Control System for Small Induction Generator Based Wind Turbines

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November 13, 2007

Layout of presentation

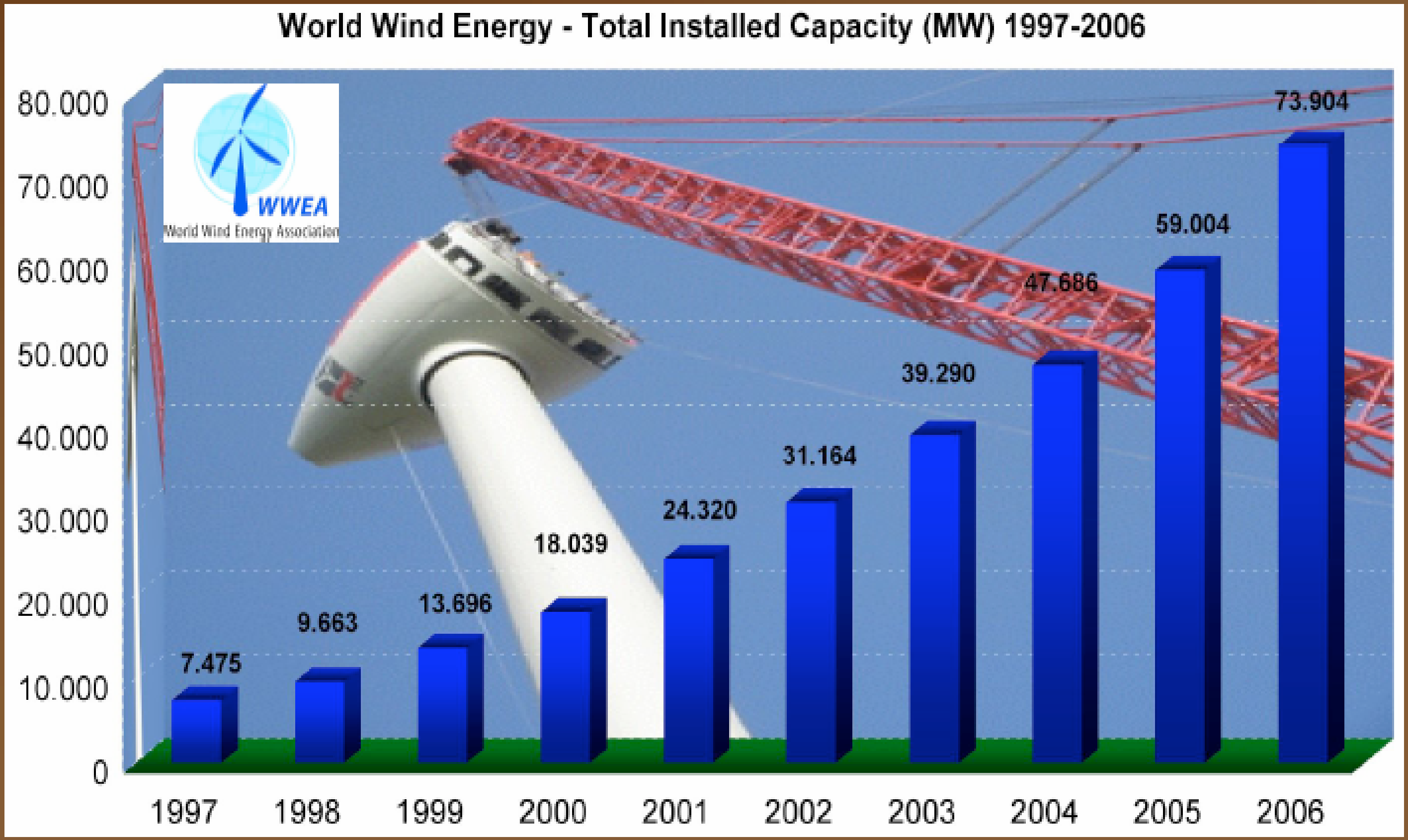
- Backgrounds
- Motivation
- Wind Turbine Simulator
- Control System Design and Operation
- Soft-starter Design
- System Instrumentations
- Experimental Test Results
- Conclusions

Backgrounds

- Wind energy is the leading and fastest growing renewable energy in the world.
  - ✓ Clean, no air pollution and abundant in nature
  - ✓ Completely renewable and reliable
  - ✓ Economical to produce large scale electricity generation
  - ✓ Remote electricity generation
  - ✓ Green engineering prospects
  - ✓ Increasing cost of fossil fuel

Backgrounds cont.

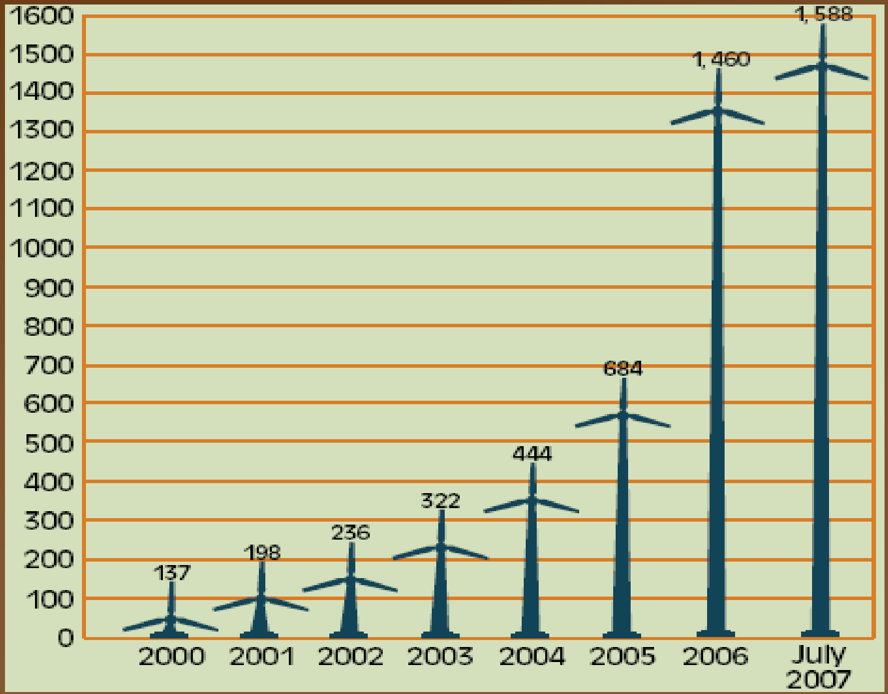
- Global wind power scenario



Source: www.wwindea.org/home/images/stories/pds

Backgrounds cont.

❖ Wind power scenario in Canada



Canada's Wind Tracker

Province	Installed	Proposed*
BC	0	325.2 MW
Alberta	384.97 MW	134 MW
Saskatchewan	171.18 MW	24.75 MW
Manitoba	103.95 MW	0 MW
Ontario	415.31 MW	994.85 MW
Quebec	321.75 MW	1105.5 MW
Newfoundland	390 kW	51 MW
PEI	43.56 MW	28.8 MW
Nova Scotia	49.26 MW	23.2 MW
New Brunswick	0	96 MW
Yukon	810 kW	0
NWT	0	0
Nunavut	0	0
Total	**1491.18 MW**	**2783.3 MW**

* Under construction or awarded a PPA

- ✓ Average annual growth rate(2000-2006): 51%
- ✓ Canada's installed capacity grew by 113% in 2006

Source: Canadian Wind Energy Association

Backgrounds cont.

❖ Top listed countries in wind power generation

Ranking total 2006	Country	Additional capacity 2006	Growth rate 2006	Total capacity end 2006	Total capacity end 2005	Ranking total 2005
		[MW]	%	[MW]	[MW]	
1	Germany	2.194	11,9	20.622	18.428	1
2	Spain	1.587	15,8	11.615	10.028	2
3	USA	2.454	26,8	11.603	9.149	3
4	India	1.840	41,5	6.270	4.430	4
5	Denmark	8	0,3	3.136	3.128	5
6	China	1.145	90,9	2.405	1.260	8
7	Italy	405	23,6	2.123	1.718	6
8	United Kingdom	610	45,1	1.963	1.353	7
9	Portugal	628	61,4	1.650	1.022	11
10	France	810	106,9	1.567	757	13
11	Netherlands	336	27,5	1.560	1.224	9
12	Canada	768	112,4	1.451	683	14
13	Japan	354	34,0	1.394	1.040	10
14	Austria	146	17,8	965	819	12
15	Australia	238	41,1	817	579	15
16	Greece	183	31,9	756	573	16
17	Ireland	147	29,6	643	496	18
18	Sweden	54	10,6	564	510	17
19	Norway	55	20,4	325	270	19
20	Brazil	208	729,6	237	29	34
	Rest	730	48,4	2.238	1.508	
TOTAL		**14.900**	**25,3**	**73.904**	**59.004**	

Source: www.wwindea.org/home/images/stories/pds

Backgrounds cont.

- Wind turbine (WT) is the one and only candidate which can harness the available kinetic energy of the wind into mechanical power.

- Wind Energy Conversion System (WECS) converts the mechanical power from the wind turbine output into electricity and supplies to the load (either grid connected or isolated).

  - ✓ Small WECS: 1-10kW
  - ✓ Intermediate WECS: 10-250kW
  - ✓ Large WECS: 660kW-2MW plus

Backgrounds cont.

ENERTECH Corporation — About 25 years back

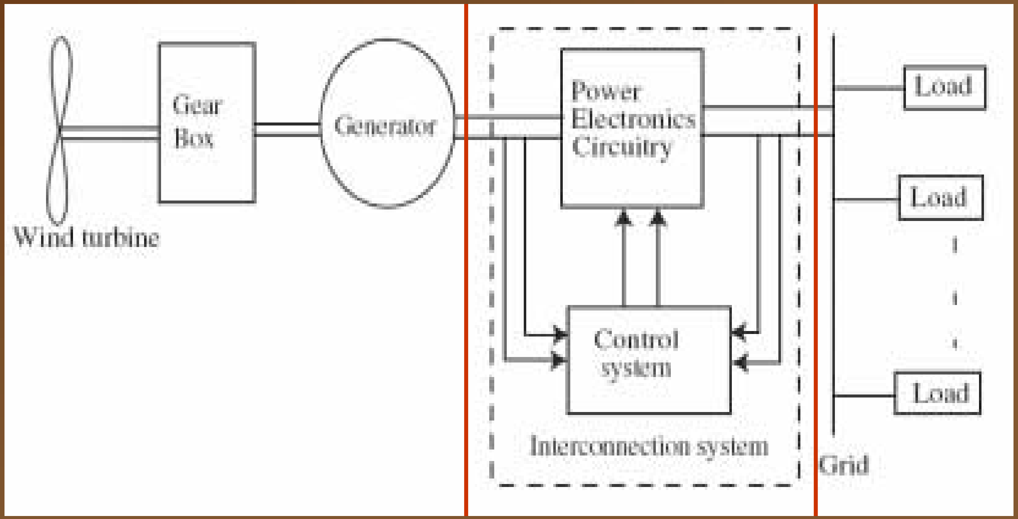
Gazelle Wind Turbine Ltd. — In 2004

aeroSmart5 — Early 2004

ENDURANCE — Expected in 2007

Motivation

- Typical Grid Connected WECS



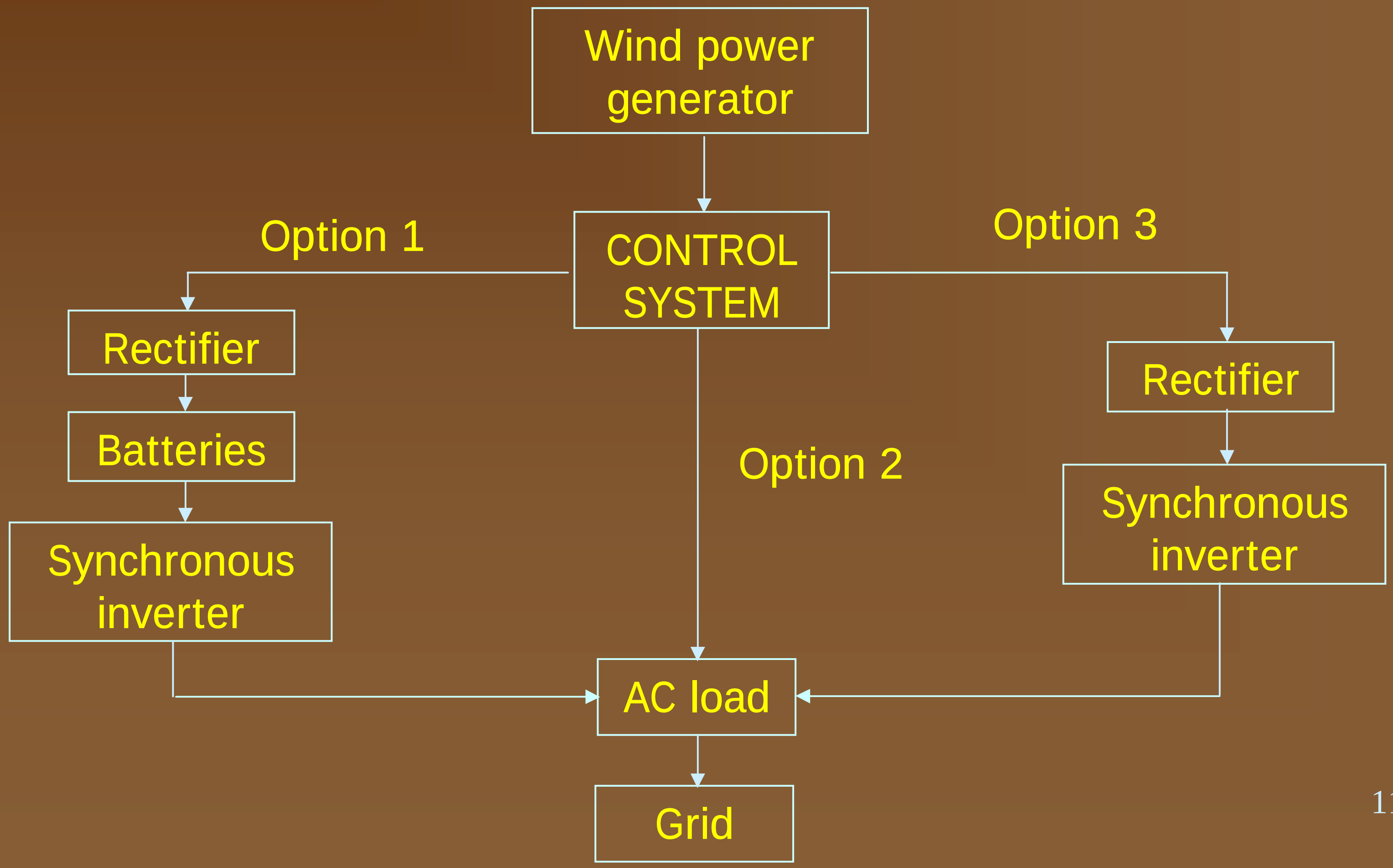
- Why grid connected Small WECS is?
  - ✓ Grid connected system reduces the system cost
  - ✓ Reduces the dependence on the grid supply
  - ✓ Energy exchange between consumer and electrical grid (Net-metering laws)
  - ✓ Ease of installation and required less spaces

Motivation cont.

- Challenges
  - ✓ Selection of the grid connection topology
  - ✓ Design of suitable controller and associated instrumentations for the operation of the WECS
  - ✓ Limit the initial surge in current during the connection process
  - ✓ Grid failure for a grid connected system
  - ✓ Grid connection standard
  - ✓ Develop a test platform for the designed controller in laboratory

Motivation cont.

- Connection Topologies



Motivation cont.

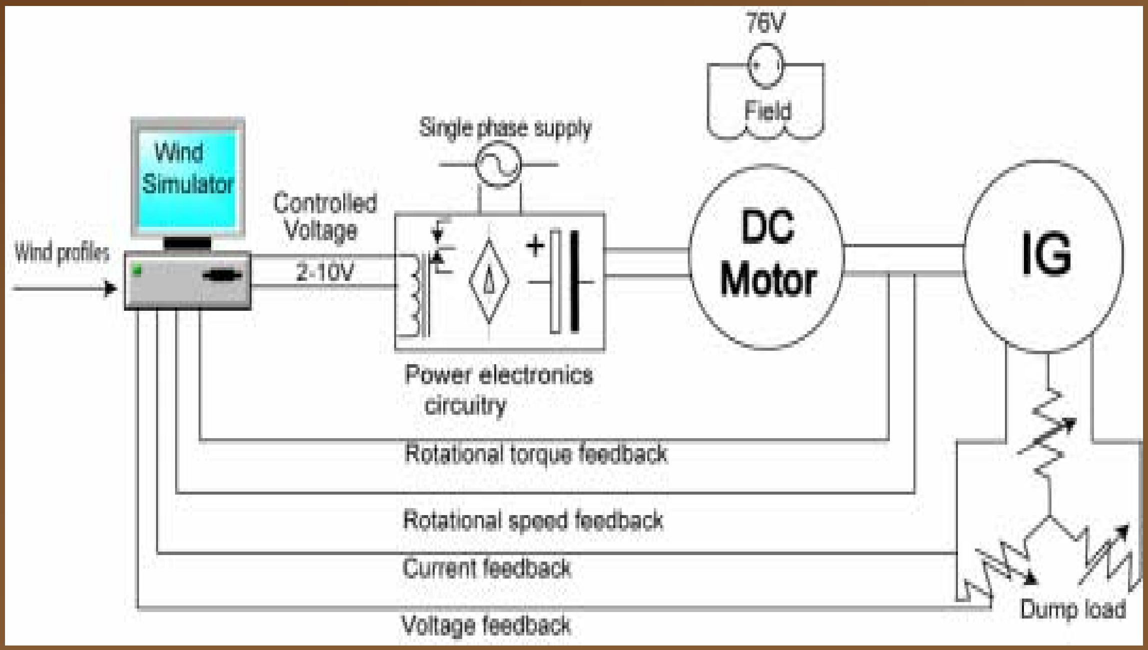
- Objectives
  - To select a simple and efficient technique for grid connection
  - To design and test a low cost control system for grid interconnection considering the grid connection standard
  - To develop instrumentations for measuring the system parameters
  - To design a soft-starter to limit the initial surge in current during connection process
  - To detect the grid failure and define the status of the wind turbine operation
  - To develop a wind turbine simulator as a test platform of the designed controller in laboratory

Wind Turbine Simulator (WTS)

- What is WTS?
  - ✓ WTS is the prototype of a wind turbine in laboratory environment.
- Why WTS is?
  - ✓ To understand the behavior of the real wind turbine in a laboratory environment.
  - ✓ To design, test and improve the control performances of a wind energy conversion systems.
- Choice of DC motor
  - ✓ Precise torque and speed control properties without sophisticated power electronics
  - ✓ Cost of the controlling equipment is lower than in the case of AC drives

Wind Turbine Simulator cont.

