Electrical Energy Storaging and Reusage in Workmachine Applications (ENTALT) 2007-2010

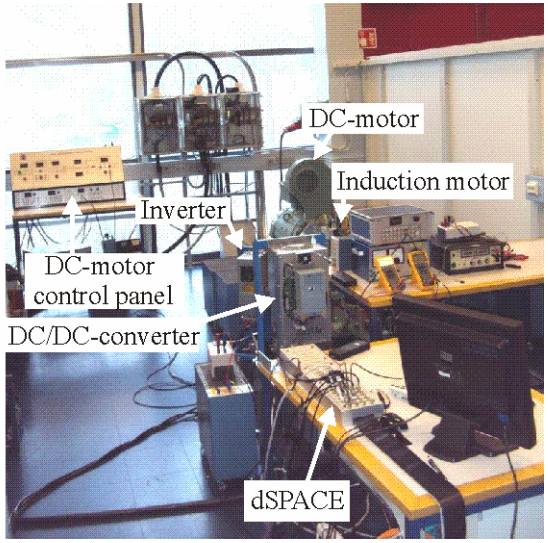
Tampere University of Technology

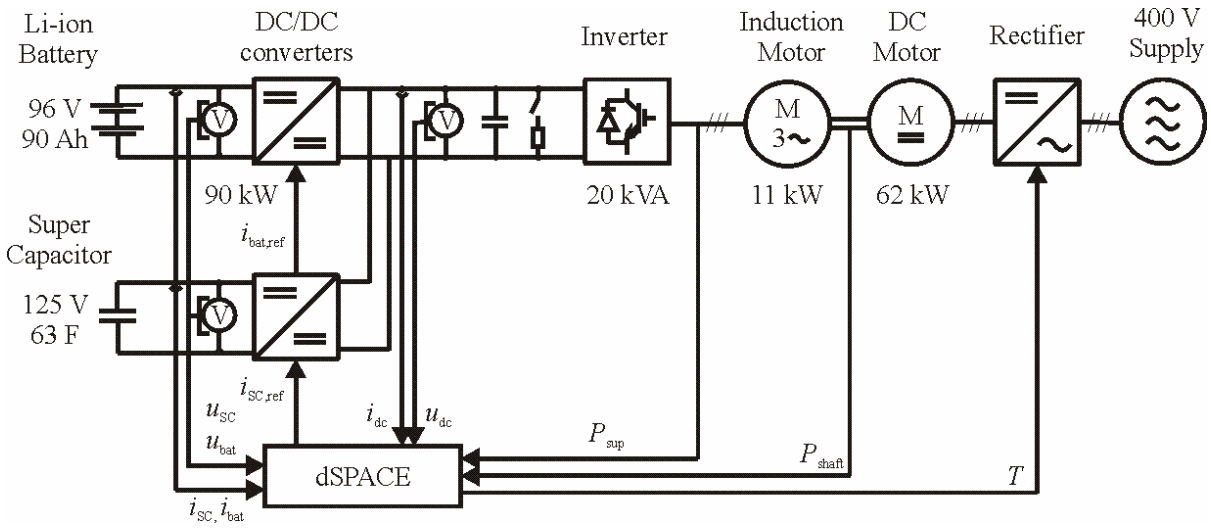
- **Presentation outline**
  - 1. Research targets and methods
  - 2. Modelling, simulation and laboratory prototype of a hybridisized RTG crane
  - 3. Dynamic modelling of supercapacitors and li-ion batteries
  - 4. Calorimetric efficiency measurements of electrical energy storages
  - 5. Dynamic modelling of diesel engines
  - 6. A power compensator for heavily varying loads

FIMA
Forum for Intelligent Machines

1. Research targets and methods

- **Research Targets**
  - Improve energy efficiency and reduce emissions in workmachines by means of hybridization
  - Gain first hand knowledge about supercapacitor and Li-ion battery energy storage capabilities
- **Research Methods**
  - Laboratory testsetup to simulate hybrid workmachine energy flow control
  - Calorimeter for measuring efficiency of supercapacitors and Li-ion batteries
  - Computer simulations of different work machine applications

