Analysis and Mitigation of Harmonics in Wind Turbine Transformers

A Major Qualifying Project by Stephen Cialdea, Marcus Peart, and Warranyu Walton

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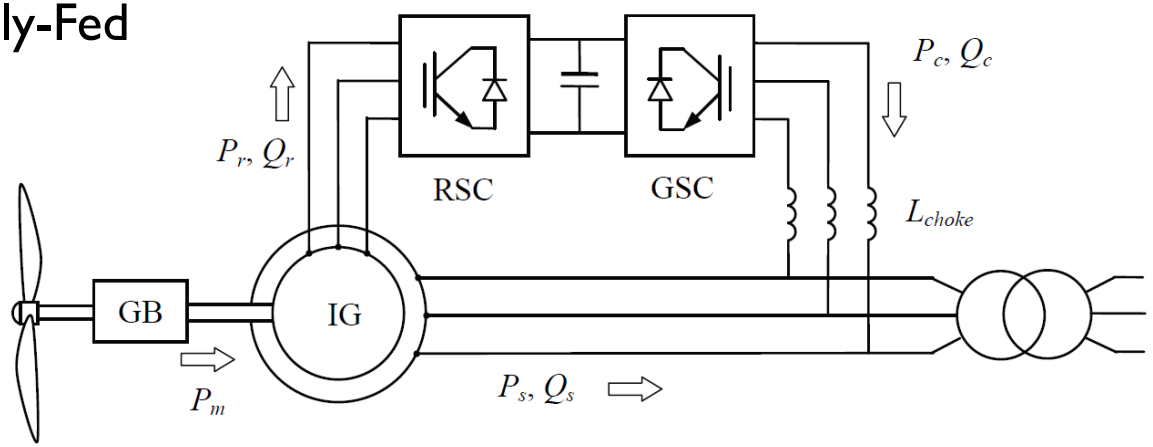
Background

- There are many types of generators used in Wind Turbine designs.
- It is chosen because of its overall efficiency and wide operating wind speed.
- A very popular wind turbine generator is the Doubly-Fed Induction Generator.



GB – Gearbox
IG – Induction Generator

RSC – Rotor-Side Converter
GSC – Grid Side Converter

John Fletcher and Jin Yang (2010). Introduction to the Doubly-Fed Induction Generator for Wind Power Applications, Paths to Sustainable Energy, Jatin Nathwani and Artie Ng (Ed.), ISBN: 978-953-307-401-6, InTech, Available from: http://www.intechopen.com/articles/show/title/introduction-to-the-doubly-fed-induction-generator-for-wind-power-applications

Problem Statement and Project Objectives

Problem:

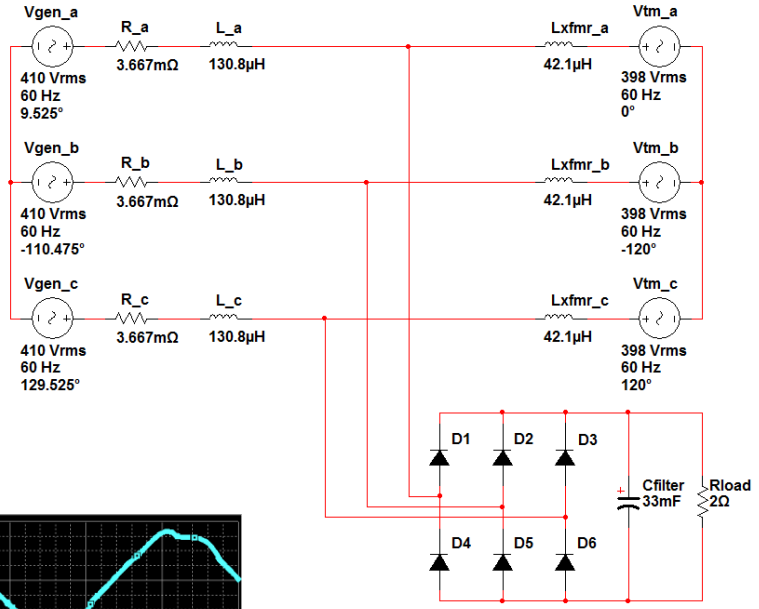
DFIG back to back converter introduces current harmonics in the line. These harmonics cause heating in the transformer connected by way of eddy current losses and skin effect losses.

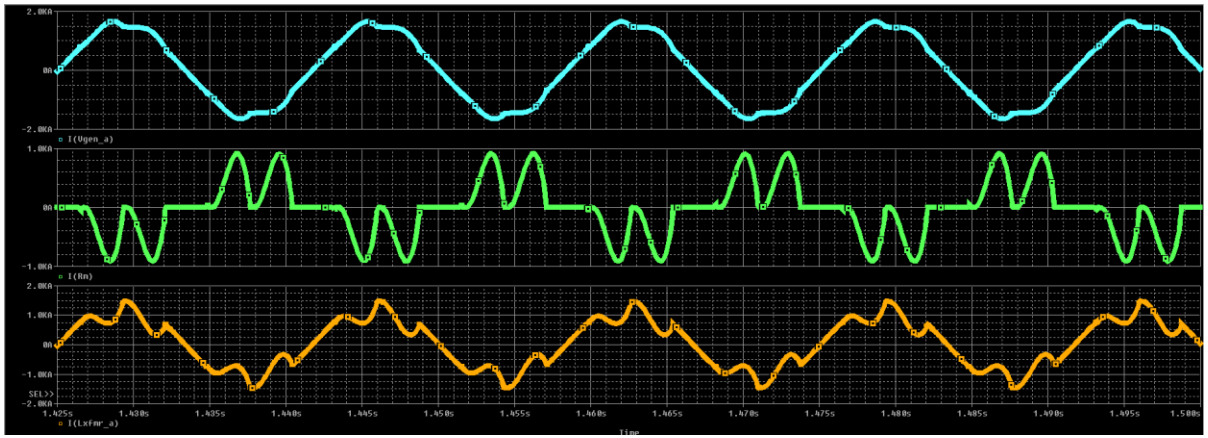
Objectives:

