UNIVERSITÉ Concordia UNIVERSITY

JOURNÉE-DE-LA-RECHERCHE-DU-FRQNT

École de technologie supérieure (Montréal)

10 AVRIL 2017

Current Research at Concordia in Electric Vehicles and Renewable Energy

Dr. Pragasen Pillay

Ph.D., P.Eng., C.Eng., FIEEE, FIET
Professor
NSERC/Hydro-Québec Senior Industrial Research Chair
Department of Electrical and Computer Engineering
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Group Members

Dr. Pragasen Pillay
Ph.D., P.Eng., C.Eng., FIEEE, FIET
Professor
NSERC/Hydro-Québec Senior Industrial Research Chair
Electric Machines, Drive Systems, Renewable Energy, Energy Storage, Energy Efficiency and Conservation

Mr. Joseph Woods
M.A.Sc.
Technician
Electrical Machines and Power Electronics

Dr. Luiz A. C. Lopes
Ph.D., ing., SMIEEE
Professor
Distributed Power Systems, Renewable Energy Sources, Microgrids, Islanding Detection Schemes, and Control of Power Electronic Converters

Dr. Maher M. Al-Badri
Ph.D., P.Eng., SMIEEE
Research Associate
Electrical Machine Efficiency, Energy Efficiency and Conservation

Dr. Akshay Kumar Rathore
Ph.D., SMIEEE
Associate Professor
Soft-Switching Techniques for High Frequency Link Power Converters, Resonant Converters, Analysis, Utility Interactive Inverters for Renewable Energy Applications, High Power Industrial AC Drives and Multilevel Inverters

NSERC CRSNG Hydro Québec Université Concordia University
FACULTY OF ENGINEERING AND COMPUTER SCIENCE

Training of Highly Qualified Personnel

April 2011-April 2017

	Currently		Over the past six years (excluding the current year)		Total
	Supervised	Co-Supervised	Supervised	Co-Supervised	
Undergraduate	0	3	4	0	7
Master's	4	0	5	2	11
Doctoral	10	1	7	6	24
Postdoctoral	1	0	8	0	9
Research Associate	1	0	2	0	3
TOTAL	16	4	26	8	54

FACULTY OF ENGINEERING AND COMPUTER SCIENCE

Research Areas of the PEER Group

- Electrical Machines and Power Electronics
  - Advanced Models for Core Losses
  - Electrical Machine Design
  - Adjustable Speed Drives
  - Digital Control of Advanced Motor Drives
  - Advanced Propulsion Applications
  - Control of Power Electronic Converters
- Renewable Energy and Energy Harvesting
  - Photovoltaic Systems (PV)
  - Waste to Energy
  - Vibration Energy Harvesting
  - Emergency Power
  - Wind Energy
  - Osmotic Power
  - Organic Fuel Cells
  - Hydro-Kinetic Power
  - Integration of Renewable Energy Sources
- Mini and Microgrids
  - Control and Communication of Mini-Grids
  - Rural Electrification
  - Distributed Power Systems
- Transportation Electrification
  - Electric and Plug-in Hybrid Electric Vehicles
  - Railway Transit Electrification
  - Traction Motor Design and Automotive Electrified Powertrain
  - Automotive Power Electronics and Motor Drives
  - Battery and Ultra-Capacitor Storage Systems
  - More Electric Aircrafts
  - Fuel Cell Vehicles

Sponsors and Collaborators

- Industry
  - Hydro-Québec: Institut de recherche d'Hydro-Québec (IREQ)
    - Dr. Jérôme Gosset
    - Dr. Gaétan Lantagne
    - Dr. Innocent Kamwa
    - Mr. Pierre Angers
    - Dr. Claude Laflamme
    - Dr. Michel Dostie
    - Dr. Jacques Brochu
    - Dr. Arezki Merkhouf
  - OPAL-RT TECHNOLOGIES
  - TM4 Inc.
  - Eskom
  - Infolytica Corporation
  - CEATI International Inc.
  - Motor and Machine Association, USA
  - Bombardier Aerospace
  - ALCOA
- Government
  - NRCan: Natural Resources Canada
  - CRSNG/NSERC: Natural Sciences and Engineering Research Council of Canada
  - FRQNT: Fonds de recherche du Québec – Nature et technologies
  - Transport Canada
  - Canadian Space Agency
  - InnovÉÉ
  - NRF: National Research Foundation, South Africa
  - Mitacs
- Non-Governmental Organization
  - Équiterre
- Academic Institutions
  - ÉTS
  - McGill University
  - University of Ontario-Institute of Technology
  - University of Cape Town

FACULTY OF ENGINEERING AND COMPUTER SCIENCE

HR Developments

Shortlist of Alumni

- **Dr. Ayman Al-Quraan**, Assistant Professor, Yarmook University, Jordan
- **Dr. John Wanjiku**, Infolytica Corporation, Canada
- **Mr. Hesam Akbarian**, accepted to PhD program in the USA.
- **Dr. Jonathan Maisonneuve**, Assistant Professor, Oakland University, USA.
- **Dr. Maher Al-Badri**, Research Associate and part time Professor, Concordia University, Canada.
- **Dr. Abhijit Choudhury**, Researcher, Experimental Power Grid Centre, Institute of Chemical and Engineering Sciences, Singapore.
- **Mr. Maninder Singh**, OPAL-RT TECHNOLOGIES, Canada.
- **Dr. Lesedi Masisi,** CSIR, South Africa.
- **Dr. Nathan Curry**, Director of Business Development for Isolated Habitats, Terragon, Canada.
- **Dr. Seyedmorteza Taghavi**, Consultant Engineer, Iran.
- **Dr. Maged Ibrahim**, Assistant Professor, Pharos University, Egypt.
- **Ms. Nazak Soleimanpour**, OPAL-RT TECHNOLOGIES, Canada.
- **Dr. Florence Berthold**, Famic Technologies, Canada.
- **Mr. Arvind Vyas Ramanan**, MDA Corporation, Canada.
- **Mr. Sean Smithson**, MDA Corp., Canada.
- **Mr. Kang Chang**, Infolytica Corp., Canada.
- **Dr. Olivare Dizune Mipoung**, Assistant Professor, Oklahoma State University, USA.
- **Ms. Lekha Sejpal**, ABB, Canada.
- **Dr. Rachel Namuli**, Consultant Engineer, Uganda.
- **Dr. Natheer Alatawneh**, PDF, McGill University, Canada.
- **Dr. Arbi Gharakhani Siraki**, Hyper-loop, USA.
- **Dr. Maged Barsom**, Rockwell Automation, Canada.
- **Mr. Mohammad Sharafat**, SES Engineering, Canada.
- **Mr. Moustafa Dalal Bachi**, Enbridge Pipelines, Canada.
- **Mr. Abdul Adud Shikder**, Private Business, Canada.
- **Dr. Reinaldo Tonkoski**, Assistant Professor, South Dakota State University, USA.
- **Dr. Youcef Berrouche**, Consultant Engineer, Canada.
- **Dr. Zahra Amjadi**, Assistant Professor, Texas Southern University, USA.
- **Mr. Peng Zang**, Air Canada, Canada.
- **Mr. Giampaolo Carli**, General Electric Lighting Solutions, Canada.
- **Mr. Pablo Cassani**, INNOVOX, Canada.
- **Mr. Xin Lee**, Bombardier Transportation, Canada.
- **Ms. Di Wu**, Bombardier Transportation, Canada.

Comité consultatif

Comité scientifique

Dr. Pragasen Pillay
Professeur et titulaire de la chaire de recherche industrielle CRSNG/Hydro-Québec

Mr. Joseph Woods
Technicien

Dr. Maher Al-Badri
Associé de recherche
Ph.D., May 2012-July2015

Machines électriques et entraînements

1. **Dr. Maged Ibrahim**
   P.D.F., July 2016-Aug. 2016
   Ph.D., Sep. 2011-Dec. 2014
2. **Dr. R. Sudharshan Kaarthik**
   P.D.F., Oct. 2015-March 2017
3. **Dr. John Wanjiku**
   P.D.F., Sep. 2016-Dec. 2016
4. **Dr. John Wanjiku**
   Ph.D., Jan. 2012-Sep. 2016
5. **Ms. Jemimah Akiror**
   Ph.D., May 2013-Date
6. **Mr. Kang Chang**
   Ph.D., Jan. 2014-Date
7. **Mr. Amirmasoud Takbash**
   Ph.D., Sep. 2014-Date
8. **Mr. Akrem Aljehaimi**
   Ph.D., Jan. 2015-Date
9. **Ms. Seyede Sara Maroufian**
   Ph.D., Jan. 2015-Date
10. **Mr. Chirag Desai**
    Ph.D., Sep. 2015-Date
11. **Mr. Mahmud Ghasemi Bijan**
    Ph.D., Jan. 2016-Date
12. **Mr. Rajendra Thike**
    Ph.D. Jan. 2017-Date
13. **Mr. Rajendra Thike**
    M.Sc., Jan. 2015-Nov. 2016
14. **Mr. Mohamed Omer**
    M.Sc., Sep. 2016-Date

Énergies renouvelables

Intégration de l'énergie renouvelable

15. **Mr. Mohammad Masadeh**
    Ph.D., Sep. 2014-Date
16. **Mr. Amitkumar Kortagere**
    Ph.D. Sep. 2016-Date
17. **Mr. Andrew Jensson**
    M.Sc., Sep. 2015-Date
18. **Mr. Tamanwè Payarou**
    M.Sc., Sep. 2016-Date

Énergie hydrolienne

19. **Mr. Mohammadhossein Ashourianjozdani**
    Ph.D., Sep. 2014-Date

FACULTY OF ENGINEERING AND COMPUTER SCIENCE

Students Completed (2009-2017)

No.	Name	Degree	End Date	Title of Project
1.	Dr. Ayman Al-Quraan	Ph.D.	Nov. 2016	Wind Energy in Urban Area
2.	Dr. John Wanjiku	Ph.D.	Nov. 2016	High Flux Density Rotational Core Loss Measurements
3.	Dr. Jonathan Maisonneuve	Ph.D.	Aug. 2015	Osmotic Power for Remote Communities in Quebec
4.	Mr. Hesam Akberain	M.A.Sc	Aug. 2015	Design of a Power Electronics Based Diesel Engine Generator Emulator for Study of Microgrid Related Applications
5.	Dr. Maher Al-Badri	Ph.D.	Jul. 2015	Algorithms for Induction Motor Efficiency Determination
6.	Dr. Seyedmorteza Taghavi	Ph.D.	Mar. 2015	Design of Synchronous Reluctance Machines for Automotive Applications
7.	Dr. Lesedi Masisi	Ph.D.	Mar. 2015	Design and Development of Novel Electric Drives for Synchronous Reluctance and PM Synchronous Machines
8.	Dr. Abhijit Choudhury	Ph.D.	Mar. 2015	Three-Level Neutral Point Clamped (NPC) Traction Inverter Drive for Electric Vehicles
9.	Dr. Nathan Curry	Ph.D.	Mar. 2015	Anaerobic Digestion CHP Solutions for the Urban and Rural Environments
10.	Dr. Maged Ibrahim	Ph.D.	Nov. 2014	Application of Magnetic Hysteresis Modeling to the Design and Analysis of Electrical Machines
11.	Dr. O. Dzune Mipoung	Ph.D.	Oct. 2012	Enhancement of Frequency Support Capabilities of Type 1 and Type 2 Wind Turbines
12.	Dr. Rachel Namuli	Ph.D.	Sep. 2012	Optimization of Rural Biomass Waste to Energy Systems
13.	Dr. Natheer Alatawneh	Ph.D.	Sep. 2012	Design of a Test Fixture for Rotational Core Losses in Electrical Machine Laminations
14.	Ms. Jemimah Akiror	M.A.Sc	Sep. 2012	“Model for Core Loss Prediction at High Frequency and High Flux Density
15.	Dr. Arbi G. Siraki	Ph.D.	Aug. 2012	Efficiency Estimation of Induction Machines with Limited Measurements
16.	Mr. Maged Ibrahim	M.A.Sc	Sep. 2011	Modeling of Core Losses in Electrical Machines Laminations Exposed to High Frequency and Non- Sinusoidal Flux
17.	Mr. Nathan Curry	M.A.Sc	Aug. 2010	Modeling and Design of Urban Biomass Waste to Energy

Current Students

No.	Name	Degree	Start Date	Title of Project
1.	Mr. Amirmasoud Takbash	Ph.D.	Sep. 2014	Analytical Modeling and Torque Ripple Reduction of Variable Flux Machine
2.	Mr. Akrem Aljehaimi	Ph.D.	Jan. 2015	Rotor Flux Linkage Estimation for Variable Flux Machine
3.	Ms. Seyede Sara Maroufian	Ph.D.	Jan. 2015	Generator Application of Synchronous Reluctance Machines (SynRM)
4.	Mr. Chirag Desai	Ph.D.	Sep. 2015	Torque and Core Loss Characterization of a Variable-Flux Permanent-Magnet Machine
5.	Mr. Mohammad Masadeh	Ph.D.	Sep. 2014	A Three-Phase Power Electronic Converter-Based Induction Machine Emulator and its Application in Renewable Energy Systems
6.	Mr. Rajendra Thike	M.A.Sc	Jan. 2015	Efficiency Improvement of Variable Flux Machine drive
7.	Ms. Samhita Dey	M.A.Sc	Jan. 2015	Micro Hydroelectric Power System Based on Osmotic Energy
8.	Mr. Mohammadhossein Ashourianjozdani	Ph.D.	Sept. 2014	Hybrid Hydro-kinetic-diesel Energy Conversion Systems
9.	Mr. Andrew Jensson	M.A.Sc	Sep. 2015	Integration of Renewable energy sources
10.	Mr. Mahmud Ghasemi Bijan	Ph.D.	Jan. 2016	Algorithms for Induction Motor Efficiency Estimation
11.	Mr. Amitkumar Kortagere	Ph.D.	Sep. 2016	Power-Hardware-in-the-loop based Emulator for Rapid Testing and Prototyping of Electric Drives
12.	Mr. Tamanwè Payarou	M.A.Sc	Sep. 2016	A Single Phase 1 kW Low Price Inverter Design
13.	Mr. Mohamed Omer	M.A.Sc	Sep. 2016	Thermal Derating of Induction Machines for Unbalanced Distorted Three Phase Supplies

Postdoctoral Fellow / Research Associate Current and Completed

No.	Name	Position	Start Date	End Date	Title of Project
1.	Dr. Maher Al-Badri	R.A.	Sep. 2015	Date	Novel Algorithms for Induction Motor Efficiency Estimation
2.	Dr. R. Sudharshan Kaarthik	P.D.F.	Oct. 2015	Feb. 2017	Emulators for Electric Vehicle and Renewable Energy Applications
3.	Dr. John Wanjiku	P.D.F.	Nov. 2016	Dec. 2016	High Flux Density Rotational Core Loss Measurements
4.	Dr. Jonathan Maisonneuve	P.D.F.	Aug. 2015	April 2016	Osmotic Power for Remote Communities in Quebec
5.	Dr. Seyedmorteza Taghavi	P.D.F.	Mar. 2015	April 2016	Design of Synchronous Reluctance Machines for Automotive Applications
6.	Dr. Abhijit Choudhury	P.D.F.	Mar. 2015	Dec. 2015	Three-Level Neutral Point Clamped (NPC) Traction Inverter Drive for Electric Vehicles
7.	Dr. Maged Ibrahim	P.D.F.	July 2016	Aug. 2016	Application of Magnetic Hysteresis Modeling to the Design and Analysis of Electrical Machines
8.	Dr. Natheer Alatawneh	P.D.F.	Nov. 2012	Nov. 2013	Design of a Test Fixture for Rotational Core Losses in Electrical Machine Laminations

Funding, Shortlist

Title of Proposal	Funding Source Program Name	TOTAL	Amount [Year]	Share of Total	Supported Period	
					From	To
Emulation and Design of Electric and Hybrid Electric Vehicle Motor Drive Systems (PI)	**NSERC-InnovÉÉ** Collaborative Research and Development and InnovÉÉ Provincial Grant	**$ 681,900**	**$ 227,300**	**$ 389,657**	**2016**	**2019**
Design and Performance of Special Electrical Machines (PI)	**NSERC/Hydro-Québec** NSERC/Hydro-Québec Industrial Chair	**$ 2,000,000**	**$ 400,000**	**$ 2,000,000**	**2014**	**2019**
Core Losses and Machine Design for Electric/ Hybrid Vehicles (PI)	**NSERC** Discovery	**$ 205,000**	**$ 41,000**	**$ 205,000**	**2013**	**2018**
Research and Training via an Institute in Water, Energy and Sustainability (Co-PI)	**NSERC** CREATE	**$ 149,500**	**$ 29,900**	**$ 149,500**	**2012**	**2017**
Lab on Chip (LOC) Based Micro Photosynthetic Cell (Co-PI)	**FQRNT**	**$ 123,000**	**$ 41,000**	**$ 18,450**	**2013**	**2016**
Test Equipment for Renewable Energy, Microgrids and Electric Vehicles (PI)	**Concordia University** Capital Research Innovation Fund	**$ 131,750**	**$ 65,875**	**$ 65,875**	**2015**	**2016**
Equipment for Upgrading the Research Infrastructure on Renewable Energy (Co-PI)	**Concordia, Vice-President, Research&Graduate** Facility Optimization Program	**$ 40,000**	**$ 40,000**	**$ 20,000**	**2015**	**2015**
Innovations in Motor Drive Technologies to Reduce or Eliminate the Need for Permanent Magnets in Electric/Hybrid Electric Vehicles (PI)	**NCE AUTO21/TM4** AUTO21	**$ 92,000**	**$ 92,000**	**$ 23,000**	**2014**	**2015**
Feasibility Of A Pressure Retarded Osmosis Process for Québec Electricity Generation (Co-PI)	**Mitacs and Hydro-Québec** Accelerate (Cluster)	**$ 40,000**	**$ 20,000**	**$ 20,000**	**2013**	**2014**
Innovations in Motor Drive Technologies to Reduce or Eliminate the Need for Permanent Magnets in Electric/Hybrid Electric Vehicles (PI)	**NCE AUTO21/TM4** AUTO21	**$ 216,000**	**$ 108,000**	**$ 64,000**	**2012**	**2014**
Energy efficiency in Electrical Machines for Small Scale Renewable Energy Production Systems	**NSERC/Hydro-Québec** NSERC/Hydro-Québec Industrial Chair	**$ 2,000,000**	**$ 400,000**	**$ 2,000,000**	**2009**	**2014**
			TOTAL SHARE	**$ 4,955,482**		

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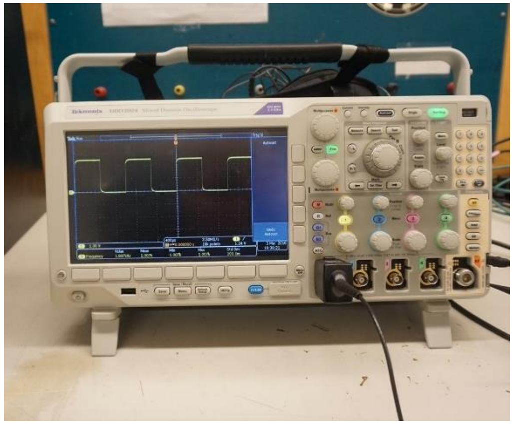
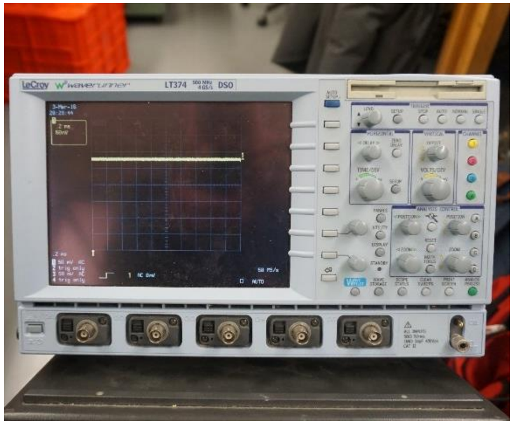
Laboratory Facilities

