without Optimization			With Optimization	
			Loss reduction [%]	
Power loss [MW]	Number of Hours [Hrs]	Energy loss w/o optimization [MWh]	Mean	Uncertainty
0-500	4850	728	3.86%	0.25%
500-1000	742	533	0.89%	0.10%
1000-1500	517	639	1.84%	0.11%
>1500	612	1181	2.91%	0.08%

Upscale case: 8760 hours

Without Optimization			With Optimization
Power loss [MW]	Energy Loss in 6721 hours [MWh]	Energy loss in 8760 hours [MWh]	Energy Saving [MWh]
0-500	728	728*8760/6721=949	949*(3.86 $\pm$ 0.25)%=36.6 $\pm$ 2.38
500-1000	533	533*8760/6721=695	695*(0.89 $\pm$ 0.1)% = 6.2 $\pm$ 0.69
1000-1500	639	639*8760/6721=833	833*(1.84 $\pm$ 0.11)% = 15.33 $\pm$ 0.92
>1500	1181	1181*8760/6721=1539	1539*(2.91 $\pm$ 0.08)%=44.78 $\pm$ 1.23
Sum	3081	4016	103 $\pm$ 2.92

Using optimization method, total energy saving of 103 $\pm$ 2.92 MWh is achieved!

Results: Voltage Sensitivity Analysis



Conclusion

- NetVind – Ongoing research work
  - Energy savings is possible through optimal control of wind power plants.
  - Without additional investment on equipment like synchronous condenser
  - WPP are higher capability to support network than the grid code requirements

Phase 2

- Using wind power support for optimization of distribution network operation:
  - Control of MVAR infeed to the transmission network
  - Voltage control in 60/10 kV network
  - Loss minimization
    - Both in the distribution network and WPP collection system
- Control WPP tap changers and load tap changers together with wind power for optimization
- Dynamic studies for improvement of voltage stability using co-ordinated voltage control of WPPs, tap-changers etc.

Q control

- Algorithm to reduce lost wind power production during maintenance
- Optimal feeder disconnection for load reduction/shedding without disconnecting renewable sources (mainly PV)

P control

- Improved filtering of input SCADA data and consider measurement inaccuracies in optimisation

Monitoring