Opportunities for Research in Energy and Power Electronics at Monash University

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with thanks to

Centre for Power Electronic Systems, Virginia Tech

Introduction

- **Electrical Power at Monash University – a short walk through history**
- What is this business called Power Electronics ?
- Power Electronics research activities at Monash
- Other Electrical Power Research Activities
  - The EPRI Project
  - High Voltage
  - Renewable Energy
- Summary

- Electrical Power has been a part of Monash Electrical Engineering since department was established.
- It has been a major contributor to both Teaching and Research.
- The focus of activities has changed over the years as older technologies have matured and new technologies have developed.
- One thing remains certain – electrical power is an essential service on which we all depend.

Power at Monash

- From 1960's to 1980's, electrical power generation, transmission and reticulation blossomed in South East Australia
- Transmission System voltages jumped from 132 kV to 220 kV to 500 kV
- Generator sizes increased from 10's MW to 500 MW units
- Many innovative ideas were implemented (SWER, SCADA control)
- Research and development in Electrical Power was a major growth activity.

Power at Monash

- **The major engineering institutions were SECV and ECNSW**
- **Major research institutions were at Monash, Sydney, and Newcastle**
- **The background research into the 500 kV transmission system in Victoria was done at Monash**
- **Major contributions to power system stability were made by Monash during the 1970's**

In the 1980's, the focus changed:

- **Power systems research moved to consider economic issues as well as technical matters**
- **New types of plant appeared, using power electronic conversion systems**
- **Monash incorporated Power Electronics into its Electrical Power research and teaching**
- **Electrical Power became "mature" in the community, always available, always reliable**

In the 1990's there were huge changes in the electrical power supply industry

- State owned utilities were broken up into small competing private companies, in the name of "efficiency"
- Economics became the dominant concern
- Companies focused on "what they were good at" – selling electricity, serving customers
- Central planning effectively ceased, leaving "the market to provide"
- The changes are in still progress!

Power at Monash

Electrical Power at Monash has managed to weather this storm for over a decade (well, at least we are still here!)

- **The Centre for Electrical Power Engineering was established in 1991 as a final contribution from the SECV**
- **8 academics were employed for over 5 years**
- **Research activities developed in several areas**
- **Power Electronics established itself as a major international research contributor**

Unfortunately nothing lasts forever!

- Funding from the electrical power generation industry has been greatly reduced
- The focus of the industry is on training and management of the existing resources, not new developments
- Electrical Power and Energy at Monash must find a new focus if it is to continue
- Power Electronics and Industrial Electronics is a world wide R&D growth market, so that is becoming a major new focus for Monash.

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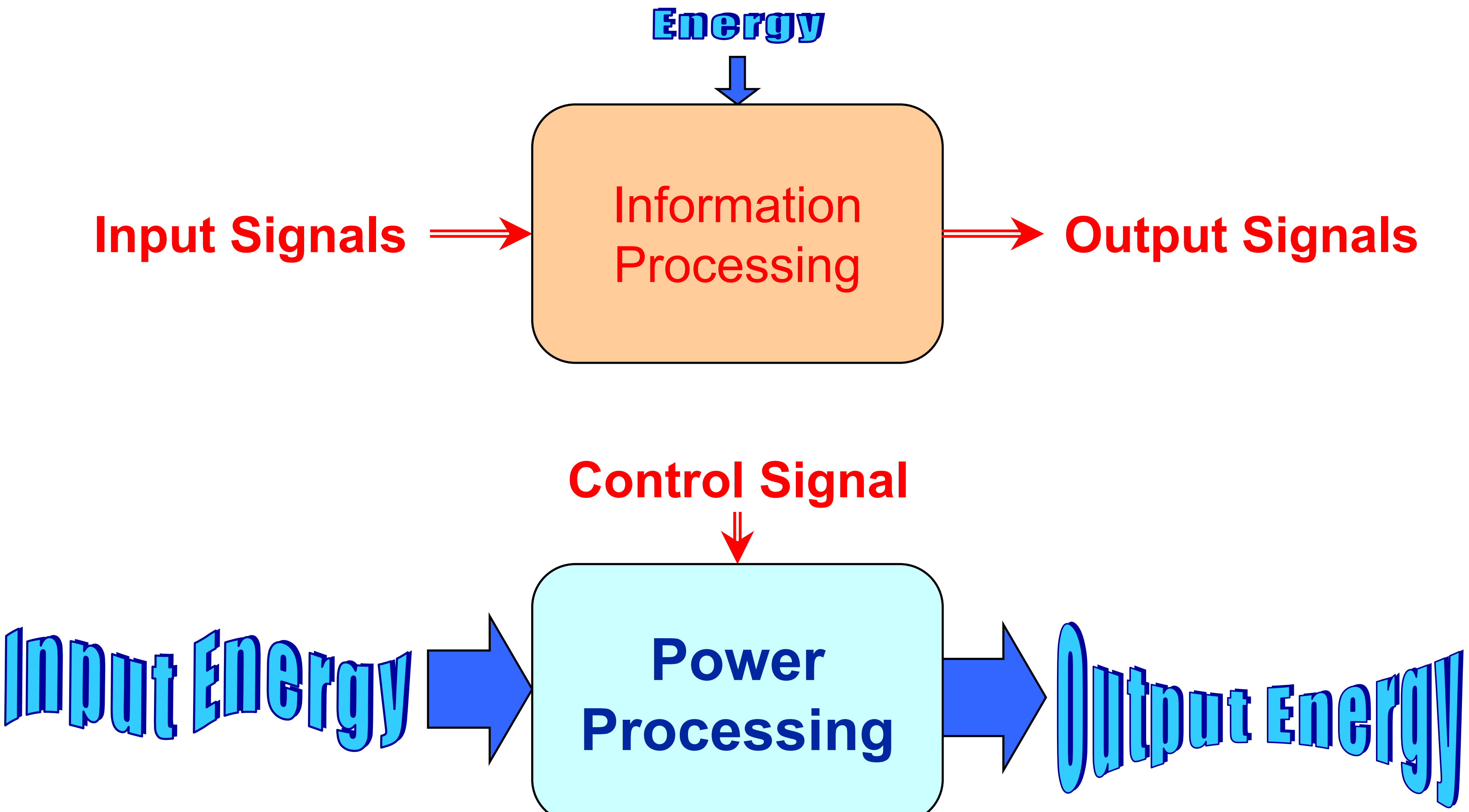
Power Electronics ?

- **Power:** turns the lights on
- **Electronics:** transistor radios

But what is Power Electronics ?

- **Power Electronic Systems use electronics to control Electrical Energy usage**
- **Power levels range from *milliwatts* to *megawatts***
- **The common element is a switched energy conversion process, smoothed by input and output filters**

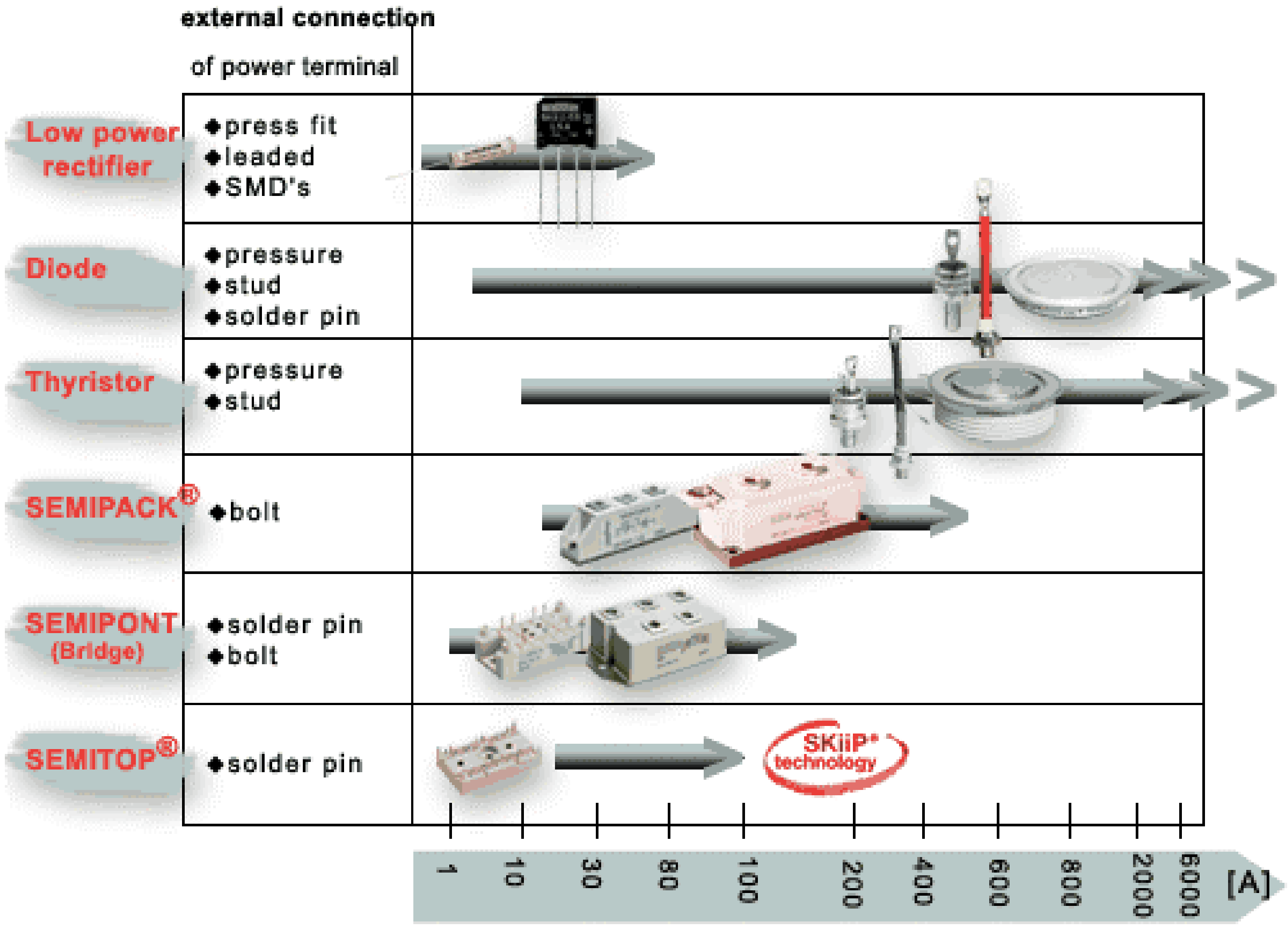
Microelectronics *vs.* Power Electronics



Power Electronics ?

- **Power Electronic converters have existed for nearly 40 years.**
- **Initially based on Silicon Controlled Rectifiers (controlled turn-on, uncontrolled turn-off).**
- **Modern semiconductor devices are:**
  - **Power MosFET's, 100's volts, 10's amps**
  - **Insulated Gate Bipolar Transistors (IGBT), 2000+ volts, 500 A**
  - **Insulated Gate Controlled Thyristor (IGCT), 4000+ volts, 1000's amps.**
  - **Gate Turn Off Thyristor (GTO), 6000+volts, 1000's amps**

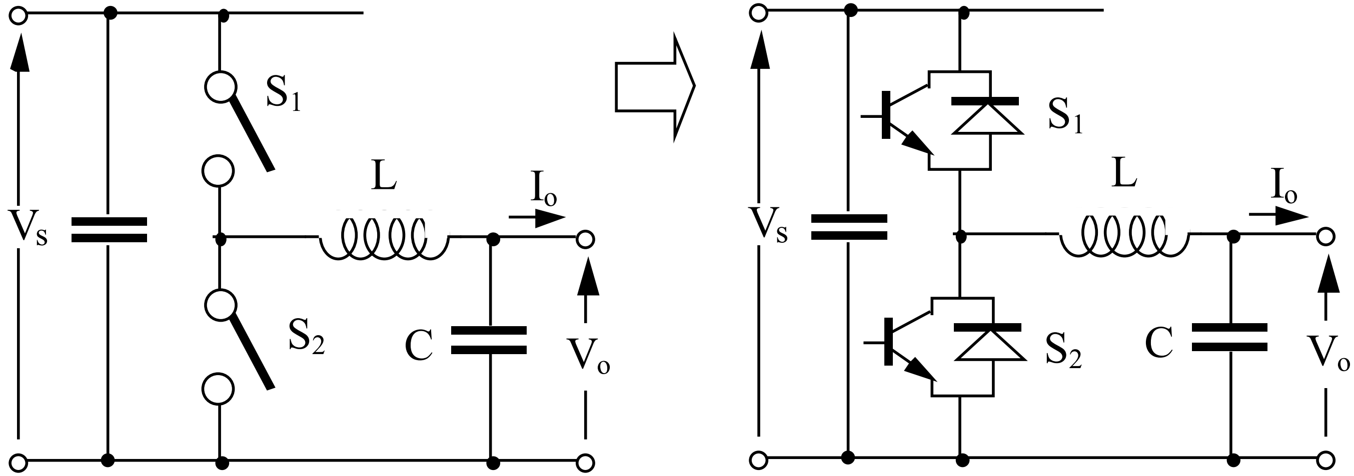
Power Electronics ?



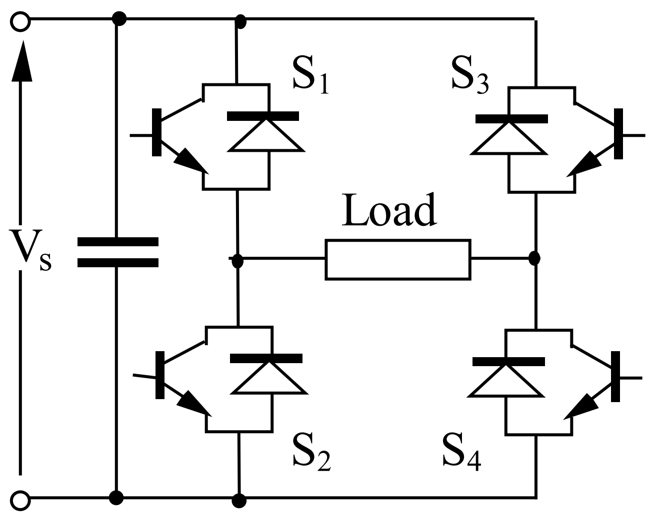
Courtesy: Semikron website

Power Electronics ?

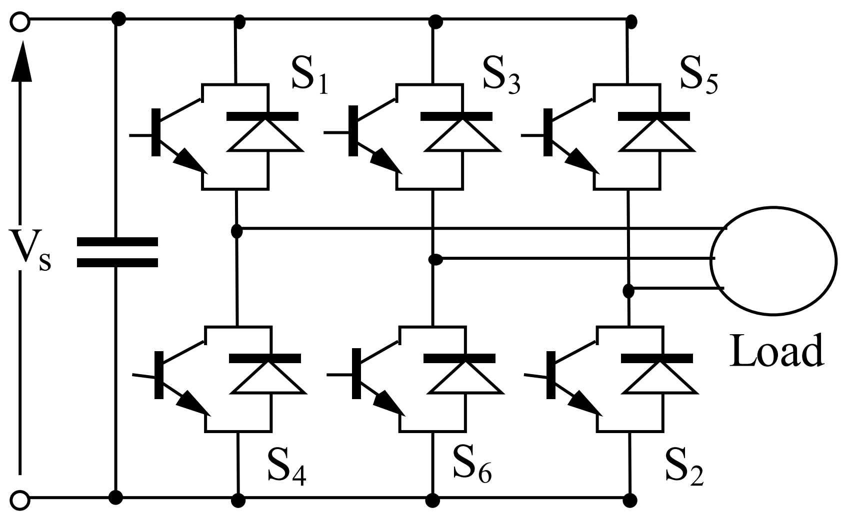
- **Basic cell structure is half bridge phase leg**
- **Generic form uses ideal switches that can block block bi-directional volt, conduct bi-directional current**
- **Conventional form uses transistor/diode combination that can block uni-directional volt**
- **Input is voltage stiff, Output is current stiff, transfer function is stepdown (buck).**



- **Voltage Source Inverter (VSI)**
  - **Smooth DC Input Voltage, Switched Input Current**
  - **Switched AC Output Voltage, Smooth Output Current**
  - **Bi-directional current and power flow**
  - **Step down voltage transfer ratio**

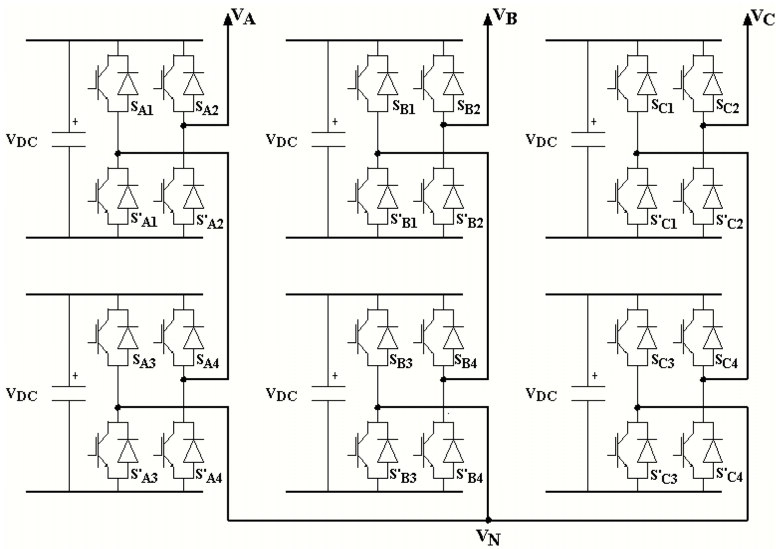


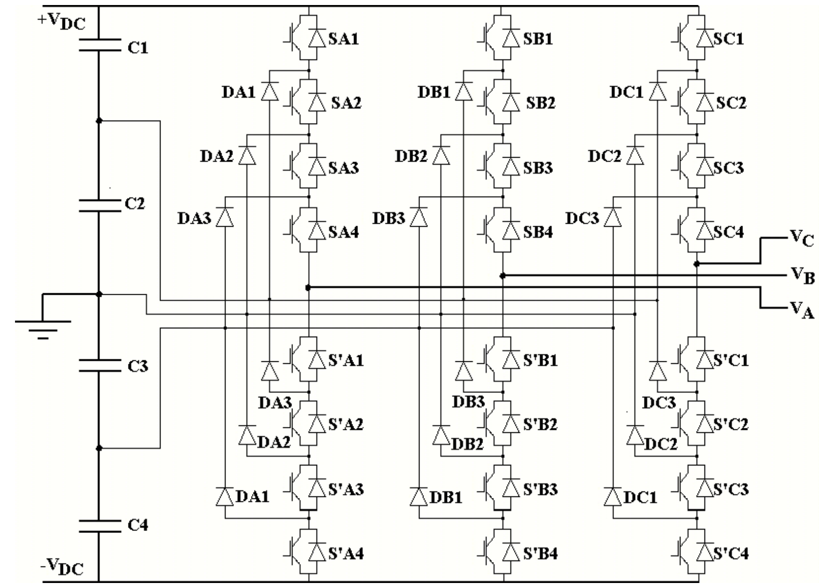
Single Phase



Three Phase

Power Electronics ?





Cascaded Topology

- Isolated DC Supplies
- Suitable for High Num Levels
- Hybrid - Unequal Supplies

Diode Clamped Topology

- One DC bus
- Capacitors form Levels
- Voltage Balance restricts No. Levels

Power Electronics ?

- Open Loop Modulation is the processing of controlling the actual switching of the semiconductor elements
- Closed Loop Regulation is a feedback arrangement to control the modulation to achieve a controlled variable outcome
- Applications are combinations of modulation and regulation processes operating as complete working systems
- Analogue controlled systems are common historically and still used for simple applications
- Digitally controlled systems are much more common and essentially now dominate

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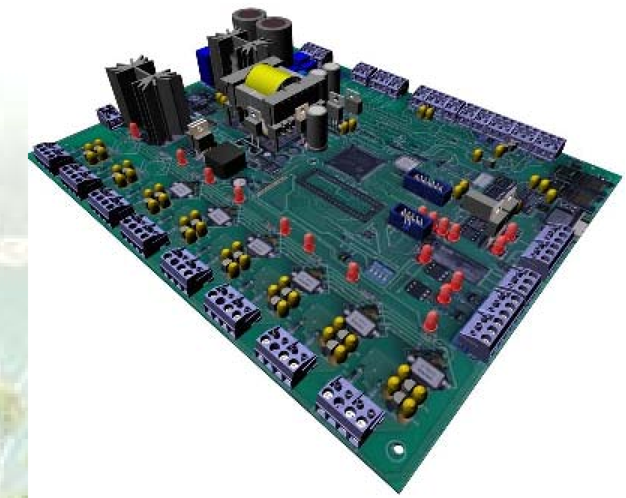
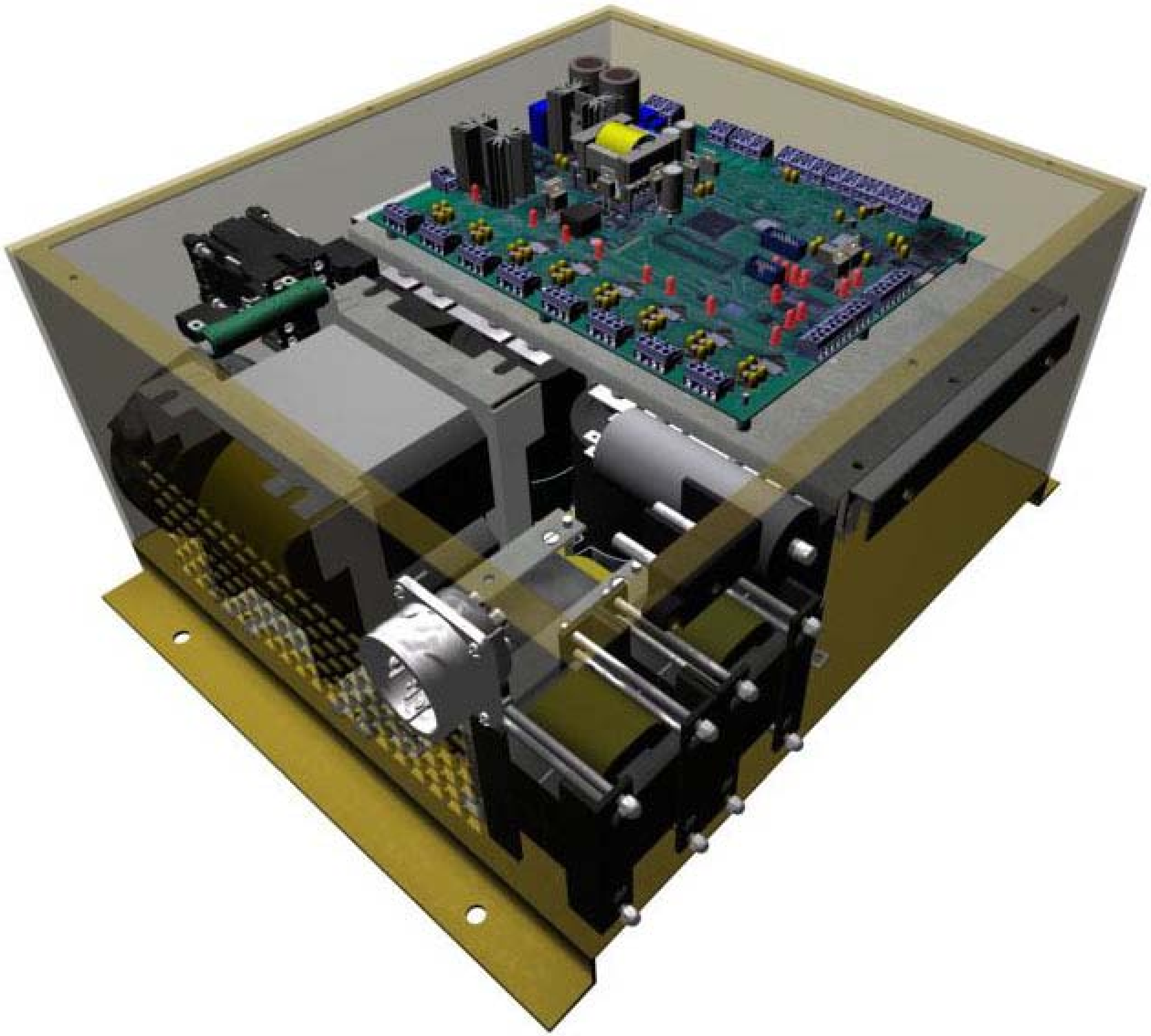
- Power Electronics Group (PEG) at Monash was started in 1995
- Staff comprises:
  - 2 academic faculty
  - employed research engineers
  - post-graduate students – Masters and PhD.
- PEG undertakes both fundamental research and practical commercial developments
- Research activities include:
  - PWM modulation
  - Open and Closed Loop control of VSI/CSI
  - Active Filters & other Custom Power applications
  - Distributed Generation in weak grid systems
  - Traction systems





Advances in Modulation Theory

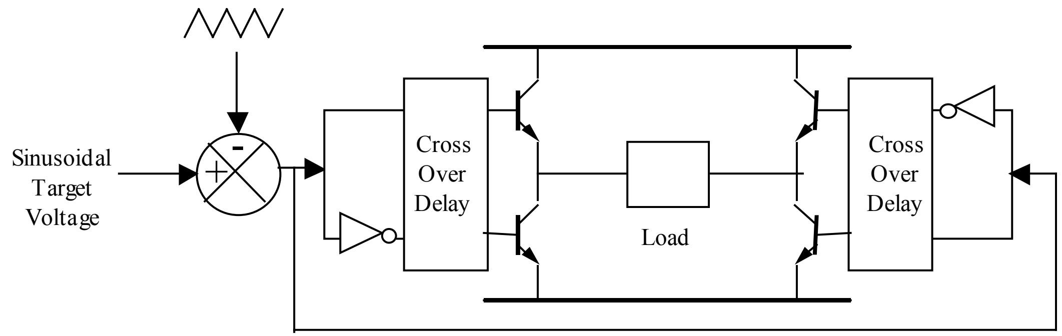
1970's: Major steps forward

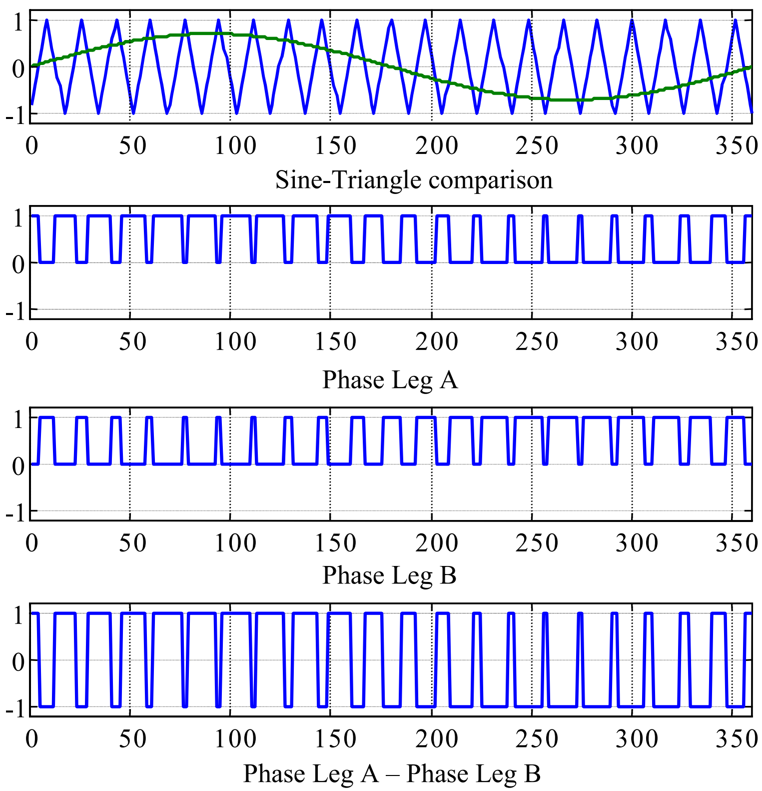
1980's: Minor improvements

Since then - refinements, despite many hundreds of papers !!!