Digital Scope and Data Acquisition

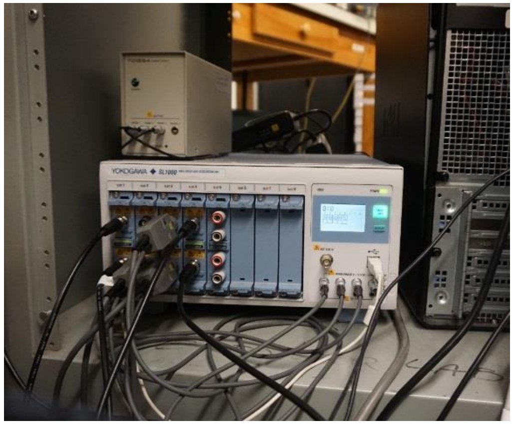
Mixed Domain Oscilloscope MDO 3024 (Tektronix)



Digital Oscilloscope 500 MHz, 4 GS/sec LT 374 (LeCroy)



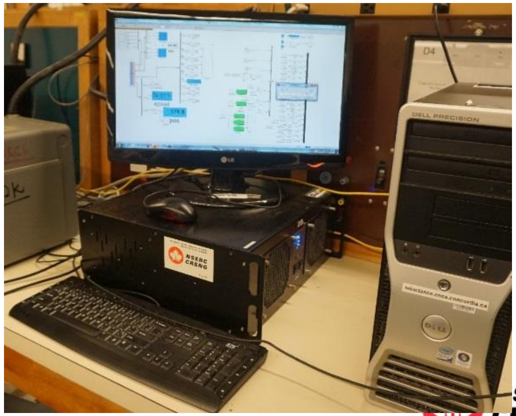
High Speed Data Acquisition SL1000 (Yokogawa)



Rapid Prototyping and Hardware-in-Loop

Rapid System Development for Power Conversion (triphase)

Real-Time Controller OP4112C (OPAL-RT)

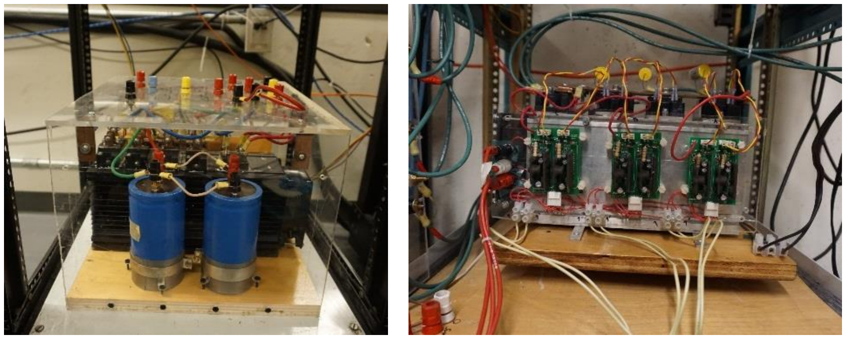


Real-Time Controller DS 1103 (dSPACE)

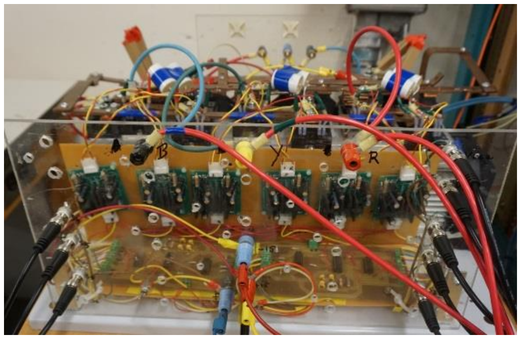
Laboratory Facilities

Power Converters

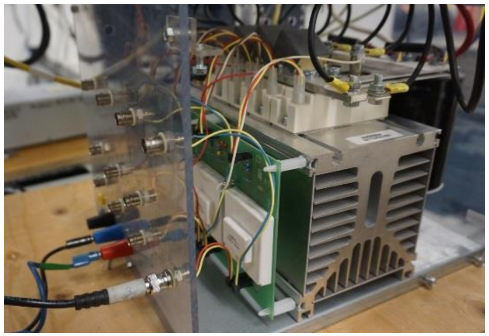
Two-Level Inverters (Custom Built)



Three-Level Inverter (Custom Built)



Three-Phase Rectifier/Inverter (Semikron)



Motor Drives

Four-Quadrant AC Drive 25 HP – ACS800 (ABB)

Four-Quadrant DC Drive 18 HP–DCS800 (ABB)

Programmable AC Power Source (California Instruments)

Laboratory Facilities

Core Loss Measurement Test Benches

Pulsating Core Loss Measurement (Donart System)

Rotational Core Loss Measurement (Custom Built)

Steel Samples

Laboratory Facilities

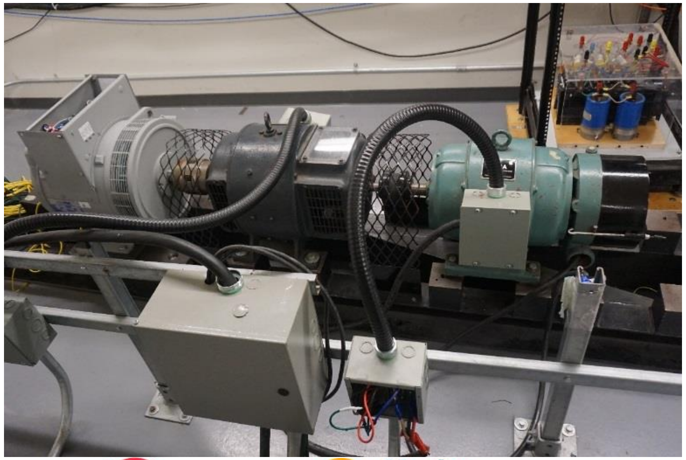
Machine Dynamometer Test Benches

13 kW Dynamometer Test Bench (Hydro-Québec)

17.5 kW Dynamometer Test Bench

5 kW Dynamometer Test Bench

3 kW Dynamometer Test Bench



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Laboratory Facilities

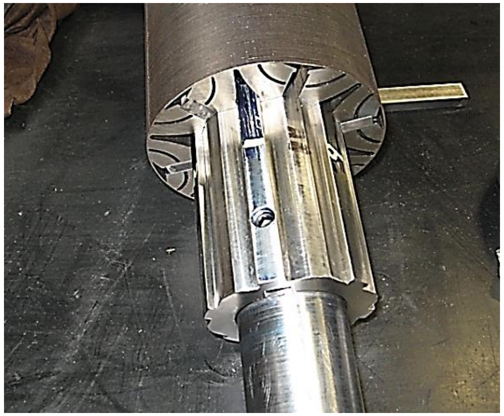
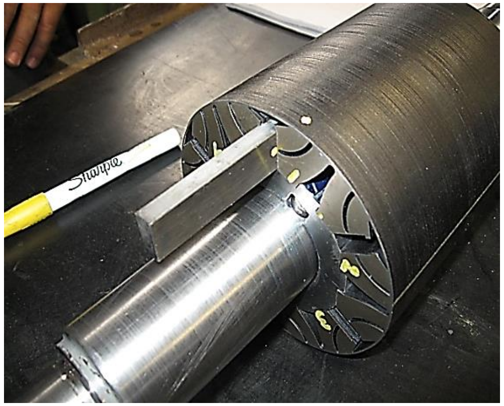
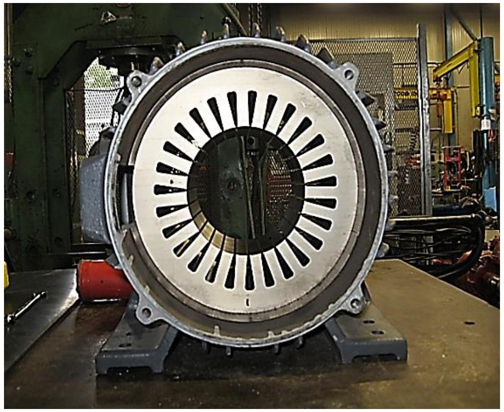
Machine Dynamometer Test Benches

112 kW Dynamometer Test Bench (Hydro-Québec)

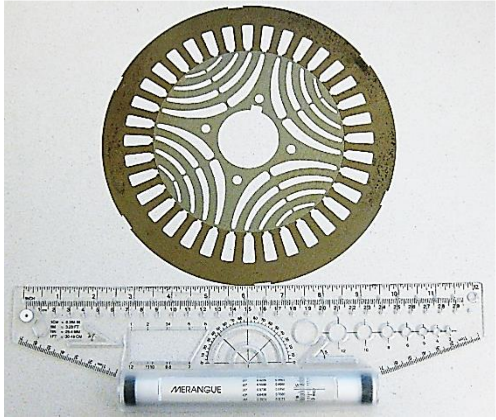
Test Bench Electric Wiring and Protection

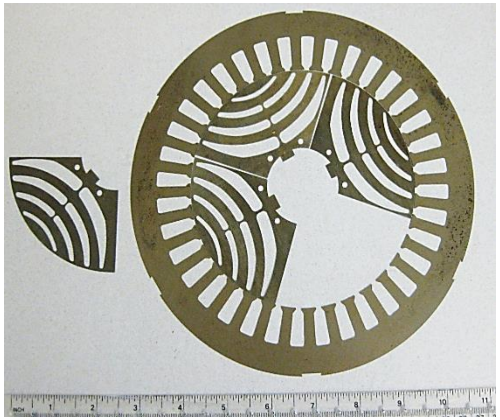
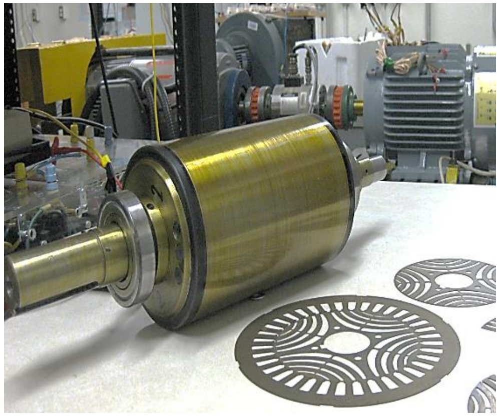
Machine Prototyping

Variable Flux Permanent Magnet (AlNiCo) Machine

Synchronous Reluctance Machine



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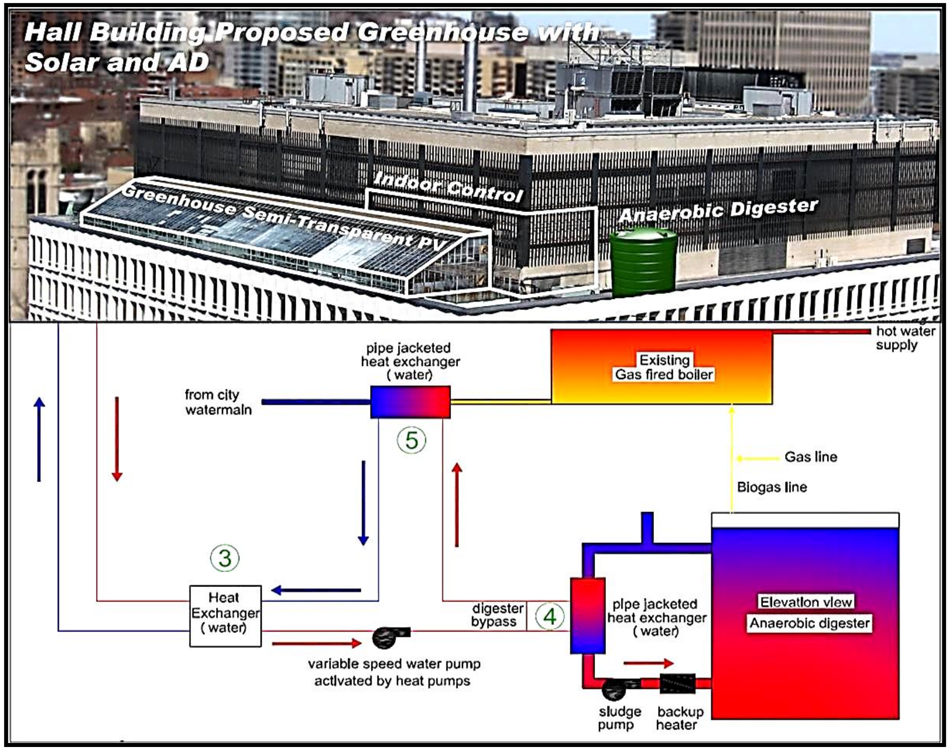
Research Facilities Under Development

Urban Biomass System for Concordia Hall Building



Solar House (Loyola Campus) – Hybrid Electric Vehicle (HEV), Solar Charging Infrastructure and Microgrid Environment

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Faculty of Engineering and Computer Science

Industrial Research Chair in Design and Performance of Special Electrical Machines (<150 kW) Research Program Summary

➢ Energy Efficiency

- Using state of the art software for the design of test fixtures to allow measurement of rotational core losses with higher flux density and harmonics.
- Measurement of induction machine losses for a variety of machines when fed from VSDs at Concordia and in collaboration with the Hydro-Québec Laboratories in Shawinigan for the higher power machines.
- Understanding the impact of temperature on motor losses and developing compensating methods to allow more rapid motor efficiency testing.

➢ Electric Machine and Drive Design

- Examining design topologies of the synchronous reluctance machine.
- Developing associated drive topologies for specific machine configurations chosen.

Industrial Research Chair in Design and Performance of Special Electrical Machines (<150 kW) Research Program Summary

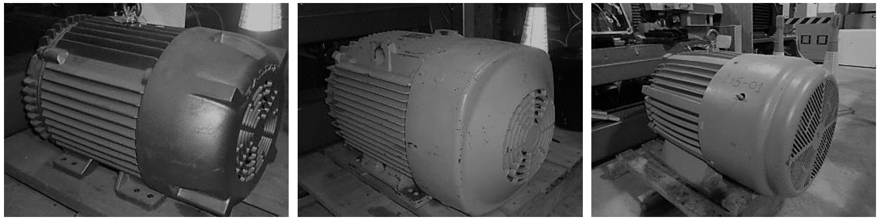
- **Novel Technologies for Exploring Renewable Energy Sources**
  - **Hydro-Kinetic: develop designs and models to allow the prediction of power and energy from hydro-kinetic systems for remote communities.**
  - **Machines for Renewable Energy Production Systems and Electrified Powertrains.**
- **Generators for Renewable Energy Production Systems**
  - **Develop the application of synchronous reluctance and PM machines for selected renewable energy applications.**
  - **Examine the possibility of designing machines using low cost magnets or no magnets.**
- **Integration of Different Renewable Energy Resources**
  - **The particular source technologies will include hydro-kinetic generator operating in parallel with diesel or wind systems for remote communities.**

Novel Algorithms for Induction Motor Efficiency Estimation

Maher Al-Badri

Background

- Environmental concerns as well as an increasing demand for energy are strong motives for further investment and research in demand side energy management techniques.
- In Canada and the United States, approximately 60% of the electrical power generated is utilized by electrical machines.
- Efficient operation of the motors can directly bring significant savings in energy consumption and indirectly reduce green house gas emissions as well as requirements for the installation of new power plants, transmission lines and distribution systems.
- Energy saving calculations by means of any tool and the relevant decisions, such as replacement of an existing motor, are strongly dependent on an accurate knowledge of the motor efficiency.
- Therefore, the evaluation of efficiency of installed motors in the field or rewound motors in the workshop is a necessity to detect the motors with poor efficiencies and to take the appropriate action.
- To do so, a credible methodology is required to make the efficiency estimation possible without performing costly dynamometer testing.



25, 60, and 100 hp induction motors tested in Hydro-Québec

Photos courtesy of Hydro-Québec

Objective

Development of a mathematical tool and a testing methodology to estimate the efficiency of repaired, rewound or any existing three-phase induction motor based on the uncoupled motor tests as well as the nameplate data which can be performed in most electric motor service centers in North America.

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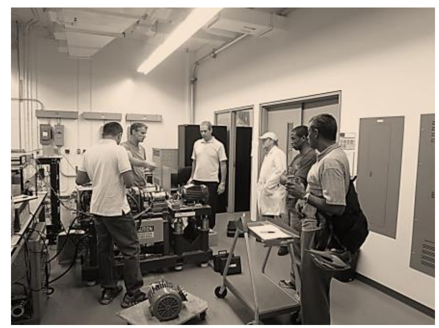
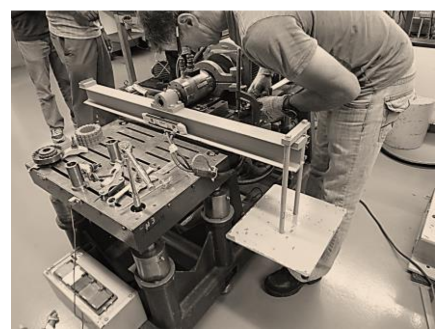
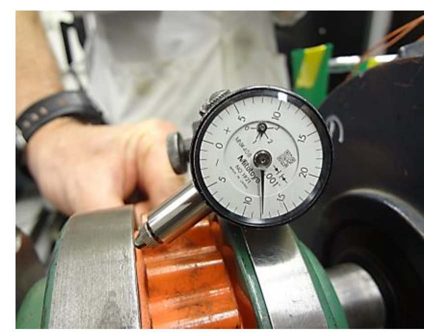
- This work presents 6 novel techniques for induction motor efficiency estimation.
- **Methods 1 & 2** are based on no-load tests.
- **Method 3** is an in-situ algorithm for induction motors operating with **balanced voltages**.
- **Method 4** is also an in-situ technique for induction motors operating with **unbalanced voltages**.
- **Method 5** is another in-situ technique for induction motors operating with **unbalanced distorted voltages**.
- **Method 6** proposes a new stray-load loss formula for small and medium sized induction motors.
- All those methods utilize large induction motor test databases provided by Hydro-Québec and BC hydro.