- Structure of WTS



Wind Turbine Simulator cont.

- Wind Turbine Model

Mechanical Power of the Wind Turbine, $P_{mech} = 0.5\rho A u_w^3 C_p(\lambda)$

Tip speed ratio can be expressed as, $\lambda = \frac{\omega_m R_t}{u_w}$

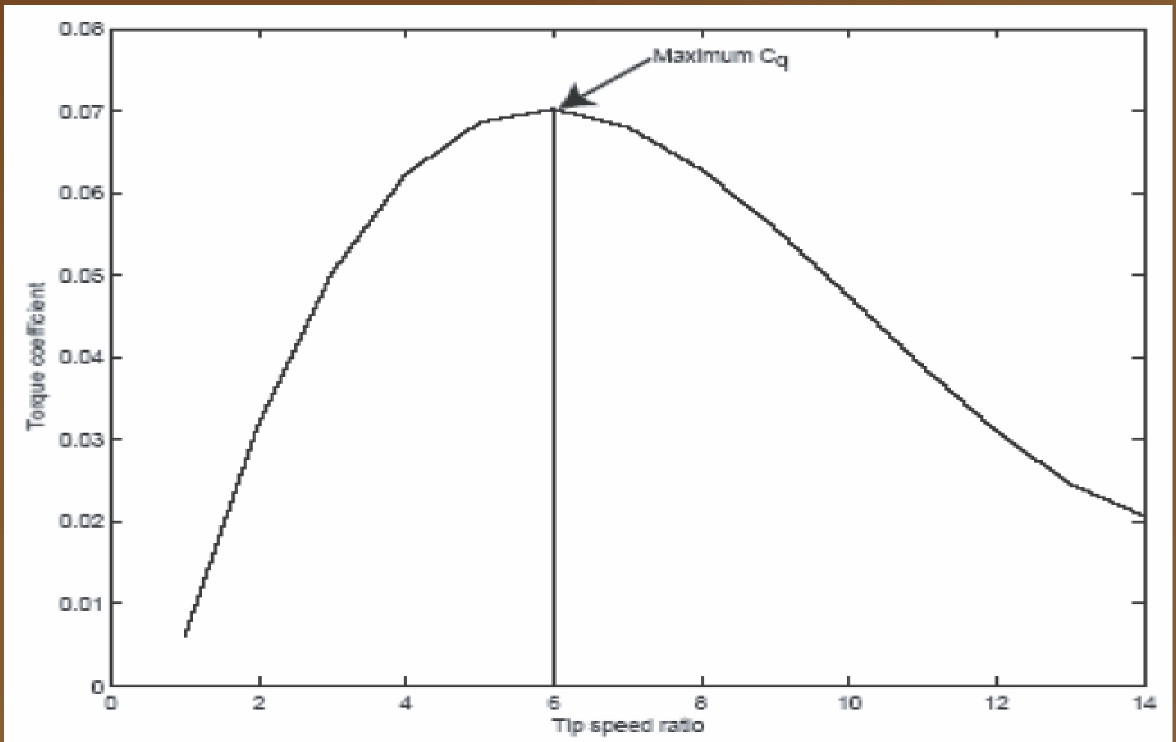
Torque of the wind turbine, $T_{av} = 0.5\rho A u_w^2 C_q(\lambda) R_t$ ◀ Reference torque

C_q is the torque coefficient which is equivalent to $\frac{C_p(\lambda)}{\lambda}$

Wind Turbine Simulator cont.

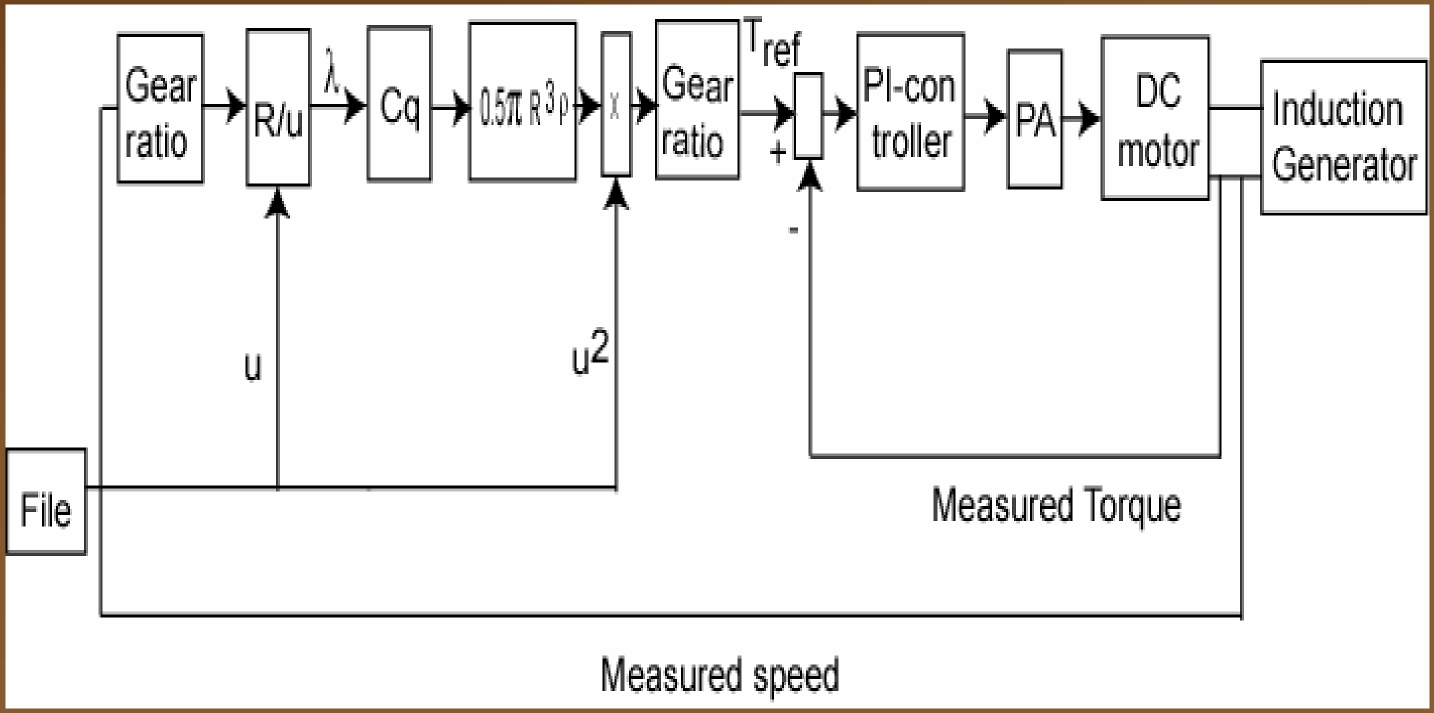
Relation between C_q and λ can be expressed as

$$C_q = -0.02812 + 0.038576\lambda - 0.0045912\lambda^2 + 0.001489\lambda^3$$



Wind Turbine Simulator cont.

- Control Block Diagram of WTS



Wind Turbine Simulator cont.

- Controller for WTS

A recursive PI controller is designed using ZN tuning methods.

- ✓ Ability to make the steady state error zero.
- ✓ Easy to tune and implement.

Recursive control algorithm is chosen

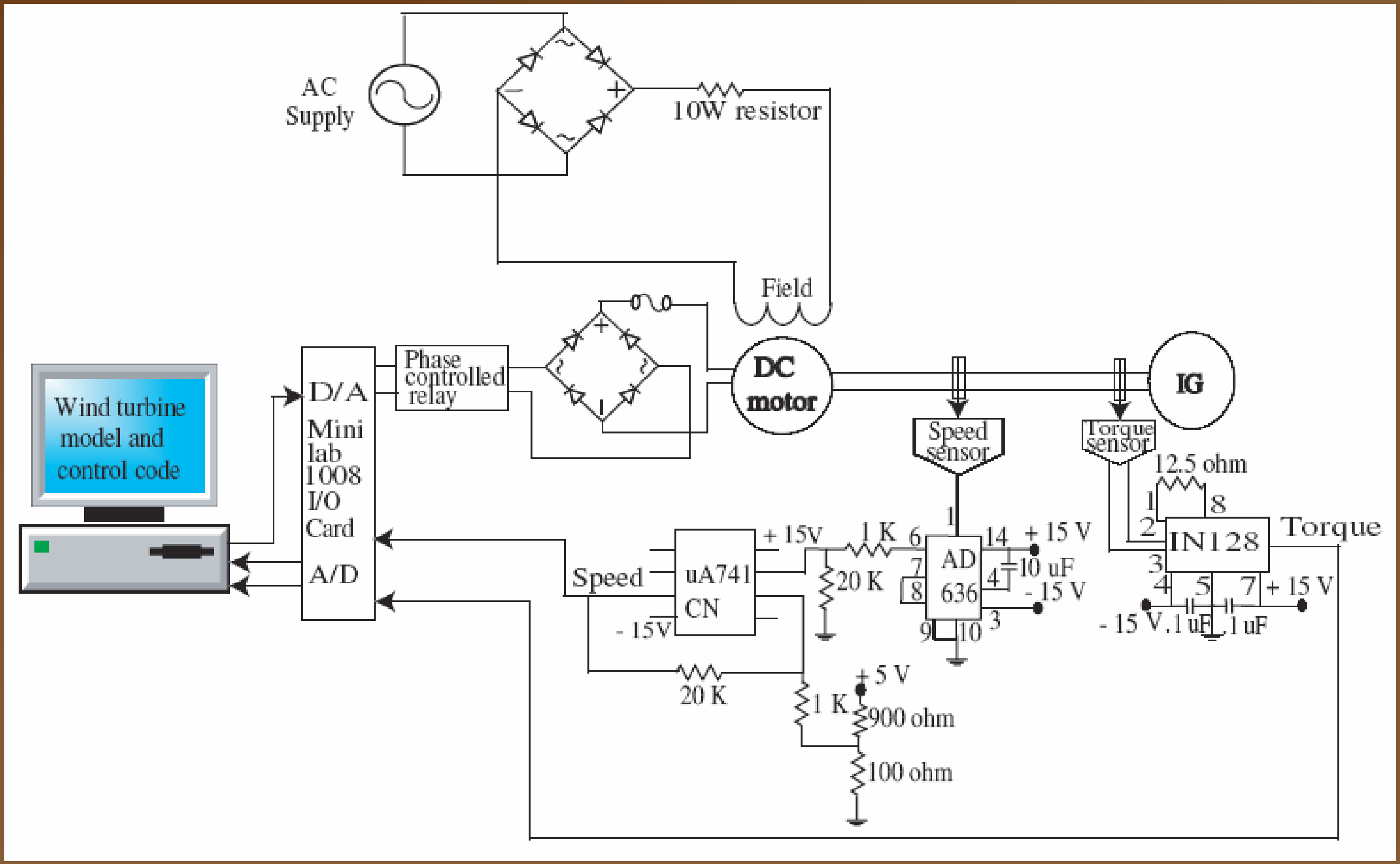
- ✓ Suitable for computer aided design
- ✓ Previous control value can be set to any reasonable arbitrary value which makes it easier to tune
- ✓ Anti integral wind up property

Best controller parameters have found

$$k_p = 0.077,\ t_i = 8.6$$

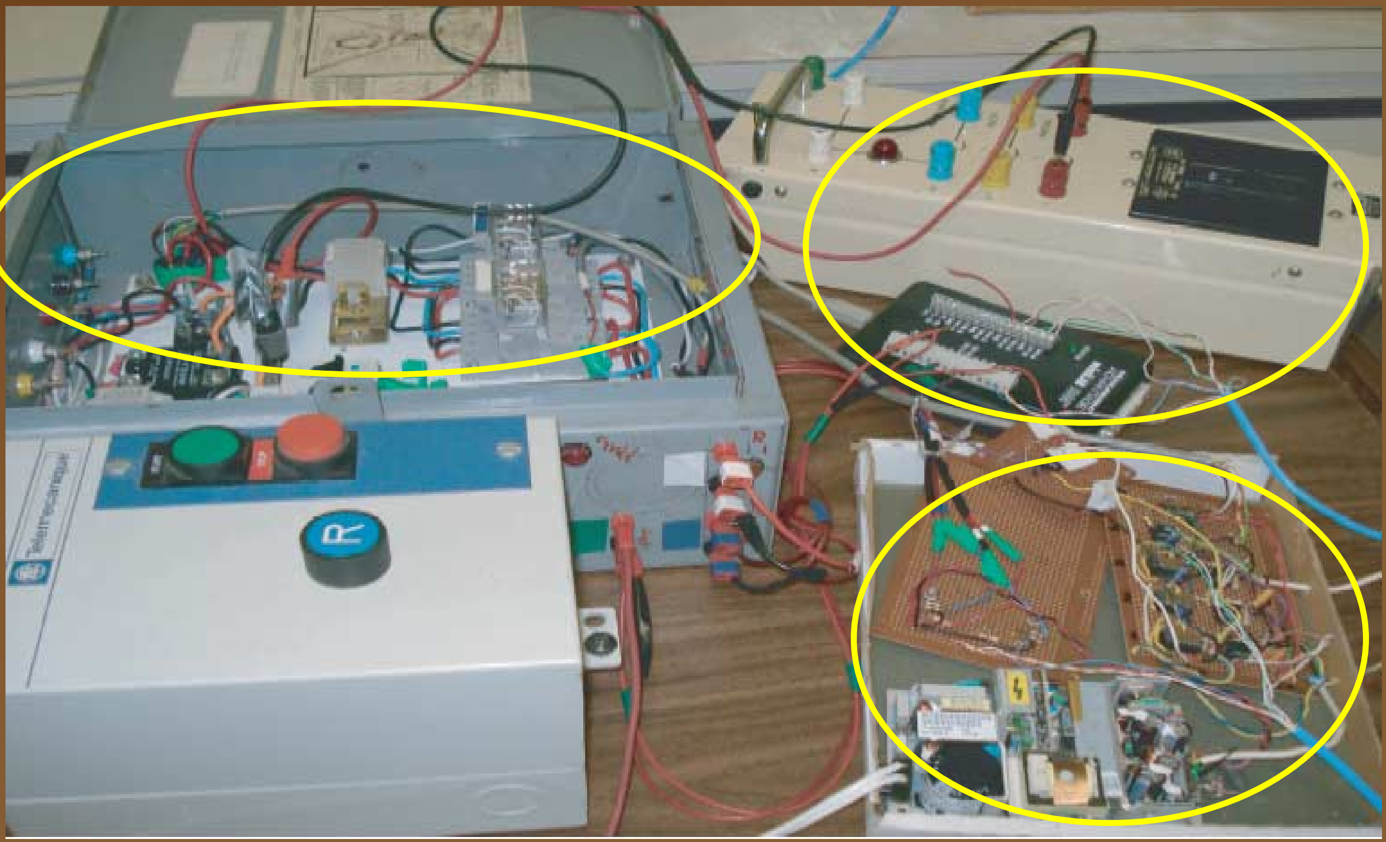
Wind Turbine Simulator cont.

- Instrumentation for WTS



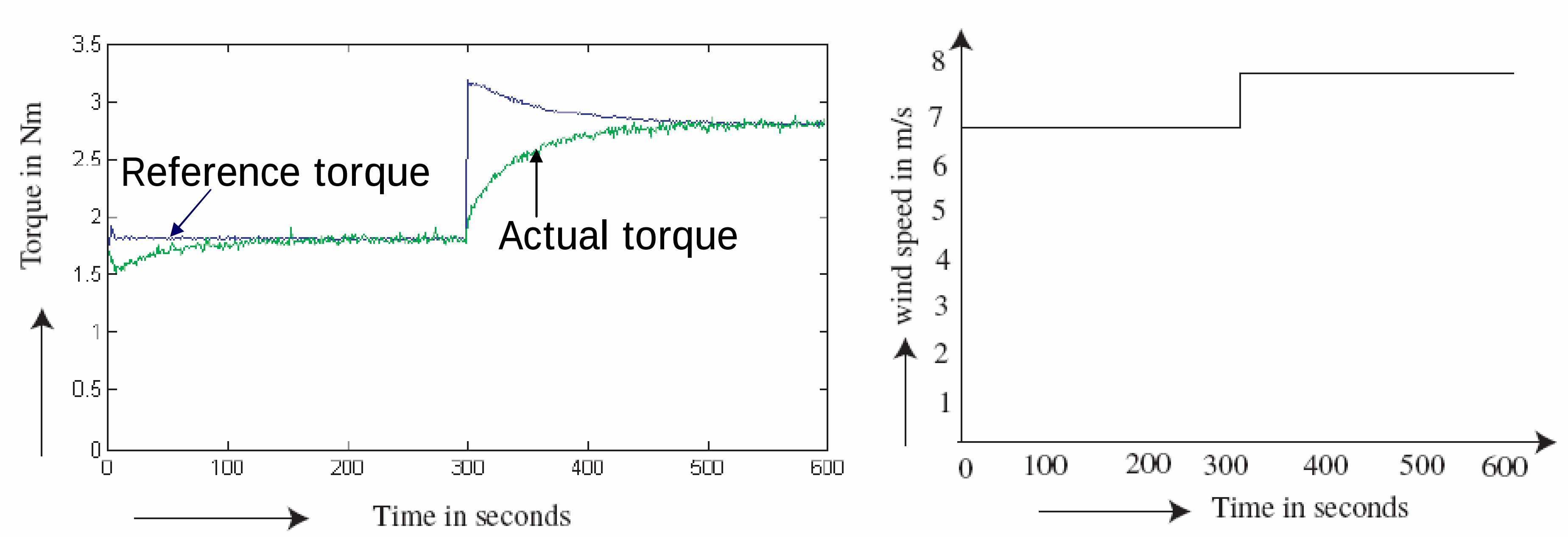
Wind Turbine Simulator cont.

- Photograph of the instrumentation at laboratory



Wind Turbine Simulator cont.