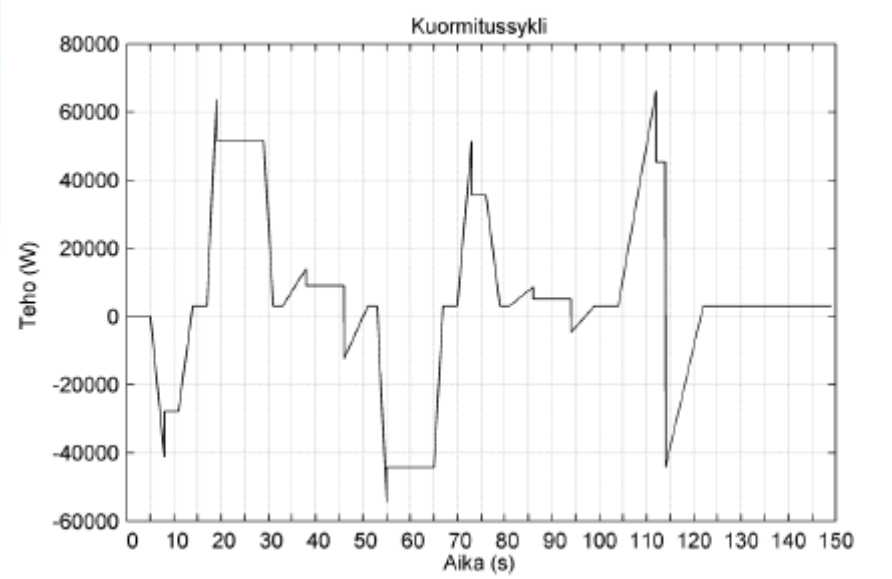




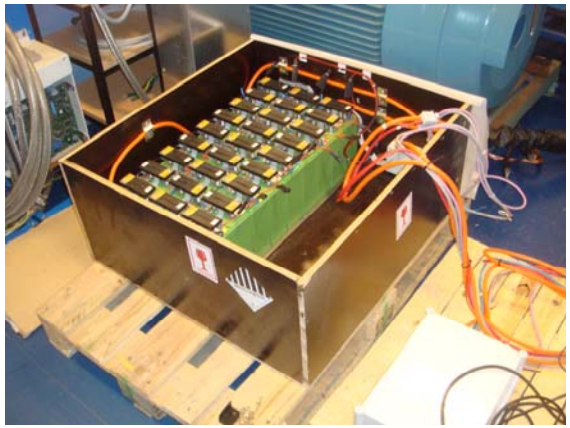
2. Modelling, simulation and laboratory prototype of a hybridisized RTG crane

(Saara Hännikäinen, M.Sc)

- Initially peak power of the diesel engine is 66 kW



- After hybridization diesel could be minimized to ~10kW

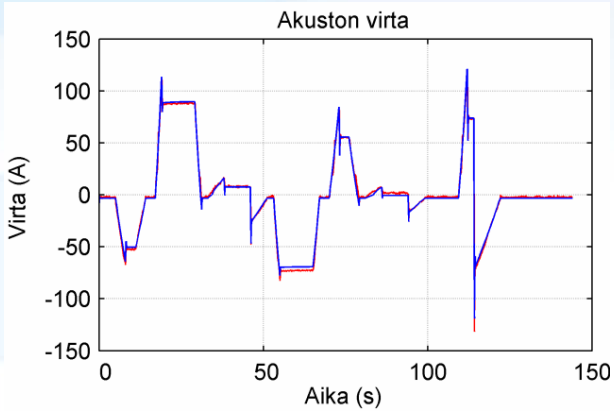


- Energy storage consists of li-ion batteries

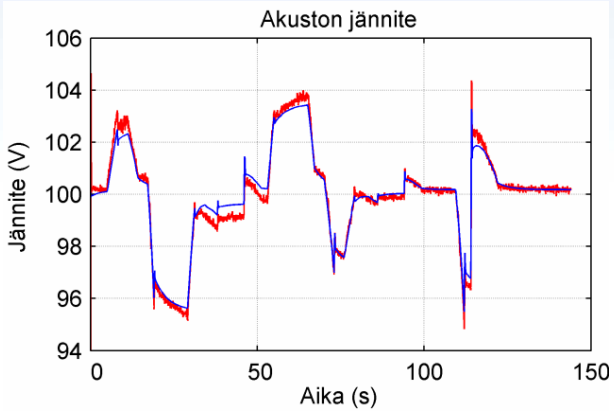
2. Modelling, simulation and laboratory prototype of a hybridisized RTG crane

(Saara Hännikäinen, M.Sc)

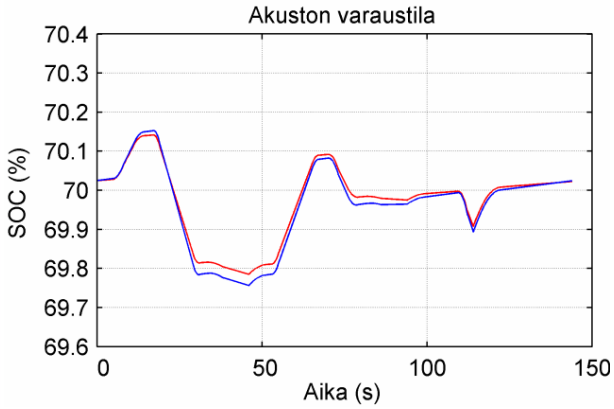
- Simulated and measured battery quantities during typical load pattern:



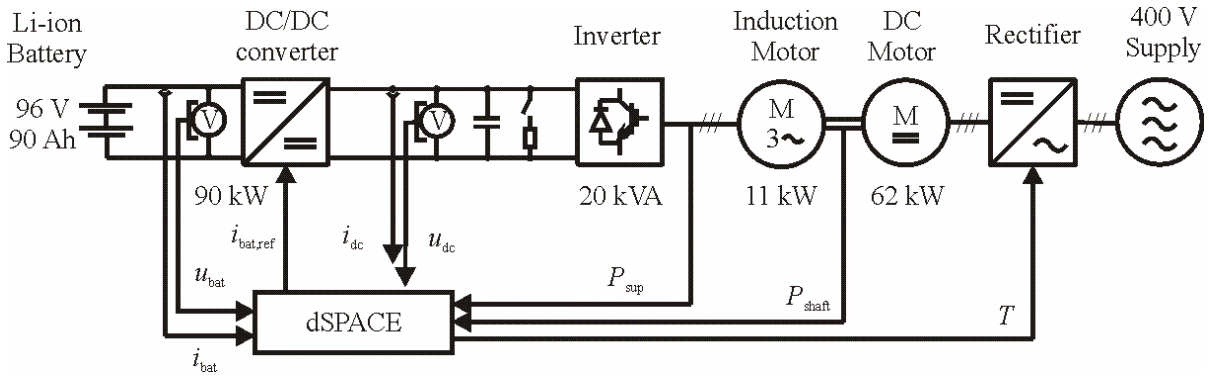
Battery current.



Battery voltage



Battery SOC.



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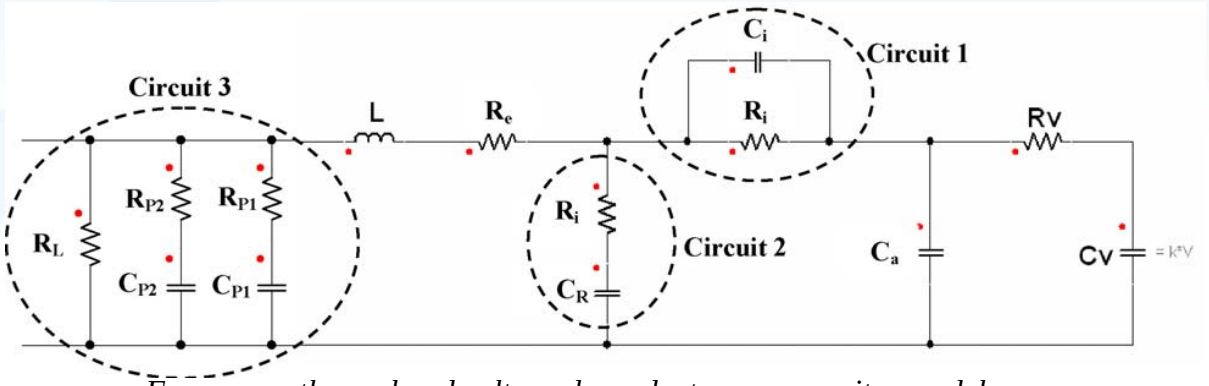
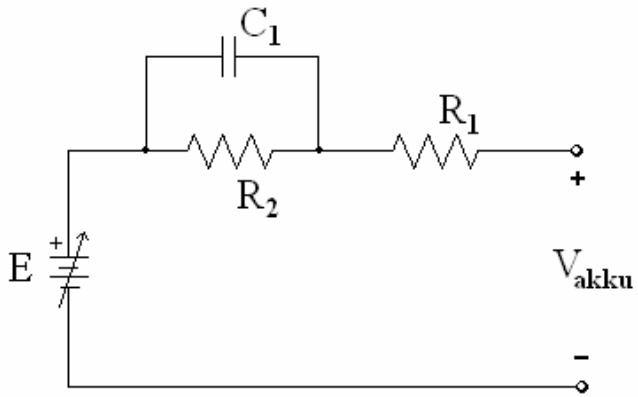
3. Dynamic modelling of supercapacitors and li-ion batteries

(Hannu Haapala, M.Sc)

- Purpose of research was to accurately model the dynamic behaviour and power losses of energy storages



Frequency, thermal and voltage dependent supercapacitor model



Dynamic li-ion battery model

4. Calorimetric efficiency measurements of electrical energy storages

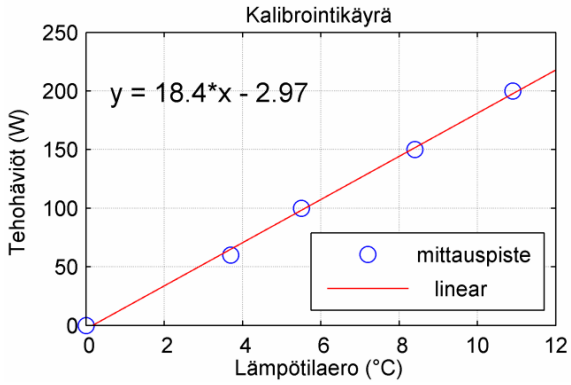
(Hannu Haapala, M.Sc & Tuomas Muhonen, M.Sc)