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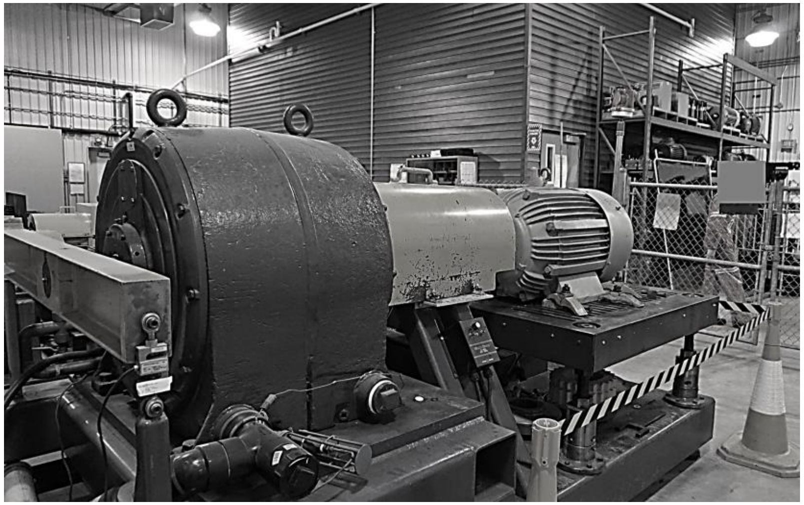
Methods 1 & 2

- **Method 1 requires one no-load test with rated voltage and rated frequency.**
- **The method utilizes Hydro-Québec/BC hydro data.**
- **It was validated by testing 196 induction motors in the range of 1-500 hp.**
- **Method 2 utilizes IEEE Method F1-Equivalent Circuit. It also utilizes Hydro-Québec/BC hydro data.**
- **It was validated by testing 8 small and medium induction motors.**
- **A software has been developed based on the two methods and it is approved as an industrial tool by several Canadian power companies including Hydro-Québec.**

Experimental setup for testing 7.5 hp induction machine in Concordia laboratory



150 hp induction machine test setup in Hydro-Québec
Photo courtesy of Hydro-Québec

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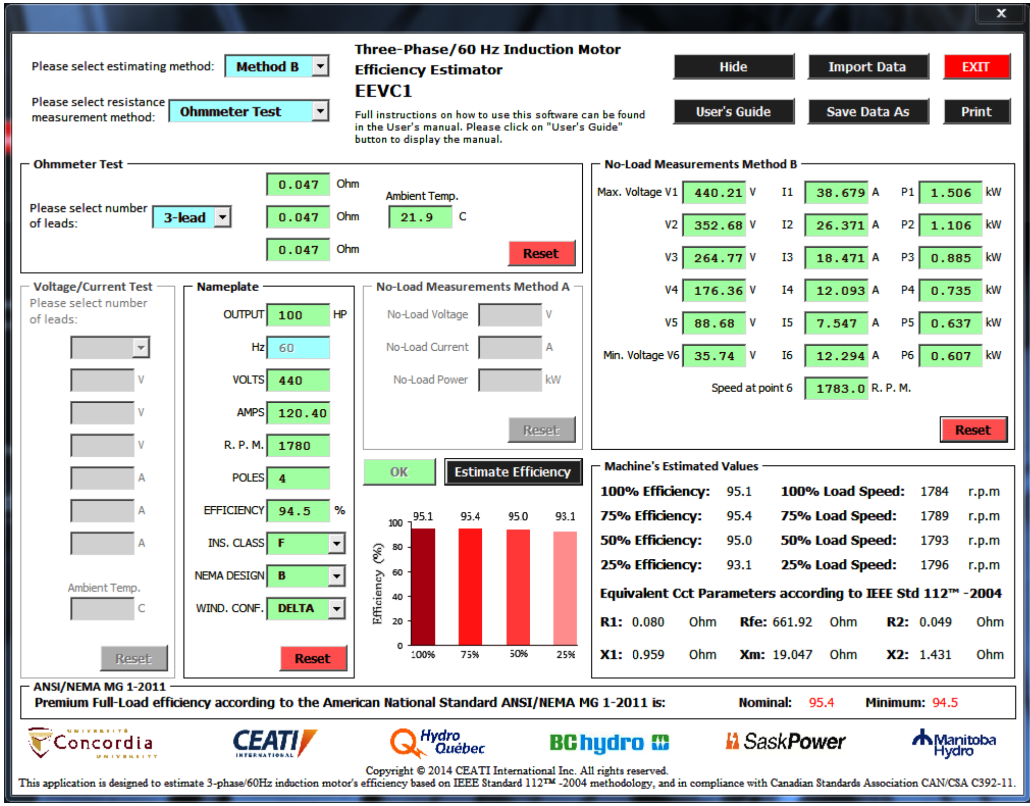
Methods 1 & 2

Method 2 Experimental Results

Motor Size (hp)		Load			
		100%	75%	50%	25%
3.0	Measured %η	80.4	79.1	75.6	63.9
	Estimated %η	80.2	79.7	76.5	65.4
	%Error	0.20	-0.60	-0.90	-1.50
7.5	Measured %η	90.5	91.2	90.8	86.9
	Estimated %η	90.1	91.1	91.0	87.3
	%Error	0.40	0.10	-0.20	-0.40
15	Measured %η	90.6	91.2	90.7	86.5
	Estimated %η	90.1	90.9	90.5	86.5
	%Error	0.50	0.30	0.20	0.00
25	Measured %η	92.0	92.8	92.8	90.3
	Estimated %η	92.7	93.4	92.8	89.3
	%Error	-0.70	-0.60	0.00	1.00
50	Measured %η	92.8	93.1	92.6	89.2
	Estimated %η	92.2	92.7	92.1	88.3
	%Error	0.60	0.40	0.50	0.90
60	Measured %η	94.8	94.9	93.9	91.0
	Estimated %η	94.3	94.7	94.4	92.8
	%Error	0.50	0.20	-0.50	-1.80
100	Measured %η	95.5	95.5	94.9	92.1
	Estimated %η	95.1	95.4	94.9	93.0
	%Error	0.40	0.10	0.00	-0.90
150	Measured %η	93.6	93.4	92.1	87.1
	Estimated %η	93.4	93.6	92.7	88.4
	%Error	0.20	-0.20	-0.60	-1.30

The Developed Software EEVC1.0



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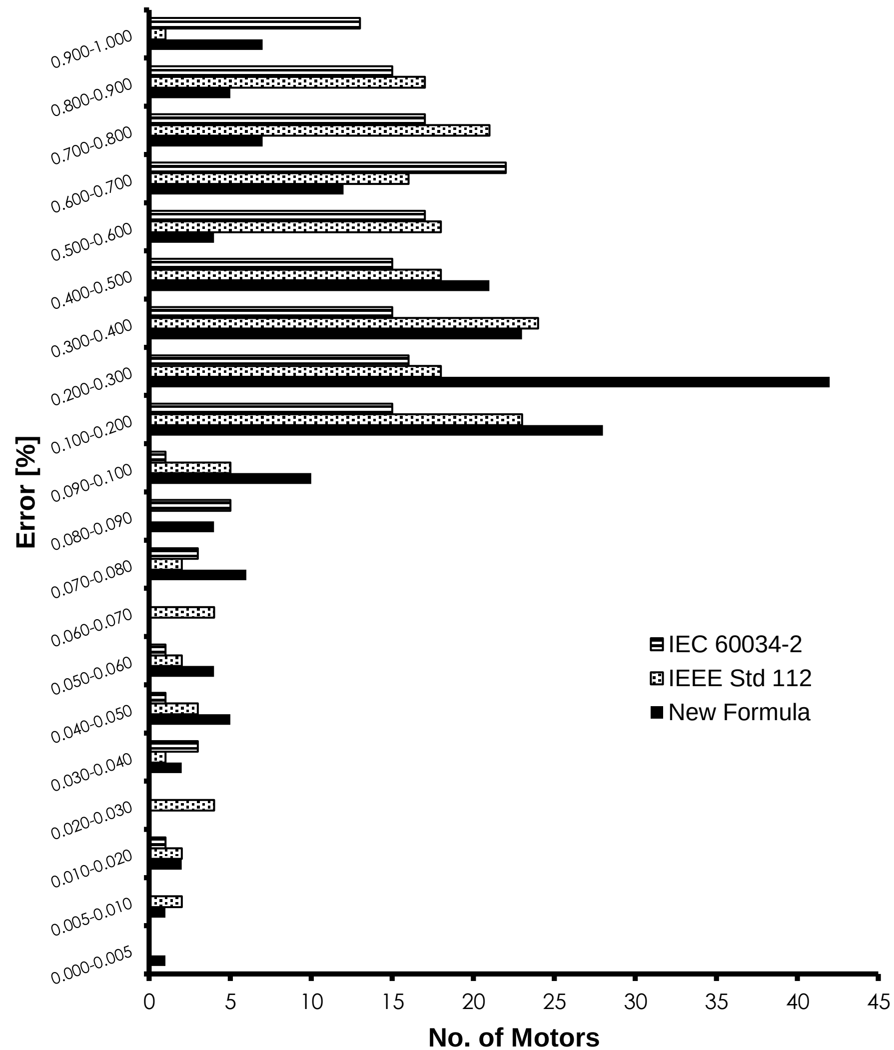
Method 6

- This method proposes a new stray-load loss formula for small and medium induction motors based on tests data of a 196, 60 Hz induction motors in the range of 1-500 hp.

- The proposed formula is validated by recalculating the efficiency of the same number of motors by using the proposed formula, as well as the IEEE Std. 112 and the IEC 60034-2-1 standards.

- The new formula demonstrates better accuracy. This formula shows the potential to replace the existing stray-load loss estimation formula for this horsepower range.



New formula accuracy evaluation

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Method 6

- The new formula estimated the stray-load loss of 94% of the total motors within the range of accuracy of 0.0-1.0%.
- IEEE Std 112 and IEC 60034-2-1 standards scored 93% and 82% within the same range of accuracy respectively.
- The proposed formula could estimate the majority of its 184 motors within the level of accuracy (0.09%-0.5%) while the majority of the 181 motors of the IEEE Std 112 is in the range of (0.1%-0.9%).
- A technical paper (TEC-00903-2015) is published in IEEE Transactions on Energy Conversion.

Accuracy Evaluation of the Proposed Formula, IEEE Std 112 and IEC 60034-2-1

Absolute Error [%]	Proposed Formula		IEEE Std 112		IEC 60034-2-1	
	No. of Motors	Percentage [%]	No. of Motors	Percentage [%]	No. of Motors	Percentage [%]
0.000-0.005	1	1	0	0	0	0
0.005-0.010	1	1	2	1	0	0
0.010-0.020	2	1	2	1	1	1
0.020-0.030	0	0	4	2	0	0
0.030-0.040	2	1	1	1	3	2
0.040-0.050	5	3	3	2	1	1
0.050-0.060	4	2	2	1	1	1
0.060-0.070	0	0	4	2	0	0
0.070-0.080	6	3	2	1	3	2
0.080-0.090	4	2	0	0	5	3
0.090-0.100	10	5	5	3	1	1
0.100-0.200	28	14	23	12	15	8
0.200-0.300	42	22	18	9	16	8
0.300-0.400	23	12	24	12	15	8
0.400-0.500	21	11	18	9	15	8
0.500-0.600	4	2	18	9	17	9
0.600-0.700	12	6	16	8	22	11
0.700-0.800	7	4	21	11	17	9
0.800-0.900	5	3	17	9	15	8
0.900-1.000	7	4	1	1	13	7
Total	**184**	**94**	**181**	**93**	**160**	**82**

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Induction Machine Parameter Estimation

Mahmud Ghasemi-Bijan

Background

- With increased energy costs in the last few decades, energy consumption and efficiency of the equipment is of great interest. Induction motors are the most widely used type of electric machines due to their simple and robust structure.
- In the two recent decades, non-invasive methods for IM efficiency estimation have been proposed. These methods use a set of input parameters such as stator voltage, stator current, input power (or input power factor) and operation speed at one or several operation points to estimate the efficiency.
- In the optimization-based techniques as a non-invasive method, the parameters of the equivalent circuit of an IM are estimated with the help of a search algorithm (such as GA). Based on estimated parameters, the losses of the IM can be estimated for each operating point, and thus, it is possible to estimate the efficiency of an IM at any desired operating condition.
- Since the GA is a search technique, it must be limited to exploring a reasonable region of variable space. The search region is smaller, is more likely to reach the correct answer.

Objective

A simple and straightforward solution for determining the range of variables are provided by using equations and NEMA design, and applying some assumptions. This method uses only nameplate data. .

Parameters Range

- **Rotor resistance (R_2)**
  The range of R_2 can be determined based on the no load current percentage. Maximum and minimum of no load current (I_0) have been determined based on the empirical results provided by Hydro-Quebec database and study of around 130 motors in the range of 1 to 500-hp with different number of poles.

$$P_{gap} = 3\frac{R_2}{s} I_2^2 \qquad\qquad I_2 = \sqrt{I_1^2 - I_0^2}$$

where s is slip, P_{gap} is determined by using output rated power and assumed values for stray load loss and friction and windage losses. I_1 is the rated current.

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Core loss resistance (R_{fe})

Recently study on 182 motors has shown that maximum core loss of an induction machine is 6% of input power at rated condition. This criteria can be helpful to determine the minimum value of R_{fe} in the range. For this purpose, by calculating input power at rated condition, the maximum P_{core} is calculated by considering as 6% of rated input power. Then $R_{fe,min}$ can be achieved by using following equation

$$R_{fe} = 3\frac{V_m^2}{P_{core}}$$

By using some assumption, V_m can be considered equal to rated voltage. For maximum value, 1% of input power can be considered as a minimum possible value of P_{core}.

Stator leakage reactance (X_1)

Reactance has two very significant effects on the size and performance of induction motors. One effect is the limitation in possible rating output power for a given speed and frame size, and the other effect is the determination of specific performance characteristics for a given design.

A minimum value of T_{max} for each motor can be determined by tables presented based on the NEMA design. Using these values and some assumptions and maximum torque equation of induction motor, maximum value of X_1 can be determined and minimum value of X_1 can be considered as half of the maximum value.

$$T_{\max} = \frac{3V_{th}^2}{(2\omega_s)\left[R_{th} + \sqrt{R_{th}^2 + (X_{th} + X_2)^2}\right]}$$

Magnetizing reactance (Xm)

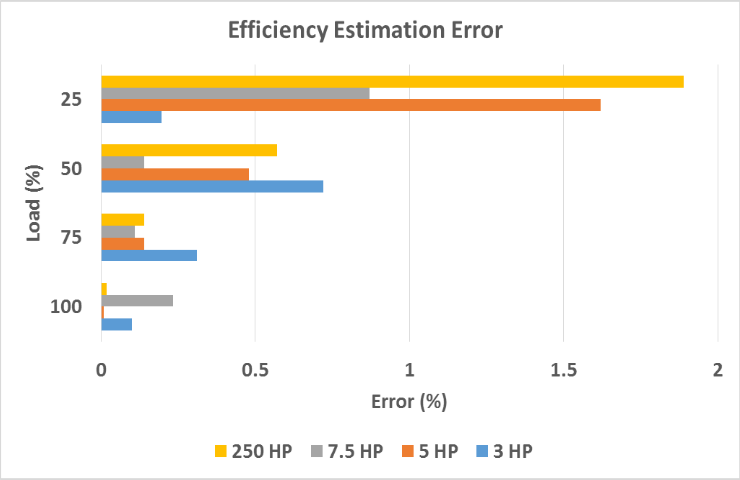
The magnetizing reactance has a significant effects on the no-load current and no-load power factor. By assuming $\cos(\varphi_0) = 0.5$ as a maximum possible no-load power factor, maximum value for X_m can be achieved by using maximum estimated value of R_{fe}.

$$X_{m,\max} = \frac{R_{fe}}{\sqrt{3}}$$

For a minimum value of X_m, the previous assumption about the no-load current can be useful.

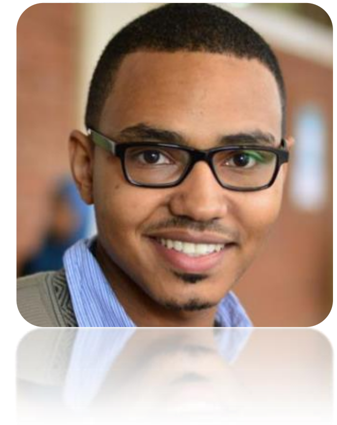
Results

The proposed method was applied to four different machines. Comparison of the results with experimental results showed the acceptable accuracy and effectiveness of the method for efficiency estimation and converging the GA.



Thermal Derating of Induction Machines for Unbalanced Distorted Three Phase Supplies

Mohamed Ismail Omer

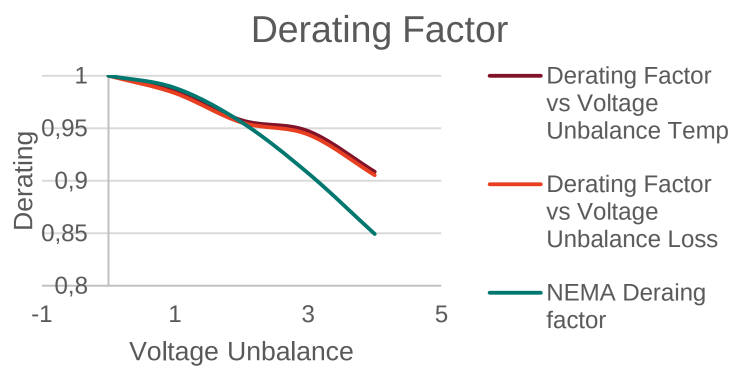


Background

- Ideally, the Grid is assumed to supply three phases that are balanced and perfectly sinusoidal, Due to many reasons this assumption is technically impossible.
- Induction machines are widely used in practice because of their robustness and practicality, approximately 60% of the generated electrical power in the US and Canada is consumed by electrical motors.
- Power quality issues such as voltage unbalance and voltage distortion affect electrical motors adversely. Therefore, the effects on electrical machines must be investigated.
- Accurate knowledge of the thermal modeling of induction machines is crucial for their safe operation.
- Therefore, identifying the power quality issues in the supply and the thermal behaviour of the machine is a major key in finding the suitable loading for the machine.

Objective

Finding the suitable derating factor for the machine, based on it's developed thermal model. The derating factor should account for the voltage unbalance and distortion at the motor's terminals. The scope could be extended to include over and under voltages.



Machine Derating Factor for voltage unbalance

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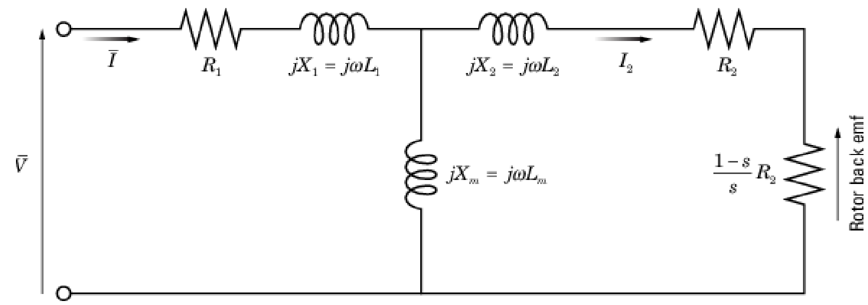
Electrical and Thermal Models

- The electrical behavior of induction machines is studied by means of the equivalent circuit of the induction machine extracted based on IEEE Std 112™-2004 -Equivalent Circuit.

- The Thermal model uses outputs from the electrical model to estimate the temperatures of the windings and the machine core.

- Accurate temperature estimation will facilitate finding the best loading point in the presence of the different power quality issues under consideration.



Per-phase equivalent circuit of a three phase induction motor

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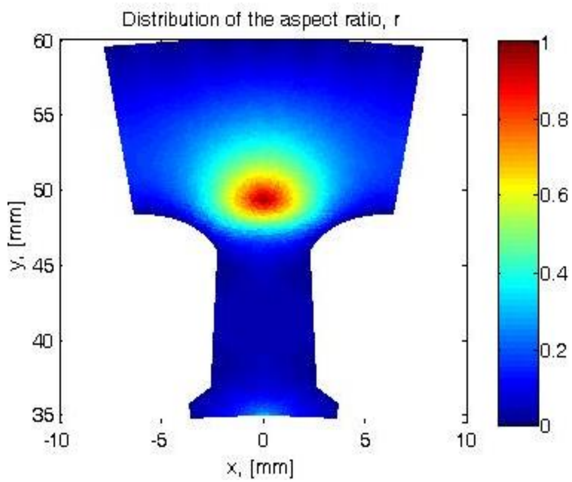
High Flux Density Rotational Core Loss Measurements

John Wanjiku

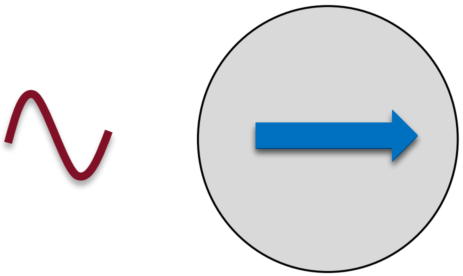
Motivation

1. **Inadequate sinusoidal pulsating core loss data**
   - Rotational magnetization zones – teeth roots
   - Rotational core loss > Pulsating core loss
   - Non-sinusoidal flux densities
2. **Hotspots analysis**
   - Uprating and upgrading of large MW machines
   - High power density machines
3. **Energy efficiency and standards**
   - Characterization of electrical steels
   - Efficient use of active materials
   - Design of high efficient class machines

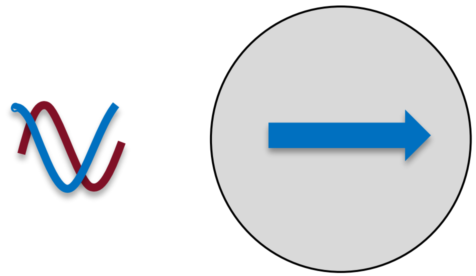


Aspect-ratio distribution in a stator tooth

Pulsating field
- Unidirectional
- Varying magnitude



Rotational field
- Varying direction
- Magnitude is fixed or varies



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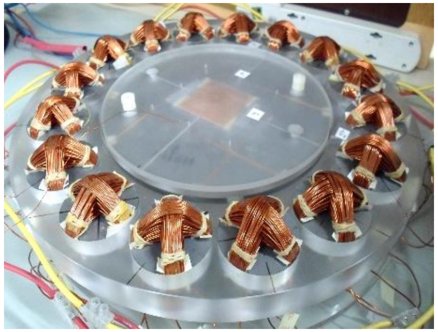
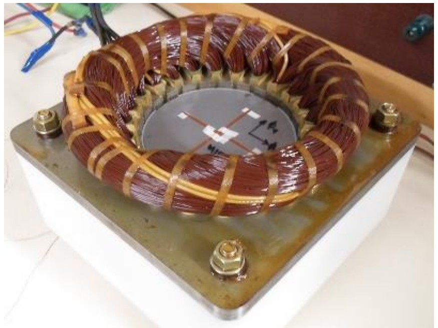
Test Benches