- Analyze a DFIG harmonics.
- Design a proof-of-concept single phase active filter that minimizes current harmonics.

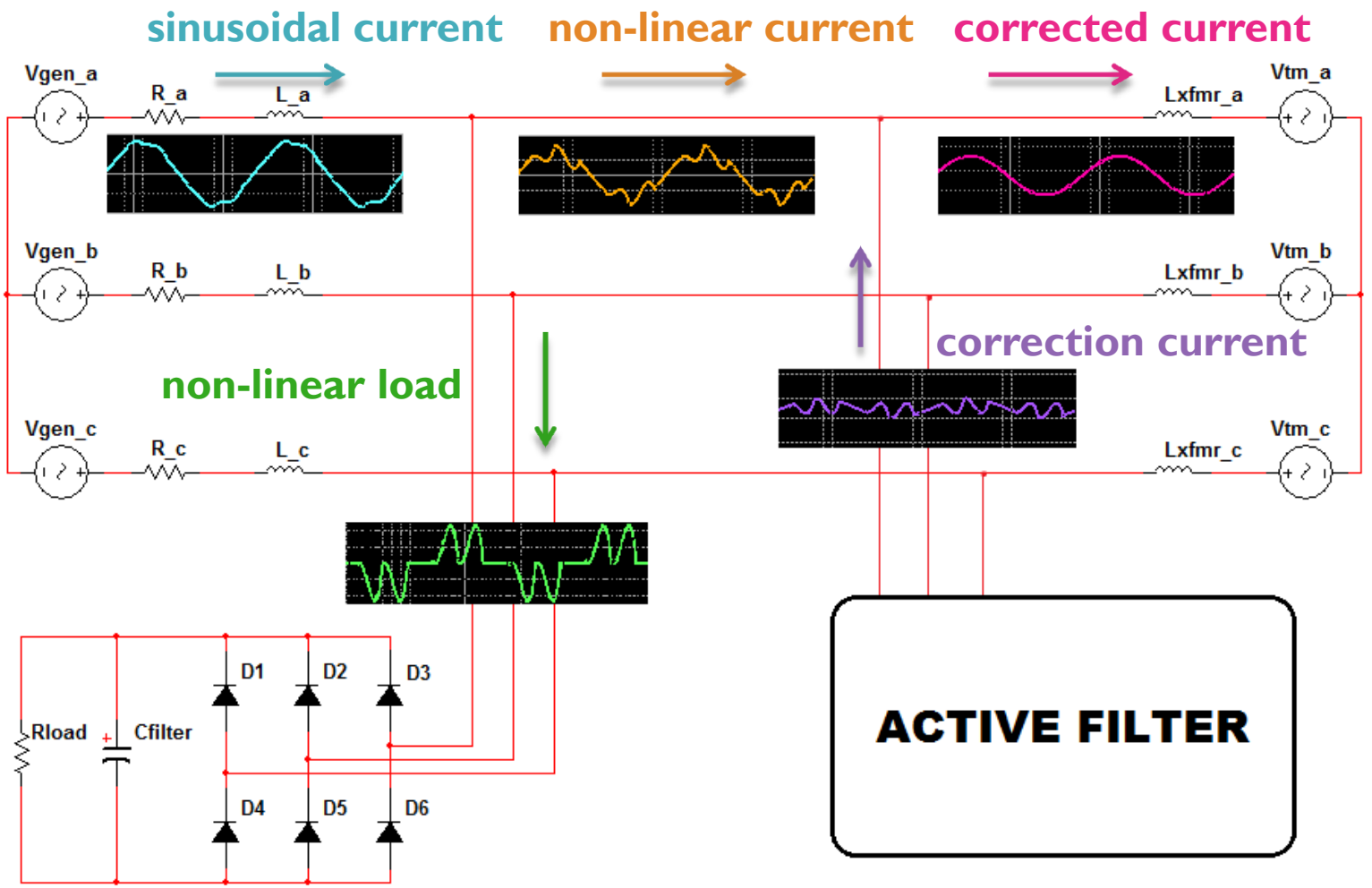
DFIG Modeling

- PSPICE was used to analyze current harmonics. Model based on Fuhrlander FL1500 wind turbine.
- Results suggests a need for either filtering system or an oversized transformer.





