The Interaction of Wind Turbine With Local Network

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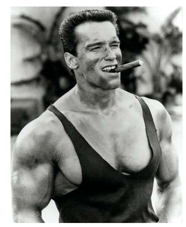
- Network strength (SCL or SCR)
- Voltage variations and flicker
- Harmonics
- Reactive power
- Protection
- Frequency
- Network stability

System Strength (SCL or SCR)

$SCR = \frac{SCL}{P_w}$, $SCL = \frac{U_{sc}^2}{Z_{sc}}$,
SCR:Short Circuit Ratio,
SCL:Short Circuit Level,
P_w:Installed wind power,



- Strong system 20<SCR<25
- Weak system 8<SCR<10

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Voltage Variations and Flicker Level

Flicker severity factor	Planning levels		Emission levels
	MV (1-36)	HV (36-230)	MV and HV
Pst	0.9	0.8	.35
Plt	0.7	0.6	0.25

$$P_{lt} = \sqrt[3]{\frac{1}{12}\sum_{j=1}^{12} P_{stj}^3}$$

P_{lt}:Long term (2 hours) flicker severity factor,
P_{st}:Short term (10 min.) flicker severity factor,
$\Delta V = 2\%$: Different for networks

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Harmonics

IEC 1000-3-6 Guidlines	Planning levels		Compatibility level
	MV	HV	MV
THD	6.5%	3%	8%

$$THD = 100\sqrt{\sum_{n=2}^{50} \frac{U_n}{U_1}}\%$$

U_n:Indivisual harmonic amplitude (or RMS) voltage,
U_1:Fundamental amplitude (or RMS) voltage

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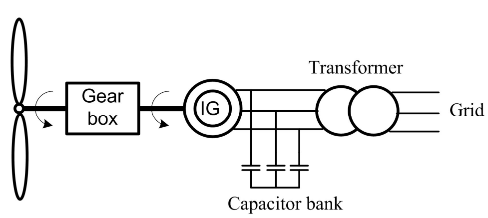
Reactive Power



Fixed speed WTs with an induction generator need reactive power support.

0.9 lagging<p.f.<.95 leading, suggestion above 0.96

Variable speed WTs with converter can have unity p.f.

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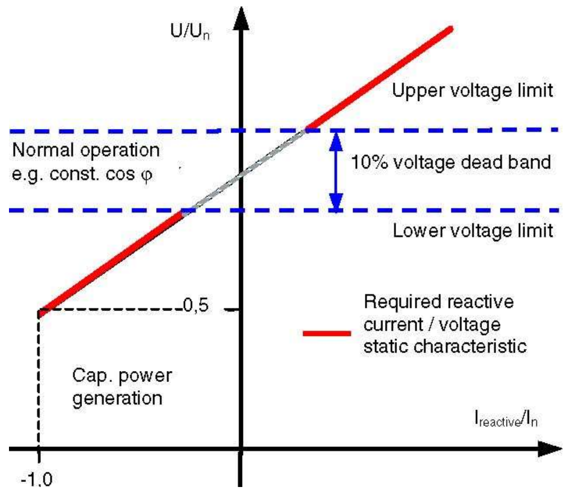
Reactive Power Support of Network



Static characteristic for back up voltage operation
Source: www.vdn-berlin.de

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Required Protection Functions

- Under frequency
- Over voltage
- Under voltage
- Loss of mains
- High over currents
- Thermal overload
- Earth fault
- Neutral voltage displacement
- Rate Of Change Of Frequency (ROCOF) relay for autonomous operation