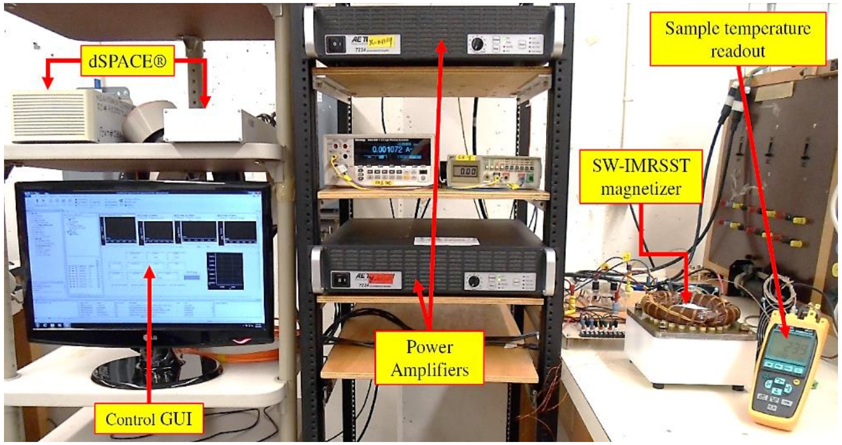
(a) Halbach tester
(~1.4 T @ 60 Hz)



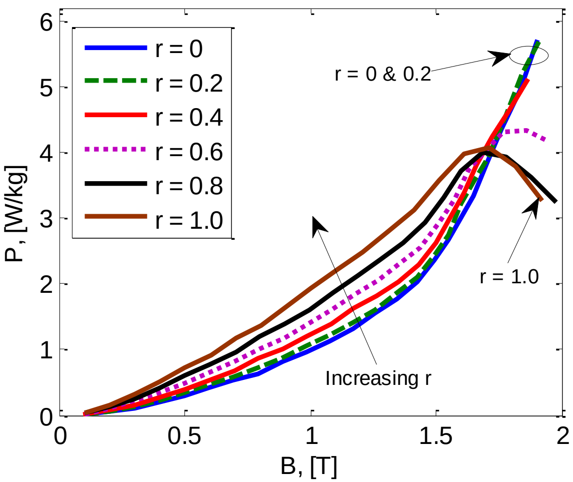
(b) Stator-based tester
(2 T @ 60 Hz)



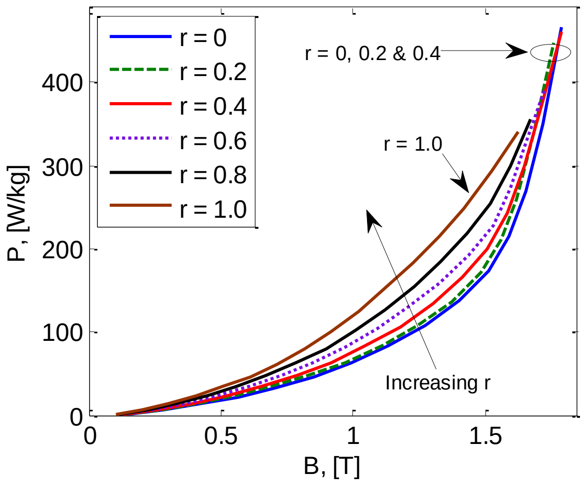
(c) Rotational core loss measurement test bench



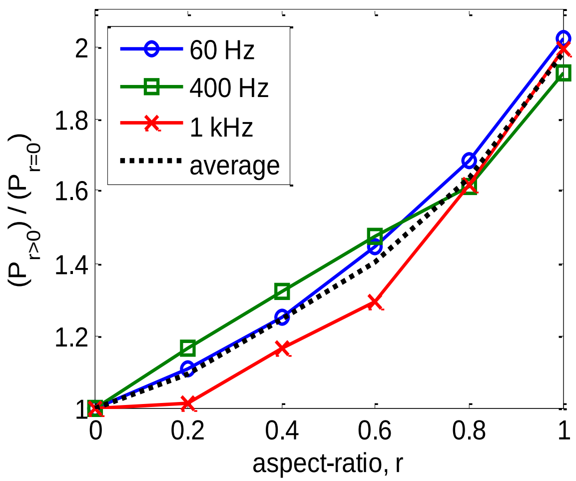
(d) 60 Hz, M19G29



(e) 1 kHz, M19G29



(f) $P_{rotational}$ / $P_{pulsating}$ M19G29



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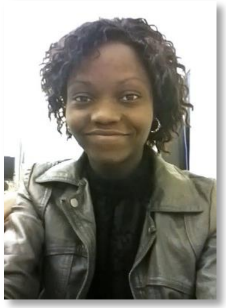
Computation of Rotational Core Losses in Hydro Generators



Jemimah Akiror

Motivation

- Demand for electricity is constantly increasing requiring uprating of existing generators
- This in turn necessitates knowledge of hotspots within the machines
- Core loss estimation and distribution under different operating conditions is key to hotspot prediction
- Accurate core loss models for hydro generators also aid in generator design, to avoid penalties charged to the designers for every extra kW loss from the guaranteed specifications

Objectives

- Measure rotational core losses in lamination steel based on the obtained FEA flux
- Develop core loss models to calculate the total core losses in the generator
- Use the results as an input to a thermal model to determine hotspots in the machine

Methodology

- Determine the distribution of rotating flux in the machine
- Study the effect of design variations and different operating conditions on rotational flux and core loss distribution
- Measure rotational losses in different magnetic materials
- Compute total core losses in the machine including rotational losses

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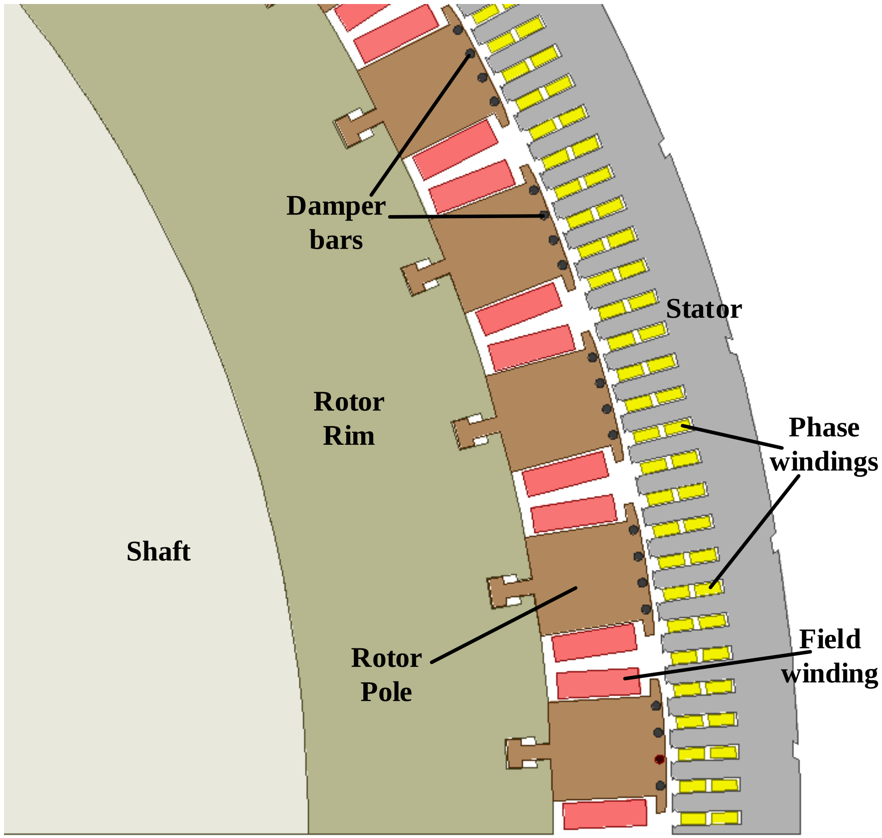
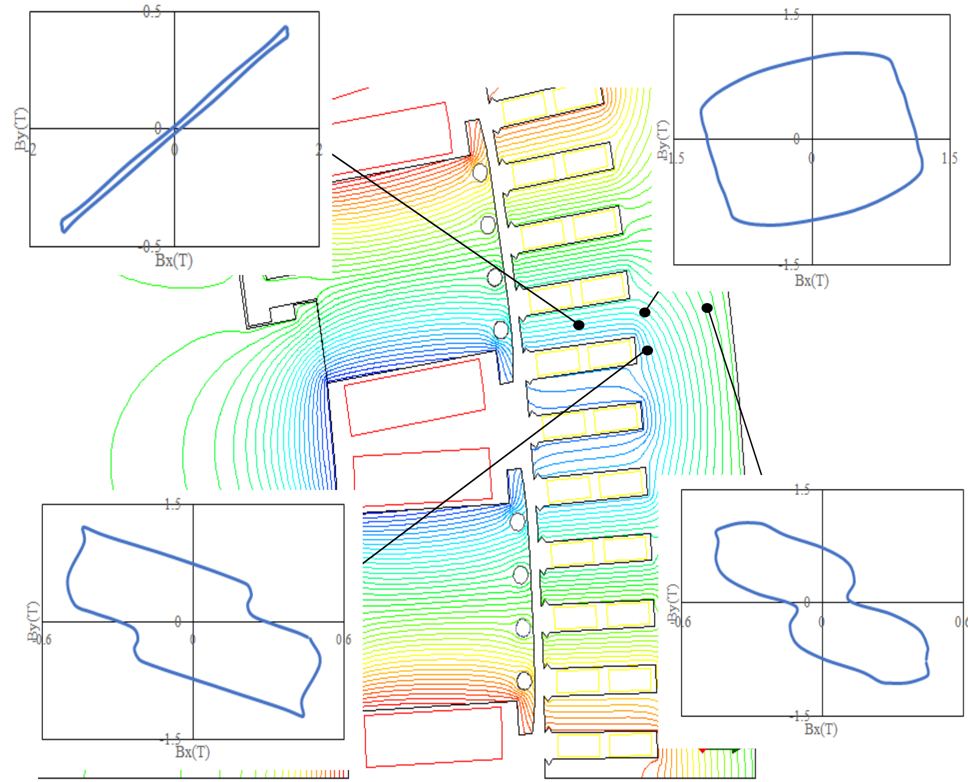
Hydro generator modelling





Rotational flux density distribution

- **Rotational flux distribution varies under different operating conditions, and with different design modifications**
- **Losses associated with rotating flux need to be accounted for in core loss prediction of hydro generators**

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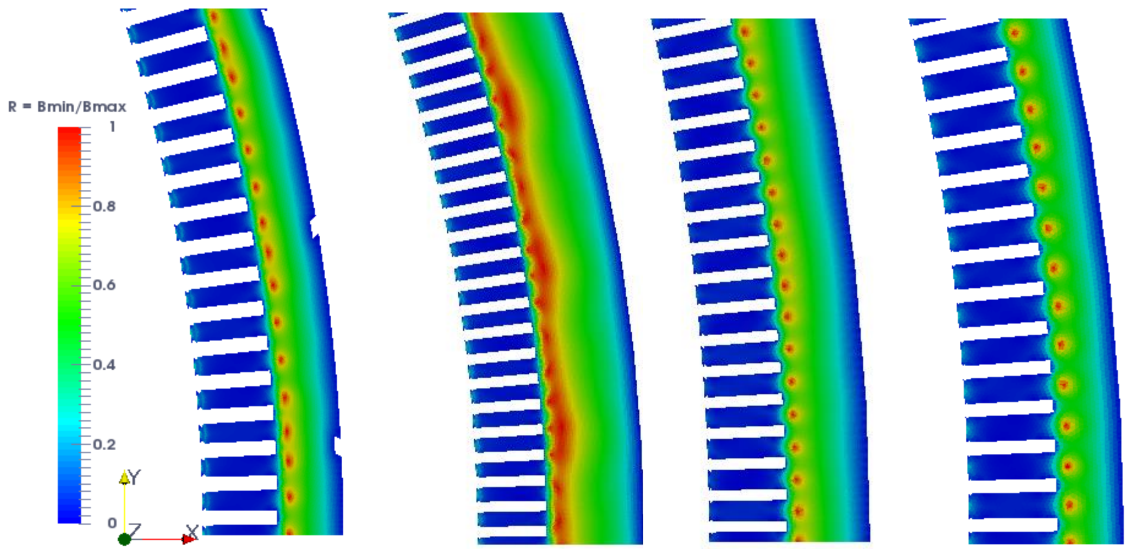
Variation of rotational flux distribution with machine design

- Aspect ratio R, defines which regions have pulsating or rotational flux. R = 0 is pulsating and R = 1 is rotating

Machine	1	2	3	4
Power rating (MVA)	19	32.5	122.6	65
Voltage (kV)	13.8	13.2	13.6	13.8
Current (A)	795	1422	5129	2719
Excitation current I_f (A)	1090	875	726	1220
Power factor	0.8	0.8	0.9	0.85
Frequency (Hz)	60	60	60	60
Speed (rpm)	120	105.9	120	94.7
Poles	60	68	60	76
Slots	336	432	504	396
Slots per pole per phase	1 13/15	2 2/17	2 4/5	1 14/19



Machine – 1 Machine – 2 Machine – 3 Machine – 4

$$R = \frac{B_{min}}{B_{max}}$$

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Analytical Modeling and Improvement in the Design of Variable Flux Machines

Amirmasoud Takbash

Background

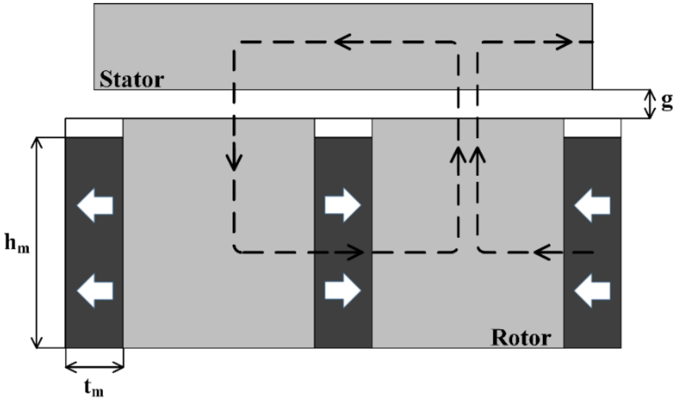
- The variable-flux machines (VFMs), are permanent magnet (PM) machines which have the ability to adjust the level of PM flux.
- Memory machines as a category of the VFMs use AlNiCo PMs, which can be demagnetized and re-magnetized easily with a short time current pulse that enables the flux variation effectively.
- The design and simulation of an AlNiCo PMSM (Variable Flux Machine) requires advanced modeling of the magnet hysteretic characteristics.
- In order to analyze the performance of the spoke type variable flux machine and to improve its design procedure, a simple and accurate analytical model of this machine is necessary.
- The torque ripple causes noise and vibration in addition to, difficulties in control.

Objective

Propose an analytical model for spoke type VFM and verify it with FEA and prototyped machine, using the torque vs. angle profile of the prototyped machine.

Design modification of the VFM to reduce the torque ripple and magnetization current.

Analytical Model



Equivalent magnetic circuit of the spoke type VFM

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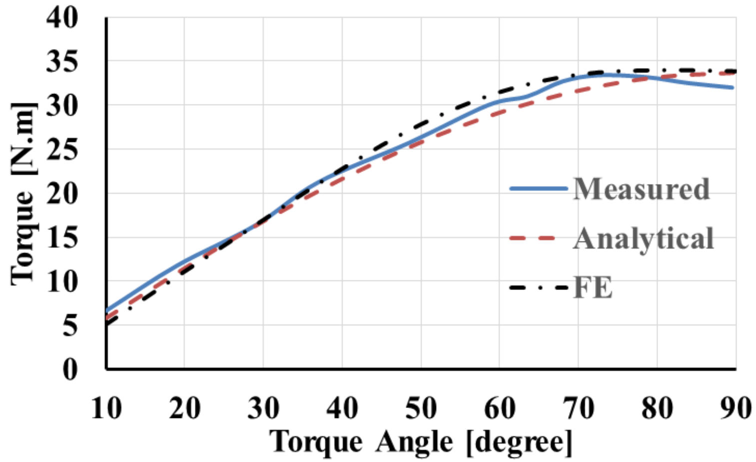
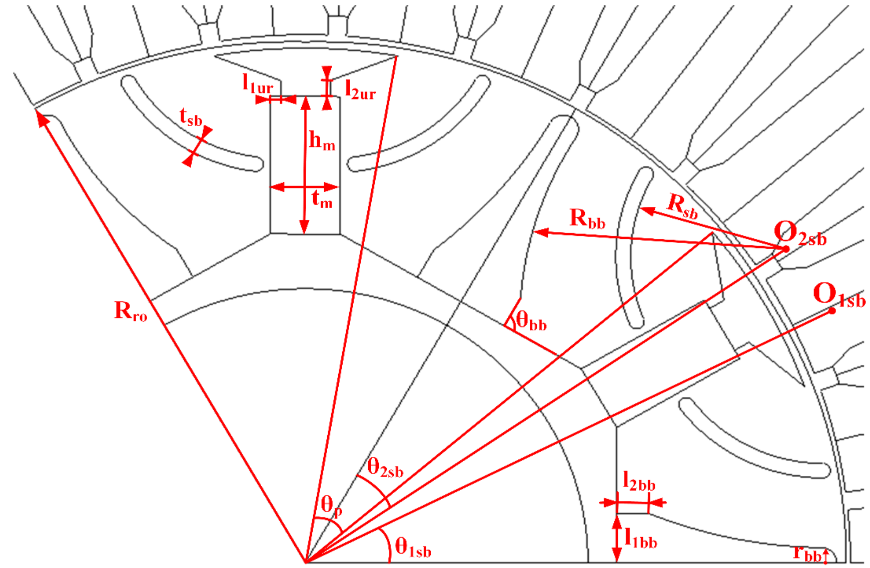
Analytical Model Verification



Average PM torque vs. torque angle

Design Optimization



Geometrical parameters for initial VFM topology

New Analytical Design Criterion

$$B_{g0}=\frac{2B_rA_m}{\left(A_g+\frac{4g\mu_{rec}A_m}{t_m}\right)}$$

$$I_{mag}=\frac{B_m}{\mu_0 aN_{spp}n_{tc}}\left(\frac{t_m}{\mu_{rec}}+\frac{2gh_m}{\tau_p-t_m}\right) \rightarrow h_m$$

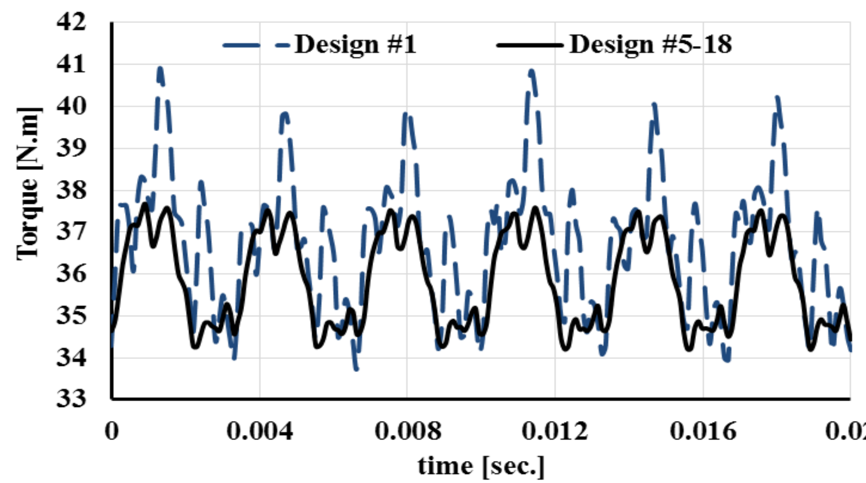
$$\downarrow$$

$$I_{mag}=\frac{B_m}{\mu_0 aN_{spp}n_{tc}}\left(\frac{t_m}{\mu_{rec}}+\frac{gB_{g0}t_m}{B_rt_m-2g\mu_{rec}B_{g0}}\right)$$

$$\downarrow$$

$$k_1k_2k_4t_m^2+t_m(-k_1k_2k_5+k_1k_3-k_4I_{mag})+k_5I_{mag}=0$$

t_m



Comparison of torque waveform for design #1 and design #5-18, (FE simulation)

Design of Synchronous Reluctance Motor for Automotive Applications

Morteza Taghavi

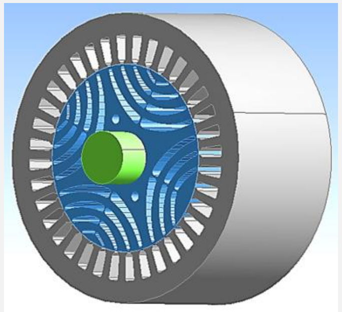
Project Objective

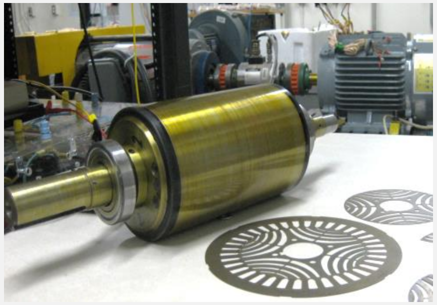
- Design of traction motors for electrified powertrains that do not depend on rare-earth permanent magnets.
- Develop testing techniques to identify motor models from laboratory measurements and detailed instrumentation.

