Line Conditioning with Grid Synchronized Inverter's Power Injection of Renewable Sources in Nonlinear Distorted Mains

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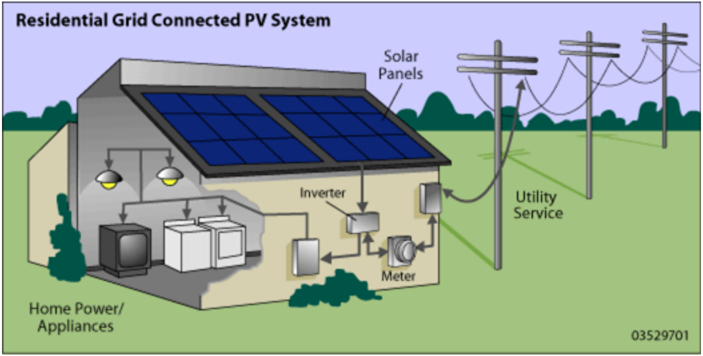
Contents

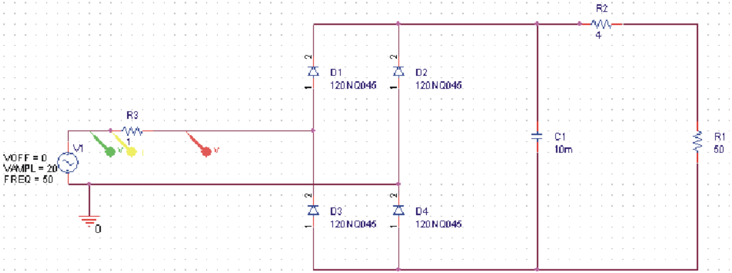
Small domestic power plants (1-5kW)



- Island mode (off grid) storage (battery, H_2- fuel cell, CAES, SMES, PHS) - In development phase or too expensive!
- Grid synchronized mode - Cost effective!

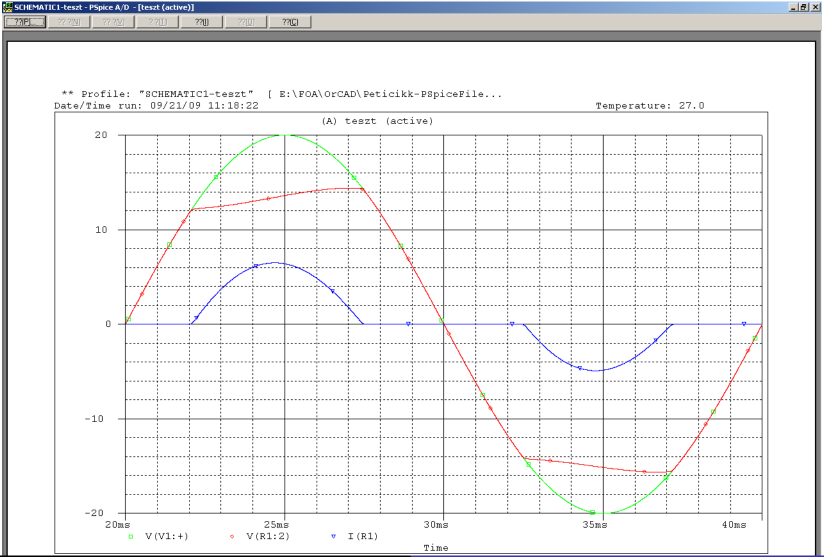
Nonlinear capacitive elements

- Low consumption switching power supplies (mobile chargers, notebooks, small variable frequency motor drives)