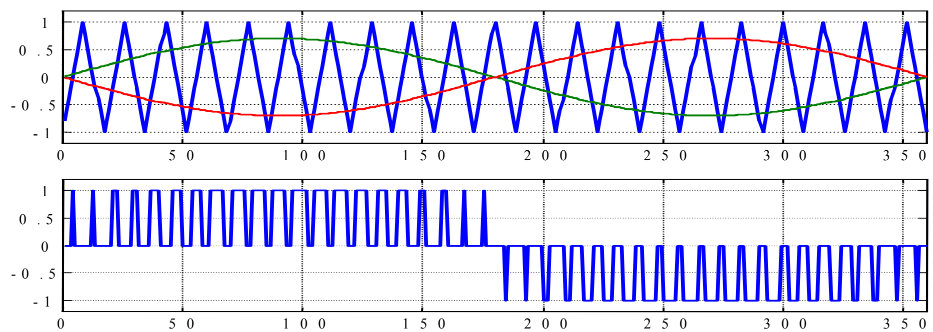
Finally, consolidation has been achieved in the last few years, with significant contributions from PEG

Simplest strategy is sin-triangle PWM





TWO LEVEL PWM



THREE LEVEL PWM

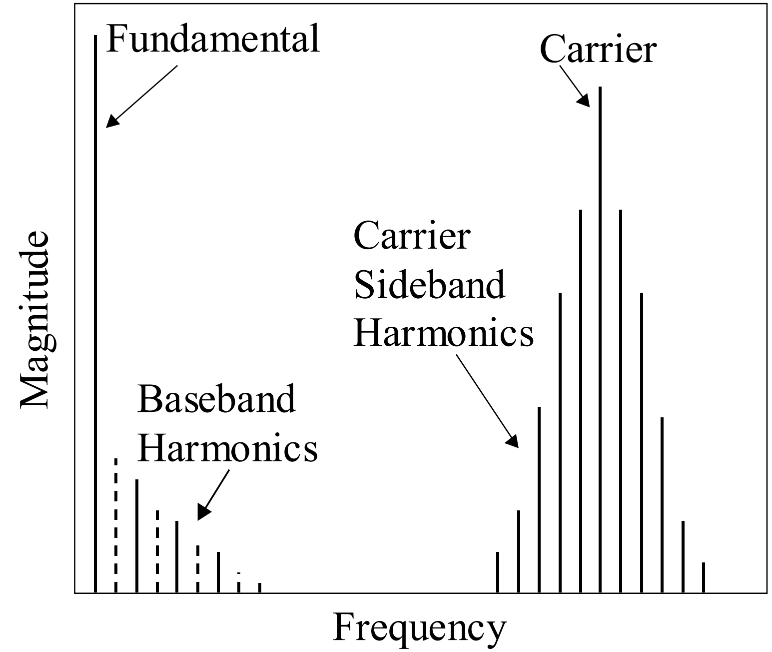
Analytical Solution is obtained by Double Fourier Analysis of the Switched Phase Leg Output Waveform, which gives:

$$F(t) = \frac{A_{00}}{2} + \sum_{n=1}^{\infty} \left\{ \begin{matrix} A_{0n} \cos(n\omega_o t) + \\ B_{0n} \sin(n\omega_o t) \end{matrix} \right\} + \sum_{m=1}^{\infty} \left\{ \begin{matrix} A_{m0} \cos(m\omega_c t) + \\ B_{m0} \sin(m\omega_c t) \end{matrix} \right\} + \sum_{m=1}^{\infty} \sum_{\substack{n=-\infty \\ n \neq 0}}^{\infty} \left\{ \begin{matrix} A_{mn} \cos(m\omega_c t + n\omega_o t) + \\ B_{mn} \sin(m\omega_c t + n\omega_o t) \end{matrix} \right\}$$

$$C_{mn} = A_{mn} + jB_{mn} = \frac{1}{2\pi^2} \int_{-\pi}^{\pi} \int_{-\pi}^{\pi} F(x,y) e^{j(mx+ny)} dx dy \,, \qquad x = \omega_c t, y = \omega_o t$$

The solution contains:

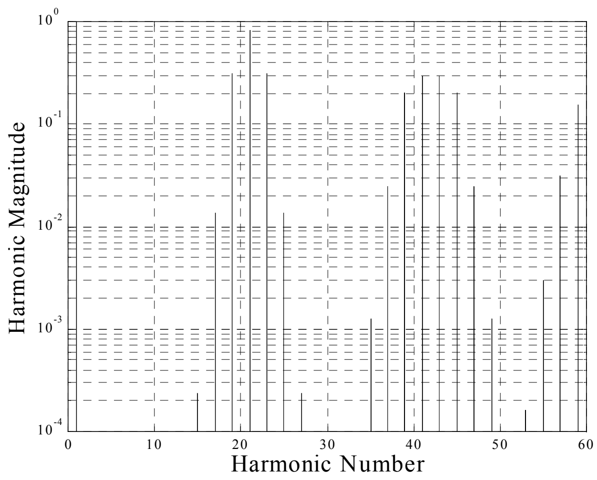
- **Fundamental component**
- **Baseband Harmonics**
- **Carrier Harmonics**
- **Sideband Harmonics**



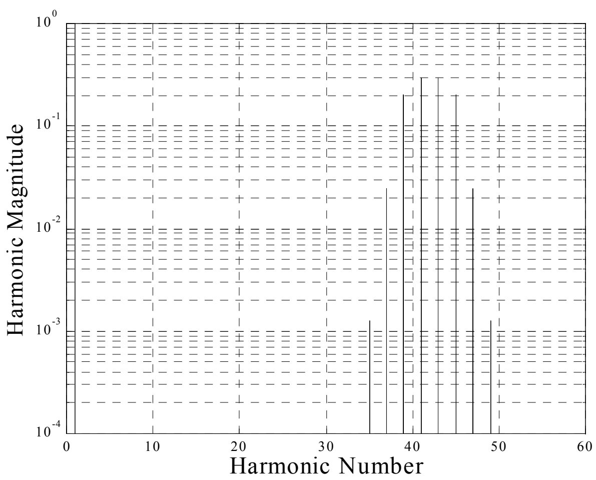
Analytical Solution for one Phase Leg is

$$v_{an}(t) = V_{dc} + MV_{dc}\cos(\omega_o t + \theta_o) + \sum_{m=1}^{\infty}\left[\frac{4V_{dc}}{m\pi} J_0\left(m\frac{\pi}{2}M\right)\sin m\frac{\pi}{2}\cos(m[\omega_c t + \theta_c])\right]$$
$$+ \sum_{m=1}^{\infty}\sum_{\substack{n=-\infty \\ (n\neq 0)}}^{\infty}\frac{4V_{dc}}{m\pi} J_n\left(m\frac{\pi}{2}M\right)\sin\left([m+n]\frac{\pi}{2}\right)\cos(m[\omega_c t + \theta_c] + n[\omega_o t + \theta_o])$$

Harmonics cancel between phase legs differently for two level and three level modulation

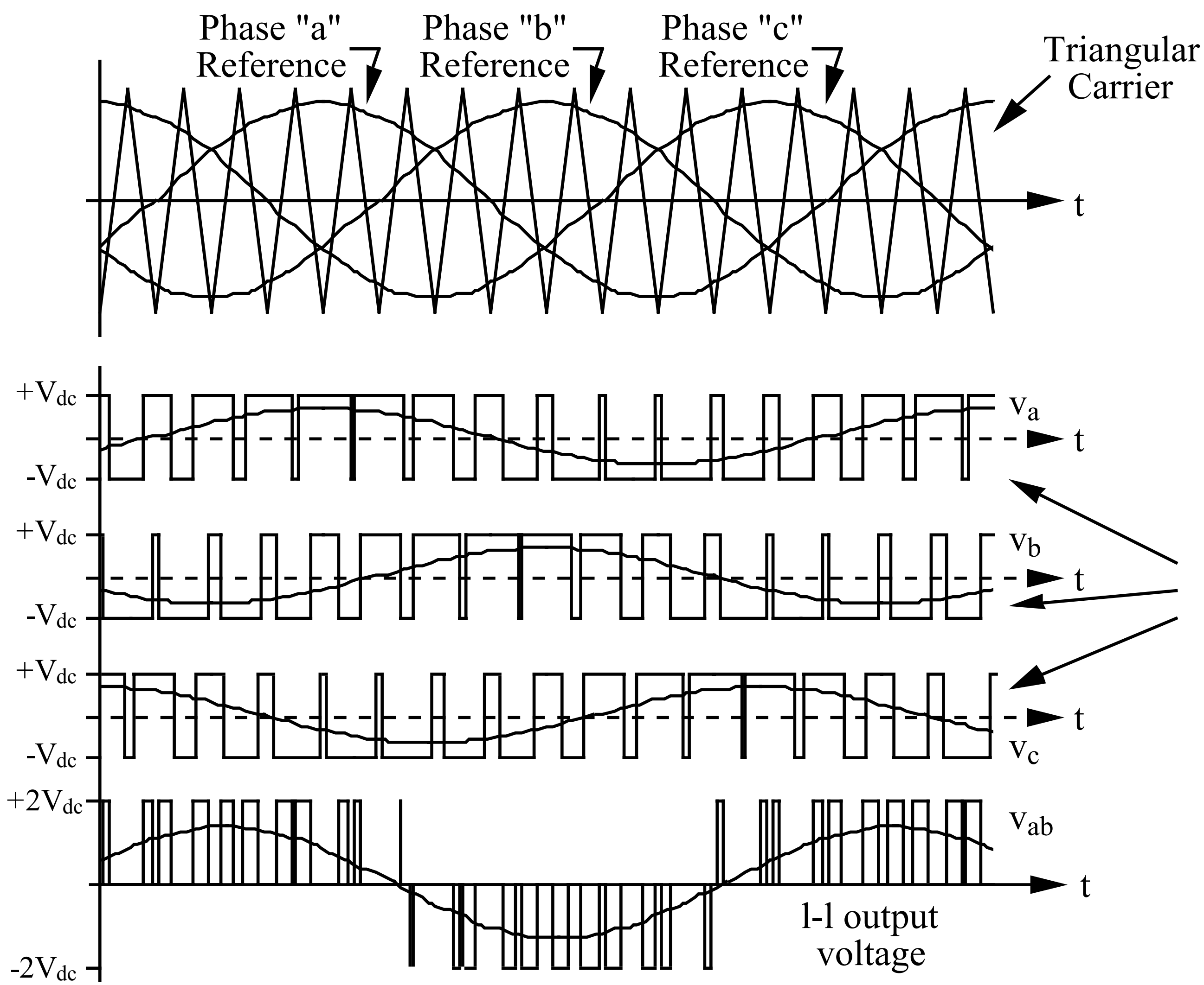


Two level PWM

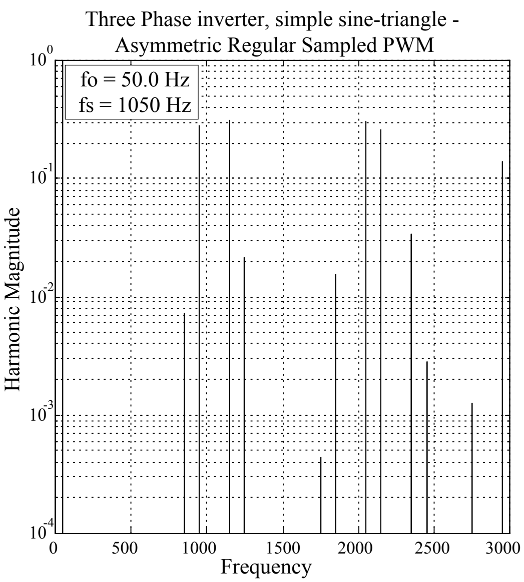


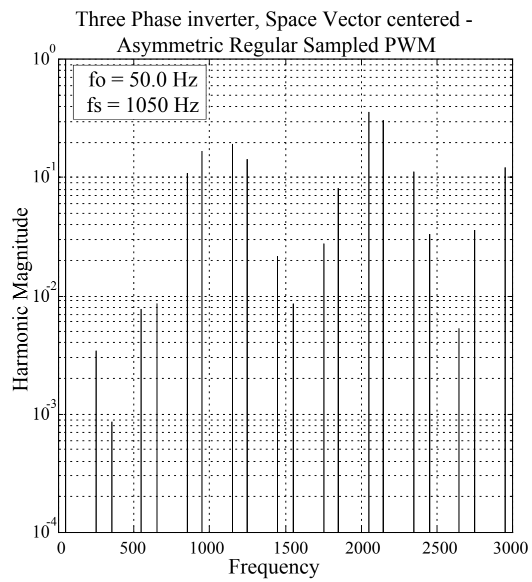
Three Level PWM

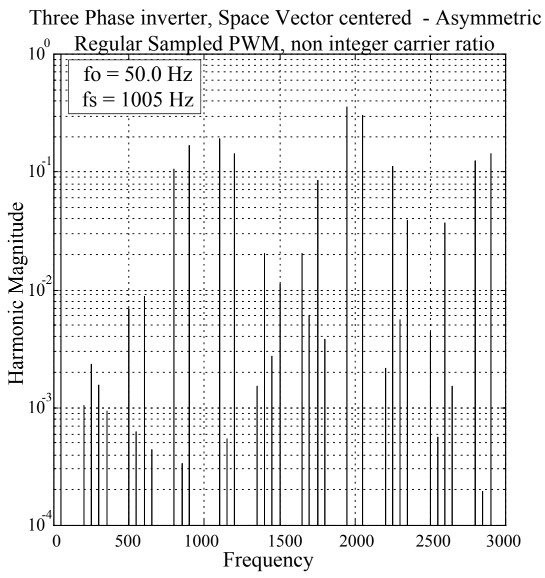
Three phase inverters use the same strategy with reference waveforms that are displaced in time by 120°.



Now the harmonics cancel between the phase legs differently, since the reference offset angles are different.



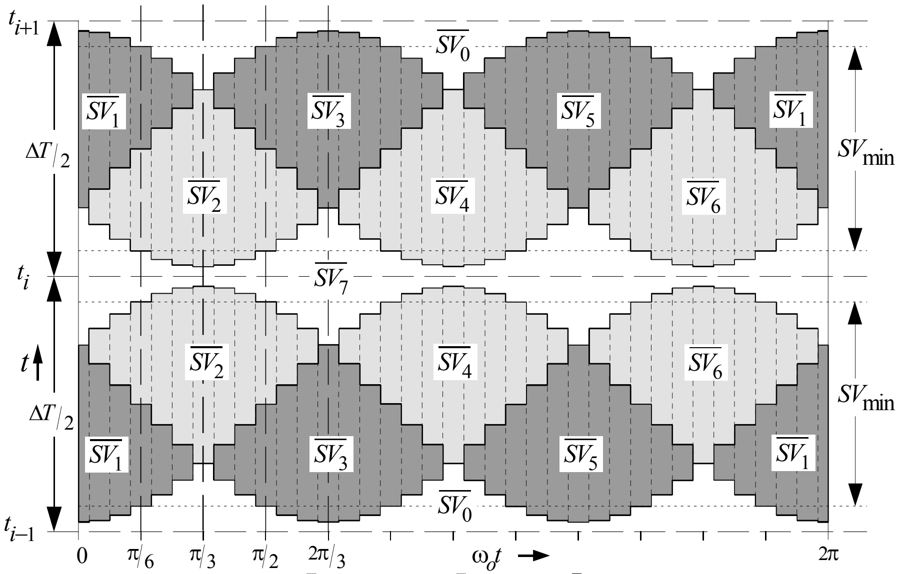




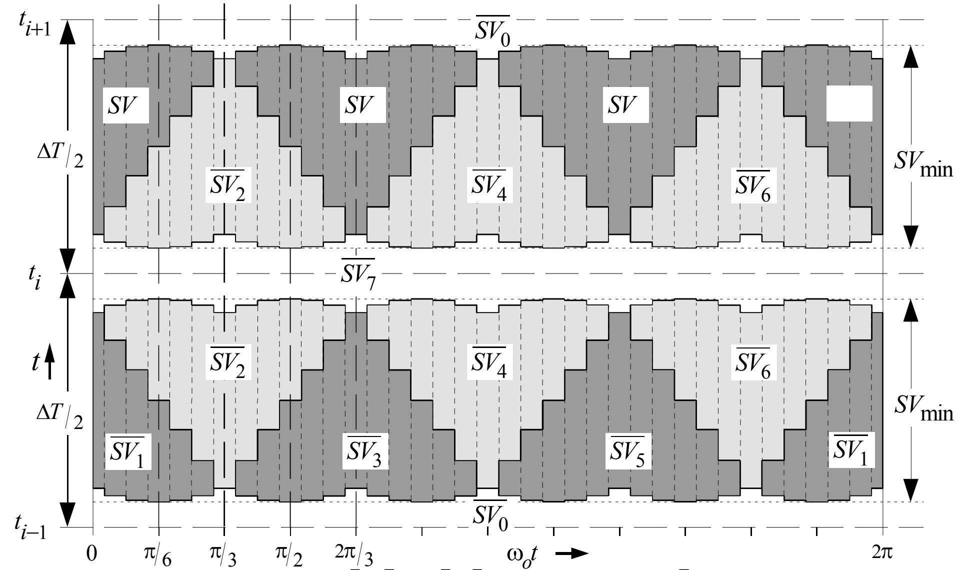
Simple Sine References

Third Harmonic Reference

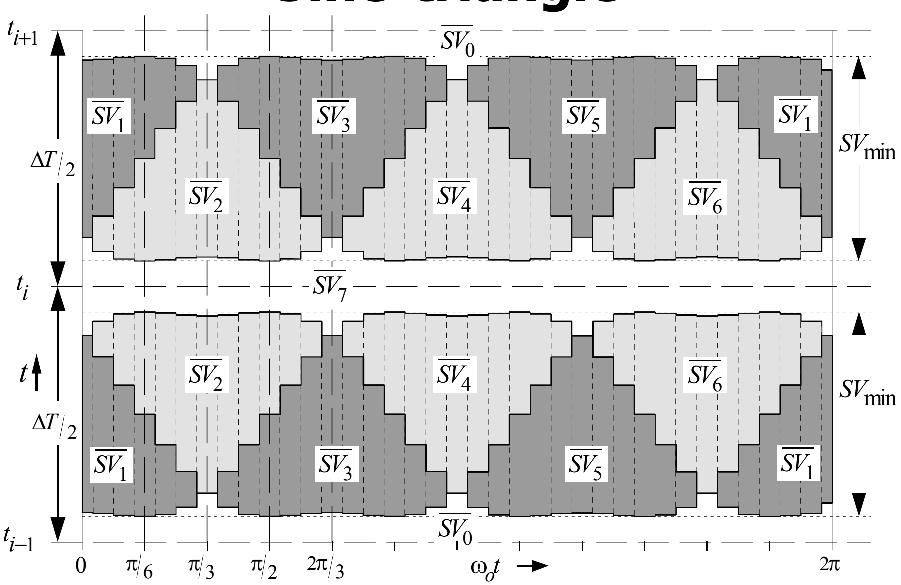
Asynchronous Pulse Ratio



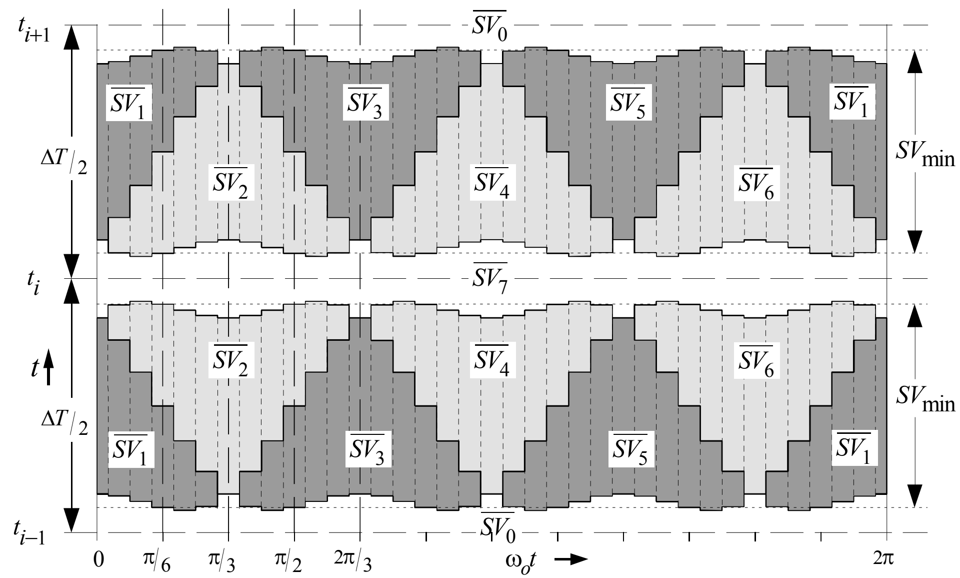
Sine-triangle



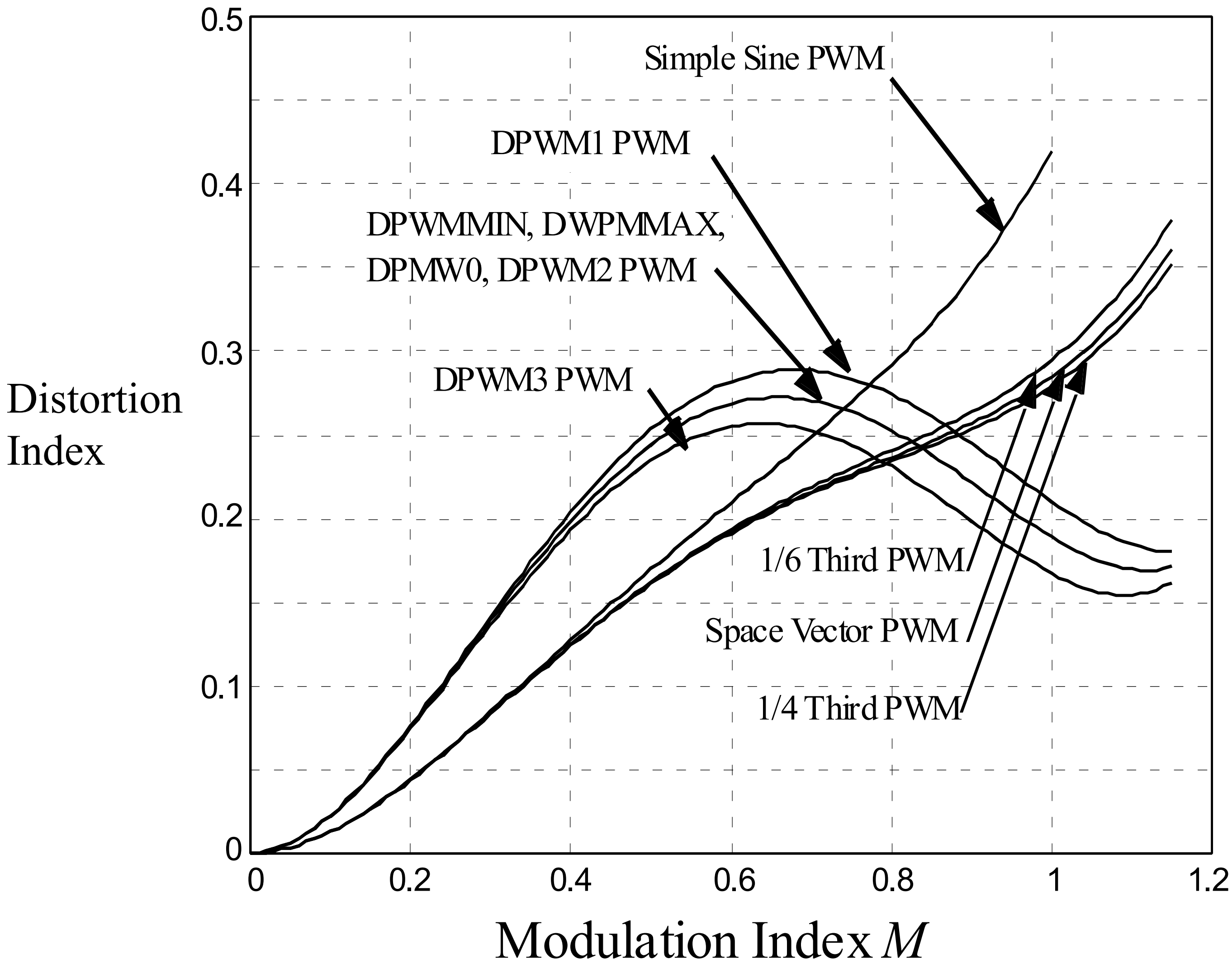
¼ third harmonic



1/6 third harmonic

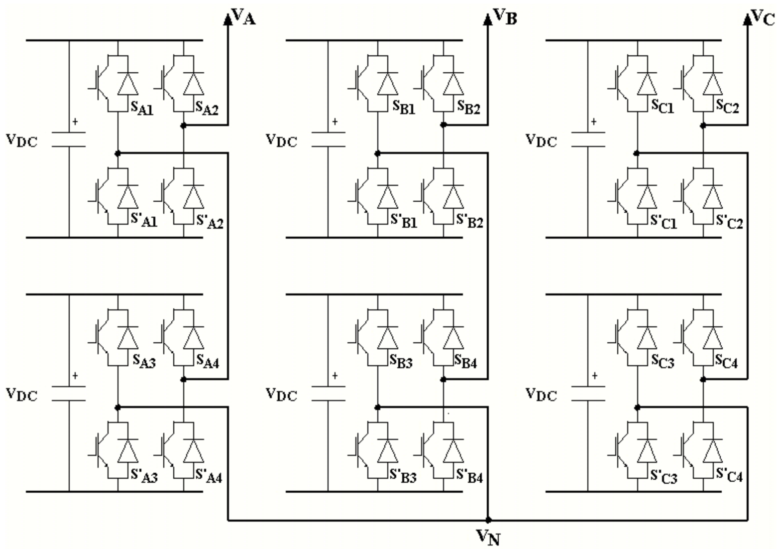


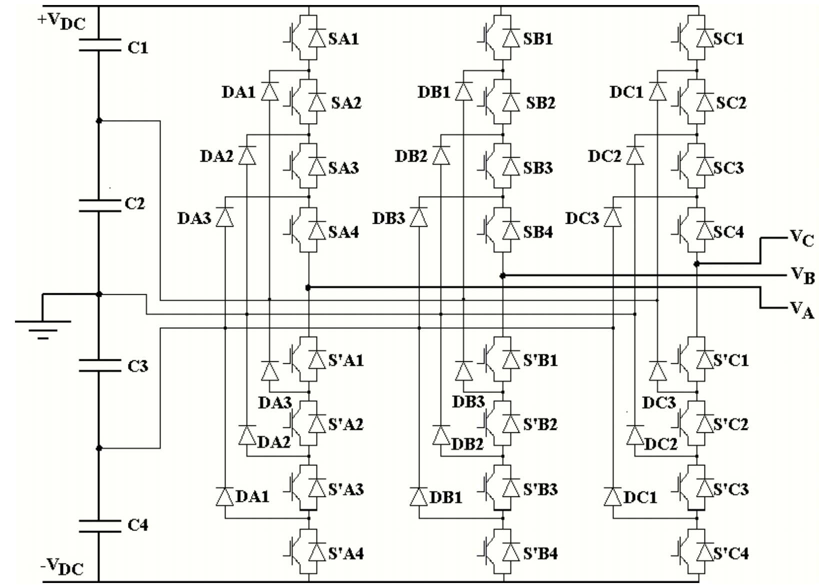
Space vector


Simple Sine PWM
DPWM1 PWM
DPWMMIN, DWPMMAX,
DPMW0, DPWM2 PWM
DPWM3 PWM
1/6 Third PWM
Space Vector PWM
1/4 Third PWM
Distortion Index
Modulation Index M
0.5
0.4
0.3
0.2
0.1
0
0
0.2
0.4
0.6
0.8
1
1.2

PWM applied to Multilevel converters

- POD/APOD/PD Sine-triangle modulation strategies
- Equivalence of Sine-triangle and SV modulation
- Reduced common mode PWM strategies



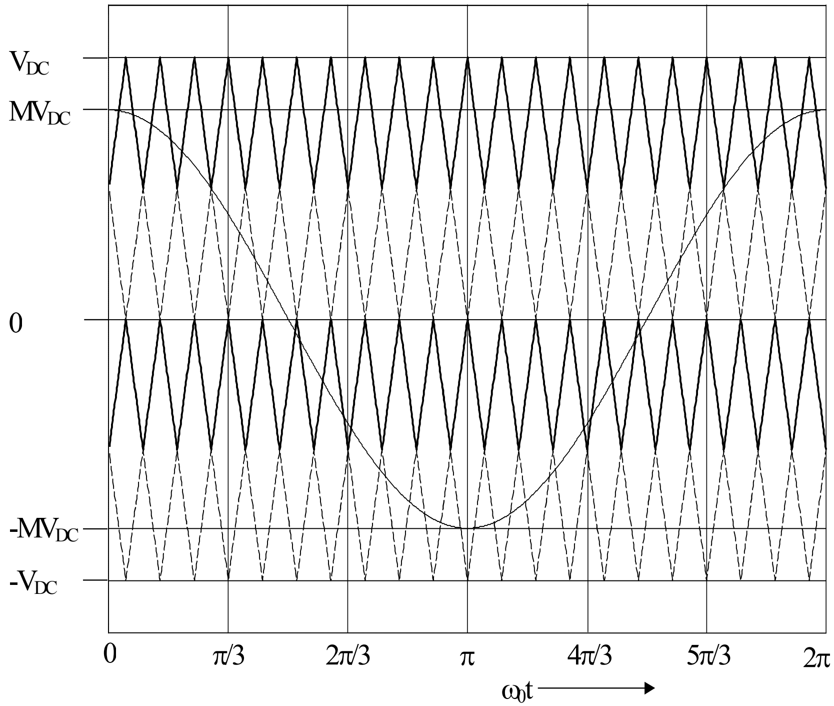


Cascaded Topology

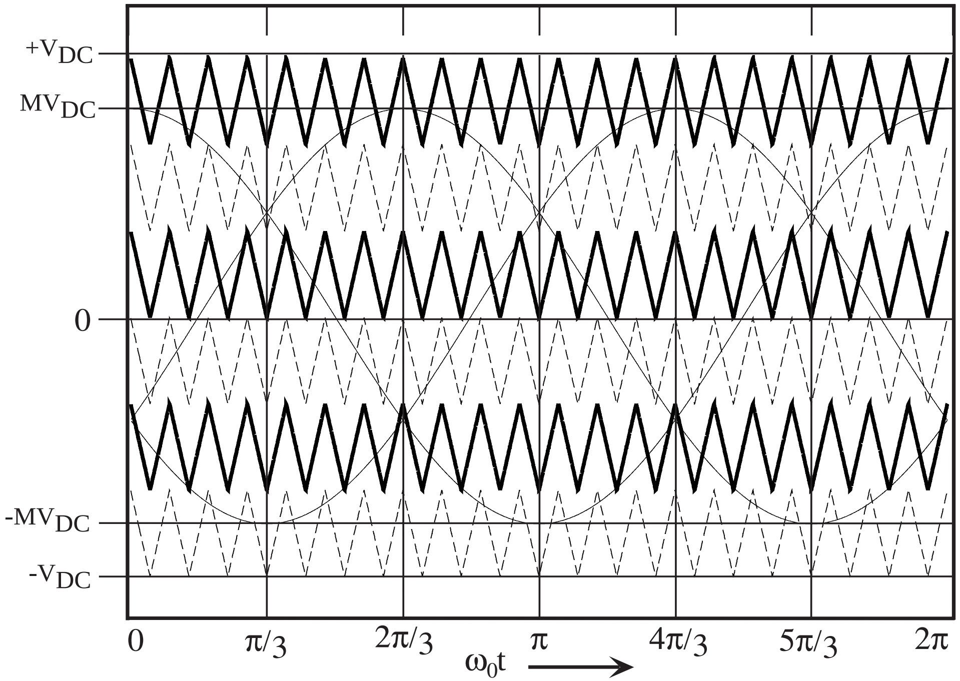
- Isolated DC Supplies
- Suitable for High Num Levels
- Hybrid - Unequal Supplies

Diode Clamped Topology

- One DC bus
- Capacitors form Levels
- Voltage Balance restricts No. Levels

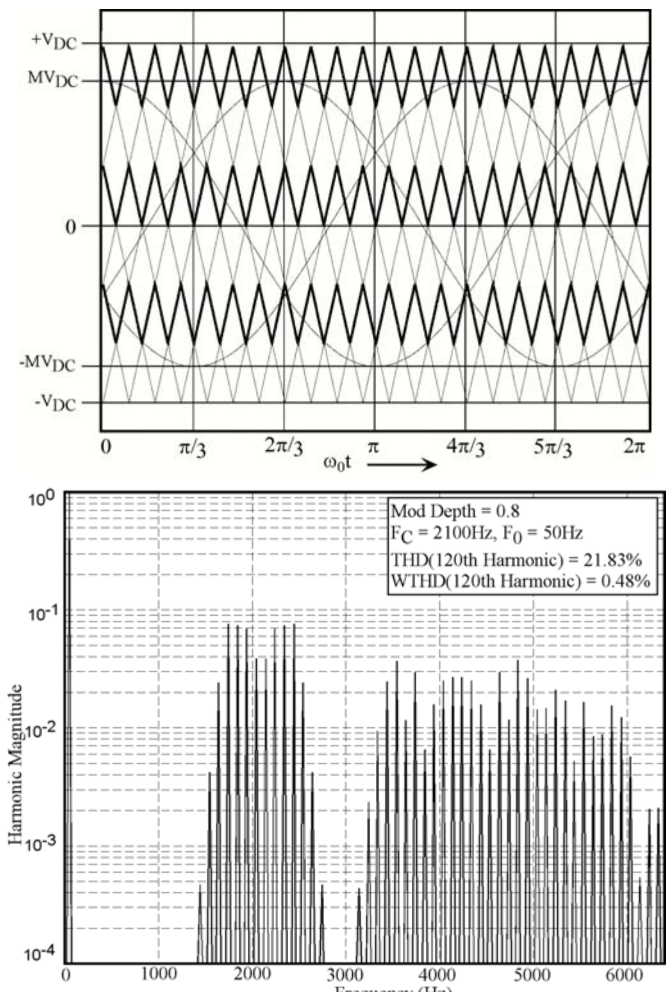


5 Level APOD Modulation

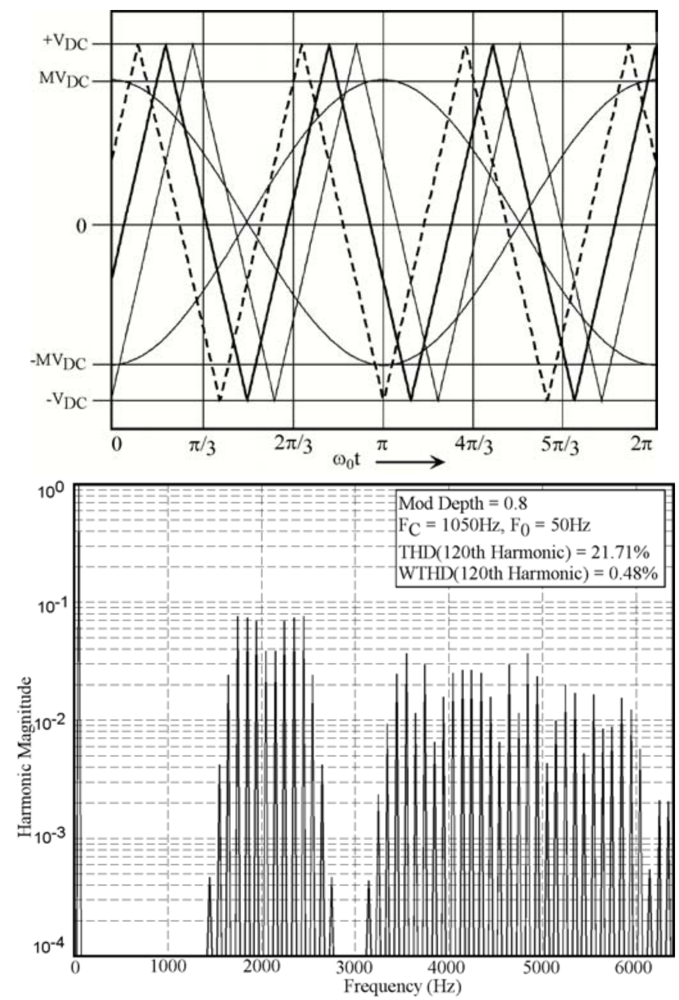


5 Level PD Modulation

Multilevel PWM is more complex to develop analytical solutions. However, the results identify a direct match between NPC APOD and cascaded inverter modulation.

