THE UNIVERSITY OF TRINIDAD AND TOBAGO

FACTS TECHNOLOGY APPLICATIONS IN RENEWABLE ENERGY AND MICRO GRID INTERFACING

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FACTS TECHNOLOGY APPLICATIONS IN ELECTRIC POWER QUALITY AND RENEWABLE GREEN POWER SYSTEMS

CONTENTS

INTRODUCTION

- Electric power distribution systems suffer both voltage and power quality problems.
- Efficient operation and loss reduction is a priority for Energy Conservation and efficient Electric Energy Utilization.
- Massive increase in the use of Nonlinear loads are causing HAVOC with Distribution and Utilization systems.

INTRODUCTION

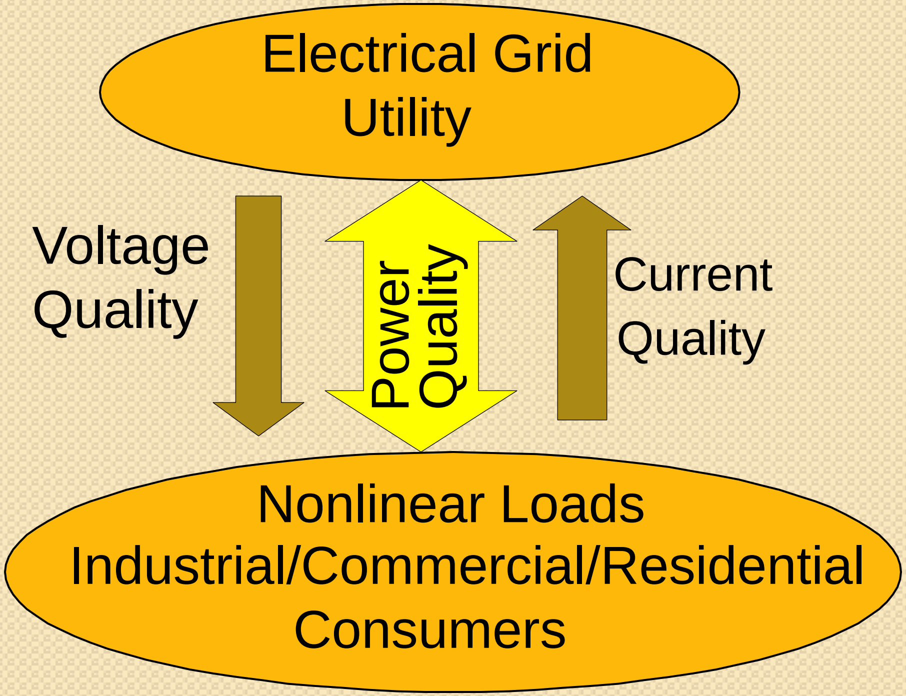
- Nonlinear loads, such as static power converters and arc furnaces cause excessive power quality problems, voltage sags/swells and harmonics.
- All contributes to extra Power/Energy Losses and voltage Stabilization problems as well as Shock Hazards, system Malfunction and and Equipment Damage
- All results in Poor Utilization and Low Power-Factor, Feeder Overloading and Noise Interference to adjacent communication systems [1].

INTRODUCTION

- In order to overcome these problems, Power Filter/CC has been used with new FACTS based devices such as:
- Active Power filters, STATCOM, MPF, Switched capacitor compensators are used to enhance power quality [2].
- The APF does not introduce resonance that can move a harmonic problem from one frequency to another.It can also be used for power factor correction and loss reduction [3].

What is Power quality ?

- *Definition :* "Power quality problem is any power problem manifested in voltage, current, or frequency deviation that results in failure or misoperation of customer equipment".
- Power quality can be simply defined as shown in the interaction diagram:



Electrical Grid Utility

Voltage Quality

Power Quality

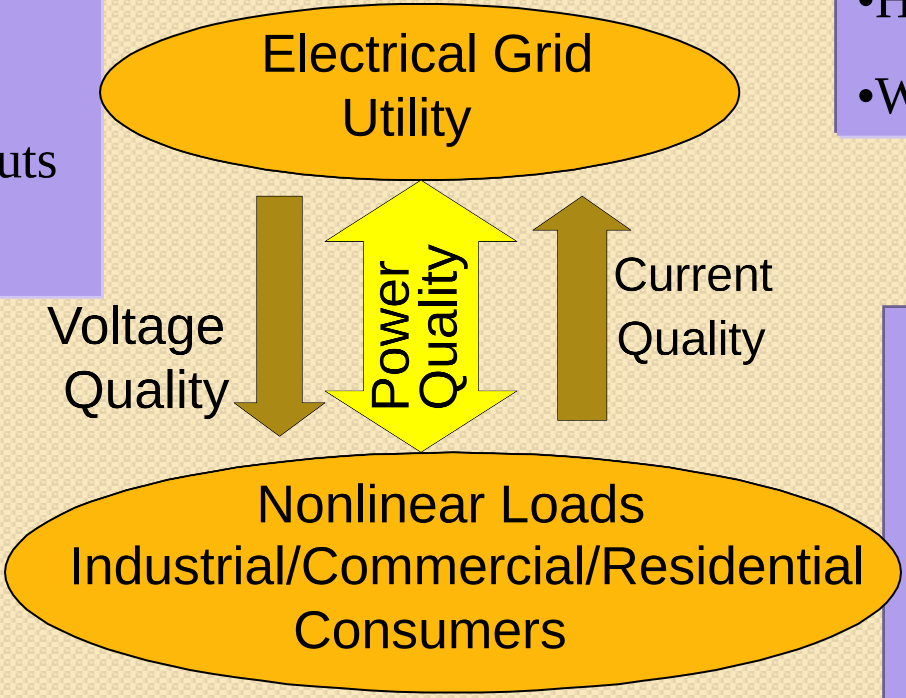
Current Quality

Nonlinear Loads Industrial/Commercial/Residential Consumers

What is Power quality ?

- Voltage Sags
- Voltage Swells
- Blackouts/Brownouts
- Transient

- Harmonics
- Waveform Distortion



Electrical Grid
Utility

Voltage
Quality

Power
Quality

Current
Quality

Nonlinear Loads
Industrial/Commercial/Residential
Consumers

- Inrush
- Overcurrent
- Flickering

- Arc Type
- Temporal
- Converter Type
- Saturation Type
- NLL-Analog/Digital Switching

Why are we concerned about PQ?

The Main reasons behind the growing concern about PQ are:

North American industries lose Tens-of-Billions of Dollars every year in downtime due to power quality problems. (Electrical Business Magazine)

Load nonlinearities in rising and is expected to reach 50 to 70% in the year 2005 (Electric Power Research Institute) [Computers, UPS, fax machines, printers, fluorescent lighting, ASD, industrial rectifiers, DC drives, arc welders, etc).

The characteristics of the electric loads have changed.

Harmonics are continuous problem not transient or intermittent.

Power Quality Issue and Problems

- Power Quality issues can be roughly broken into a number of sub-categories:
- Harmonics (sub, super and interharmonics);
- Voltage swells, sags, fluctuations, flicker, and transients
- Voltage magnitude and frequency deviation, voltage imbalance (3ph sys.)
- Hot grounding loops and ground potential rise (GPR)–Safety & Fire Hazards
- Monitoring and measurement.

Power Quality PQ Issue

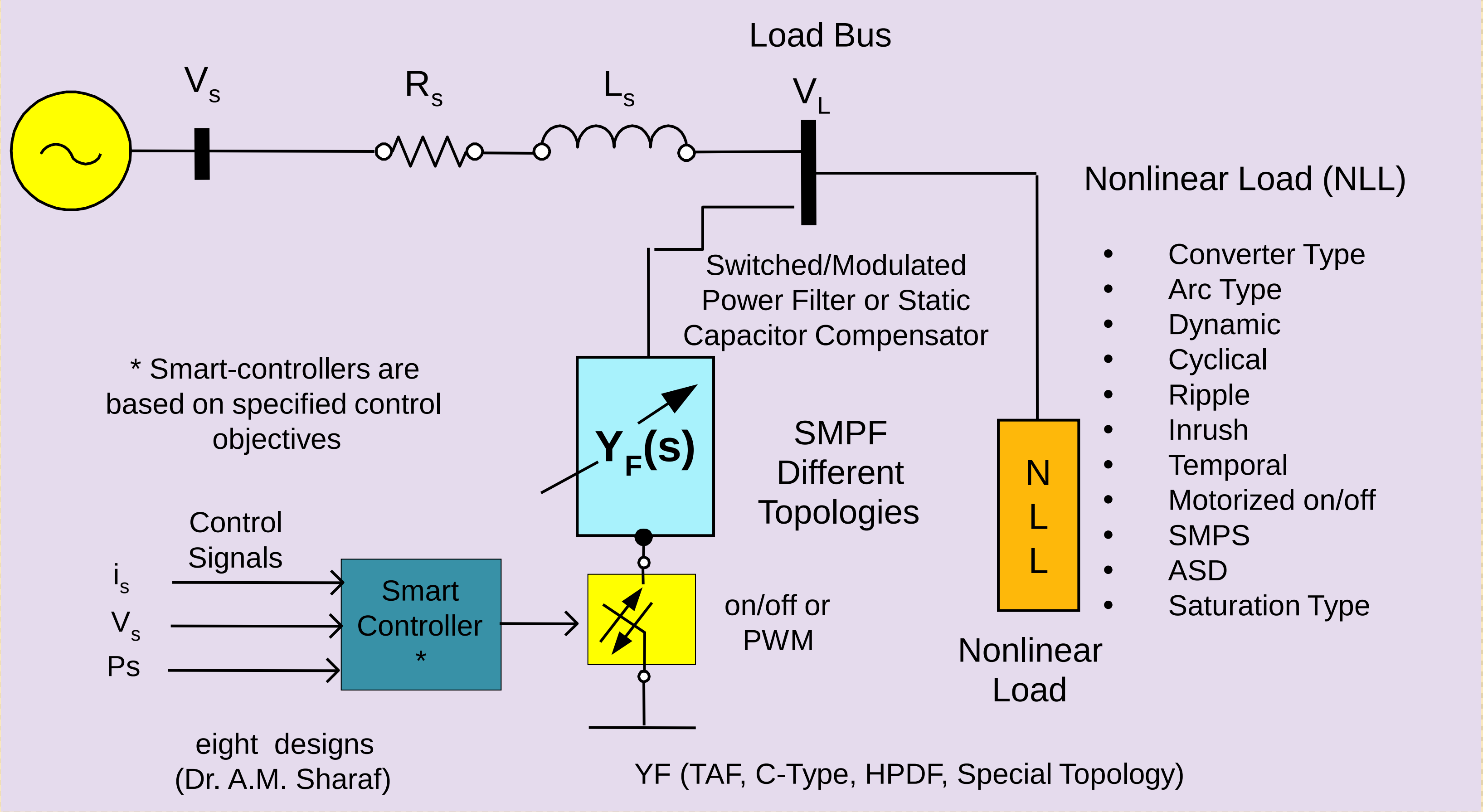
Harmonics and NLL issues:

The harmonic issue (waveform distortion) is a top priority to for all equipment manufacturer, users and Electric Utilities (New IEC, ANSI, IEEE Standards).

$$\left(THD_i\right) = \left[\frac{\sqrt{\sum_{n=2}^{\infty} I_n^2}}{I_1}\right]$$

$$PF = \frac{1}{\sqrt{1+THD_i^2}} DPF$$

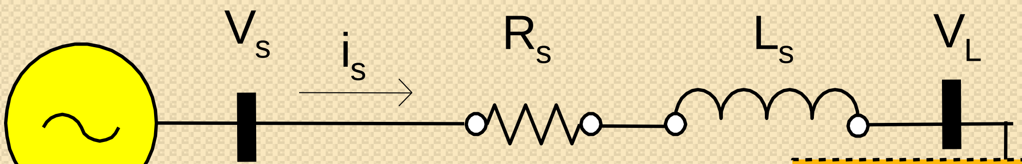
SYSTEM MODELS

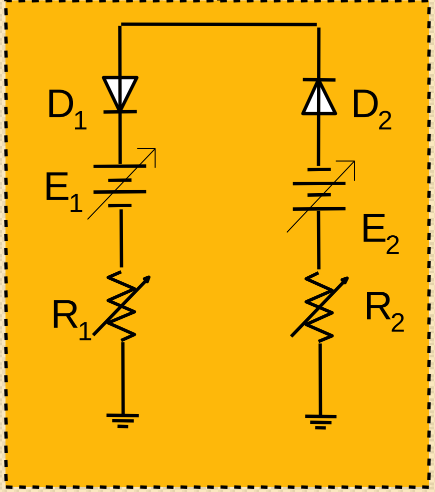


- Converter Type
- Arc Type
- Dynamic
- Cyclical
- Ripple
- Inrush
- Temporal
- Motorized on/off
- SMPS
- ASD
- Saturation Type

Single Line Diagram of Radial Utilization System

Nonlinear Load Models

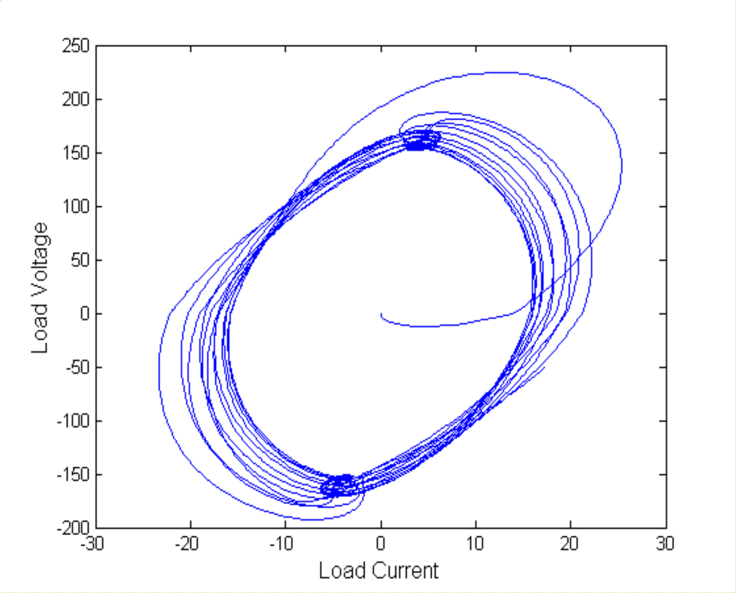




Arc Nonlinear Load/ Cyclical

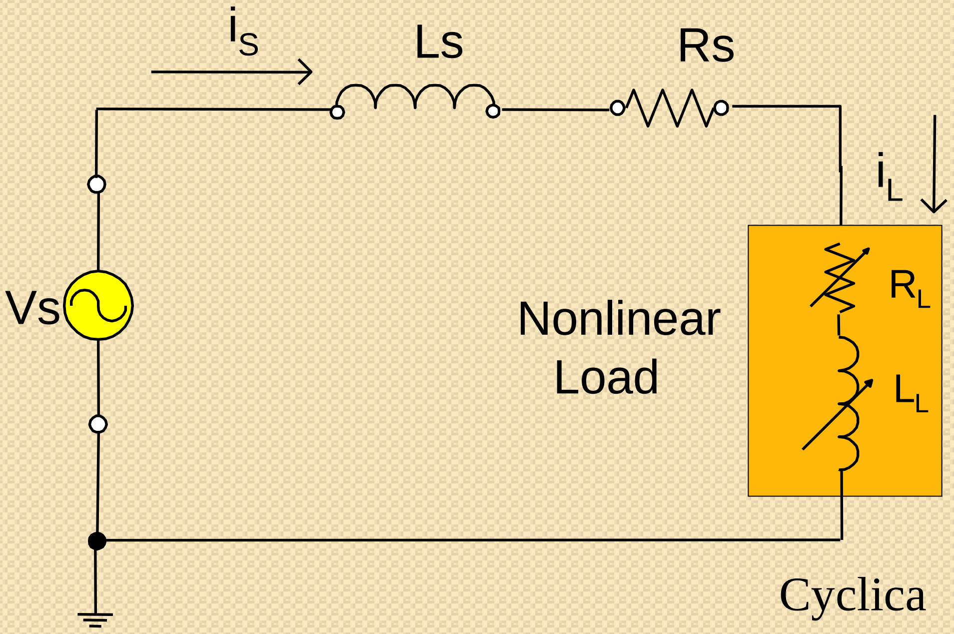
Arc Type

Symmetrical
Asymmetrical
E1 different from E2
R1 different from R2

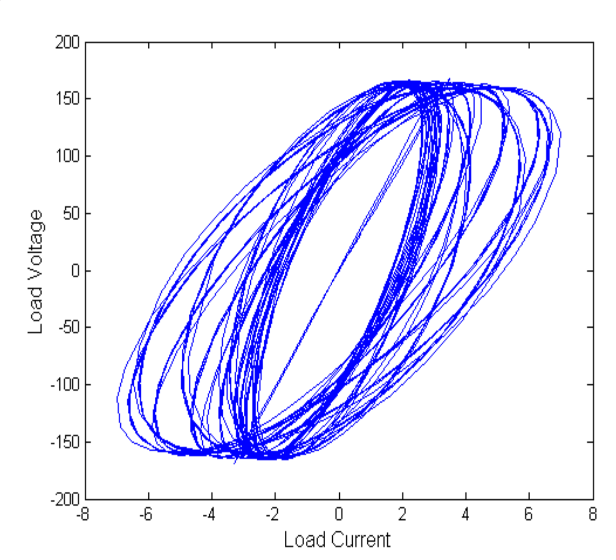


Volt-Ampere ($V_L - I_L$)

Nonlinear Load Models



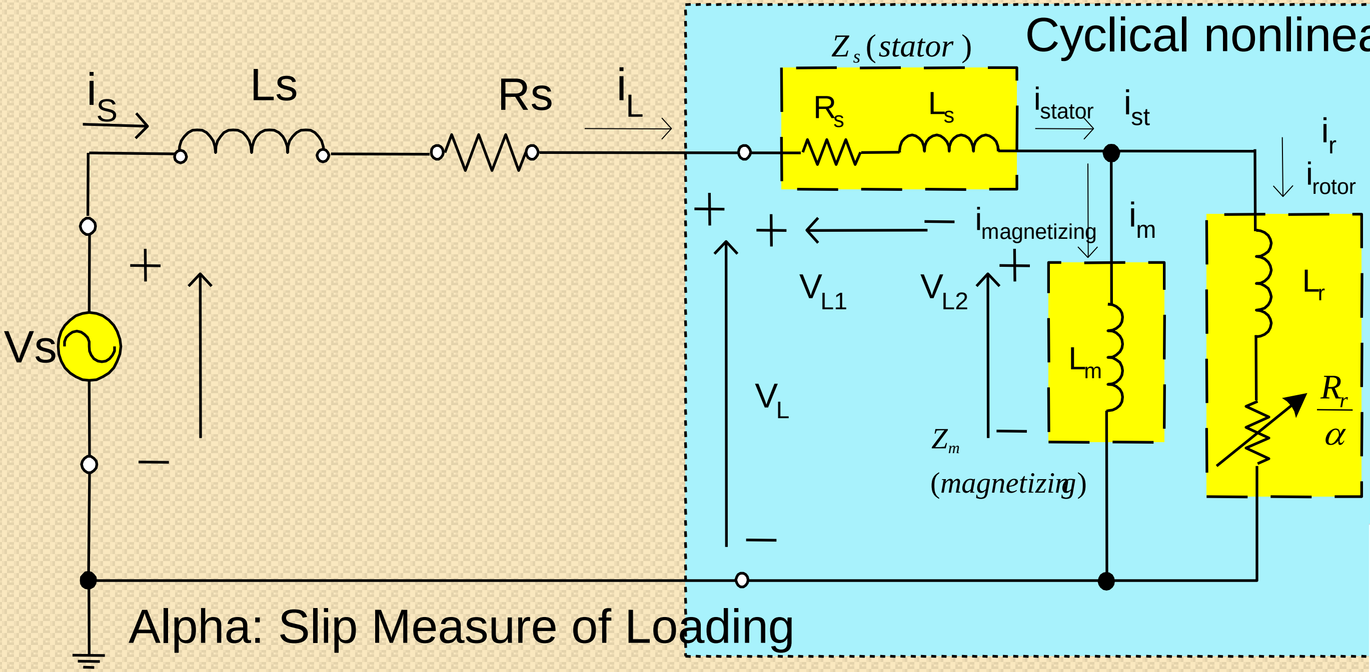
Cyclica
l Load



Volt-Ampere ($V_L – I_L$)

Temporal time-dependent (Cyclical load)

Nonlinear Load Models

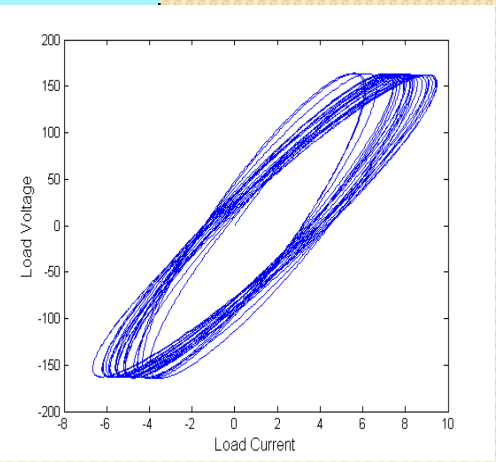


Alpha: Slip Measure of Loading

Industrial
Motorized
Load

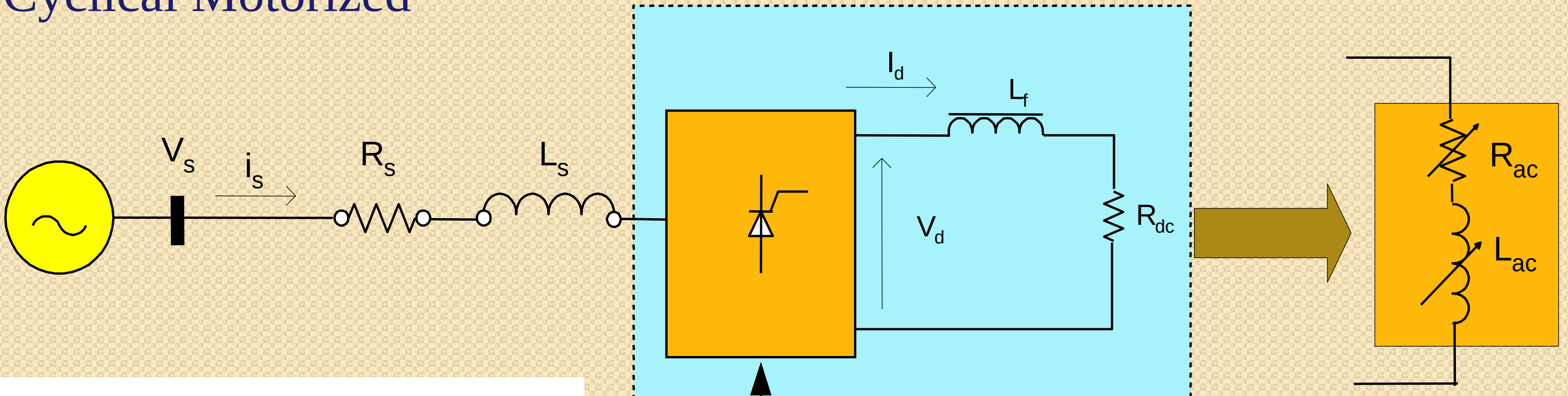
Cyclical Motorized

Volt-Ampere ($V_L – I_L$)