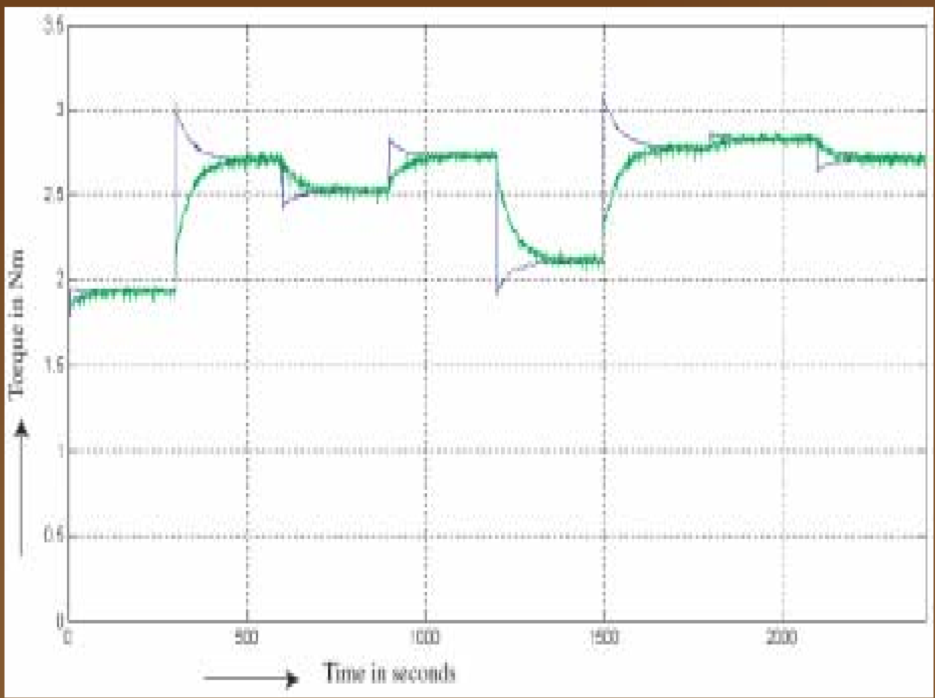
- Test Results of WTS

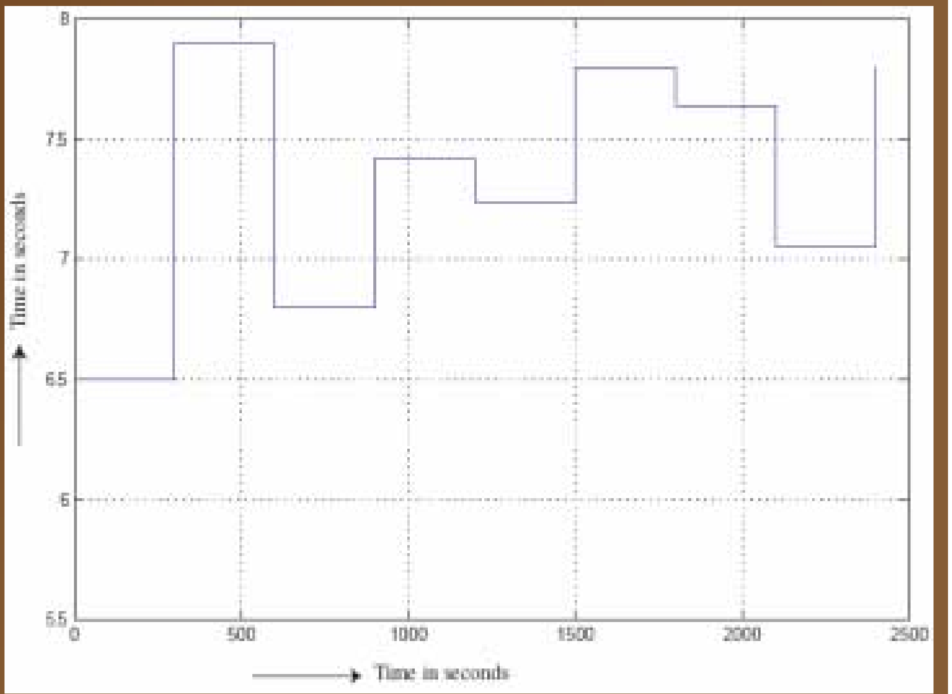


- ✓ Constant wind speed 7 m/sec
- ✓ Step change in wind speed from 7m/sec to 8m/sec

Wind Turbine Simulator cont.

- Test Results of WTS





✓ Variation in wind speed in between 6.5m/sec to 7.9 m/sec

Wind Turbine Simulator cont.

- Conclusions

  - ✓ A DC motor is simulated which follows the torque produced by the wind turbine rotor.
  - ✓ A recursive PI controller is designed that makes sure DC motor is operating as wind turbine rotor.
  - ✓ Performance of the WTS was expected and is used for the proposed system controller test.

Control system design and operation

- Control for a wind energy conversion system
  - ✓ Aerodynamic control
  - ✓ Machine control
  - ✓ System controller

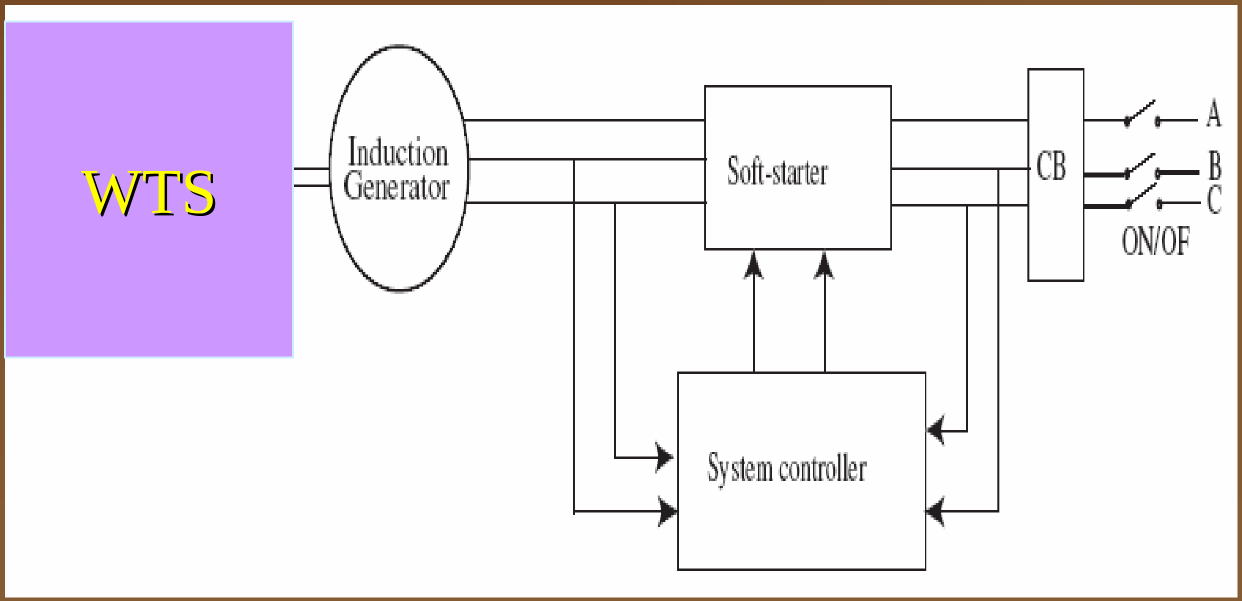
- Choice of System Controller
  - ✓ Personal computer (PC)
  - ✓ Programmable logic controller (PLC)
  - ✓ Single board computer
  - ✓ Peripheral interfacing controller (PIC)

Control system design and operation cont.

- Features of the system controller
  - ✓ No wind speed sensor
  - ✓ Assist to connect/disconnect the system with grid and also to maintain the grid connection
  - ✓ Grid connection through soft-starter
  - ✓ Monitoring and measurement of system parameters
  - ✓ Disconnect the system from the grid within a very short period
  - ✓ Detect the grid failure and switch over the system operation in off-grid mode
  - ✓ Islanding protection
  - ✓ Identify the grid recovery and back the system connected to the grid

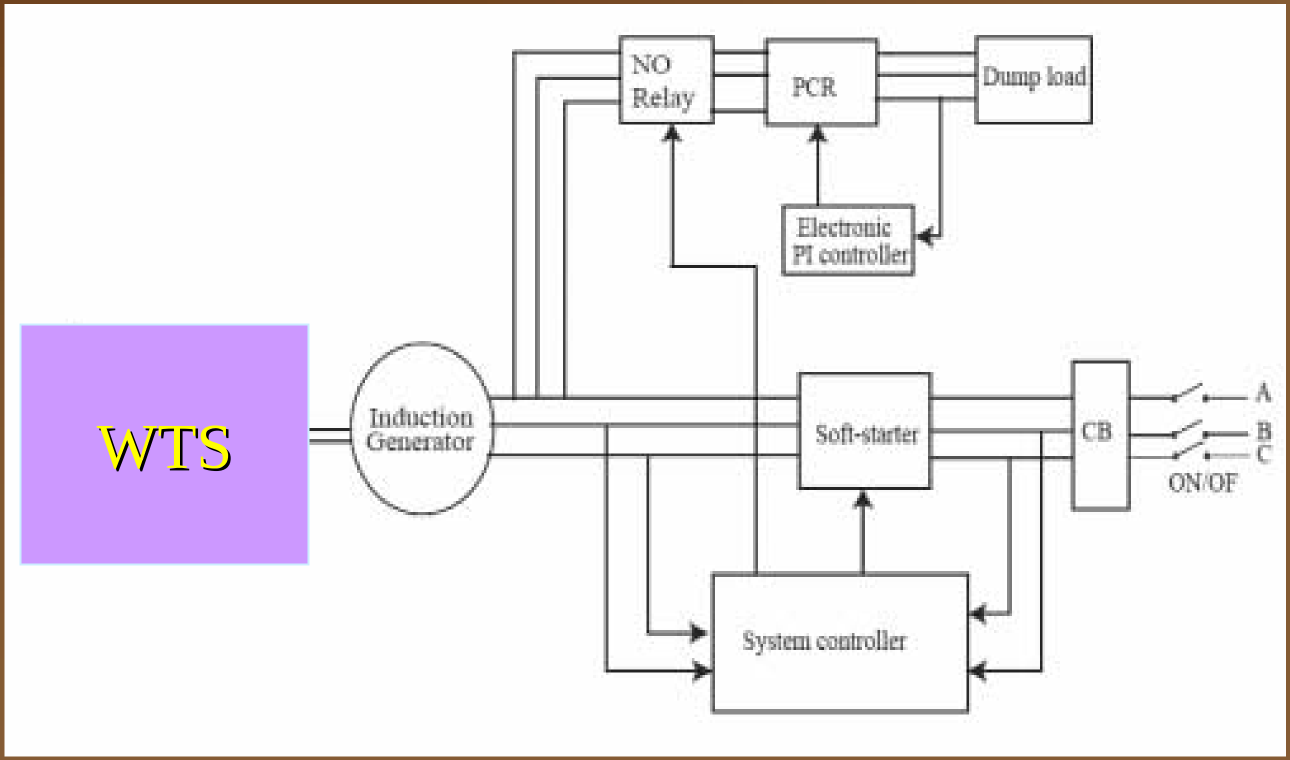
Control system design and operation cont.

- Control Modes of the System Controller
  - ✓ Grid connected mode



Control system design and operation cont.

- ✓ Off-grid mode

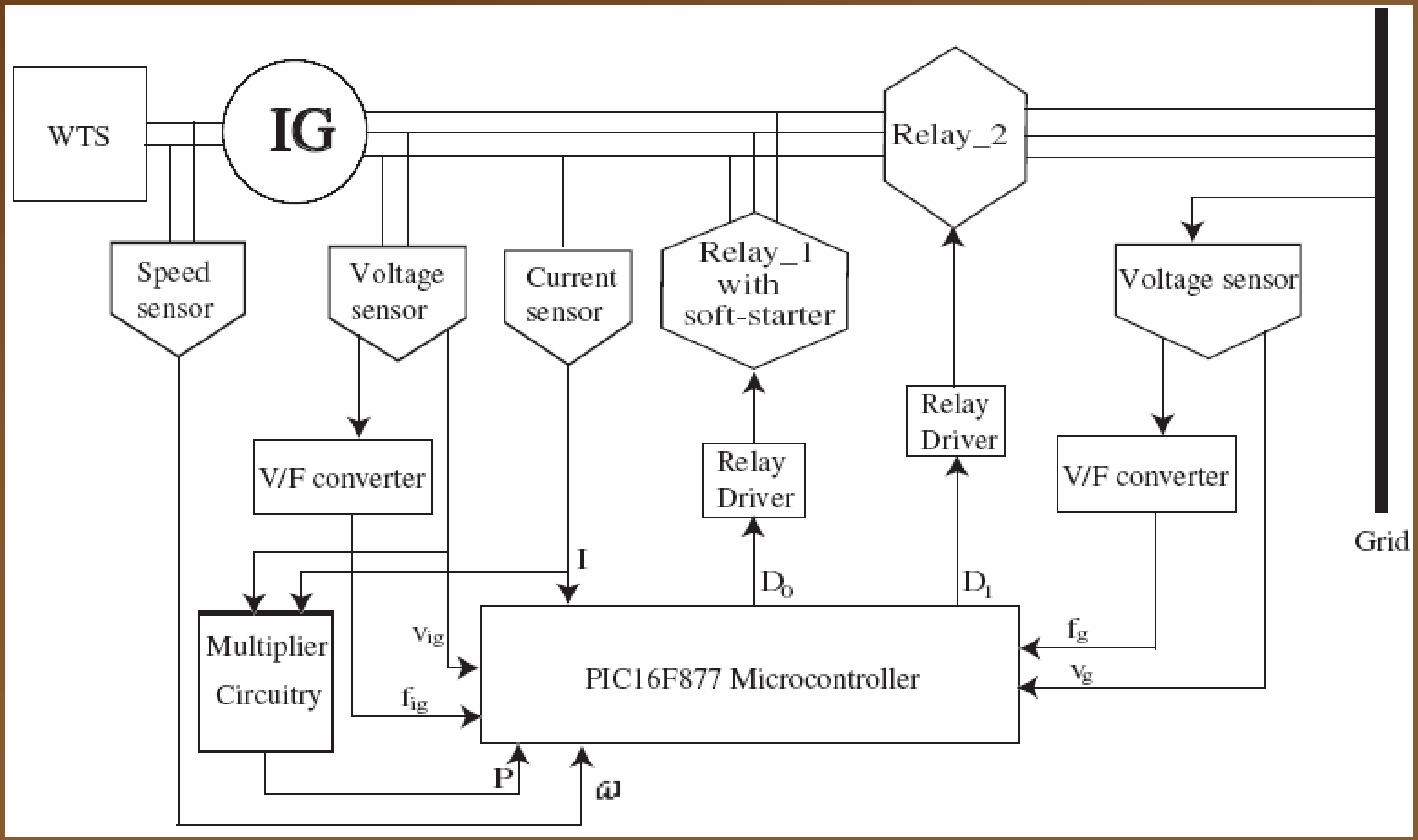


Control system design and operation cont.

Grid connected control mode

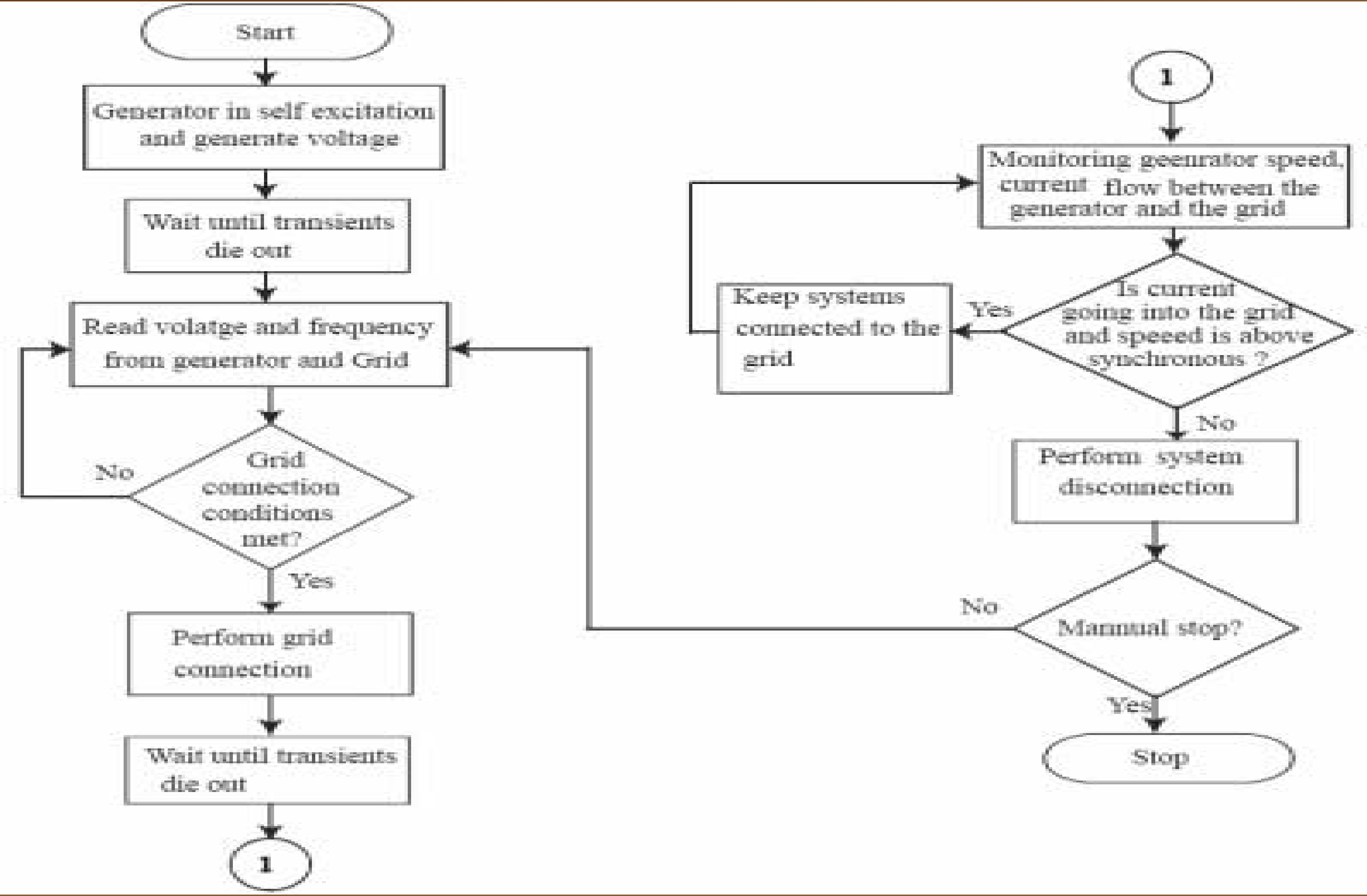
Control system design and operation cont.