Supercapacitor power loss, R_{ESR} and efficiency

$i_{SC,rms}$ (A)	f (Hz)	ΔT (°C)	P_{loss} (W)	$R_{ESR,SC}$ (mΩ)	η_{SC} (%)
50	0,2	2,7	55	15,6	97,6
50	1	2,4	49	13,2	97,8
50	5	2,4	49	13,2	97,8
50	10	2,3	48	12,8	97,9
84	0,2	6,5	134	16,7	96,5
84	1	6,3	130	16,1	96,6
84	5	6,1	126	15,6	96,7
84	10	5,6	116	14,2	97,0

Li-ion battery power loss, R_{ESR} and efficiency

$i_{es,rms}$ (A)	f (Hz)	ΔT (°C)	P_{loss} (W)	$R_{ESR,BAT}$ (mΩ)	η_{BAT} (%)
32	0,01	4,1	73	38,1	94,9
32	0,1	4,0	71	36,1	95,1
32	0,5	4,0	71	36,1	95,1
32	1	3,9	69	34,2	95,2
32	5	3,8	67	32,2	95,4
32	10	3,7	65	30,3	95,5
64	0,1	7,6	137	25	95,3
64	10	7,4	133	24,2	95,4

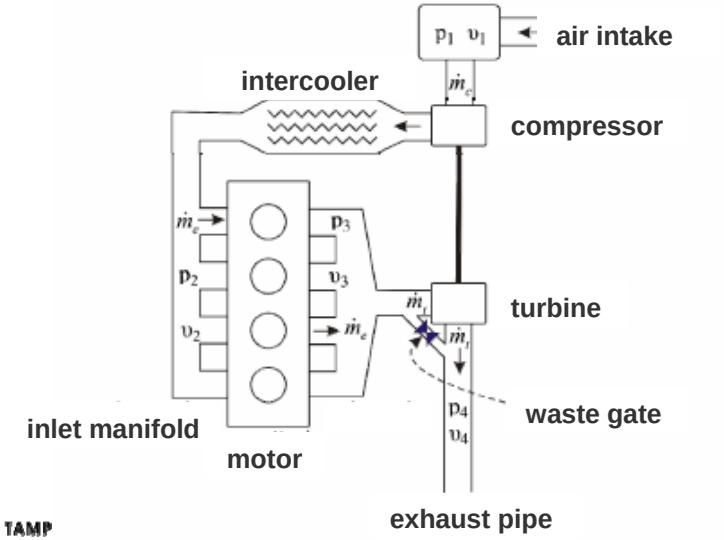


Calorimeter calibration curve

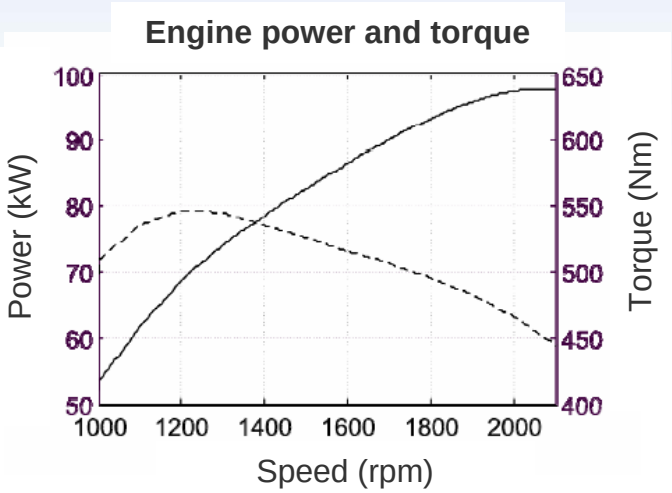
5. Dynamic modelling of diesel engines

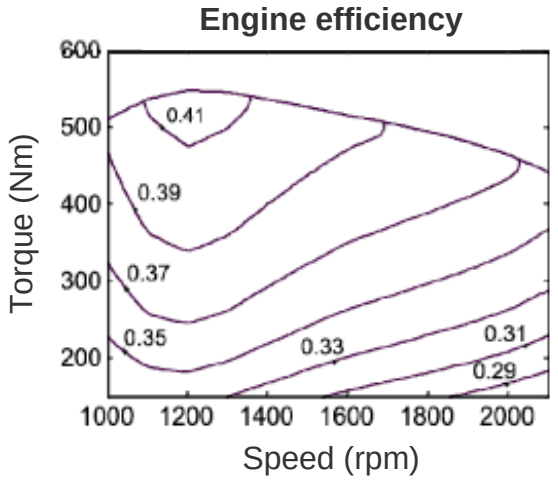
(Ilari Äijälä, M.Sc)

- Purpose of research was to develop a dynamic diesel engine model for use in system level models of hybrid workmachines
  - Engine specs:
    - Turbocharged 4-cylinder Sisu Diesel
    - Stroke capacity 4,9l
    - Nominal power 96kW
    - Nominal speed 2000rpm
    - Maximum torque 540Nm @ 1200rpm