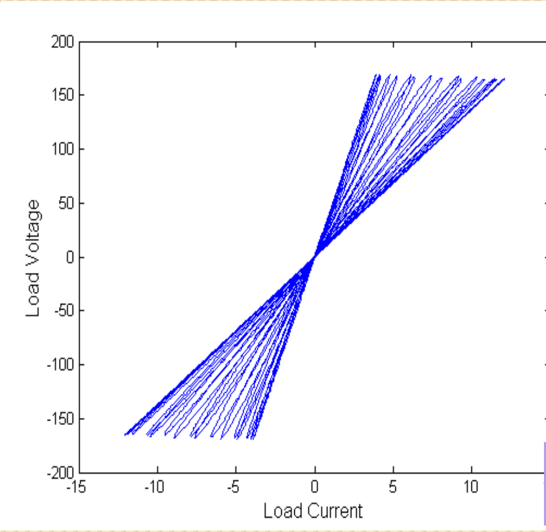
Nonlinear Load Models

Cyclical Motorized

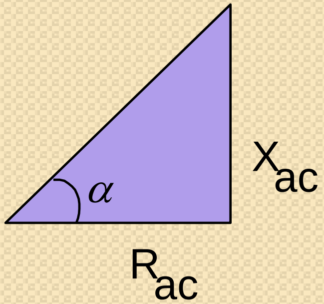


Modulated Load

Converter-Rectifier Modulated

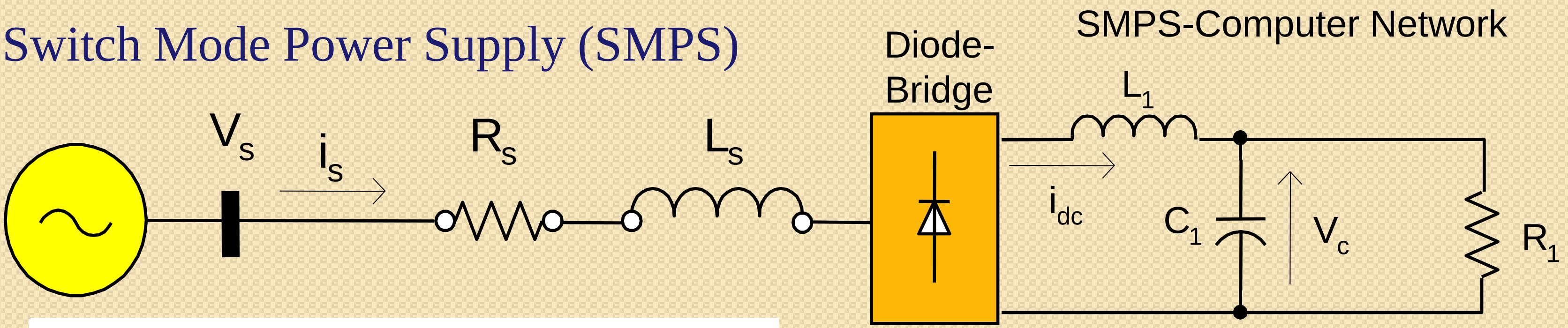


Modulated Fanning Effect

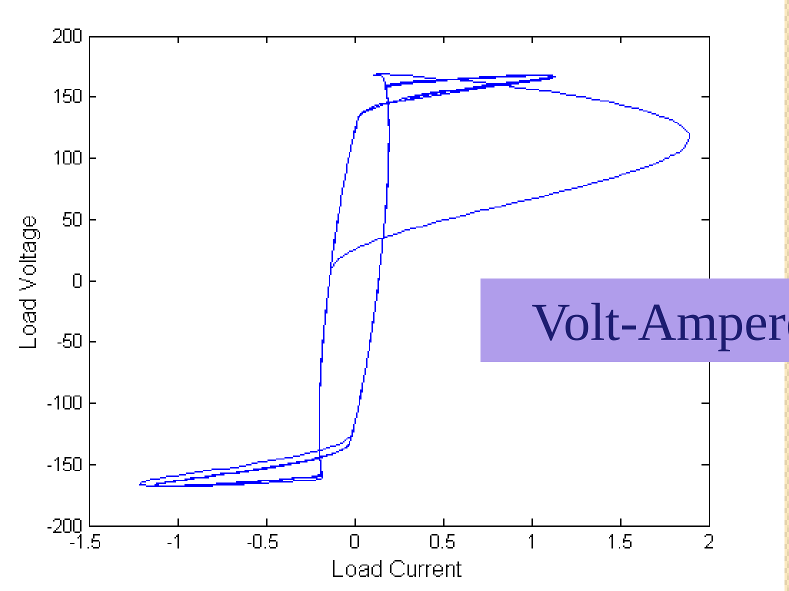


Nonlinear Load Models

Switch Mode Power Supply (SMPS)

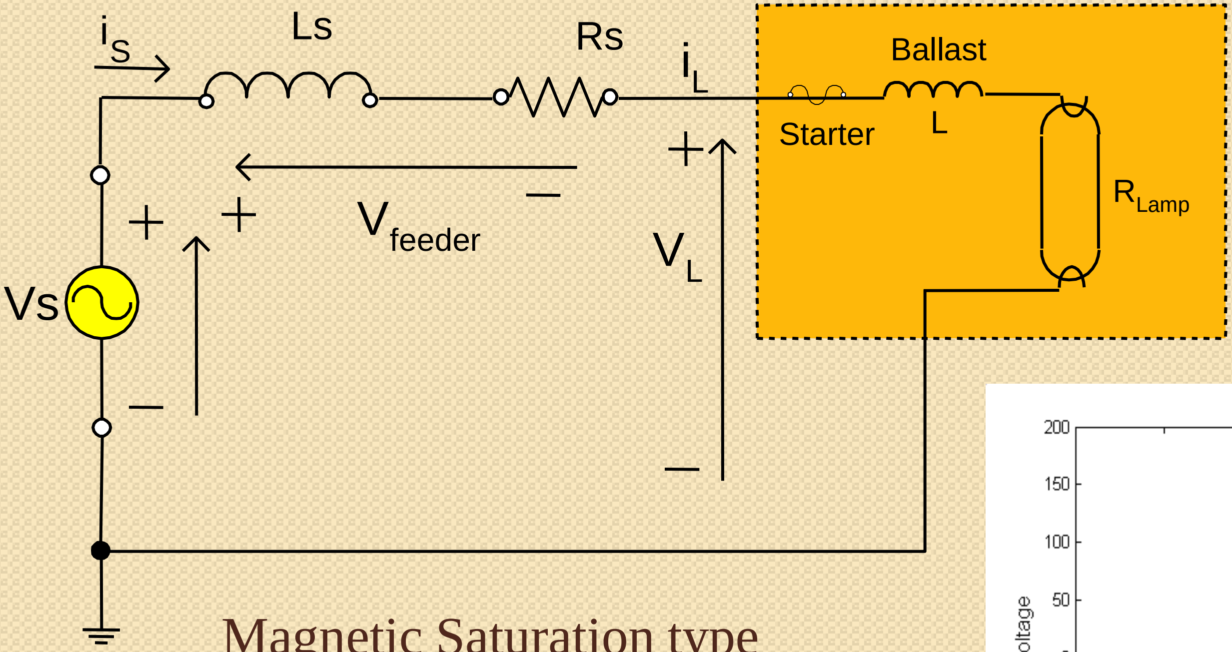


Limiter Type



Volt-Ampere ($V_L – I_L$)

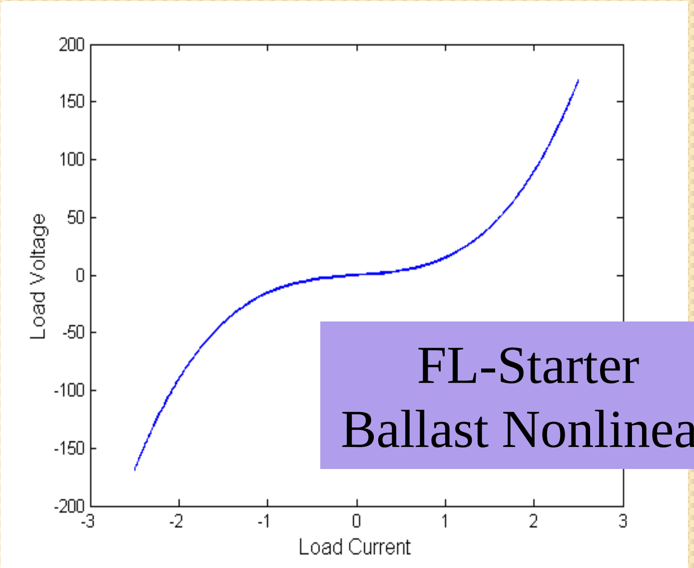
Nonlinear Load Models



Fluorescent Lamp

Magnetic Saturation-
Transformer
type Nonlinear Load

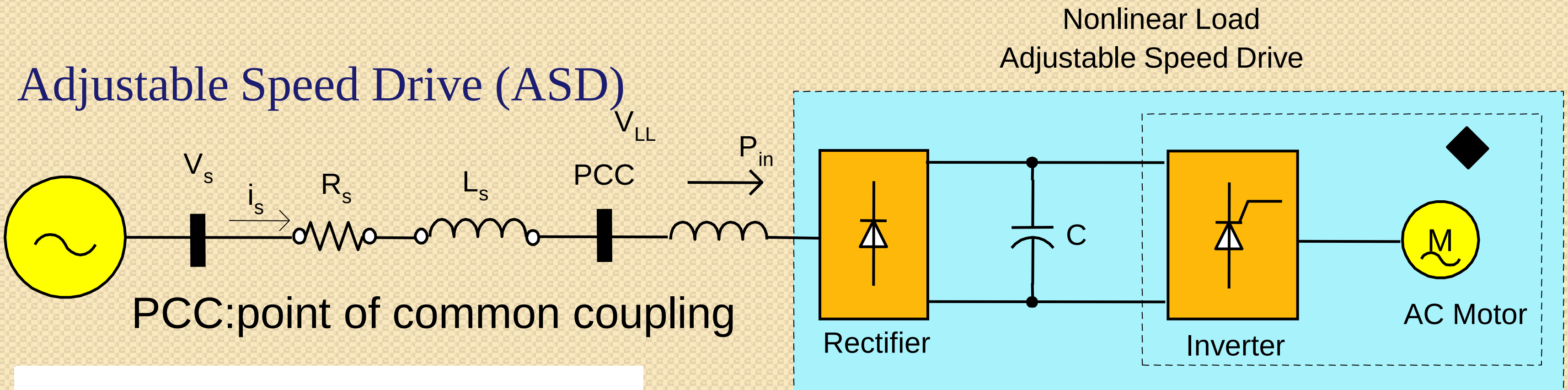
Magnetic Saturation type



FL-Starter
Ballast Nonlinear

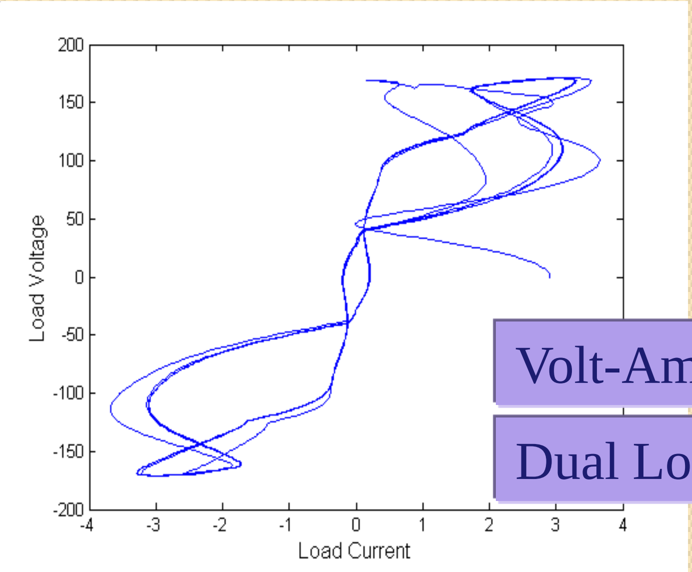
Nonlinear Load Models

Adjustable Speed Drive (ASD)



PCC:point of common coupling

- AC Motor and Inverter have been replaced by an equivalent resistor

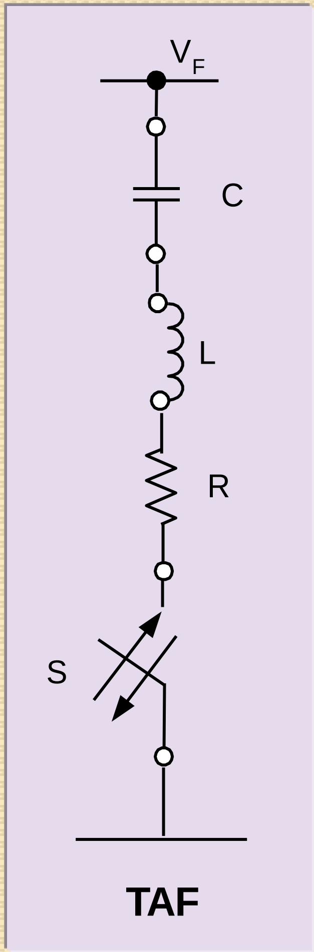


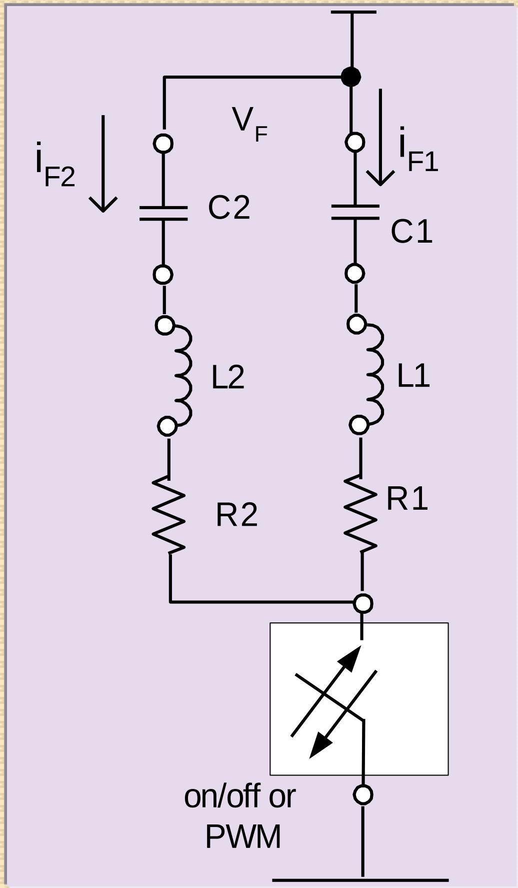
Volt-Ampere ($V_L – I_L$)

Dual Loop Nonlinear

Switched Modulated Power Filters and Capacitor Compensators

Tuned-Arm Filter (TAF)



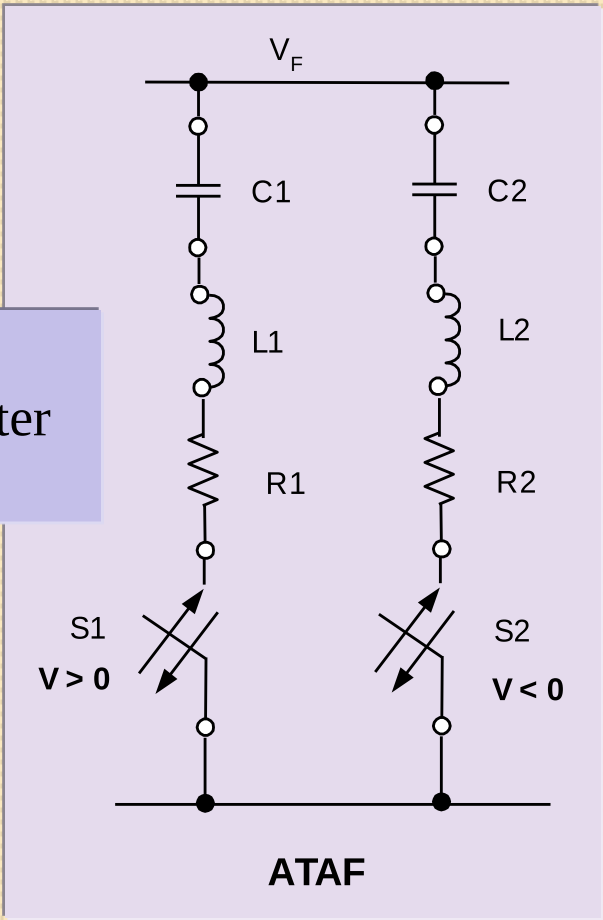


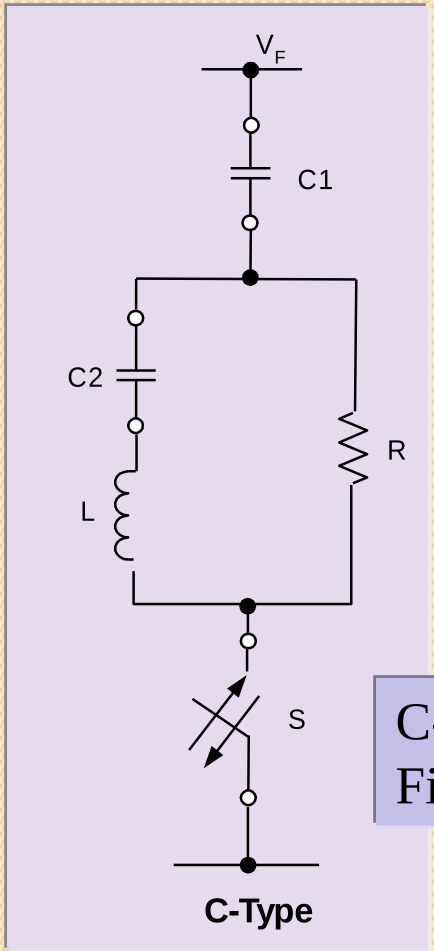
Dual-Tuned-Arm Filter

MPF/SPF(Family of Filters – Compensators) Developed by Dr. A. M. Sharaf

Switched Modulated Power Filters and Capacitor Compensators

Asymmetrical Tuned-Arm Filter (ATAF)

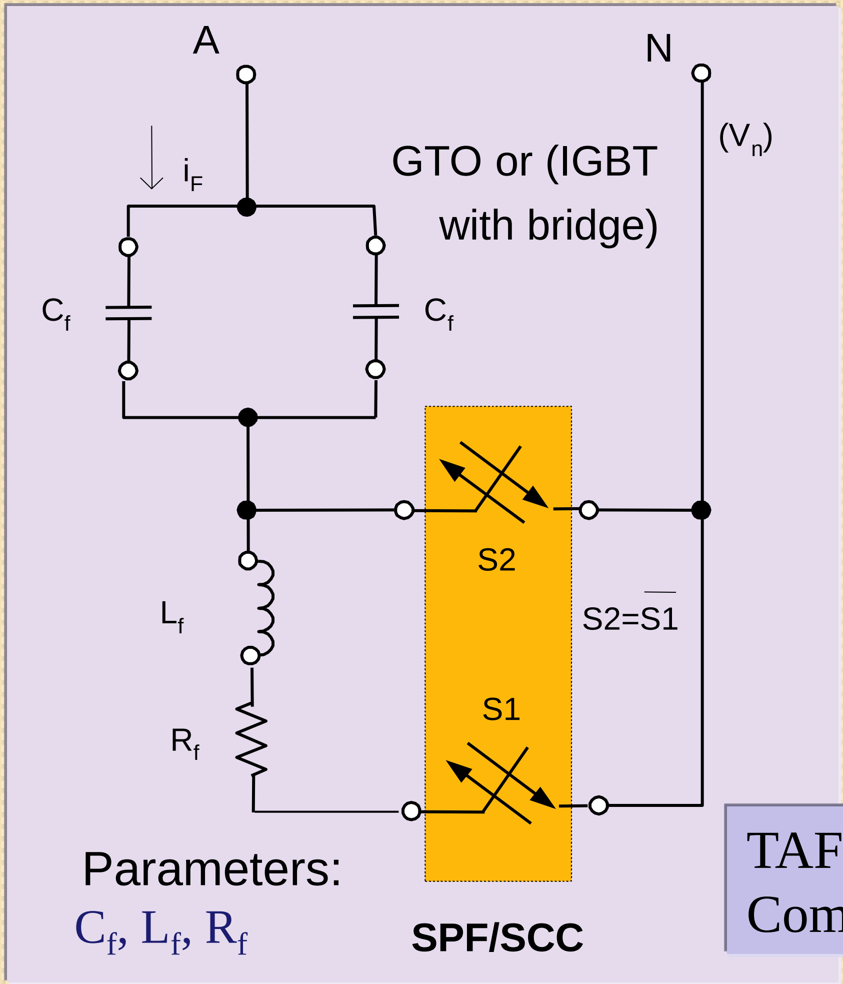




C-Type Filter

MPF/SPF(Family of Filters – Compensators) Developed by Dr. A. M. Sharaf

Switched Modulated Power Filters and Capacitor Compensators



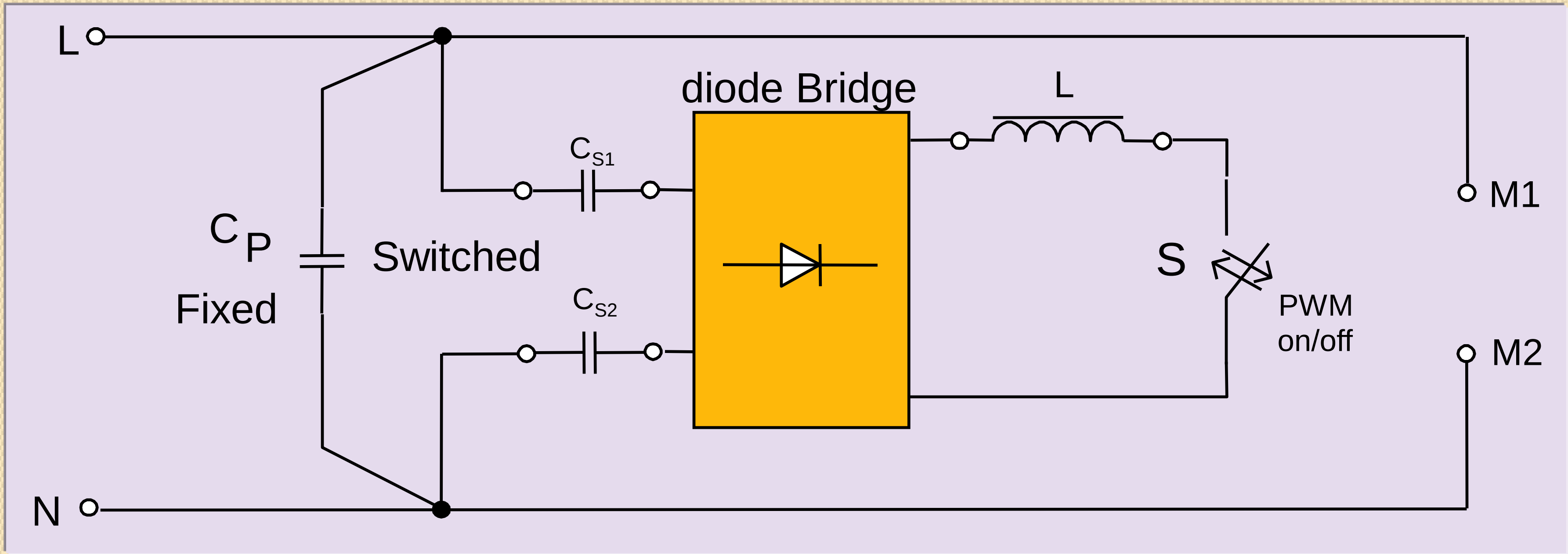
Parameters:

C_f, L_f, R_f

TAF + Static Capacitor Compensator

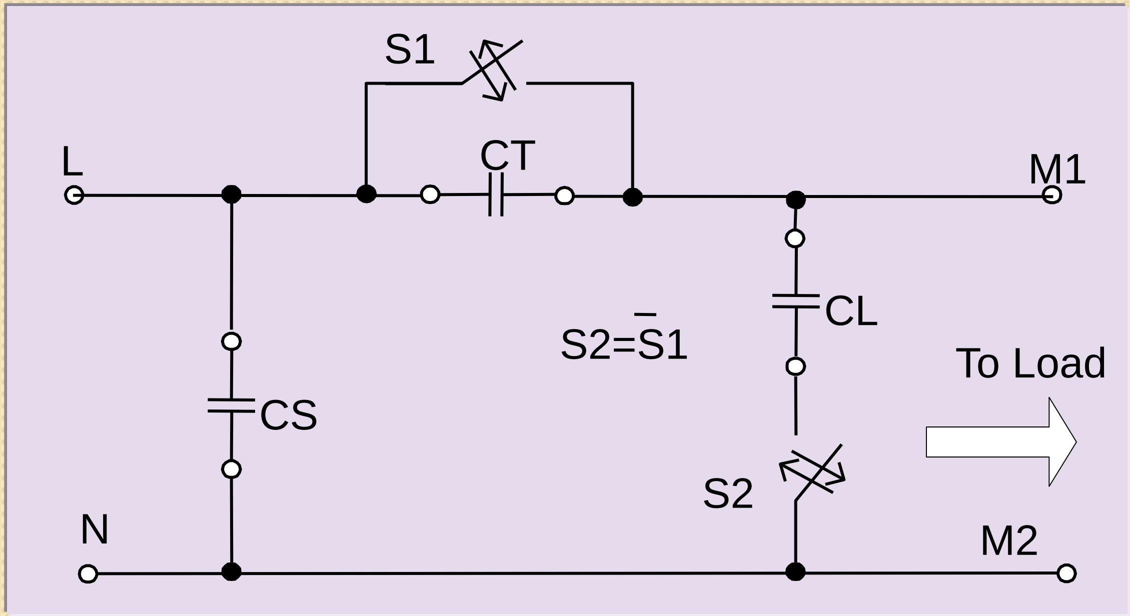
MPF/SPF(Family of Filters – Compensators) Developed by Dr. A. M. Sharaf

Switched Modulated Power Filters and Capacitor Compensators



Economic Tuned-Arm Power Filter and Capacitor Compensator Scheme
(used in S-phase 2 wire loads)

Switched Modulated Power Filters and Capacitor Compensators



Switched Capacitor Compensator Scheme
(used for on/off Motorized loads)

Motorized Inrush Loads

- Water Pumps
- A/C
- Refrigeration
- Blower / Fans

Novel Dynamic Tracking Controllers

(Family of Smart Controllers Developed by Dr. A. M. Sharaf)