- Block diagram representation of the grid mode controller



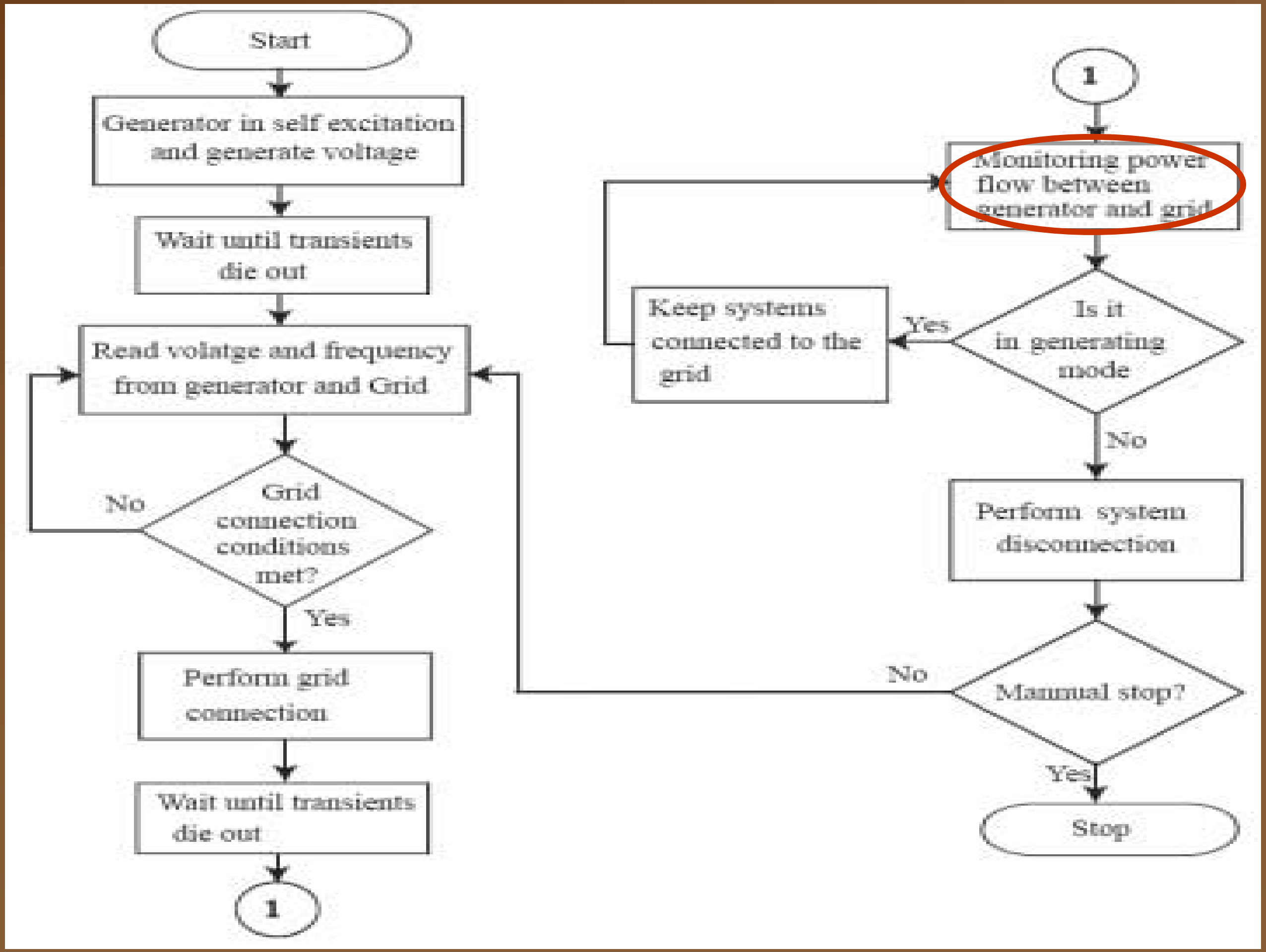
Control system design and operation cont.

- Implementation of the grid mode controller: Current



Control system design and operation cont.

- Implementation of the grid mode controller: Power

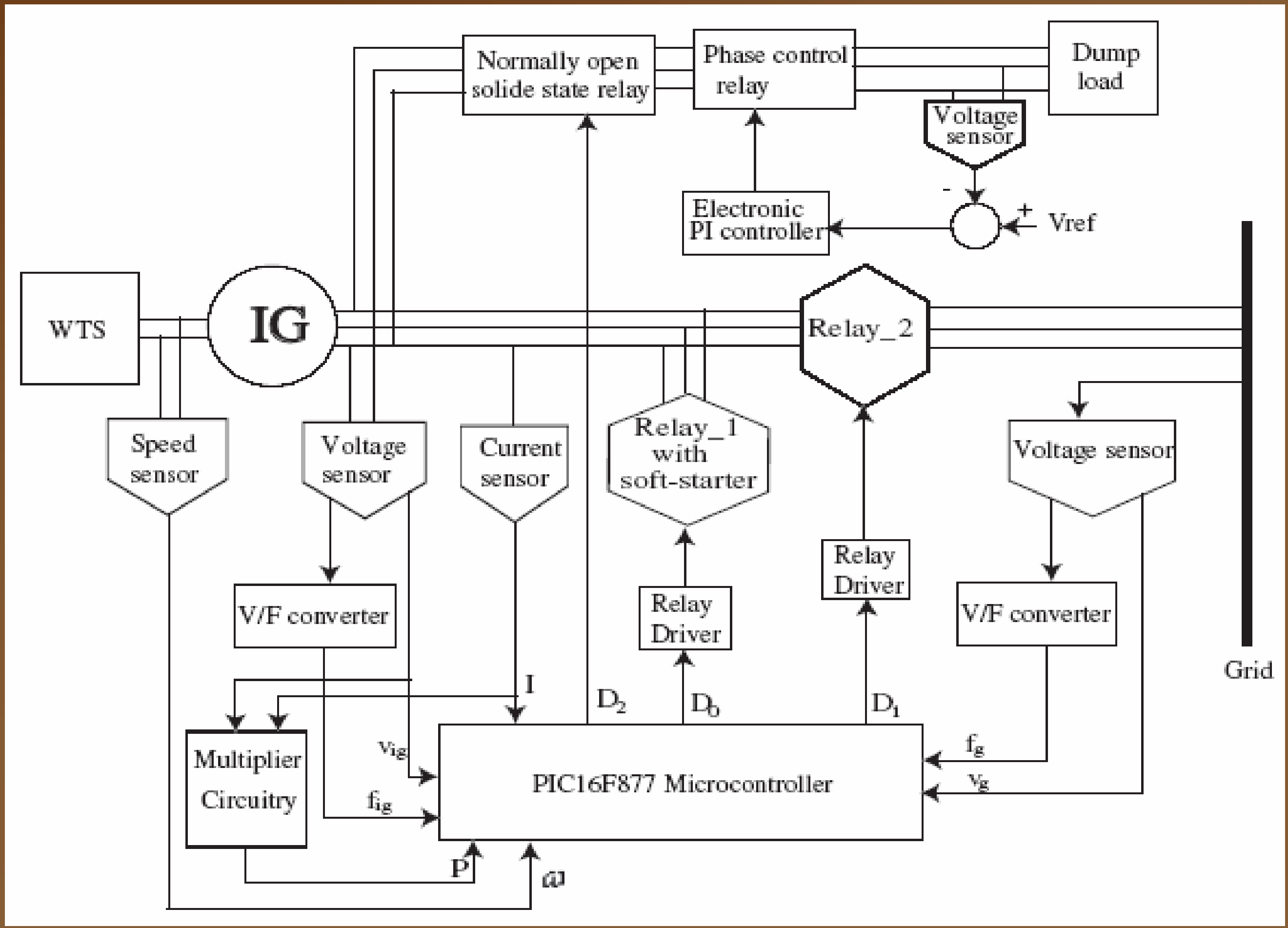


Control system design and operation cont.

Off-grid control mode

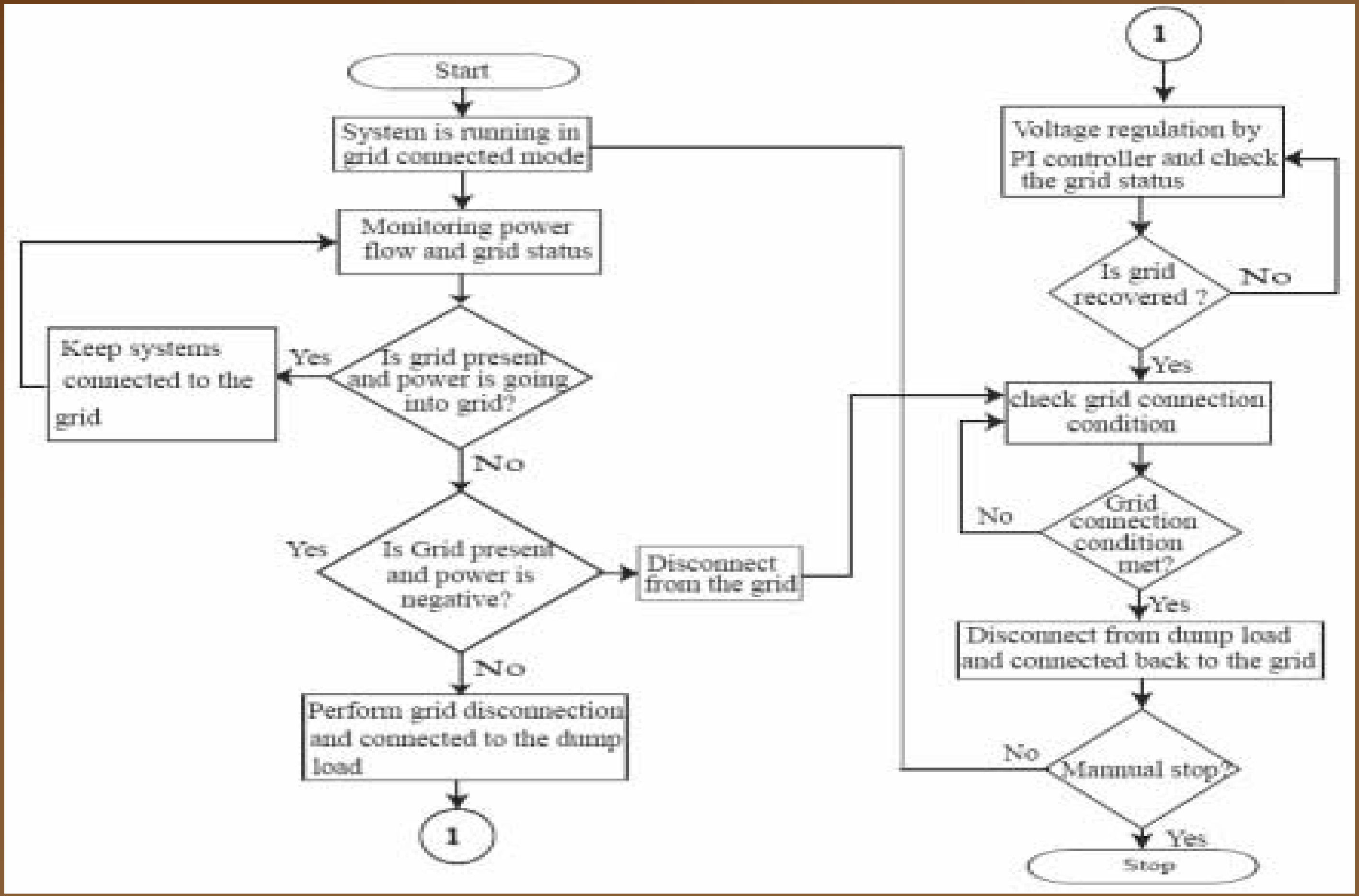
Control system design and operation cont.

- Block diagram representation of the off-grid control mode



Control system design and operation cont.

- Implementation of the off-grid control mode: Power

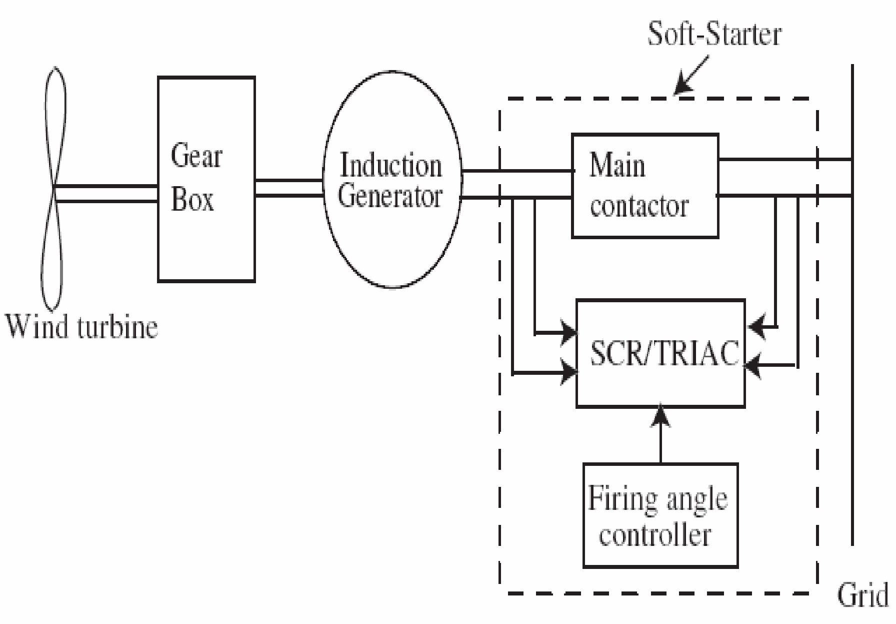


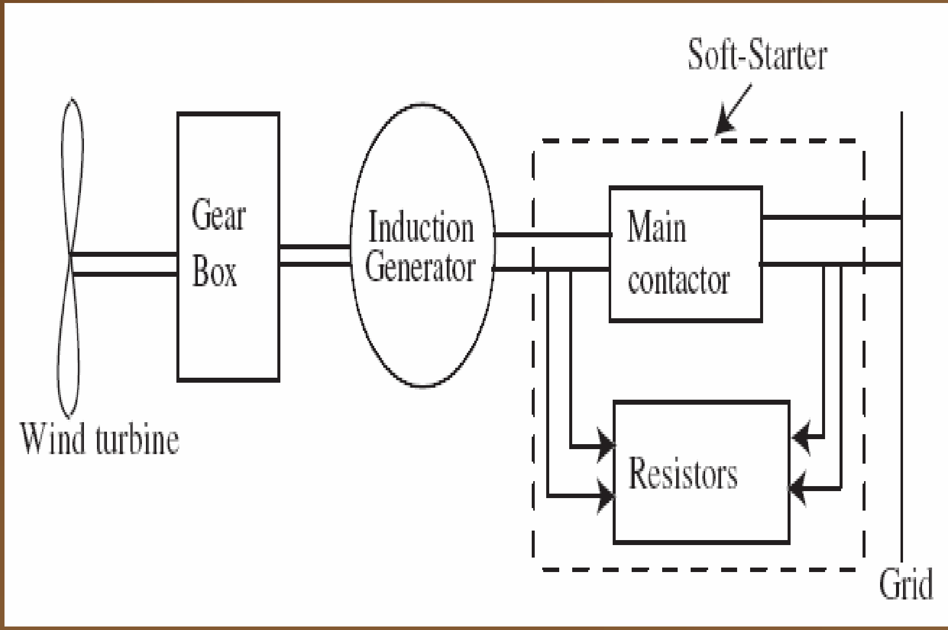
Soft-starter design

- What is Soft-starter?
  - ✓ Deals with solid state devices to limit the initial current surge during the connection of the wind power generator to the grid.
- Why is it power resistor based?
  - ✓ Cheaper and simpler
  - ✓ Control is not required unlike SCR/TRIAC