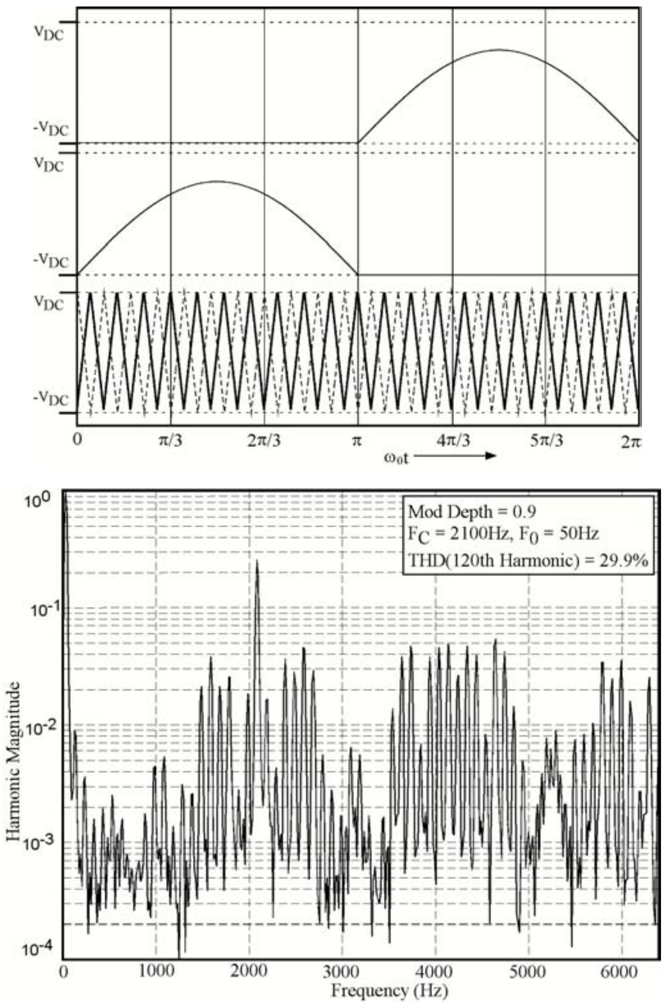


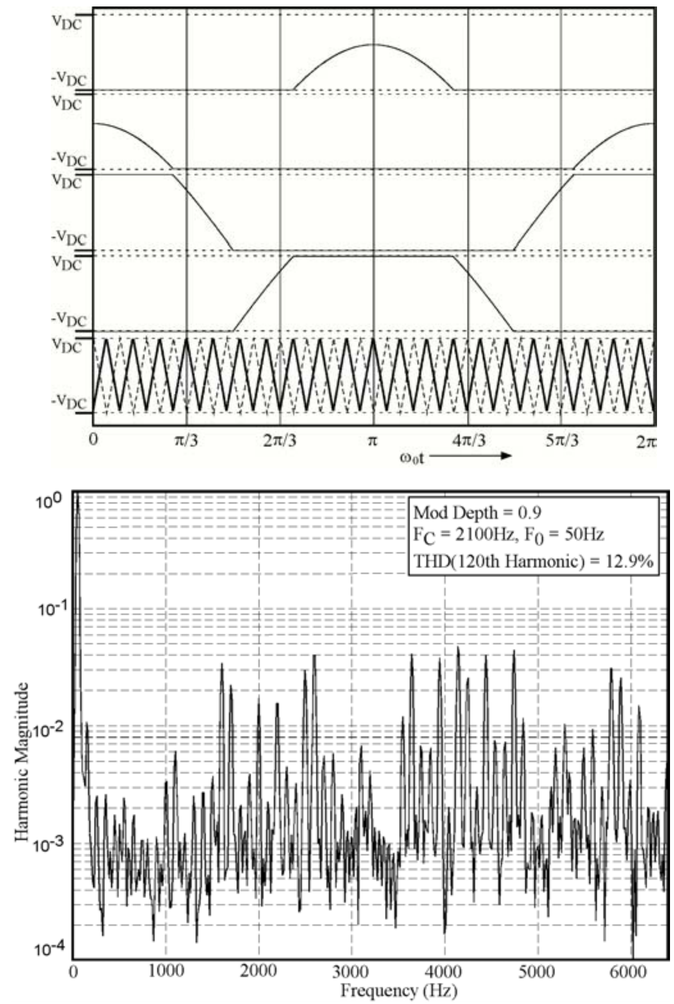
Phase Leg Harmonics



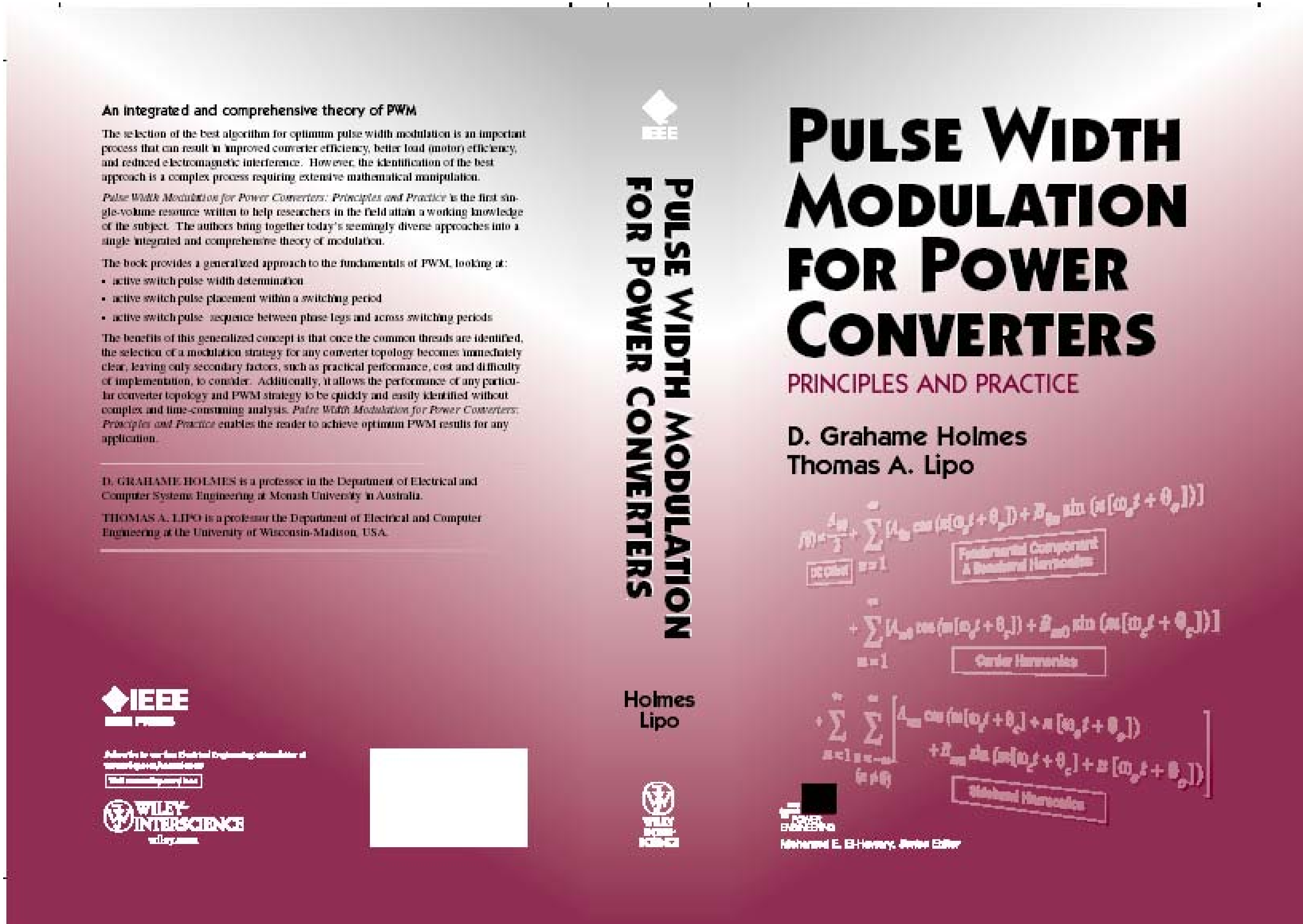
L-L Harmonics

This in turn allows a new modulation strategy to be developed for Cascaded Inverters, which achieves PD type harmonic response.





- **Target Objectives of a modulation system are to switch an inverter to achieve an "average" output voltage.**
- **Once this is achieved, the secondary objectives of reduced harmonics and minimised losses can be considered.**
- **These objectives are achieved by using the three nearest active space vectors to the target reference phasor, and placing these vectors centrally in the carrier period.**
- **Carrier-based and SV strategies can achieve identical harmonic results provided a suitable offset waveform is defined.**
- **Concepts readily extrapolate to multilevel inverters.**


An integrated and comprehensive theory of PWM
The selection of the best algorithm for optimum pulse width modulation is an important process that can result in improved converter efficiency, better load (motor) efficiency, and reduced electromagnetic interference. However, the identification of the best approach is a complex process requiring extensive mathematical manipulation.
Pulse Width Modulation for Power Converters: Principles and Practice is the first single-volume resource written to help researchers in the field attain a working knowledge of the subject. The authors bring together today's seemingly diverse approaches into a single integrated and comprehensive theory of modulation.
The book provides a generalized approach to the fundamentals of PWM, looking at:
• active switch pulse width determination
• active switch pulse placement within a switching period
• active switch pulse sequence between phase legs and across switching periods
The benefits of this generalized concept is that once the common threads are identified, the selection of a modulation strategy for any converter topology becomes immediately clear, leaving only secondary factors, such as practical performance, cost and difficulty of implementation, to consider. Additionally, it allows the performance of any particular converter topology and PWM strategy to be quickly and easily identified without complex and time-consuming analysis. Pulse Width Modulation for Power Converters: Principles and Practice enables the reader to achieve optimum PWM results for any application.
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THOMAS A. LIPO is a professor the Department of Electrical and Computer Engineering at the University of Wisconsin-Madison, USA.
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Fundamental Component & Baseband Harmonics
Carrier Harmonics
Sideband Harmonics
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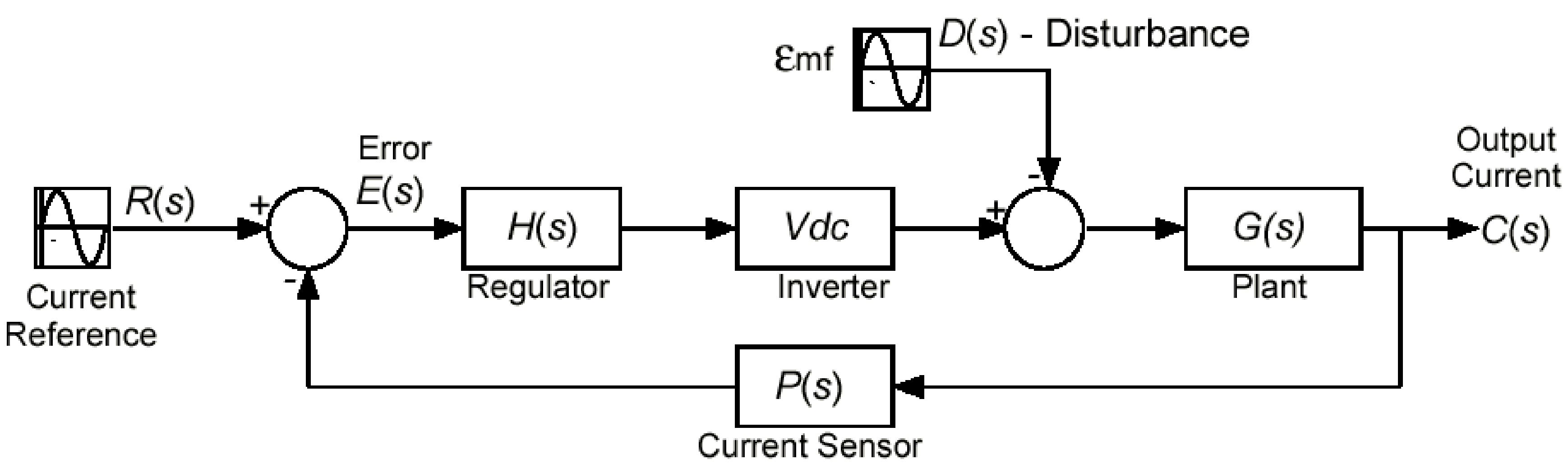
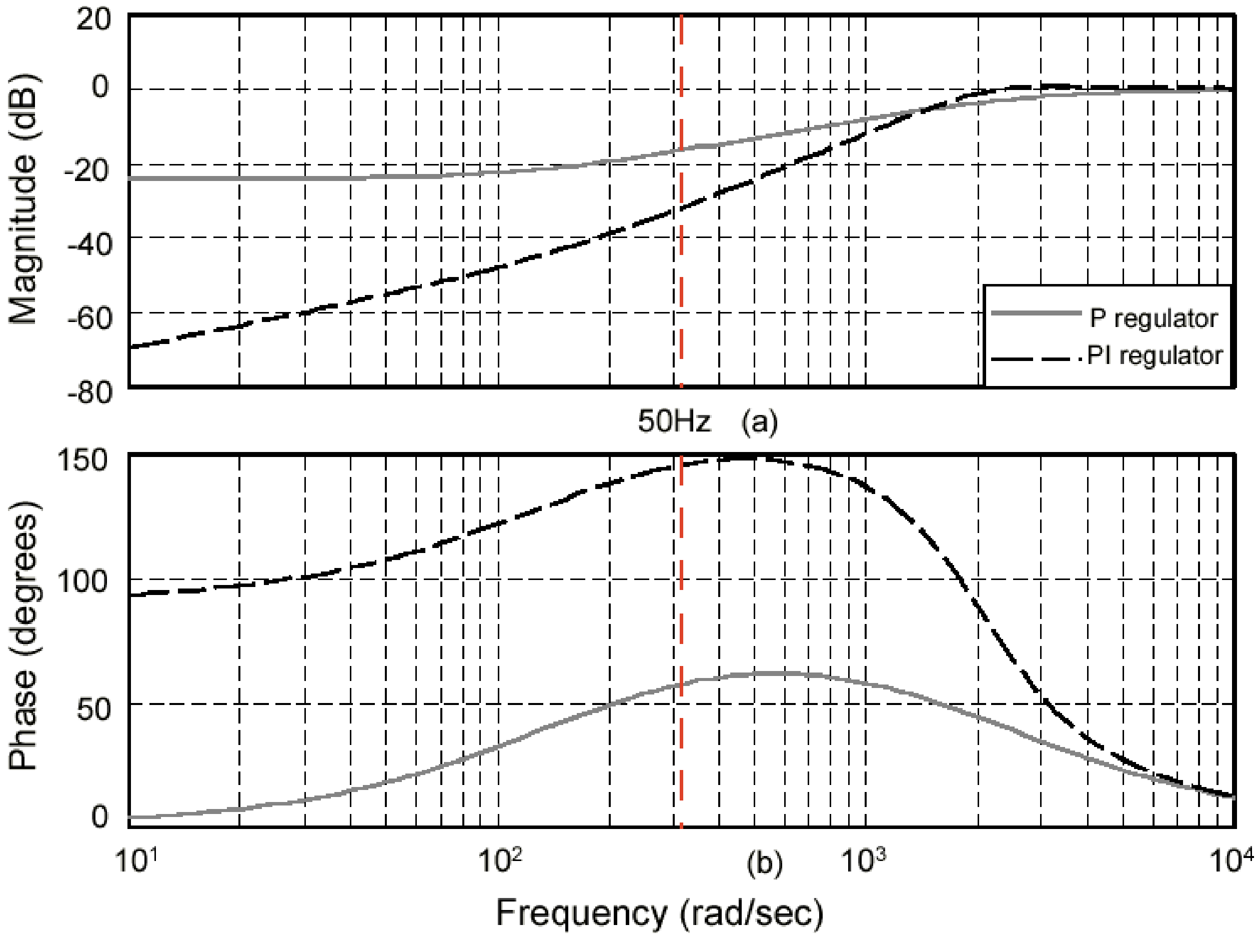
LINEAR CLOSED LOOP CONTROL

- **Conventional Closed Loop Control uses Proportional and integral Gain in the forward path to minimise error.**
- **Typical application is current controlled inverter**

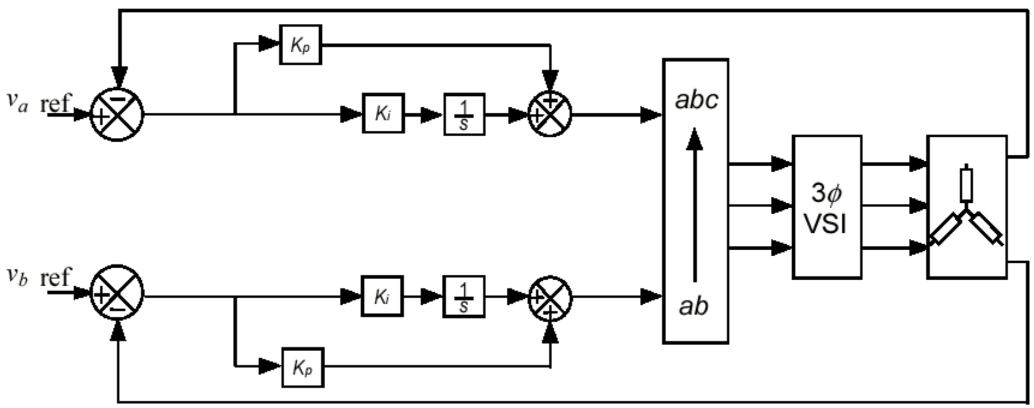


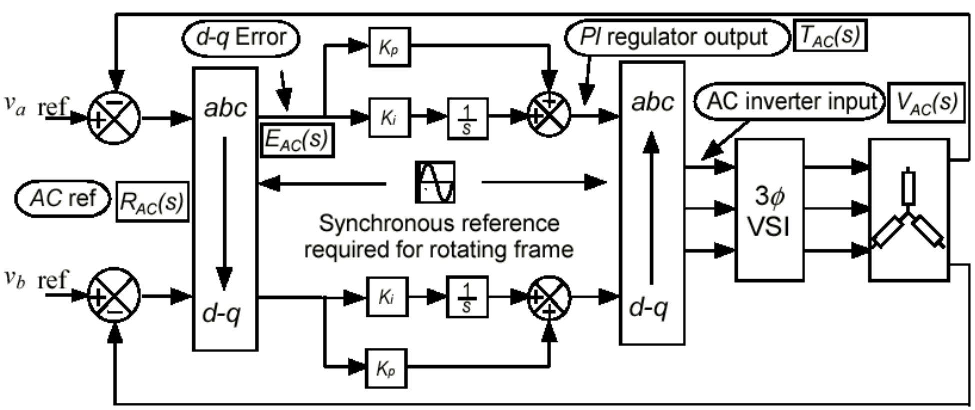
This type of system is known to create steady state error for AC regulation systems.



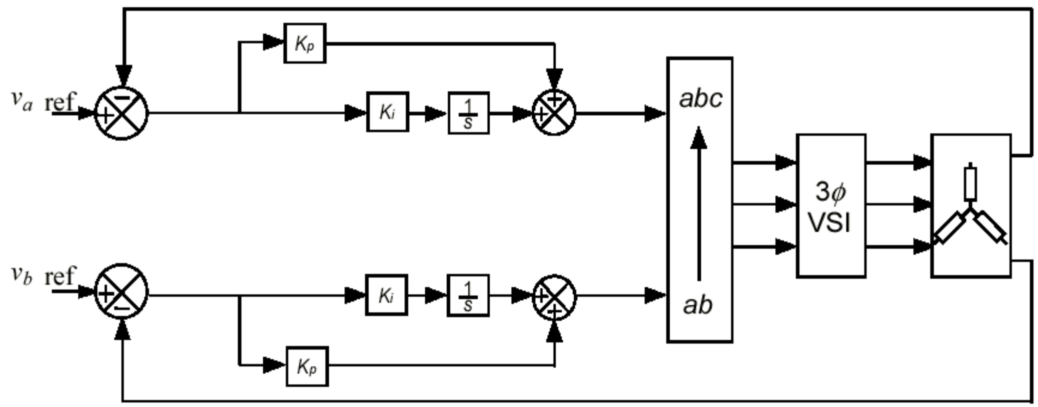
Plot of error verses reference as frequency varies

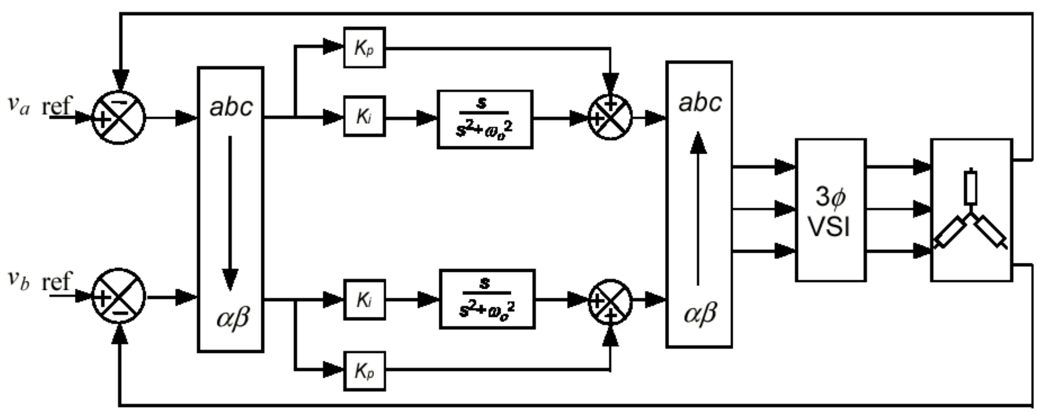
- **For Three Phase systems, regulation in the synchronous d-q frame eliminates steady state error.**
- **There is no simple single phase equivalent**



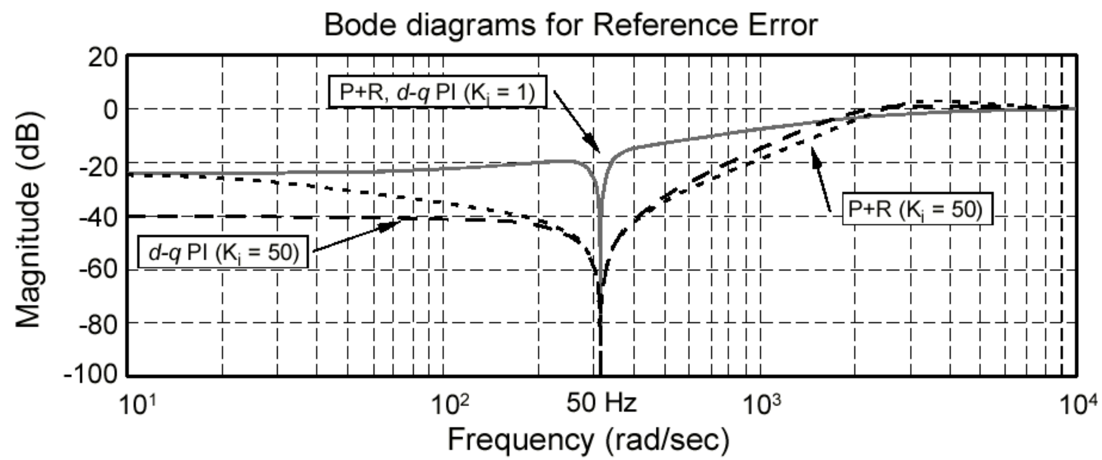


- **Can get an equivalent response by implementing a resonant gain block in the stationary frame.**
- **Equally applicable to single or three phase systems**

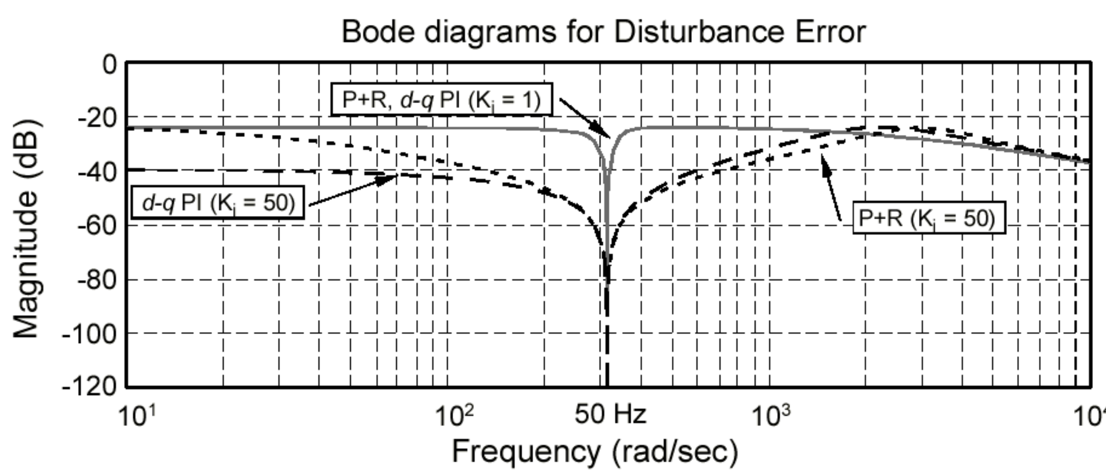




- **The notch filter achieved almost infinite gain at the target frequency and hence almost zero error**

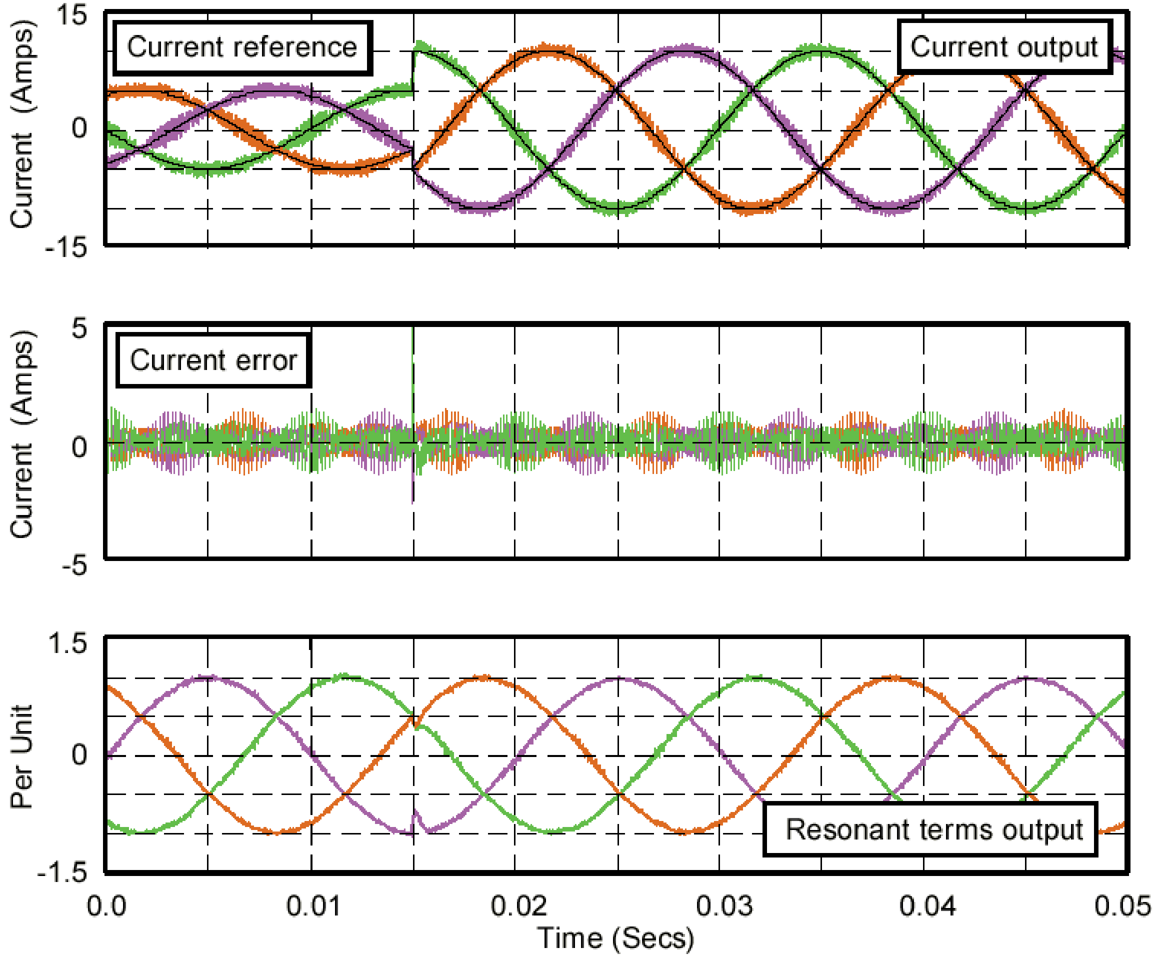


(b) Reference error $\frac{E_a(s)}{I_a^*(s)}$



(c) Disturbance error $\frac{E_a(s)}{D_a(s)}$

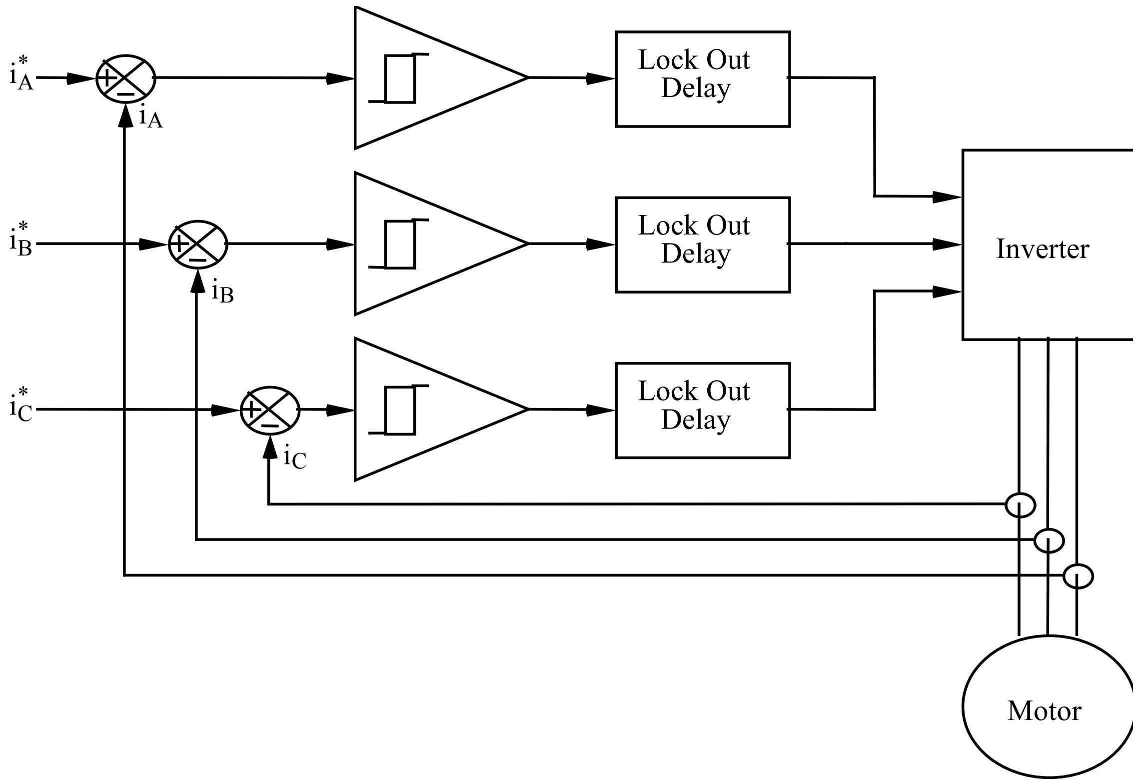
- **The performance of the *P+ resonant* controller is excellent as a current regulator**



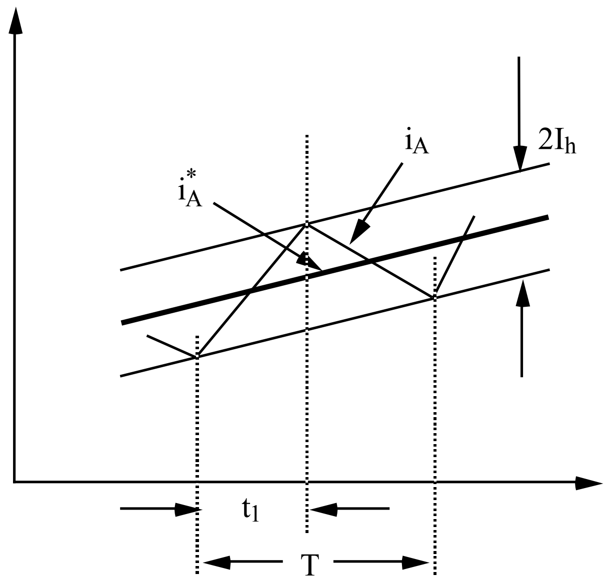
(a) P+Resonant regulator with an $R - L - \varepsilon mf$ load

NON LINEAR CONTROL

- Non Linear Converter control systems directly control the switches from the control algorithm.
- Most common example is hysteresis control.