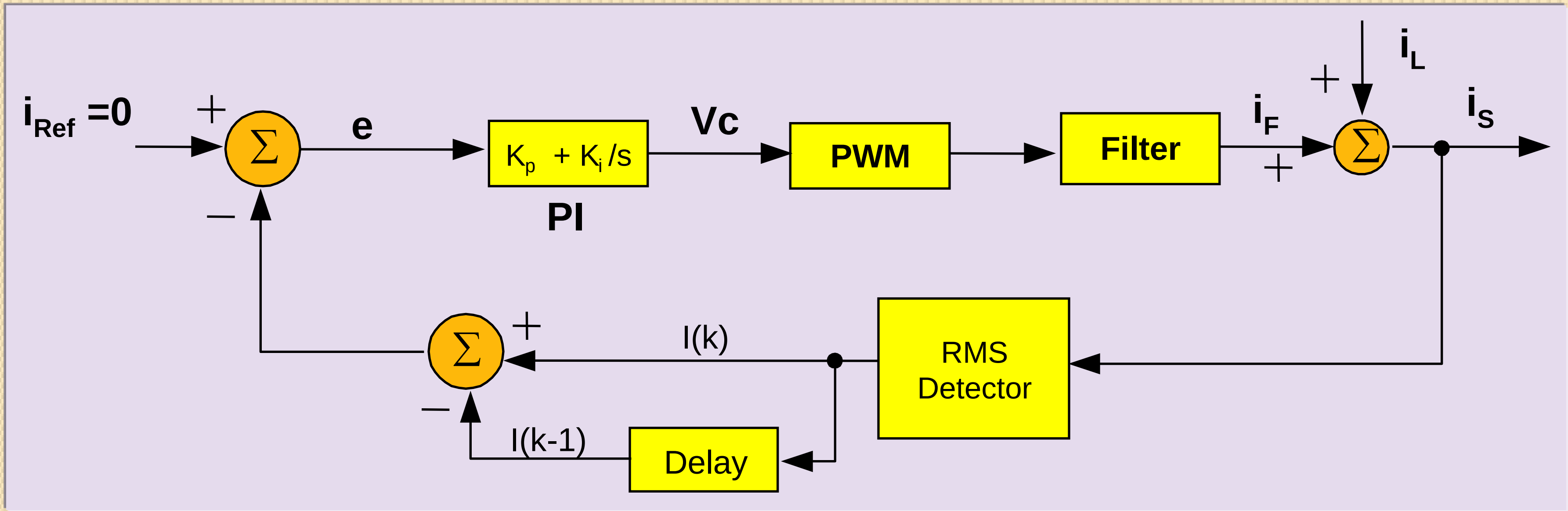
The Dynamic Control Strategies are:

- Dynamic minimum current ripple tracking
- Dynamic minimum current level
- Dynamic minimum power tracking
- Dynamic minimum effective power ripple tracking
- Dynamic minimum RMS source current tracking
- Dynamic maximum power factor
- Minimum Harmonic ripple content
- Minimum reference harmonic ripple content

- Electric Power/Energy Savings

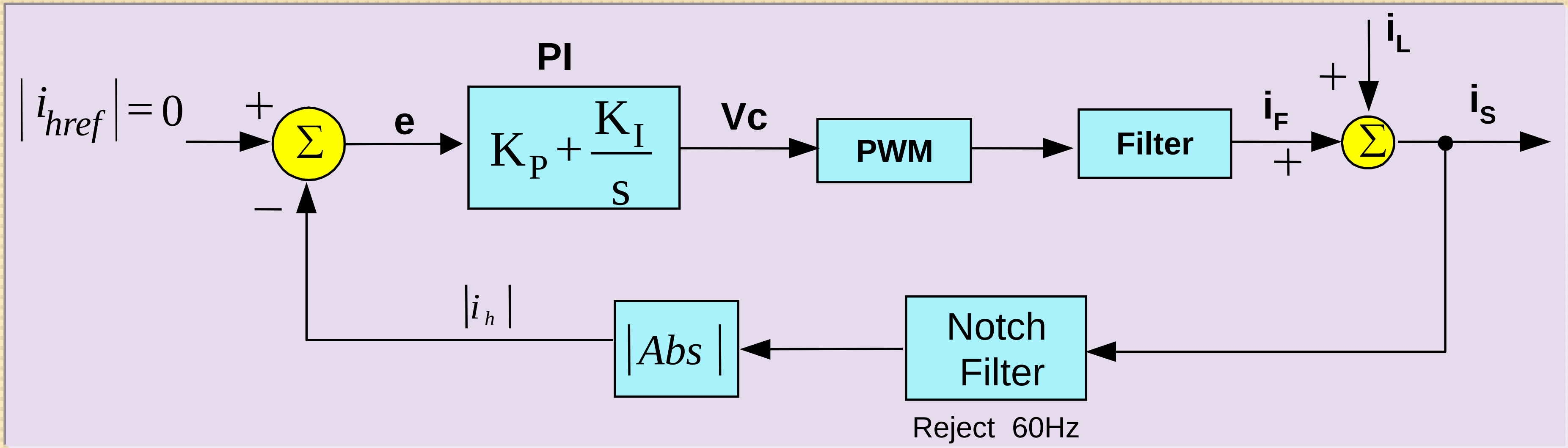
- Improve Supply PQ by reducing Harmonics and improve power factor and enhance waveforms as close as possible to sine wave

Novel Dynamic Controllers



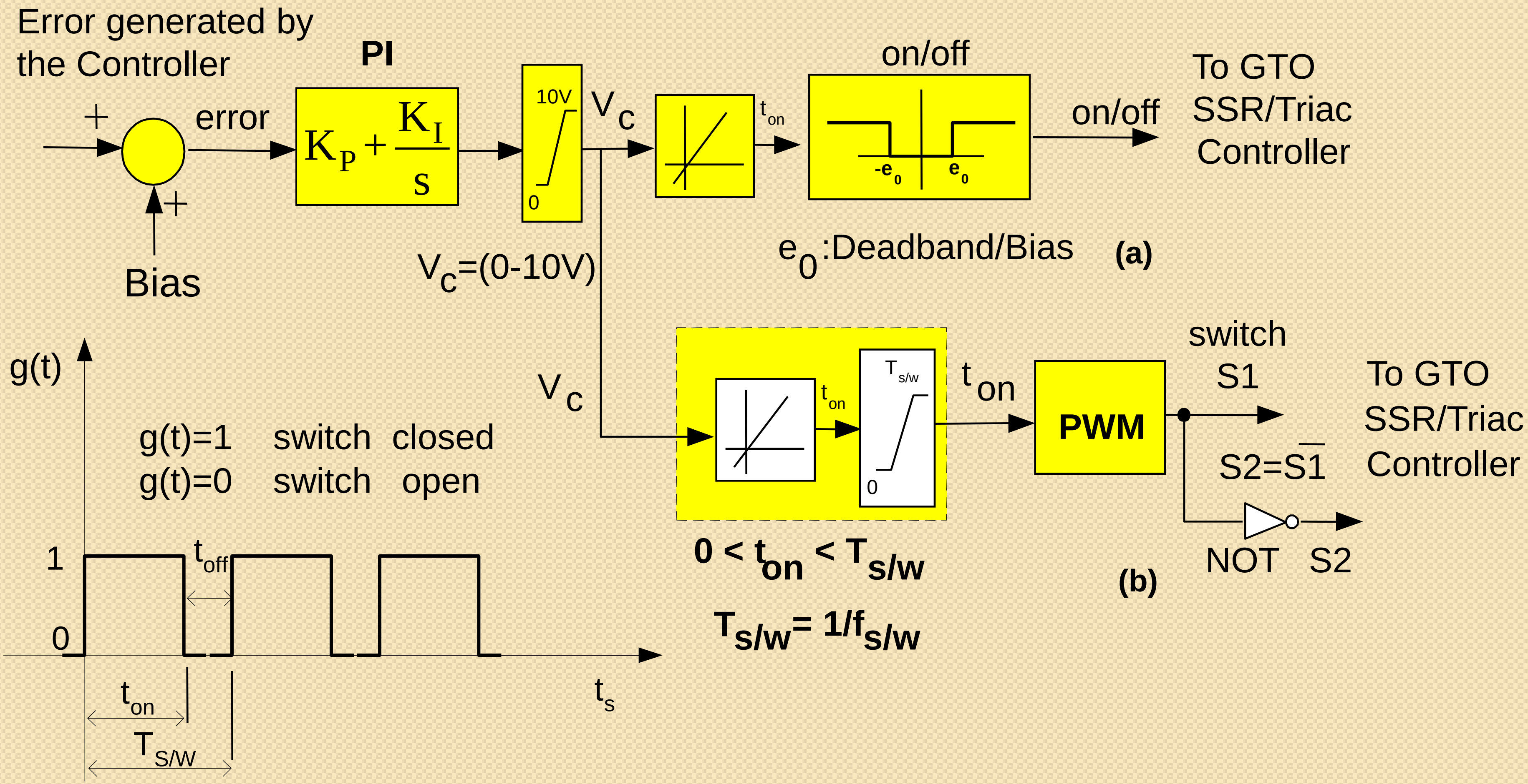
Dynamic Minimum-RMS Current tracking

Novel Dynamic Controllers



Minimum Harmonic Reference Content

Switching Devices (on/off or PWM)



Error generated by the Controller

PI

$K_P + \frac{K_I}{s}$

error

+

+

Bias

10V

0

V_c

t_{on}

on/off

$-e_0$

e_0

on/off

To GTO SSR/Triac Controller

V_c=(0-10V)

e_0:Deadband/Bias

(a)

V_c

t_{on}

$T_{s/w}$

0

t_{on}

PWM

switch S1

$S2=\overline{S1}$

NOT

S2

To GTO SSR/Triac Controller

(b)

$0 < t_{on} < T_{s/w}$

$T_{s/w} = 1/f_{s/w}$

g(t)

g(t)=1 switch closed

g(t)=0 switch open

1

0

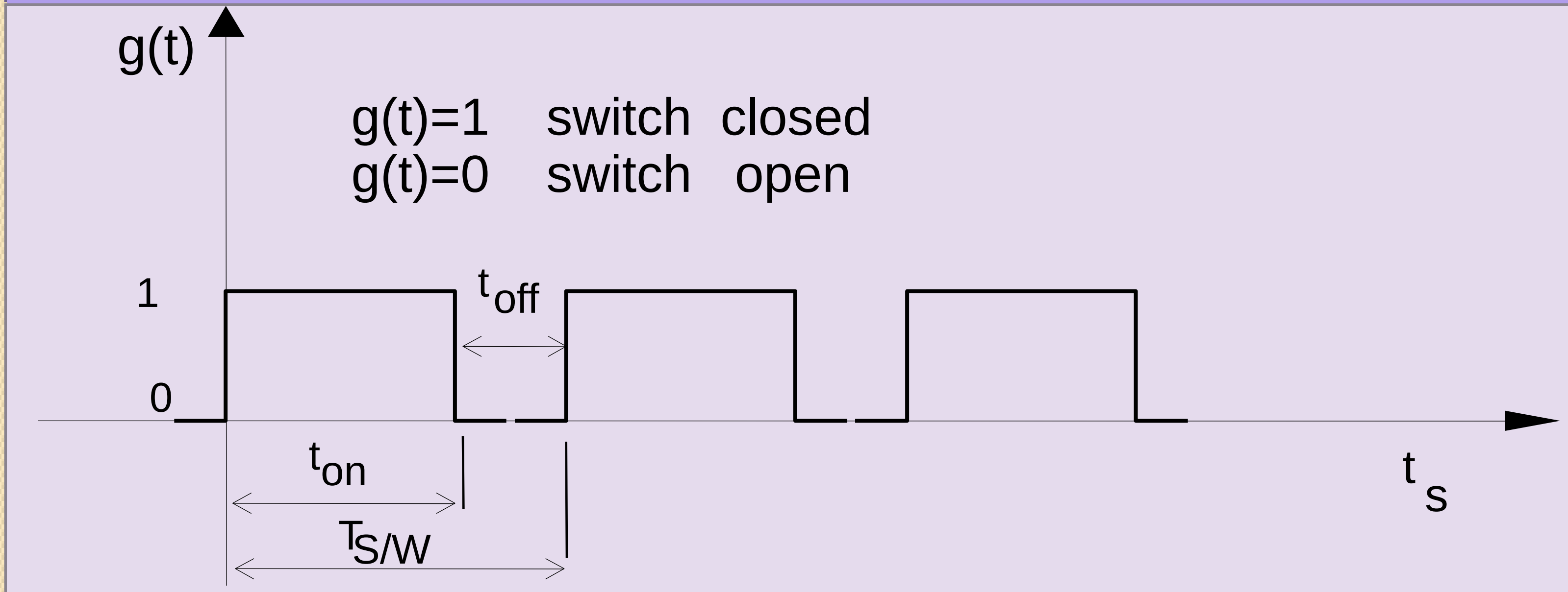
t_{off}

t_{on}

$T_{S/W}$

t_s

Switching Devices (on/off or PWM)

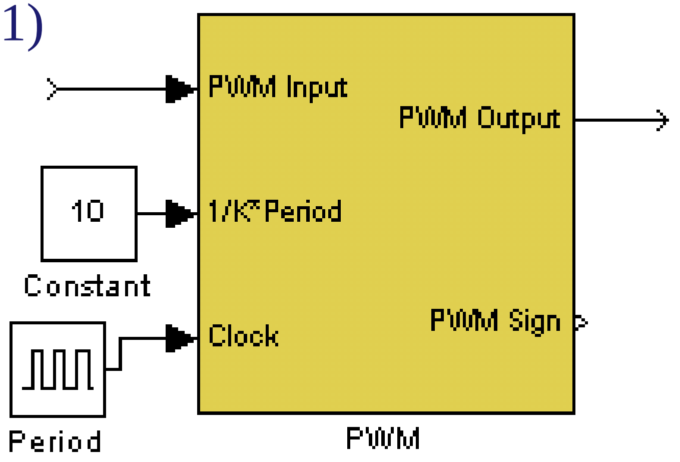


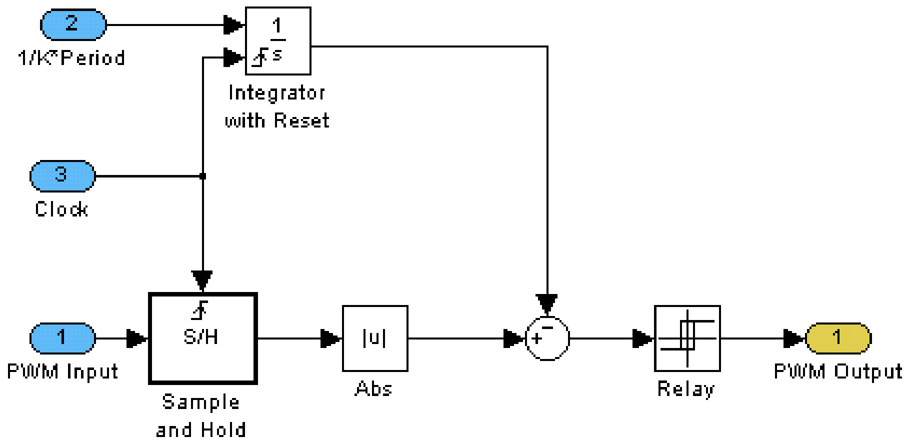
The solid-state switches (S1, S2) are usually (GTO, IGBT/bridge, MOSFET/bridge, SSR, TRIAC) turns “ON” when a pulse g(t) is applied to its control gate terminal by the activation switching circuit. Removing the pulse will turn the solid-state switch “OFF”

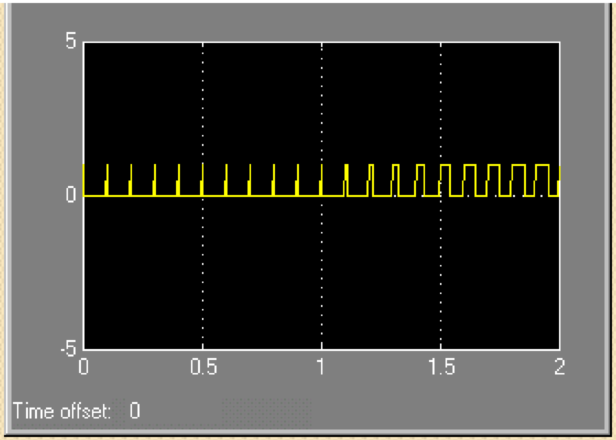
$T_{S/W}=1/f_S = (t_{on} + t_{off})$ $0<t_{on}<T_{S/W}$

Switching Devices – PWM Circuits

(1)



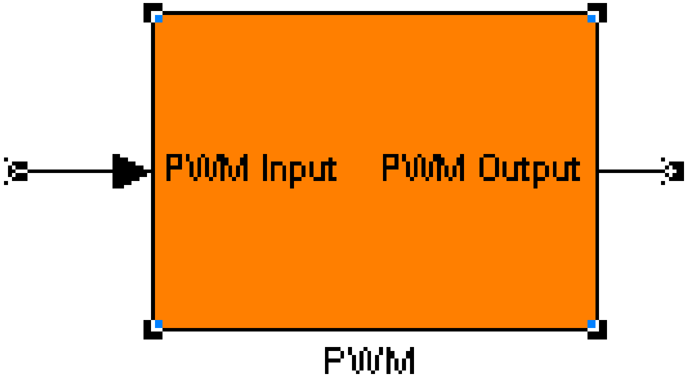


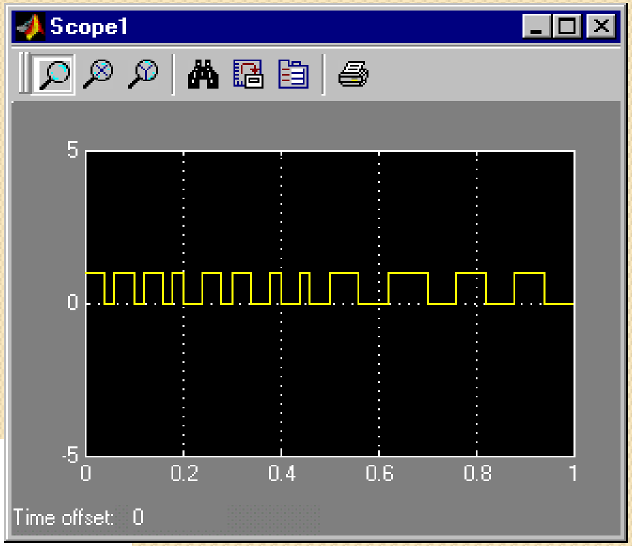


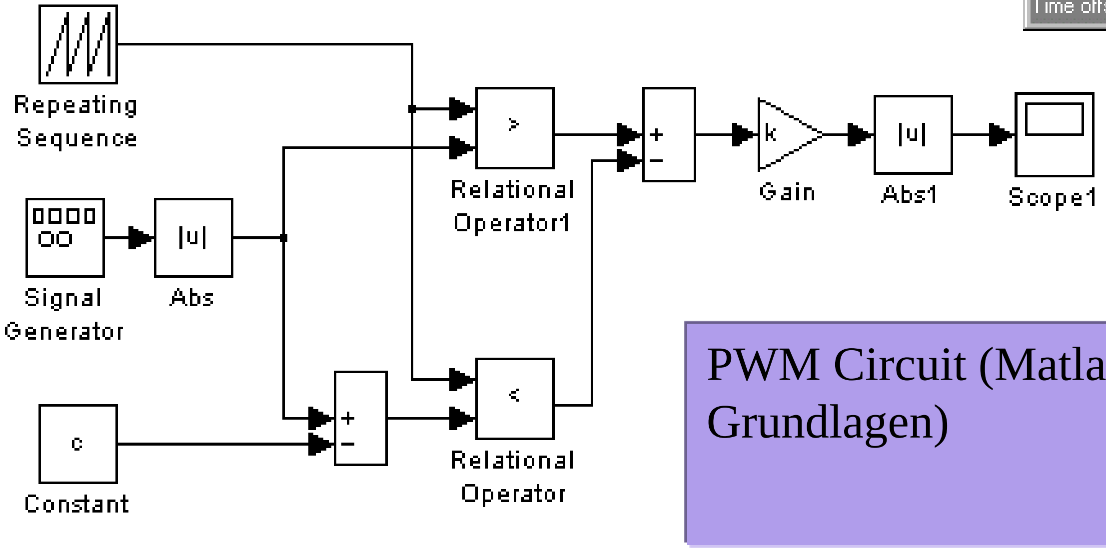
PWM Circuit (Developed by Dr. C. Diduch) for use with Matlab/Simulink

Switching Devices – PWM Circuits

(2)

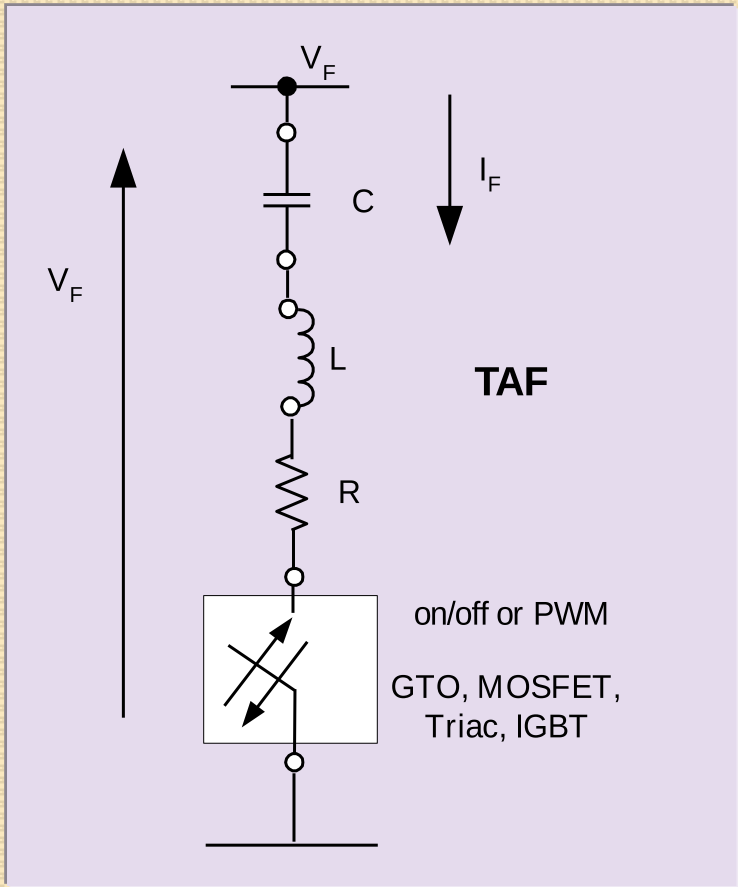




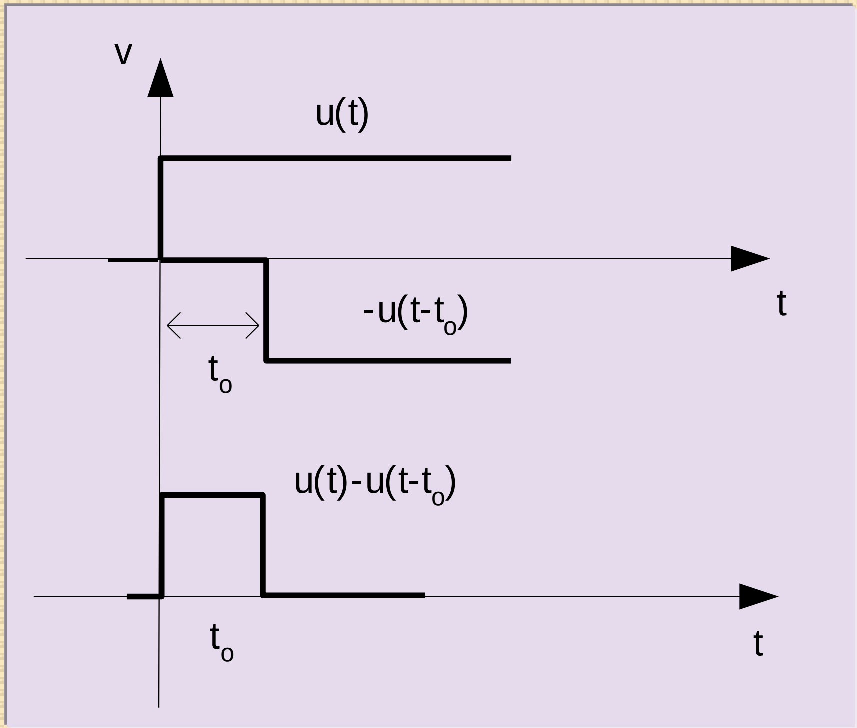


PWM Circuit (Matlab/Simulink/Stateflow-Grundlagen)

Concept of Modulated Power Filters (MPF)