Soft-starter design

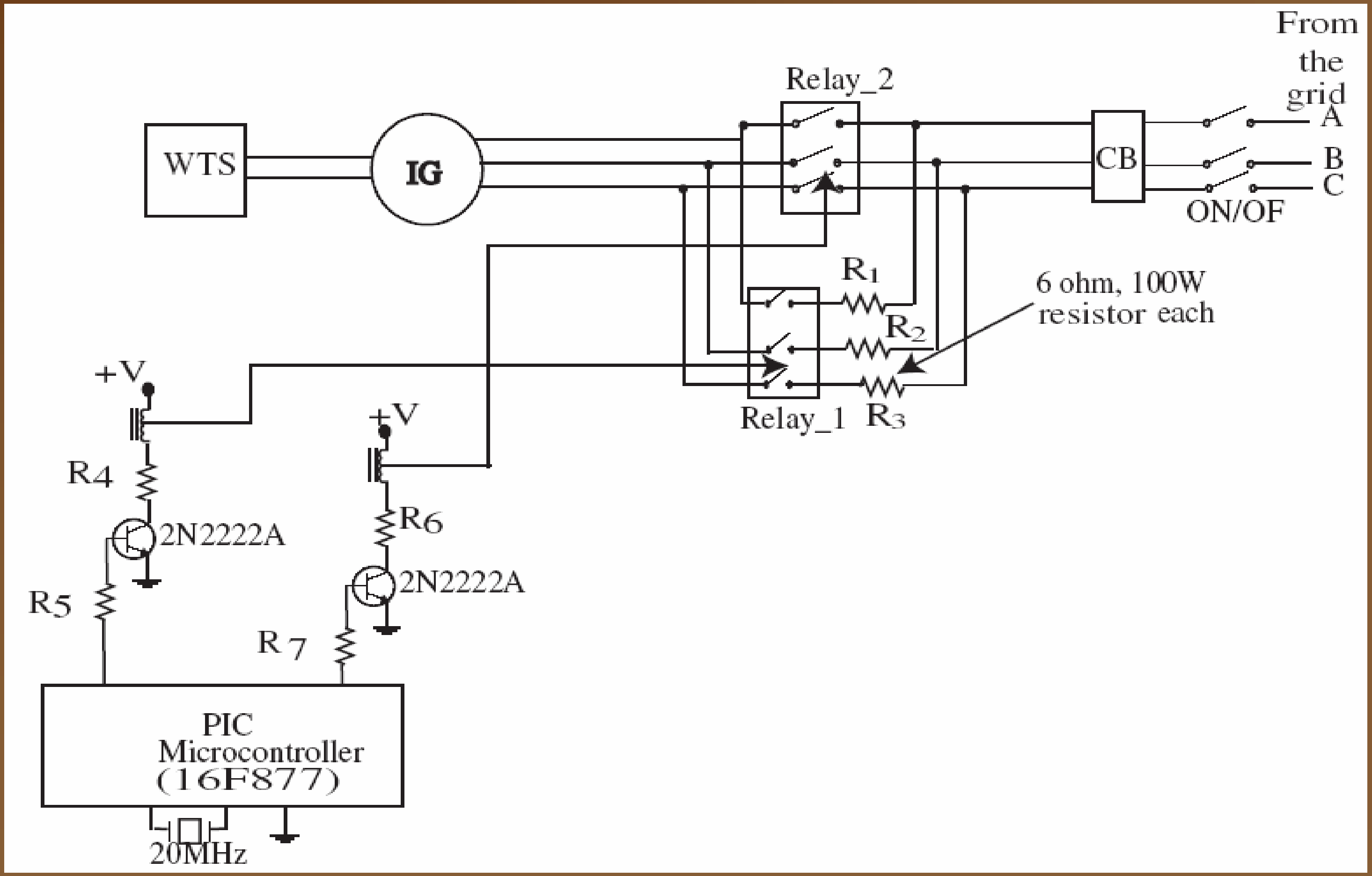
- Soft-connection topologies





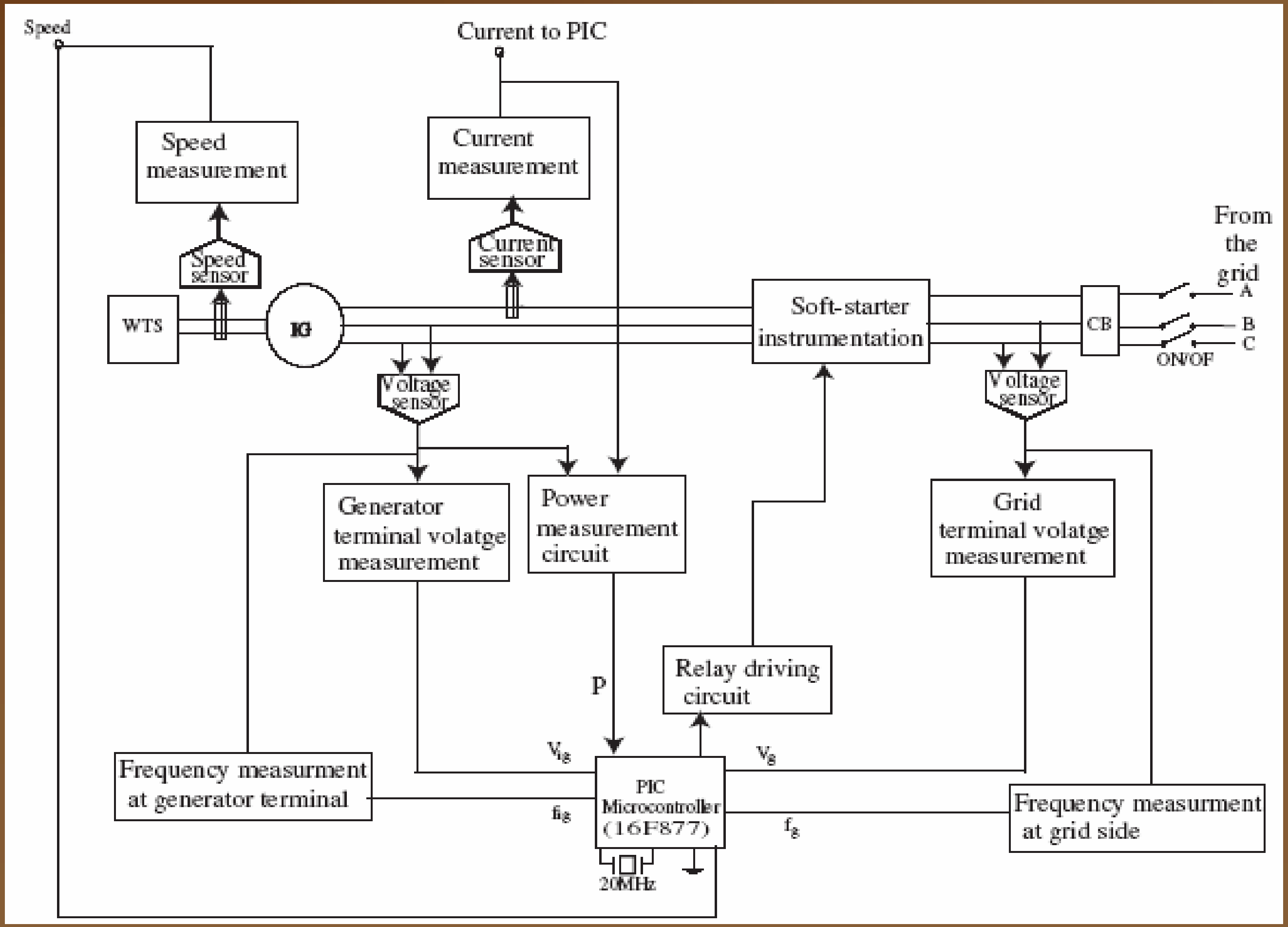
Soft-starter design

❖ Schematic of the designed soft-starter

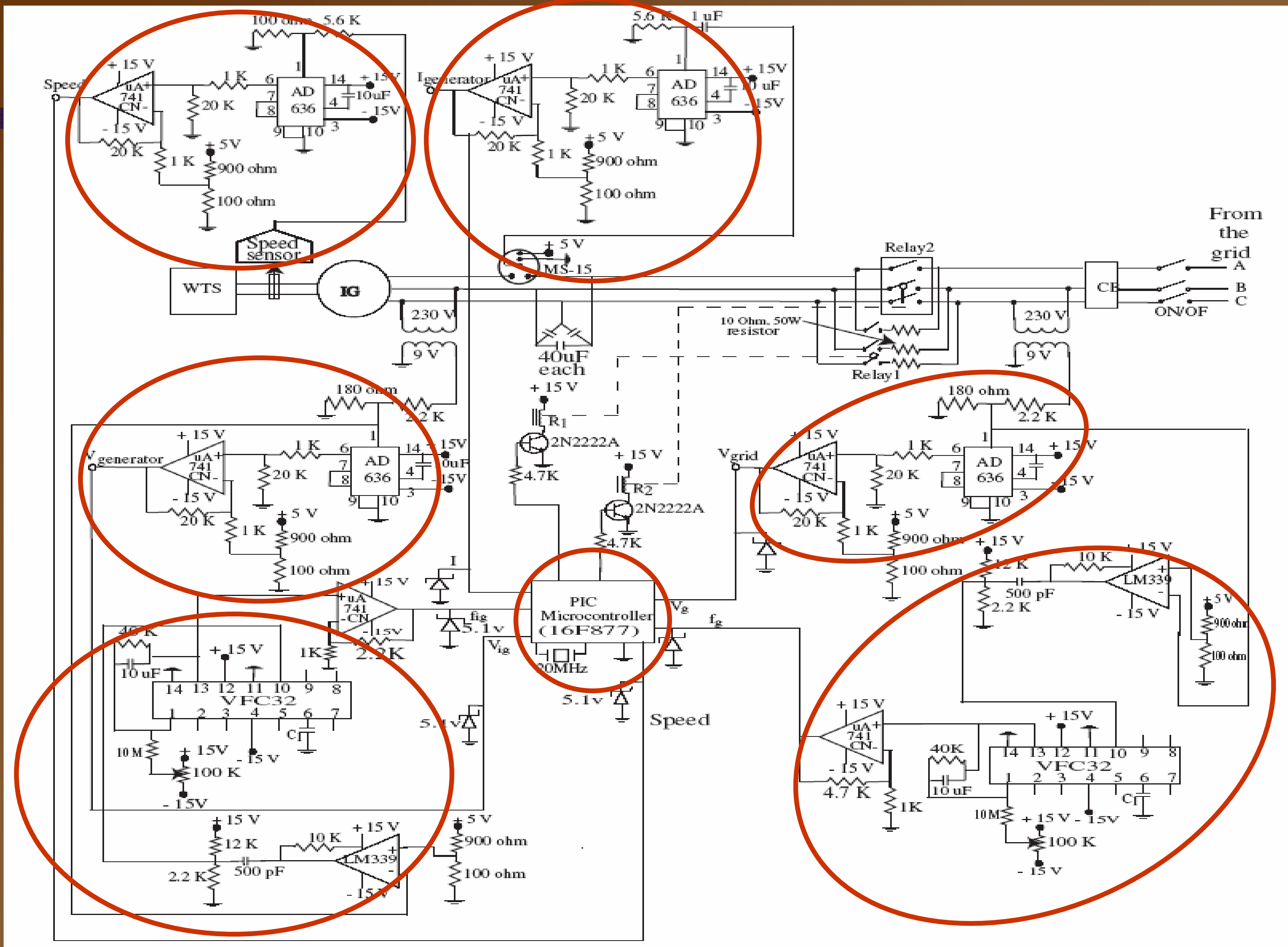


System instrumentations

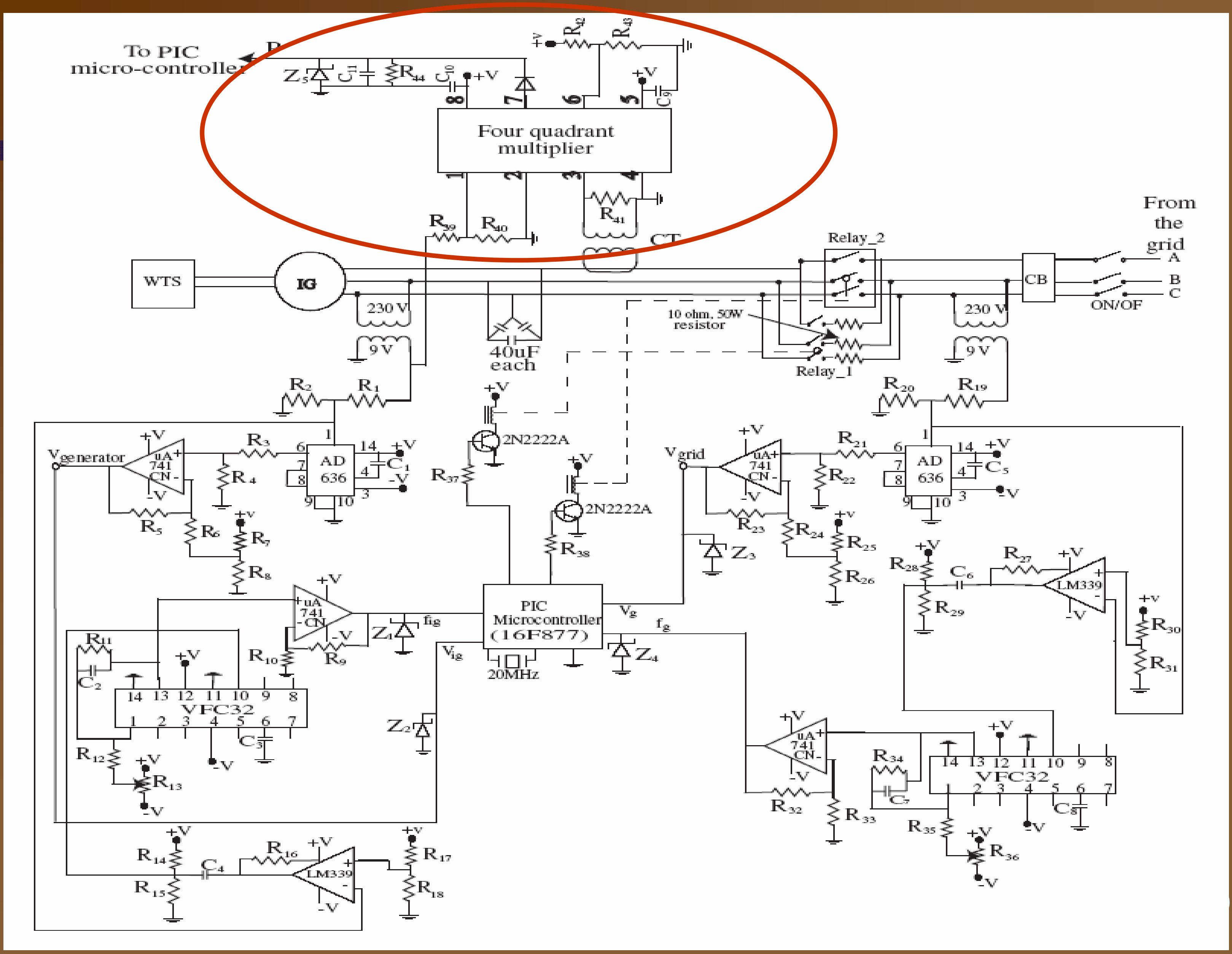
- Block diagram representation of grid mode instrumentation



❖ Schematic of the grid mode system instrumentations

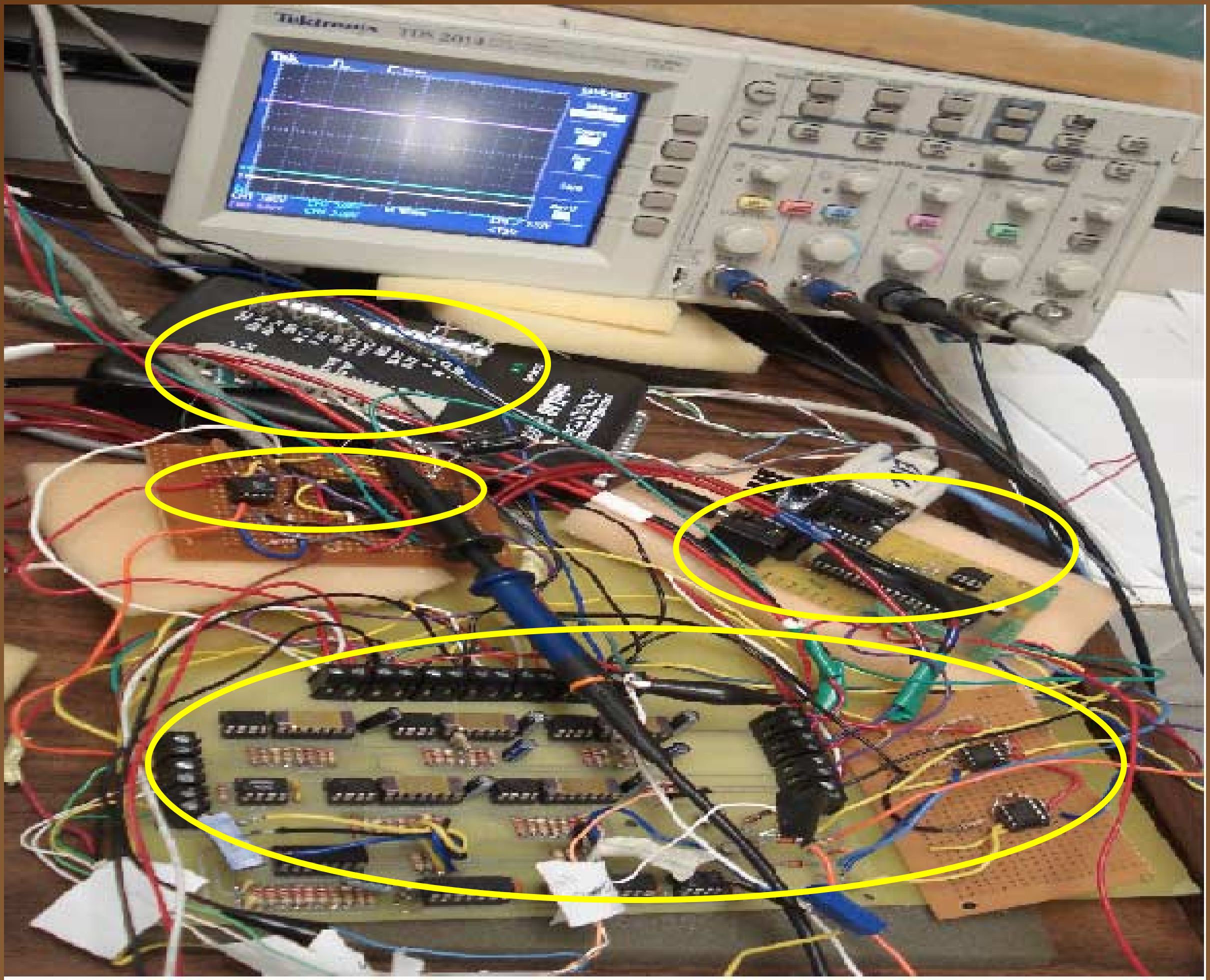


❖ Schematic of the grid mode system instrumentations



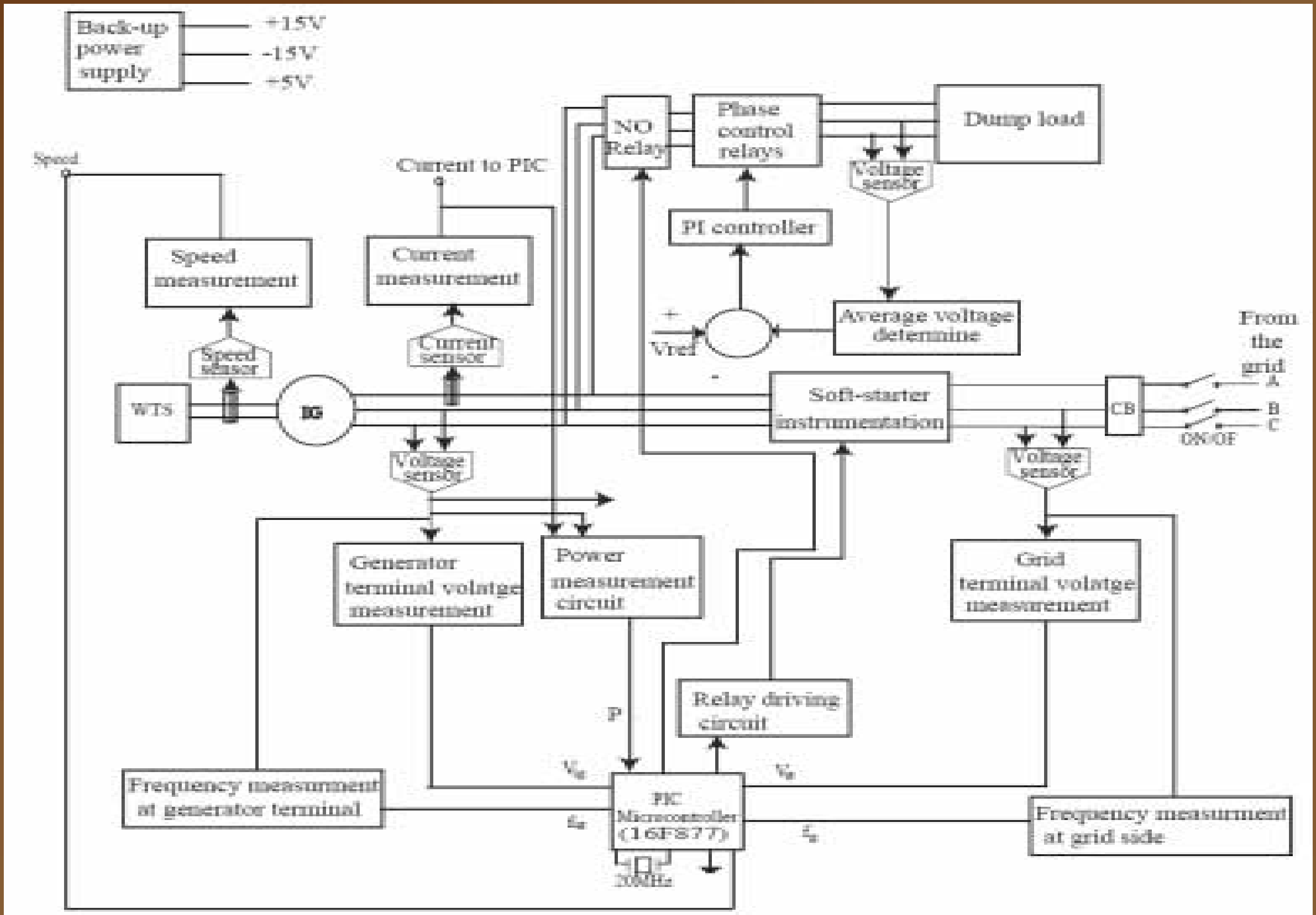
System instrumentations cont.