Active Filter Basic Concept

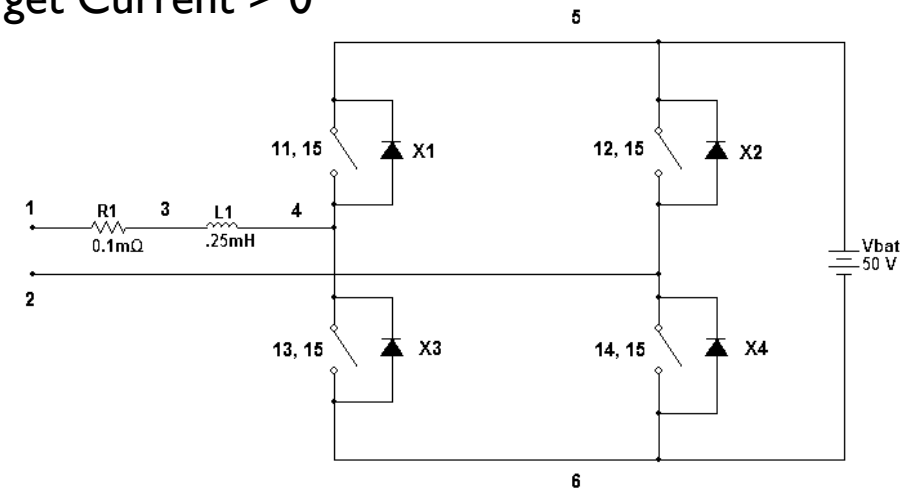


Design Objectives

- Develop a reduced scale model, single phase active filter that can be scaled up to higher power ratings.
- Significantly reduces 2^{nd} to 13^{th} harmonics.
- Operates at a line voltage of 12Vrms
- Up to 10A peak correction current

Preliminary Modeling

- PSPICE models
  - Used to verify IGBT switching logic for generating arbitrary waveforms
    - Conditions:
      - A: Target Current > 0
      - B: Correction Current – Target Current > 0
      - X1, X4 = A && ~B
      - X2, X3 = B && ~A



.SUBCKT ActiveFilterV1 1 2 11 12 13 14 15

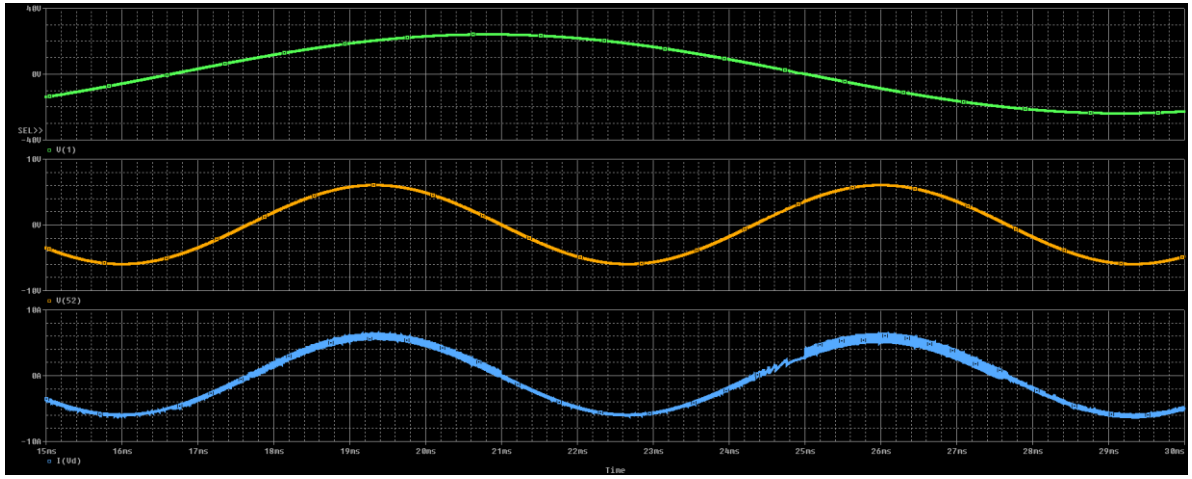
X1-X4 are .SUBCKT IdealTransistorSwitch

Modeling Continued

Line Voltage (60Hz)

Arbitrary Target Current (300Hz)