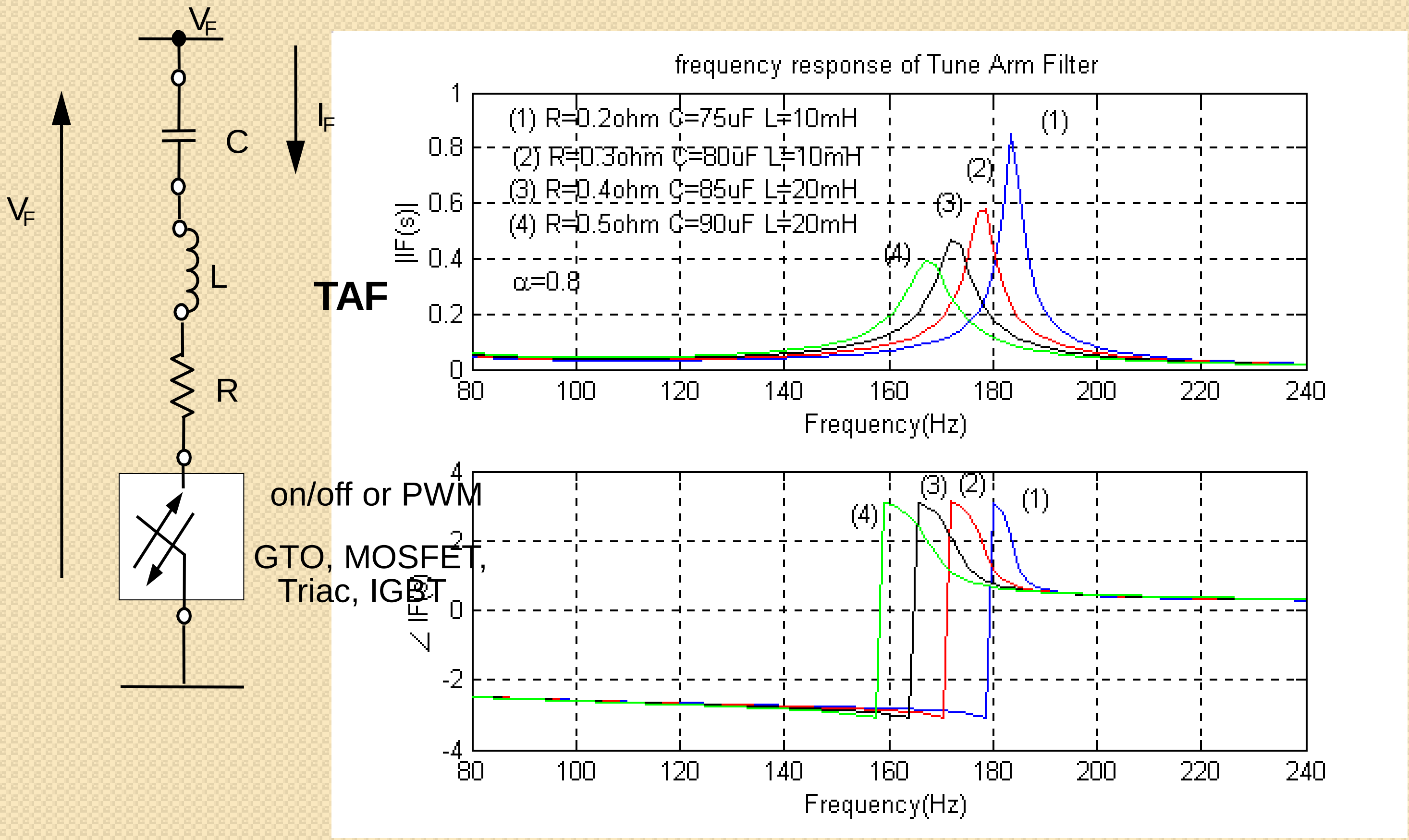


Tune Arm Filter layout

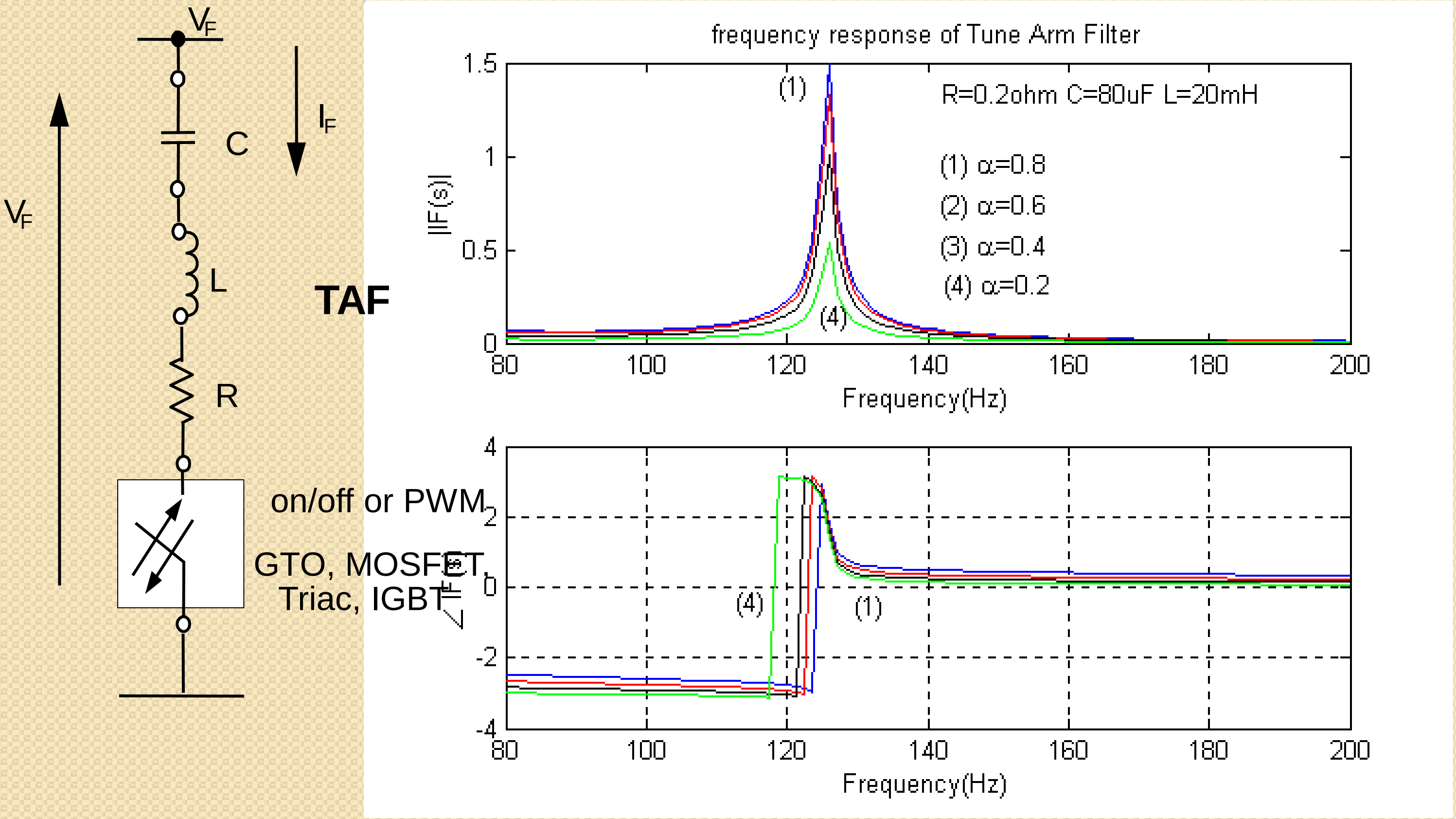


The Linear Combination of two Unit Step Functions to describe a Pulse of Amplitude 1 and duration t_0.

Concept of Modulated Power Filters (MPF)



Concept of Modulated Power Filters (MPF)



Modulated Tuned Arm Filter (Sym. & Asym.)

Load is either:

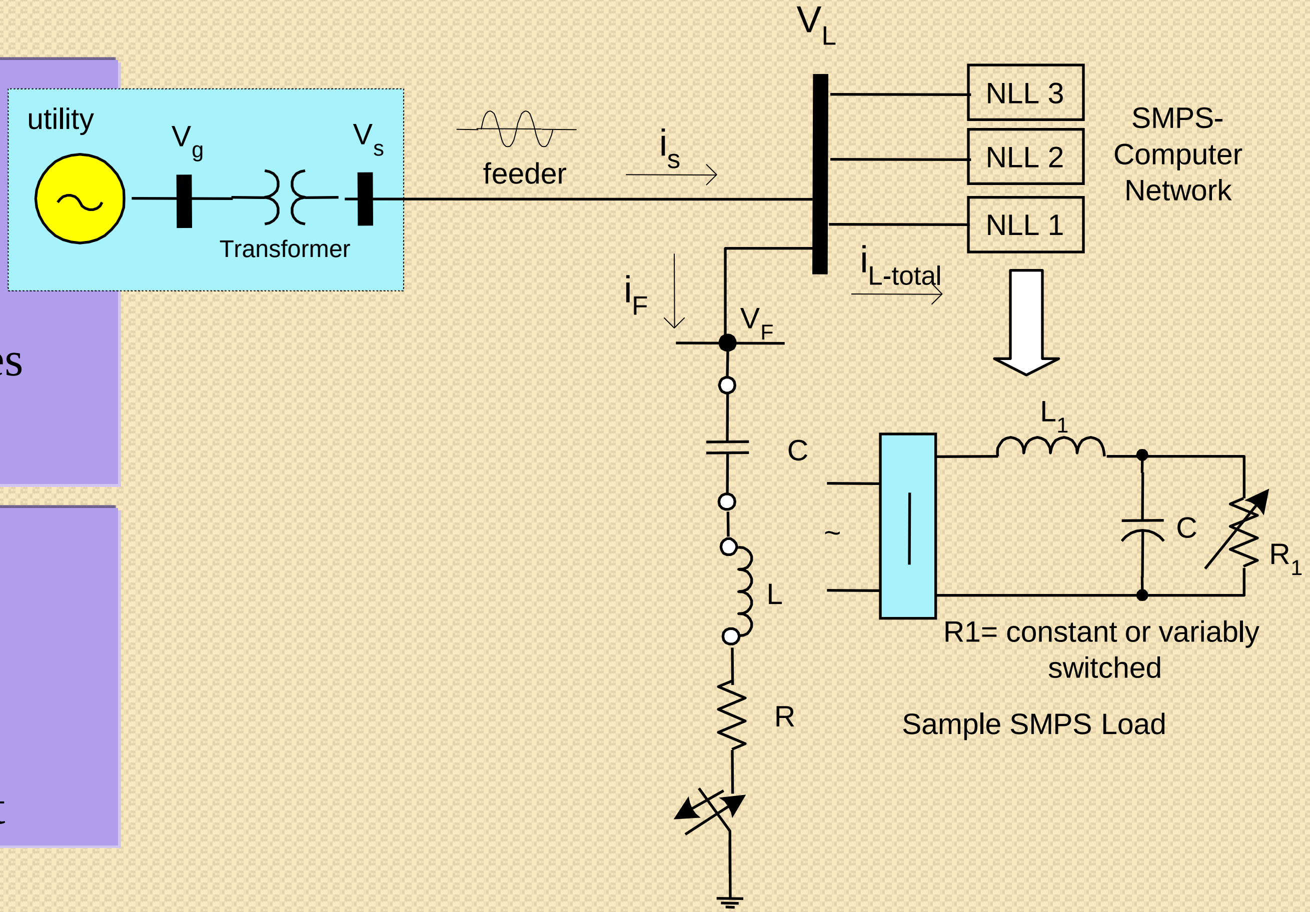
- Symmetrical Arc Type
- **SMPS**
- Adjustable Speed Drives
- Asymmetrical Arc-type

Dynamic Controller:

-Min. effec. Power

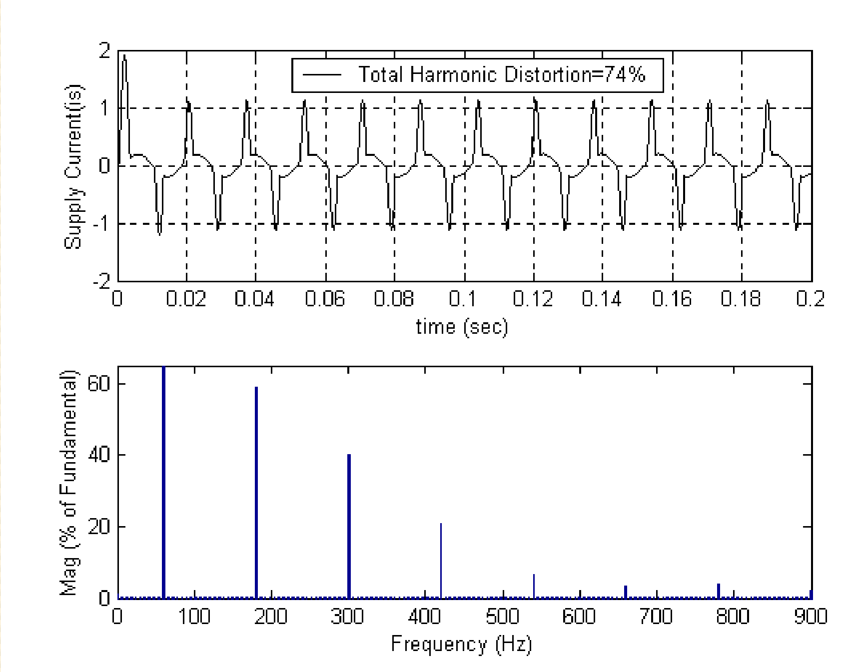
-RMS current tracking

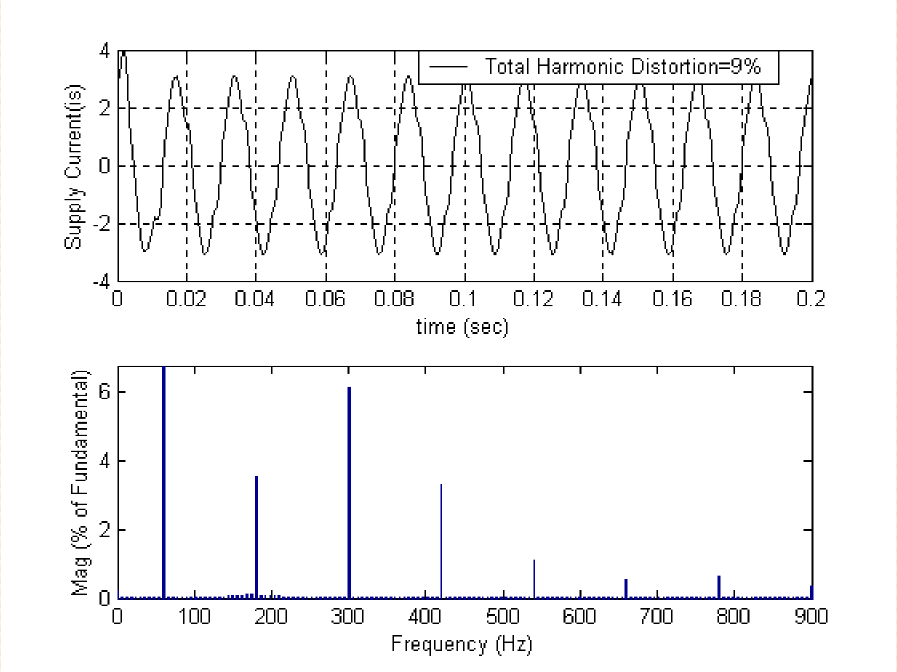
-Min. Harmonic Content



Single Line Diagram of System and Modulated / PWM Tuned-Arm Filter

Modulated Tuned Arm Filter with (SMPS) Load





Without (THD=74%)

With (THD=9%)

Modulated Asymmetrical Tuned-Arm Filter

Nonlinear Temporal Load Parameters:

$R_1=R_{01}+R_{11}\sin(wr1*t);$
$E_1=E_{01}+E_{11}\sin(wr2*t);$

$R_2=R_{02}+R_{22}\sin(wr1*t);$
$E_2=E_{02}+E_{22}\sin(wr2*t);$

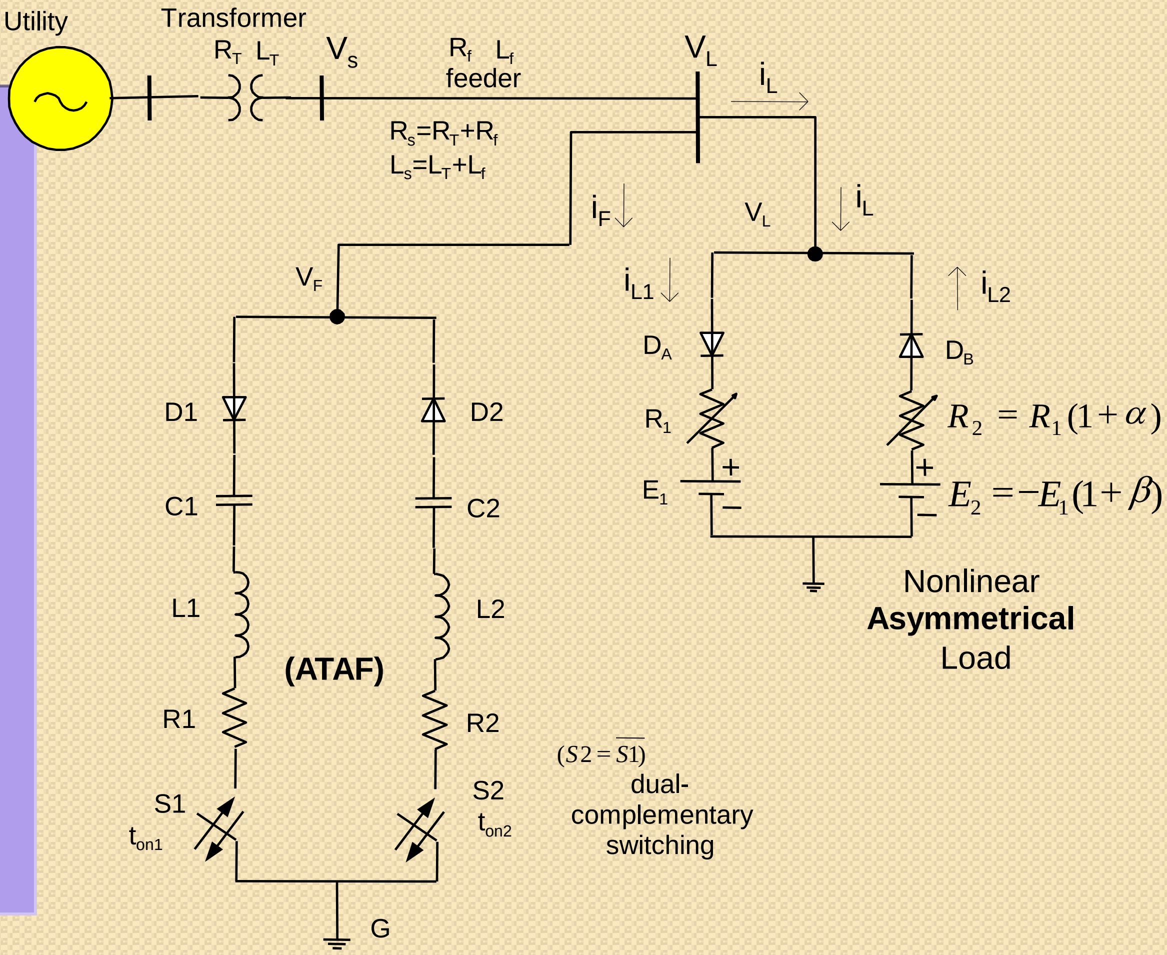
$R_2= R_1(1+\alpha)$ $R_{01}=8$ $R_{02}=12$

$R_{11}=2$ $R_{22}=6$ $wr1=15$

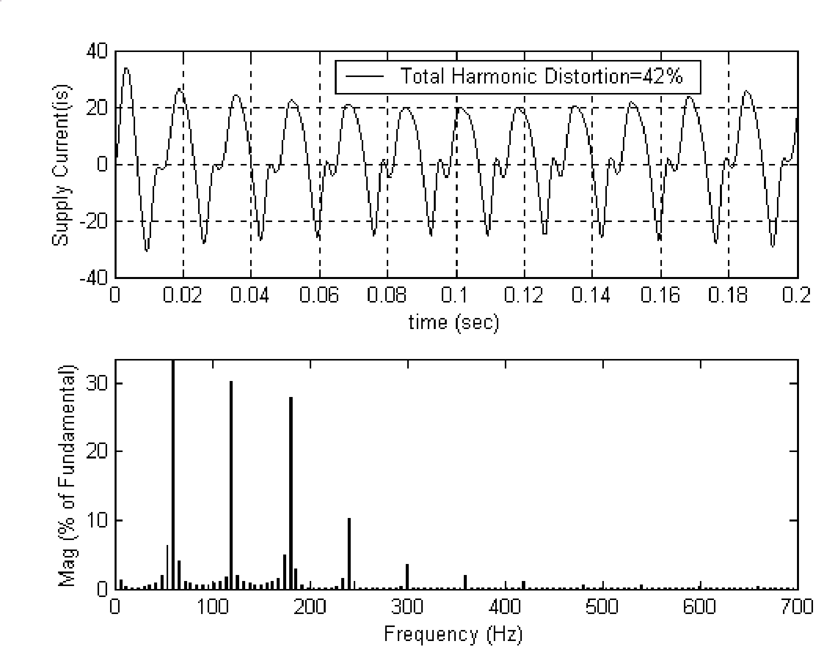
$E_2= -E_1(1+\beta)$

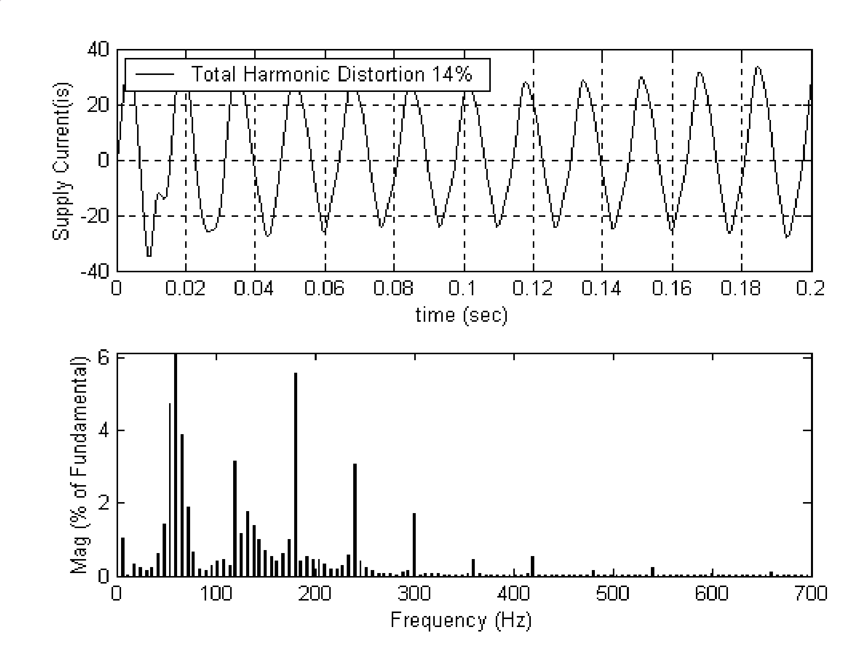
$E_{01}= 46$ $E_{02}=70$

$E_{11}=12$ $E_{22}=35$ $wr2=5$



Modulated Asymmetrical Tuned-Arm Filter





Without (THD=42%)

With (THD=14%)

Dynamic Controller: Dual loop of RMS current tracking and Min. Harmonic Content

Green Plug Filter-GPF

Professor Dr. Adel M Sharaf, P. Eng., SMIEEE
UTT

Description of Green Plug

- Modulated/Switched Dynamic Filter/Compensator (MSDFC) for Energy Efficiency, Savings and Power Quality Enhancement for Households

Outline

- Objectives
- Designs
- Benefits / Application
- Strategies
- Digital Simulation
- Conclusion
- Future / Extended Work

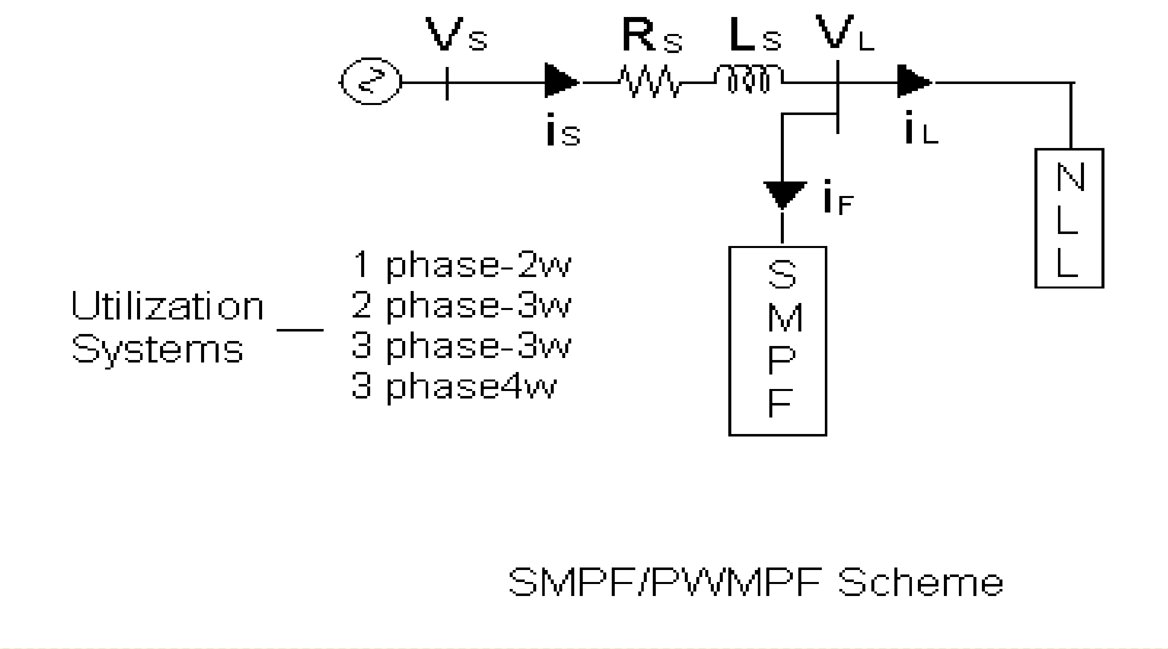
Objectives

- Create a low cost Green Plug design by using the neutral or return current for the control loop input
- Run various simulation scenario's to test the Green Plug and control loop's portability
- Come up with a final design

Designs

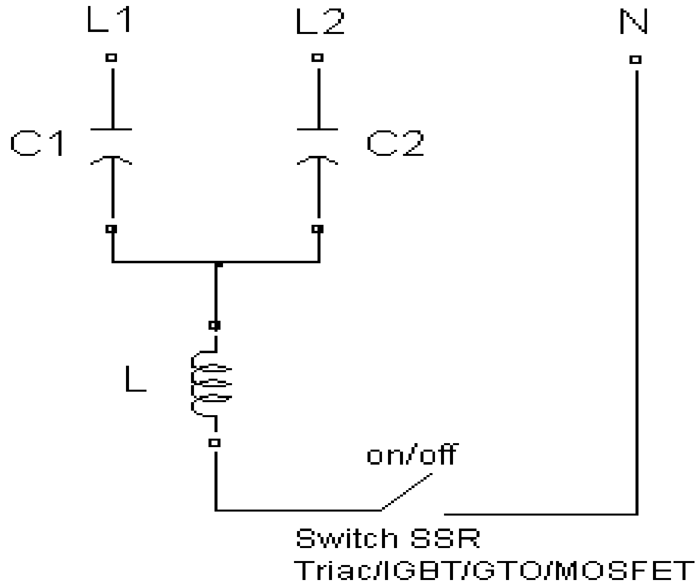
Family of Green Plugs, Energy Misers & MPF/SPF Compensator