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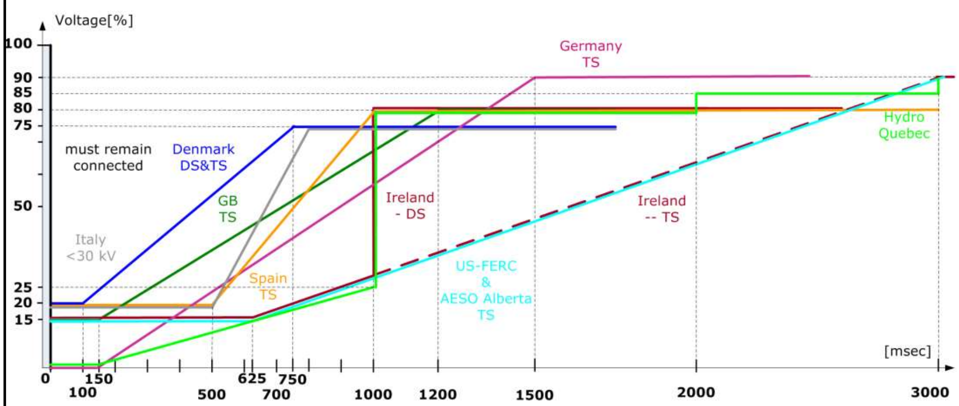
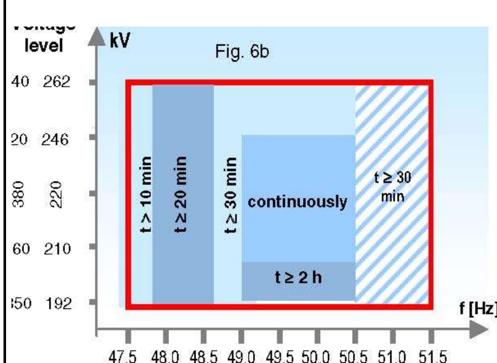
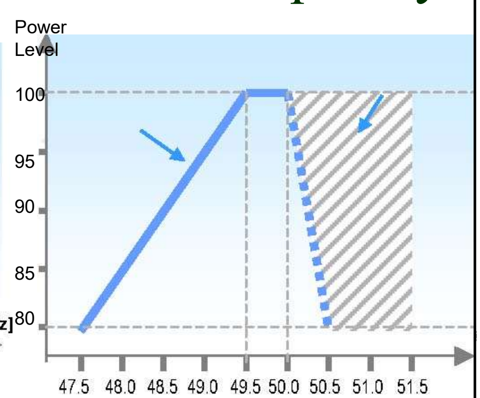
Review of fault ride through requirements for wind power in European grid codes



Operating Requirements Depending onNetwork Frequency

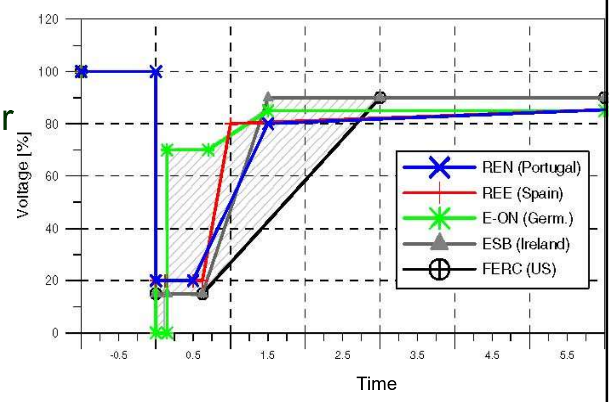




Operating requirements depending on network frequency
Source: E.ON Netz, a grid operator in Northern Germany

Fault Ride-Through

- Voltage dip requirements
- The effect of power system voltage dips on both electrical and mechanical parts of wind turbine
- The stability of wind turbine controllers



LVRTF requirements for several grid codes

Some Guidelines for Grid Connection Considering Power Quality Issue Based on IEC 61400-21 (Calculation Method)

Steady State Voltage Change by WT

Load flow as the best method:
low (high) loads and low (high) wind power

A simple method:
$d = \frac{S_{60}}{S_k}|cos(\psi - \varphi)|$ for $cos(\psi - \varphi) > 0.1$,
S_k:Short circuit Power at PCC,
S_{60}:Apparent power at the 1-min. active power peak,
d:steady state voltage change of the grid at PCC (normalised to nominal voltage),
φ:Phase angle between voltage and current,
ψ:Grid impedance phase angle

Voltage Change Due to Switching Operations of a WT

$$d = K_u(\psi_k).\frac{S_n}{S_k}$$

S_k:Short circuit Power of grid at PCC,
S_n:Apparent power of WT at raterd power,
d:Relative voltage change,
$K_u(\psi_k)$:Voltage change factor,
ψ_k:Grid impedance phase angle at PCC

Flicker Due to Continuous Operation of a Single WT and Multiple WTs

$$P_{lt} = c(\psi_k, v_a).\frac{S_n}{S_k}$$

S_k:Short circuit Power of grid at PCC,
S_n:Apparent power of WT at raterd power,
P_{lt}:Flicker distortion,
$c(\psi_k, v_a)$:Flicker coefficient,
v_a:Annual average wind speed,
ψ_k:Grid impedance phase angle at PCC,