Methodology

1. Analytical design
2. Rotor geometry design
3. Finite element analysis
4. Performance optimization
5. Prototype
6. Load test

SynRM Operation





- Synchronous reluctance machines (SynRM) produce reluctance torque by variation of the reluctance caused by rotor position.
- The SynRM utilizes the same stator as Induction machine.
- No magnet or cage on the rotor structure.
- The SynRM potentially is an alternative for less-expensive and accurate AC drives.

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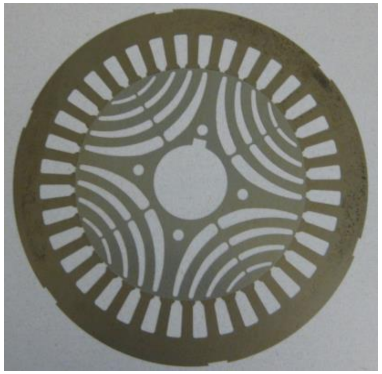
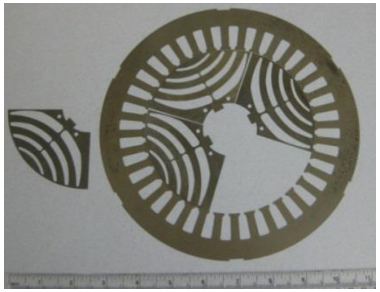
Research Work Contributions

1. Proposed a sizing mythology for automotive applications using the torque envelop.
2. Proposed a geometrical method to minimize torque ripple.
3. Proposed an innovative rotor core lamination to improve the average torque using grain oriented steel.
4. Proposed a “Variable Ampere-Turn” design to extend the speed range for automotive applications.

- ❑ Motor lamination with integrated-pole using geometrical method for reduced torque ripple



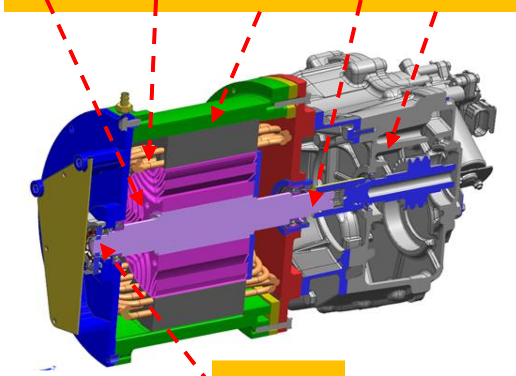
- ❑ Motor lamination with segmented-pole using CRGO for higher torque density



50hp/170Nm
10000rpm

Industrial Prototypes

TM4



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Torque and Core Loss Characterization of Electrical Machine

Chirag Desai

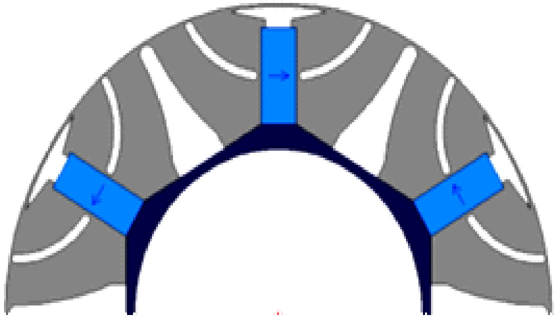
Background

➢PMSM with rare-earth permanent magnets are widely employed in electric and hybrid electric drivetrains.

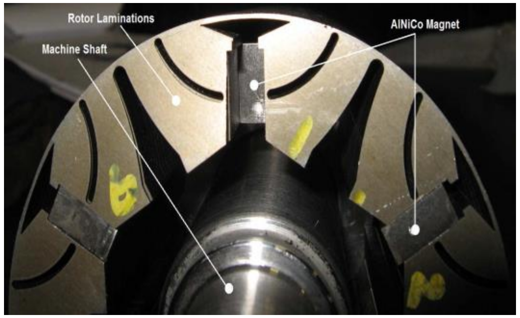
➢The cost of rare-earth magnets is increasing rapidly as well as the supply and resources are limited.

➢AlNiCo magnets can operate at high temperatures and at flux densities close to rare-earth permanent magnets.

➢PMSMs with AlNiCo magnets with controllable demagnetization can provide efficiencies and torque densities as good as rare-earth PMSMs.



(a)



(b)

Laboratory Prototype
(a) Rotor geometry, (b) Prototyped rotor

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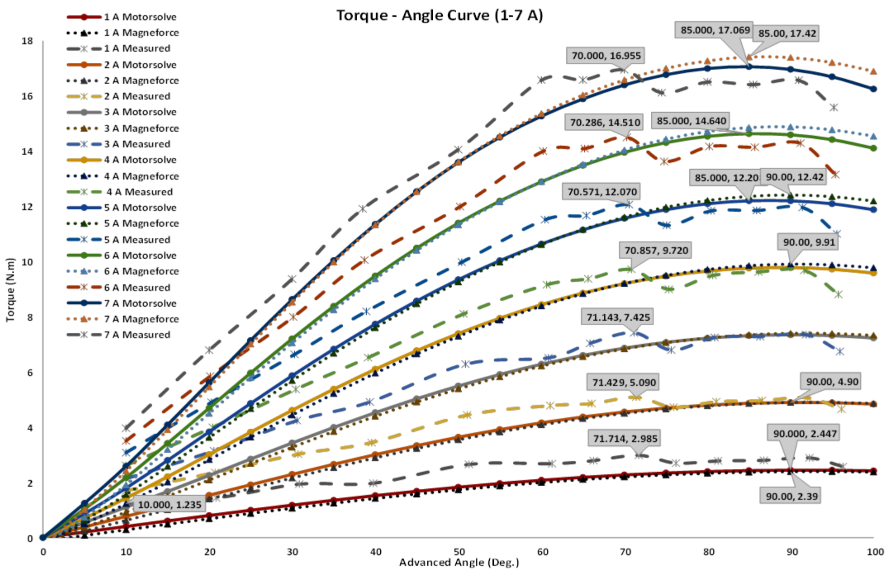
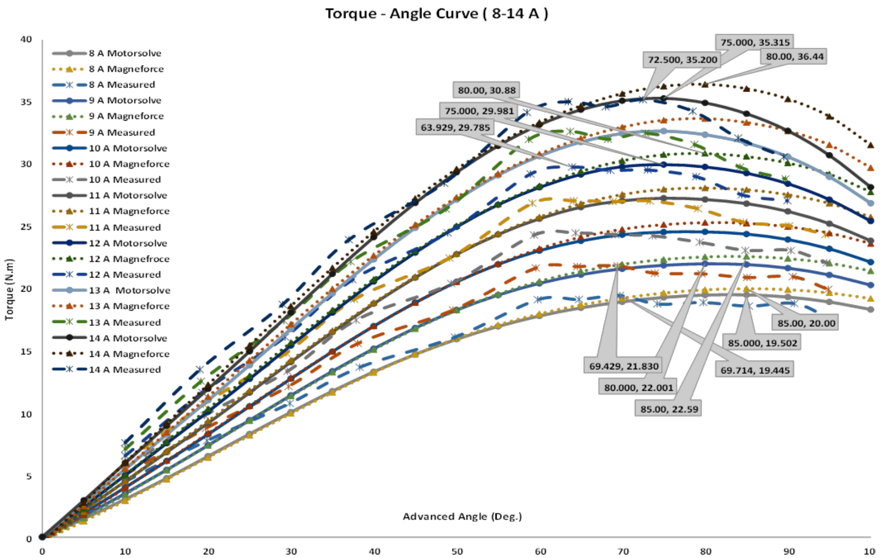


(a)



(b)

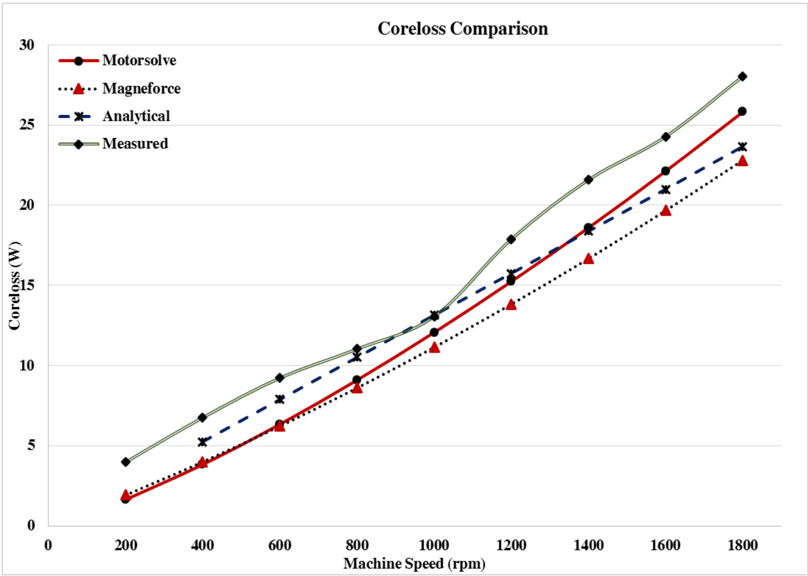
Torque vs. angle curve for 100% magnetization

Objective

➢ To obtain torque for different rotor angles and motor currents to improve torque-to-current ratio at various magnetization levels.

➢ A precise quantification of core losses over an extensive frequency and flux density range.

➢ Comparison of the measured torque and core loss with the simulated results from Magneforce and MotorSolve.



Core loss comparison at 100% magnetization

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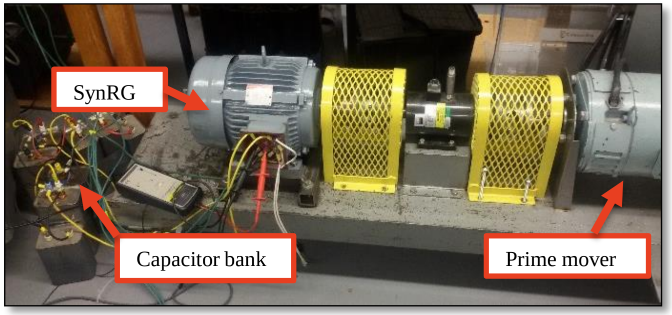
Synchronous Reluctance Machine (SynRM) Design and Application

Sara Maroufian

Background

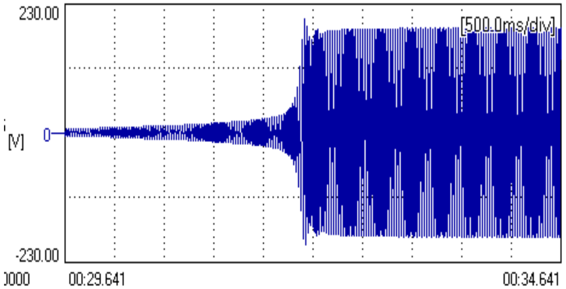
- SynRM have several advantages over PM machines and Induction machines, which are low cost, high efficiency, fast dynamic response, low maintenance cost, and robust and simple structure.
- The synchronous reluctance generator (SynRG) can operate in stand-alone or in grid connected mode.
- In the stand alone mode, a properly sized capacitor bank must be connected to the phase windings to make self-excitation possible and supply the reactive power to the generator and the load.
- The self-excitation phenomenon in induction generators and SynRG relies on the nonlinear characteristic of the ferromagnetic core, as well as the initial conditions which can be either the capacitor initial voltage or the residual flux in the machine's core.



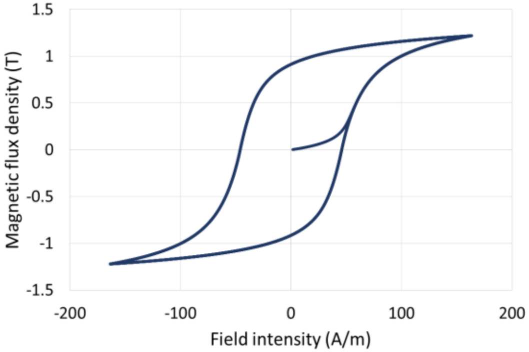
Experimental test setup of the SynRG

Objective

- The aim of this project is to identify the criteria that ensures the occurrence of the self-excitation in terms of minimum required initial condition and startup acceleration.
- The ferromagnetic core analysis is performed using the energetic model.



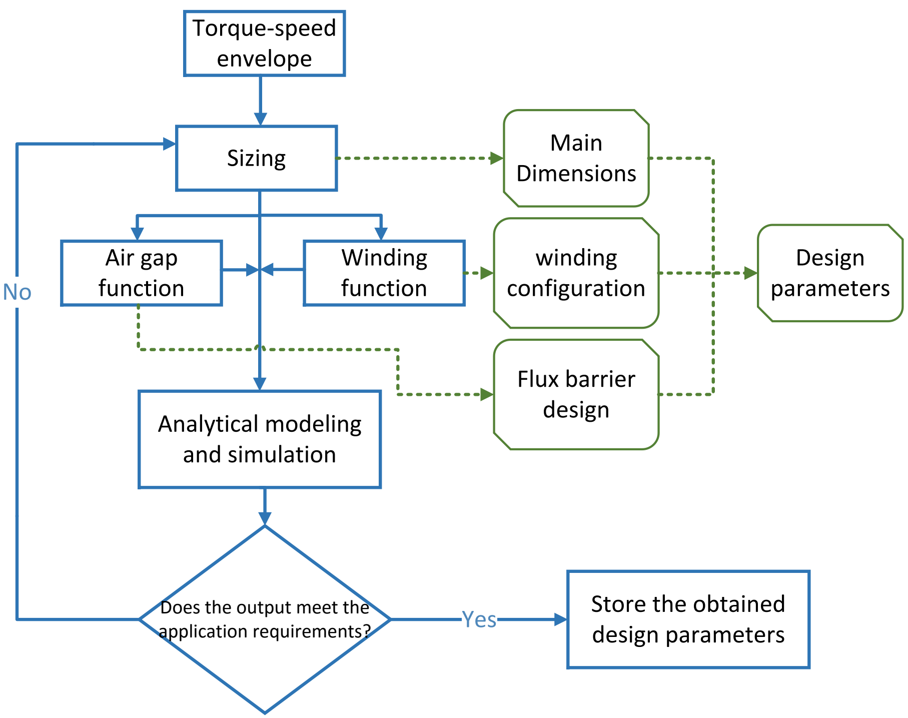
Experimental result of the phase voltage



BH curve of the core material estimated using the Energetic Model

Design Objective

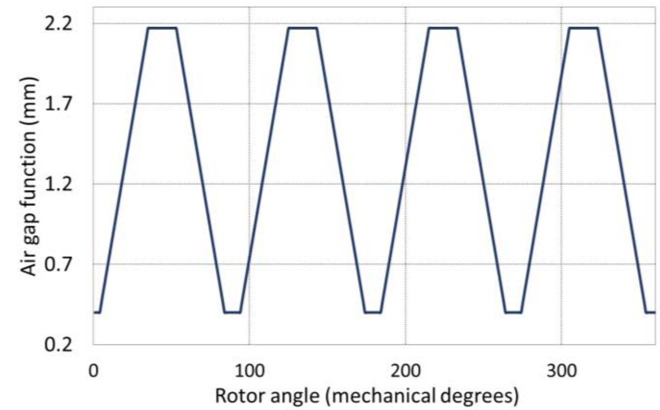
- Developing an analytical design method through which the SynRM can be designed for the specific application with desired characteristics.
- The analytical approach is based on an available sizing methodology of the SynRM combined with an analytical method named as Winding Function.



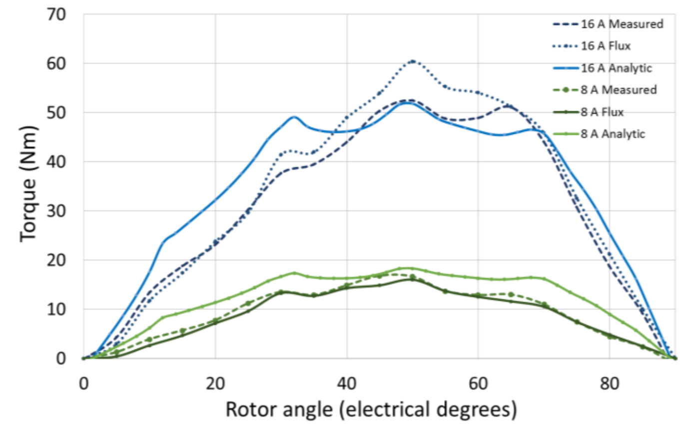
The flowchart of the analytical design method

Analytical Method Verification

- The winding function method is applied to a previously designed and prototyped SynRM.
- The rotor structure is estimated using circular shapes.



Air gap function of the SynRM



Torque-angle curves compared with measurement and finite element analysis

Self-Excitation of Synchronous Reluctance Generators

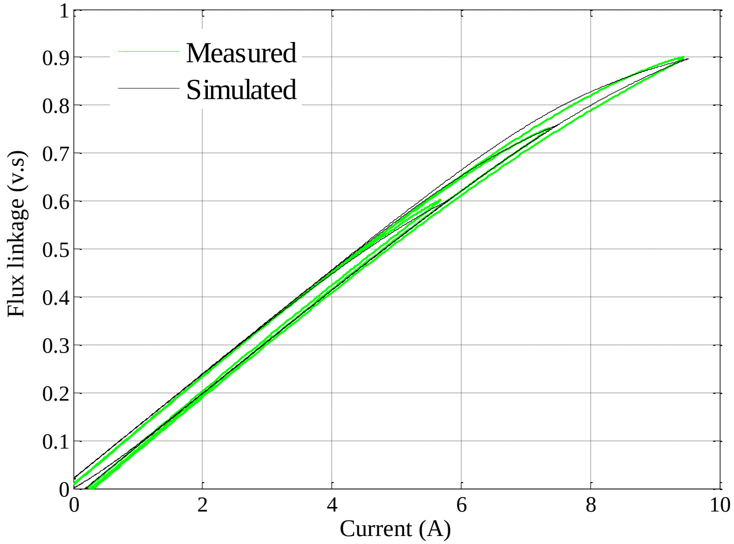
Maged Ibrahim

Background

- The synchronous reluctance generator (SynRG) is considered a promising alternative to conventional induction and permanent magnet synchronous generators due its simple rotor construction and its low short circuit current.
- In various renewable energy applications like wind and hydro generators, the SynRG may operate in stand-alone mode, where the generator excitation is initiated by the residual flux in the rotor steel core. As the rotor accelerates, the generator voltage builds up through capacitor banks connected to the generator terminals till steady-state is reached.

Research Objectives

- The simulation of the SynRG self-excitation process requires prior knowledge of the residual flux in the machine core, which depends on the core magnetic properties and the previous machine operating condition.
- In this research, the flux linkage-current curves of the SynRG are simulated using the Energetic hysteresis model for different operating conditions. The calculated residual flux density is then utilized to predict the machine self-excitation capability for the subsequent operation using the machine dq model.