System Output Matching Arbitrary Target



Single Phase Active Filter Design

Hardware

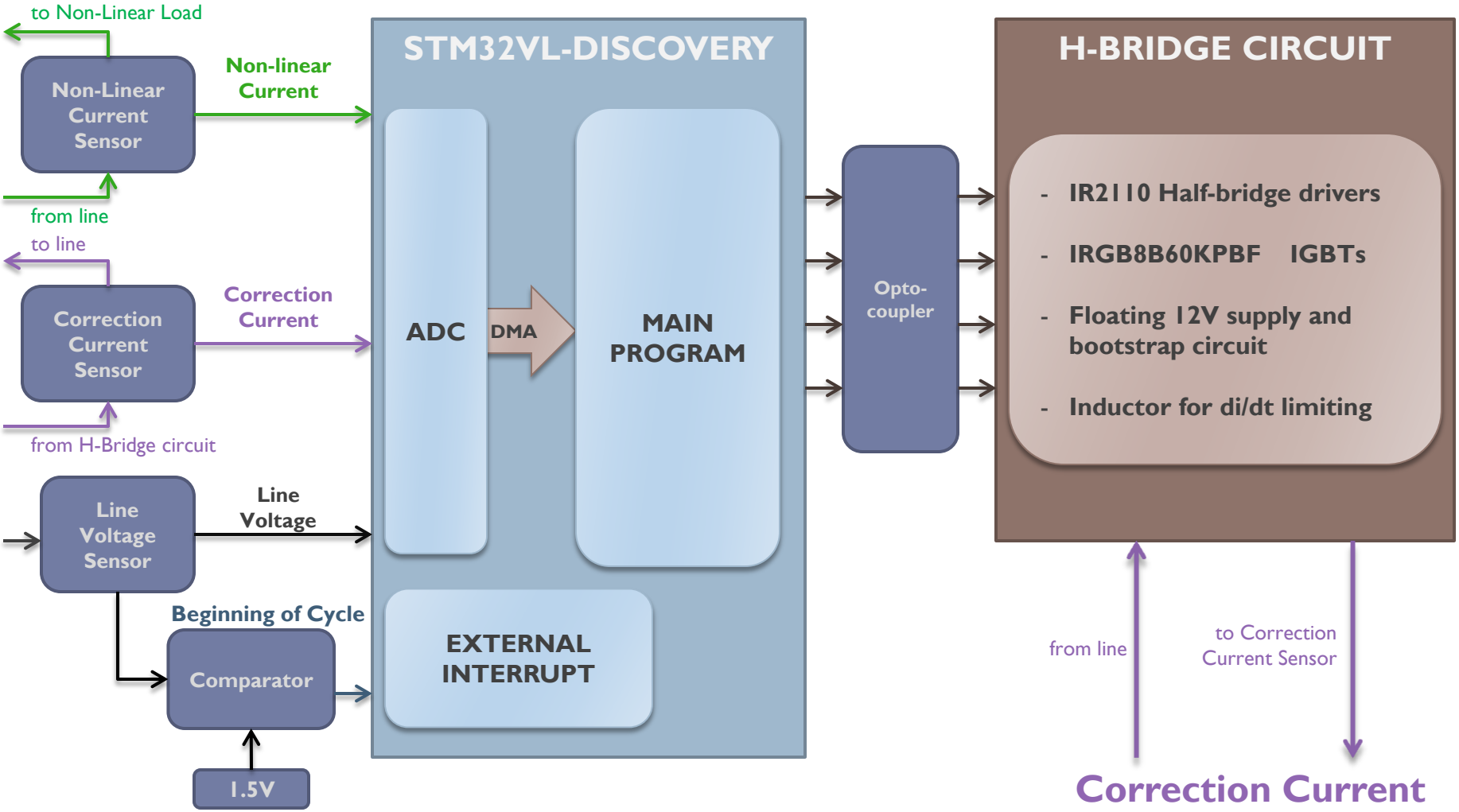
- Allegro ACS714 Hall Effect Sensor
  - Handles up to 20A
  - 100mV per 1A resolution

- International Rectifier IRGB8B60KPBF
  - Continuous collector current of 19A at 100^0C
  - $V_{GE(th)}$ of 4.5V typical

- International Rectifier IR2110 High and Low Side Driver
  - Floating channel design for bootstrap operation
  - Gate drive supply range 10-20V

- STM32VL-Discovery Evaluation Board
  - 24MHz Operation
  - Easy to integrate peripherals with ST standard peripheral library
  - Free Atollic C Compiler and IDE.