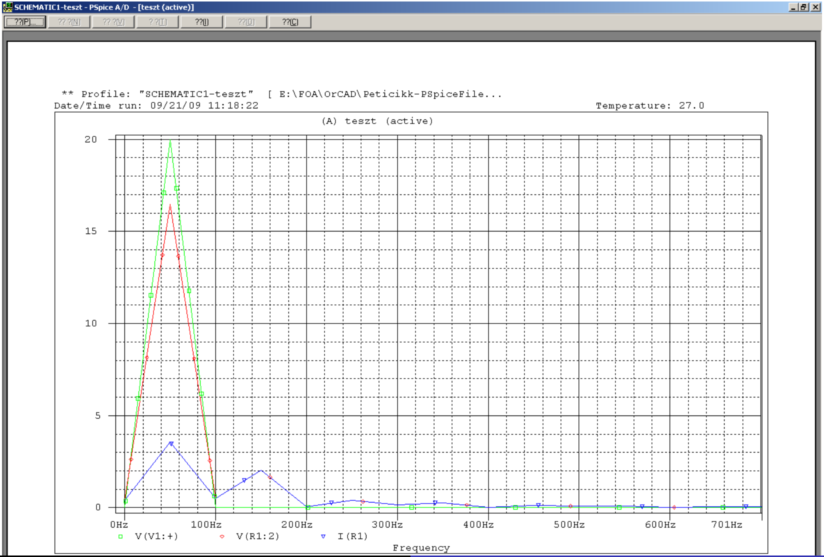


- Capacitive input stage - nonlinear load (PSpice model)

Capacitive input stage model time domain analysis



Capacitive input stage model frequency domain analysis



Distortion, active and reactive power

- Significant 3rd and 5th upper harmonic component
- Overall reactive power:

$$Q_B = \sum_{k=1}^{n} Q_k = \sum_{k=1}^{n} \frac{|\hat{V}_s(k)||\hat{I}_l(k)| \sin \phi(k)}{2}$$

  - $\hat{V}_s(k)$ Peak Voltage of the source
  - $\hat{I}_l(k)$ Peak Current of the load
  - $\phi(k)$ Phase difference between the voltage and current

Distortion, active and reactive power

- Power factor:

$$PF = \frac{\langle V_s, I_s \rangle}{||V_s|| ||I_s||}$$

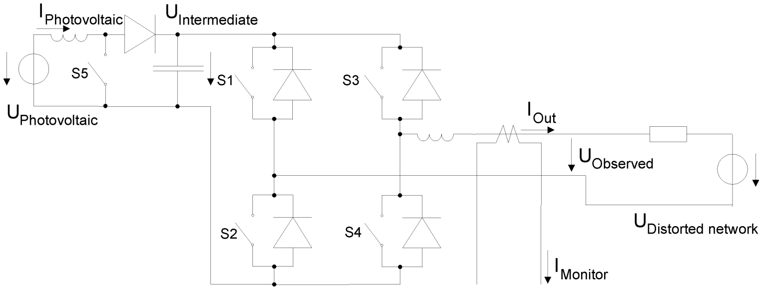
  - $\langle V_s, I_s \rangle$ Active power of the source
  - $||V_s|| ||I_s||$ Apparent power of the source

- Total harmonic distortion:

$$THD = \sqrt{\frac{\sum_{k=2}^{\infty} (|V_k|^2)}{|V_1|^2}}$$

  - V_k k-th harmonic effective voltage
  - V_1 Base harmonic effective voltage

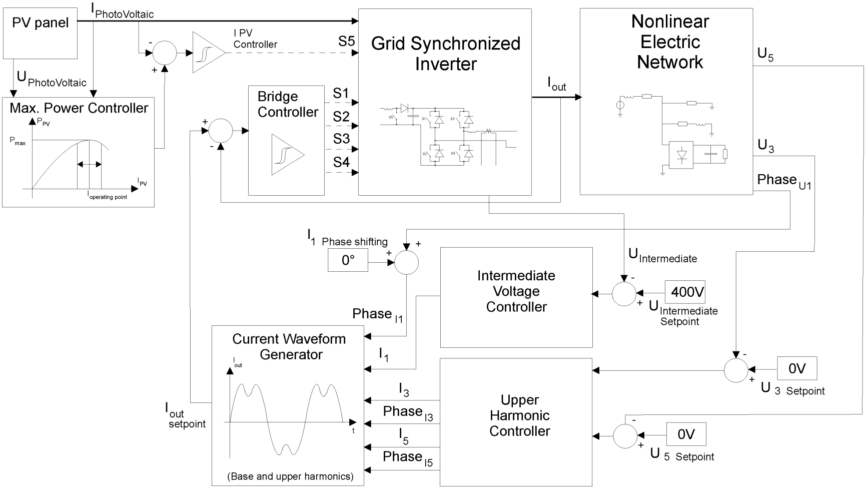
Grid tie inverter schematics



Elements of the inverter

- Boost converter: Input serial inductor, diode and IGBT switch
- Middle stage puffer capacitor
- IGBT bridge with built in reverse diodes, Output serial inductor
- Voltage and Current sensing

Control flow chart

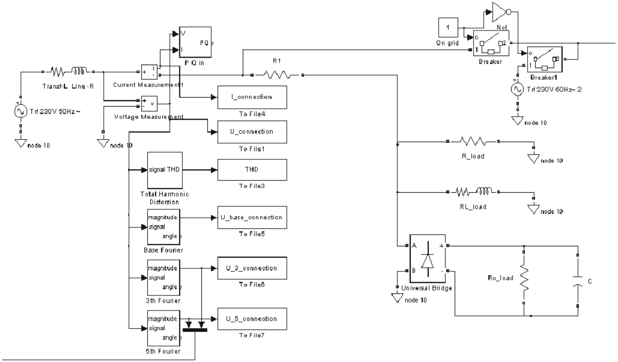


Elements of the control system

- Max power controller
  - maximizes the output power of the photovoltaic panel
- Bridge controller
  - controls the IGBT-s in the bridge (nonlinear, hysteresic)
- Grid synchronized inverter *
- Nonlinear electric network *
- Upper Harmonic controller *
- Intermediate voltage controller *
- Current waveform generator
  - Current control setpoint production

* present work, details later

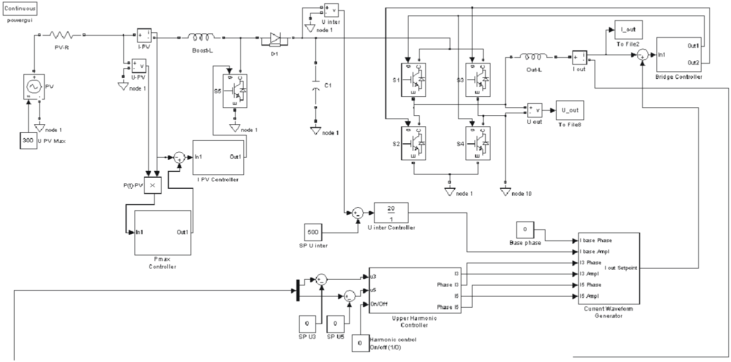
Nonlinear network model



Param.	Value
U_{tfr}	230V
L_{trf}	3.185mH
$R_{s,line}$	0.5Ω
R_1	0.2Ω
R_{Load}	50Ω
R_{RLload}	35.35Ω
L_{RLload}	112.5mH
R_{RCload}	25Ω
C_{RCload}	10mF

- Low Voltage transformer with serial inductance, Line loss resistances
- Resistive load, Inductive and resistive load, Nonlinear Capacitive resistive load
- Voltage and Current measurement at connection point (Power meter, P, Q)
- Fourier analysis for harmonic amplitudes and phases

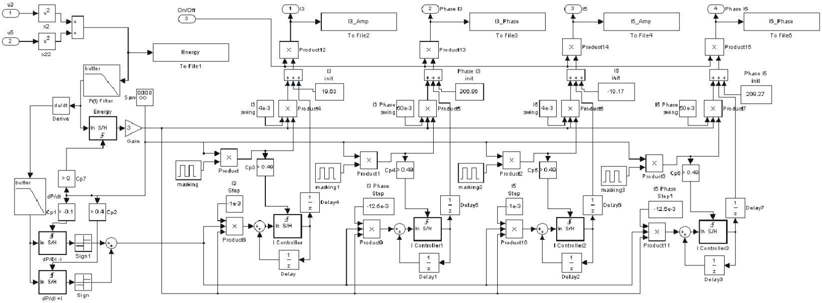
Inverter model



Param.	Value
L_{Boost}	100mH
L_{out}	10mH
C_{inter}	100mF

- Inverter schematic in Power Electronics Toolbox
- Control System Elements
- Harmonic Components Values from the Nonlinear Network
- Current Output to the Nonlinear Network