Developed by Dr. A.M. Sharaf

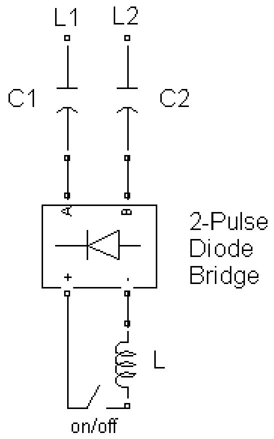


SMPF/PWMPF Scheme

Designs

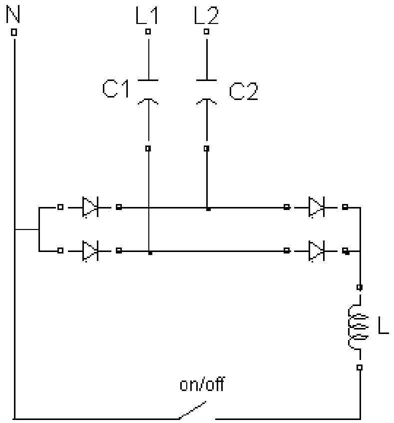


Triac/GTO switched MPF Filter

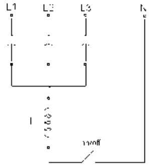


MOSFET/IGBT switched MPF Filter

Designs

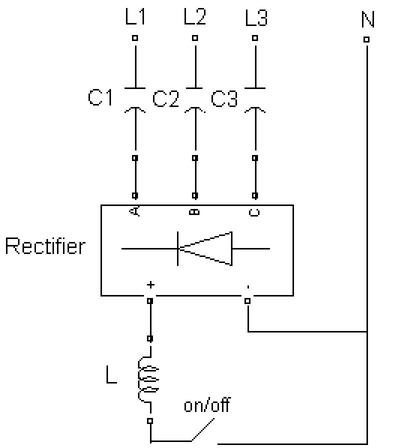


MOSFET switched MPF Filter

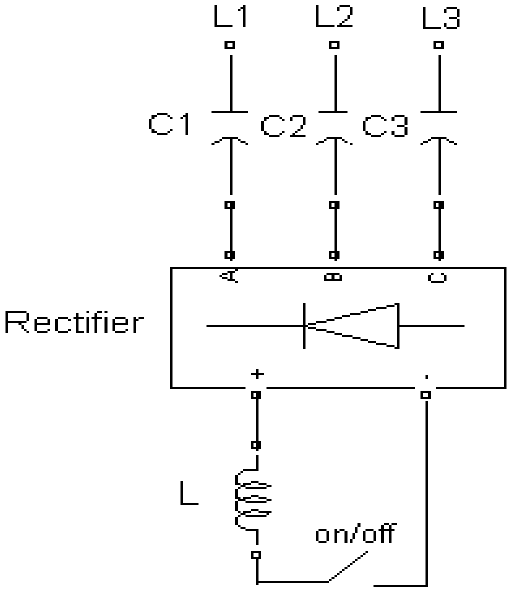


Switched (3phase-4w) MPF-Triac/GTO switch

Designs

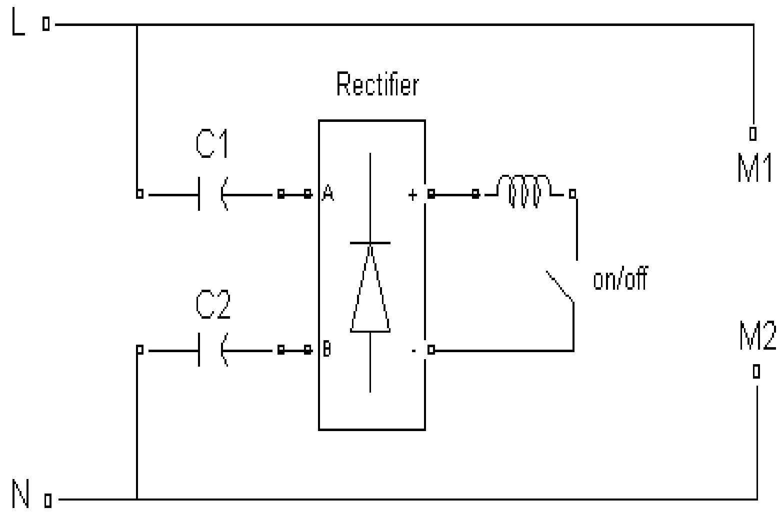


Switched (3phase -4w) MPF-
Triac/GTO switch

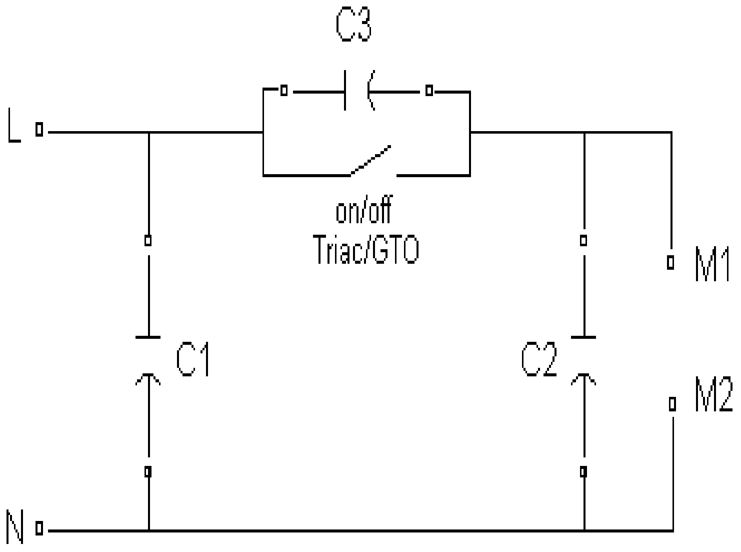


Switched/Modulated PWM Scheme
for 3phase-3w Utilization System

Designs



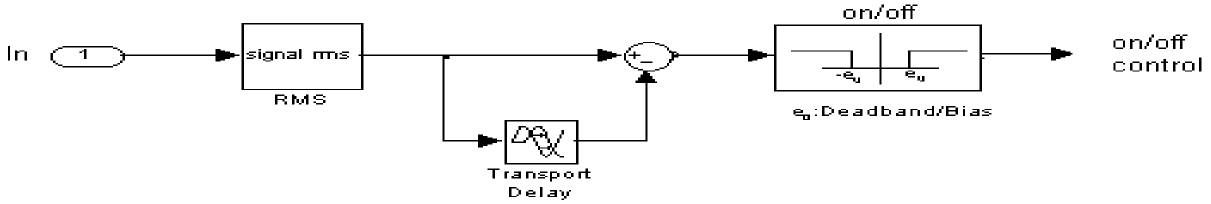
Switched MPF for Cyclical Single phase-2w Loads



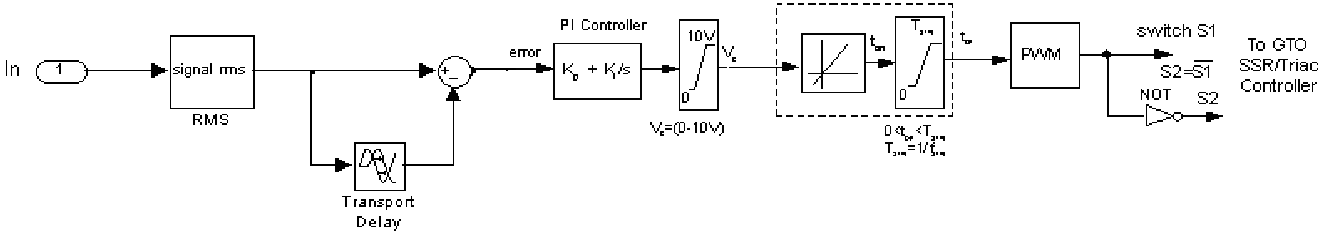
Switched MPF for Cyclical Motorized Single phase-2w Loads

Designs

Control Schemes

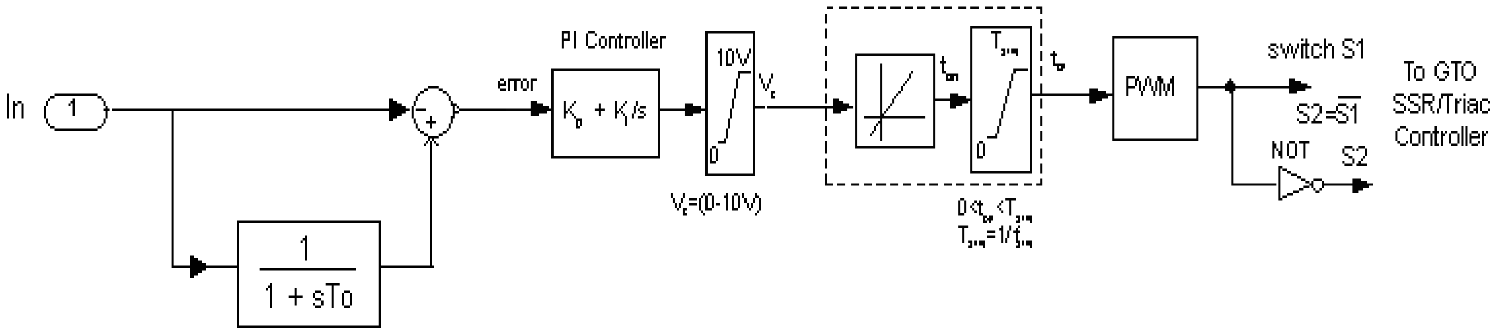


on/off Controller Scheme

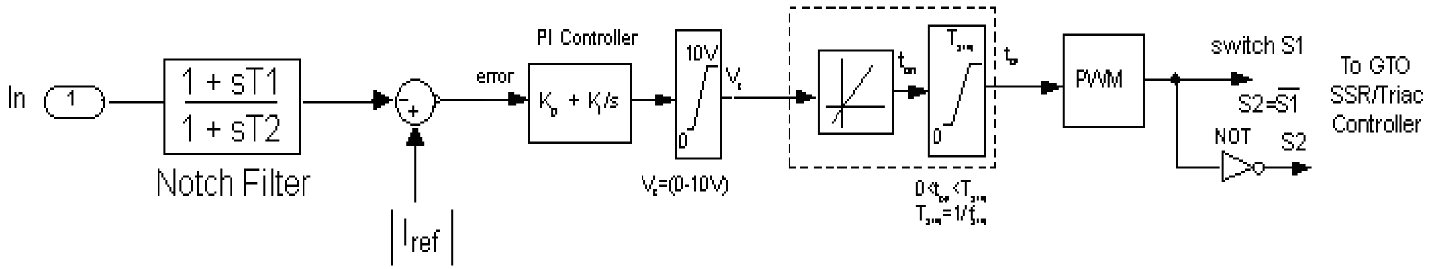


Current Dynamic Tracking Controller

Designs

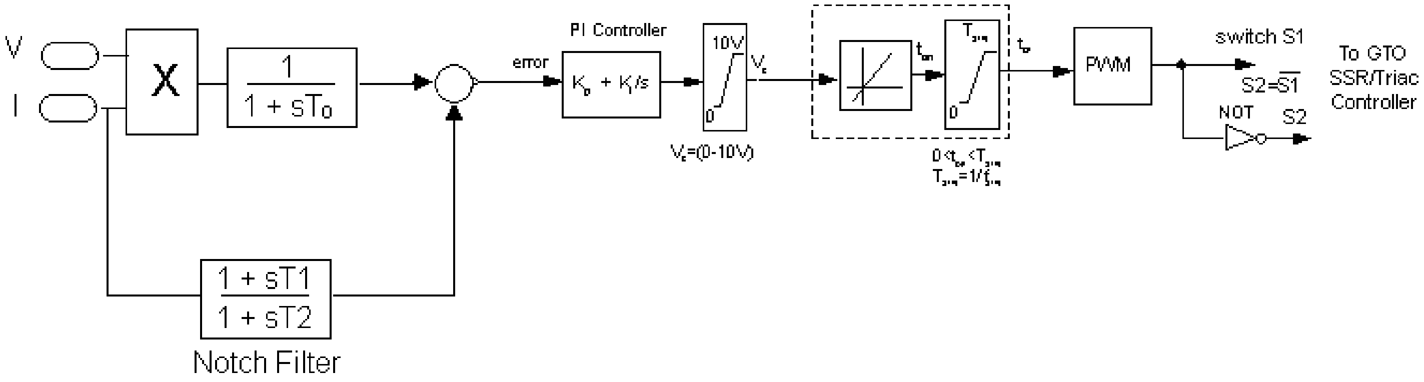


Dynamic Ripple Reduction Controller



Minimum Harmonic Ripple - PQ Enhancement Controller

Designs



Minimum Power Tracking Controller

A. M. Sharaf

Benefits / Application

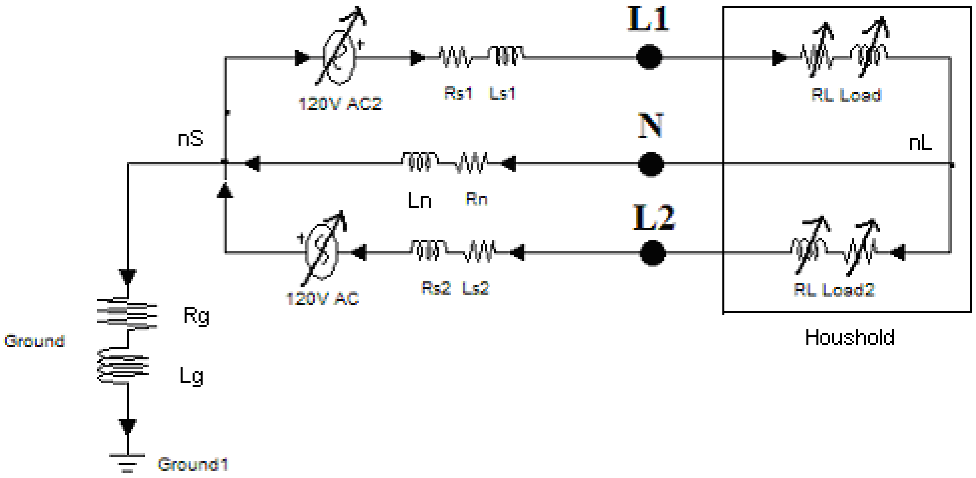
- Enhance Power Quality
- Reduce Energy Consumption
- Improve Power Factor
- Reduce THD
- Clean Waveforms
- Regulate Voltage
- Reduce Light Flickering
- Reduce GPR, neutral voltage/current

Strategies

- Digital Simulation using SIMULINK, MATALAB software developer for model analysis and function constructor

Strategies

2 Phase 3 Wire Scott Connection Household Model



A. M. Sharaf

Digital Simulation

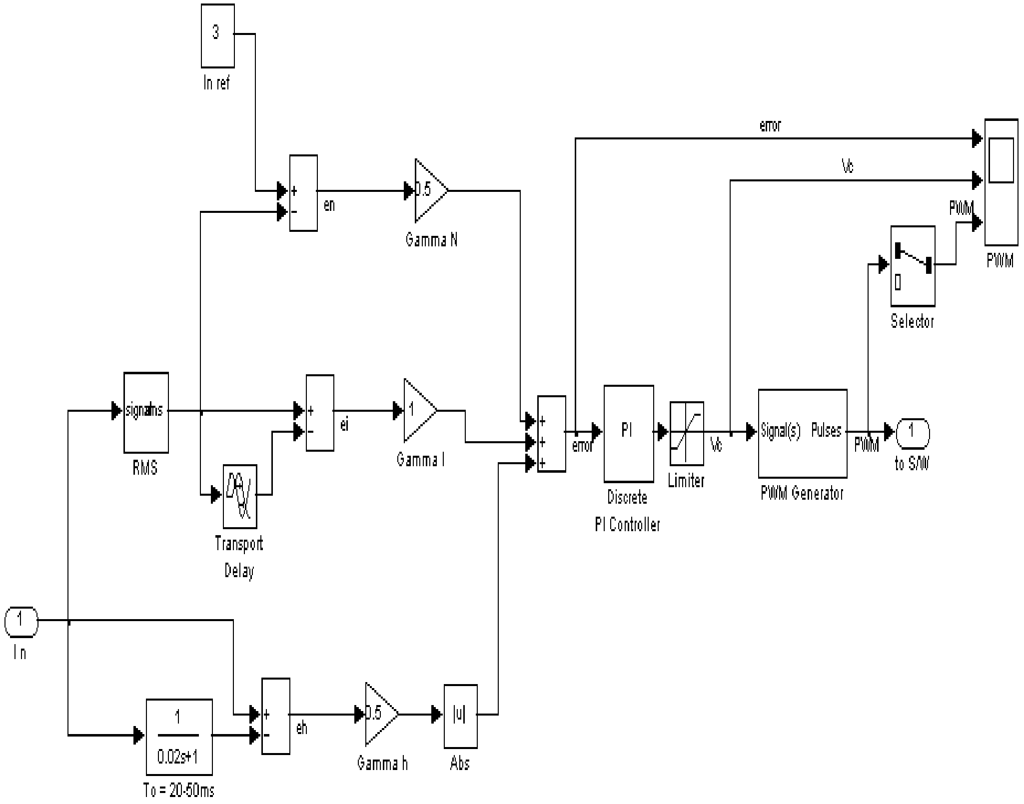
- Green Plug Scheme 1, 2, and 3
  - Balanced Case (4.5kW + 1.9kVAR)
  - Unbalanced 1 (Phase 1: 4.5kW + 1.9kVAR; Phase 2: 3.5kW + 1000VAR)
  - Unbalanced 2 (Phase 1: 4.5kW + 1.9kVAR; Phase 2: 5.5kW + 2.5VAR)
  - Non-Linear (Phase 1: 500W + 60VAR RECTIFIED; Phase 2: 2kW + 150VAR)
  - Fault Cases: One Phase Open Circuit; One Phase Short Circuit.

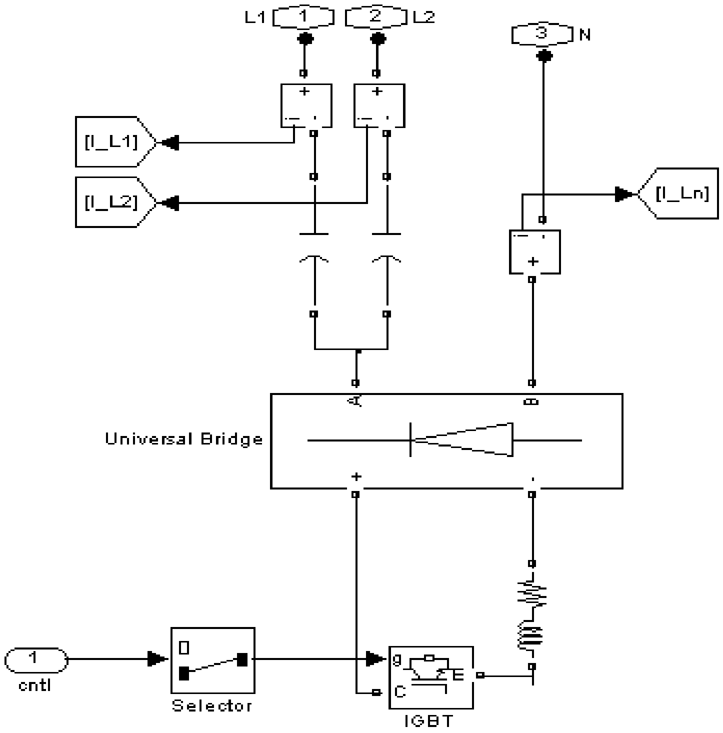
Digital Simulation

- Approximate 9kVA loading @ 90%PF
- Filters:
  - 150uF, 10mH, & 0.25 ohms

Digital Simulation

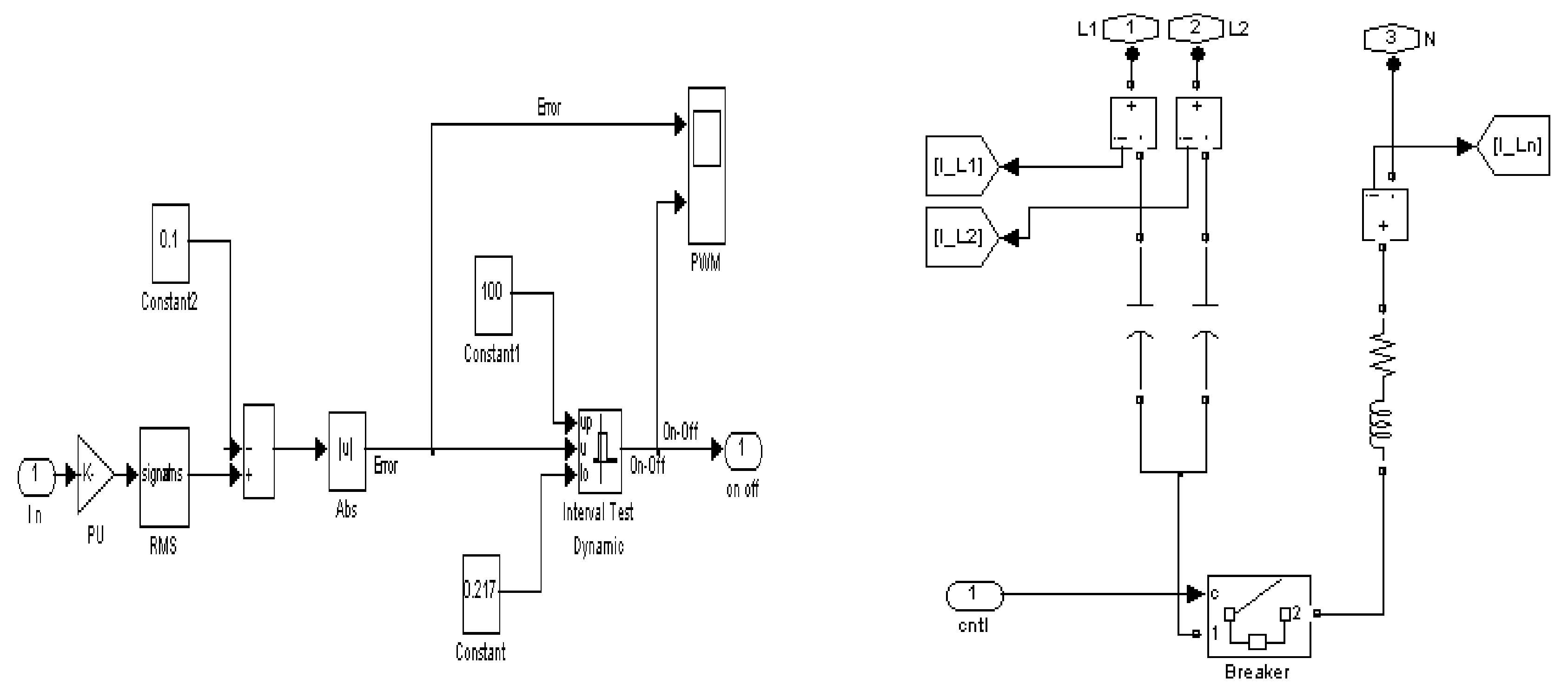
- Green Plug Design 1





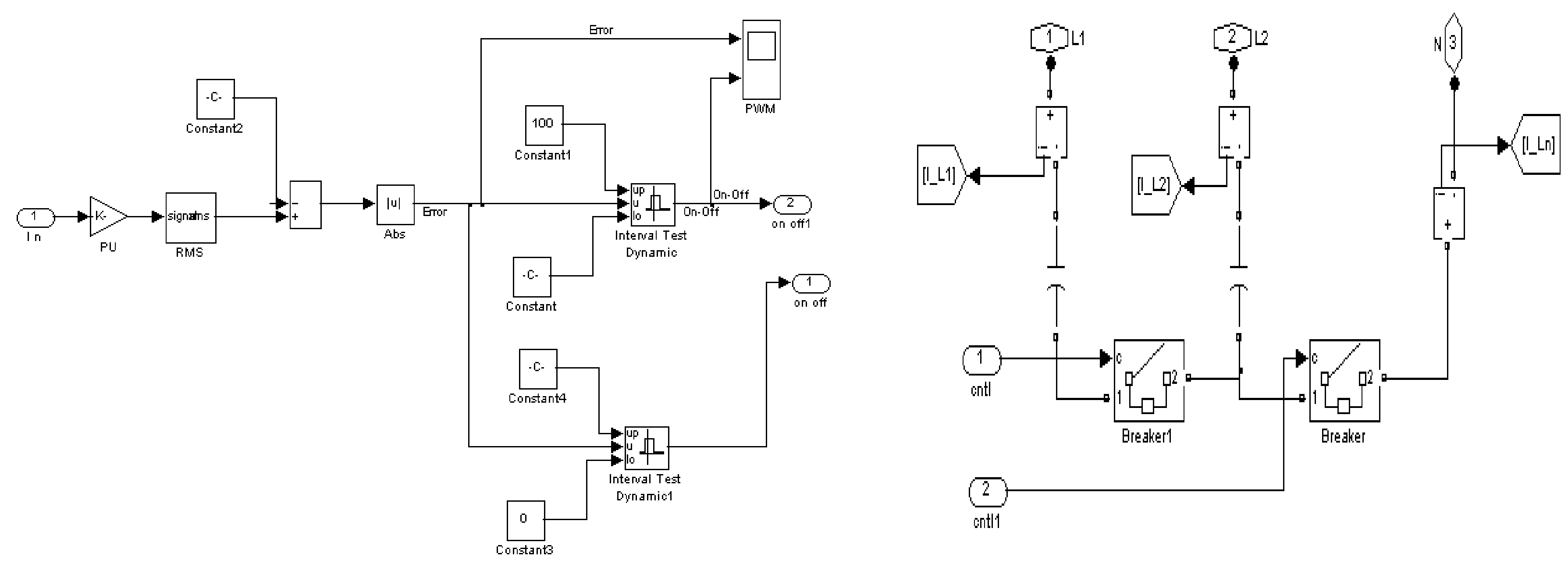
Digital Simulation

- Green Plug Design 2



Digital Simulation

- Green Plug Design 3



Conclusion

- Green Plug:
  - Raised PF by average 5%
  - Reduced Energy Consumption by an average 5%
  - Reduced Harmonics almost 50% on NL load
  - Fault Cases showed no sign of excess currents that would harm the filter
  - All controllers had similar controllability, the filters varied the performance
  - Seems they need to be "Tailor Made"

Conclusion

- Neutral current control has limited capabilities which in turn showed limited portability
- Green Plug design 2 performed the best

Future / Extended Work

- Study on household: loading, THD…
- Use maximum PF controller, or minimum power controller with Green Plug, which uses both phase current and voltage (more costly, and compare advantages)
- Uses single phase filters on both phases
- Transient Analysis on Green Plug / Household Model

Future / Extended Work

- Build Prototype, Lab testing, & Field Testing

THE UNIVERSITY OF TRINIDAD AND TOBAGO

A NOVEL POWER QUALITY PQ ENHANCEMENT SCHEME USING MODULATED POWER FILTER COMPENSATOR

A. M. Sharaf

Outline

- Introduction
- System Description
- Novel Tri loop Dynamic PWM Switching Control Scheme
- MATLAB/SIMULINK Analysis
- Conclusions
- References

Introduction

- Electric power distribution systems suffer both voltage and power quality problems.
- Efficient operation and loss reduction is a priority for Energy Conservation and efficient Electric Energy Utilization.