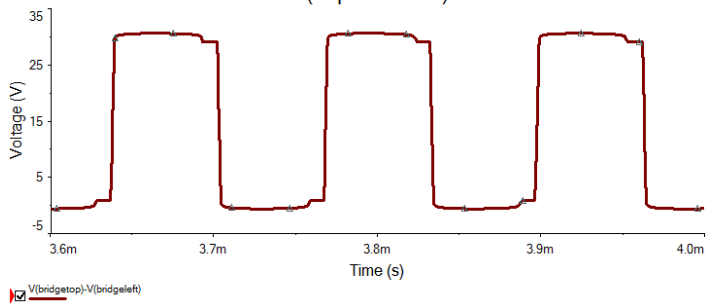
Active Filter Block Diagram

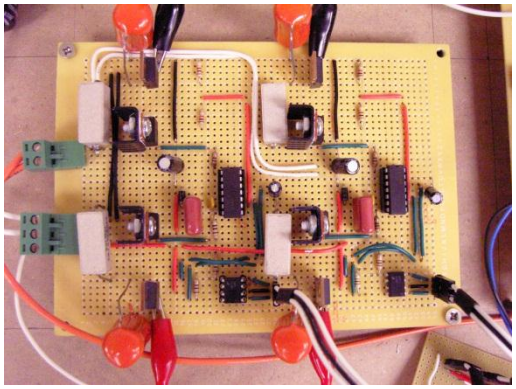


Modeling

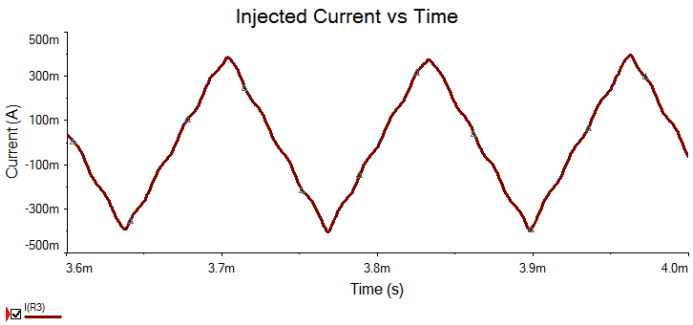
- H-Bridge Circuit Simple Switching

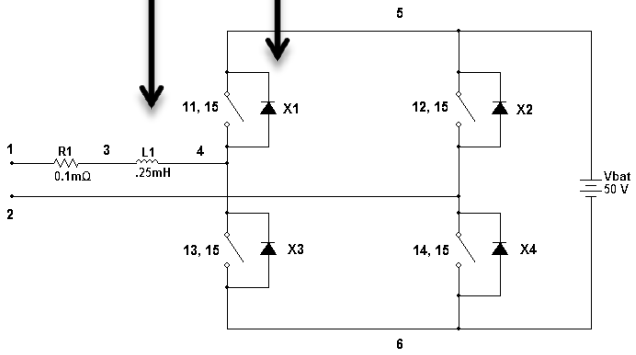
V_{CE} for U4





Output Current





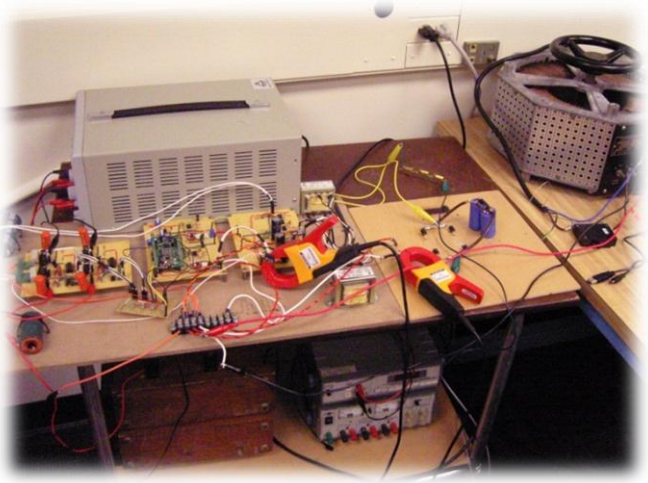
.SUBCKT ActiveFilterV1 1 2 11 12 13 14 15

X1-X4 are .SUBCKT IdealTransistorSwitch

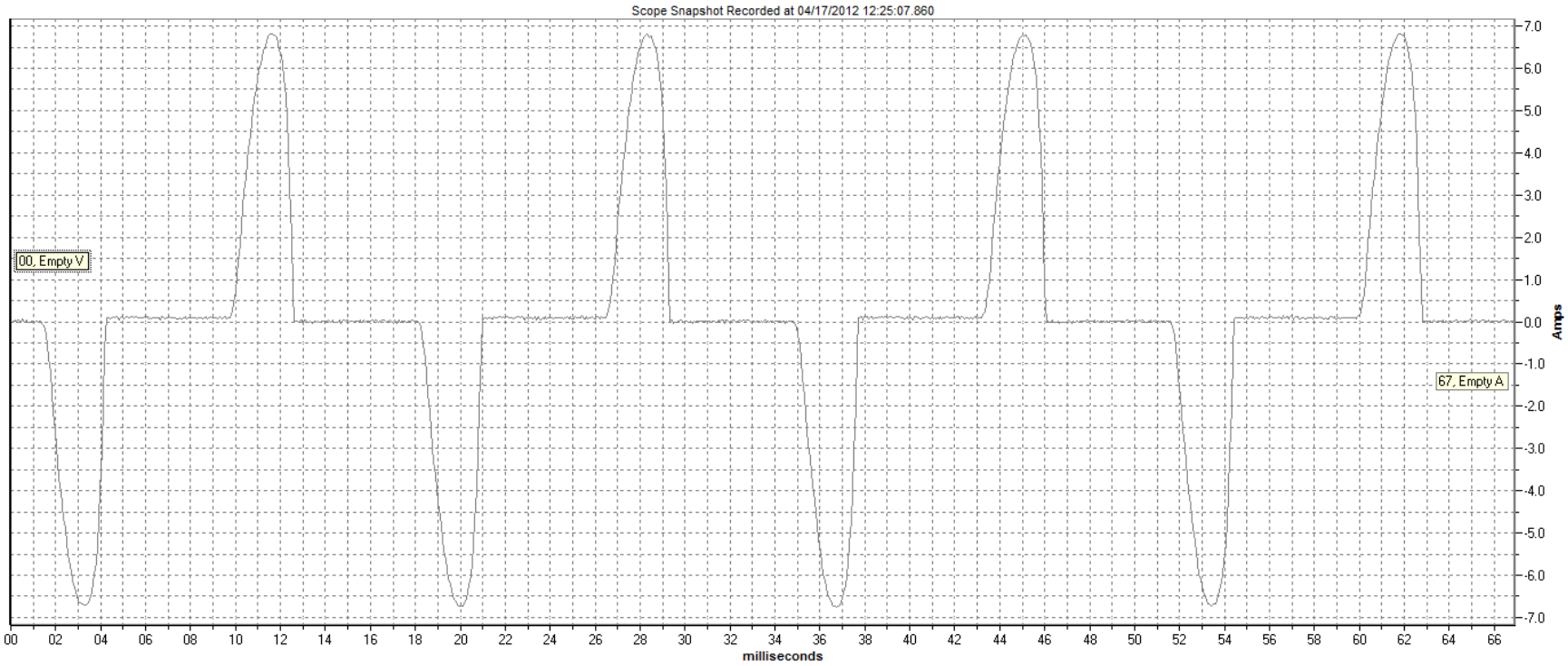
- No problems with switching.