Comparison between measured and simulated flux linkage-current loops of a synchronous reluctance machine

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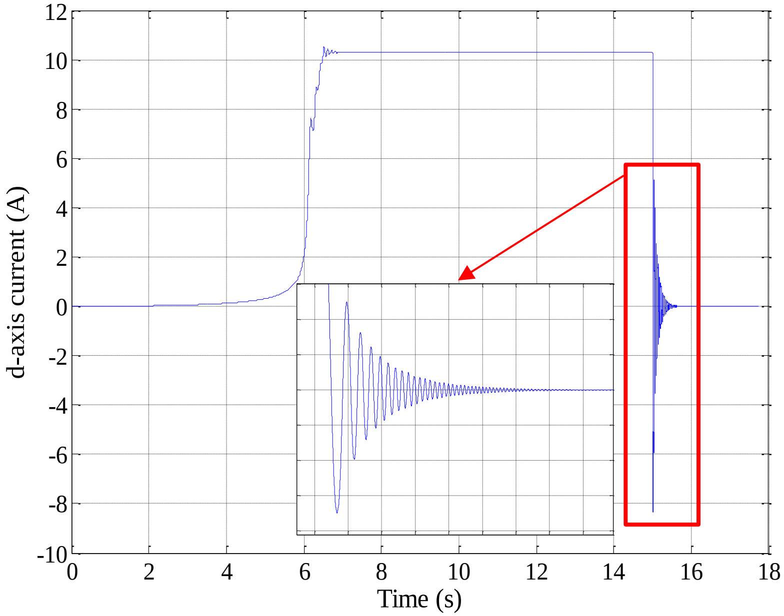
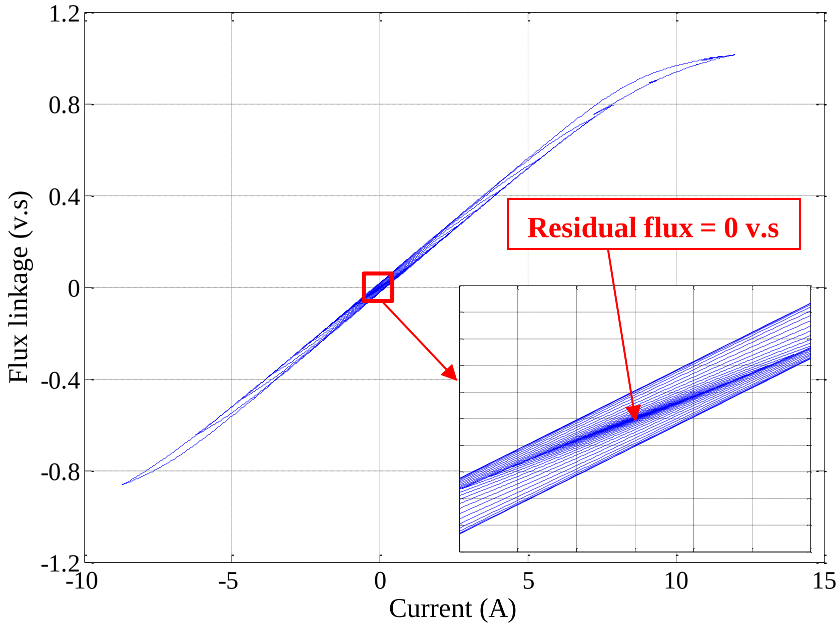
Results

- For normal shut-down of the SynRG, the machine flux linkage-current curves follow a trajectory that allow the machine core to retain sufficient residual flux for initiating the self-excitation process during the next start-up.
- On the other hand, when a 3-phase short circuit is applied to the machine, the flux linkage current curves follow symmetric hysteresis loops of decreasing magnitude that ends up with machine core losing its residual magnetism. As a result, the SynRG will not be able to start-up until the machine core is re-magnetized by an external power source.



Simulated d-axis current during a short circuit



Simulated flux linkage-current loops during a short circuit

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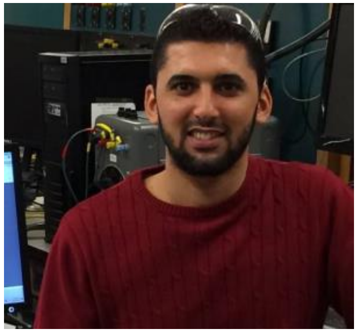
Drive Design for Variable Flux Machines



Akrem Mohamed Aljehaimi

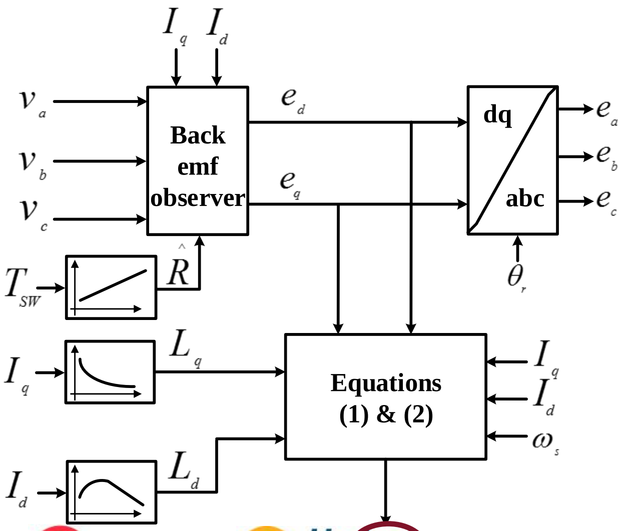
Background

- Magnet flux can be altered by a stator current pulse.
- A particular current needed to get a magnetization state (MS) depends on machine parameters, i.e. stator resistance and inductance, which do change depending the machine working condition, e.g. temperature.
- A lookup table of magnet flux vs. current fails to depict the actual MS of the magnets.
- Failing to depict the actual MS of the magnets means a mismatch between the magnet flux in the control circuit and the real magnet flux in the machine, which directly affects the resultant torque and the machine current.
- Estimating the actual magnetization state of the magnets is necessary to improve the torque control altogether.

Objective

- Developing a reliable method which can estimate the rotor flux linkage of VFM taking into account the:
  - ✓ change in stator resistance due to temperature
  - ✓ variation of d-q axis inductances with current

Proposed Scheme



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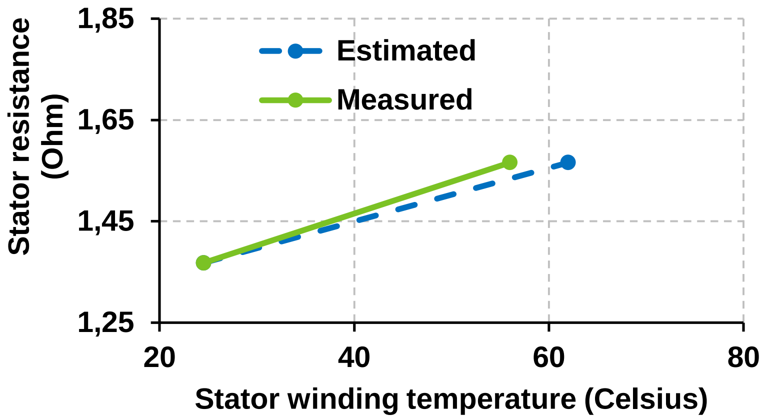
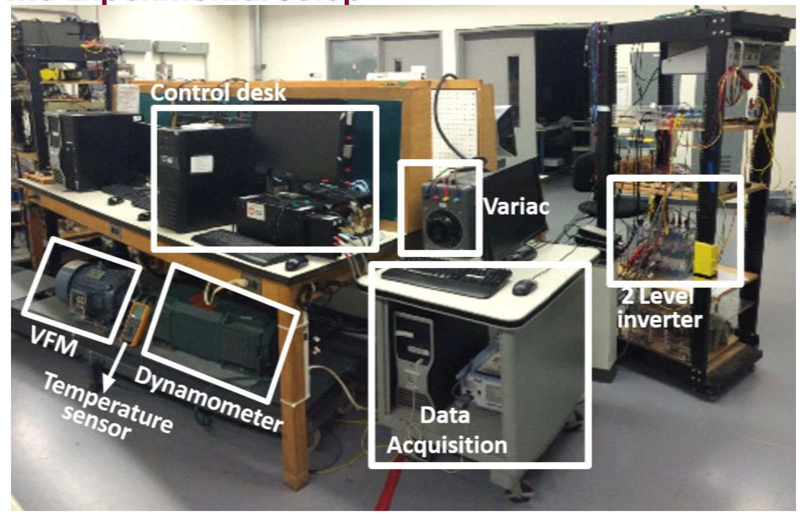
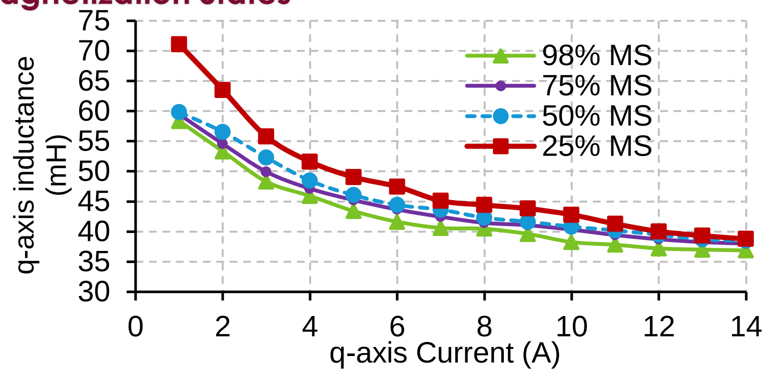
Stator Winding Resistance versus Temperature Test

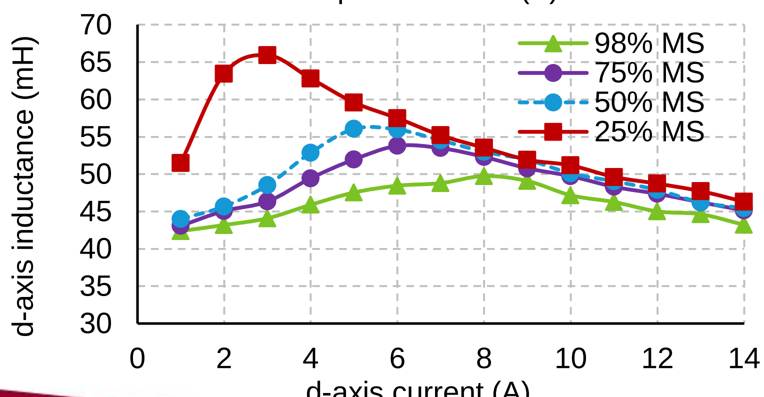


The Experimental Setup

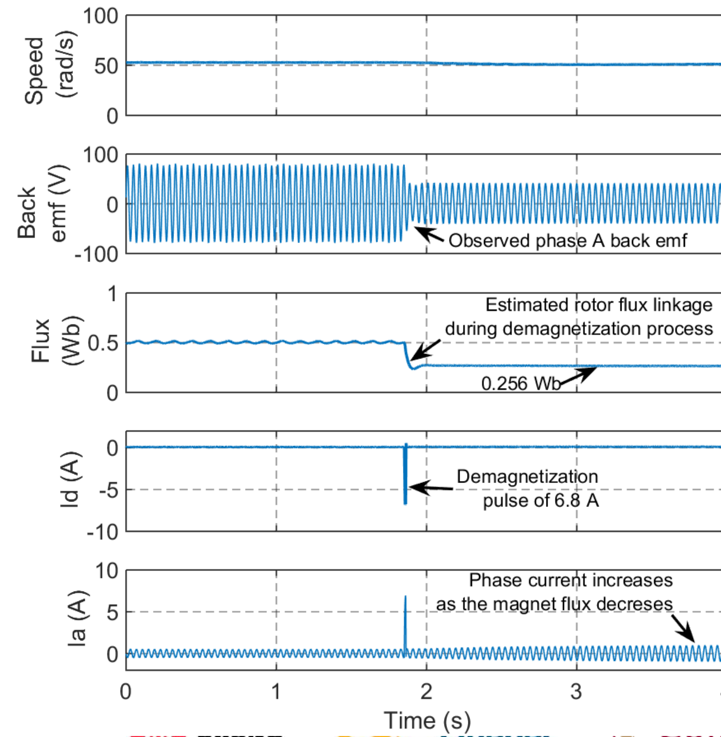


Measured q-axis and d-axis Inductances at Different Magnetization States





The Experimental Results



Parameter Estimation Techniques for Permanent Magnet Machine

Rajendra Thike

Background

- Permanent magnet synchronous machines (PMSMs) are widely used in servo drives, electric vehicles, and renewable energy applications.
- Variable flux machines use low coercive-force magnets to control the air-gap flux density.
- Inductance is one of the main parameters in an electric machine.
- Accurate estimate of inductances allow better performance of a drive system.
- Inductance maps are required in the implementation of control strategies like maximum torque per ampere (MTPA) and maximum efficiency per ampere (MEPA).

Objective

Development of a technique to determine the inductances of a Variable Flux Machine.

DC standstill test

$$\lambda'_d = \int_0^t \{v_d(\tau) - i_d(\tau)R_s\}d\tau \qquad L_d = \frac{\lambda'_d}{i_d}$$

$$\lambda'_q = \int_0^t \{v_q(\tau) - i_q(\tau)R_s\}d\tau \qquad L_q = \frac{\lambda'_q}{i_q}$$

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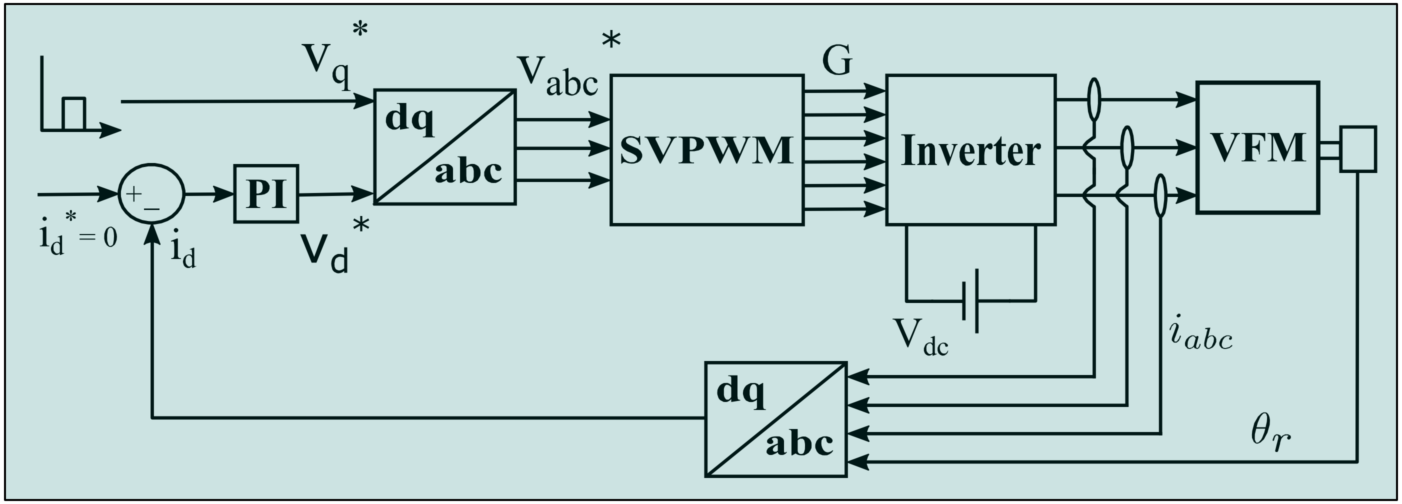
Proposed Technique

- In the proposed technique, a pulsed q-axis voltage is applied while controlling the d-axis current to zero to measure the q-axis Inductances and vice versa.
- Vector control drive was used to sent both the direct and quadrature axis voltage pulses to measure the inductances.
- The same controller is able to vary the magnetization level of the magnets in the machine. Allow fast measurement of current dependent inductances at any magnetization level.
- The rotor can be locked at any arbitrary position for the measurement of inductances at different magnetization levels.
- No additional hardware required as an existing vector controlled drive was used .



Vector control technique to measure the inductances of a VFM

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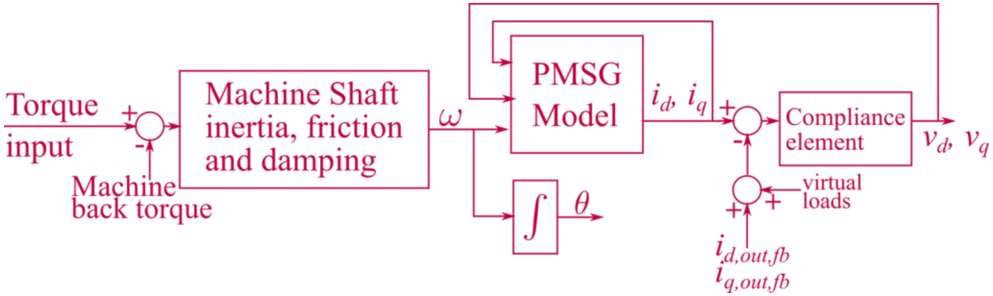
EMULATORS FOR ELECTRIC VEHICLES AND RENEWABLE ENERGY APPLICATIONS

S u d h a r s h a n
K a a r t h i k

B a c k g r o u n d

- Electric Vehicle technology is being developed at an accelerated pace.
- Allows drives engineers to develop and test power converters and control topologies prior to the development of machine prototypes
- A Power Hardware-in-the-loop (PHIL) emulator provides real currents and voltages at the output which allows testing of inverters and control algorithms
- Power Electronic Emulators provide effective and economic ways to test and validate control strategies in real-time.
- Several Machine types can be emulated, different parameter can be loaded into the model to emulate various designs of the machine



Model of a permanent magnet machine operated as a generator running on the real-time processor. This sets the references to the power amplifier for the PHIL emulation.

O b j e c t i v e s

Development of a reconfigurable machine emulator test bench for machine emulation studies.

To provide a validation methods for Rapid Control Prototyping (RCP) of the motor drive

Accurate real-time emulation of the machine including details pertaining to geometry

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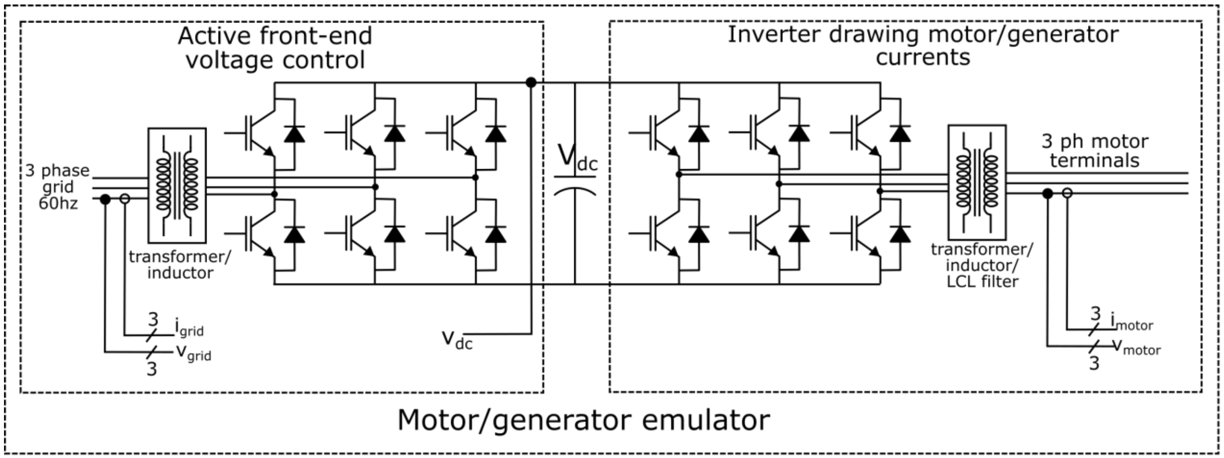
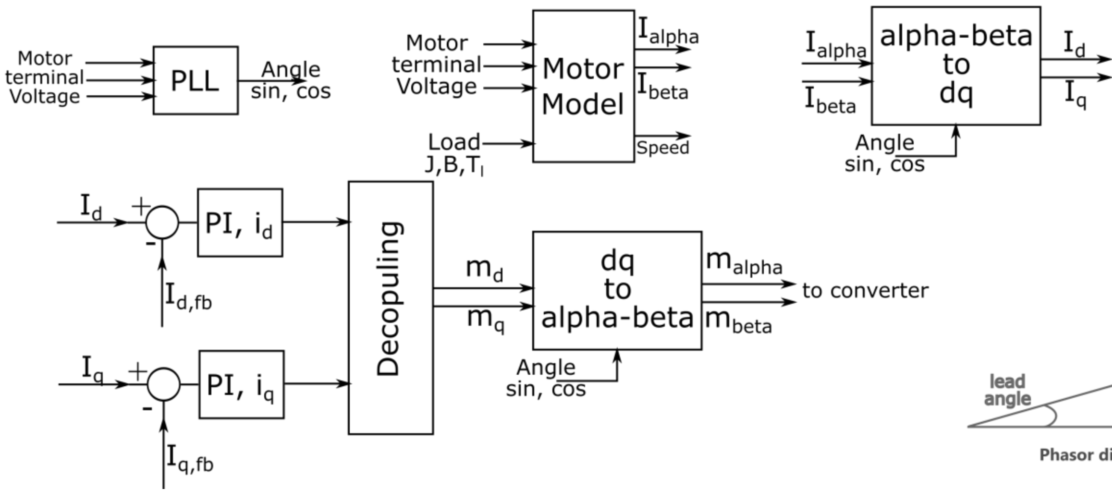
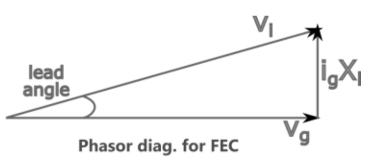
Power Amplifier Circuit





- The line currents are sensed and fed back to the real-time model. This enables the PHIL emulator to respond to the load variations in real-time.
- An option of emulating the system with virtual load helps in the study of dynamics of the machine without excessive power consumption.
- Various machines with different parameter can be emulated with the same test bench – Suitability of various drive systems can be tested and validated.