Upper harmonic controller

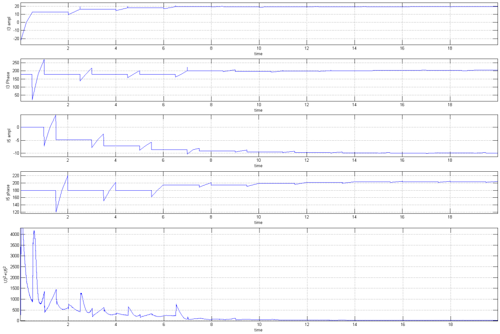


- Error Function: $U_3^2 + U_5^2$
- Controller inputs: 3rd an 5th harmonic Voltage Amplitudes
- Controller outputs: 3rd an 5th harmonic Current Amplitudes and Phases
- Time divided multiplex gradient method for Error function minimization

Simulation experiments

Parameter	Value
I_1 Amplitude init (IVC)	0A
I_1 Phase init (IVC)	0^o
I_3 Amplitude init (UHC)	0A
I_3 Phase init (UHC)	180^o
I_5 Amplitude init	0A
I_5 Phase init	180^o
3rd Current Amplitude swing (UHC)	Error Function Value*0.012
3rd Current Phase swing (UHC)	Error Function Value*0.15
5th Current Amplitude swing (UHC)	Error Function Value*0.012
5th Current Phase swing (UHC)	Error Function Value*0.15
Intermediate Voltage Contr. prop. value	20
$I_{PV}(MPC)$ Initial value	30A
$I_{PV}(MPC)$ swing	1A

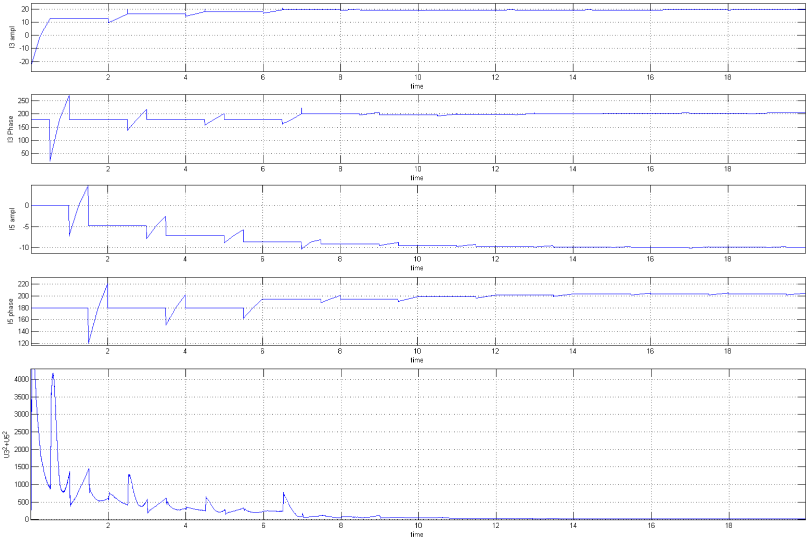
Current Parameters



- Output current 3rd amplitude
- Output current 3rd phase
- Output current 5th amplitude
- Output current 5th phase
- Error Function: $U_3^2 + U_5^2$