- Photograph of the grid mode instrumentation at laboratory

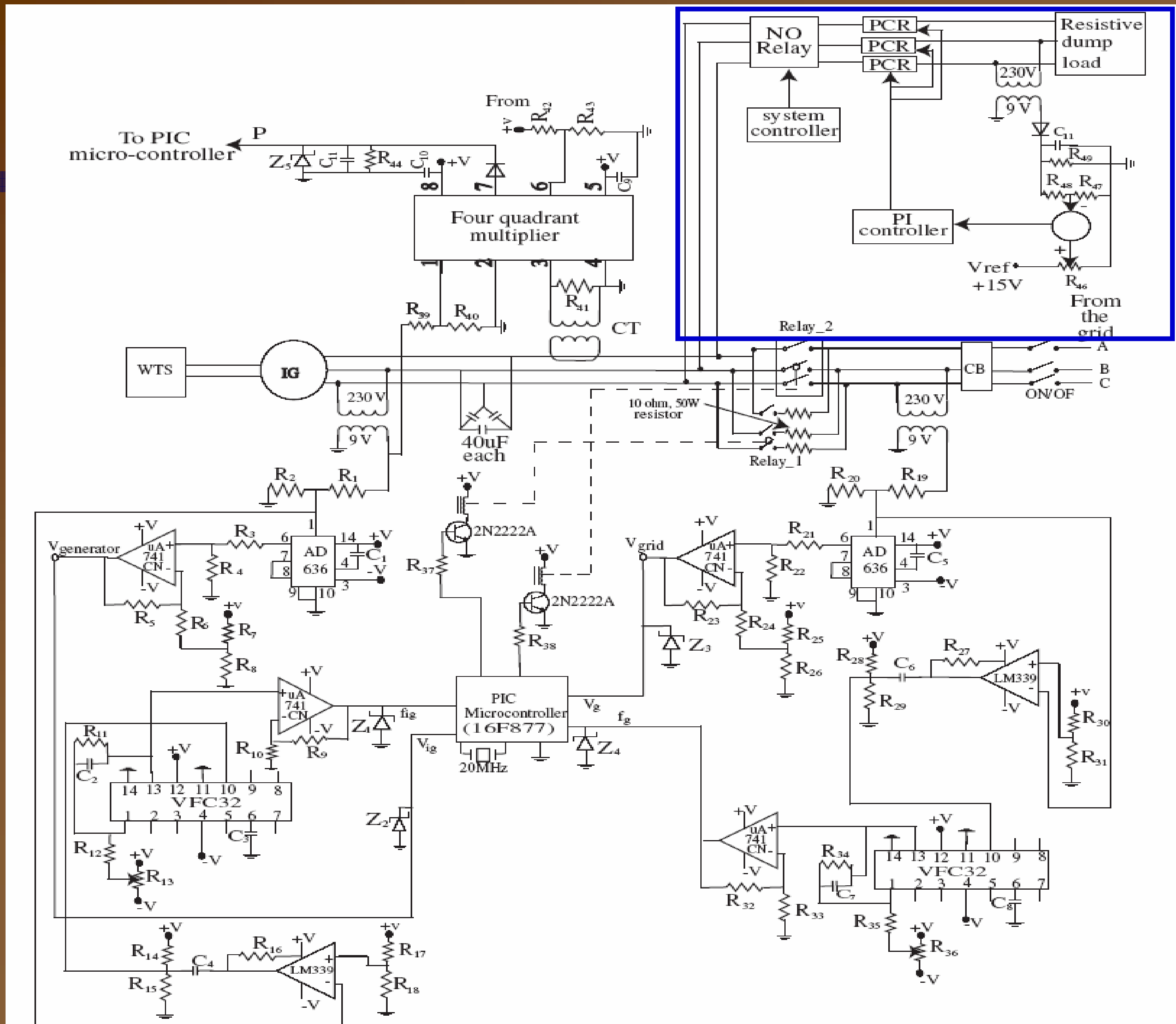


System instrumentations cont.

- Block diagram of instrumentations during off grid mode

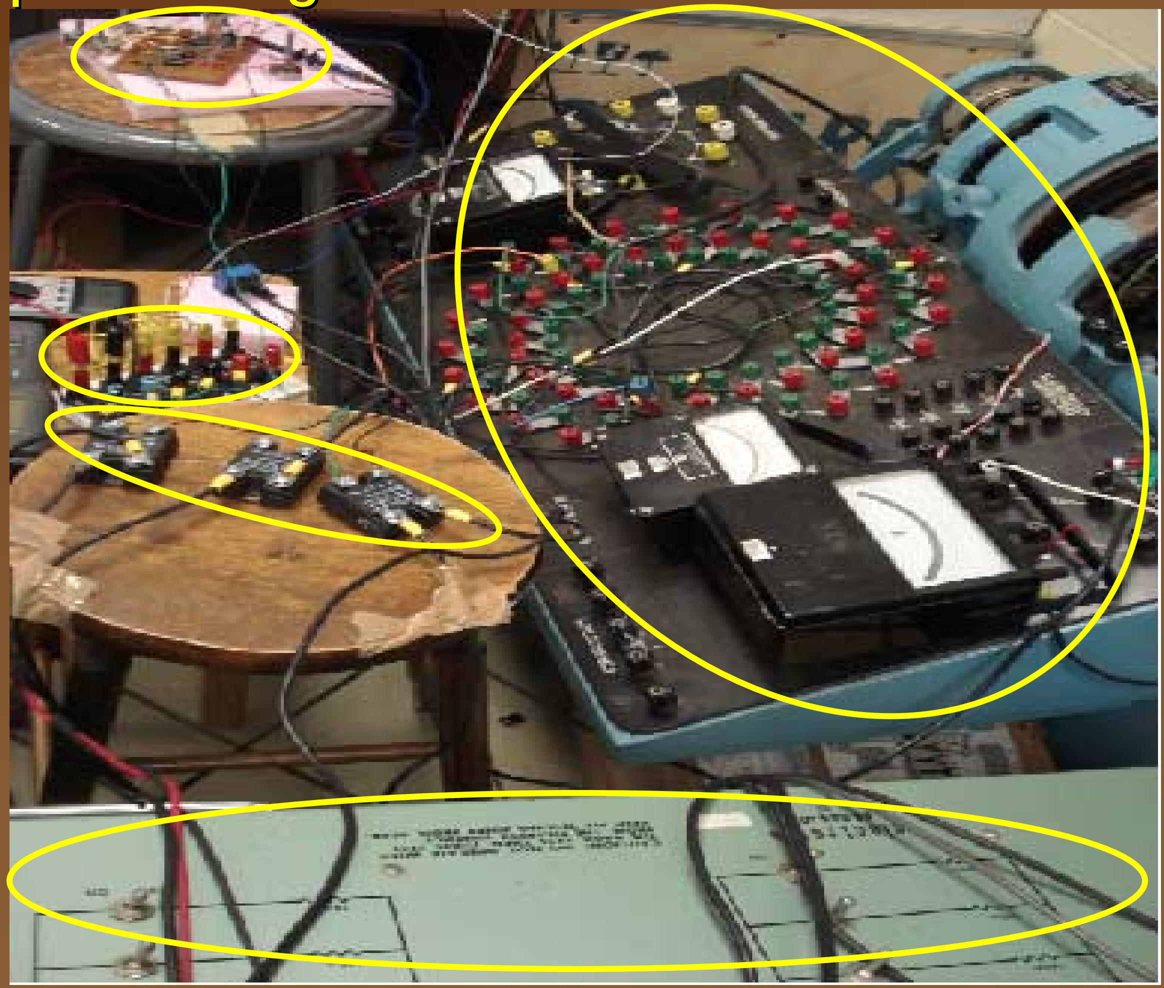


❖ Schematic of the off-grid mode system instrumentations



System instrumentations cont.

- Photograph of the grid mode instrumentation at laboratory



Experimental test results

- Current and speed feedback controller during grid mode

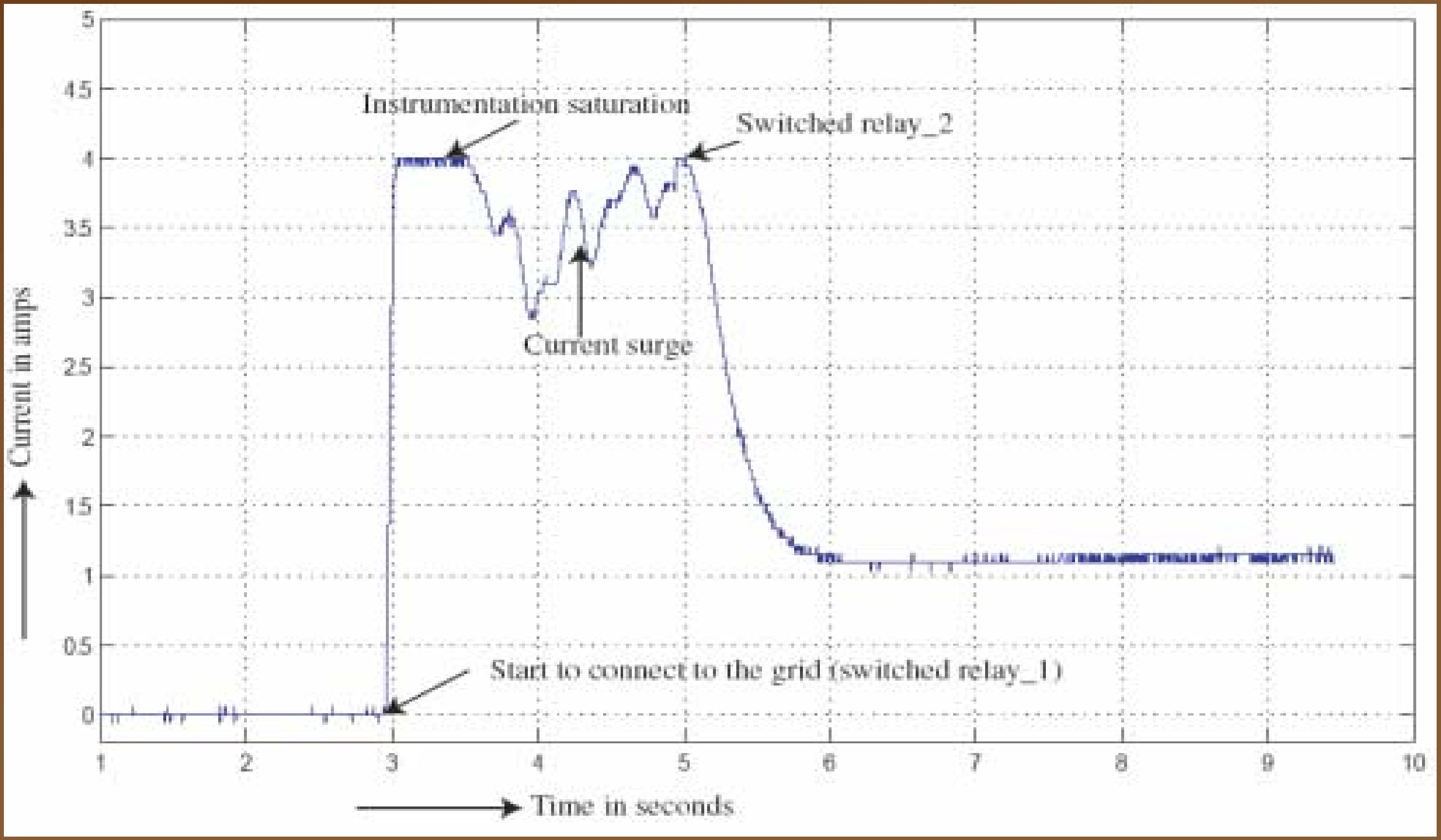


Fig: Current flow between the generator and the grid during grid connection

Experimental test results cont.

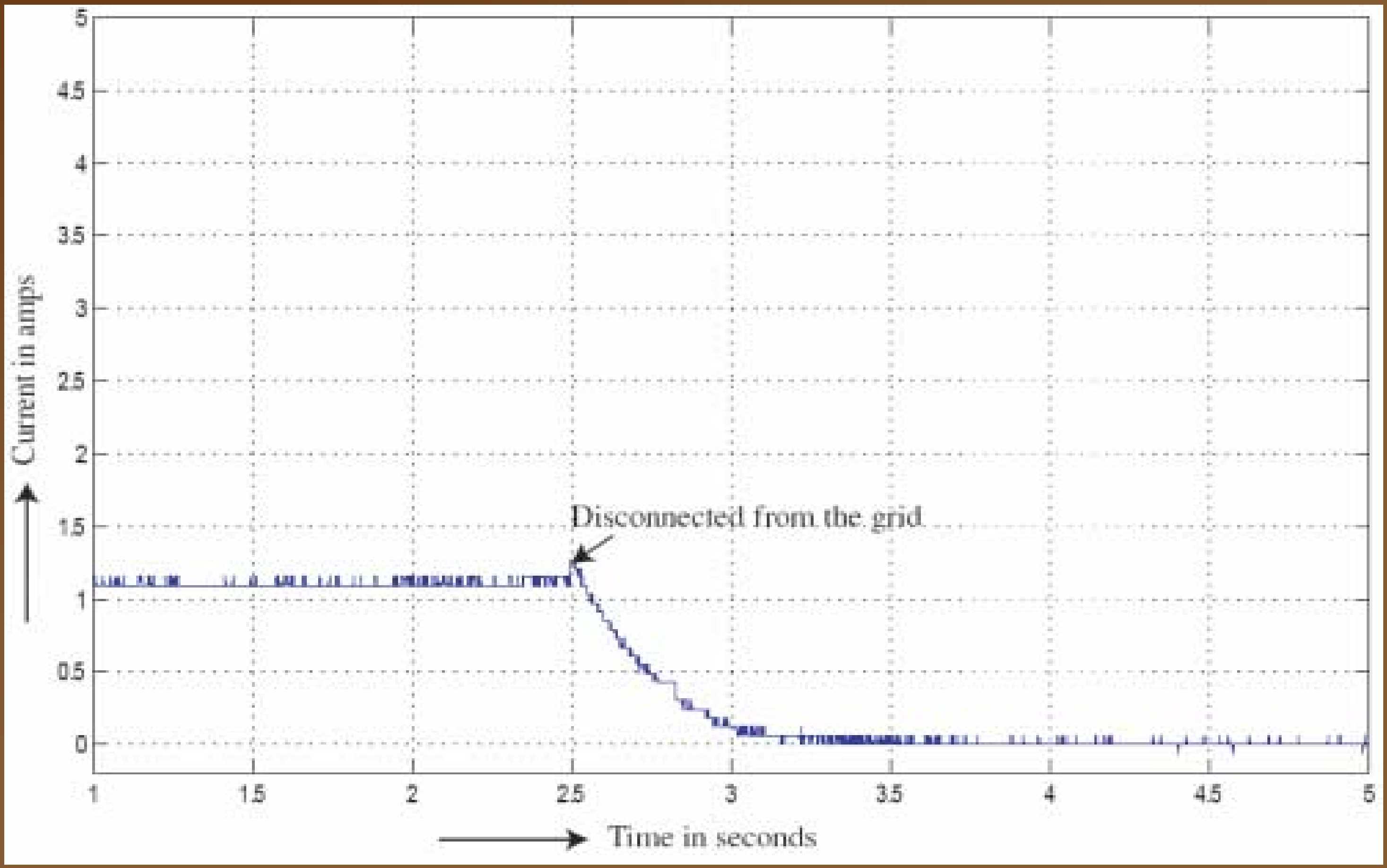


Fig: Current flow between the generator and the grid during grid disconnection

Experimental test results cont.