- Massive increase in the use of Nonlinear loads are causing havoc with Distribution and Utilization systems.

Introduction

- Nonlinear loads, such as static power converters and arc furnaces cause excessive power quality problems, voltage sags/swells and harmonics.
- All contributes to extra Power/Energy Losses and voltage Stabilization problems as well as Shock Hazards, system Malfunction and and Equipment Damage

- All results in Poor Utilization and Low Power-Factor, Feeder Overloading and Noise Interference to adjacent communication systems [1].

Introduction

- In order to overcome these problems, Power Filter/CC has been used with new FACTS based devices such as:
- Active Power filters, STATCOM, MPF, Switched capacitor compensators are used to enhance power quality [2]

- The APF does not introduce resonance that can move a harmonic problem from one frequency to another.It can also be used for power factor correction and loss reduction [3].

Introduction

- In this presentation, the novel dynamic Filter/Capacitor Compensator scheme is used in the radial distribution feeder shown in Figure.1as a Dynamic Voltage Regulator
- This Hybrid Dynamic Voltage Regulator (DVR)/ Modulated Power Filter (MPF)/ Capacitor Compensator (CC) is valid ted using Matlab/Simulink/Sim-Power .

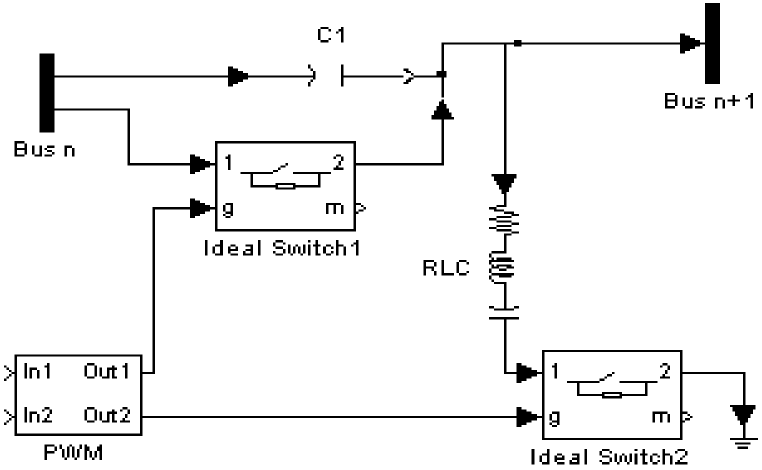


Figure.1 DVR/MPF/CC scheme

System Description

- A sample single-line diagram of a radial distribution feeder study system is shown in Figure.2 (single-line) and Figure.3 (simulink). The system comprises a 10 MVA substation, a step down transformer of 138/25kV, several 2km distribution sections as well as six linear type loads and one nonlinear load connected by radial feeder.

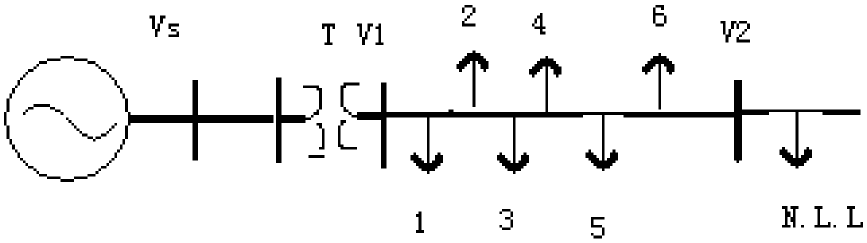


Figure.2 Sample radial distribution network

System Description

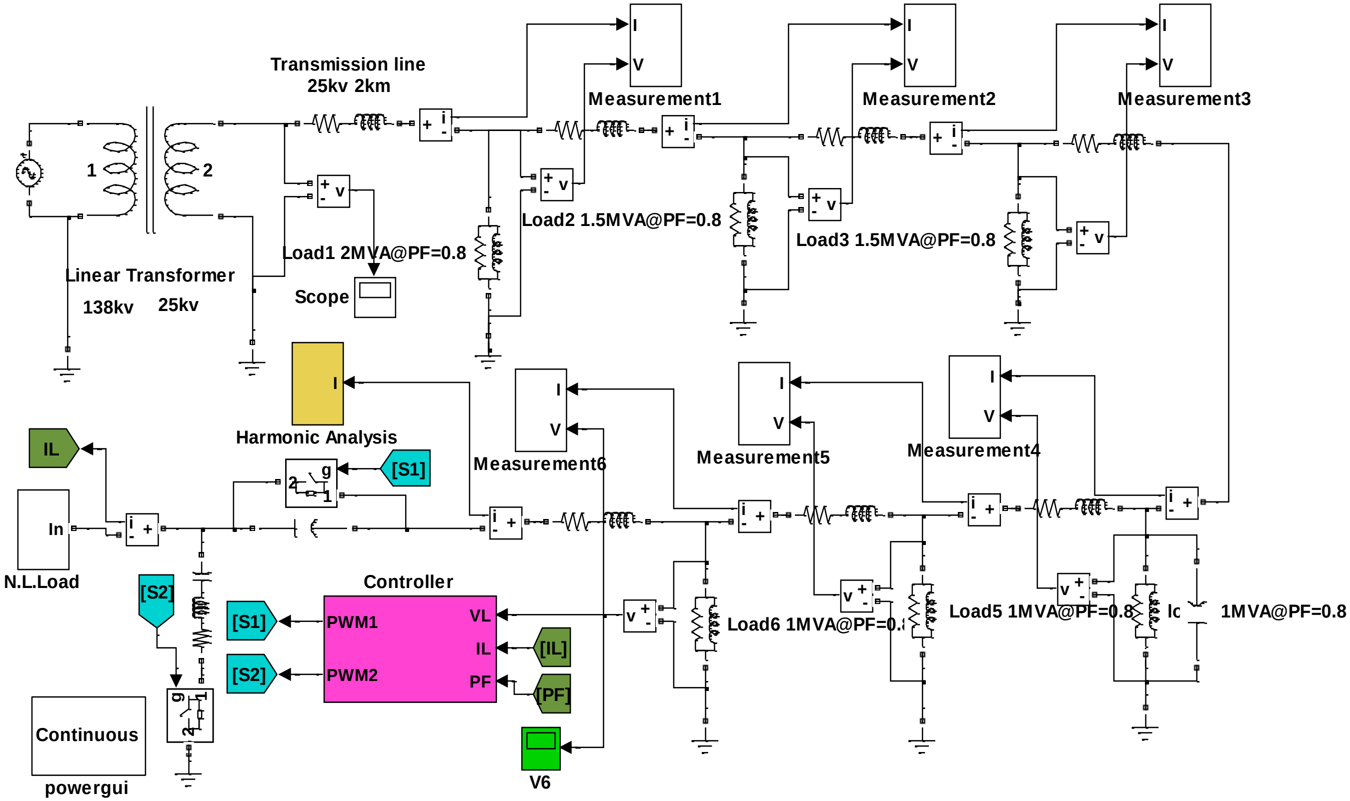


Figure.3 Matlab/Simulink Unified Functional model of the radial distribution system

A. M. Sharaf

Novel PWM Switching Control Scheme

- A dynamic tri-loop error driven controller is used to adjust the switching/pulsing sequence of the GTO complementary switches 1 and 2 in the modulated power filter compensator [4]. The topology of dynamic tri-loop error driven controller is shown in Figure 4.

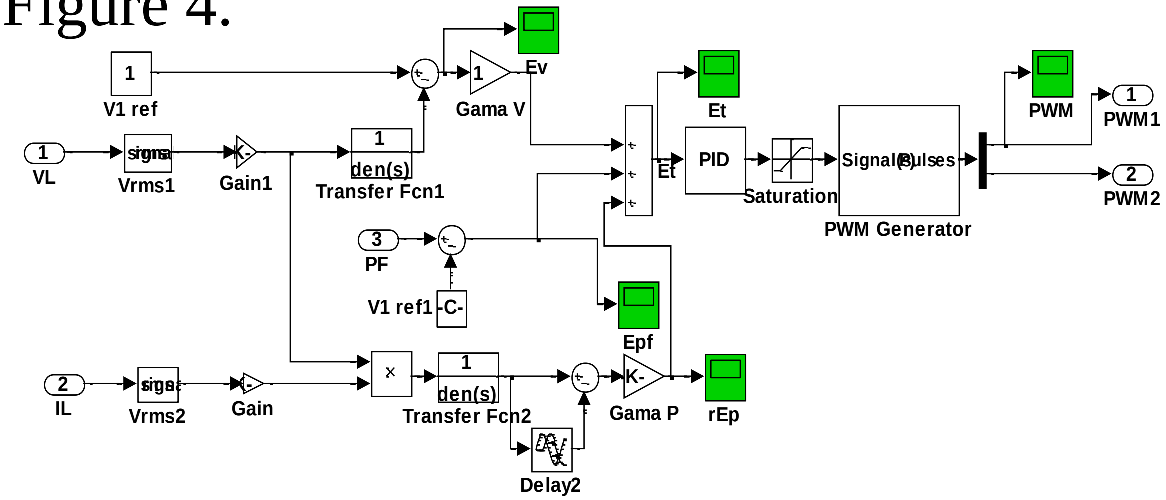


Figure.4 Dynamic Tri-loop error driven PID controller

Novel PWM Switching Control Scheme

- The dynamic error driven controller comprises three basic regulating loops.

- The main loop is the voltage stabilization loop, which functions as a tracking minimum voltage error loop for load voltage at a radial distribution bus (6) and maintaining this bus-voltage at 1.0 per unit.

Novel PWM Switching Control Scheme

- The second one is an auxiliary loop is the load /current-dynamic error tracking loop, which is an additional loop to compensate for any sudden electrical load excursion.

- The third one is an second auxiliary loop for power factor improvement.

Novel PWM Switching Control Scheme

- All the values of scaling and time delay of the controller were selected by an offline guided trial and error method to insure fast response and minimize total Squared error Functional [5].
- The total dynamic error signal (Et) is the sum of all three weighted loop-errors and is used as input to the PI controller whose proportional and integral gains are 5 and 0.05, respectively.

Novel PWM Switching Control Scheme

- The output signal of the PI controller is employed to adjust PWM reference voltage (modulating voltage) and it is compared with a fixed carrier signal to produce two complementary pulses, which are used as the external control signal for the ideal IGBT switches. With different states of the switches 1 and 2, the equivalent admittance of the filter is modulated [6].

MATLAB/SIMULINK Analysis

- Three Sample-Study cases were simulated :
- The first case is the radial distribution system without any reactive power Compensating-Device.
- In the second case, a fixed shunt capacitor (Cf) with capacitance of 0.20 per unit which is connected at local bus 4.
- Finally, a dynamic hybrid-type Filter-Compensator (DVR /MPF/ SCC) is interfaced in between the last linear load bus and the nonlinear load bus in the third case.

MATLAB/SIMULINK Analysis

- Without any compensation, the system has bad dynamic performance, poor power factor, voltage regulation problems and higher harmonic content due to the existence of the nonlinear load.

- With a fixed SVC-Capacitor C=0.2pu at bus 4 (in the middle of the system), the power factor and the voltage profile were somewhat improved but not sufficiently!

- With the additional-dynamic-Switched (DVR) compensation device located near the end of the distribution feeder, both power factor and power quality are enhanced significantly. So, the DVR compensation Scheme can greatly enhance the power factor, voltage profile and power quality.

MATLAB/SIMULINK Analysis

- Comparison of the total harmonic distortion (THD) and Fourier analysis of the current at each bus was made for the cases with and without DVR as shown in Table 1. The total harmonic distortion is apparently reduced by applying the proposed DVR scheme.

Table.1 The total harmonic distortion and Fourier analysis

Current	1st	3rd	5th	7th	9th	THD
Without Compensation	468.7	19.74	5.769	2.546	1.731	1.170
With SVC	463.0	16.00	5.404	1.527	1.459	1.157
With DVR	93.12	10.02	0.091	0.530	1.355	0.285

MATLAB/SIMULINK Analysis

- The dynamic responses of the digital simulation like the voltage profile is shown in Figure.5.

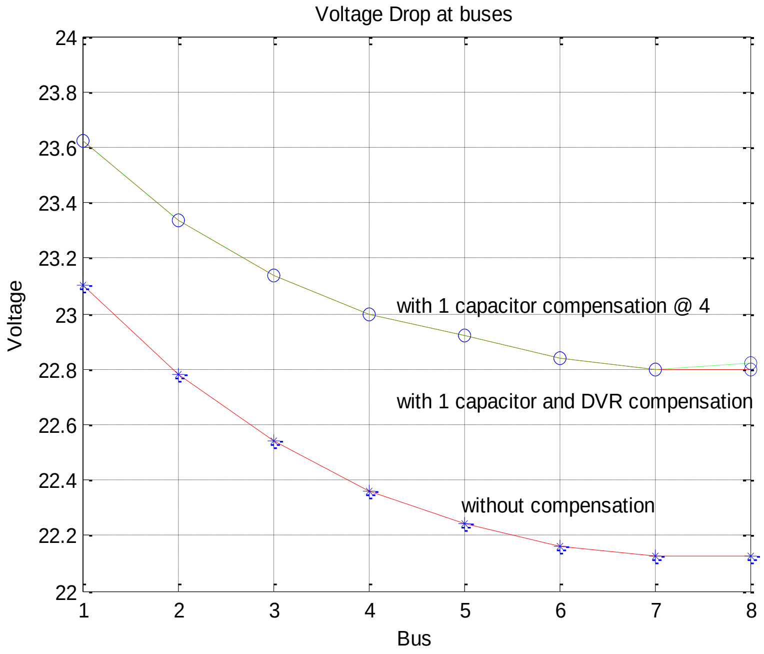


Figure.5 Voltage profile of three schemes

MATLAB/SIMULINK Analysis

- Total Feeder Power Losses, current and voltage waveforms of both linear and nonlinear load, real and reactive power at each bus are all examined in the case of DVR –device disconnected and connected, as shown in Figure.6, Figure.7, Figure.8 and Figure.9, respectively.

MATLAB/SIMULINK Analysis

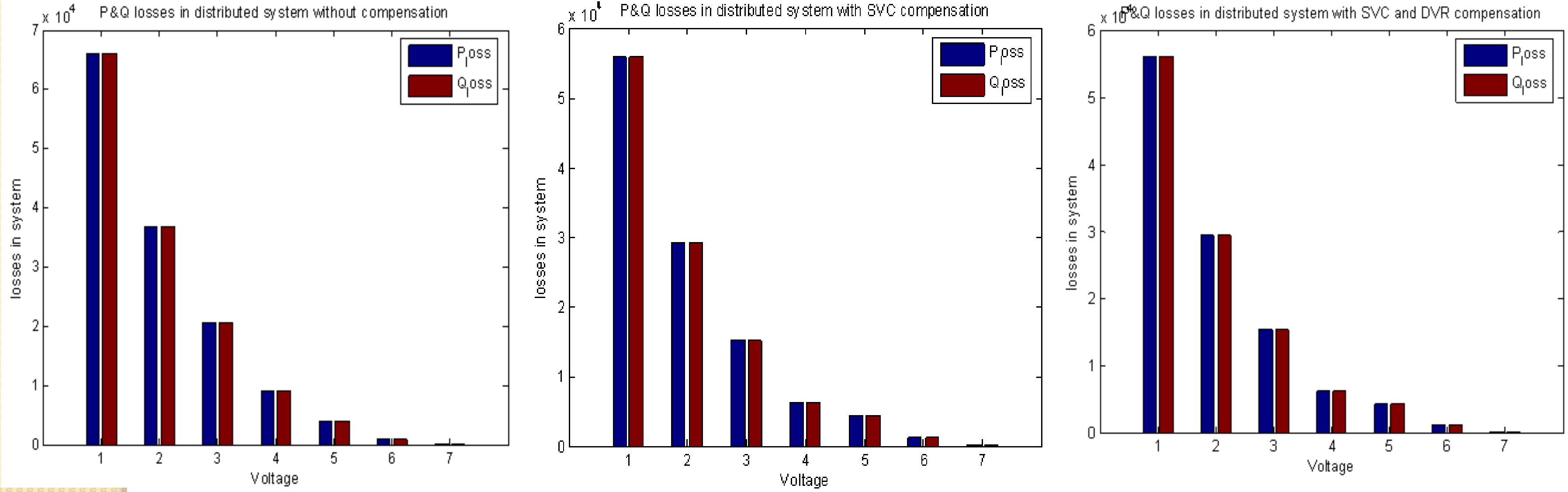
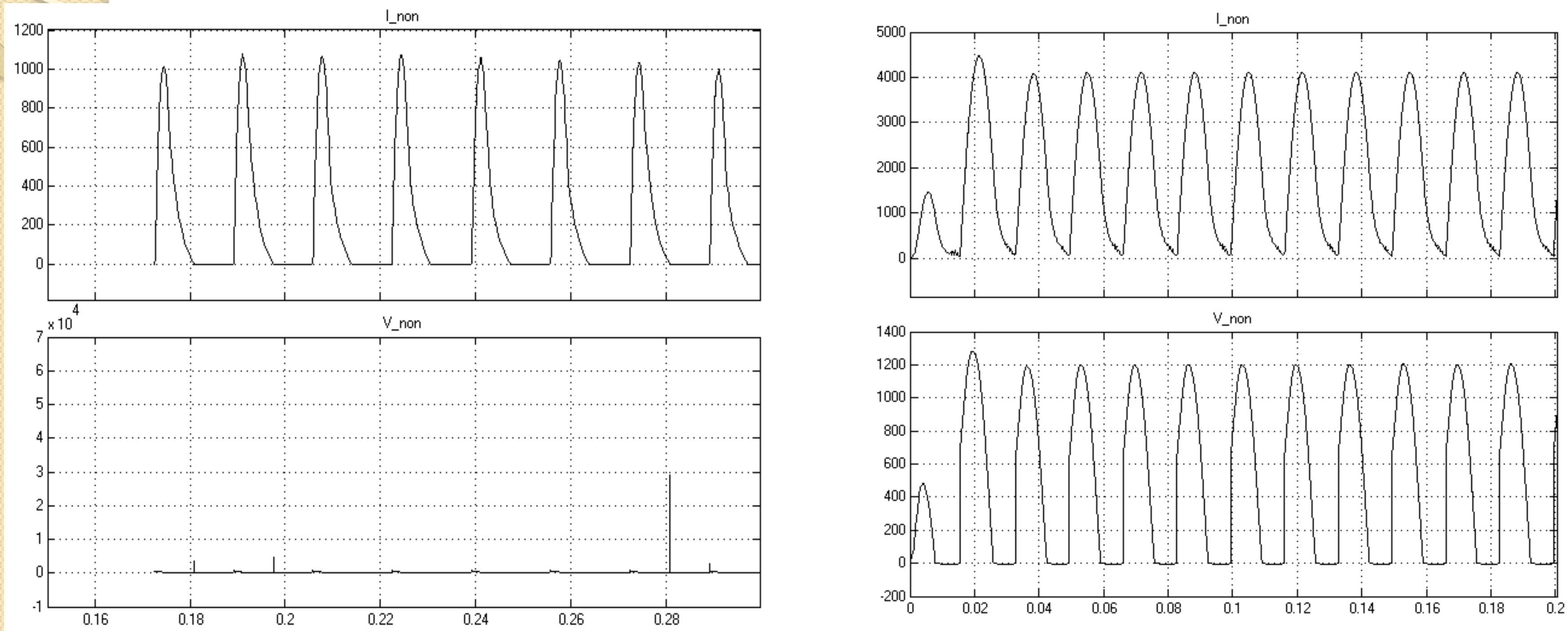


Figure.6 Total power losses of three schemes

MATLAB/SIMULINK Analysis

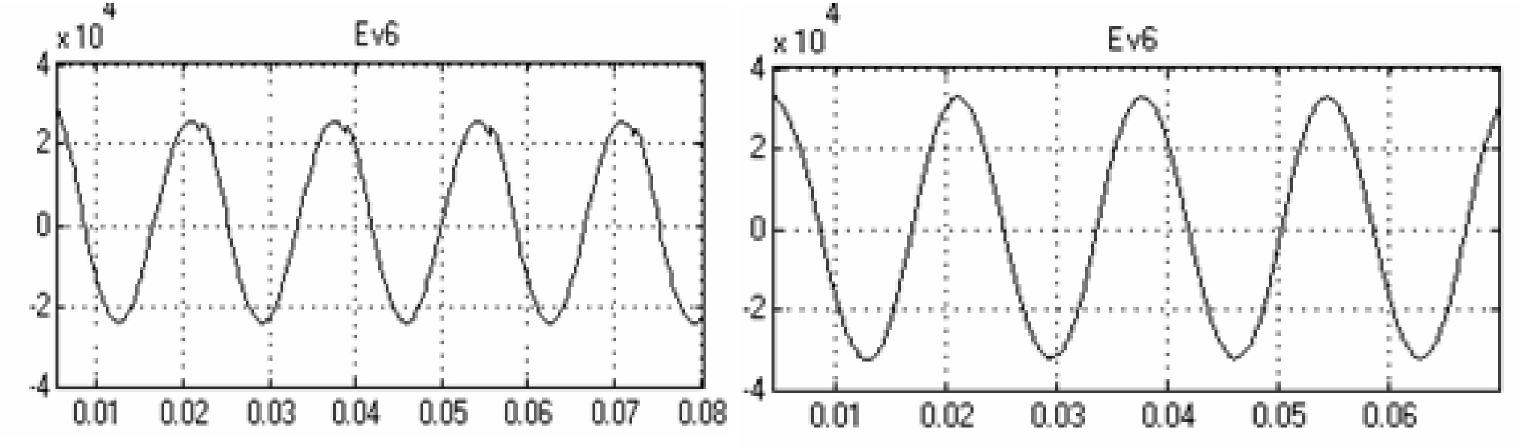


(a) Without DVR compensation

(b) With added DVR compensation

Figure.7 Current and voltage waveforms of the nonlinear load without and with DVR compensation

MATLAB/SIMULINK Analysis

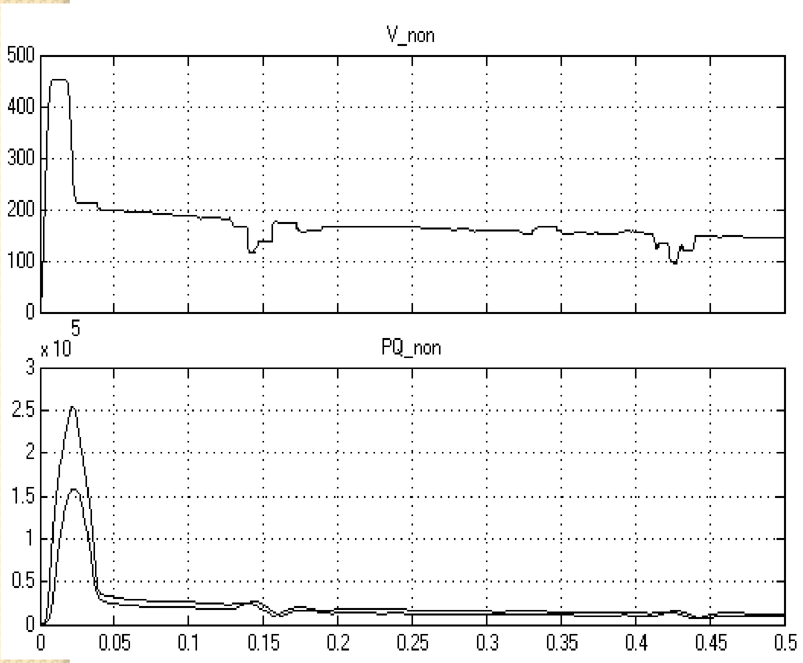


(a) Without DVR

(b) With DVR

Figure.8 Voltage waveforms of the linear load (Bus 6)

MATLAB/SIMULINK Analysis



gure.9.1 Voltage waveforms and P-Q profile without DVR compensation

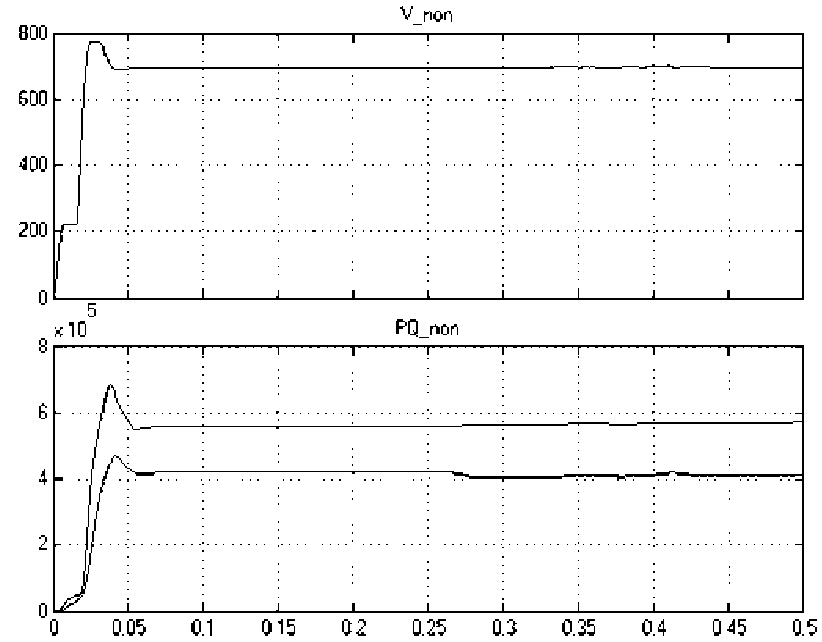


Figure.9.2 Voltage and P-Q profil with added DVR compensation

MATLAB/SIMULINK Analysis

- Figure.10 shows the portrait of the loop-error signals in for each tracking loop-Vs-total error signal.