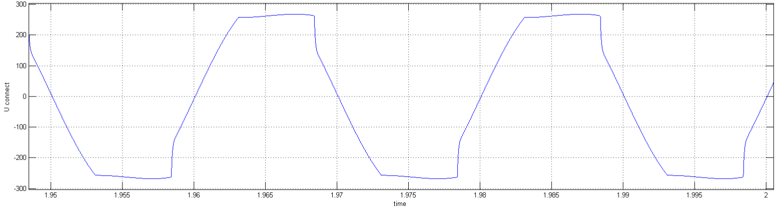
- Time divided multiplex gradient method for Error function minimization
- 1 cycle 4 time slice = 2 seconds
- 4 dimension parameter space
- steps are made along the axes directions

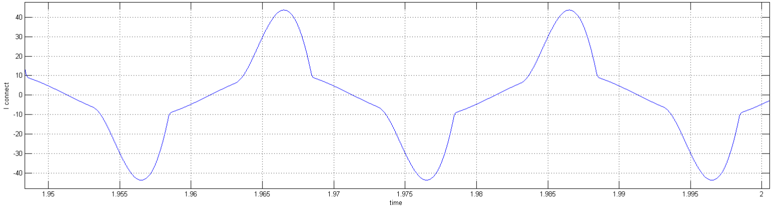
Current Parameters



U,I at the connection point (Inverter:OFF)

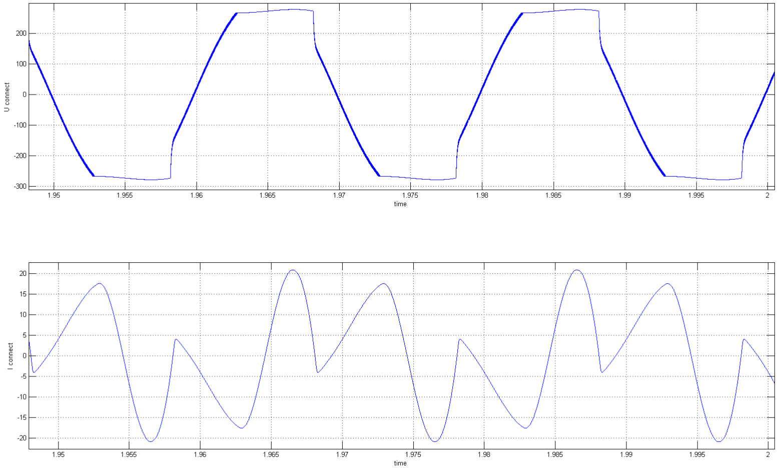
Distortion from the network





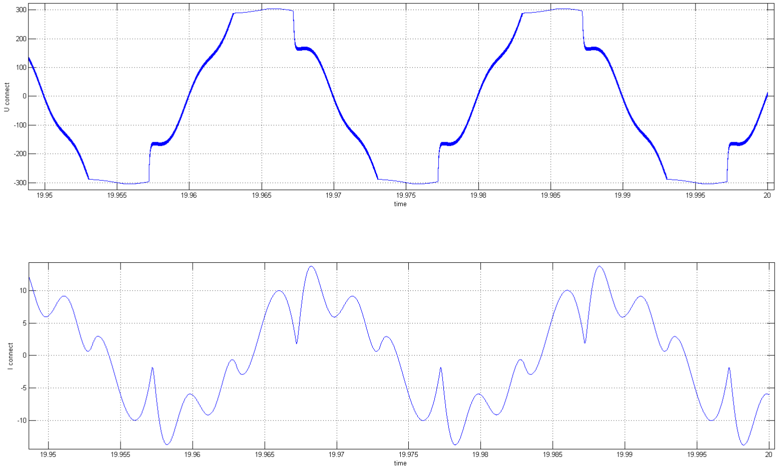
U,I at the conn. point (Inverter:ON Complex control:OFF)

The effect of the inverter

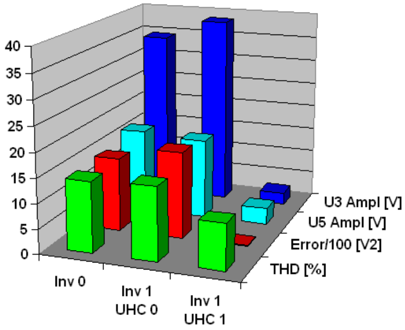


U,I at connection point (Inverter:ON Complex control:ON)