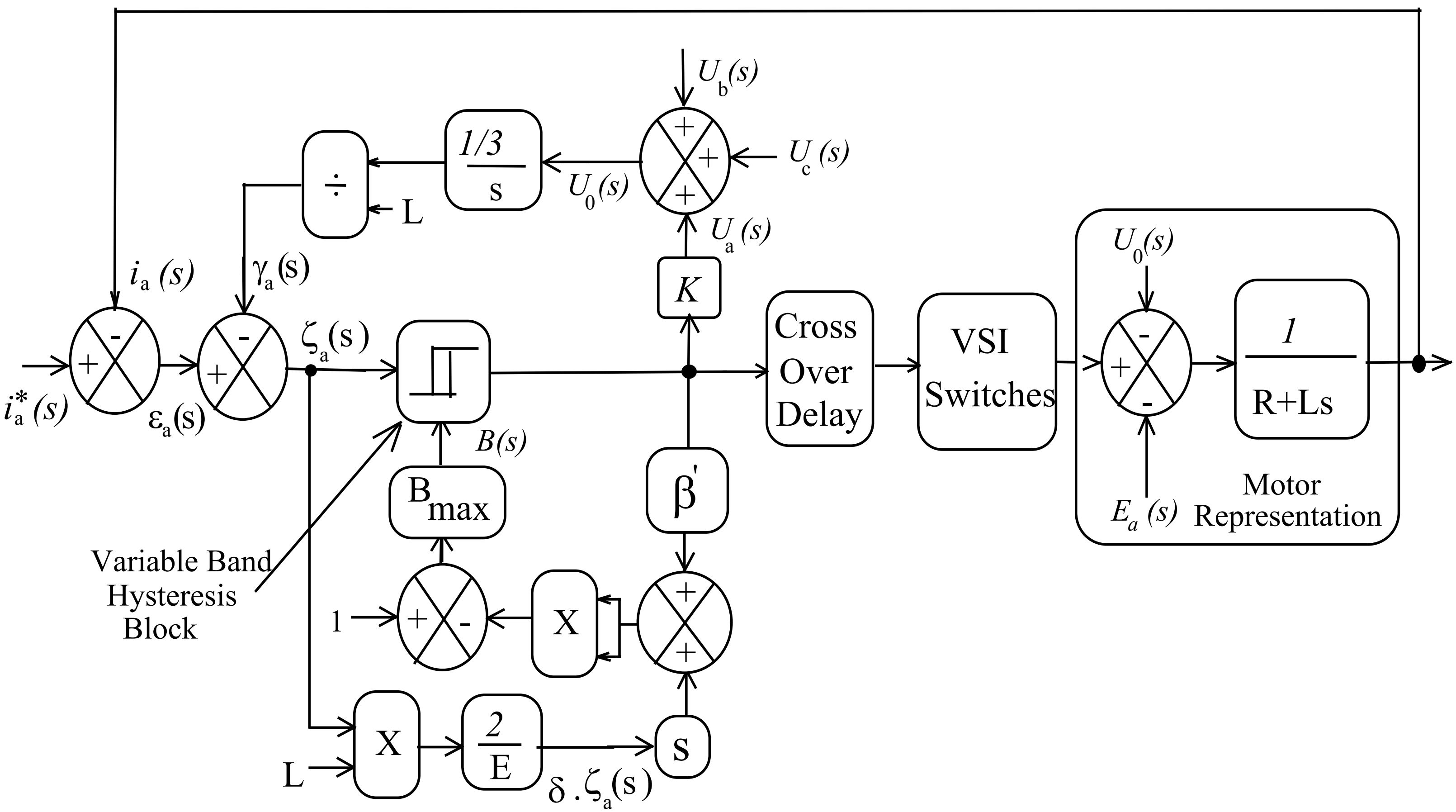
- **Non Linear Converter control systems directly control the switches from the control algorithm.**
- **Most common example is hysteresis control.**

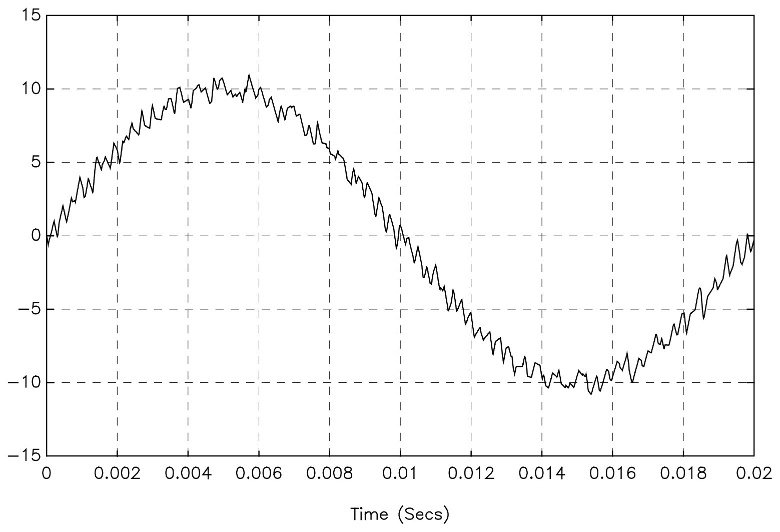


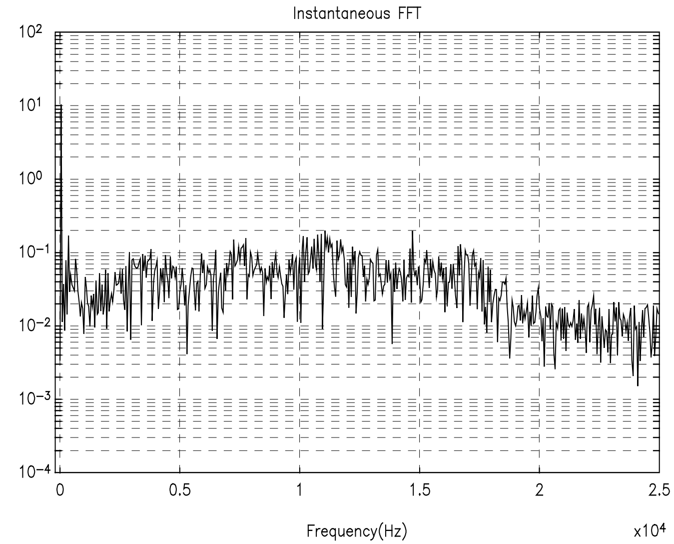
Problems with conventional hysteresis control are:

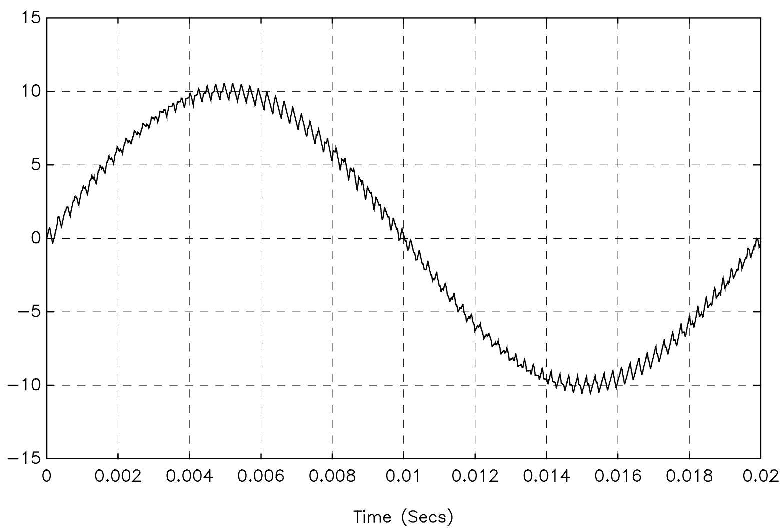
- **Variable frequency switching.**
- **Sub optimal switching pattern for both single and three phase.**
- **Limit cycle hazard.**

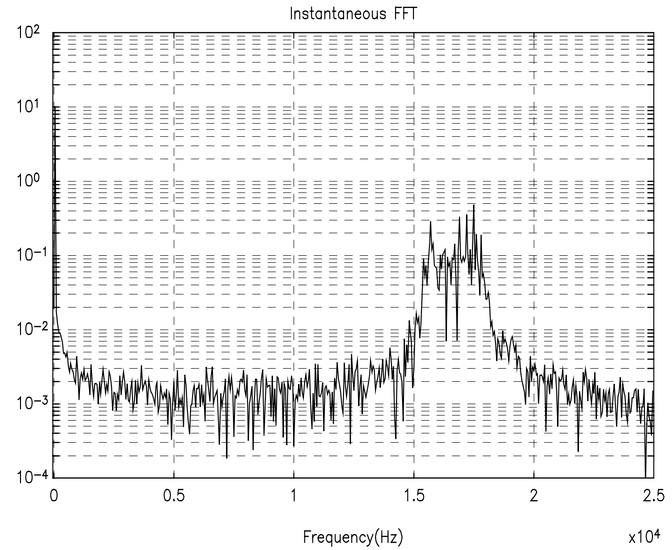
- **Variable band width switching solves most of these problems.**





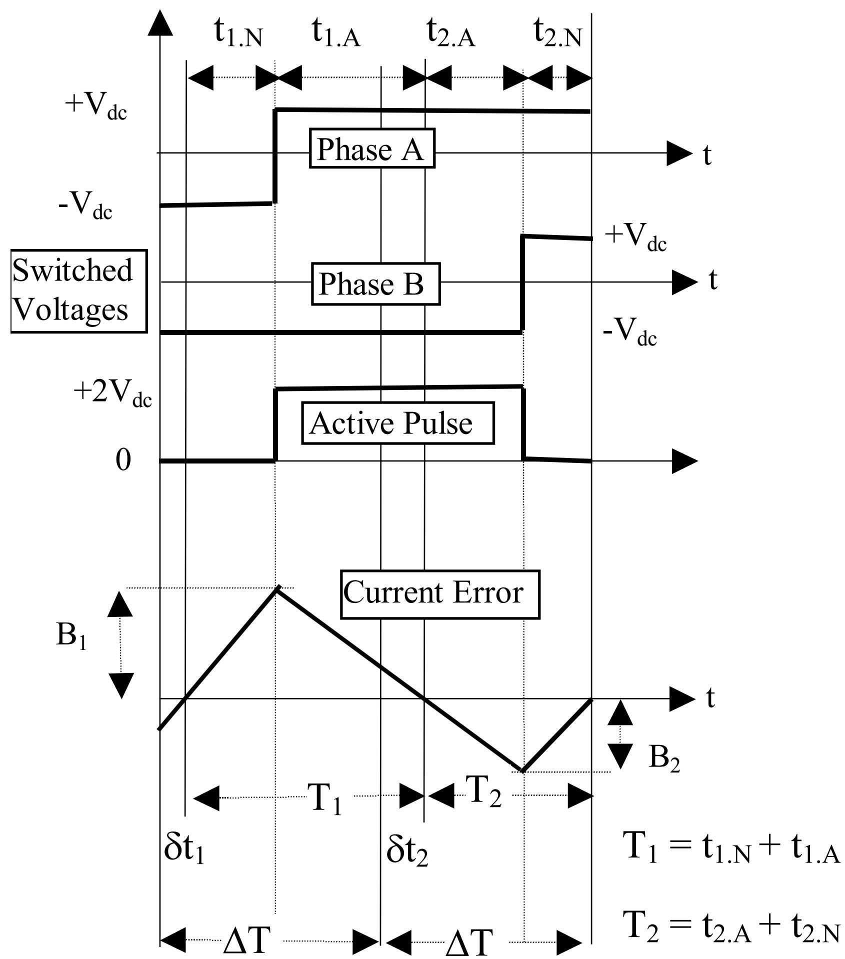


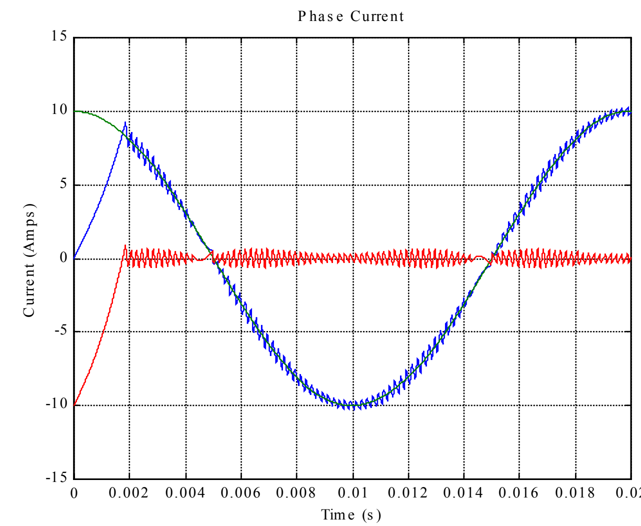


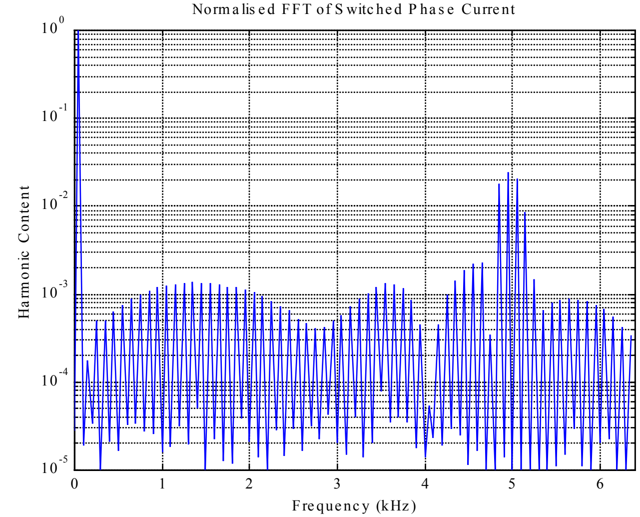


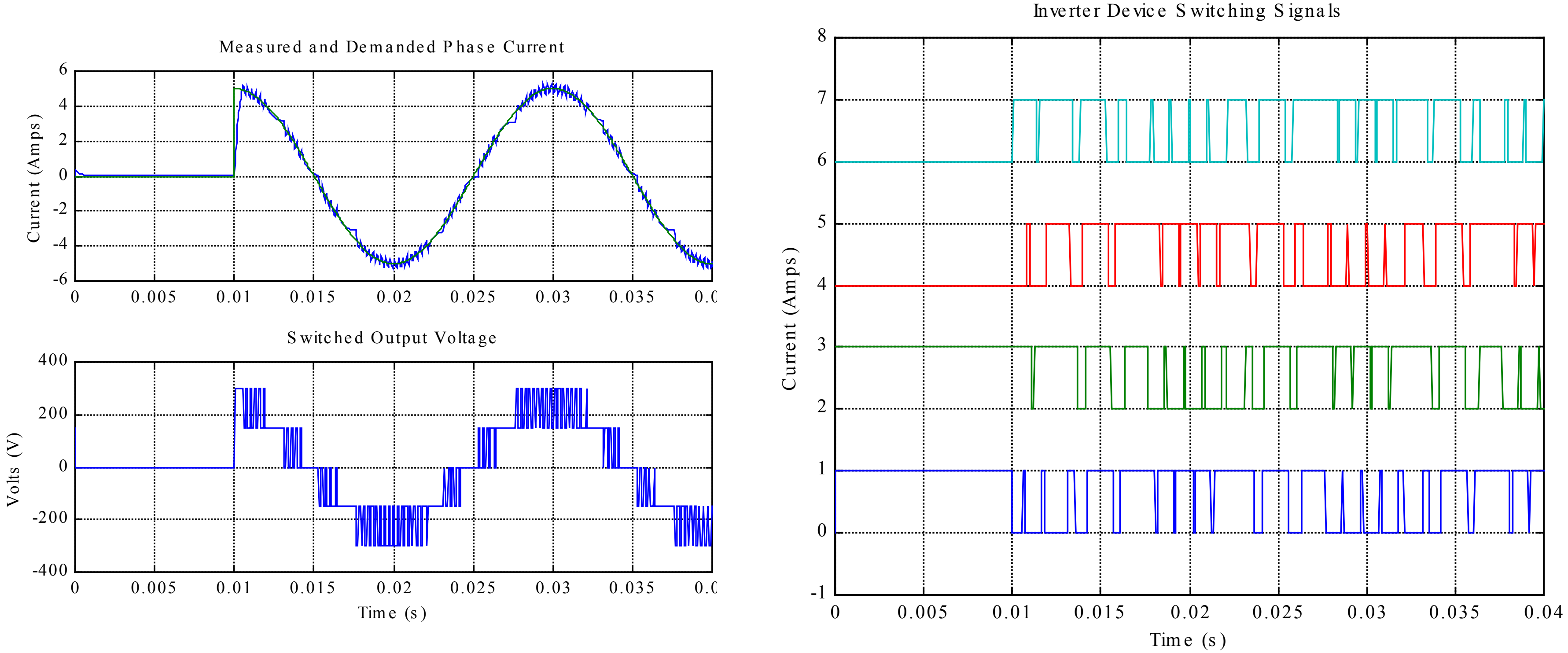
Variable band hysteresis control

Linking variable band hysteresis with deadbeat control improves the performance even further.









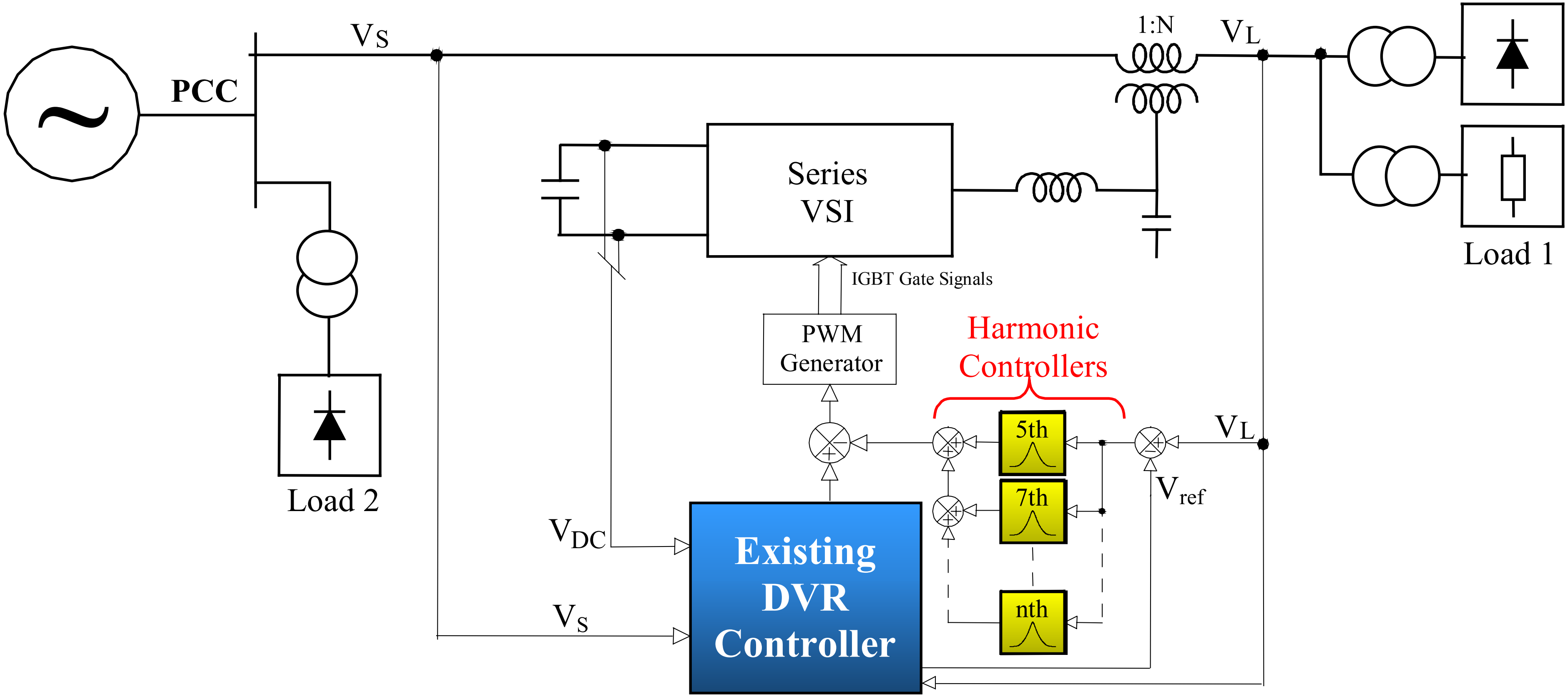
Multilevel Hysteresis Control: 5 Level Cascaded Inverter

Extending the Power Quality Compensation Capabilities of Dynamic Voltage Restorers

Michael John Newman

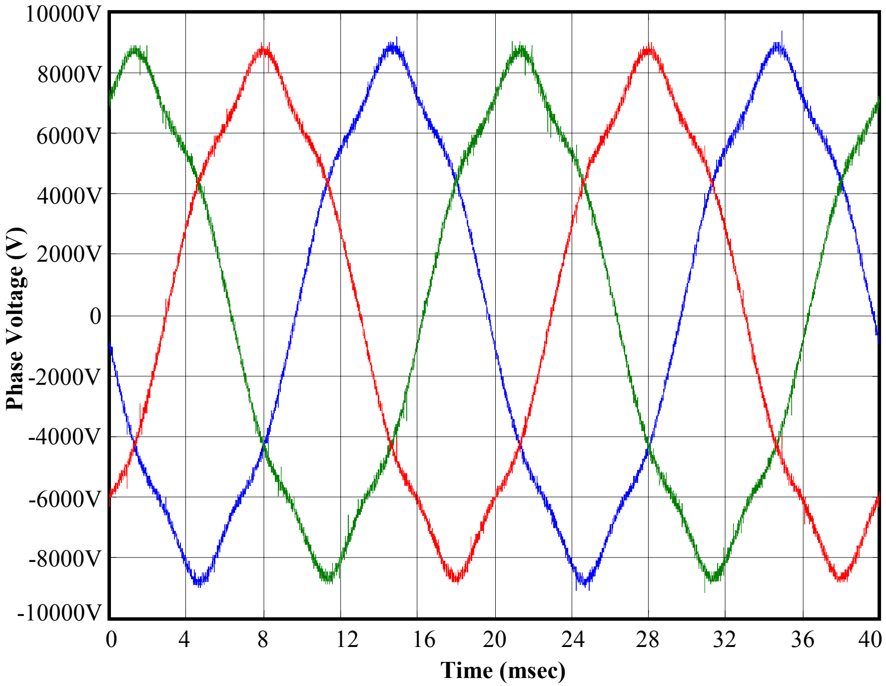
Monash University
Melbourne, Australia

Proposed additional control system



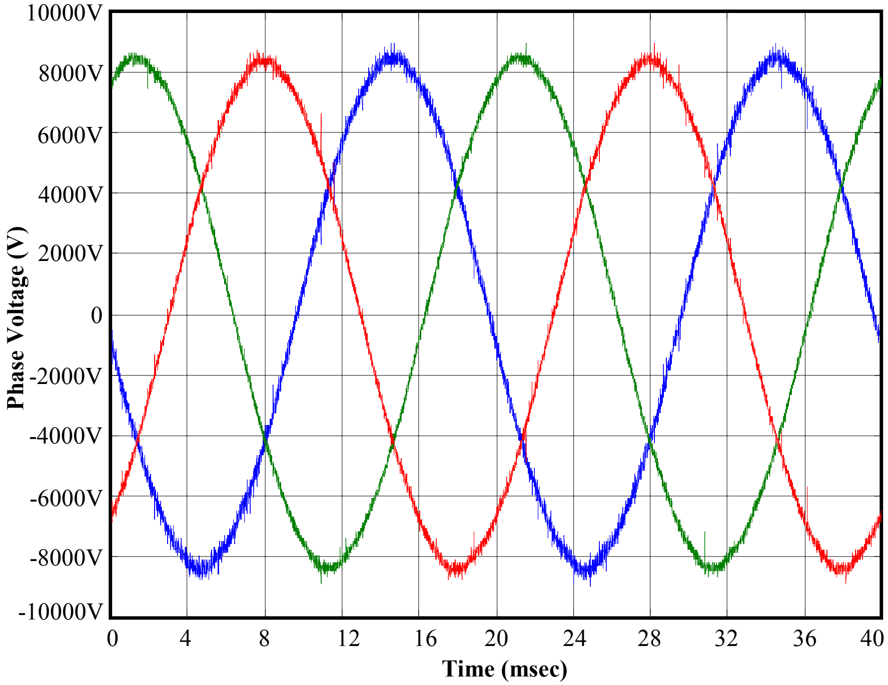
- **DVR primary value adding objective:**
  - **Sag Compensation**
- **Other possible value adding objectives:**
  - **Harmonic voltage compensation**
  - **Harmonic isolation**
  - **Fundamental Voltage Regulation**
    - Reactive Injection (requires large series rating – fine for DVR)
    - Real Injection (requires power source – possibly bi-directional)
  - **Flicker compensation (more temporary energy storage may be required)**
  - **Swell regulation (requires bi-directional supply)**
- **Ideal design criteria for value adding DVR systems**
  - **Addition should not affect the transient response of the DVR**
  - **The topology should preferably not be altered**
    - **Primary aim is to provide extra value added services to the customer using the exact same equipment, with minimal adverse affects**

Supply Voltage: 5th: 5%, 7th:2%



1. Steady-state Results: Distorted Supply

Load Voltage: 5th: 0.4%, 7th:0.3%

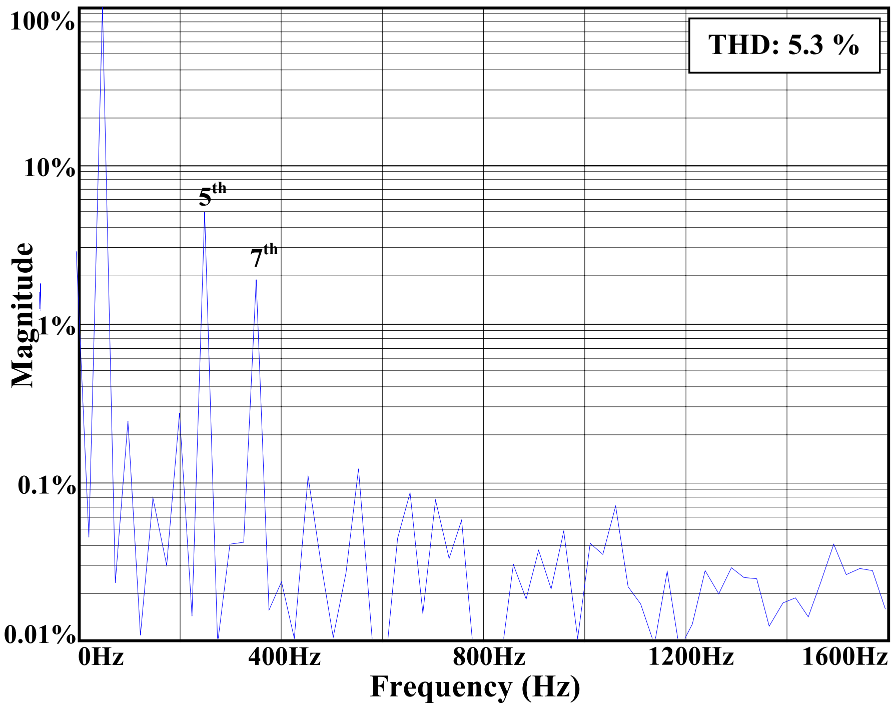


Test 1 Conditions:

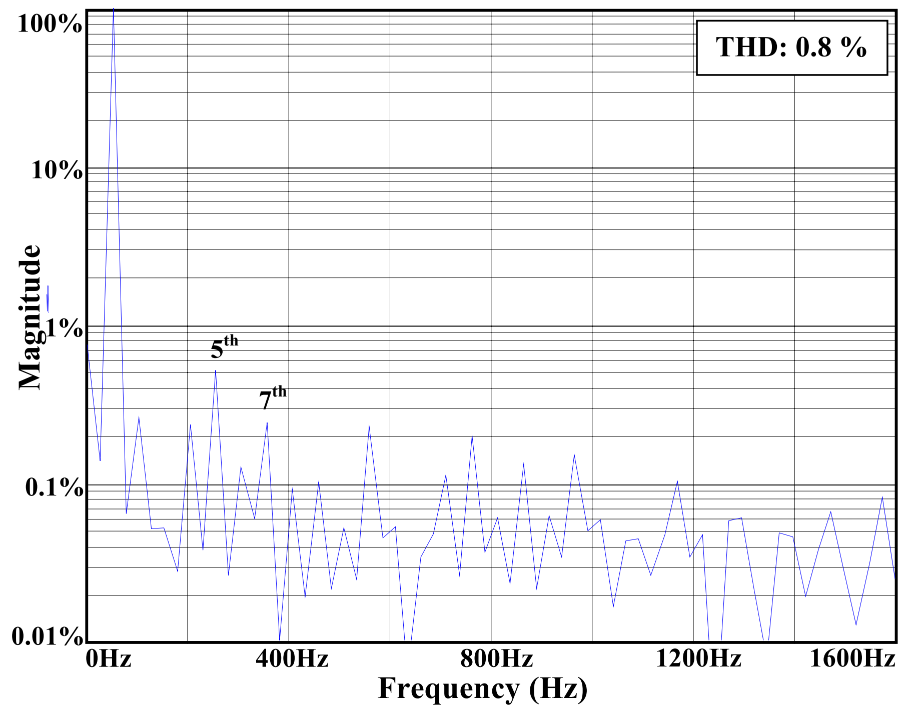
- *Test AC Voltage: 10kV l-l rms*
- *Distorted voltage from programmable supply*
- *Linear passive load (approx. 2kW)*
- *DC Bus voltage of 400V*

1. Steady-state Results: Distorted Supply

Supply Voltage: 5th: 5%, 7th:2%



Load Voltage: 5th: 0.5%, 7th:0.25%

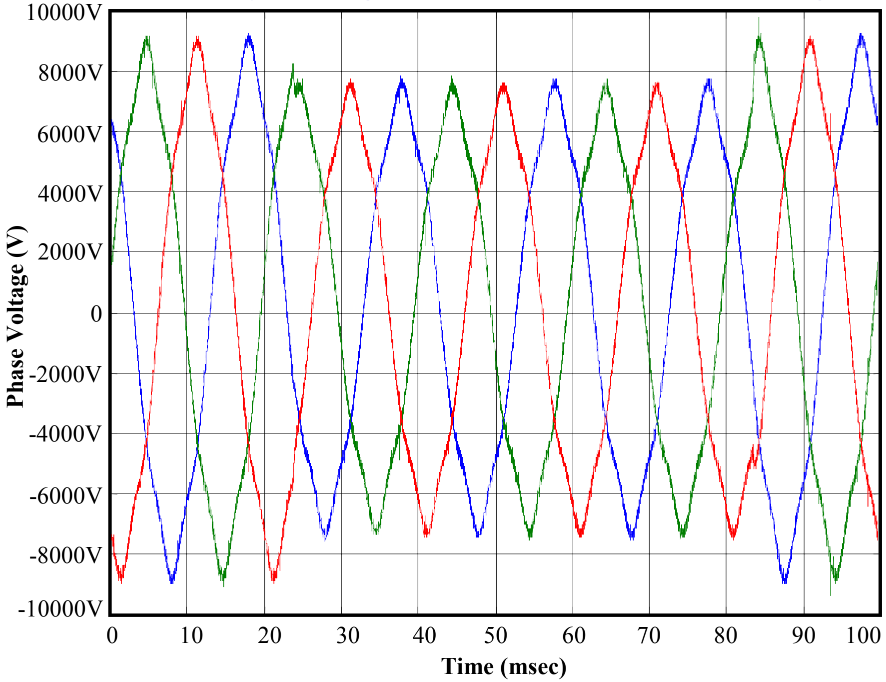


Test 1 Conditions:

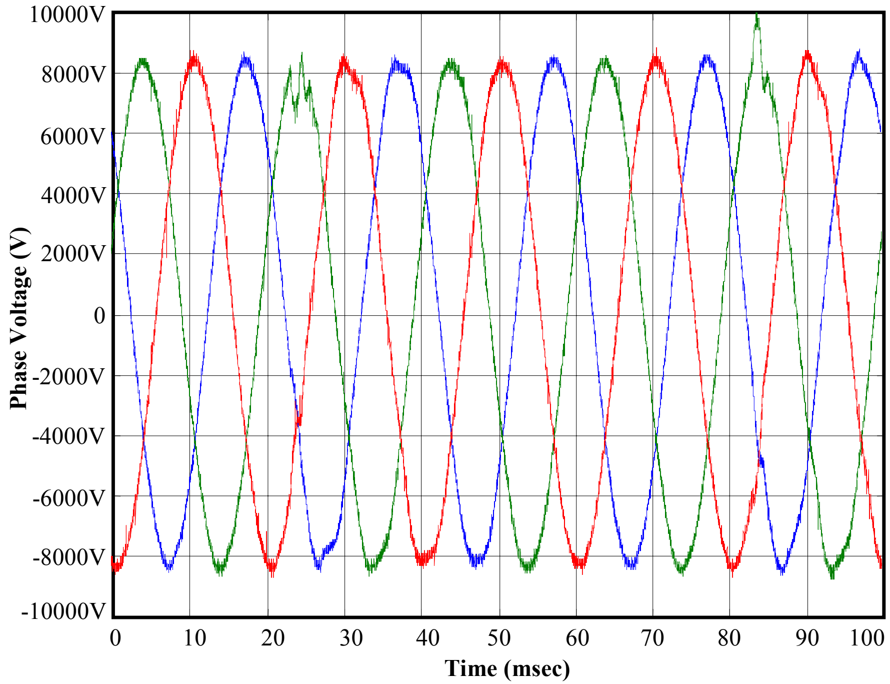
- *Test AC Voltage: 10kV l-l rms*
- *Distorted voltage from programmable supply*
- *Linear passive load (approx. 2kW)*
- *DC Bus voltage of 400V*

2. Transient Results: Distorted Supply with Sag

Supply Voltage: 5^{th}: 5%, 7^{th}:2%, 0.83pu sag



Compensated Load Voltage



Test 2 Conditions:

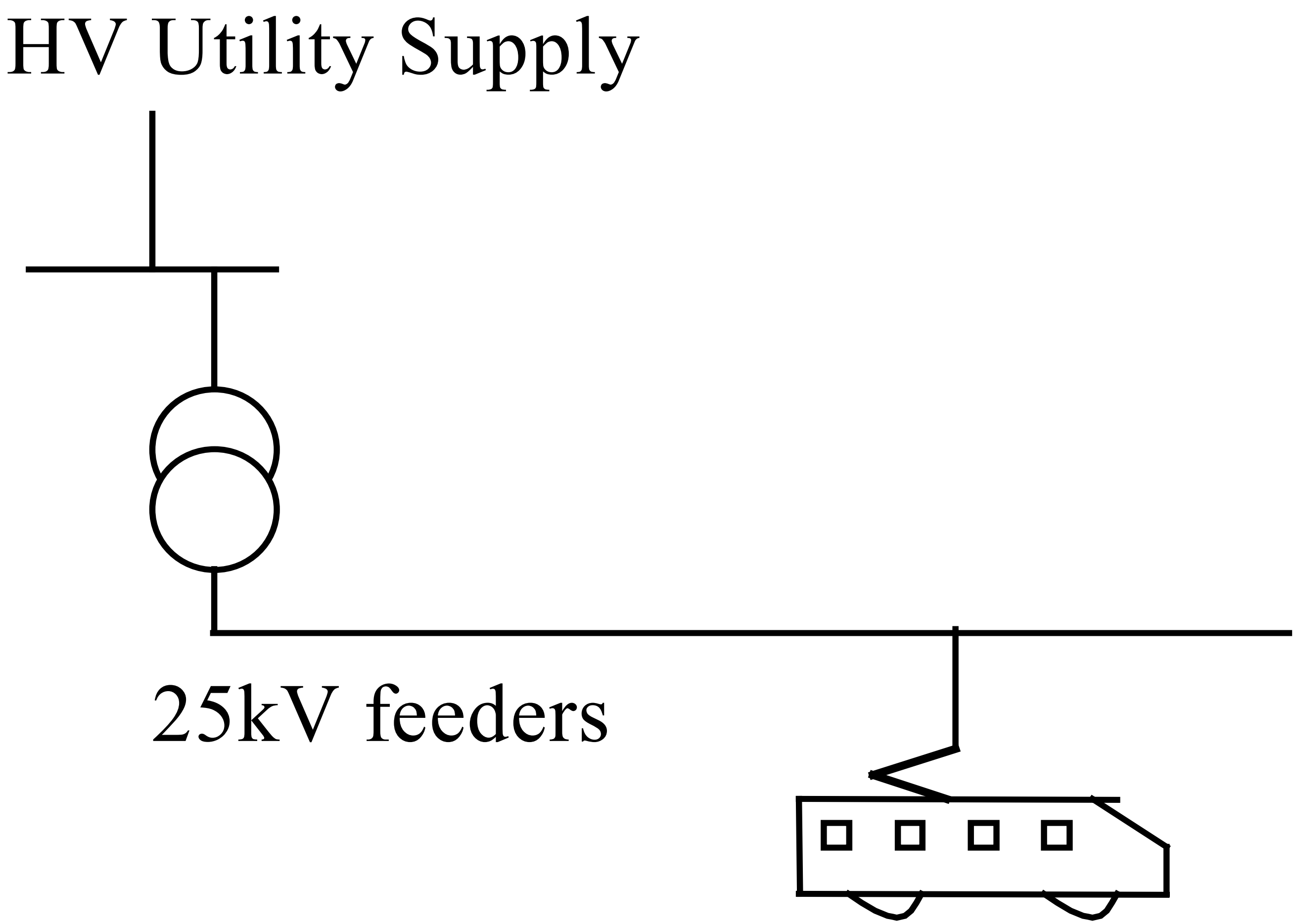
- *Distorted voltage from programmable supply*
- *Linear passive load (approx. 2kW)*
- *0.83p.u. Sag*
- *DC Bus voltage of 400V*

A Robust Multilevel Hybrid Compensation System for 25kV Electrified Railway Applications

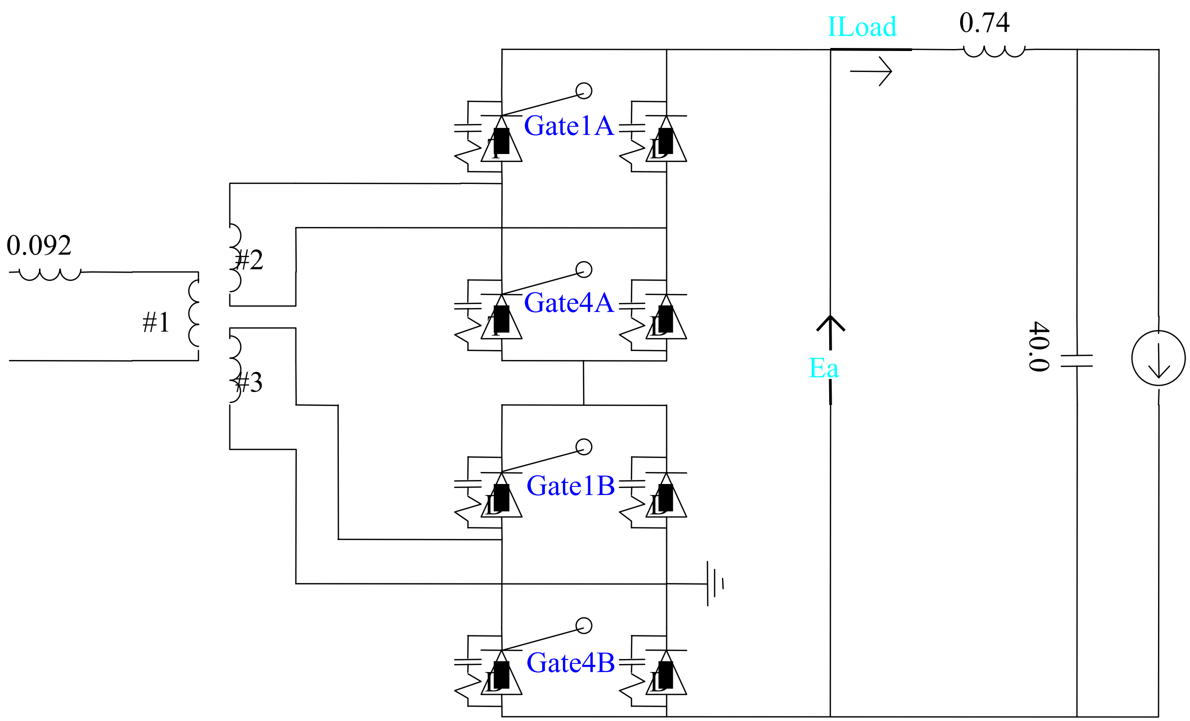
P. C. Tan, P. C. Loh, D. G. Holmes

Centre of Electrical Power Engineering,
Dept. of Electrical and Computer System Engineering,
Monash University, Australia

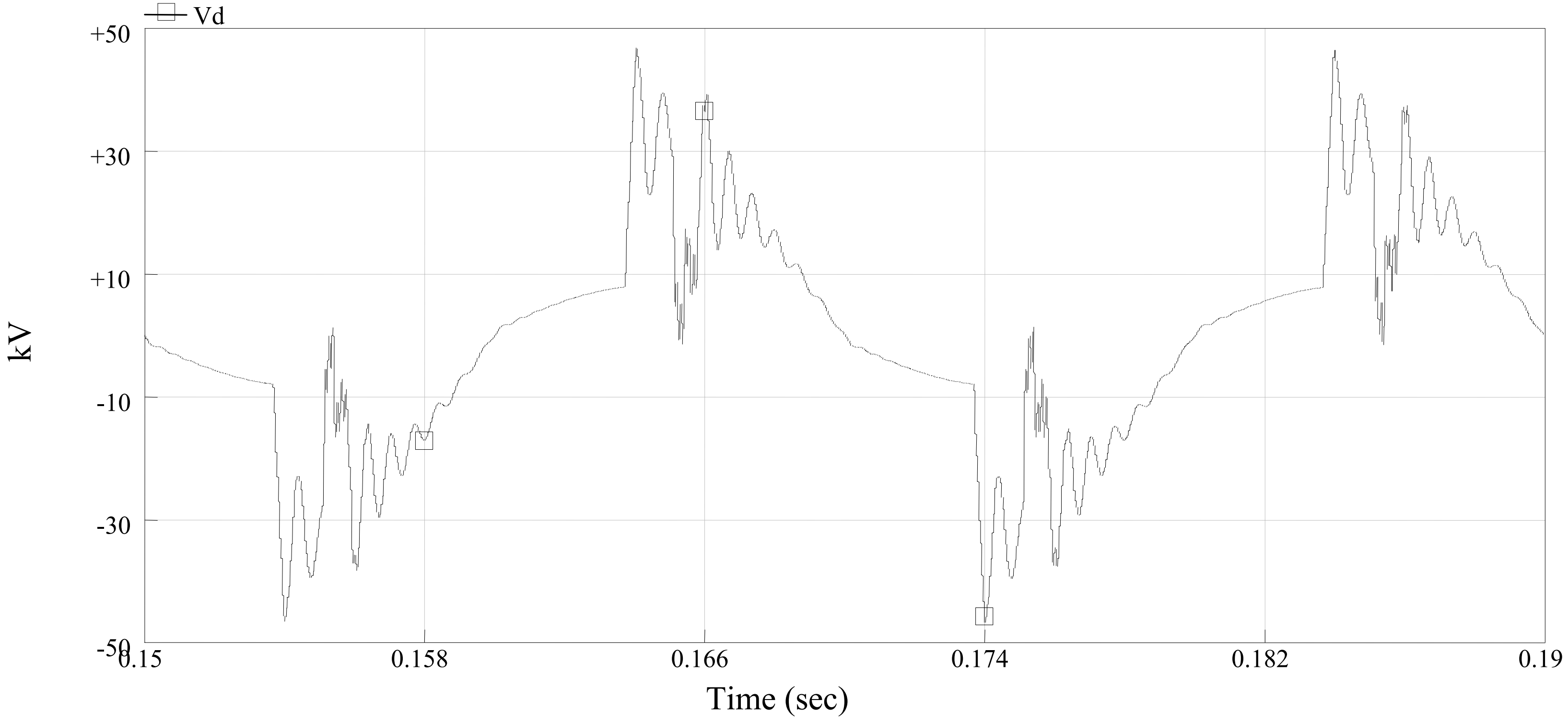
AC Traction System



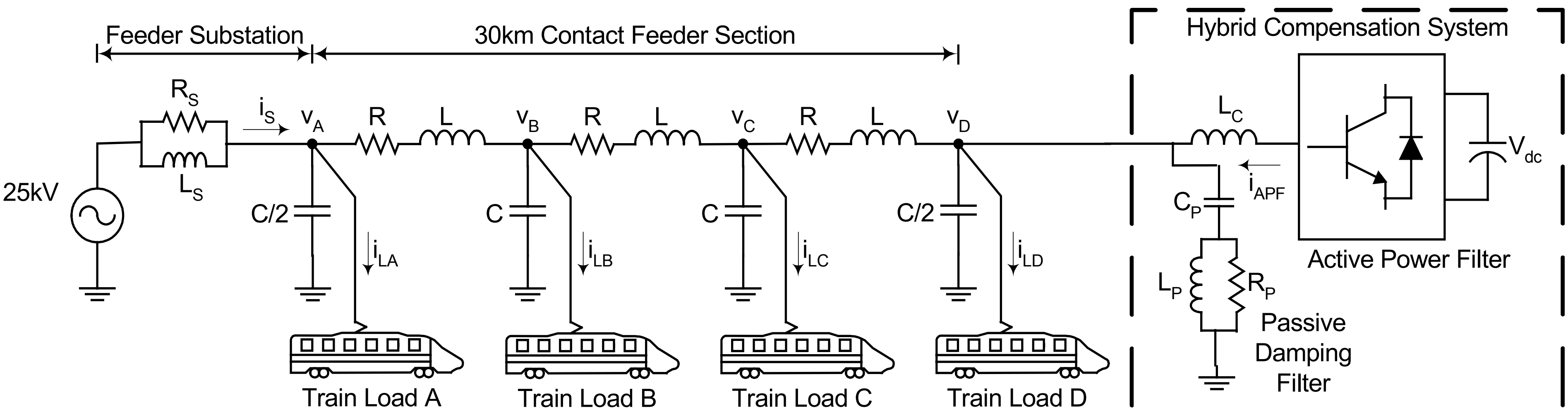
Railway locomotive model



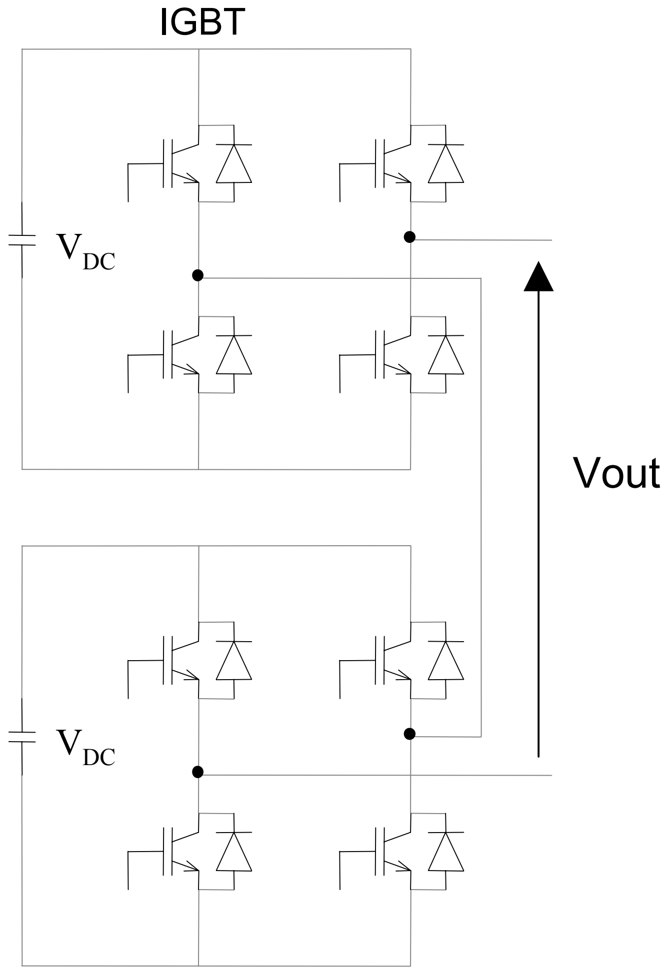
Typical trackside voltage waveform



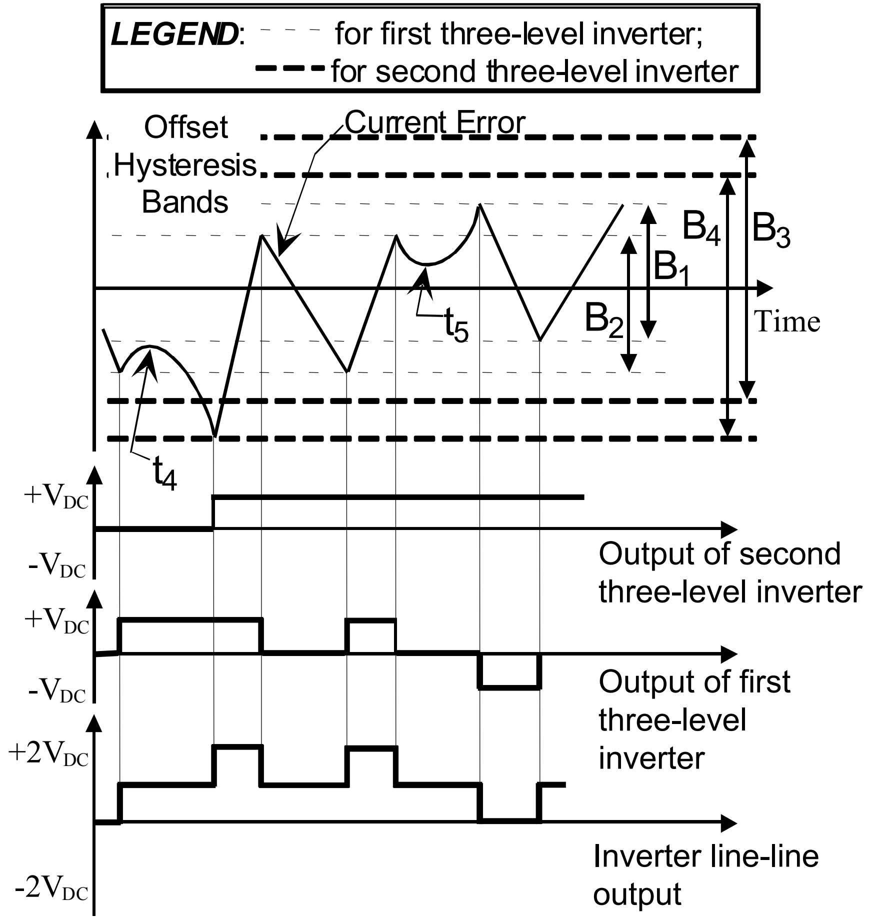
Railway traction system model



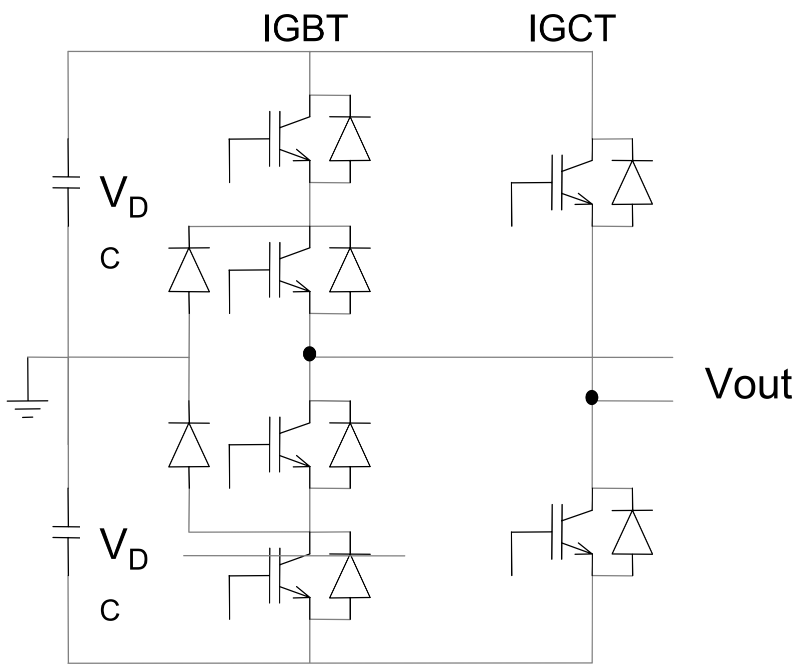
Hysteresis current regulation



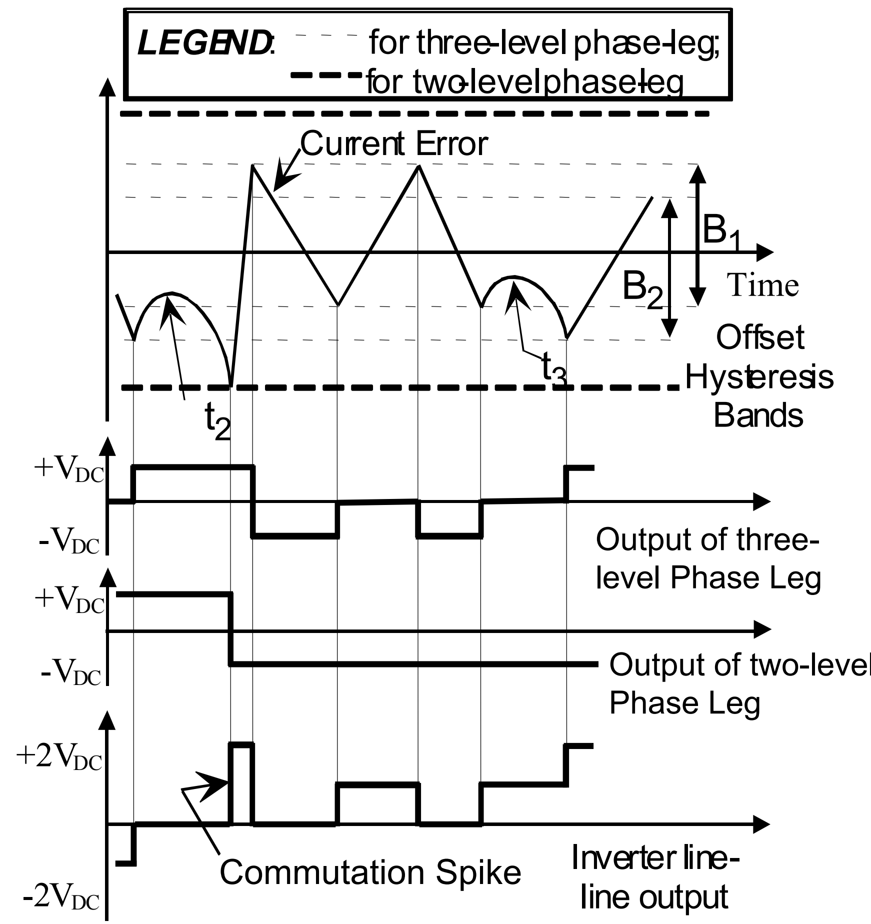
Cascaded inverter



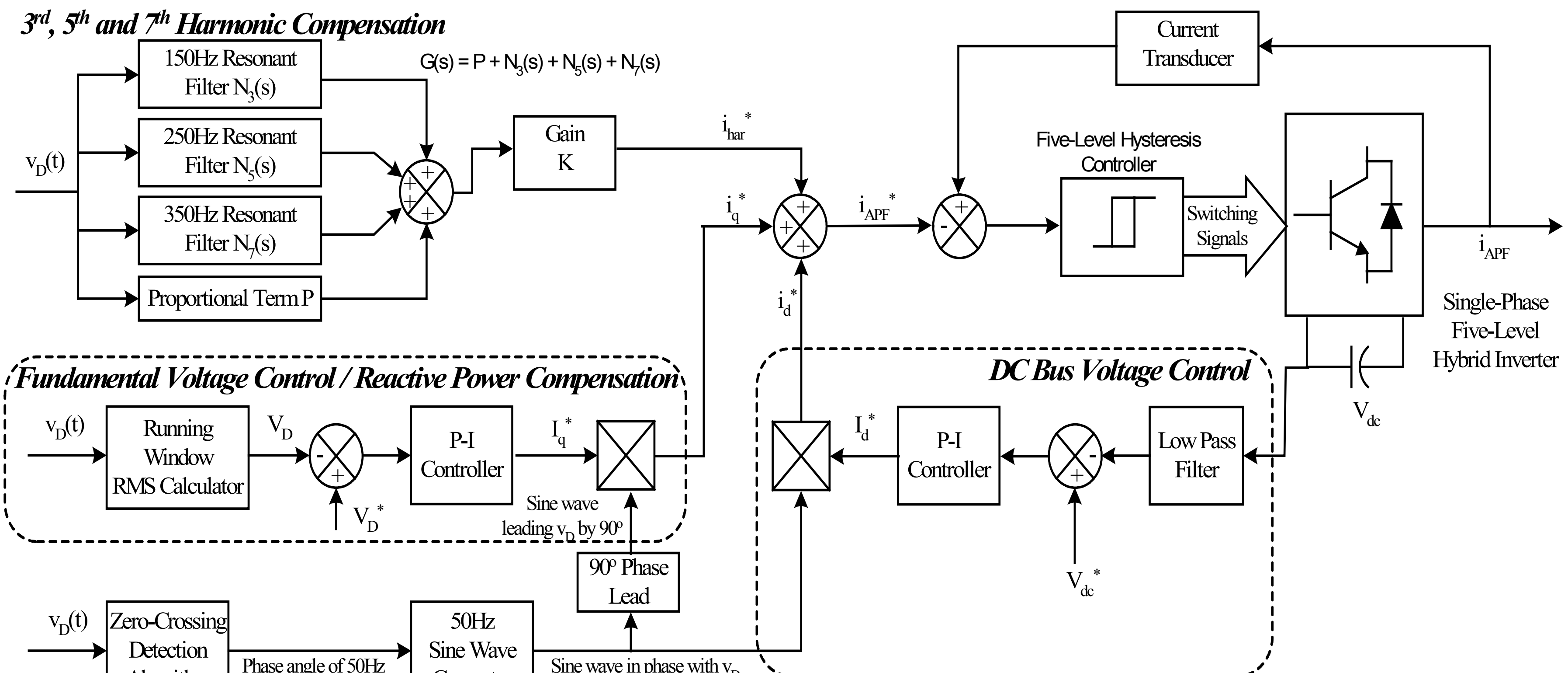
Hysteresis current regulation



5 level Reduced inverter

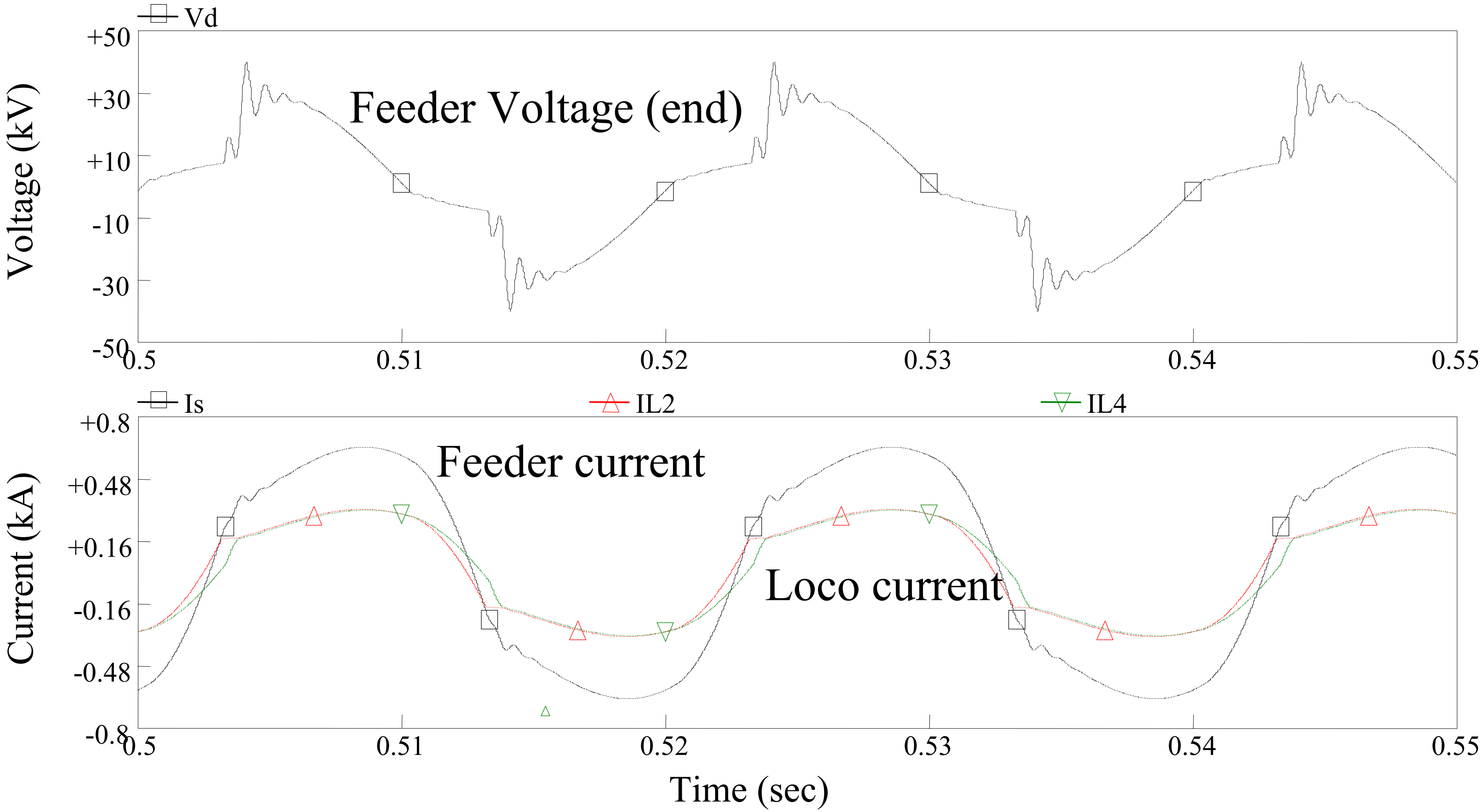


Active power filter control



Compensator controller block diagram

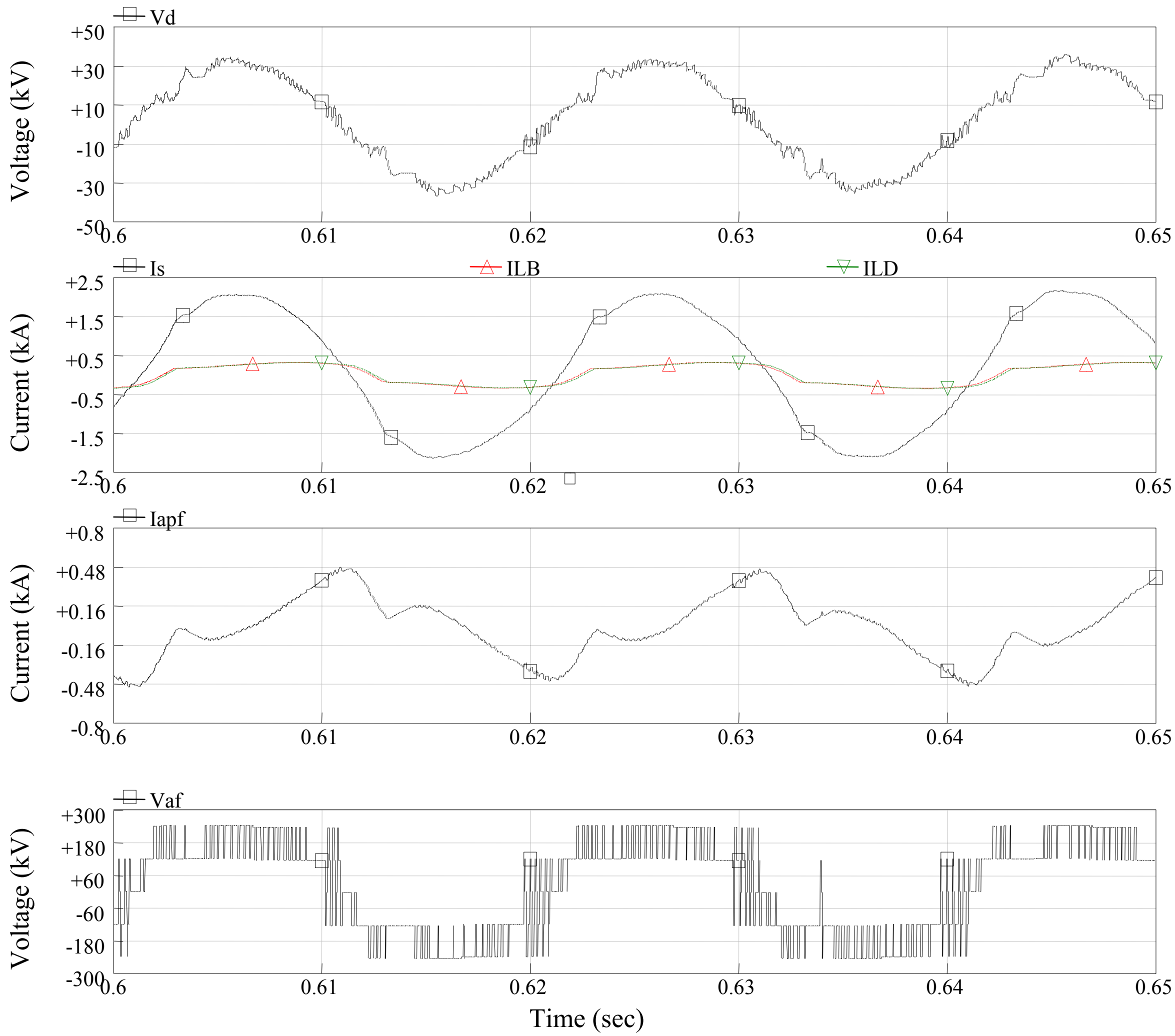
Simulation results   Before compensation



2x5MW located at middle and end of feeder.