Experimental Setup

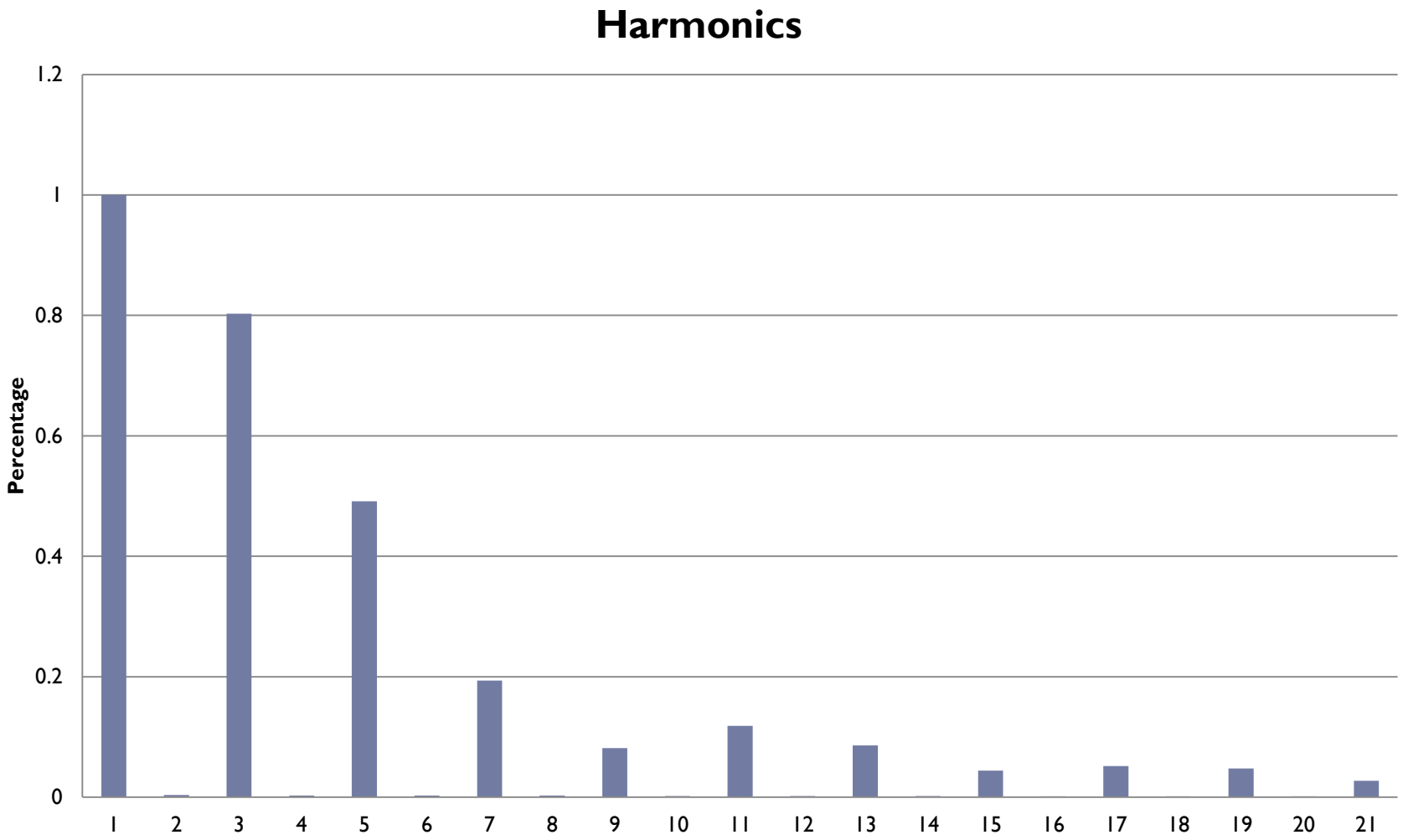
- Large auto-transformer to step down input voltage to 12VAC.
- Single phase rectifier as source of non-linear current.
  - Drawing a peak current of approximately 7A