The effect of the inverter and the controller



Numerical results



	Inv 0	Inv 1 UHC 0	Inv 1 UHC 1
THD [%]	14,26	14,75	9,3
Error/100 [V2]	14,8029	17,5654	0,1792
U5 Ampl [V]	16,99	16,28	3,41
U3 Ampl [V]	34,52	38,62	2,51

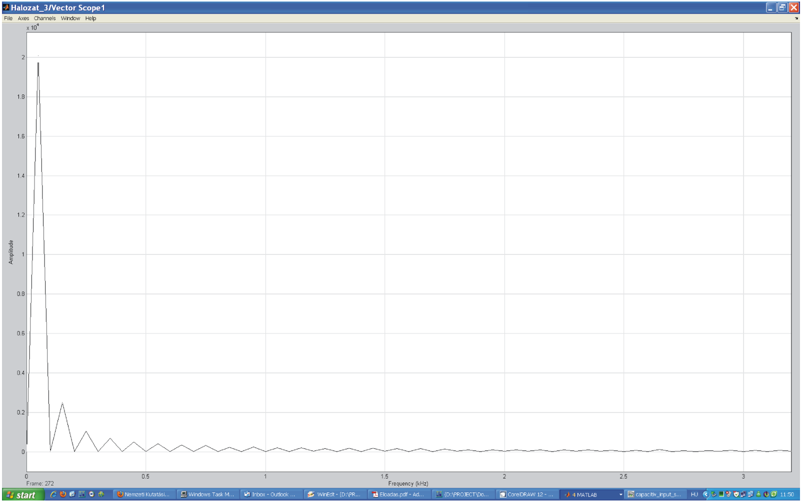
Conclusions

- A novel "line-friendly" control method
  - optimizes the working point
  - implements active PF correction
  - lowers the extant harmonic distortion
- Matlab simulation
  - substantial improvement of the output voltage and current waveform could be achieved
- Difficulties
  - deviations of error function - filtering slows the controller
- Lower THD reduction than in the literature
  - impossible to perform exact current measurement at the connection point

Further work

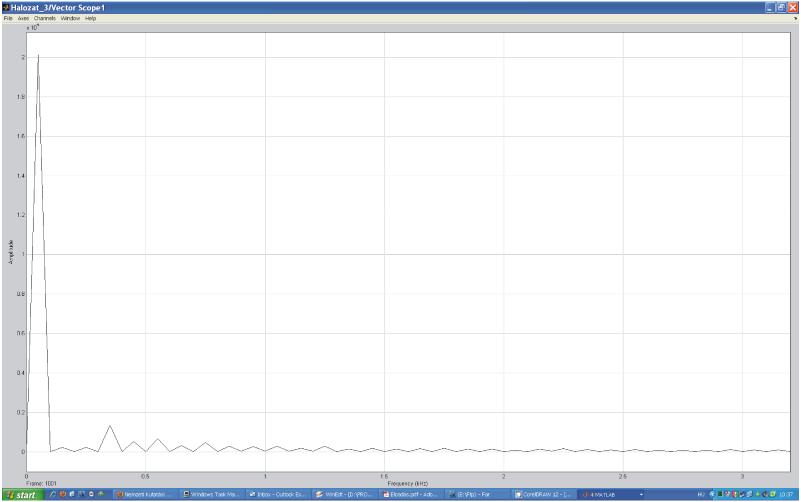
- Modify the control method to enhance its performance
  - more effective derivative computation
  - more effective optimization algorithm
  - more upper harmonic component
- Build a low scale model of the equipment
  - laboratory-size wind turbine
  - controller will be implemented on a DSP

Nonlinear network spectral analysis



- Spectrum of Voltage at the connection point (UHC OFF)

Nonlinear network spectral analysis



- Spectrum of Voltage at the connection point (UHC ON)