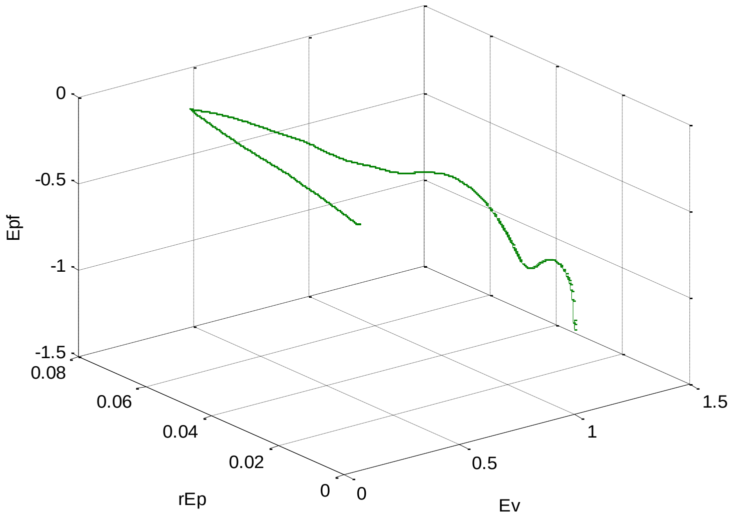


Figure.10 Error phase-portrait plane for the tri-loop error controller

Conclusions

- A novel PWM- switched dynamic voltage regulator/power filter/ capacitor compensator for combined:
- Voltage-Stabilization and loss Reduction scheme is presented for use in radial distribution /utilization Feeders supplying nonlinear loads (ARC, Temporal, Cyclical, Inrush, Converter type,…).

- The proposed dynamic DVR-FACTS-device is controlled using a tri-loop error driven PI controller.
- The objective of the added DVR is combined Loss Reduction and feeder Voltage Stabilization

Conclusion

- The DVR-Added FACTS device and dynamic tri-loop dynamic controller is very effective as a low cost tool in voltage stabilization, power quality improvement and power factor correction.

- The same DVR-FACTS Scheme can be extended for use in Renewable Green Energy, dispersed and distributed generation systems (Wind, Wave, Small Hydro, Hybrid).

Reference

[1] B. Singh, K. Al-Haddad and A. Chandra, Active PowerFilter with Sliding mode control, *IEE Proc.-Gener. Transm. Distrib*., Vol.144, No.6, November 1997

[2] B.-R.Lin, S.-C.Tsay and M.-S.Liao Integrated power factor compensator based on sliding jca-icc mode controller.

[3] M. Izhar, C. M. Hadzer, Syafrudin.M, S.Taib and S. Idris, Performance for Passive and, Active Power Filter in Reducing Harmonics in the Distribution System, *Notional Power & Energy Conference (PECon) 2004 Proceedings*, Kuala Lumpur, Malaysia

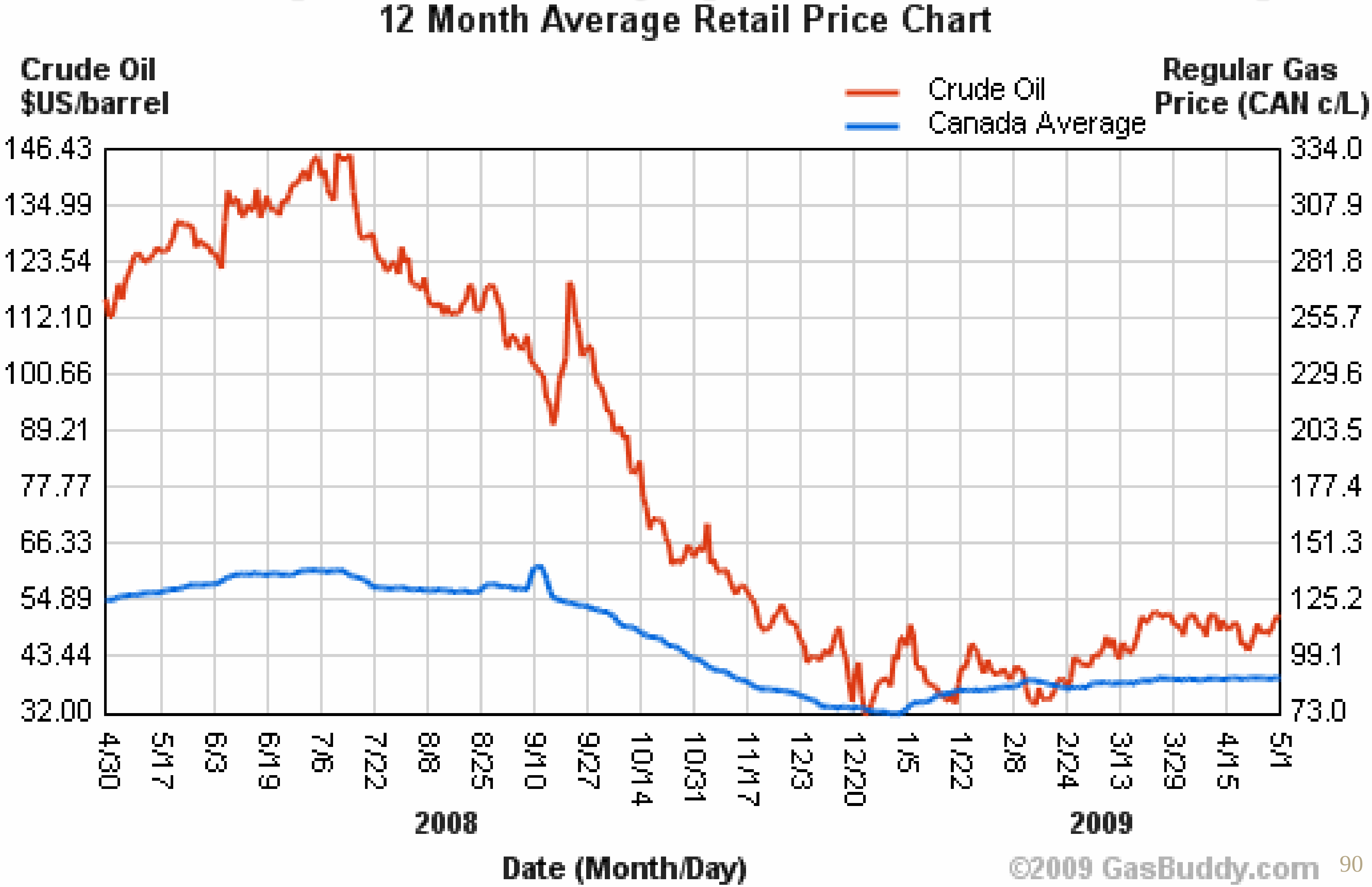
Reference

[4] Sharaf, Adel M and Guosheng Wang, Wind energy system voltage and energy enhancement using low cost dynamic capacitor compensation scheme, *Proceedings – 2004 International Conference on Electrical, Electronic and Computer engineering, ICEEC'04*, 2004, p 804-807

[5] El-Moursi, M.S. and Sharaf, A.M. , Novel STATCOM controllers for voltage stabilization of wind energy scheme, *Int. J. Global Energy Issues*,2005 [2] Paul S.

[6] A.M. Sharaf and Weihua Wang, A Low-cost Voltage Stabilization and Power Quality Enhancement Scheme for a Small Renewable Wind Energy Scheme, *proceedings-International Symposium on Industrial Electronics 2006*, ISIE 2006

Source: http://www.ontariogasprices.com/crude_chart.aspx



THE UNIVERSITY OF TRINIDAD AND TOBAGO

A Novel Dynamic Voltage Regulator Compensation Scheme for a Standalone Village Electricity Wind Energy Conversion System

A. M. Sharaf

Layout

- Introduction to Wind Energy and Wind Energy Conversions Systems (WECS),
- Test Network Layout and Modeling,
- Dynamic Voltage Regulator (DVR) Concept,
- The Tri-Loop Dynamic Error-Driven PI Controller,
- Digital Simulation Results,
- Conclusions.

Wind Energy

- Wind energy is one of the fastest growing renewable energy technologies.
- Increasing by approximately 25% annually over the period between 2002-2007.
- As of January 1st 2009, wind energy production in Canada is 1,876 MW, powering 563,000 Canadian home.
- There is the potential in Canada for wind energy to meet about 20% of all its electricity needs, which can power 17 million Canadian home.

Why Wind Energy?

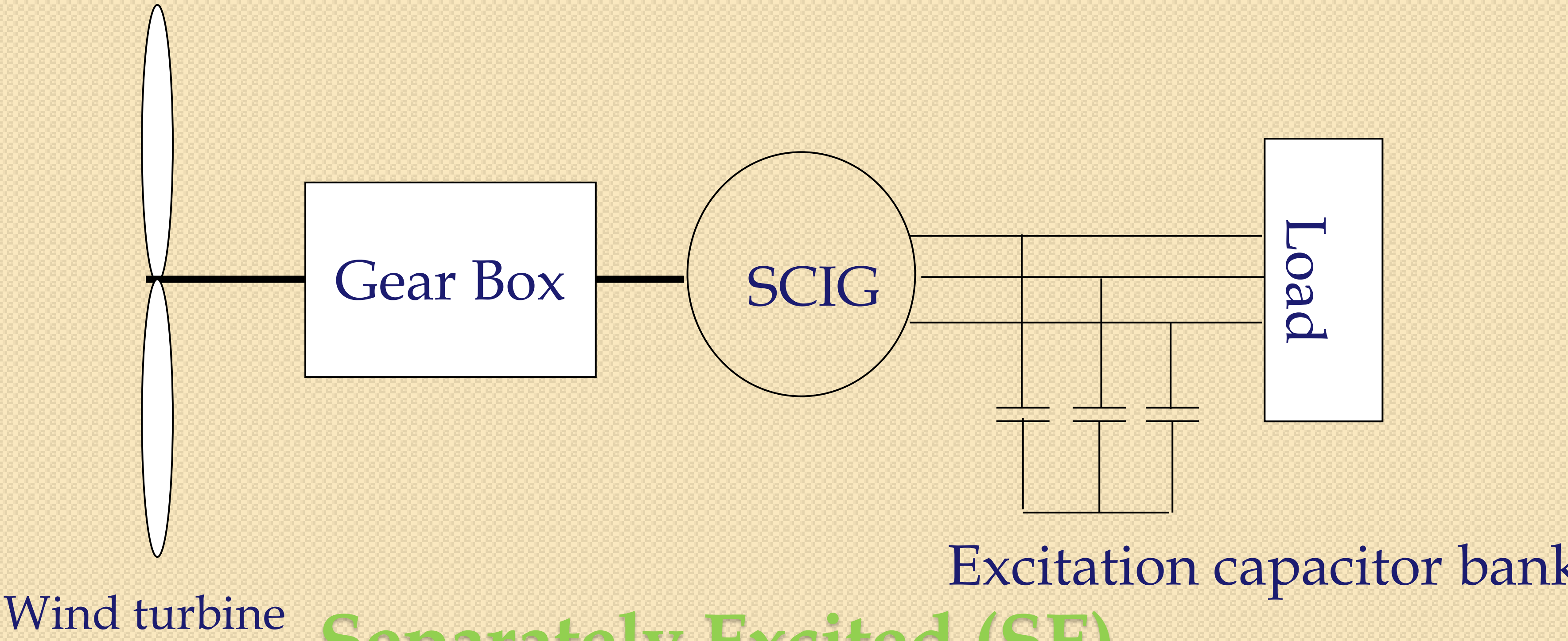
- Pros:
  - Low Running Cost
  - Clean Source of Power “No Emissions”
  - Abundant, Low Cost $ 0.05-0.06/Kwh
  - Completely renewable source of power.
- Cons:
  - High Initial Cost-$ 1800-2800/Kw
  - Low Power Quality (Voltage, Frequency, Harmonics & Inertia)

Rural Areas & Wind Energy

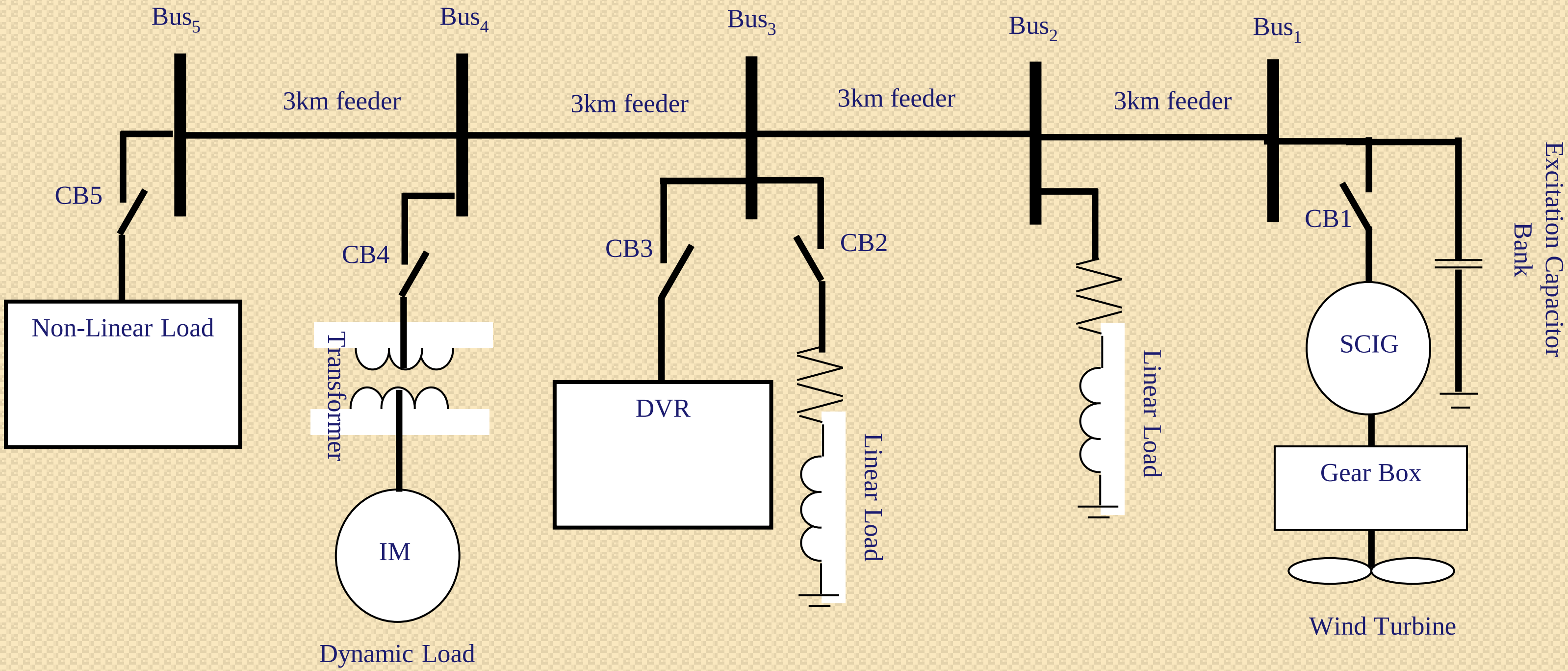
- ✓It is economical to use in producing power in rural isolated/Island/Coastal Off Shore and On Shore areas.
- ✓ Problems are caused by the continuous stochastic variation in the wind speed and load disturbances.
- ✓ They results in significant fluctuations in output power, voltages of the network in addition to a low power factor.

Wind Energy Conversion Systems

	DFIG	**PMSG**	**SCIG (Stand alone)**
Method of operation	Back to back VSI	Back to back VSI	Directly connected to grid
Gearbox	Yes	No Direct Drive	Yes
Excitation	Grid	Magnet	Excitation Capacitors
Voltage Control	Easy	Easy	complicated
Frequency Control	Easy	Easy	complicated
Inertia	Negligible	Negligible	Considerable



Separately Excited (SE)
Squirrel Cage Induction Generator (SCIG)



System Layout

WIND TURBINE MODELING

The output mechanical power of the wind turbine is

$$P_m = \frac{1}{2} C_p(\lambda, \beta) \rho A v_w^3$$

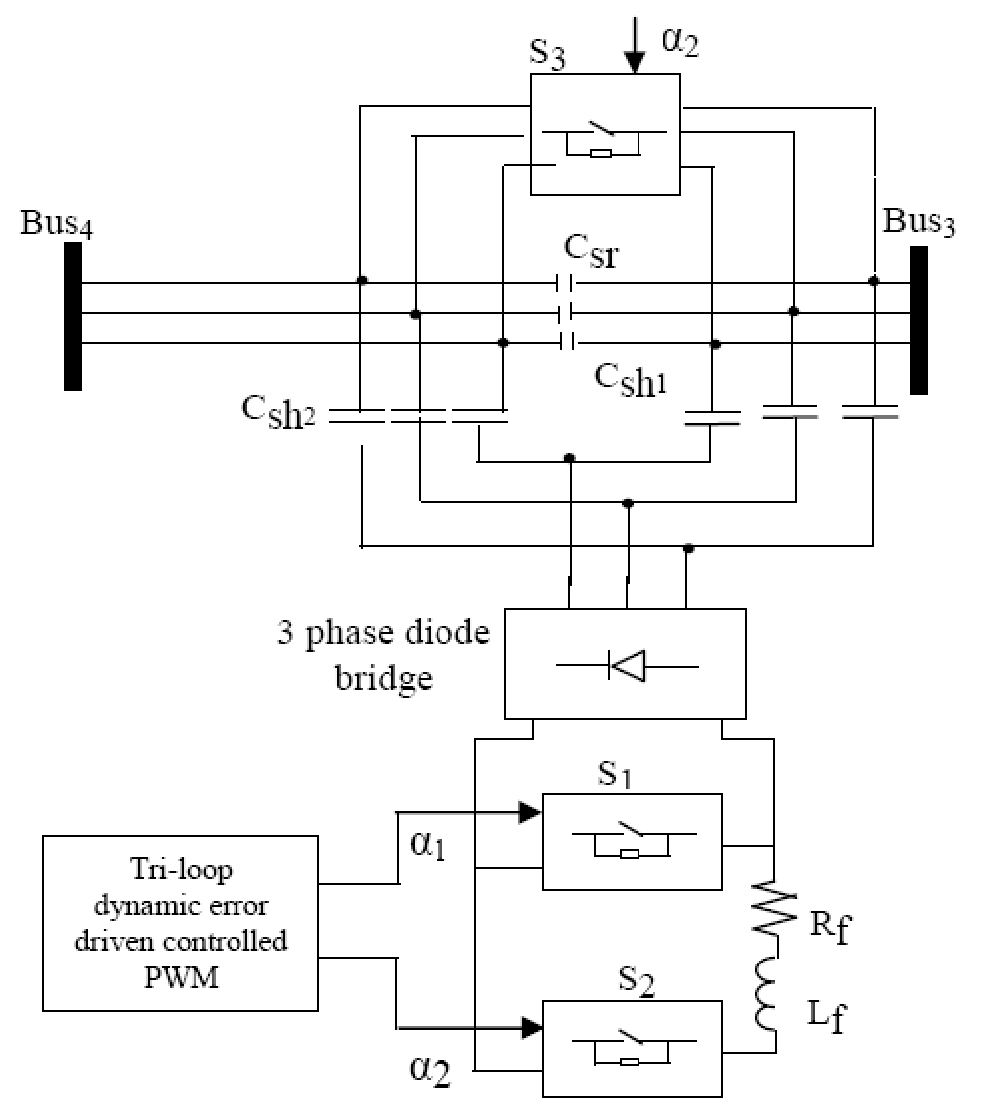
The tip speed ratio is calculated as:

$$\lambda = \frac{R\omega_m}{v_w}$$

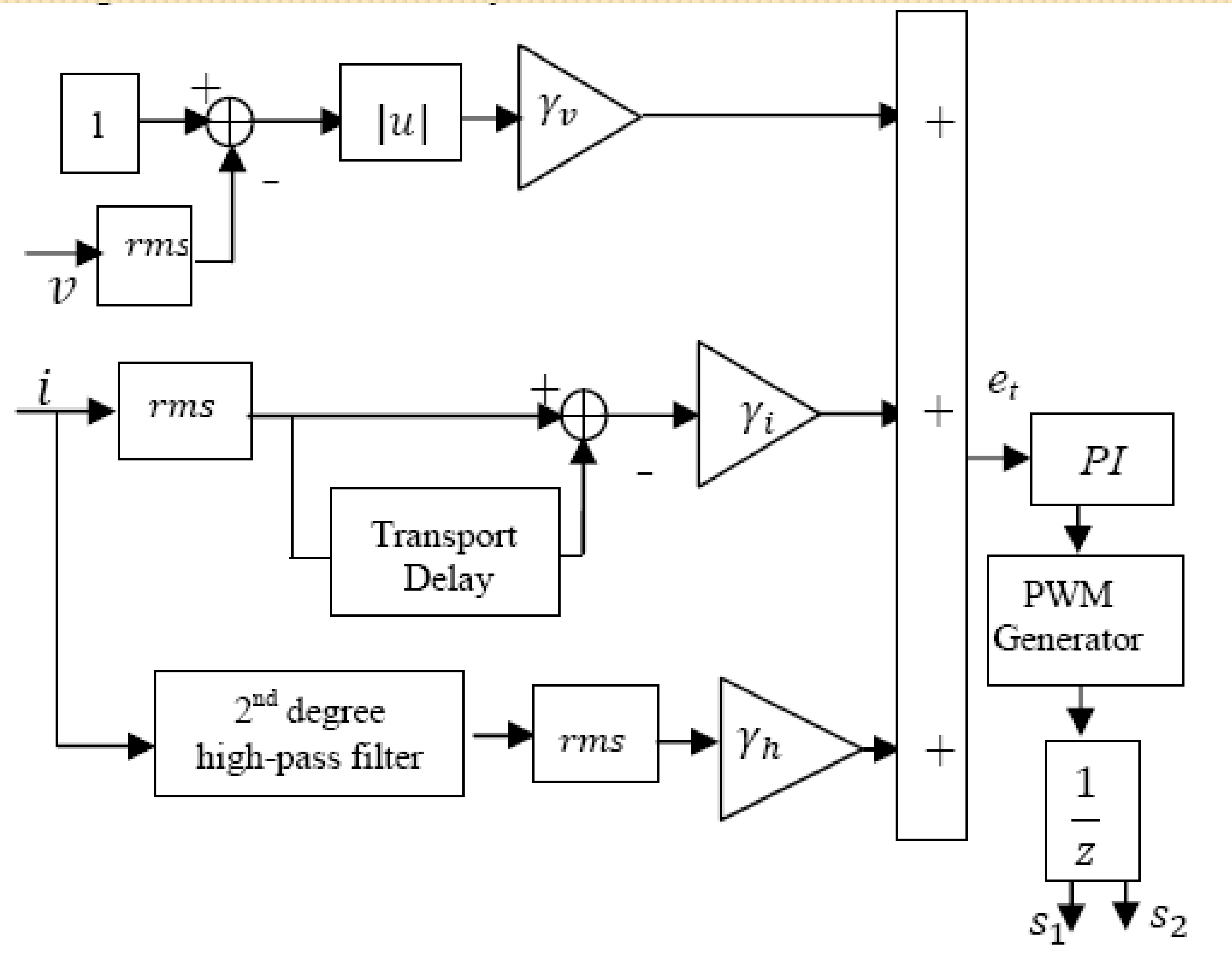
$$C_p(\lambda, \beta) = c_1 \left(c_2 \frac{1}{\Lambda} - c_3 \beta - c_4 \beta^x - c_5 \right) e^{c_6 \frac{1}{\Lambda}}$$

$$\frac{1}{\Lambda} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1}$$

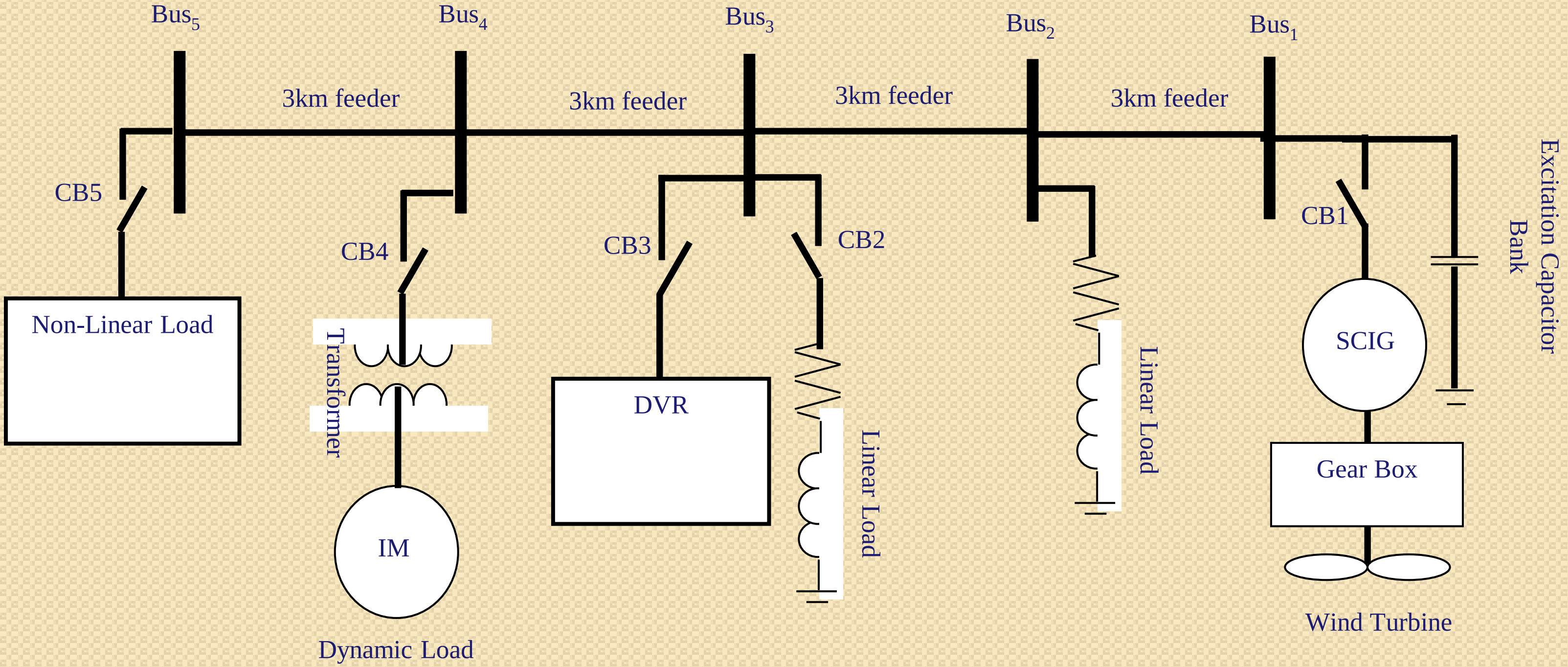
The Dynamic Voltage Regulator (DVR)