Simulation Results

After compensation



Feeder Voltage (end)

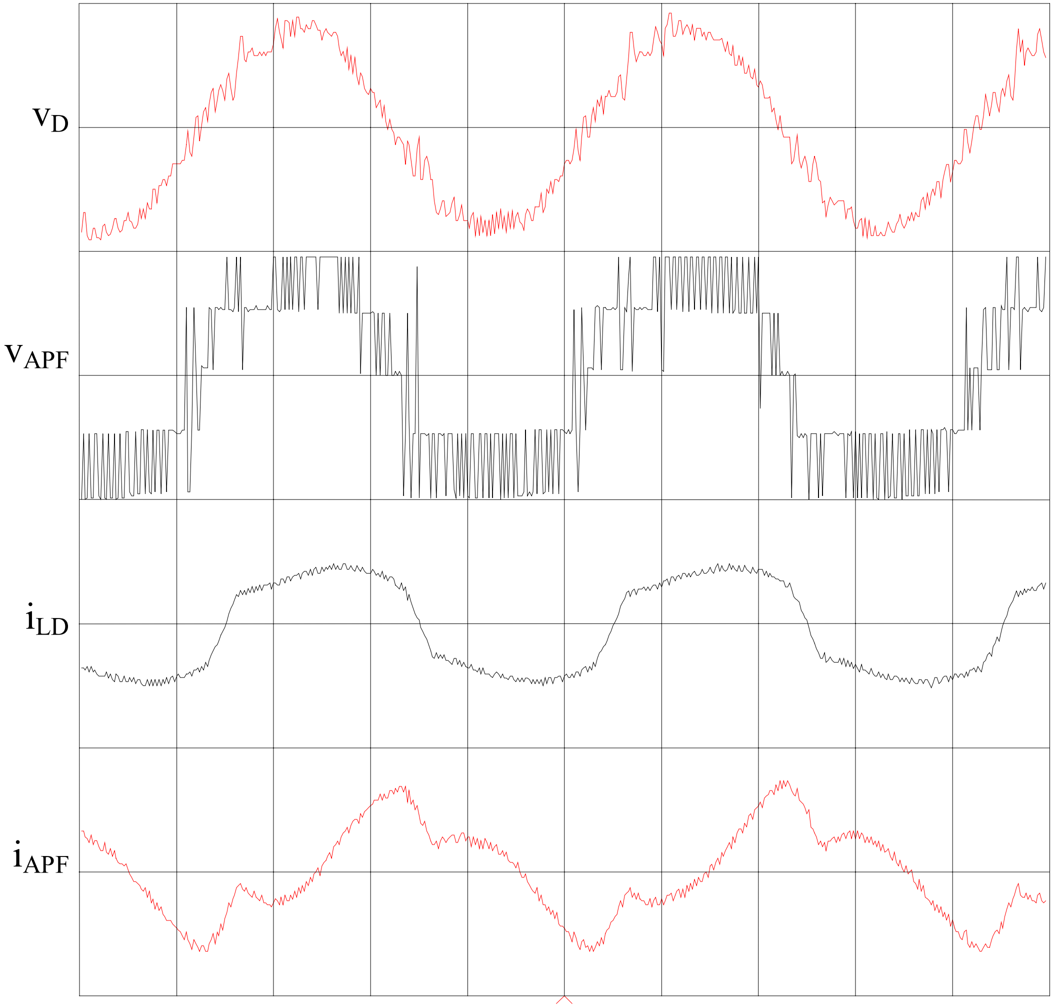
Feeder & Loco Currents

Active Filter Current

Active Filter Voltage

Experimental results

After compensation

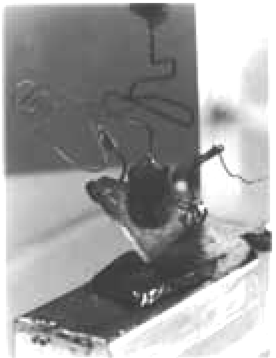


Current Power Electronic Research Projects

- Distributed PE compensation systems for electrical grids
- Auxiliary power supplies for high voltage converters
- High performance drive systems
- EPLD implementation of high performance modulation
- Low inertia induction motor
- Intrinsically safe switch mode power supplies
- Reduction of EMI for power converter systems

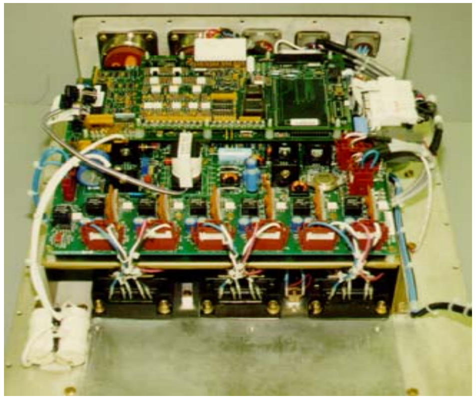
What is the Future of Power Electronics?

Micro-electronics



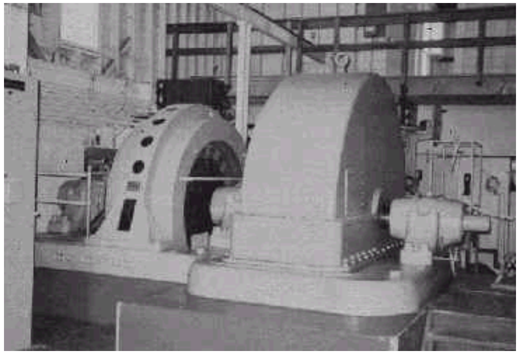
Moore's Law:
"Every 1.5 years the cost of a 'bit' drops 50%."

Power Electronics



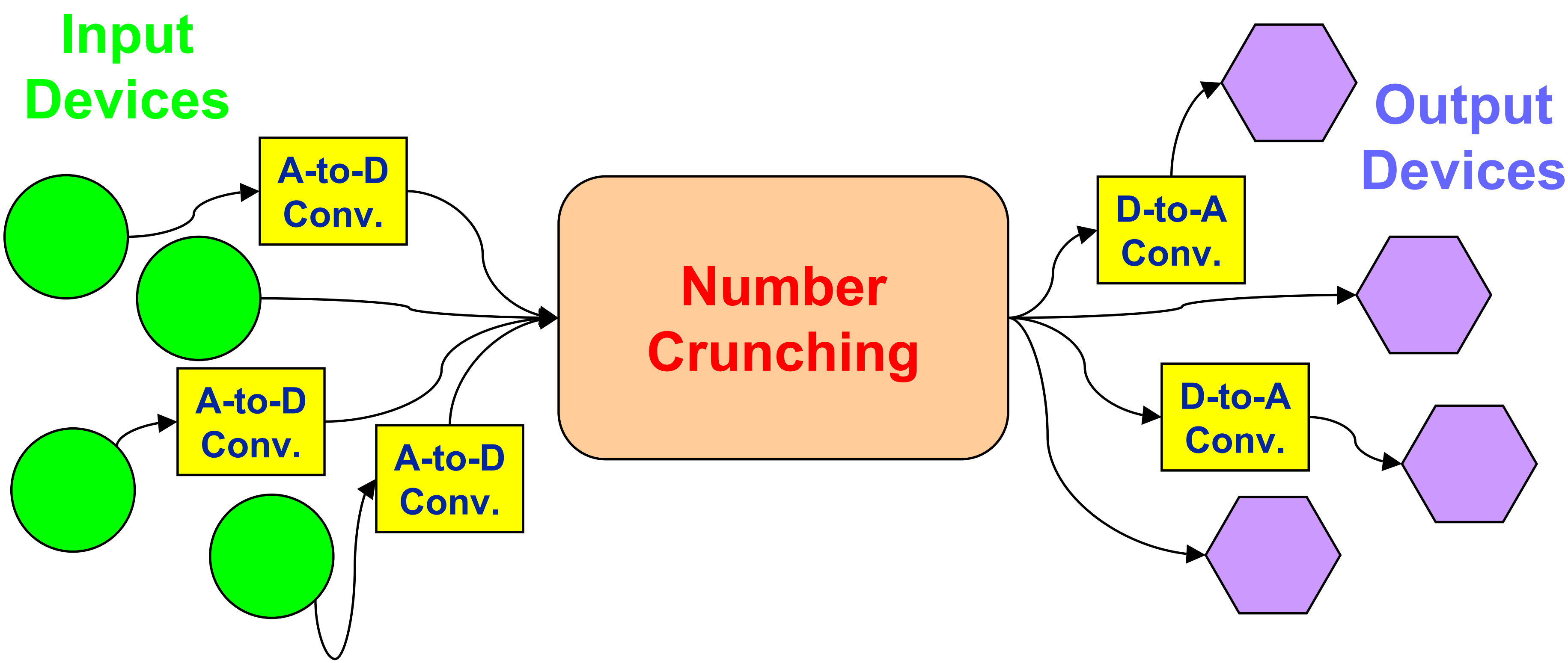
?

Electric Power



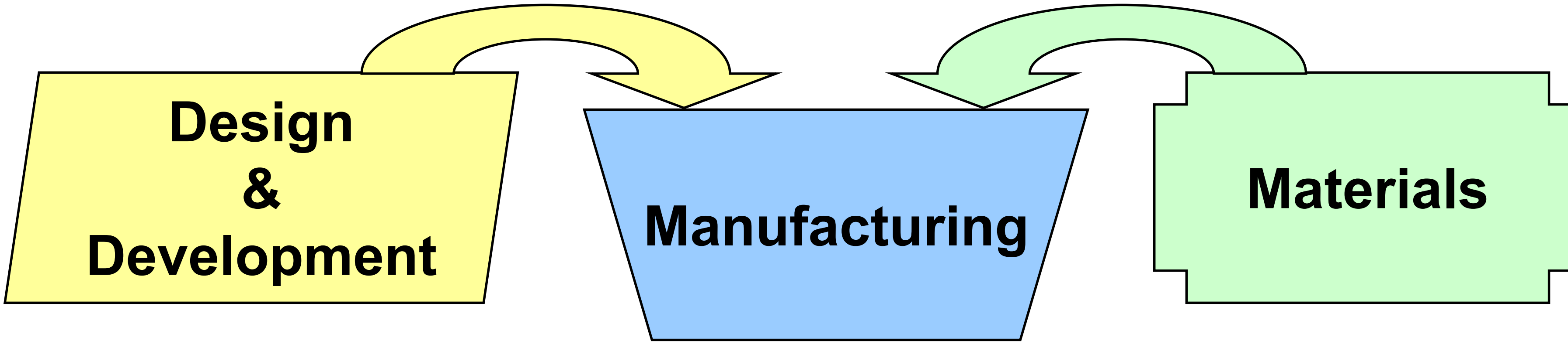
Between 1920 - 1970, every 1.5 years the cost of kWh dropped 5%.
Since then it is constant.

Digital Revolution



Most of Information Processing has been reduced to arithmetic and logic manipulation of binary numbers

Product Quality, Reliability, and Cost Factors:



- Optimized general purpose design

  μP

- Automated dedicated design

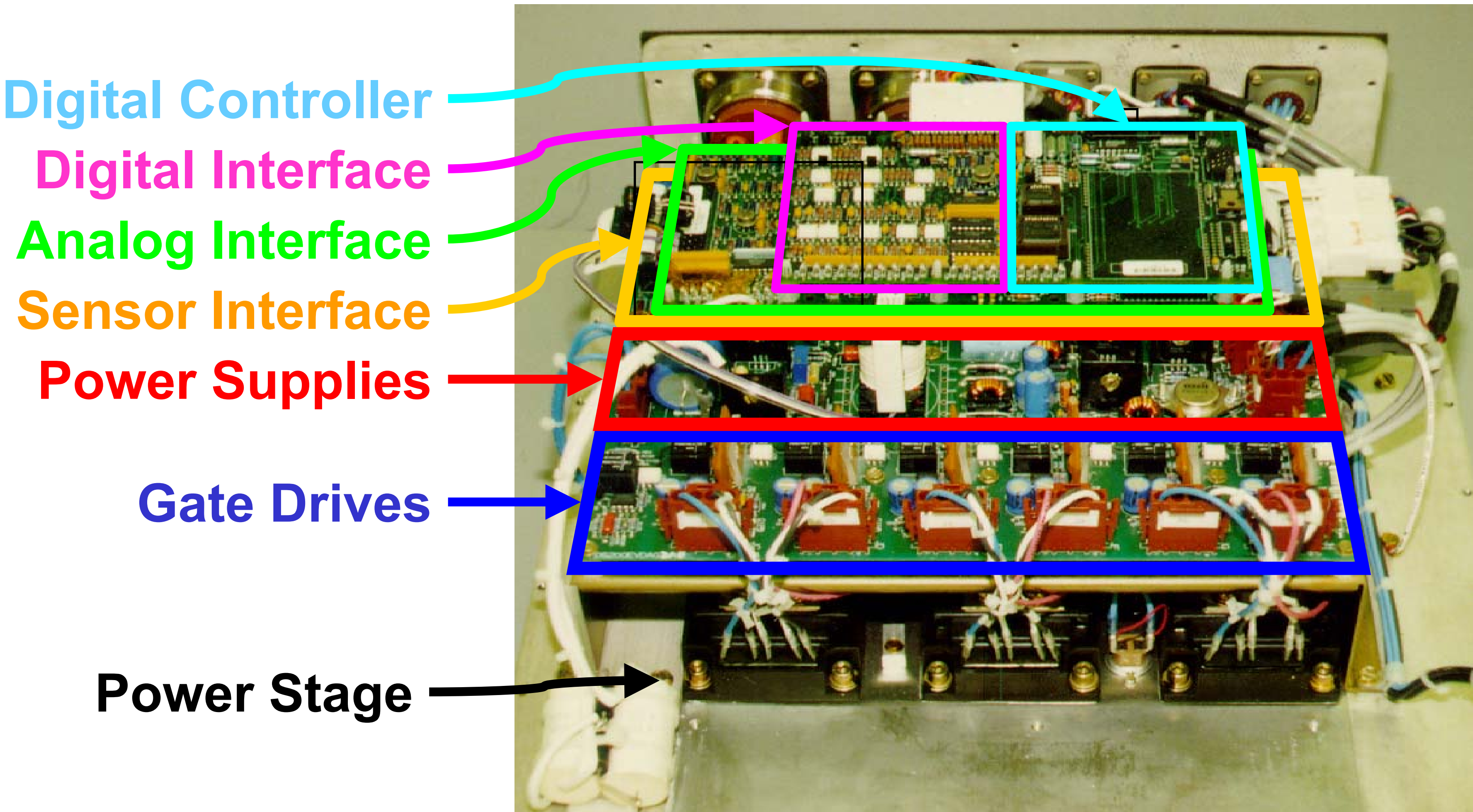
  ASIC

- Batch processing
- Small number of steps
- Small number of different materials
- Efficient use of materials

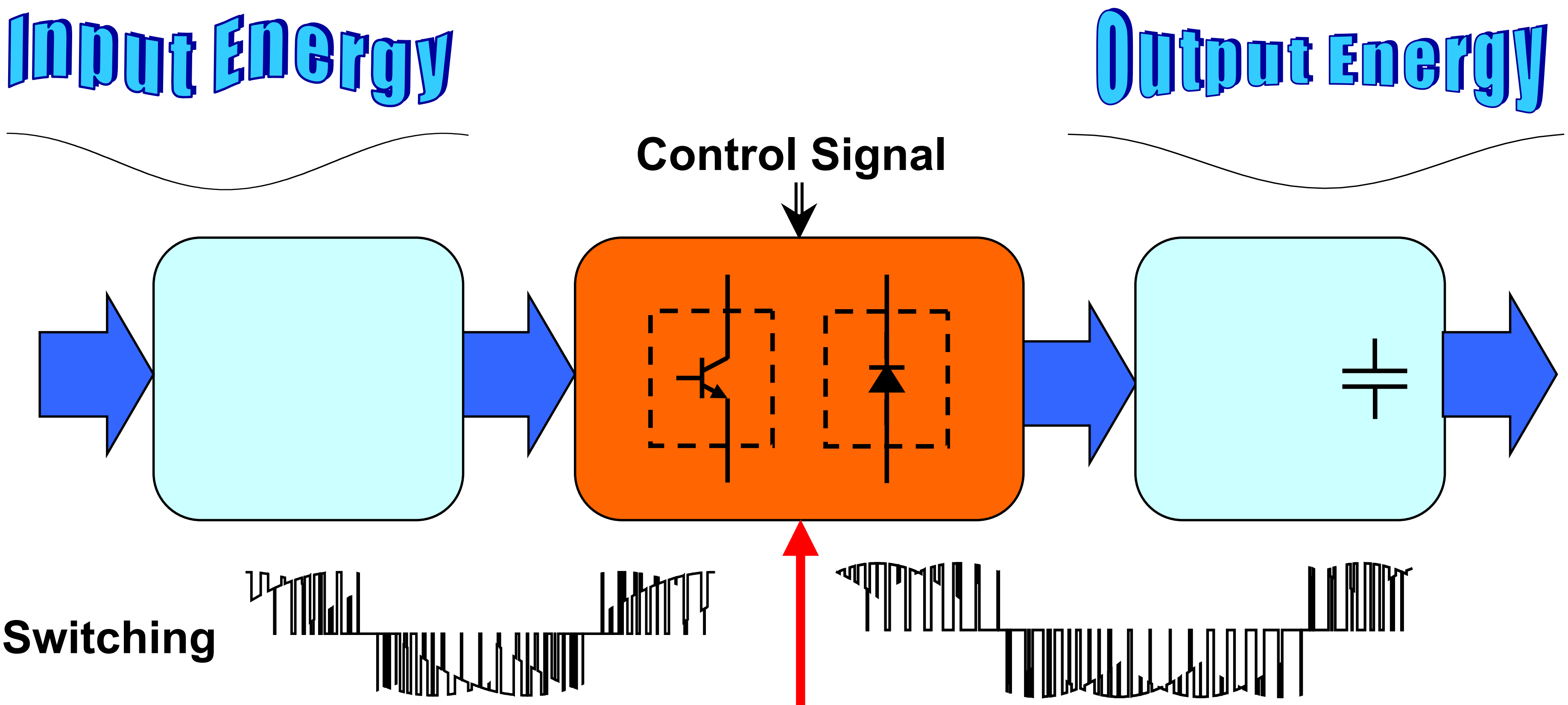
Volume Production

Cost Reduction

Or Power Electronics Converter Design in the Last Century



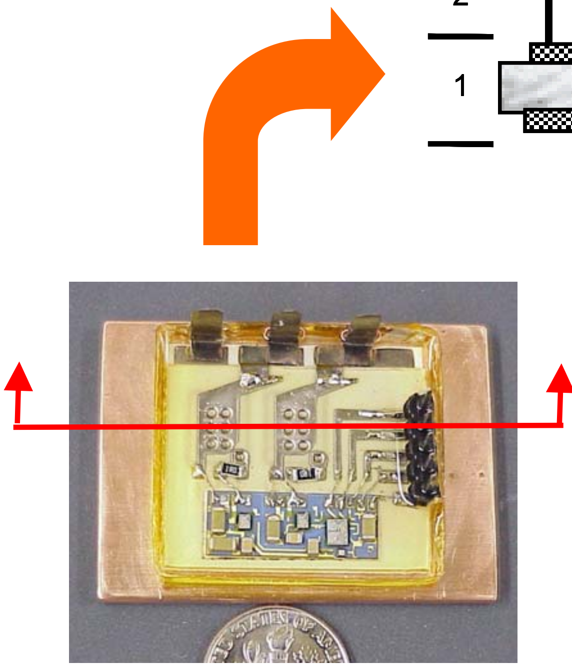
High Frequency Synthesis (PWM)

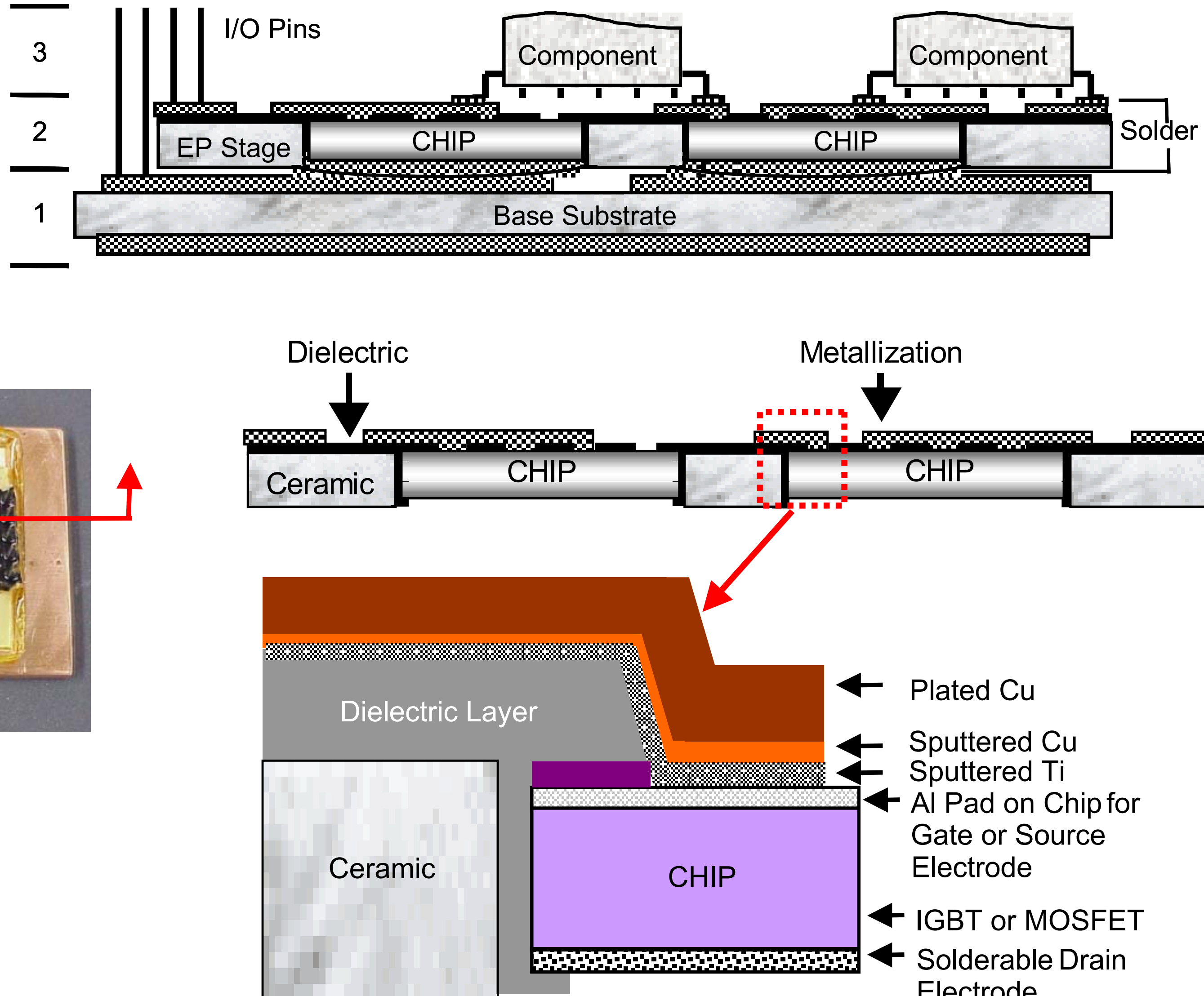


Integration of the Active Switching Stages

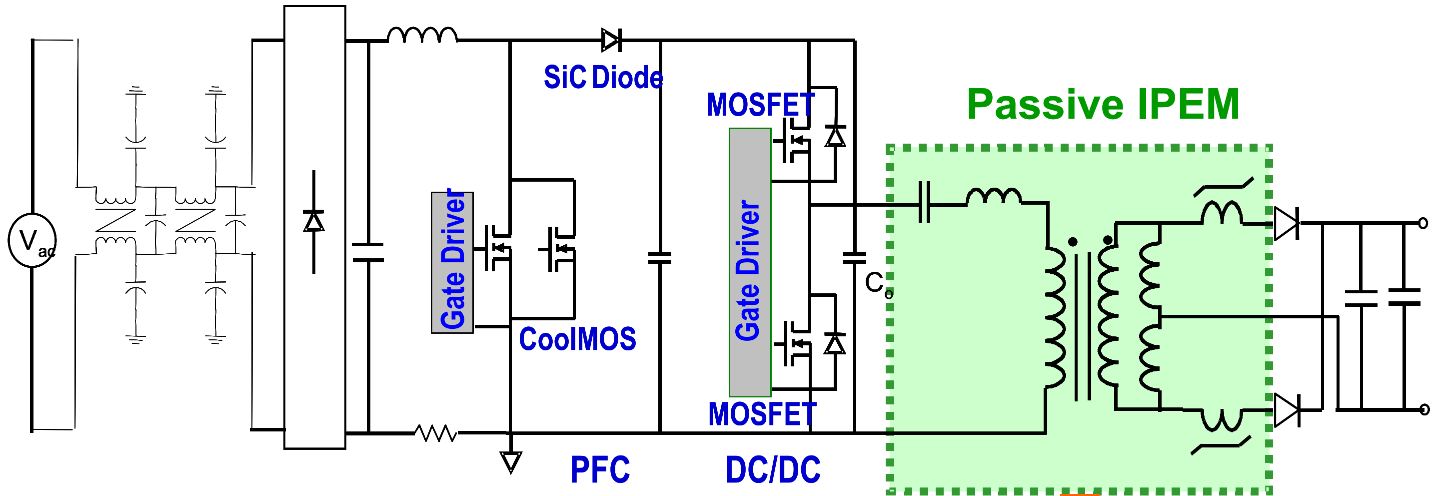
Active Switching Stages: Embedded Power

Cross-sectional view

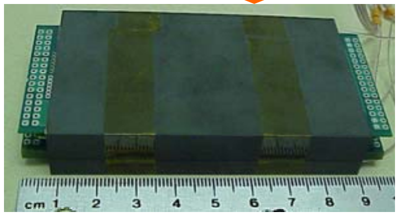


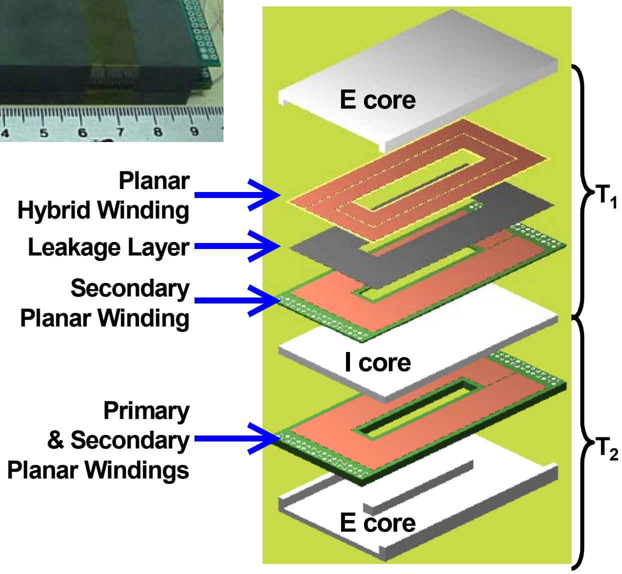


DPS Integration: Power Passives



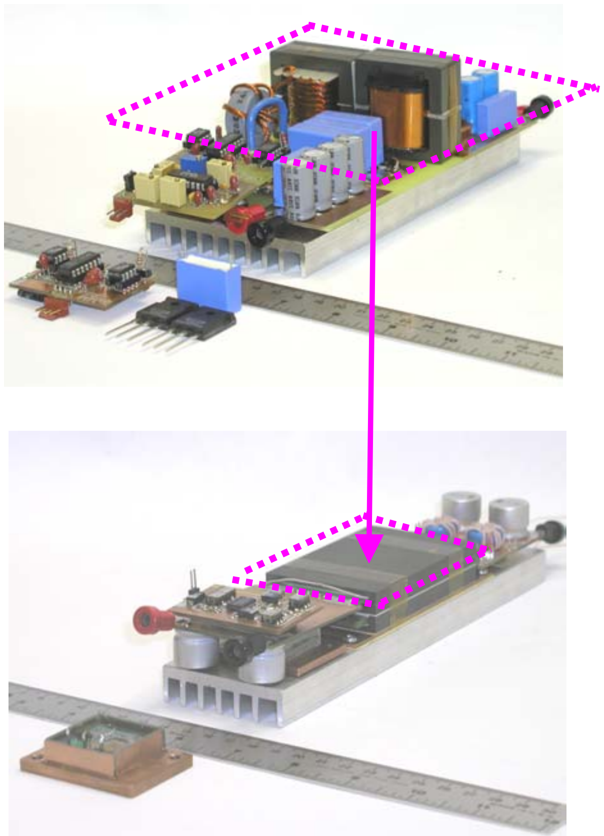
Parameter	*Discrete*	*Passive IPEM*
Power (kVA)	1.0	1.0
F_s (kHz)	45	45
$L_{m1,2}$ (uH)	45	45
L_s (uH)	2	1.8
C (uF)	2.3	2.5
No. of Components	**7**	**1**
No. of Terminals	**17**	**5**
Total Profile (mm)	**42**	**16**
Total Volume (cm^3)	**168**	**82**
Power Density (W/in^3)	**97**	**200**





Improvements

Discrete DC/DC Converter

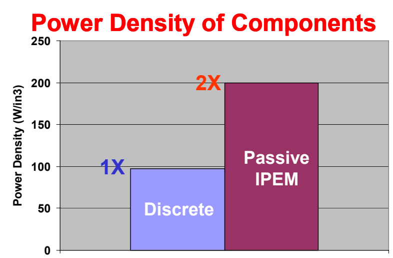


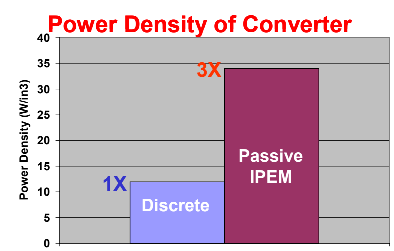
Integrated DC/DC Converter

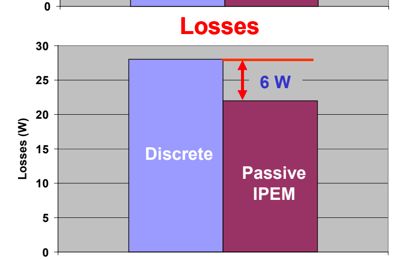
1. Standard Fabrication techniques:

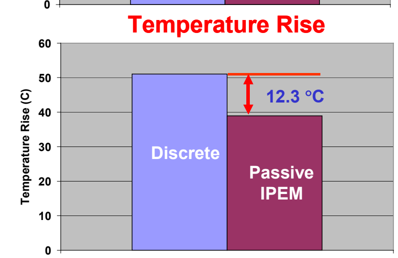
- Direct metal deposition;
- Electro-plating;
- Photolithography;
- Wet-etching;
- Laser cutting;
- Reflow soldering;

2. Improved power density, efficiency and thermal performance:





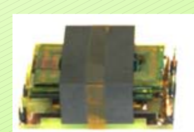




The Future

Discrete EMI Filter+ Discrete DPS

Integrated EMI Filter+ Integrated DPS

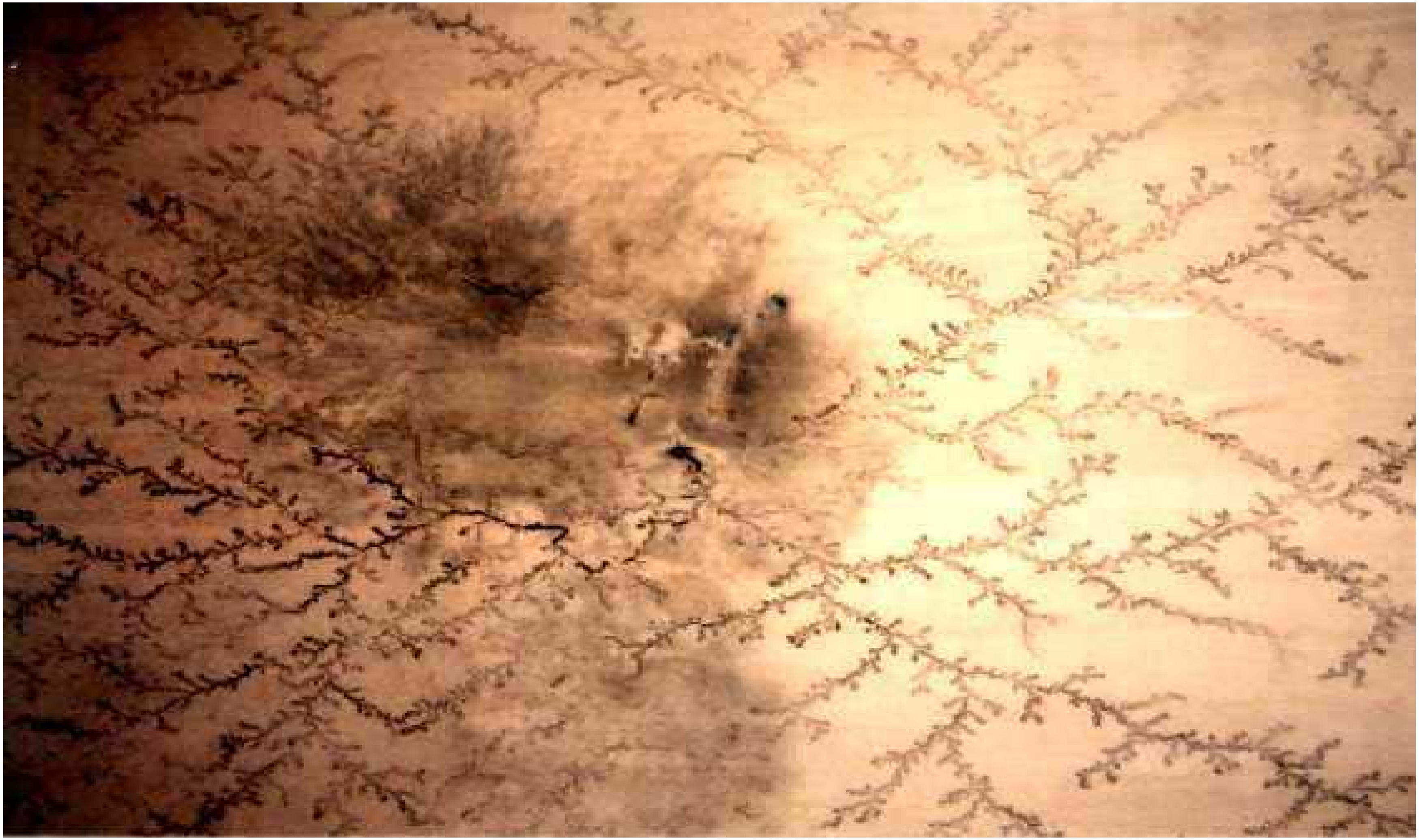


- Electrical Power at Monash University – a short walk through history
- What is this business called Power Electronics ?
- Power Electronics research activities at Monash
- **Other Electrical Power Research Activities**
  - **The EPRI Project**
  - High Voltage
  - Renewable Energy
- Summary

EPRI-Monash Work:
Moisture in Transformers

- Started in mid 1990's to investigate aging transformer insulation
- One of the longest running EPRI funded projects in the world
- A world leader in modelling moisture content in electrical power transformers
- Headed by Dr Valery Davydov

Moisture in Thick Insulation: Electrical Treeing and Deterioration

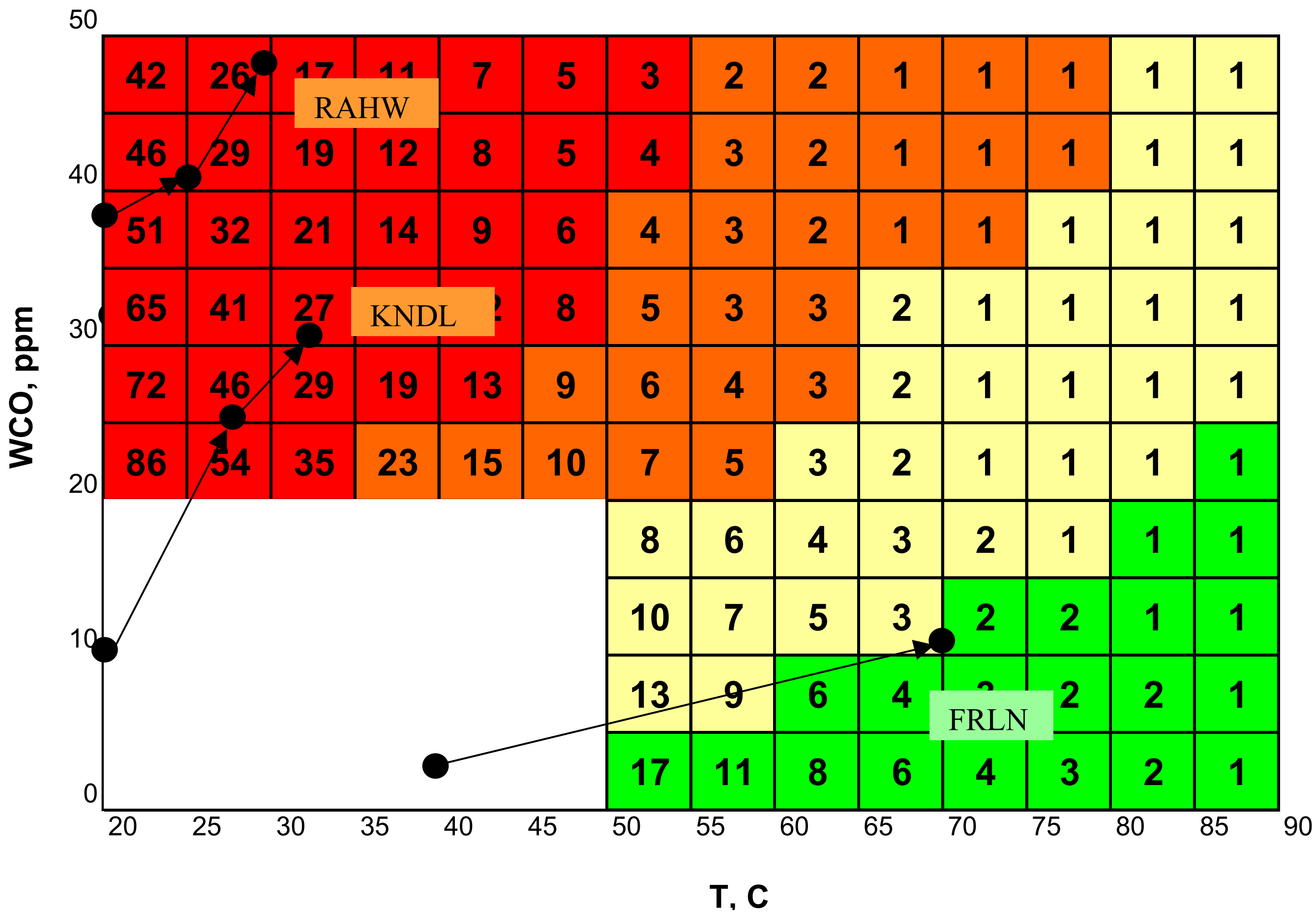


Moisture in Thin Insulation: Failure of the Transformer

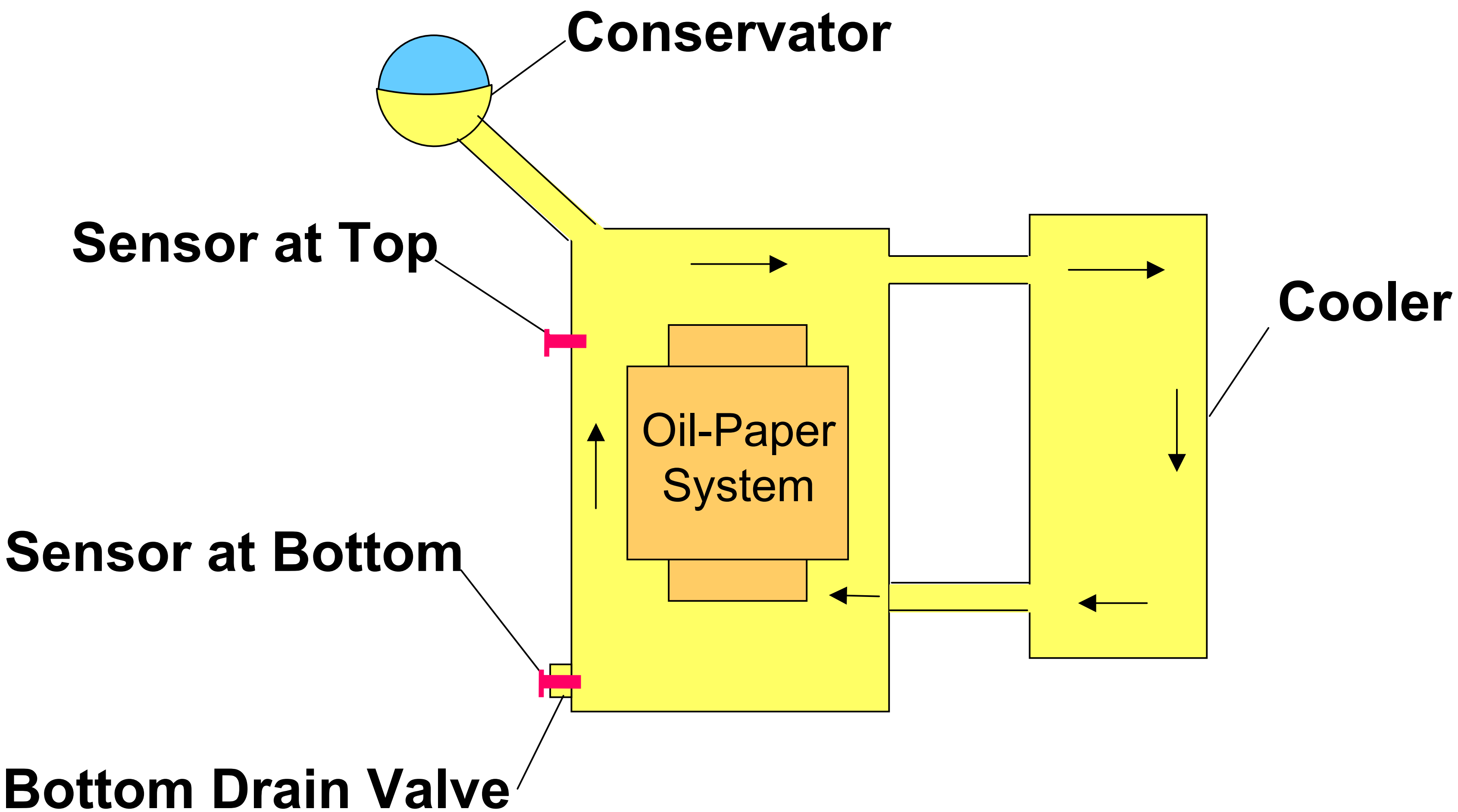
Moisture Determination Procedure

1. Measure water content of oil at low temperature, i.e. when oil temperature indicator reads minimum value for the day
2. Measure water content of oil taken from the same port at higher temperature (can be on the same day, depending on oil temperature cycle)
3. Plot results of two consecutive measurements on the Color Chart
4. Observe where the rate of change in WCO vector is headed. Direction of this vector is indicative of moisture state in transformer
5. If both measurements fall into the uncertain area, repeat the measurements during the higher temperature season or during the load increase period

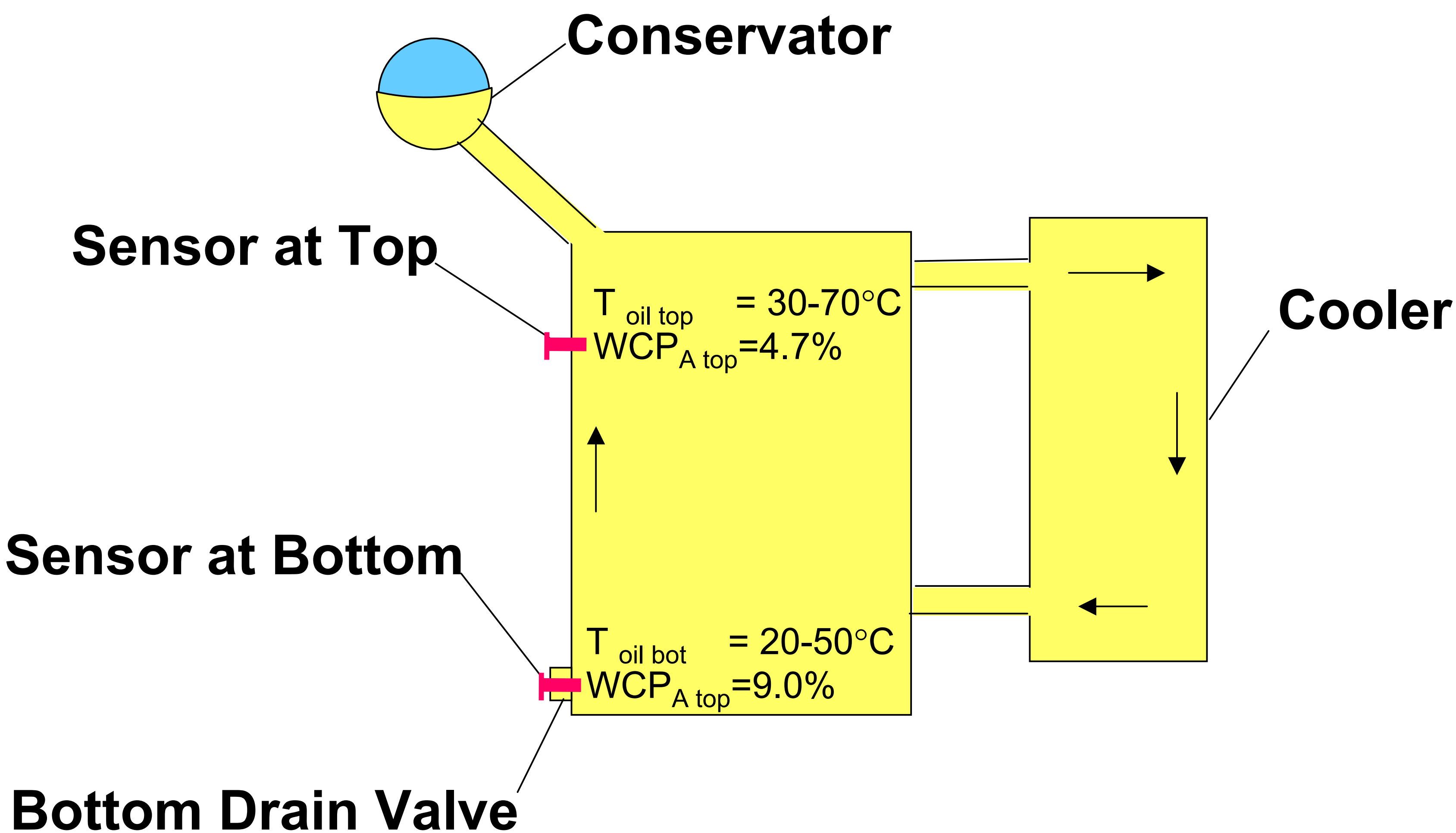
Classification Chart Usage



Trf with Natural Oil Circulation:Position of Sensors



Results of Moisture Assessment



Monash WIP Algorithm (Simplified)

Measurement of True %RS

↓

Water Solubility Test

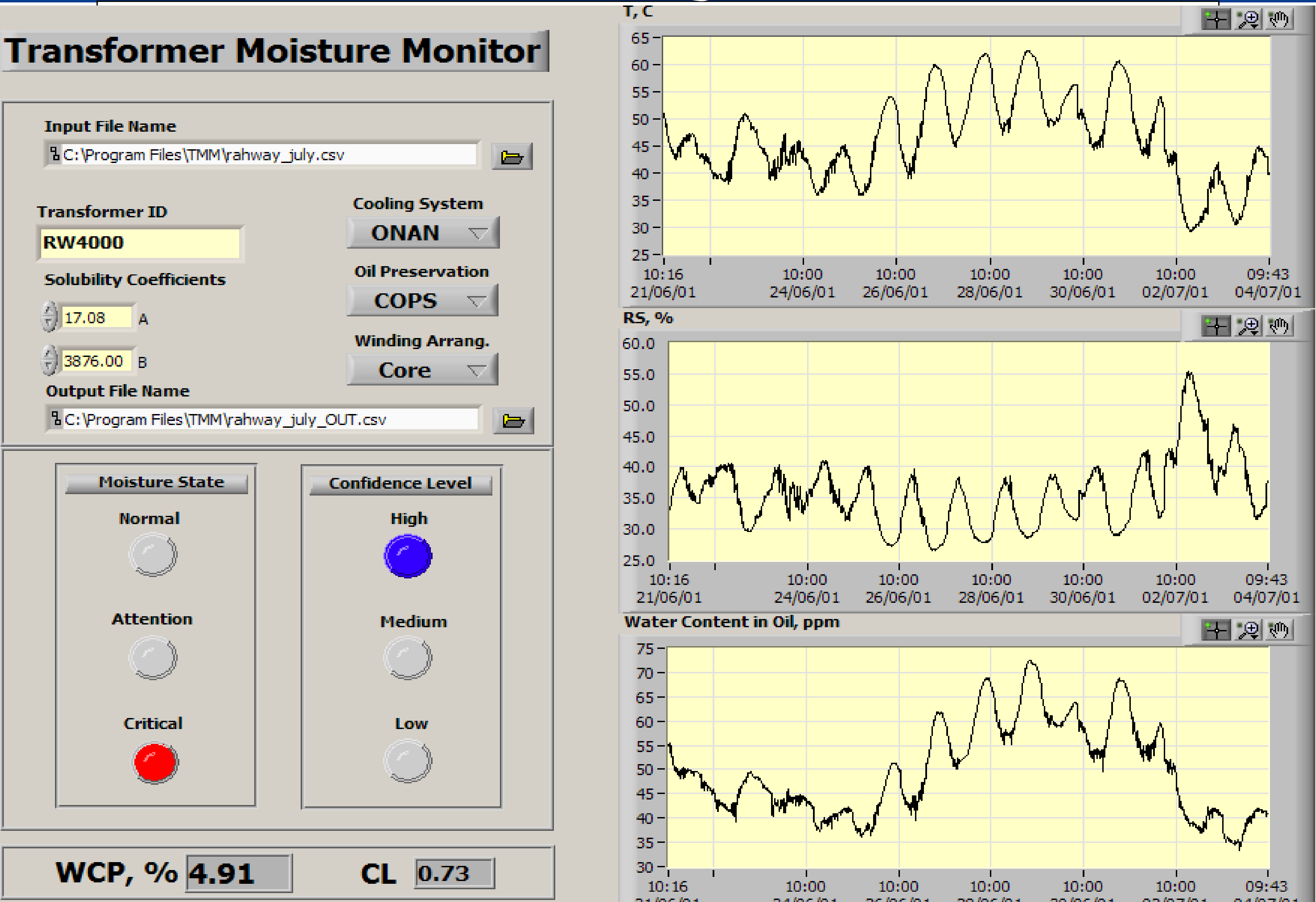
↓

Determination of WCP_A

Power Electronics Group

EPRI Project

Centre for Electrical Power Engineering



New Laboratory for the EPRI-Monash Project

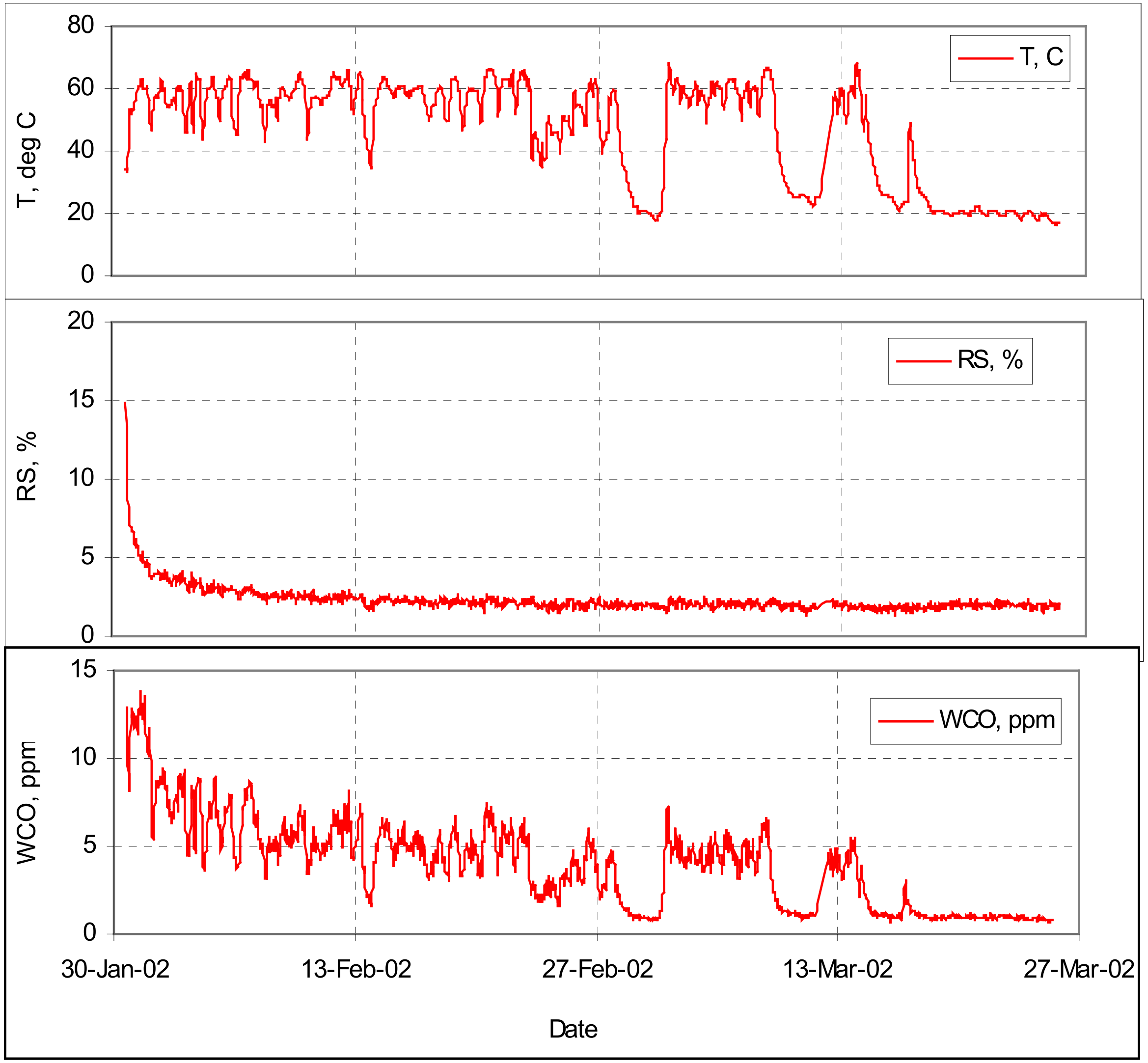
- Monash University has invested a sum of approx. USD $250,000 from its non-EPRI funds into construction of the New EPRI-Monash Project Laboratory
- Another USD $50,000 from non-EPRI funds are being spent for purchasing laboratory equipment
- The New Lab will become fully operational following installation and commissioning of the new equipment in 2004

Monash Assessment of
On-Load Dryout of EdF 22.5 MVA Trf

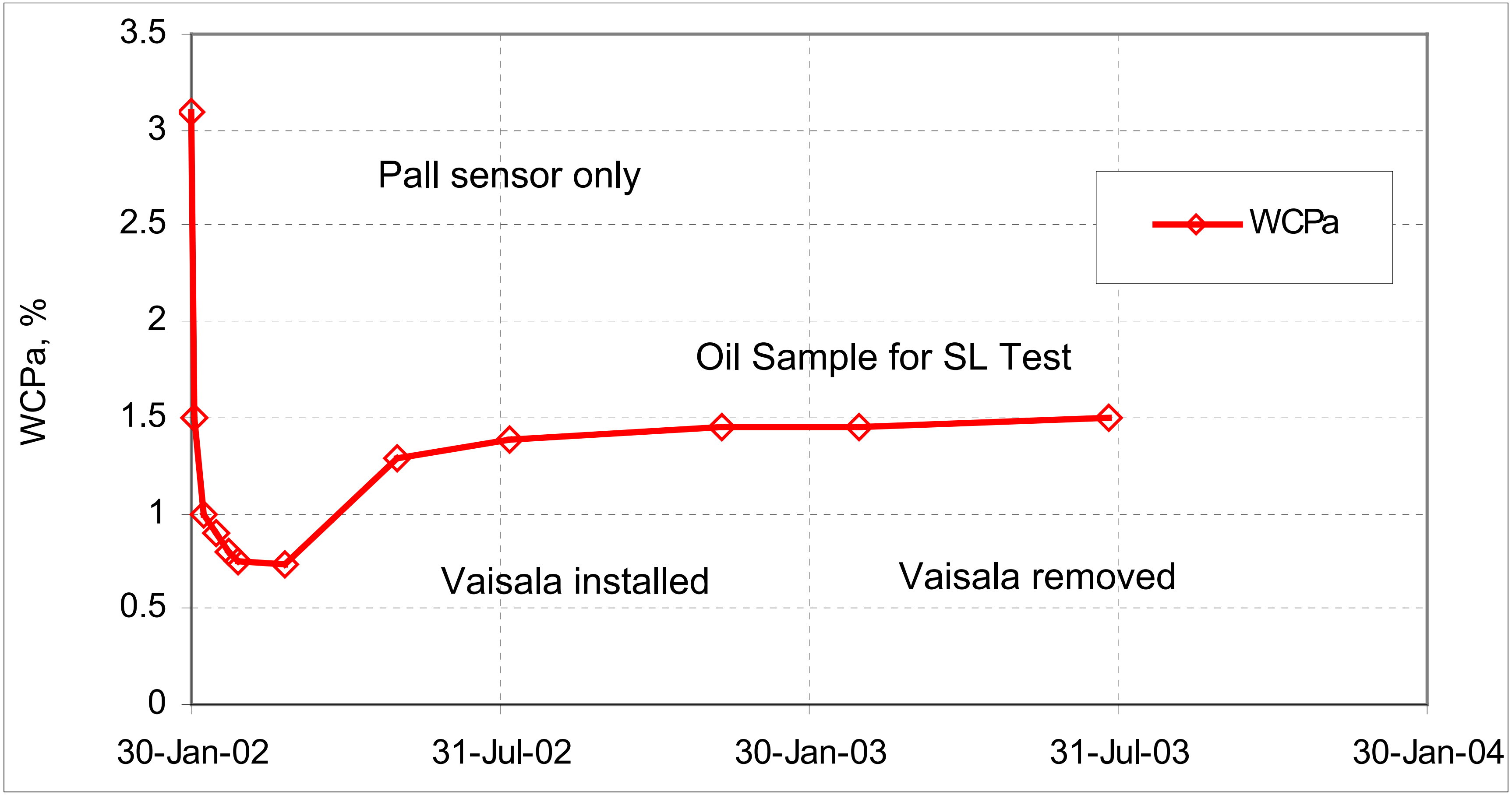
Aims

- Dry out the transformer on-load
- Assess dryout using Monash WIP algorithm
- Compare FRA signatures before and after to assess effect

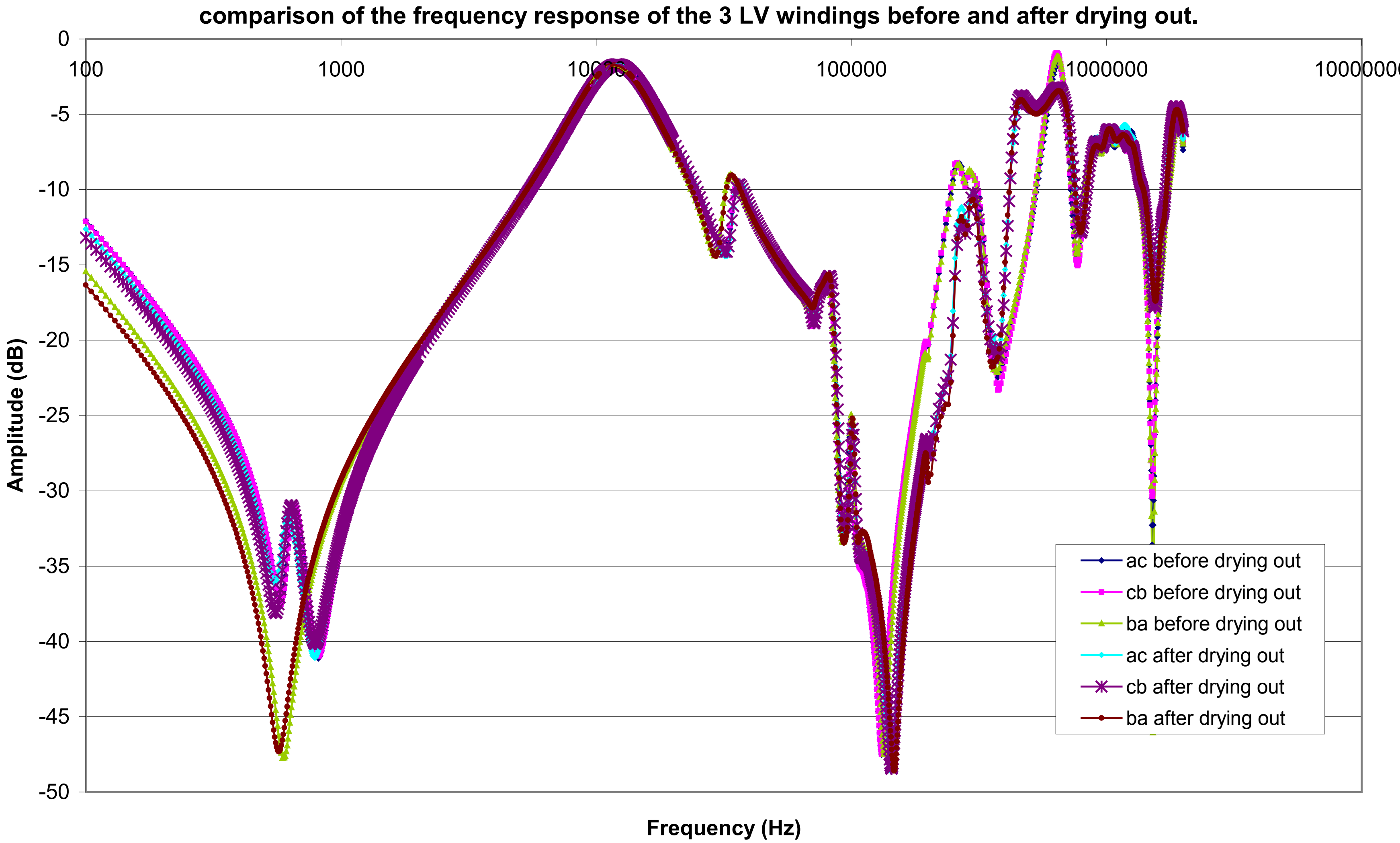
Monitoring of On-Load Drying for 8 Weeks