$P_{lt-(nWTs)} = \sqrt{n}.P_{lt-(singleWT)}$,
n:Number of wind turbines

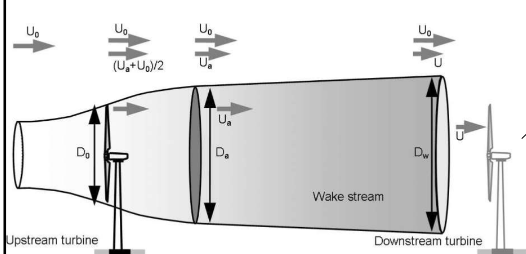
Flicker Due to Switching Operations of a single WT

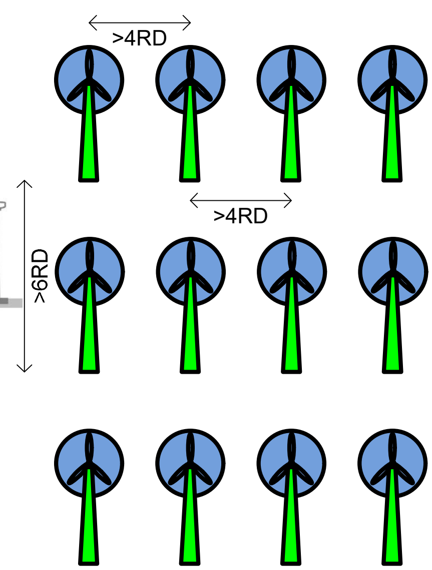
$$P_{lt} = 8.N_{120}.K_f(\psi_k).\frac{S_n}{S_k}$$

S_k:Short circuit Power of grid at PCC,
S_n:Apparent power of WT at raterd power,
P_{lt}:Flicker distortion,
$K_f(\psi_k)$:Flicker step factor,
N_{120}:Number of switching within a 2 hours period,
ψ_k:Grid impedance phase angle at PCC

Flicker Contribution of a Wind Power Plant with Single and Multiple Turbine Representations

Typical Wind Turbine Spacing





- The wind turbine wake effect
- Rotor Diameters (RD).

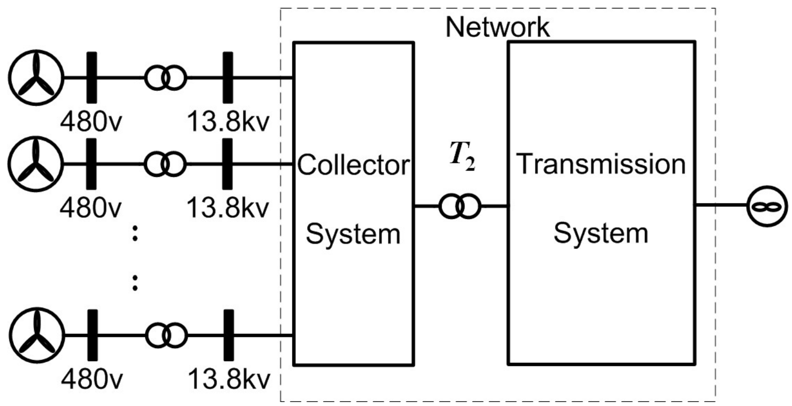
Power Quality and Flicker Issue

- Wind speed fluctuation can cause power variations in a wind power system.
- FLicker and voltage variations are induced by load flow changes in the grid.
- The flicker emission produced by a wind power plant during normal operation is mainly caused by fluctuations in the output power due to wind speed variations, tower shadow effect, and wind shears.

Aeroelastic Issues and Power Quality

- Aerodynamic Issues
  - Wind velocity variations (Stochastic)
  - Wind shear (Periodic)
  - Tower shadow (Periodic)
  - Yaw error (Periodic)
- Mechanical Issues
  - Tower and blades vibration

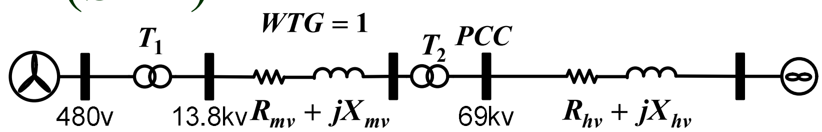
System Configuration



Wind Power Plant Representations

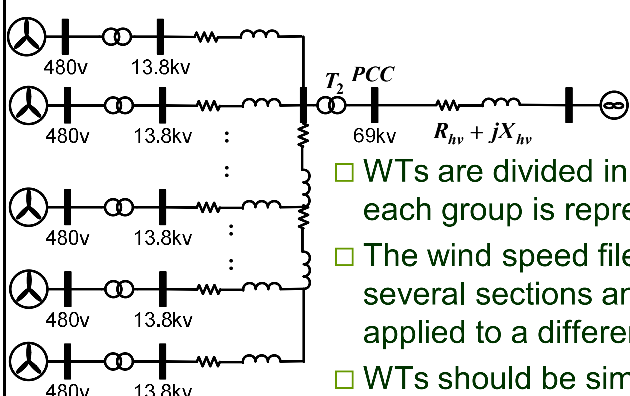
- Single Turbine Representation (STR)
- Multiple Turbine Representation (MTR)
- Quasi Multiple Turbine Representation (QMTR)