Tri-Loop Dynamic Error Driven PI Controller PWM

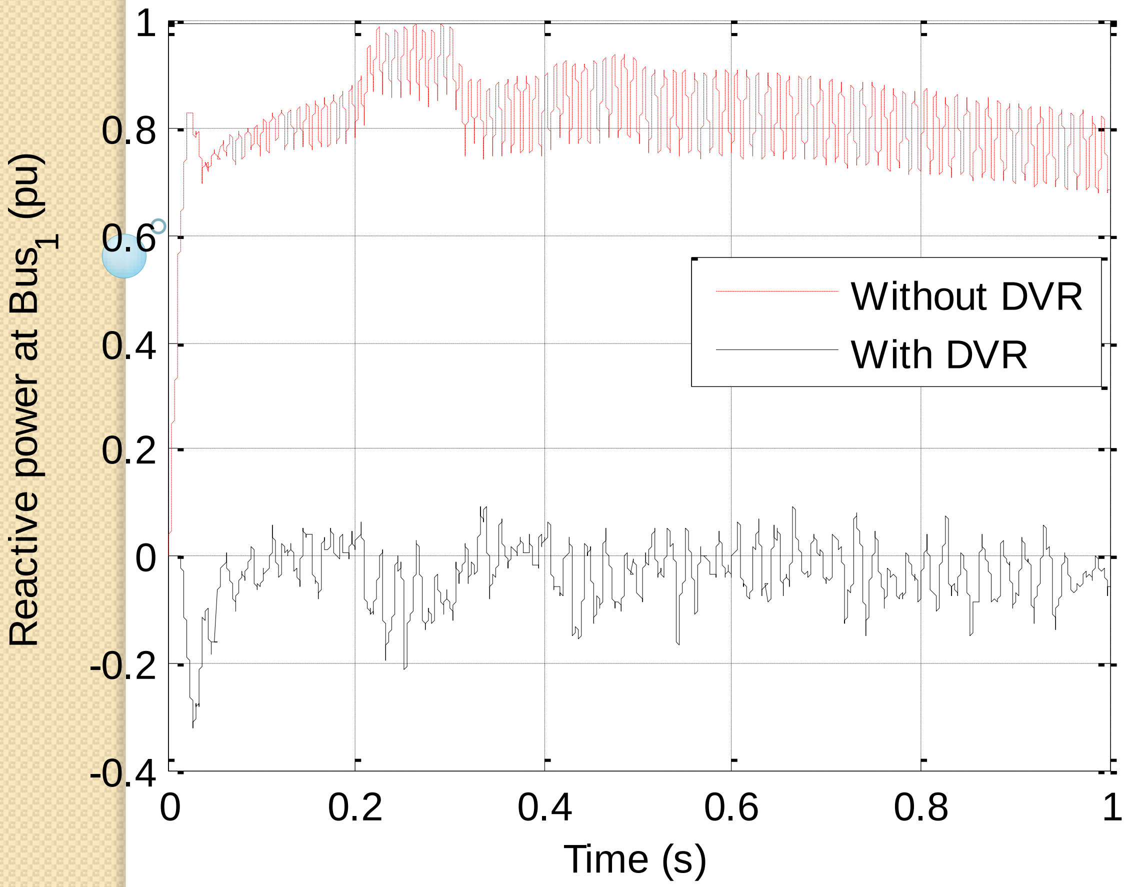


System Layout

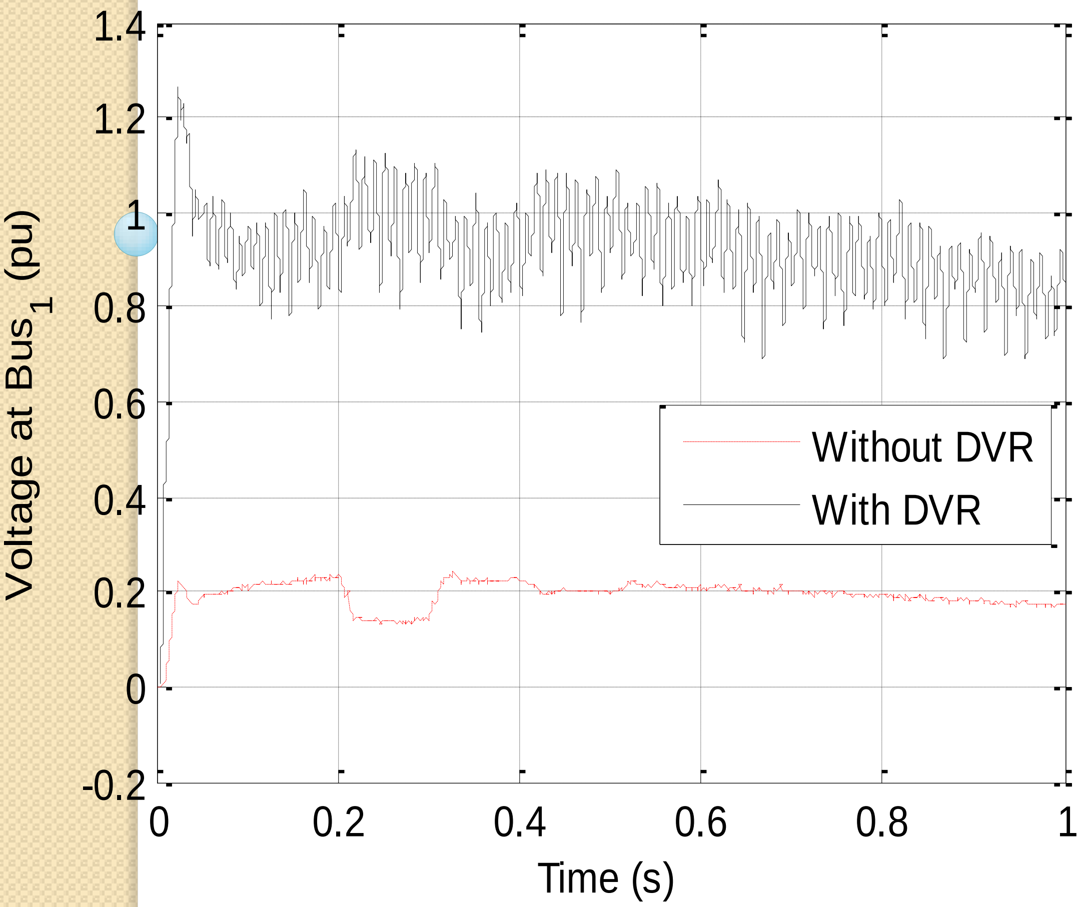


- the dynamic load is disconnected by opening CB$_4$ at t=0.2s and is reclosed at t=0.3s.
- The linear load connected at bus 3, is disconnected by opening CB$_2$ at t=0.4s and is connected at t=0.5s, by closing CB$_2$.

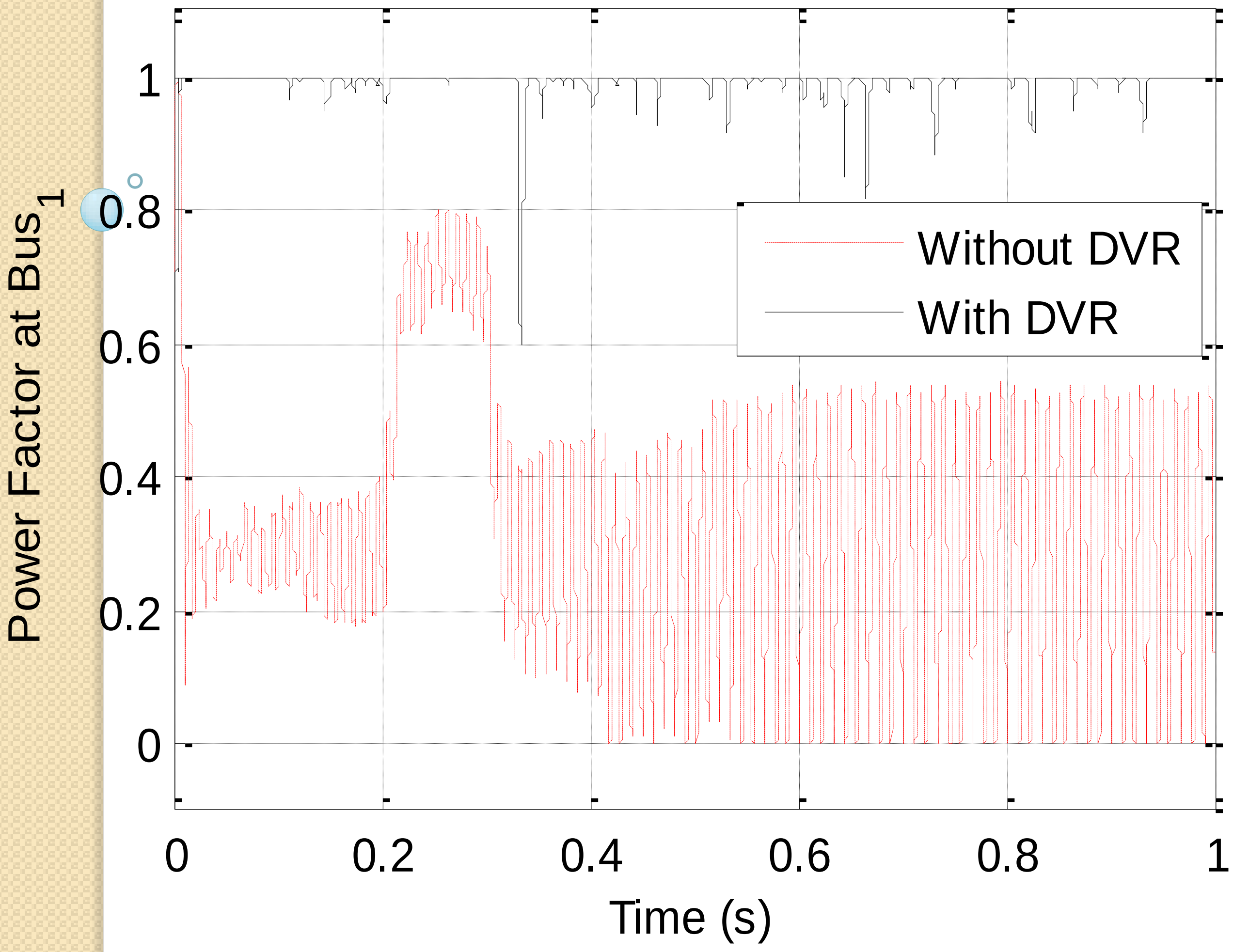
SIMULATION RESULTS



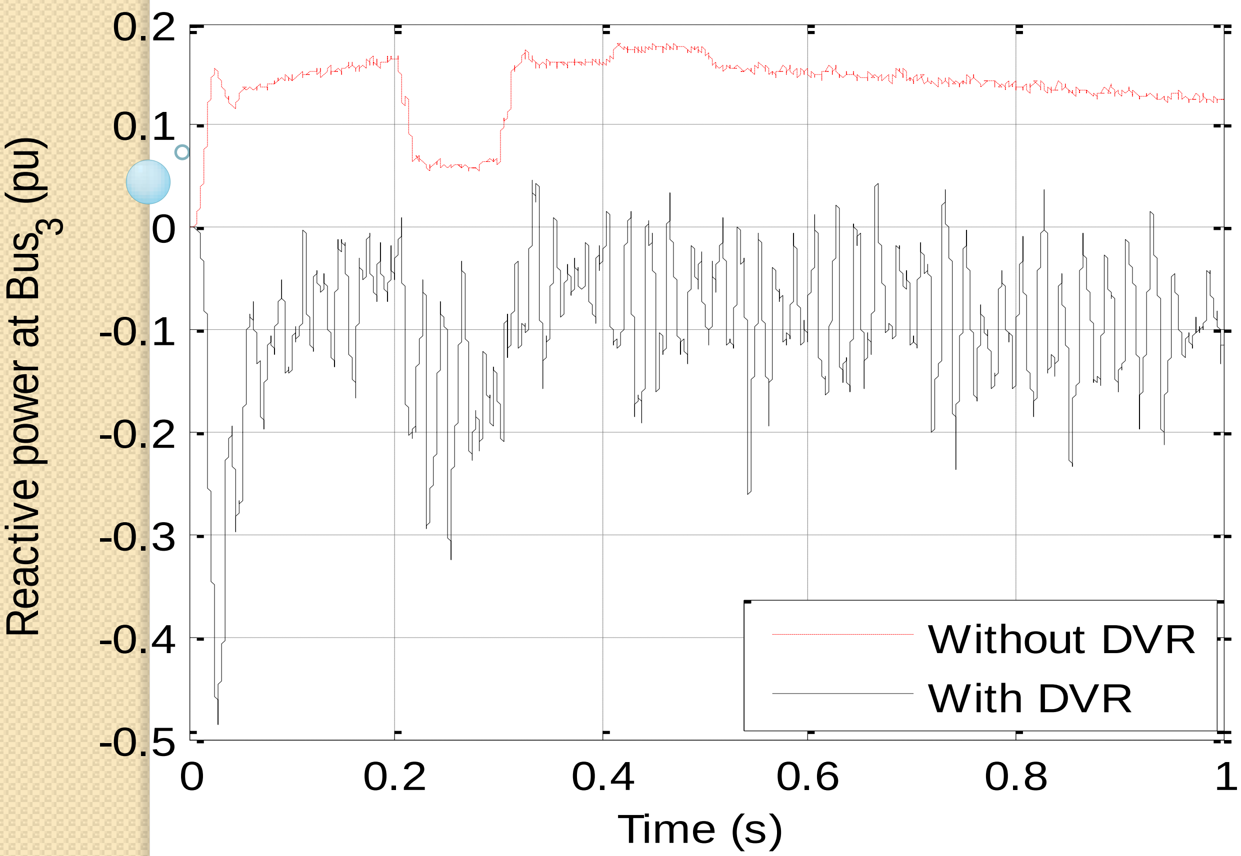
SIMULATION RESULTS



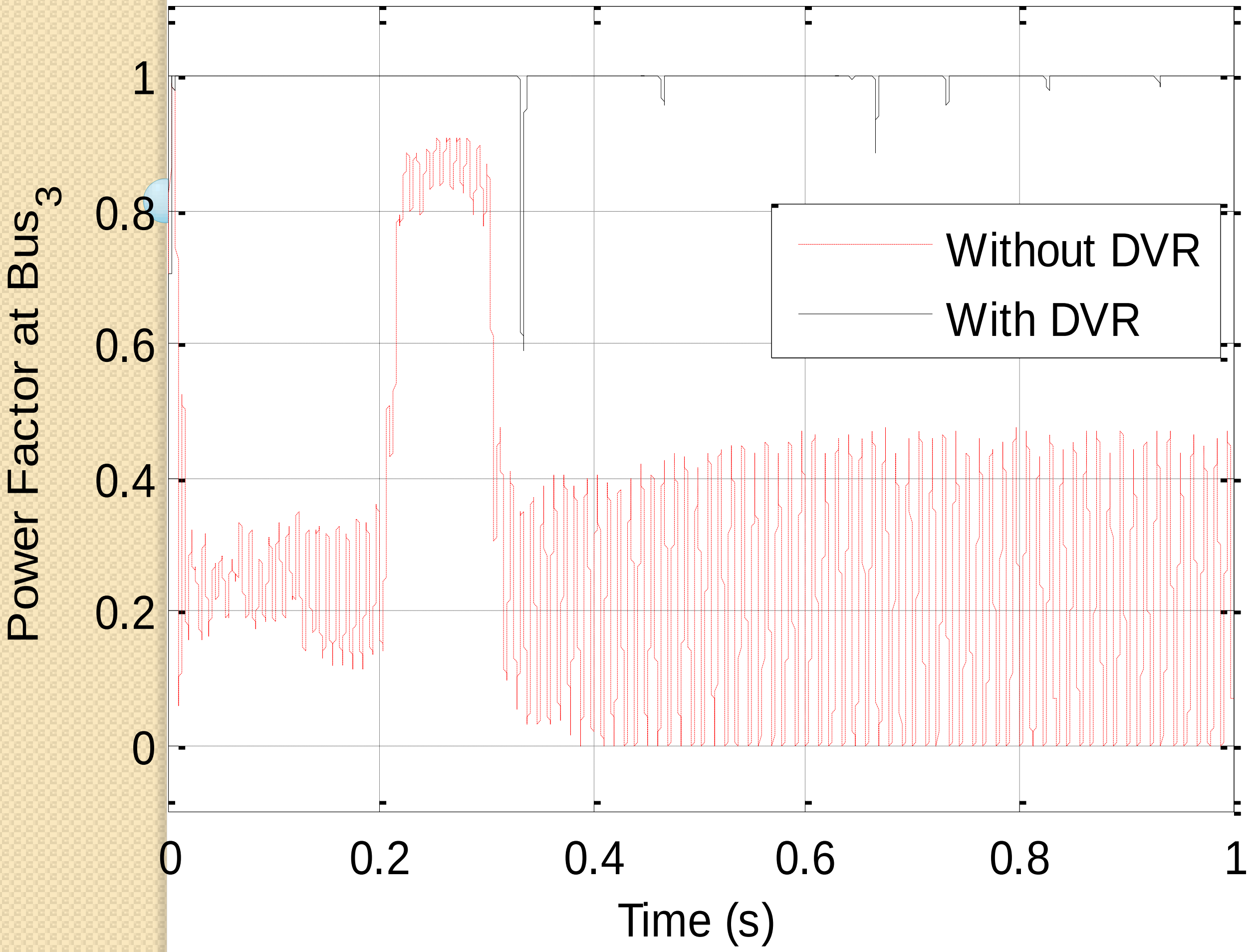
SIMULATION RESULTS



SIMULATION RESULTS



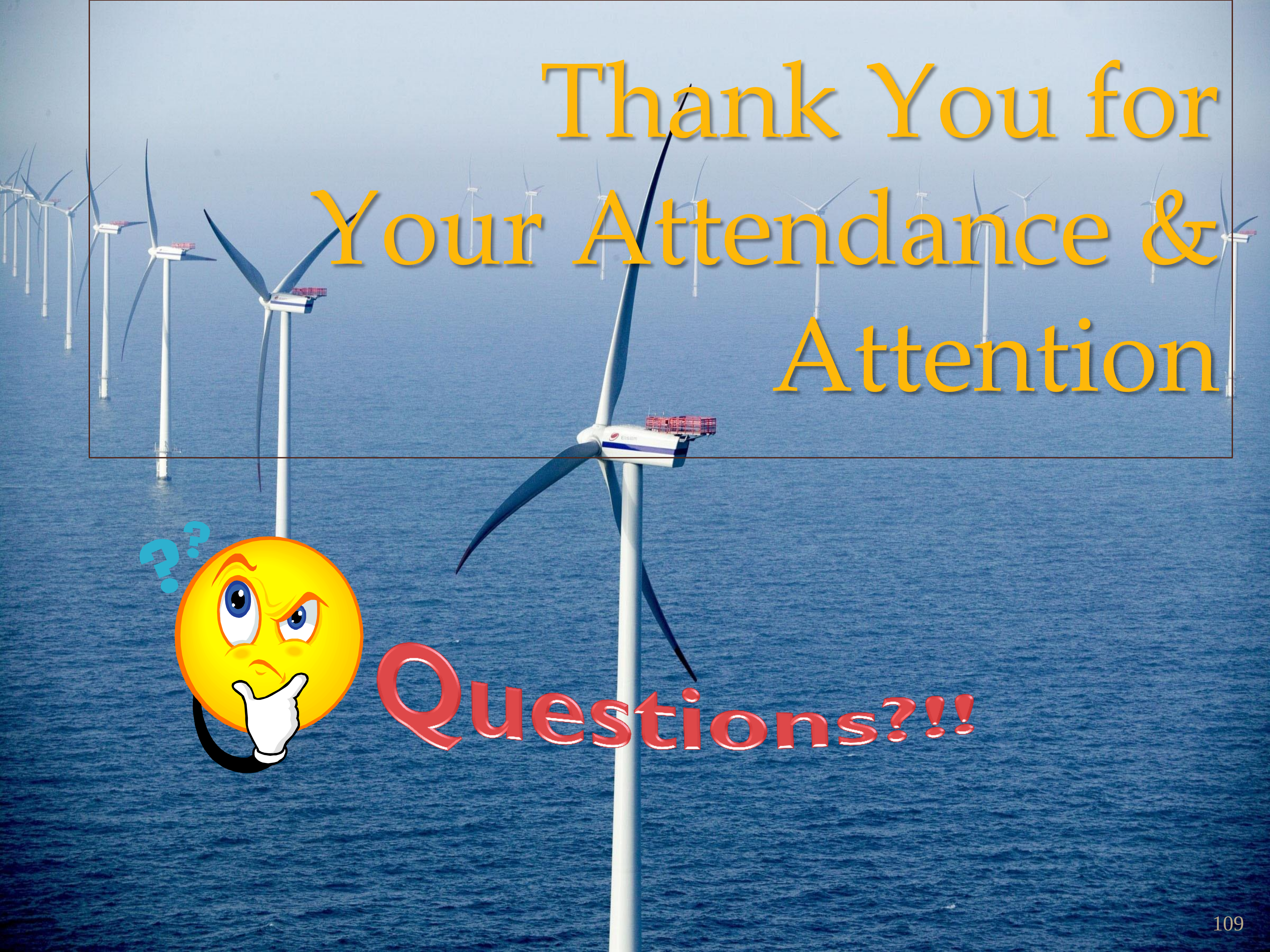
SIMULATION RESULTS



Conclusions

- Introduction to Wind Energy and Wind Energy Conversions Systems (WECS),
- Test Network Layout and Modeling,
- Dynamic Voltage Regulator (DVR) Concept,
- The Tri-Loop Dynamic Error-Driven PI Controller,
- Simulation Results,
- Conclusion.

Thank You for Your Attendance & Attention



Questions?!!