- A voltage-in current-out model for the motor emulation and a torque/speed-in voltage-out model for a generator can be emulated for the electrical machine. The emulator can operate in both motoring and generating mode akin to a real machine.

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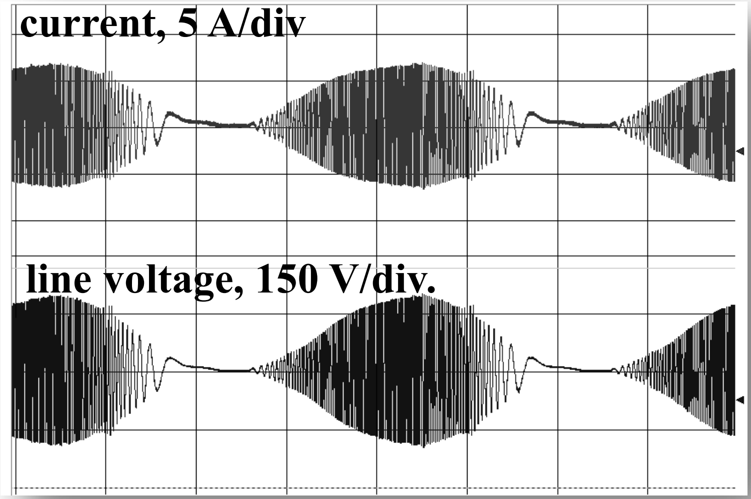
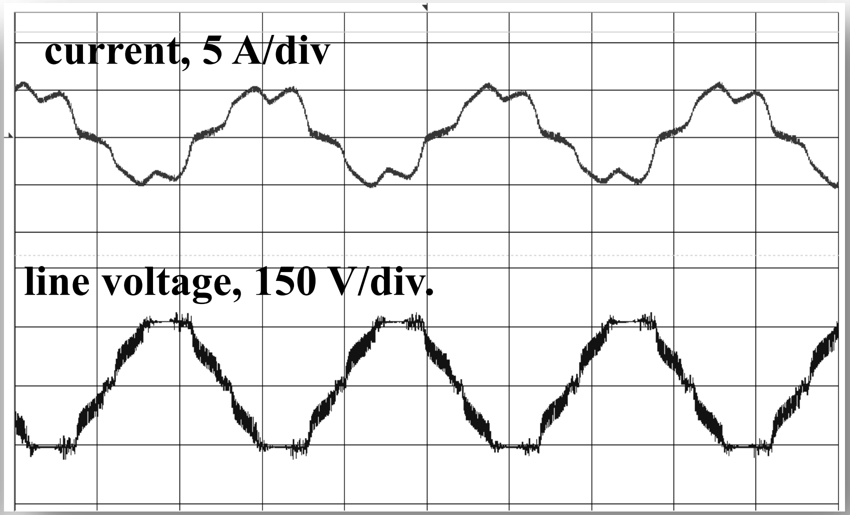
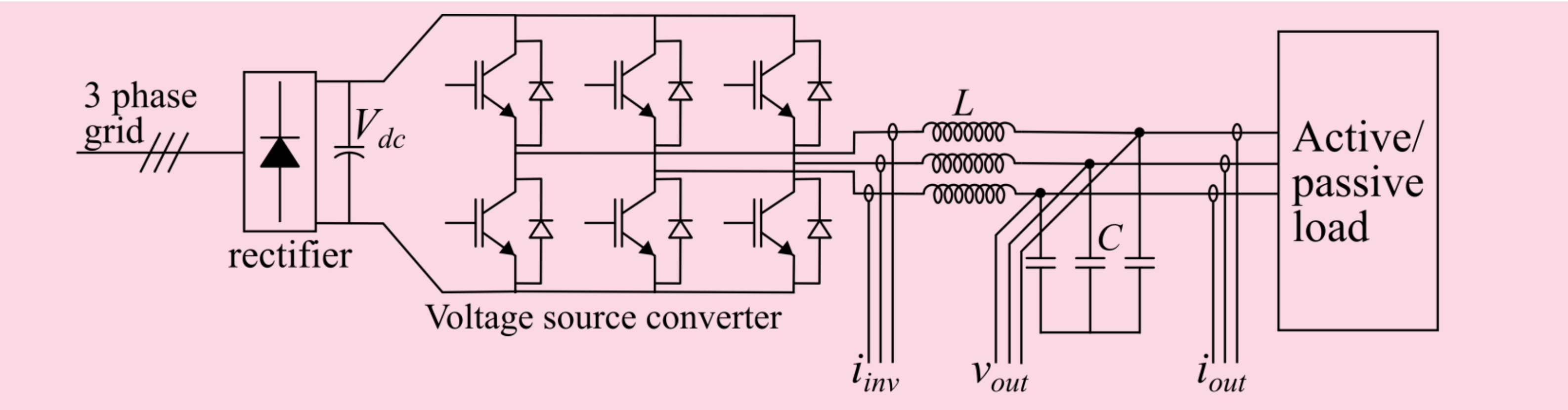
PMSG Emulation: Transients/non-linear load



Start-up and run-down of the system. Current and voltage waveforms from the proposed emulator, time axis: 2 sec/div.



PHIL Emulator connected to a rectifier load. Current and voltage waveforms from the proposed emulator, time axis: 10 ms/div.



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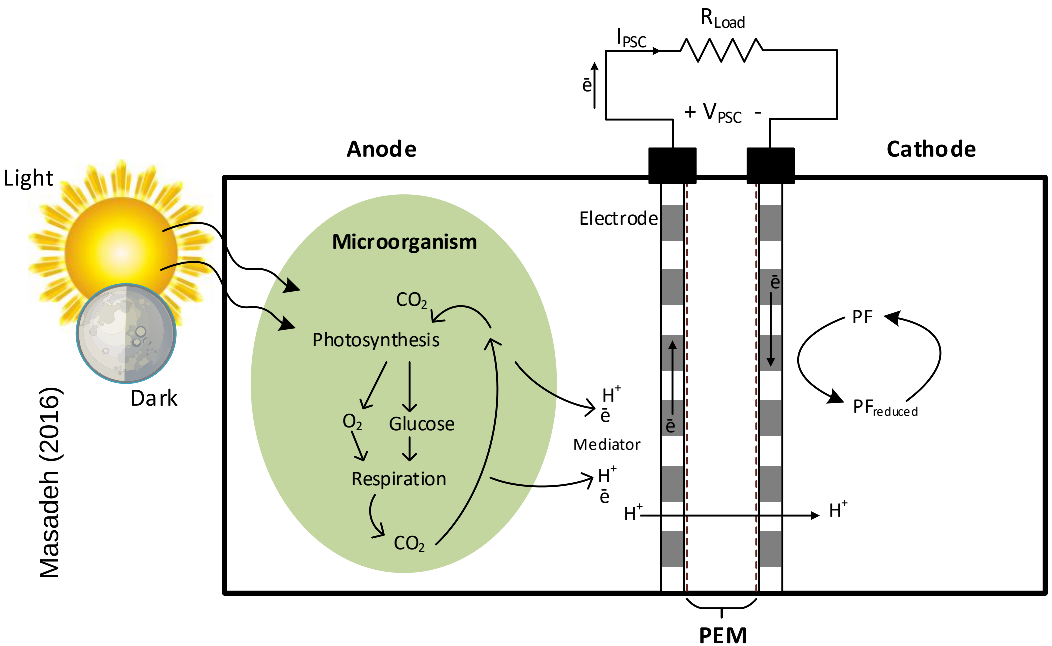
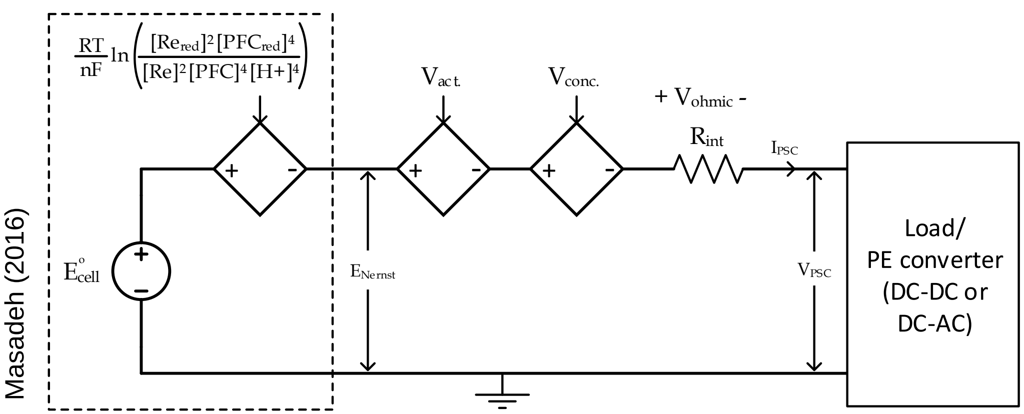
PHOTOSYNTHETIC FUEL CELLS FOR SOLAR ENERGY HARVESTING



Schematic of micro-photosynthetic fuel cell



Equivalent circuit of fuel cell

Background

- During photosynthesis and respiration electrons and protons are released
- When this occurs in the presence of a selective membrane, protons will pass through the membrane while electrons are directed outside the cell and across some load.
- This produces electric power with inputs of sunlight, water and CO_2 and outputs of O_2 and H_2O

Modeling

- An equivalent circuit representation of the chemical and electrical processes is under development

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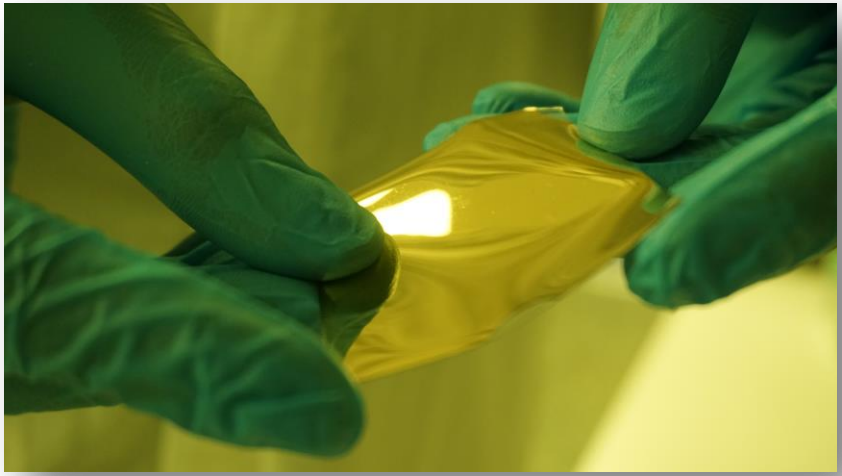
Prototyping

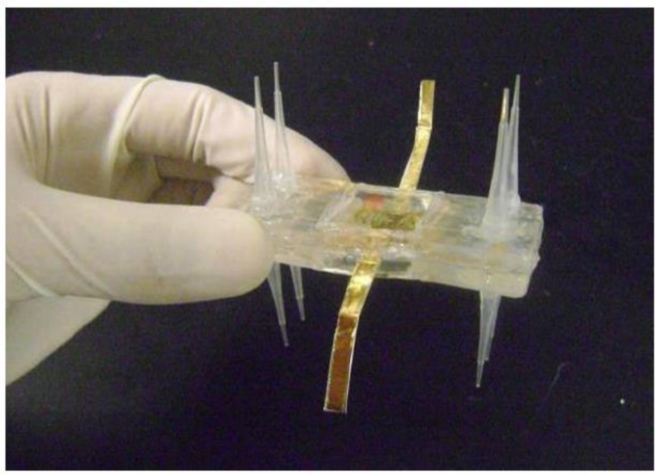
- **Design, assembly and testing of micro-photosynthetic fuel cells**



Thin layer of gold sputtered film at the surface of the Proton Exchange Membrane (PEM)

UV exposure of gold layer to form patterned electrode

Packirisamy et al (2015)



Micro-photosynthetic fuel cell ready for testing

Algae samples housed in grow chamber

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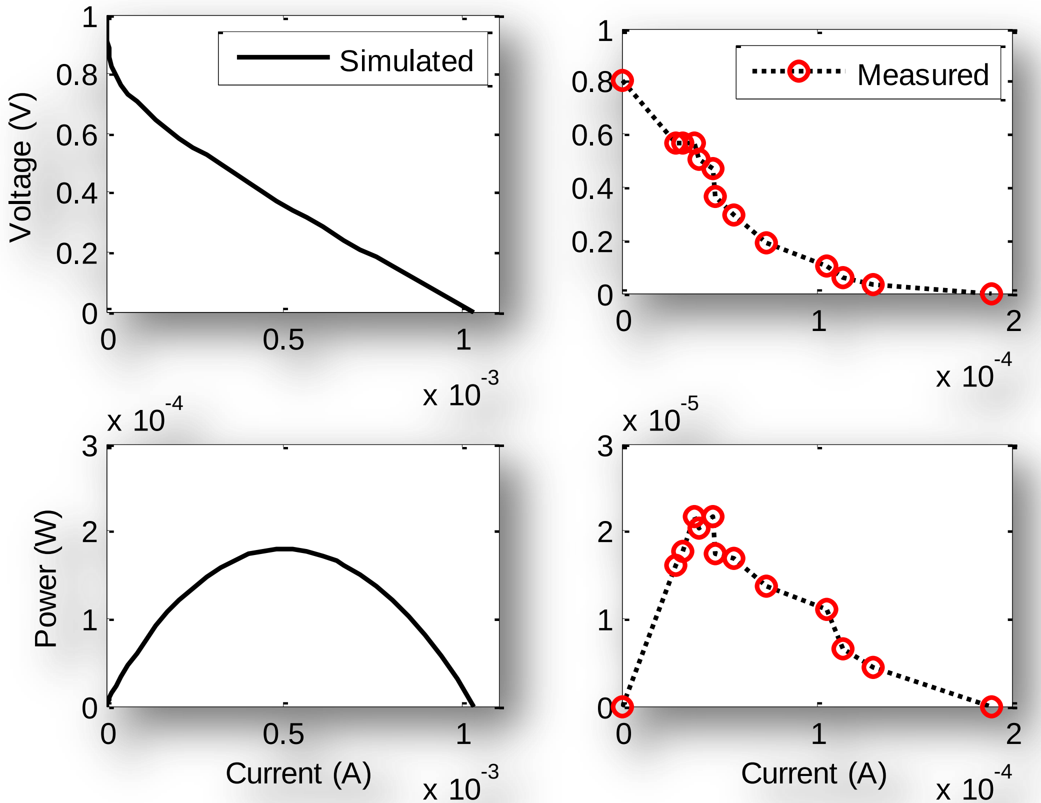
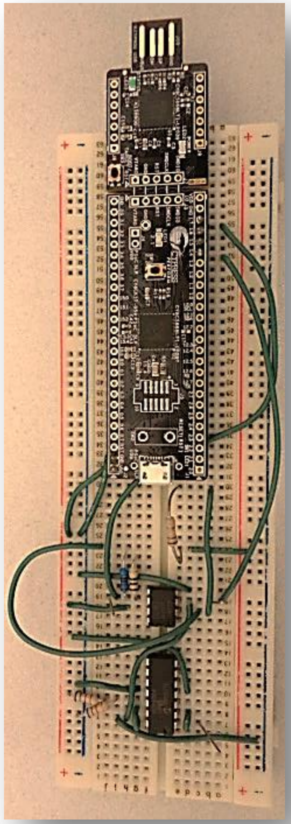
Photosynthetic fuel cell - characterization





- A 2cm x 2cm cell provides a maximum power of 200 uW
- Open circuit voltage: 0.8 V
  Short circuit current: 20 uA

Precision current sensing system
Range: 1 nA to 2 mA ±1%

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Summary and Conclusion

- A permanent magnet synchronous generator was emulated
- Transient operations and non-linear load performance was tested and validated

- A 2cm x 2cm photosynthetic fuel cell was fabricated
- The cell was characterized – Steady state performance of the cell is being studied
- A precision current sensing circuit and data acquisition system was built

Future Work

- Improvements in the existing model to include faster synchronous generator dynamics
- Saturation effects in the synchronous generator
- Variations in the system parameters with operating conditions

- Dynamic Model of the photosynthetic cell
- Energy Harvester design and prototyping

Power-Hardware-In-The-Loop Based Emulator for Rapid Testing and Prototyping of Electric Drives

Amitkumar K. S.

Background

- Power Hardware-in-the loop (PHIL) based machine emulators are gaining wide popularity as an alternative to conventional test-beds for electric drive testing.
- The main advantage of a PHIL system is with respect to testing of driving inverters in an electric drive system. Since the machine is being emulated, several motor types/ ratings, and its corresponding impact on the driving inverter can be studied before the actual motor is developed (prototyped), thus reducing the time to market significantly.
- The accuracy of the emulated machine, to a great extent depends on the machine model used in the real-time controller.
- Most research work has focussed on simplifying machine models to ease their implementation on real-time controllers.
- However, such models will not accurately describe the machine performance during various transient conditions such as start-up, saturation, faults etc.
- There have been a few attempts to introduce saturation effects in the machine models by utilizing flux/ inductance tables, but there still a certain amount of equivalencing done to enable real-time implementation of these models.

Objective

The objective of this research work is to develop a comprehensive PHIL system which uses real-time motor models based on FEA data, thus implementing a PHIL system which is both accurate and versatile. The proposed PHIL test-bed can be used for emulating a variety of motor types and ratings. Further, since the proposed PHIL system uses FEA data, aspects relating to machine geometry and saturation can be easily emulated.