Components of diesel engine model

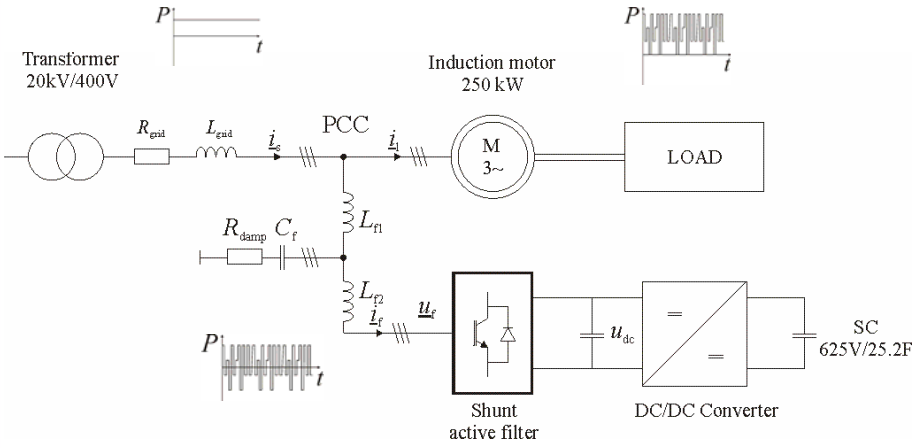


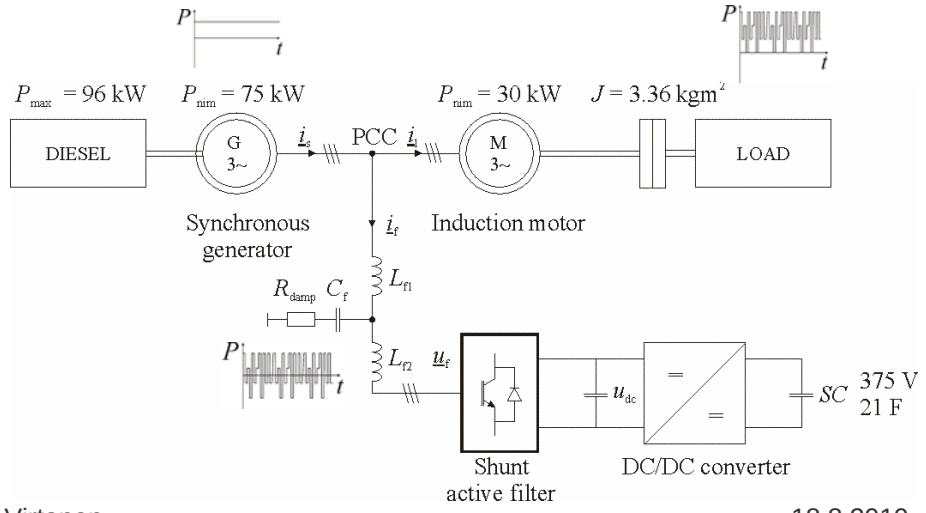


6. A power compensator for heavily varying loads

(Antti Virtanen, M.Sc)

- Purpose of research is to lighten stress of supply within heavily varying loads
  - Active power at PCC becomes levelled
  - Reactive power at PCC is compensated to zero
- Energy savings are possible when
  - The utility grid is very weak
  - The diesel generator speed and torque are levelled and the diesel efficiency is optimized



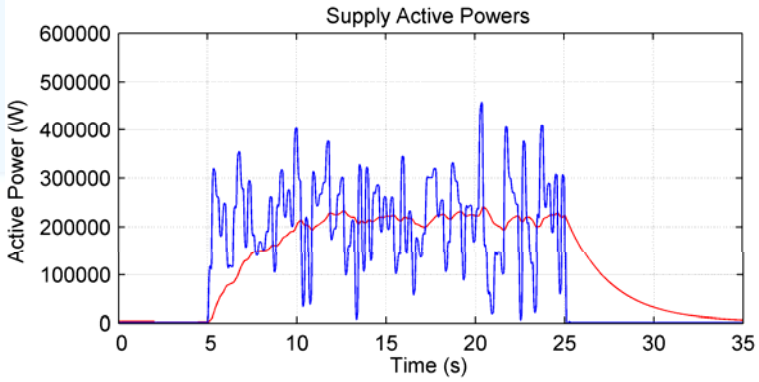


6. A power compensator for heavily varying loads

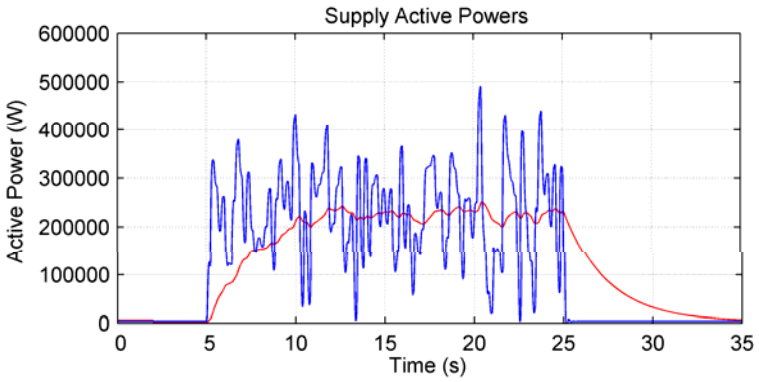
(Antti Virtanen, M.Sc)