Single Turbine Representation (STR)



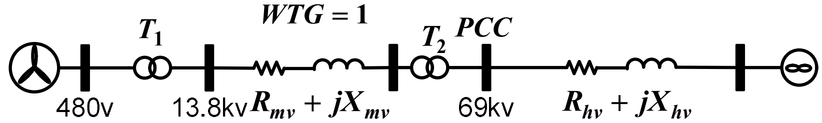
- The WTG units is replaced by an equivalent WTG unit.
- The collector system is represented by an equivalent impedance.
- This is the worst-case assumption and the same wind fluctuations and tower shadow effects will affect the output power of the wind power plant and the power quality at the PCC.

Multiple Turbine Representation (MTR)



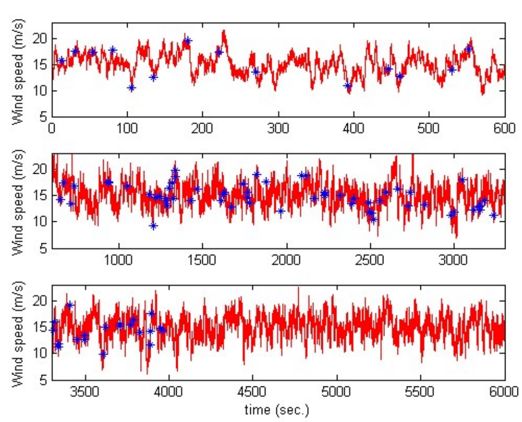
- WTs are divided in several groups and each group is represented by a WT.
- The wind speed file is subdivided into several sections and each subdivision is applied to a different group of WTs.
- WTs should be simultaneously modeled.
- Computational time.
- Still all WTs are not modeled.

Quasi Multiple Turbine Representation (QMTR)



- The STR is used.
- The time series of wind file is subdivided into several sections and are applied to STR of wind farm.
- Considering WTs as independent sources connected to a linear network, the average of the results for the network quantities (i.e. the voltage, active power, and reactive power) at PCC are calculated.

The Wind Speed Distribution



- The time series of wind speed is divided into 96 different files with the starting times shown by stars (*)

The Computation Load for QMTR and MTR Methods

$C_1 = C_{wt}.T_1 + C_{avr}$, $C_2 = N.C_{wt}.T_2$
C_1,C_2:Computation loads for QMTR and MTR,
T_1,T_2:Simulation times for QMTR and MTR
N: WTs in wind farm,
C_{wt}:Computational load of a WT for 1 Sec.,
C_{avr}:Averaging computation load,

To simulate wind farm for 600 Sec. we have:
$N = 96$, $T_1 = 600 + 96 \times 60$, $T_2 = 600$, and
$C_{avr} \approx C_{wt}$ it can be concluded that
$C_2 \approx 9 \times C_1$.

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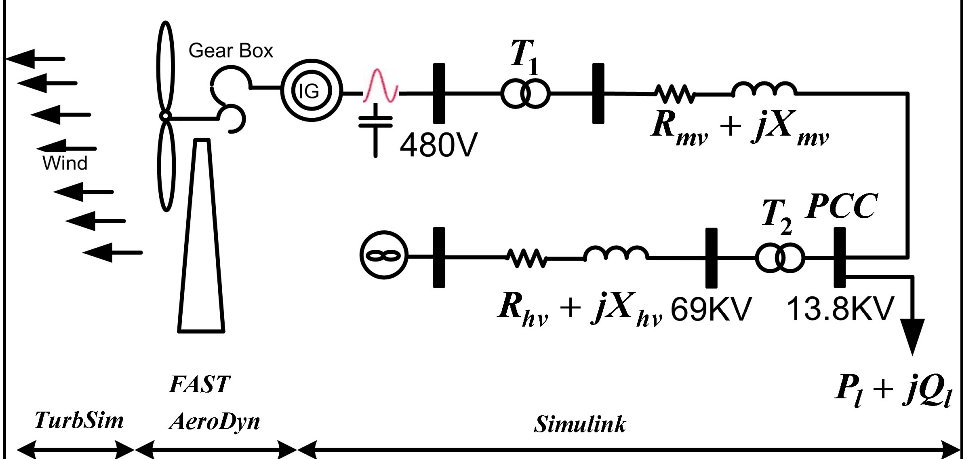
Simulation Structure