Changes in <u>Active</u> WCP during and after Dryout



FRA Signatures for EdF Transformer before and after Dryout



Factors which may affect FRA Signatures following Dryout

- **Changes in the temperature of transformer**
- **Changes in moisture content of insulation**
- **Possible slackness of transformer windings due to reduction of**

FRA Studies conducted in 2003

- Changes in the temperature of windings
- Changes in moisture content of insulation due to dryout
- Changes in geometry of windings due to a mechanical shift following re-clamping of the new transformer

Tests conducted on new transformer and on Monash model

66 kV Winding of the WTC New 150 MVA, 220/66/11 kV Transformer

Proposed FRA Studies for 2004-06 (ARC Project)

- Effect of changes in clamping pressure simulated on test models
- Effect of winding slackness simulated on test models
- Effect of dryout of newly built and older repaired transformers at the plant
- Effect of on-load dryout in the field

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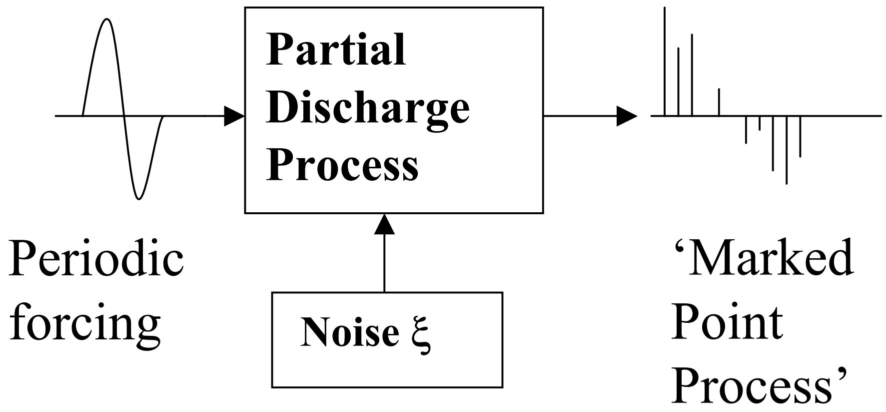
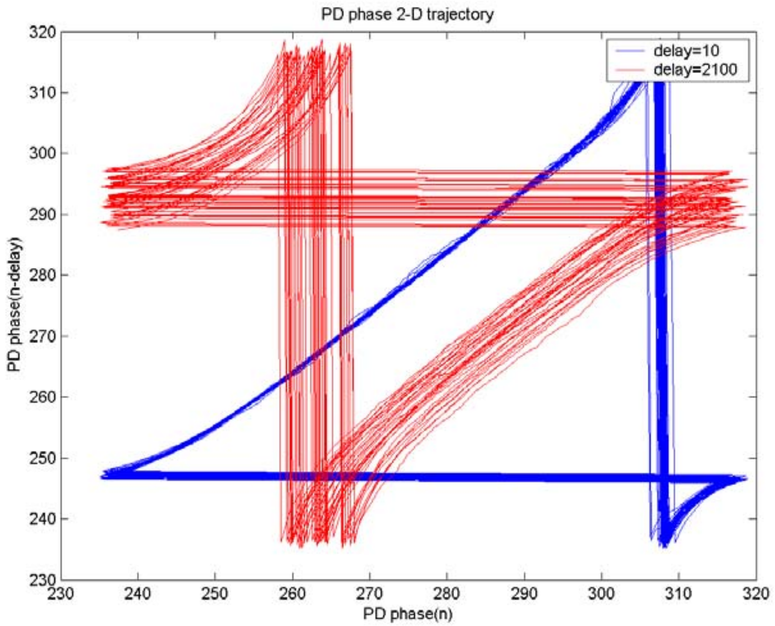
PARTIAL DISCHARGE ANALYSIS
A DETERMINISTIC APPROACH

Input-output representation of partial discharge process



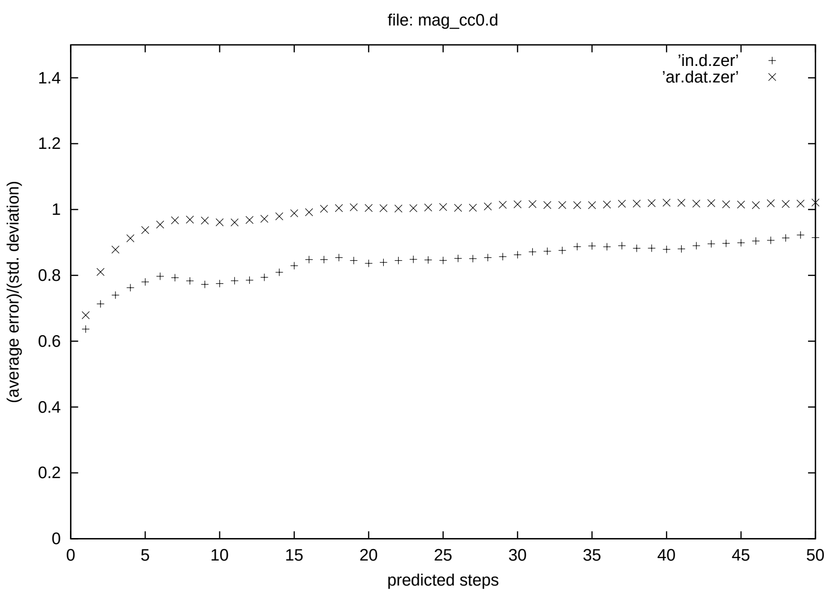
Deterministic dynamic model

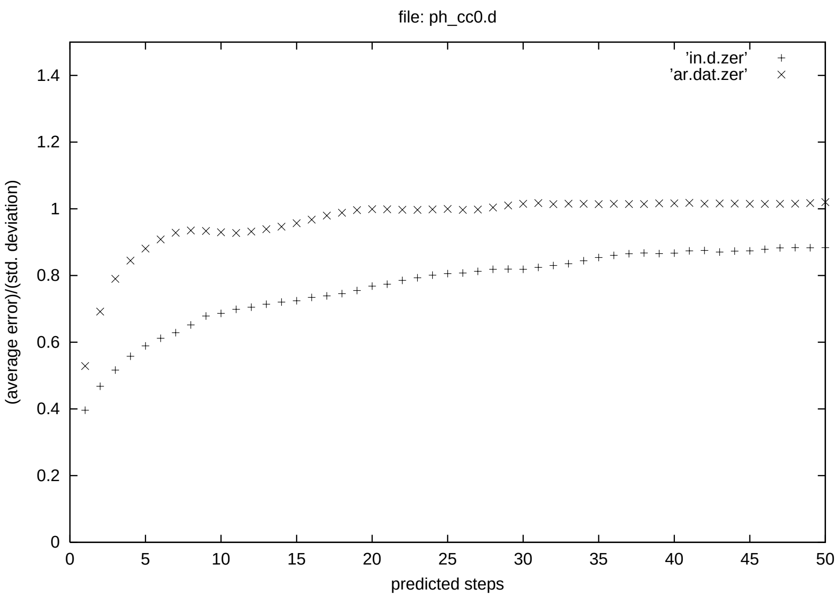
$$PD_{ph}(n+1), PD_m(n+1) =$$
$$f\left[PD_{ph}(n), PD_m(n), \cdots, PD_{ph}(1), PD_m(1\right.$$



⌘ 'Apparently stochastic' output from a deterministic process

Stochastic vs. non-linear – which one predicts better?



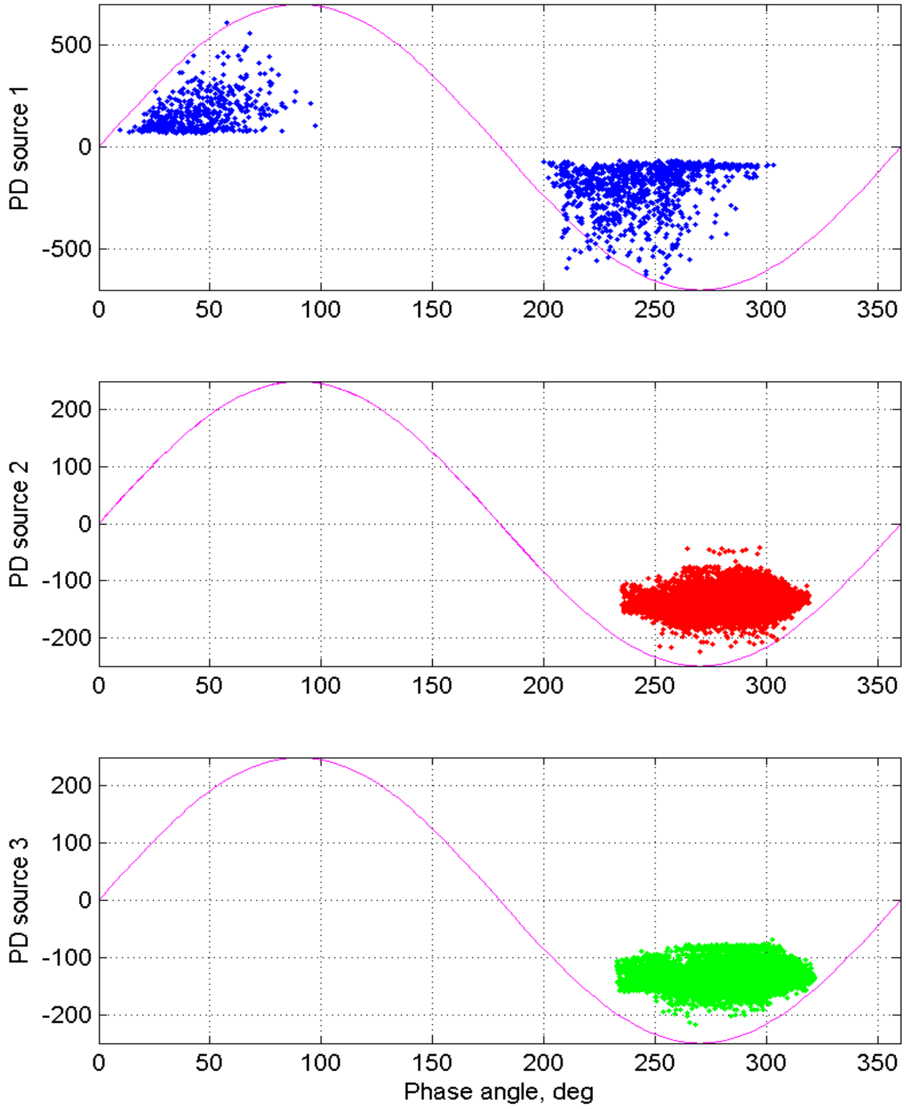


PD phase

Prediction errors from the global AR(10) model (xxx) and the local linear model (+++)

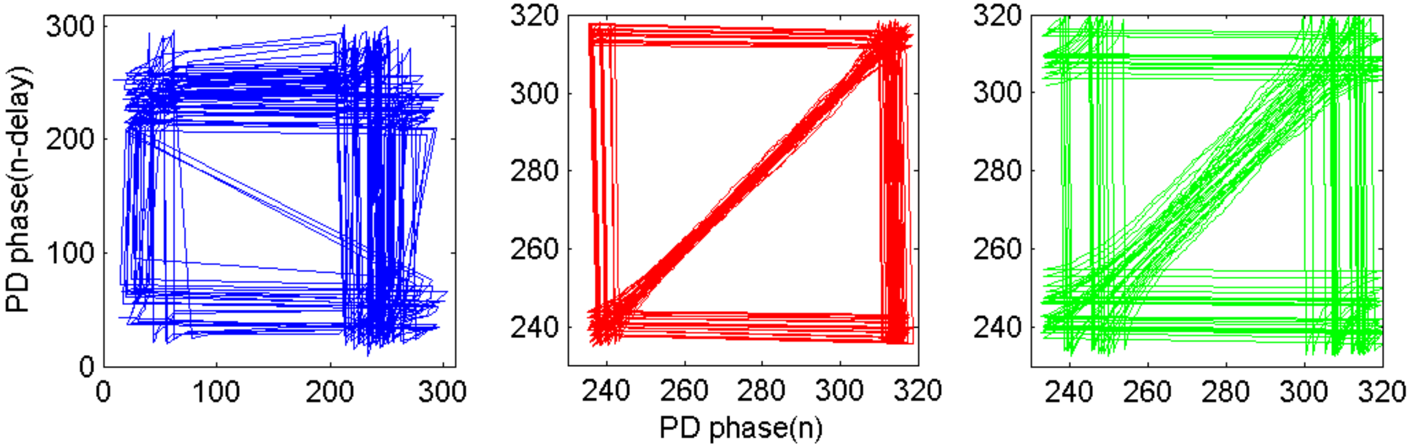
Classified PD signals

Phase resolved plots



Classified PD signals

Trajectory plots



Classification results

Confusion table of RMS errors for classified series

		Reference series							
		A	B	C	D	E	F	G	H
Classified series	A: PD source 1	**0.84**	1.06	1.09	1.4	1.56	1.2	1.22	1.03
	B: PD source 2	1.12	**0.52**	*0.73*	1.74	1.35	1.06	1.13	1.06
	C: PD source 3	1.08	*0.62*	**0.43**	1.77	1.34	1.02	1.13	1.01
	D: PD simulated	1.05	1.26	1.22	**0.04**	1.1	1.08	1.39	1.15
	E: periodic	1.24	1.09	1.13	1.41	**0.01**	0.51	1.39	1.03
	F: periodic+noise	1.55	1.3	1.39	2.08	1.07	**0.59**	1.87	1.07
	G: chaotic cont.	1.11	1.04	0.98	1.59	1.49	1.15	**0.09**	1.01
	H: chaotic disc.	1.13	1.11	1.13	1.48	1.37	1.1	1.29	**1.01**

Is classification robust?

Confusion table of RMS errors for the robustness test

		Reference series					
		A	B	C	D	E	F
Classified series	A: periodic, n/s=0	**0.03**	0.29	0.47	0.61	0.67	1.01
	B: periodic, n/s=20%	0.31	**0.23**	0.37	0.57	0.6	1.02
	C: periodic, n/s=40%	0.73	0.45	**0.39**	0.54	0.53	1.01
	D: periodic, n/s=60%	0.96	0.68	**0.56**	*0.63*	0.61	1.04
	E: periodic, n/s=80%	1.08	0.83	**0.69**	0.72	*0.71*	1.06
	F: random Gaussian	1.65	1.4	1.2	1.14	1.08	**1.02**

- Classification seems robust for noise levels up to 50% of the signal

Signal discrimination by non-linear dynamics

This idea is demonstrated by using synthetic data

- Process 1

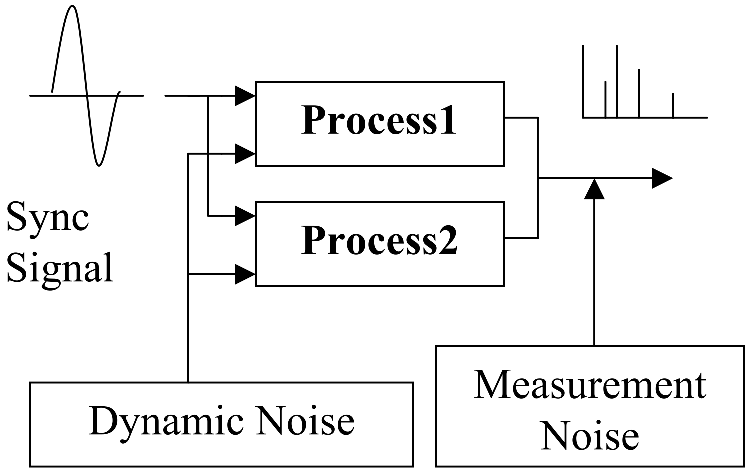
Logistic generator (chaotic)

- Process 2

$x_{n+1}=2\pi\cdot\sin(x_n)$

Processes synchronised by external signal

Random noise added to both inputs and the output



Output signal trajectory reveals the input signal dynamics

Conclusions

- Deterministic model predicts better than the stochastic one, so PD process is likely to have dominating deterministic component
- The error of prediction can be used as the discriminating statistic for PD source identification
- Mixed signals can be unscrambled by using trajectory plots, a promise for discrimination of PDs from mixed sources

- Electrical Power at Monash University – a short walk through history
- What is this business called Power Electronics ?
- Power Electronics research activities at Monash
- **Other Electrical Power Research Activities**
    - The EPRI Project
    - High Voltage
    - **Renewable Energy**
- Summary

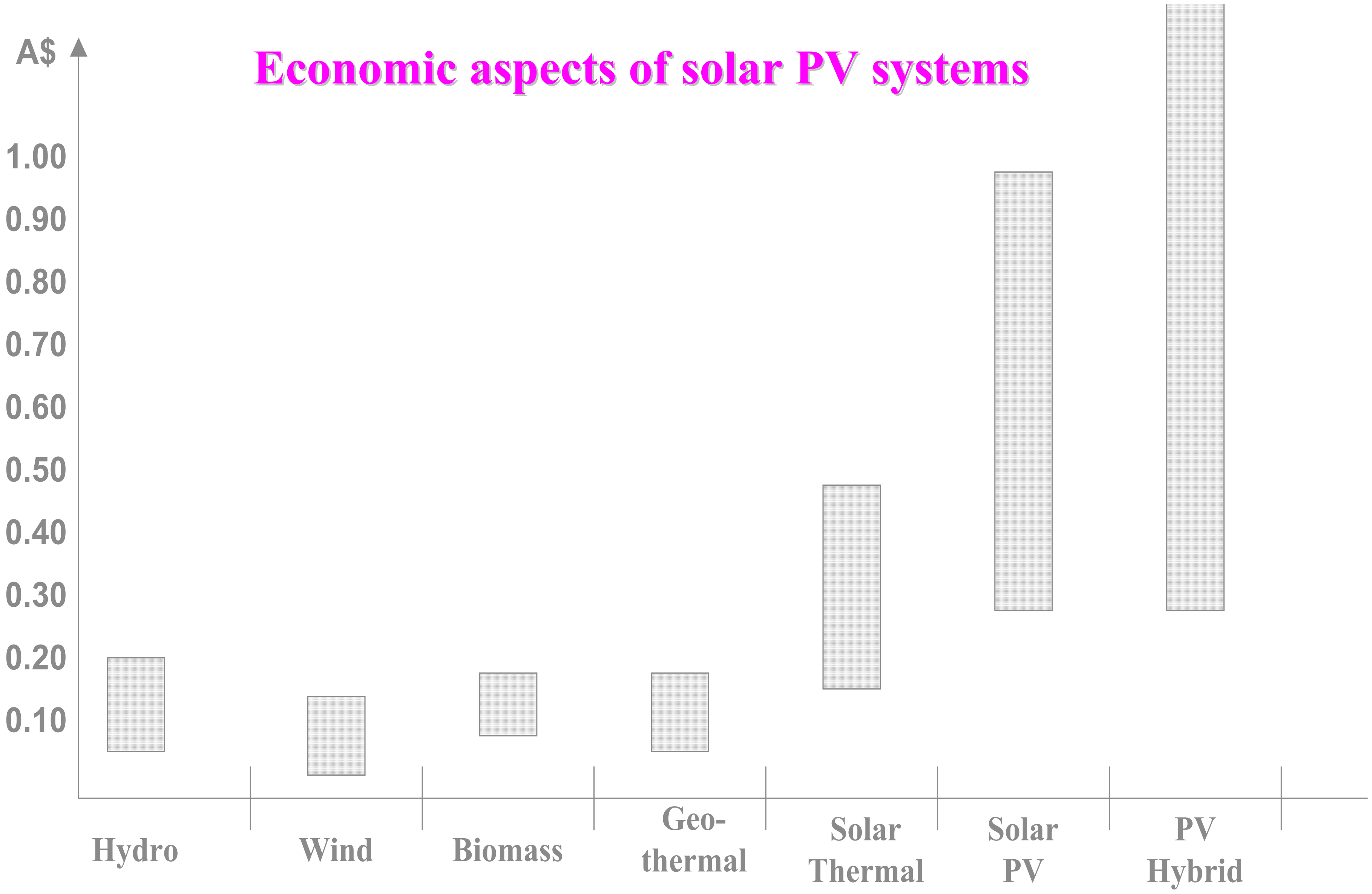
Australia: Target 2% new renewables by 2010

Solar Photovoltaic, Wind and Biomass

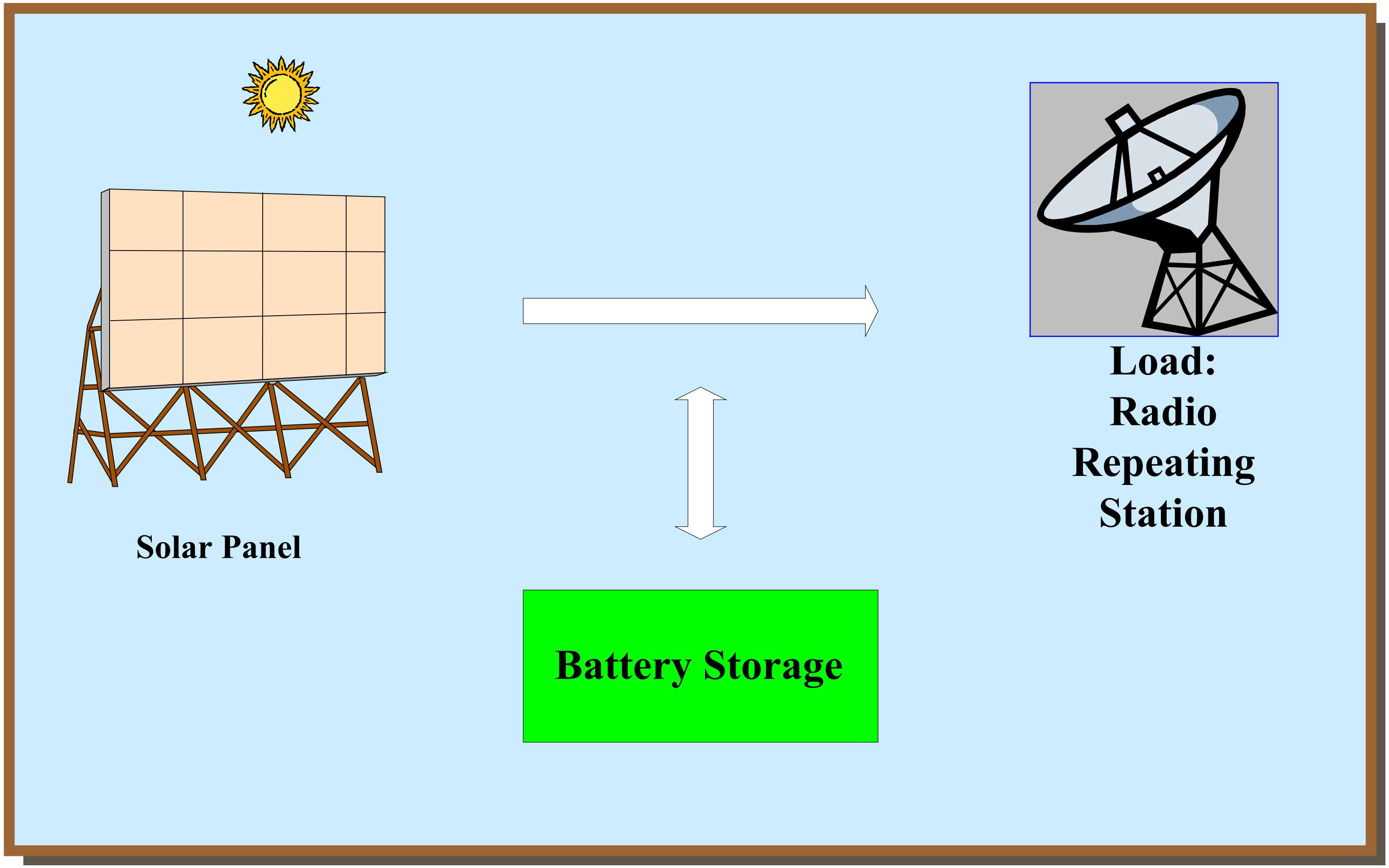
Main applications of solar PV energy systems

- Off-Grid Domestic
- Off-Grid Non-Domestic
- Mini Grid Hybrid
- Grid-tied distributed
- Grid-tied central

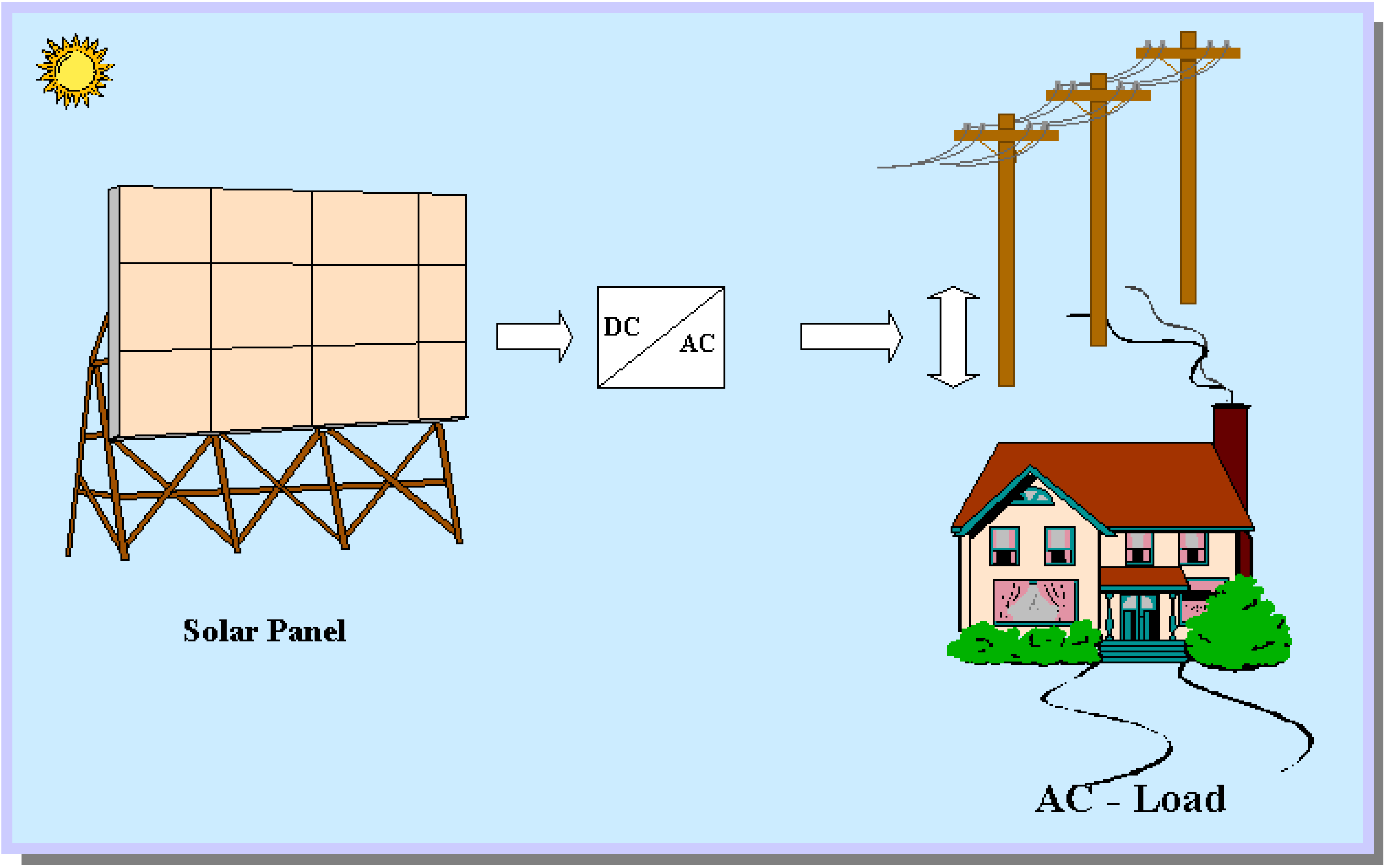
Economic aspects of solar PV systems



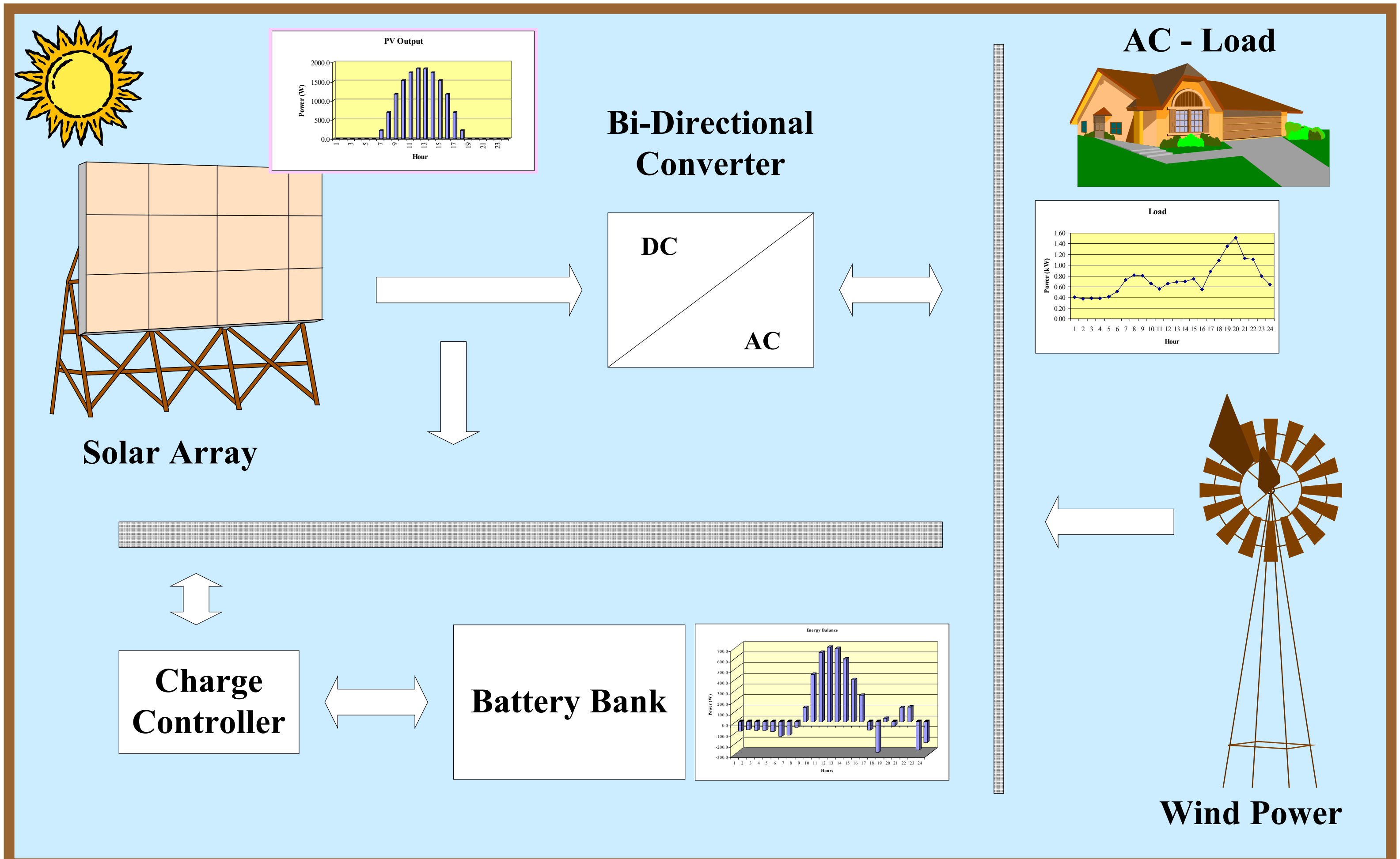
Design and Optimum sizing of PV systems for Telecommunication Companies, ie Telstra



Grid-tied PV system, Quality of Electricity Islanding, Harmonics & Voltage variation



Hybrid systems, Modelling, Performance prediction



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  - Renewable Energy
- **Research Opportunities – electrical energy conversion applications**

(Centre for Energy and Power Electronics ?)