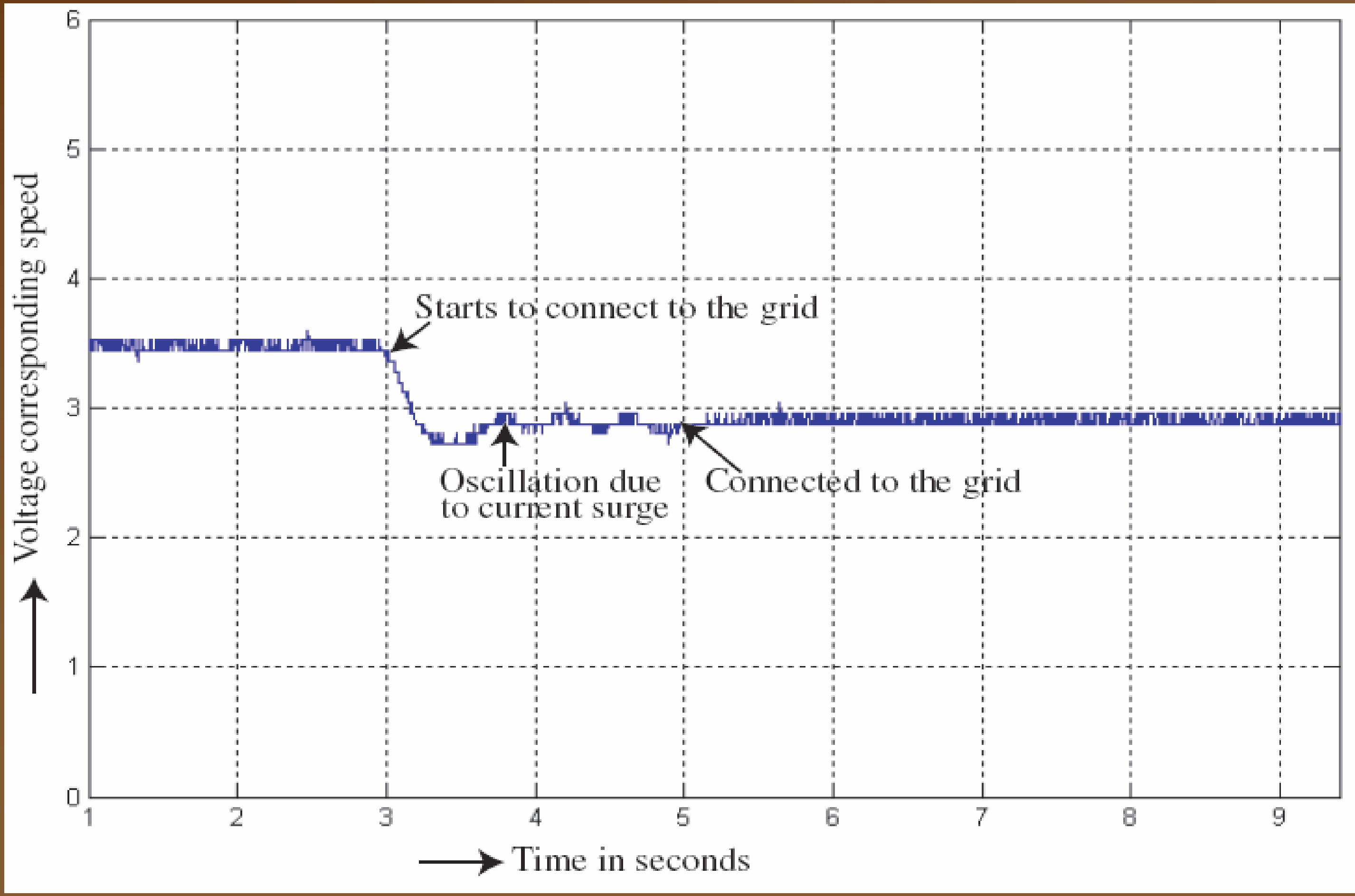


Fig: Generator speed during grid connection

Experimental test results cont.

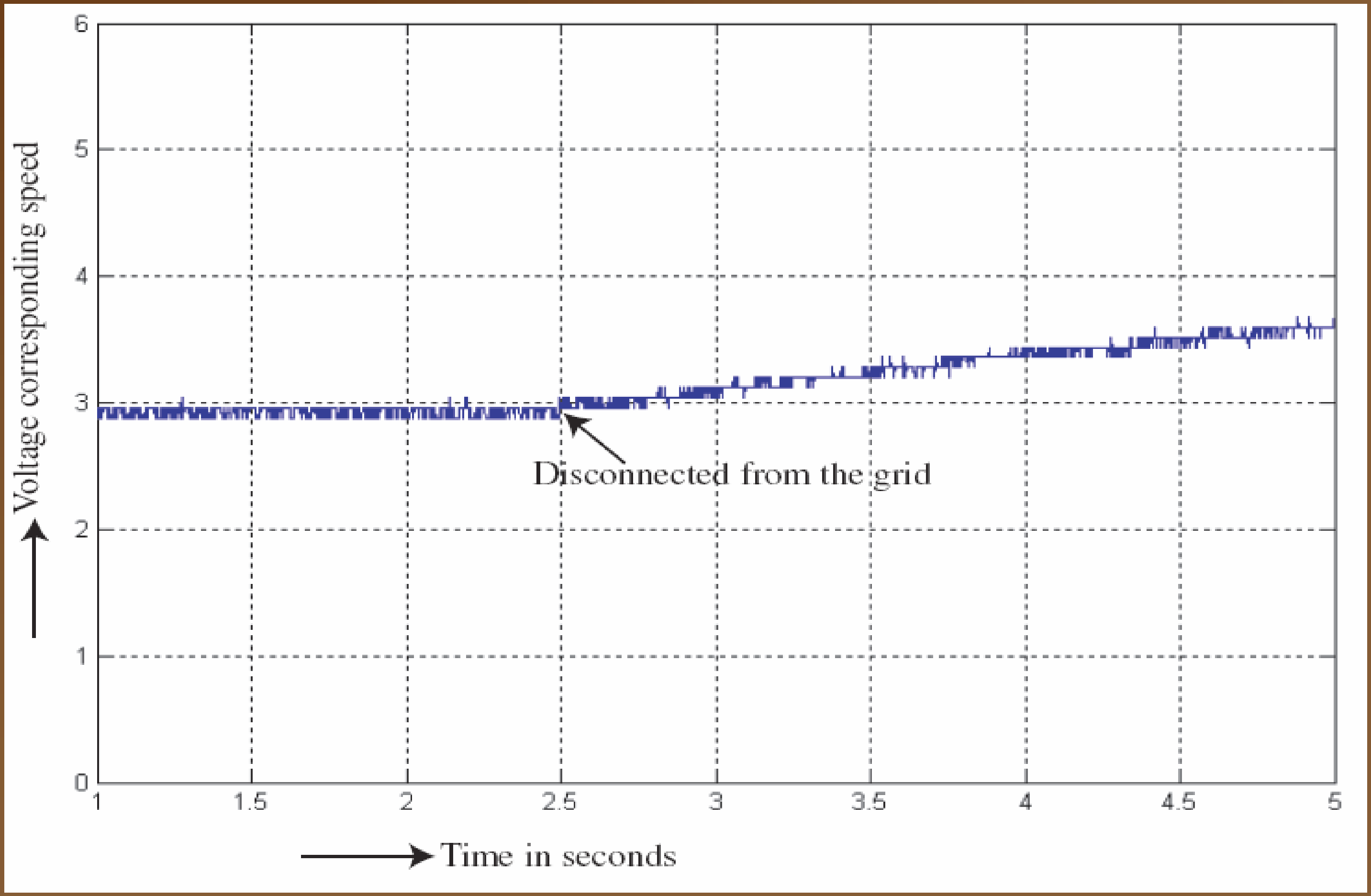


Fig: Generator speed during grid disconnection

Experimental test results cont.

❖ Power feedback controller during grid mode

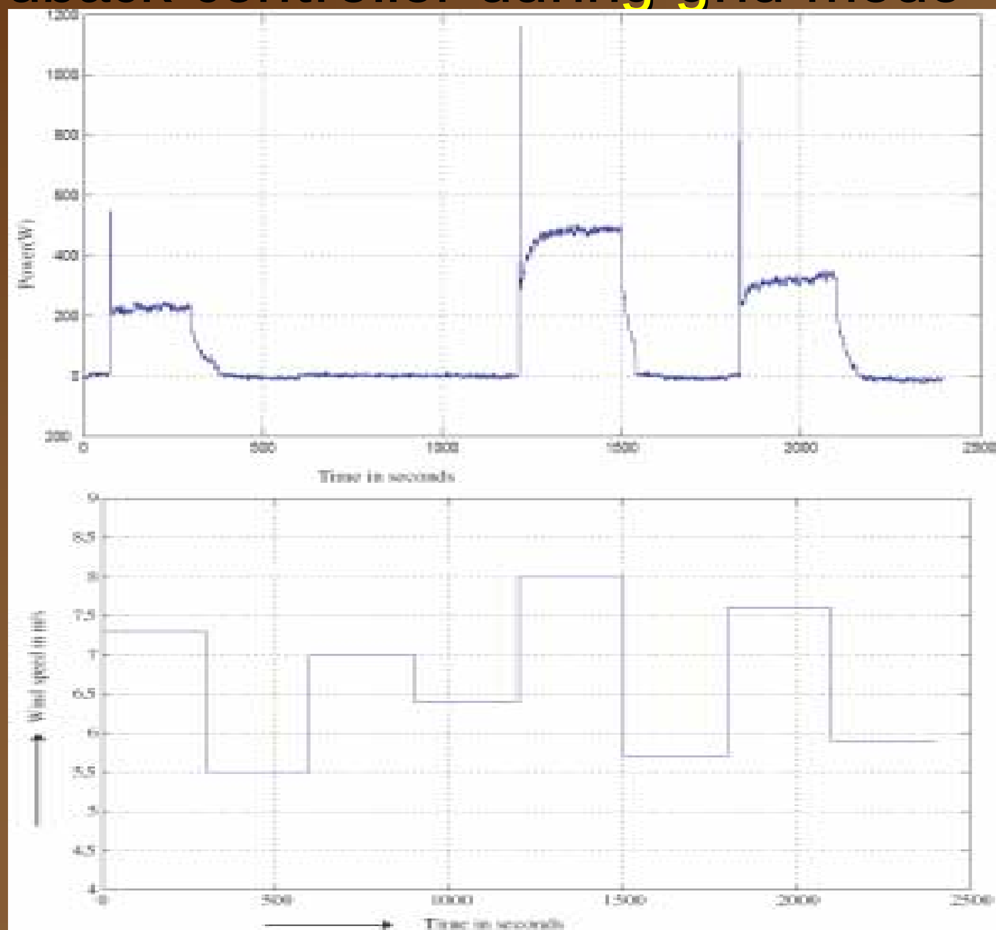


Fig. Power during grid connection and disconnection with variation in wind speed

Experimental test results cont.

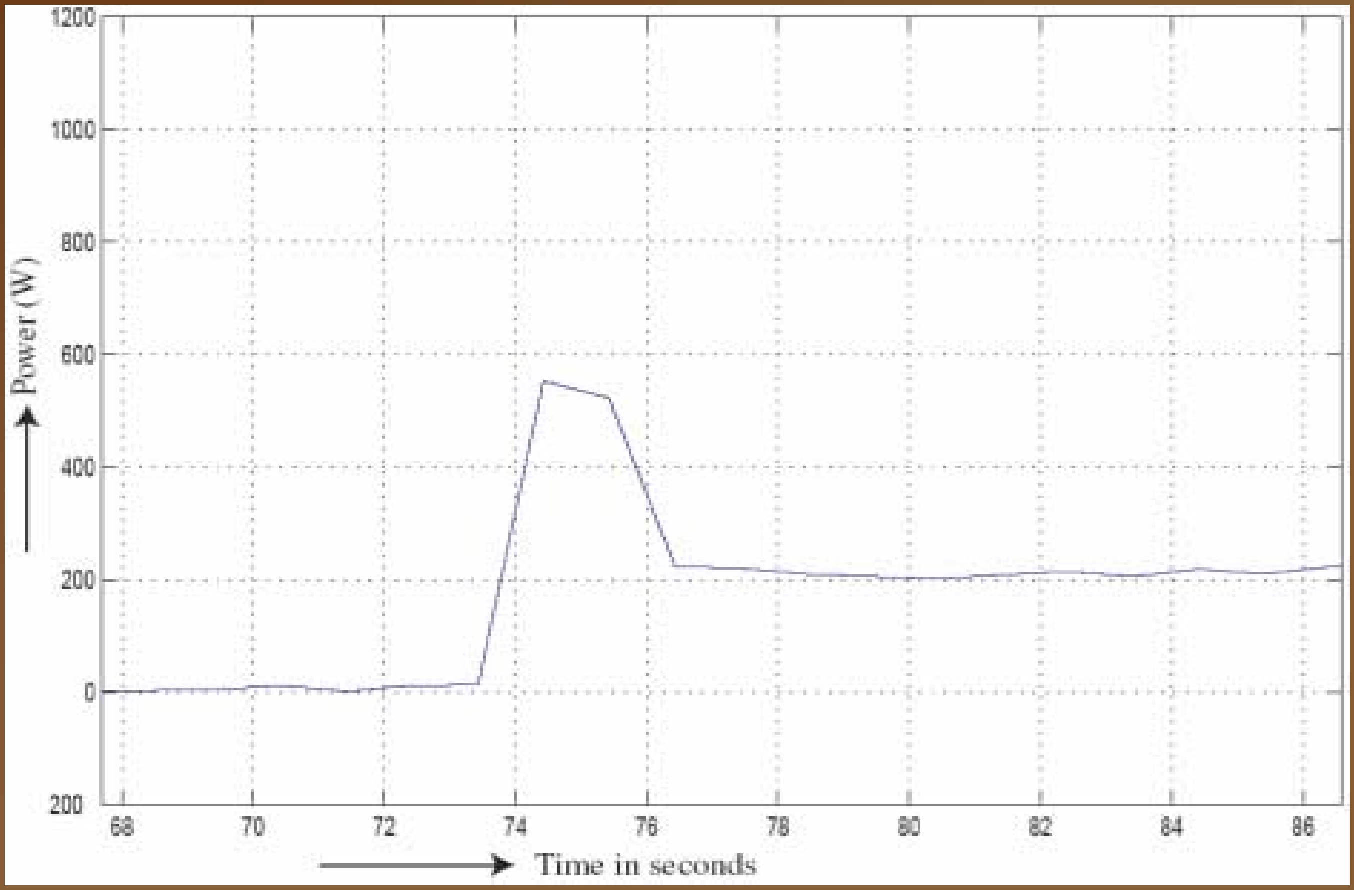


Fig. Transient in power during the system connection to the grid

Experimental test results cont.

- Voltage regulation during off-grid mode

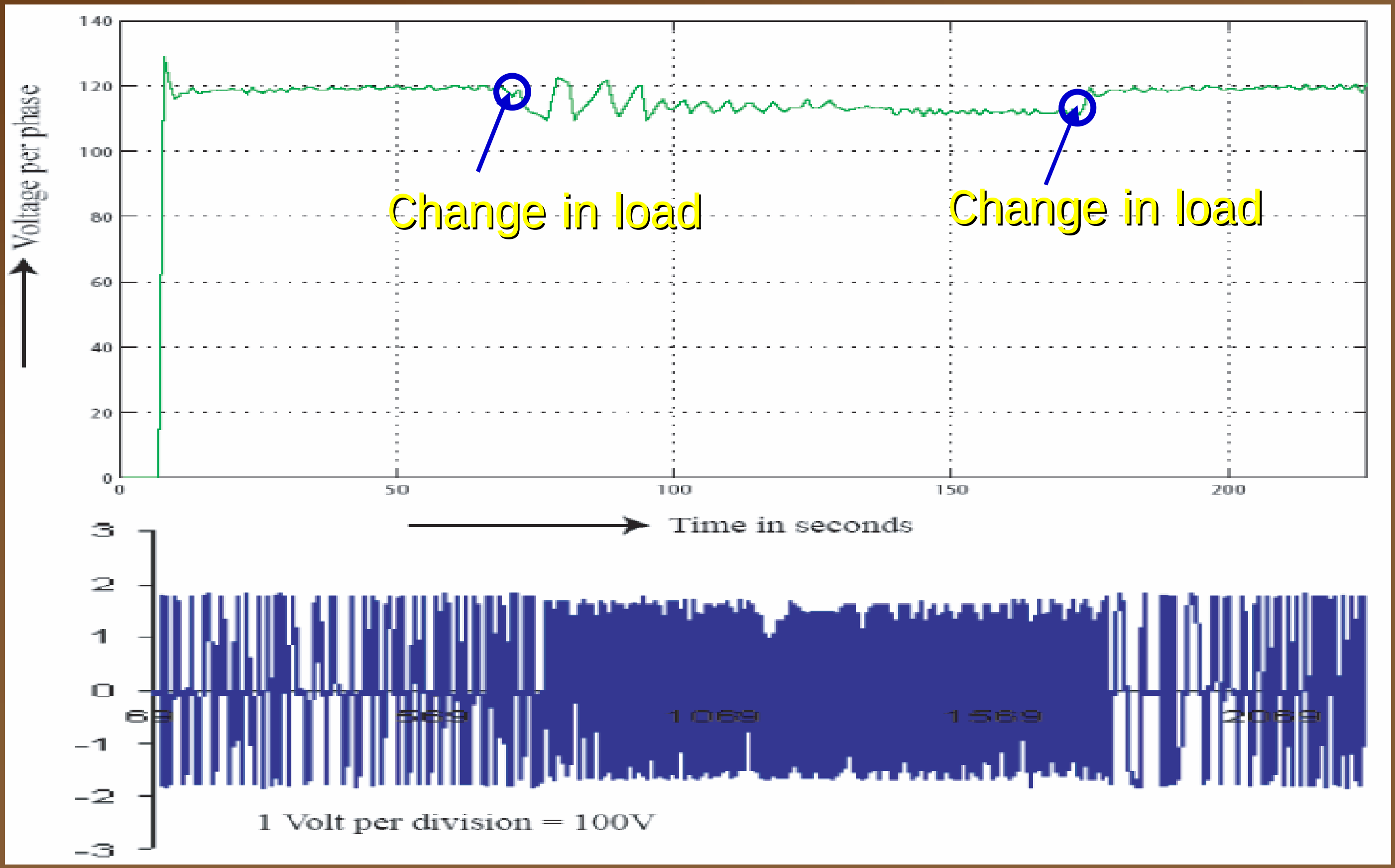


Fig. Load terminal voltage during off-grid mode

Experimental test results cont.