- **Simulation results for of directly grid connected stone crusher system**
  - Strong grid (500 kVA transformer + 200m of AMMK 3*2*300 cable)
  - Medium grid (500 kVA transformer + 500m of AMMK 3*2*300 cable)
  - Weak grid (500 kVA transformer + 1000m of AMMK 3*2*300 cable)

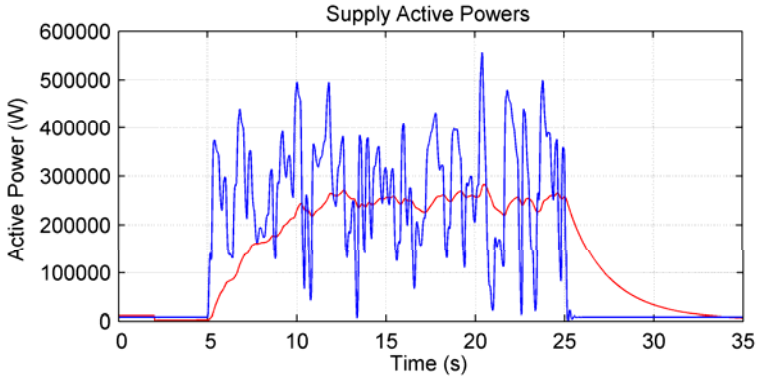
Strong grid



Medium grid



Weak grid



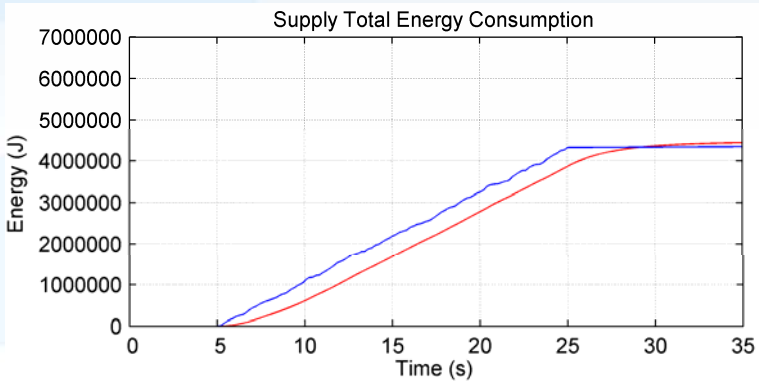
Compensated

Noncompensated

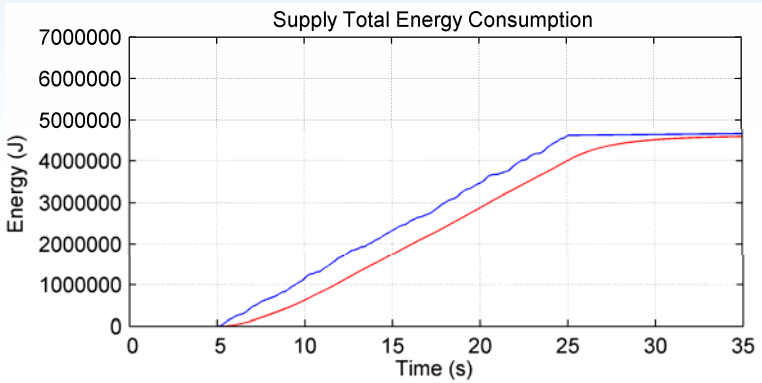
6. A power compensator for heavily varying loads

(Antti Virtanen, M.Sc)