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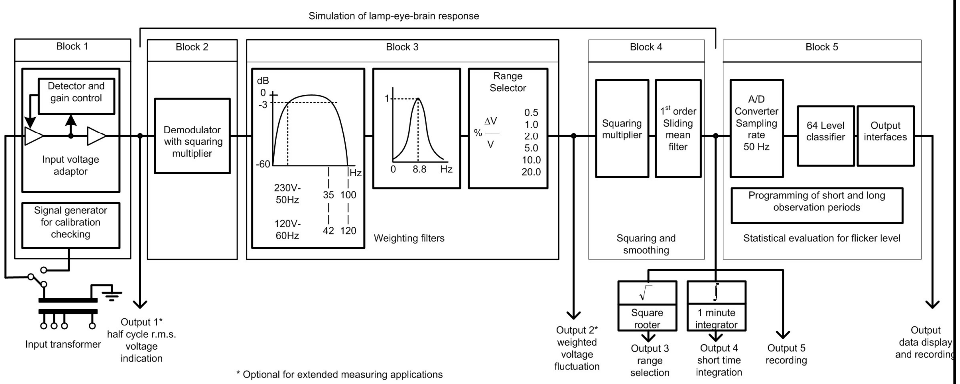
Simulation Steps

- Task 1:Simulation of wind and aerodynamic forces using TurbSim and AeroDyn
- Task 2:Simulation of mechanical parts of wind turbine using FAST
- Task 3:Time domain simulation of the induction generator and grid (including transformers, collector system, and transmission system)

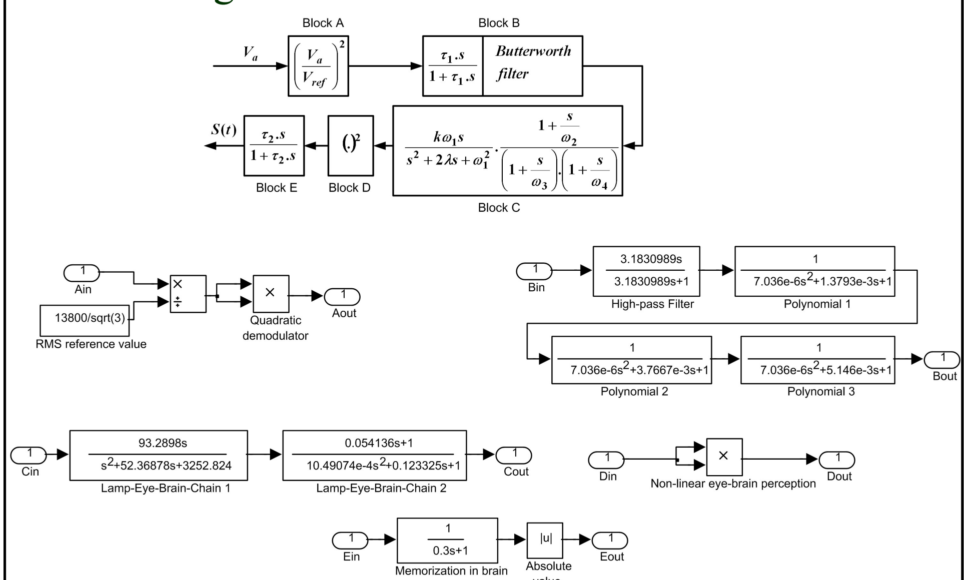
Simulation Steps (contd.)