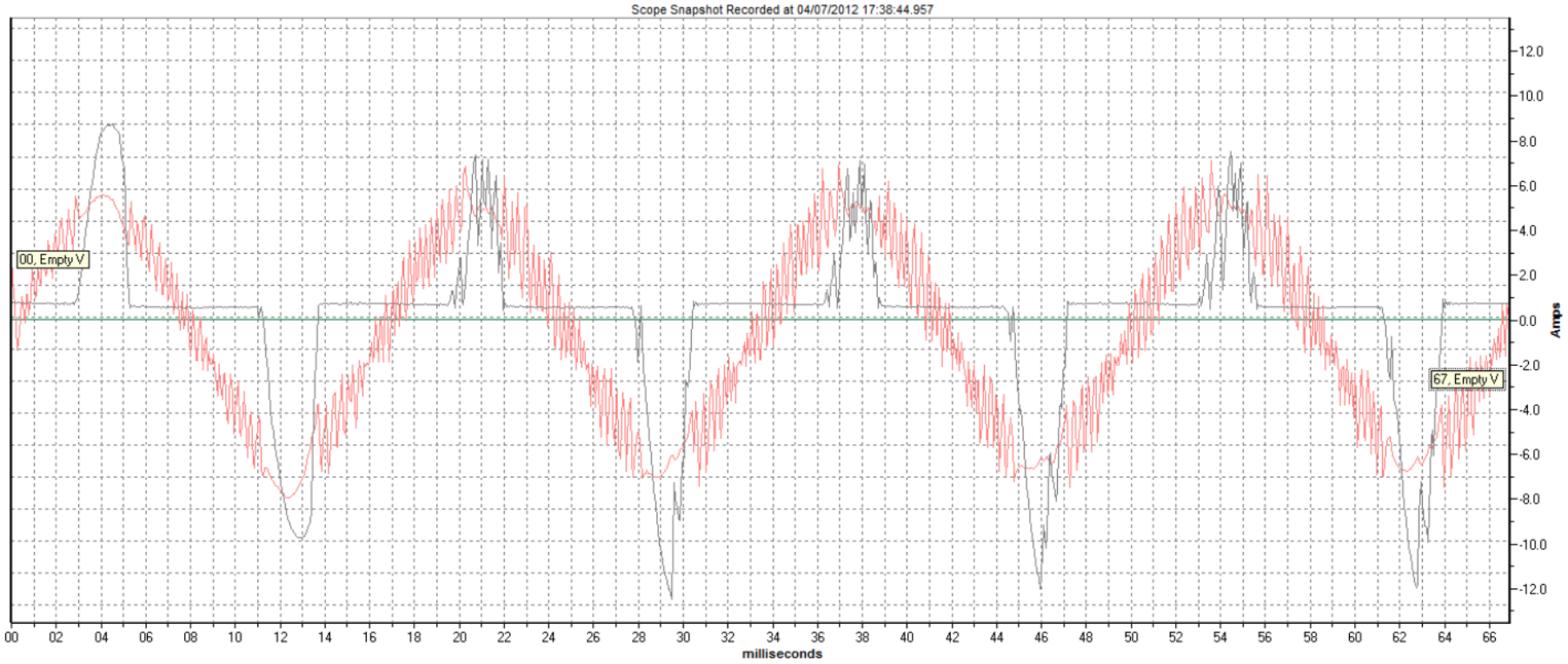
Non-Linear Waveform



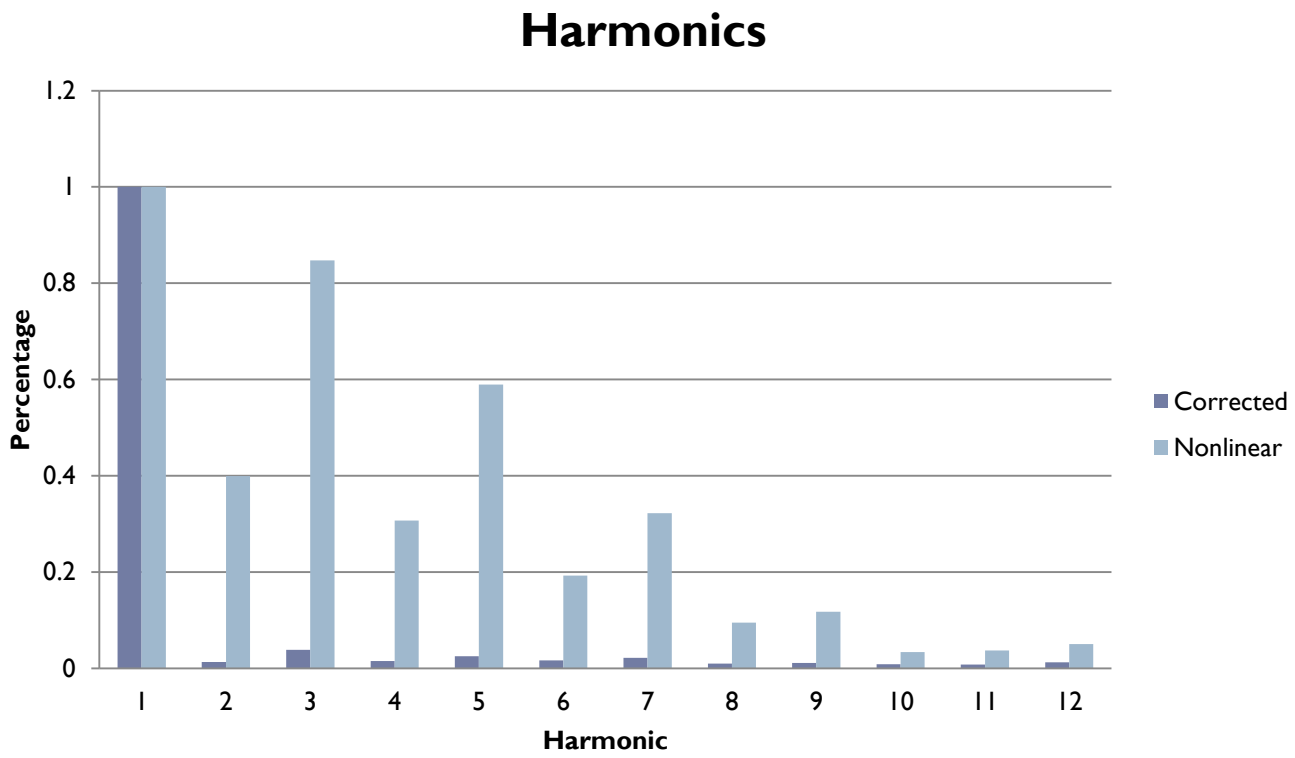
Non-Linear Harmonics



Experimental Results



Experimental Results (Cont.)