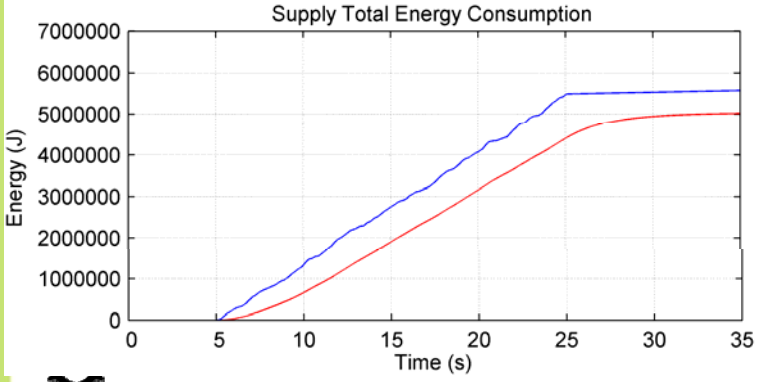
Strong grid



Medium grid



Weak grid

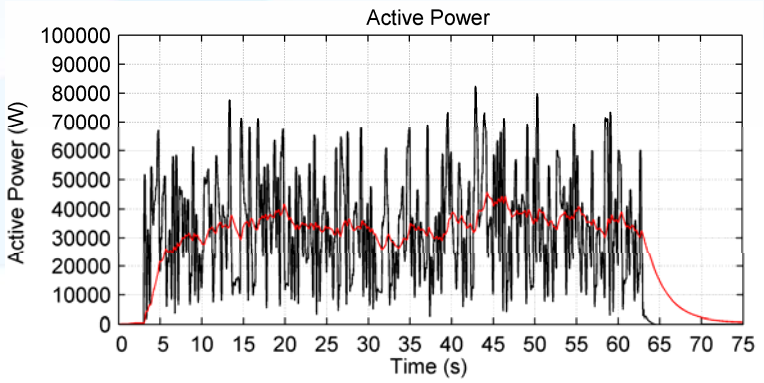


Total energy consumption (MJ / %)		
Case	Compensated	Non compensated
Strong grid	**4,44 MJ / 102,3%**	**4,34 MJ / 100%**
Medium grid	**4,59 MJ / 98,3%**	**4,67 MJ / 100%**
Weak grid	**5,02 MJ / 89,9%**	**5,58 MJ / 100%**

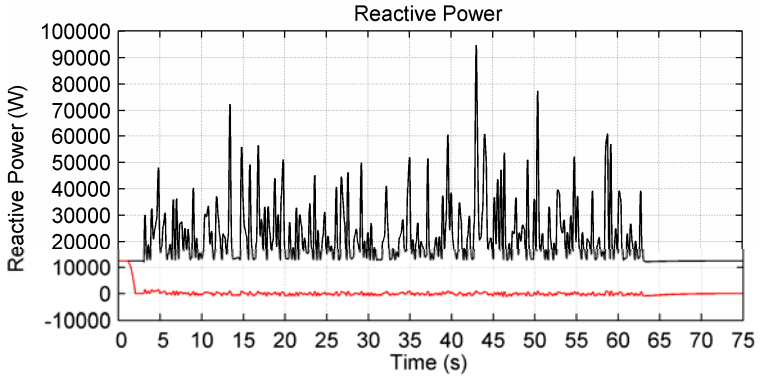
6. A power compensator for heavily varying loads

(Antti Virtanen, M.Sc)

- **Simulation results of diesel generator fed stone crusher system**
  - Load active power vs.
    generator active power



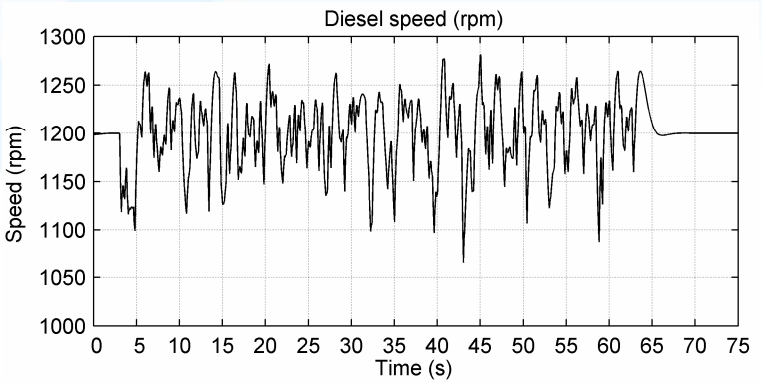
  - Load reactive power vs.
    generator reactive power

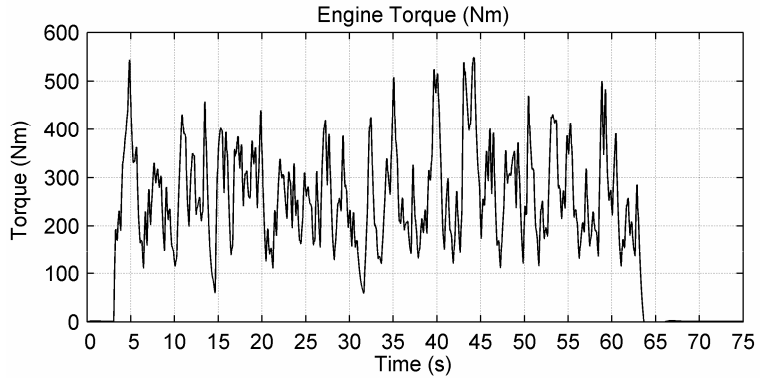


6. A power compensator for heavily varying loads

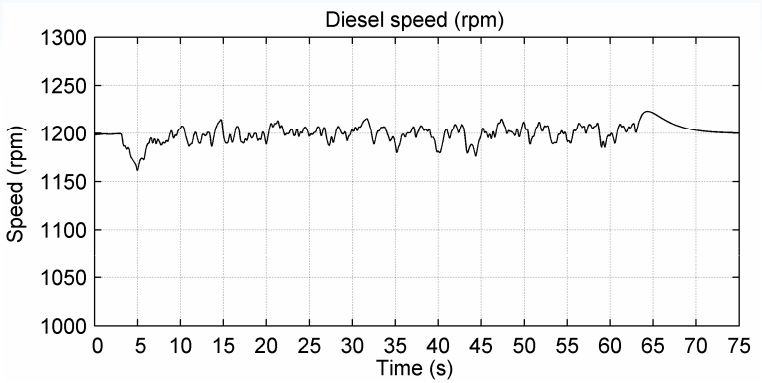
(Antti Virtanen, M.Sc)