- Task 5: Averaging of variables (i.e. voltage and powers) at PCC using recorded data
- Task 6: Implementing the IEEE flickermeter to calculate the instantaneous flicker level sensation signal using recorded data

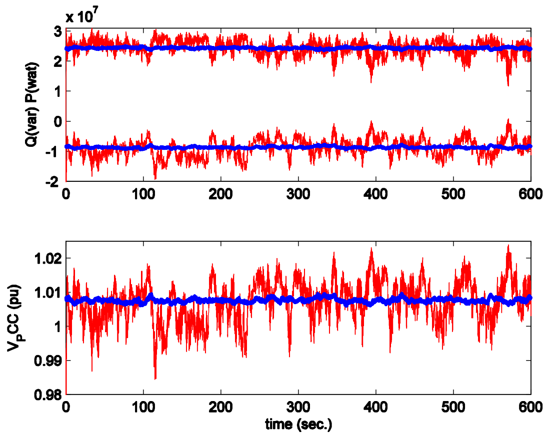
The IEEE (IEC) Flickermeter



Implementation of the IEEE Flickermeter Using Simulink



Simulation Results for STR and QMTR



The active, reactive powers and Voltage at PCC for STR and QMTR.

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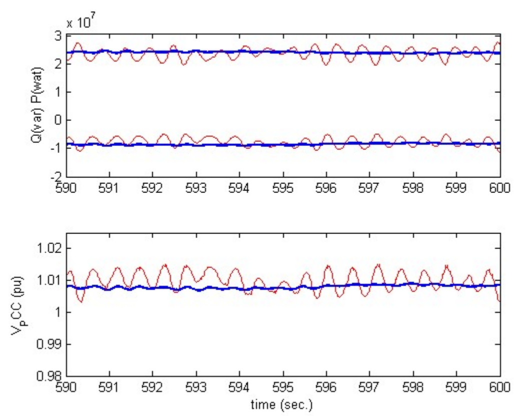
Simulation Results for STR and QMTR



The active, reactive powers and Voltage at PCC for STR and QMTR.

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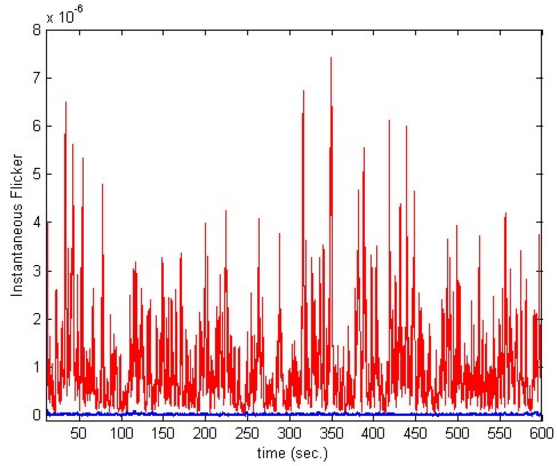
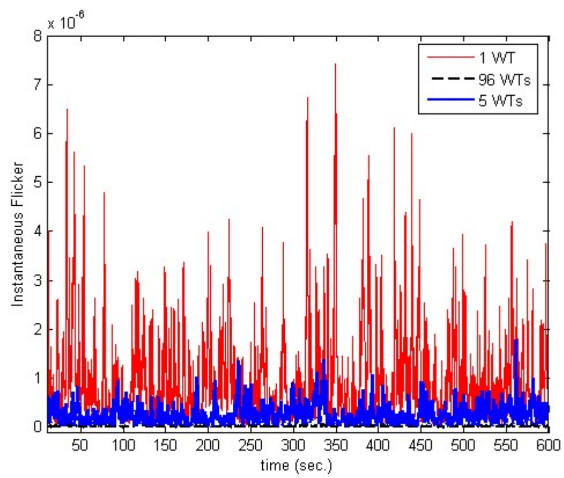
Flicker Sensation at PCC



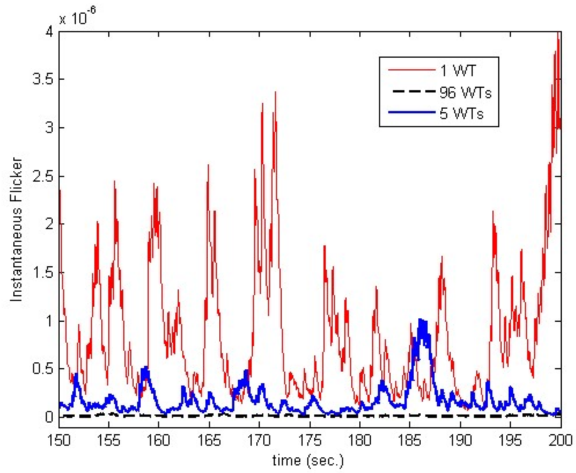
Instantaneous flicker sensation at PCC with STR and QMTR

Flicker Sensation at PCC



Instantaneous flicker sensation at PCC with different numbers of WTs

Flicker Sensation at PCC



Instantaneous flicker sensation at PCC with different numbers of WTs

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