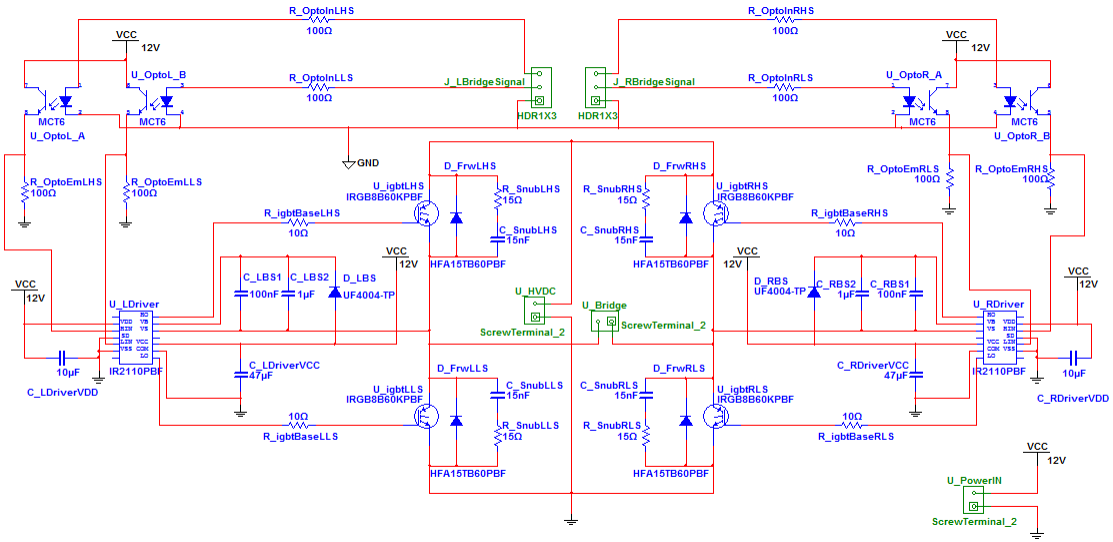
	A	B
% THD	123.8	13.4
% Odd Harmonic	110.0	9.7
% Even Harmonic	56.9	9.3

Conclusion

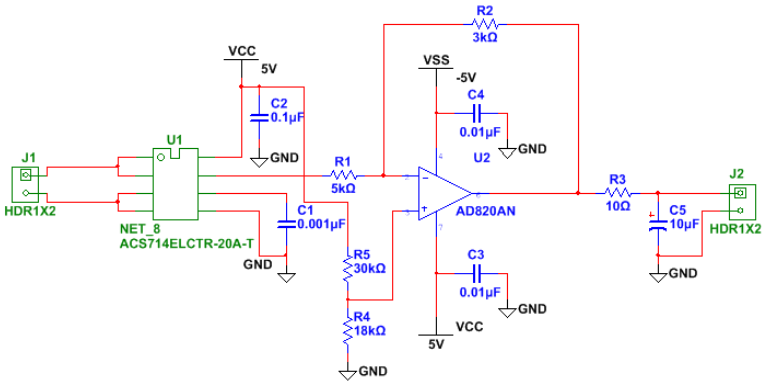
- Our single phase active filter performed satisfactorily.
- Switching noise from the active filter may be eliminated via a passive filter.
- A more fine tuned inductor would improve performance and reduce switching noise.

Schematics

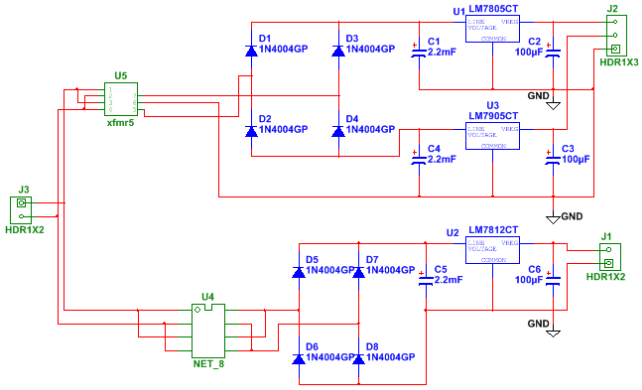
H-Bridge



Current Sensor



Power Supply



Future Recommendations

- Capacitor instead of power supply
- 3 phase
- High power
- Additional passive filter to eliminate switching noise

Acknowledgement

- Professor Alexander Emanuel
- Three-C Electrical Inc.
- Princeton Municipal Power and Light
- Professor Stephen Bitar