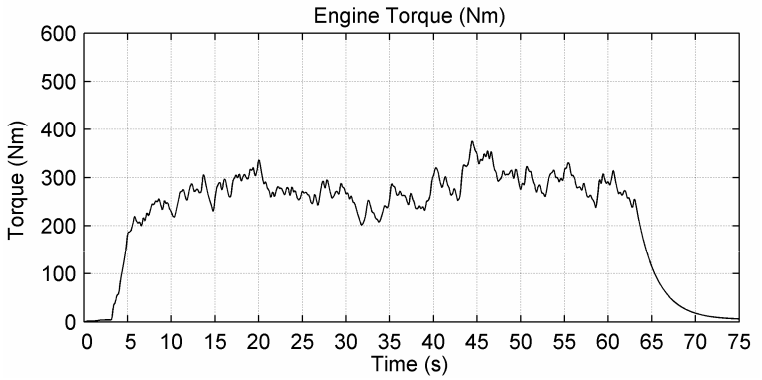
- Noncompensated diesel speed and torque





- Compensated diesel speed and torque

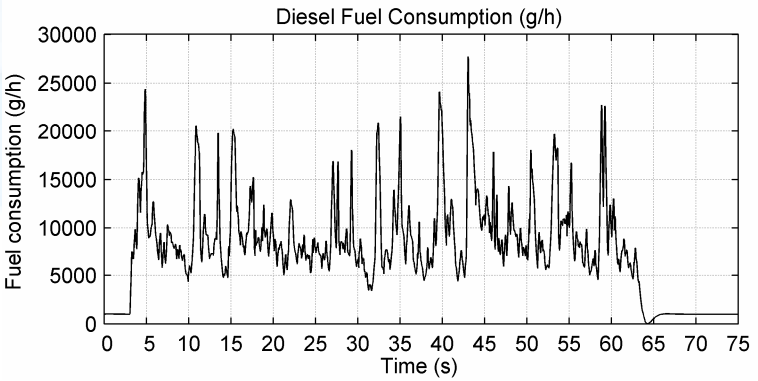




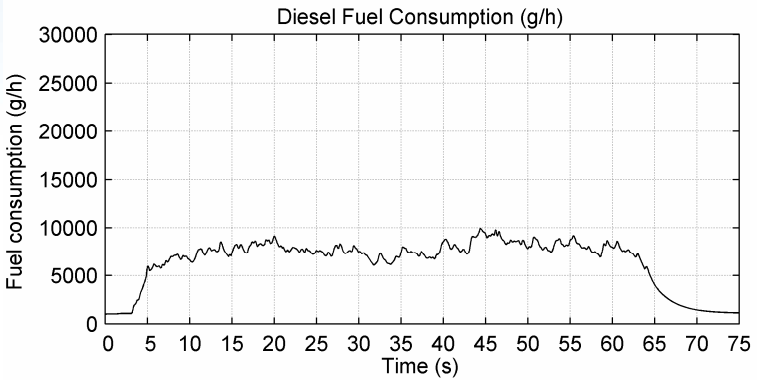
6. A power compensator for heavily varying loads

(Antti Virtanen, M.Sc)

- Noncompensated diesel fuel consumption



- Compensated diesel fuel consumption



- Noncompensated average fuel consumption 9,19 l/h
- Compensated average fuel consumption 7,67 l/h
- Compensated system consumes 16,5% less fuel than noncompensated

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Heikki Tuusa*, Antti Virtanen*, Juha Jokipii*, Tuomas Muhonen, Saara Hännikäinen, Ilari Äijälä, Hannu Haapala, Mikko Kouvo

- **M.Sc. Theses**
  - Kouvo, M., 'Sähköinen Energian Talteenotto Hybridivoimansiirrossa (Electrical Energy Recovery in Hybrid Powertrain)', M.Sc. Thesis, June 2008, 86 p.
  - Muhonen, T., 'Energiavarastojen Tehon Ohjaus Hybridivoimansiirrossa (Energy Storage Power Management in Hybrid Powertrain)', M.Sc. Thesis, May 2009, 81 p.
  - Äijälä, I., 'Jaetuntehon Hybridijärjestelmän Mallintaminen (Modelling of Power Split Hybrid System)', M.Sc. Thesis, May 2009, 98 p.
  - Haapala, H., 'Sähköisten Energiavarastojen Mallintaminen (Modelling of Electrical Energy Storages)', M.Sc. Thesis, February 2010, 92p.
  - Hännikäinen, S., 'Akuston Liittäminen Hybridijärjestelmään (Connecting Battery to a Hybrid System)', M.Sc. Thesis, June 2010, 71 p.

- **Conference Proceedings**
  - Virtanen, A., Tuusa, H., 'Power Compensator for High Power Fluctuating Loads with a Supercapacitor Bank Energy Storage', in *Proc. IEEE PECon'08,* December 2008, Johor Bahru, Malaysia, pp. 977-982.

* Active members of research group