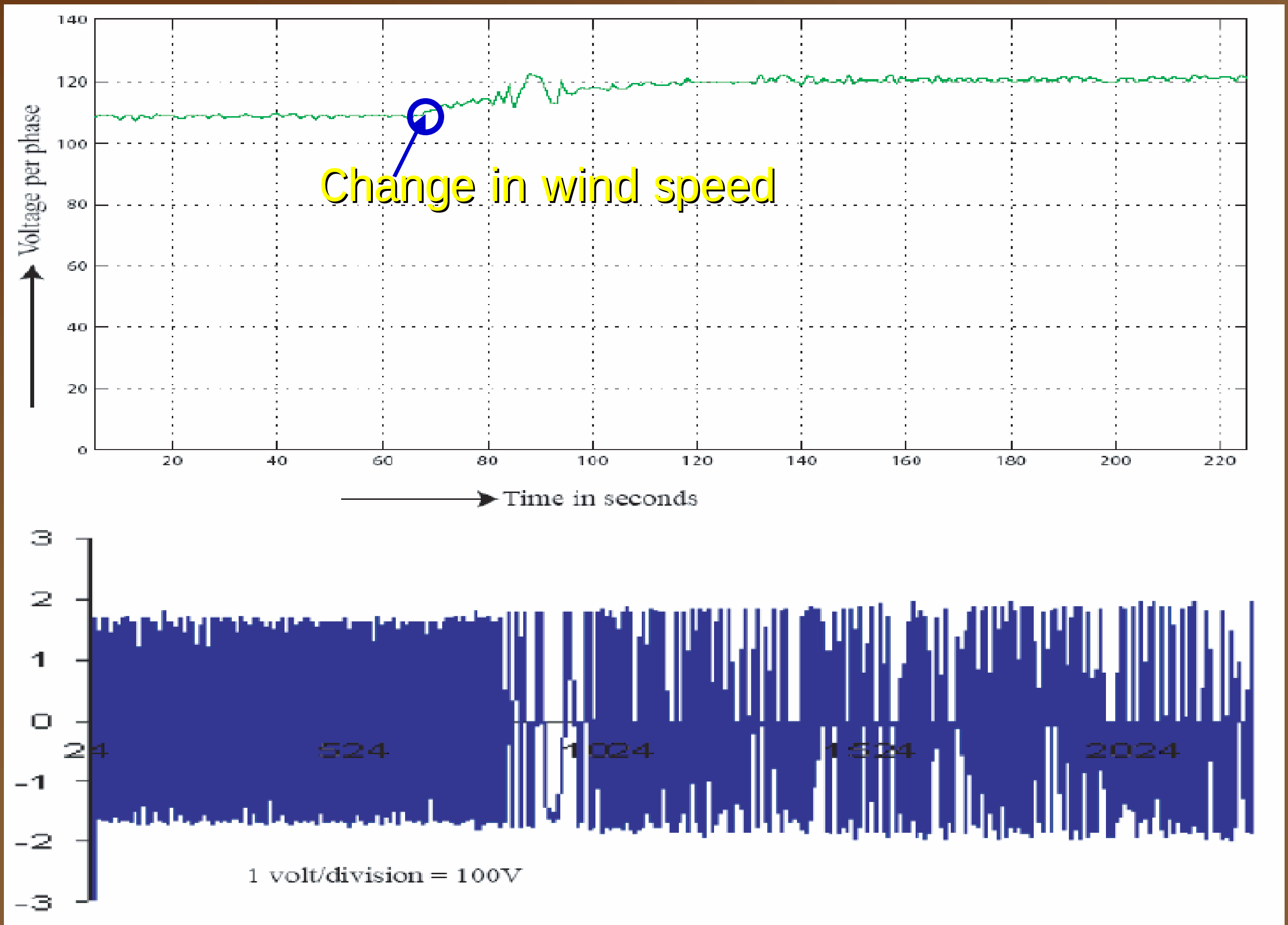


Fig. Load terminal voltage due to wind speed change during off-grid mode

Experimental test results cont.

- Soft-starter test results

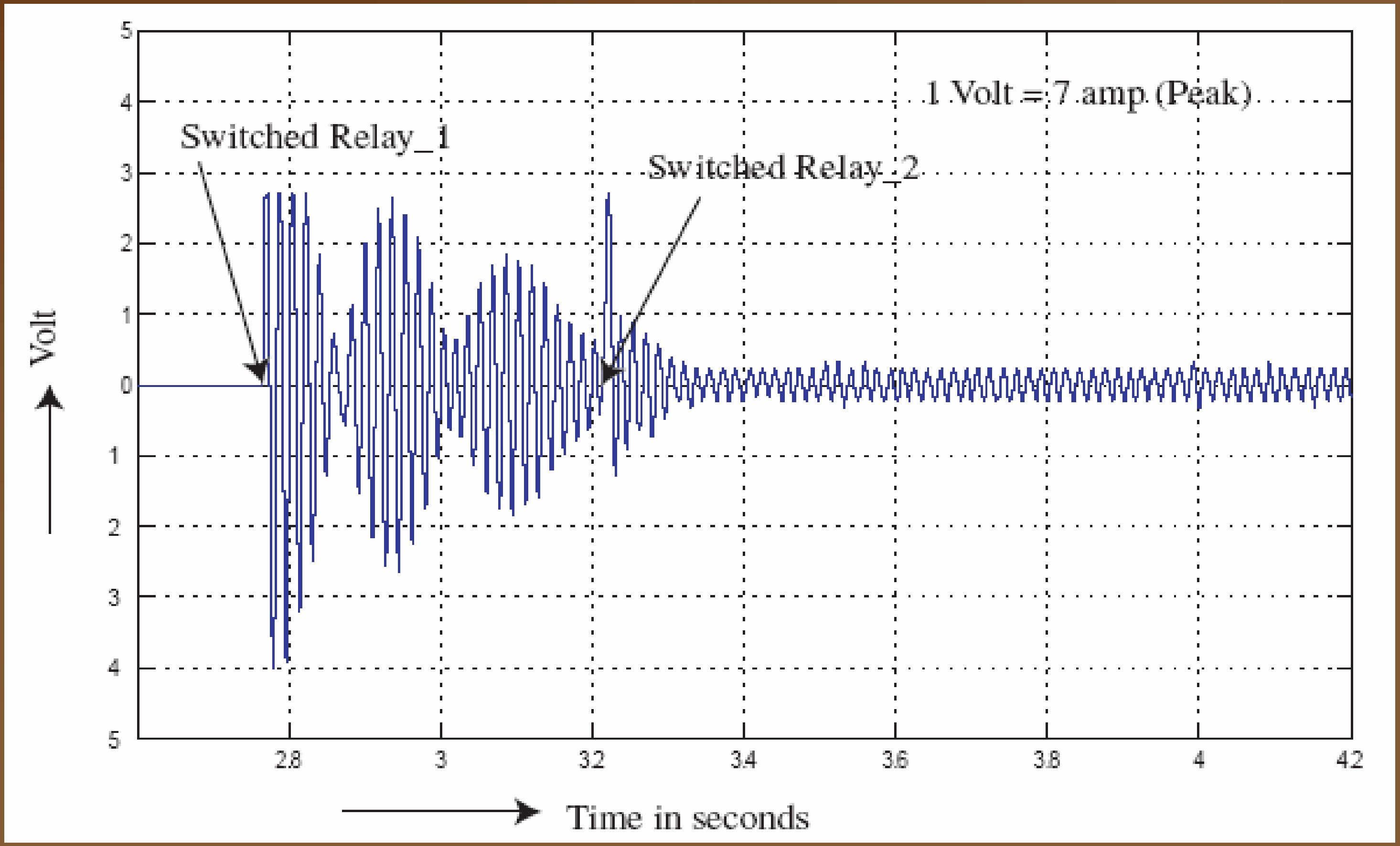


Fig. Current surge while the switching time difference between the relays is 450 milliseconds

Experimental test results cont.

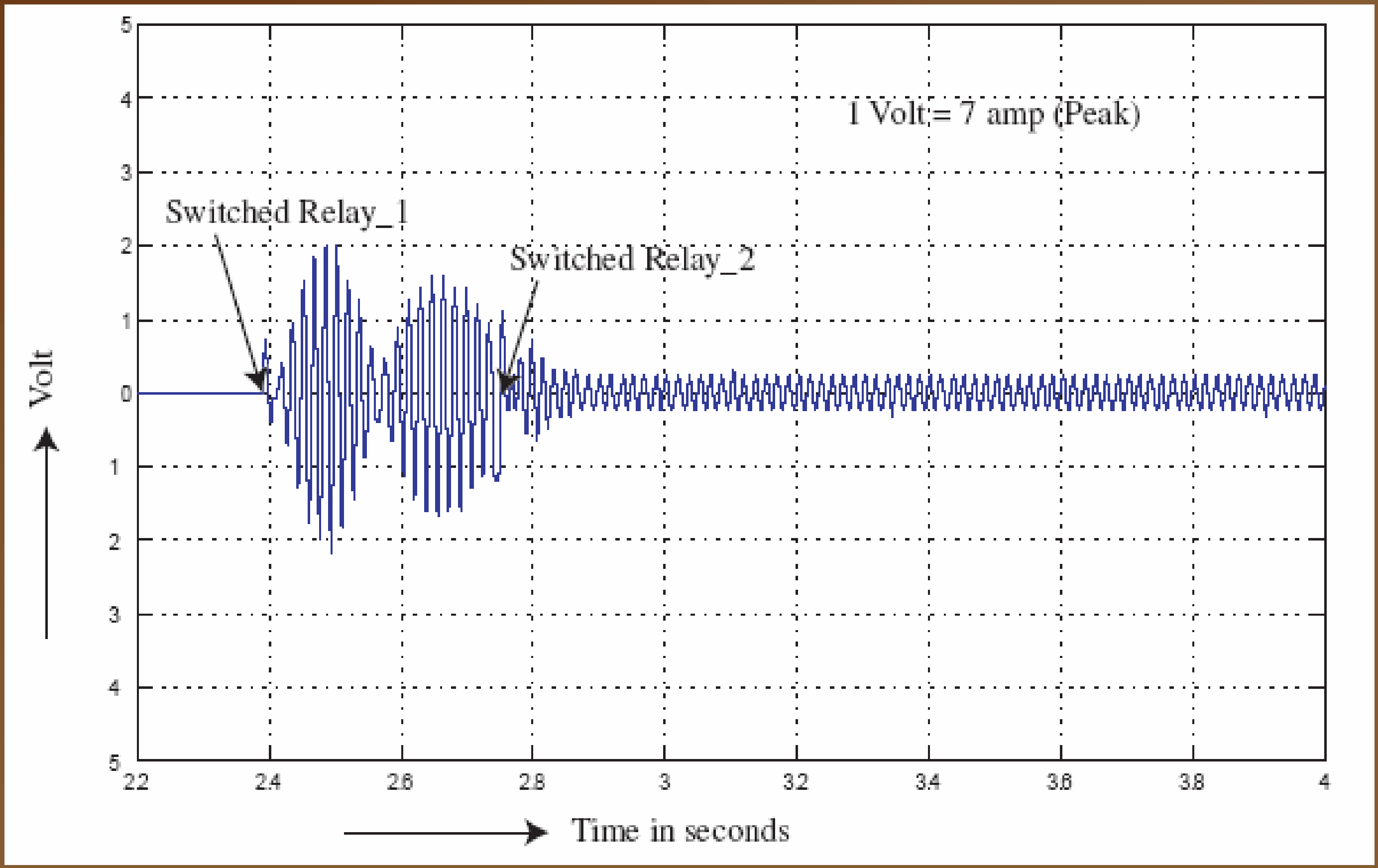


Fig. Current surge while the switching time difference between the relays is 350 milliseconds

Experimental test results cont.

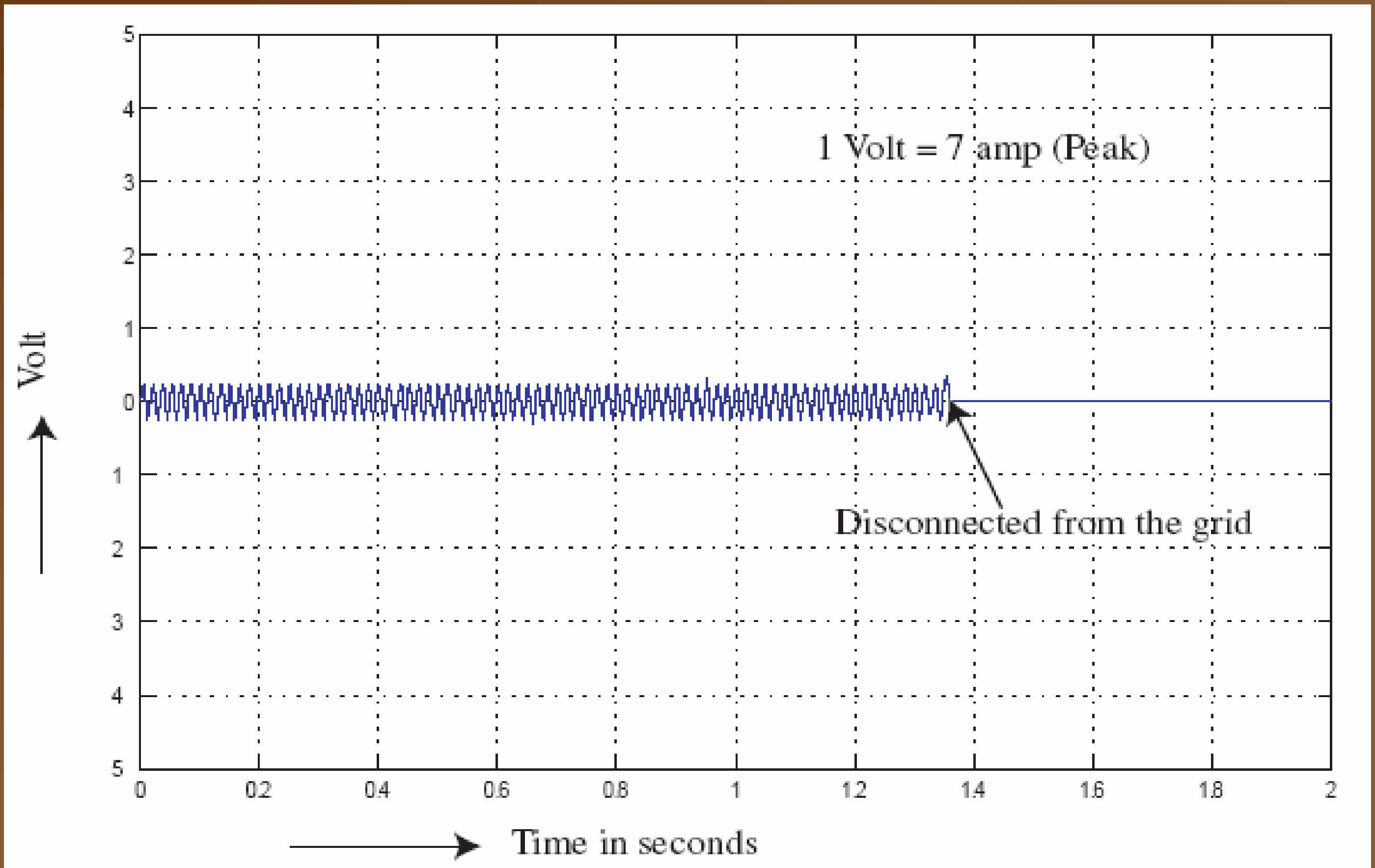


Fig. Current while the system is disconnected and the switching time difference between the relays is 350 milliseconds

Conclusions

- Small induction generator based wind turbine simulator is developed as a test bed of the proposed system controller.
- A PIC16F877 is selected as a system controller which helps to connect/disconnect the system with the grid and also to maintain the grid connection.
- System controller is designed and tested for grid connected mode based on current and power measurement.
- System controller is able to detect the grid failure and switchover the system operation in off-grid mode.
- Voltage regulation in off-grid mode is achieved using a phase control relay based electronic PI controller.
- System instrumentation is developed to measure the system parameters.
- Power resistor based soft-starter is designed to limit the initial surge during the connection process of the wind turbine generator to the grid.
- Experimental results for each test show the performances as expected.

Future works

- WTS could be more realistic by incorporating dynamics and pitching mechanism.
- Advanced control techniques such as Model Predictive Control (MPC), FLC can be applied to develop the WTS with maximum power point tracker.
- The system controller needs to be tuned to reach the grid connection standard.
- System controller needs to be further investigated to handle the situation for over and under voltage, and abnormal frequency situation.
- Voltage regulation during off-grid control mode for inductive and capacitive load could be investigated.

Publications

- Journal papers
  - R. Ahshan, M. T. Iqbal, George K. I. Mann, " A New Control Approach for Small Grid Connected Wind Turbine," To be appeared in Vol. 31, Issue 5, 2007, *Wind Engineering Journal*.
  - R. Ahshan, M. T. Iqbal, George K. I. Mann, " Controller for Small Induction Generator Based Wind Turbine," Accepted for Publication in *Applied Energy Journal* 2007.

- Conference papers
  - R. Ahshan, M. T. Iqbal, George K. I. Mann, " Performance of a Controller for Small Grid Connected Wind Turbine," Proceedings, *IEEE 7th Electrical Power Conference*, EPC07, October 25-26, 2007, Montreal, Canada.

Publications

- ✓ R. Ahshan, M. T. Iqbal, George K. I. Mann, " Small Induction Generator Based Wind Turbine Simulator," Proceedings, *16th IEEE NECEC*, November 9, 2006, St. John's, NL.

- ✓ R. Ahshan, M. T. Iqbal, George K. I. Mann, " Power Resistors Based Soft-Starter for a Small Grid Connected Induction Generator Based Wind Turbine," Proceedings, *17th IEEE NECEC*, November 8, 2006, St. John's, NL.

- Article under review
  - ✓ R. Ahshan, M. T. Iqbal, George K. I. Mann, "Voltage regulation during off-grid operation of a Small Grid Connected Wind Turbine," Submitted in *Renewable Energy* Journal.

Acknowledgements

- Supervisors
  - ✓ Dr. M. Tariq Iqbal
  - ✓ Dr. George K. I. Mann
- NSERC
- Atlantic Innovation fund Canada
- School of Graduate Studies
- Memorial University of Newfoundland

Thanks

Q & A