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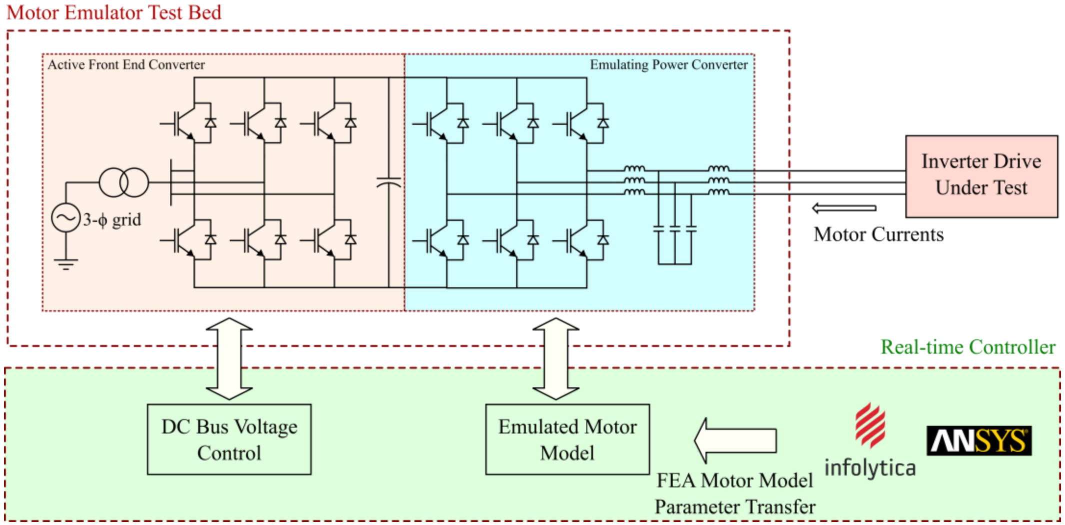
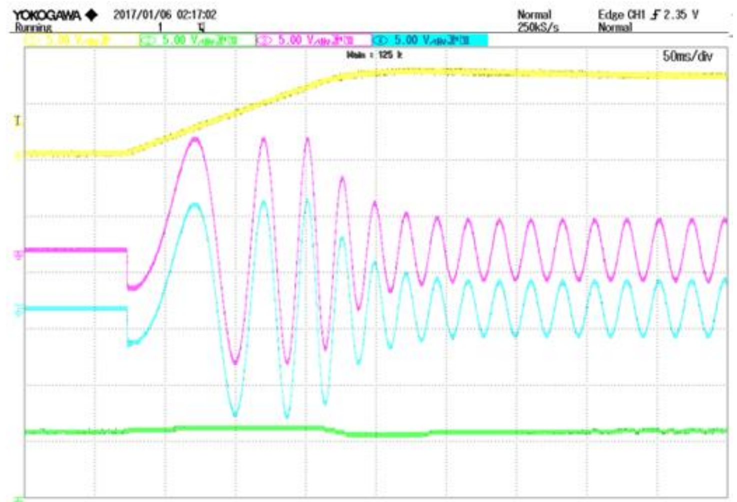
Proposed Methodology



Proposed PHIL Test System



Preliminary Results Obtained(Magenta and cyan traces are reference motor current and emulated motor current respectively)

- The proposed PHIL system utilizes 2 two-level voltage source converters connected in a back-back fashion, thus forming a four-quadrant converter. A four-quadrant power amplifier will allow for both motoring and generating mode emulation of electrical machines. Choice of switching frequencies, filter structures and control structures will be investigated to obtain the highest bandwidth possible.
- The emulated motor model will directly read machine geometric and magnetic data from an FEA file. Motor models available with OPAL-RT® will be used as a starting point.
- Transient and steady state results obtained using the PHIL machine emulator test-bed will be compared with measurements obtained off a physical motor drive. Deviations in results will give a better insight into improving the motor modelling accuracy, FEA data import accuracy, and so on.
- The emulation of several motor types will be attempted, thus verifying the modeling accuracy of the same.
- Improvement to the power converter structure of the PHIL test-bed will also be one of the outcomes of this research.

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An Induction Machine Emulator for Renewable Energy Systems

Mohammad A. Masadeh

Background

- Electric motors with their drive systems are considered as the largest power consumers in industry. Therefore, optimizing a motor and its corresponding drive system with their control can definitely save energy and improve the system efficiency.

- Various power electronic converters can be controlled to run as numerous electrical sources and loads. This provides a flexible and easy way to test and analyze the characteristics of the emulated machines or the instrument under test as well.

- Power converters can emulate distinctively various kinds of dynamic loads e.g. induction motors and synchronous generators as well as static loads e.g. transformers and different power system loads for diverse testing purposes. The complete system and its control signals are shown in Fig. 1.

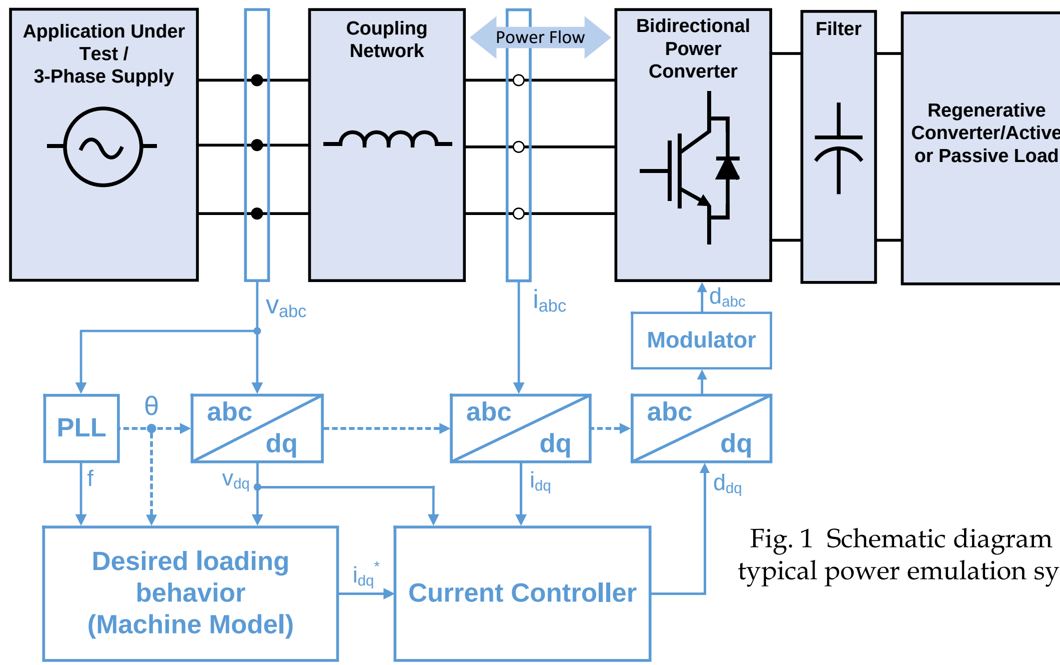

Fig. 1 Schematic diagram of a typical power emulation system

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IM Emulator Operation

- Due to the incessant increasing power demand and the requirement for a clean energy, renewable energy sources and related topics have lastly drawn more attention. Among them, wind energy is becoming an important component in the modern power grid, and its penetration percentage continues a steady increase. In order to analyze its behavior and system impact, and to verify the feasibility to emulate the renewables in a hardware emulation testing platform, full-converter wind turbine based on induction generator will be developed in this research project.

Objectives

- Building the real-time model of induction machine and using its parameters as reference signals for the control of a three-phase, full converter emulation system.

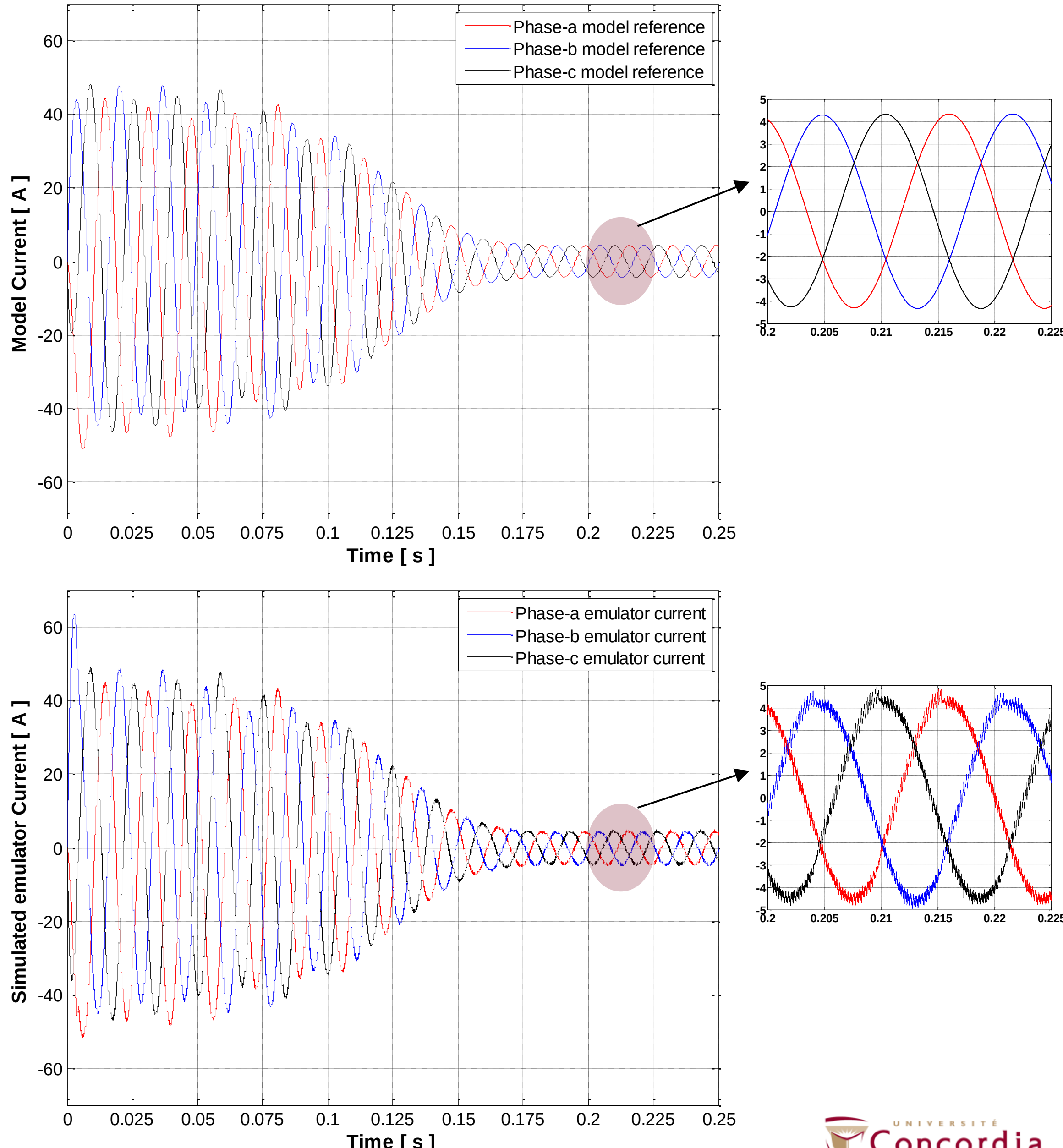

Fig. 2 Three-phase currents waveforms for simulated model and emulator at free acceleration start-up.

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Objectives… cont'd

- Analyzing the operation of induction machine emulator in two operating modes; as a motor (energy sink), and as either off-grid and grid-connected generator (energy source).
- Developing a three-phase power electronic converter-based induction motor/generator drive system emulator.
- Extracting induction machine model parameters in order to represent the emulated machine closely to the real one.

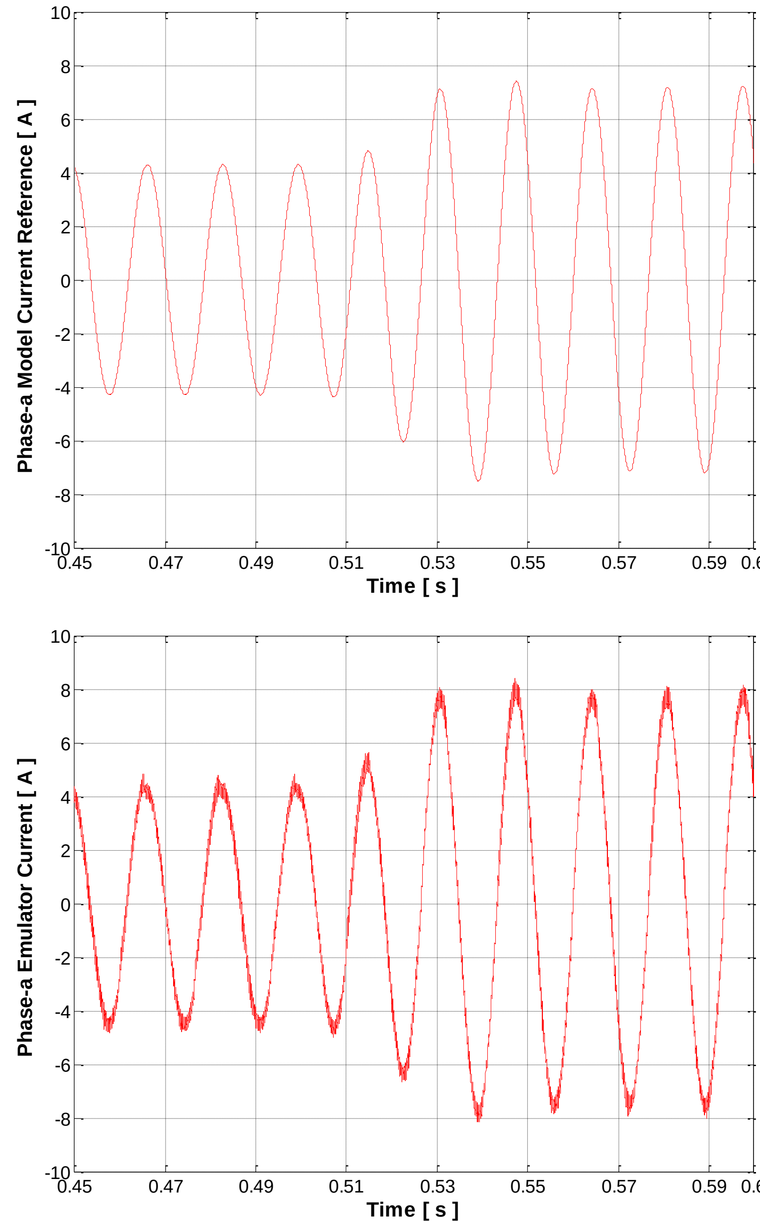


Fig. 3 Model and emulator phase-a current when it is subjected to load torque.

IM Model Verification

- Experimentally measured parameters:

2-hp, three-phase, 208 V, 60 Hz, 6.1 A, 1725 rpm 4-pole squirrel cage induction machine Y-connected, Class B, Baldor Industrial Motor	
Parameter	**Evaluated value**
R_s	1.4506 Ω
R_r	0.9834 Ω
X_{ls}	1.1342 Ω
X_{lr}	1.6928 Ω
X_M	38.6016 Ω
J	0.01550 Kg/m^2 - coupled to a DC machine
B	0.00281 N.m/rad/s

5-hp, three-phase, 208 V, 60 Hz, 16 A, 1730 rpm 4-pole squirrel cage induction machine Δ-connected, Class B, Happy Engineering	
Parameter	**Evaluated value**
R_s	1.0873 Ω
R_r	1.3046 Ω
X_{ls}	2.4317 Ω
X_{lr}	3.6475 Ω
X_M	80.8581 Ω
J	0.00209 Kg/m^2 - with no coupling
B	0.0155 N.m/rad/s

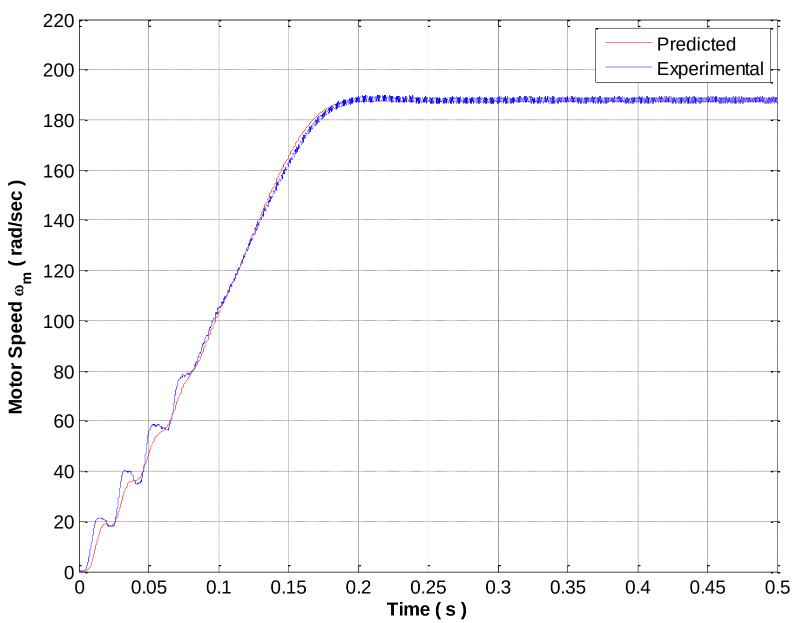


Fig. 5 Experimental and predicted line voltage and speed responses during direct online start-up for 2-hp IM.

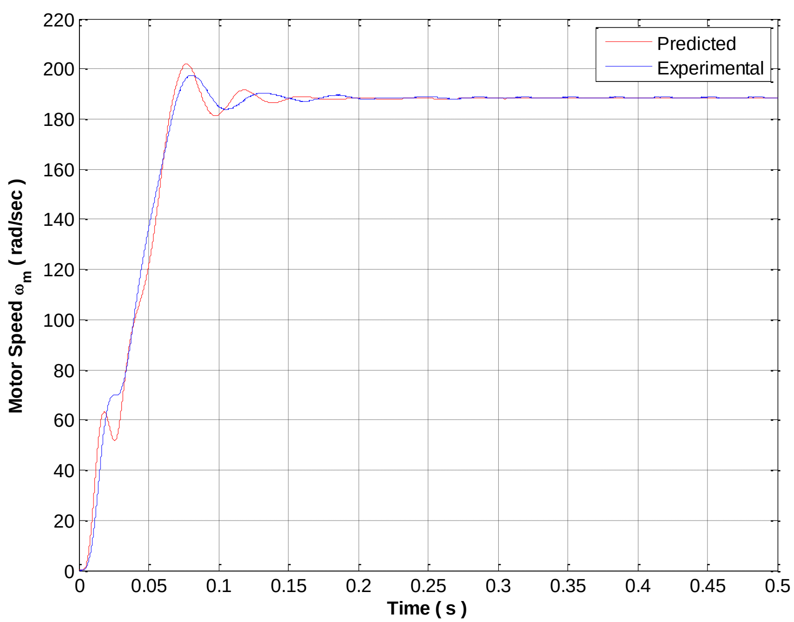


Fig. 6 Experimental and predicted line voltage and speed responses during direct online start-up for 5-hp IM.

IM Model Verification

- Experimental and predicted responses for <u>2-hp</u> and <u>5</u>-hp IMs

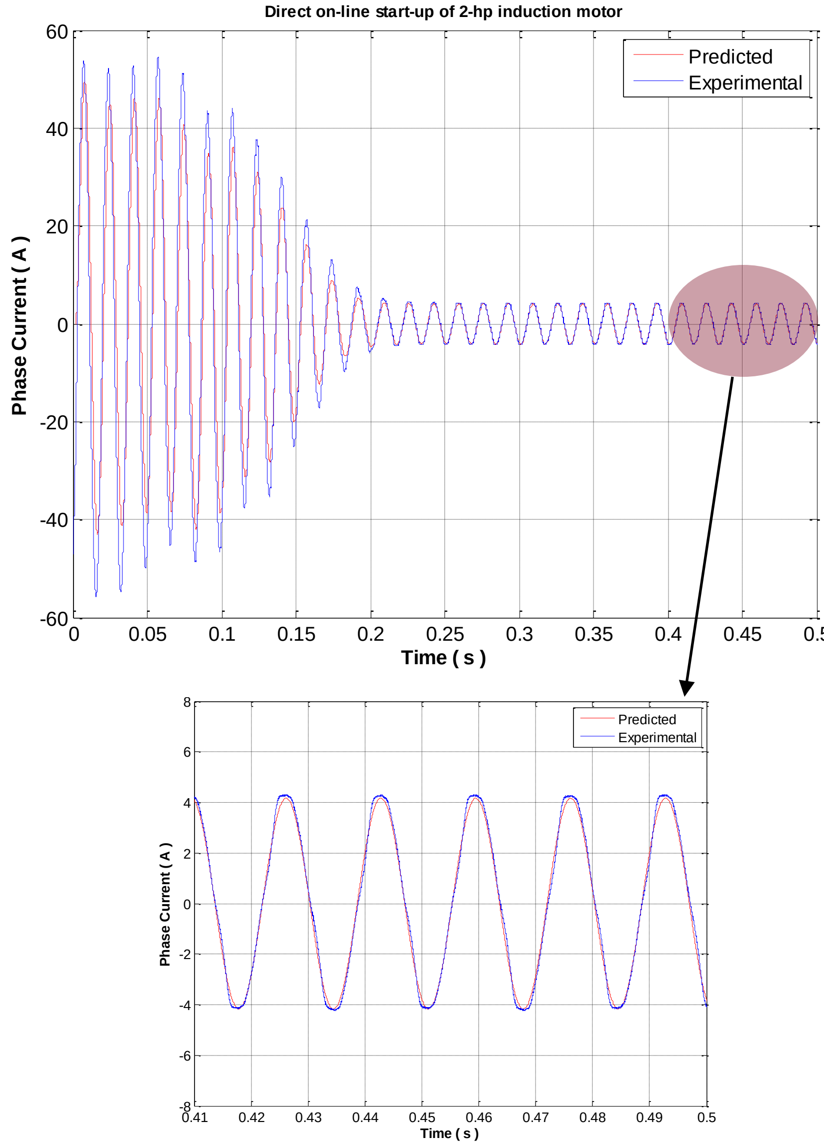
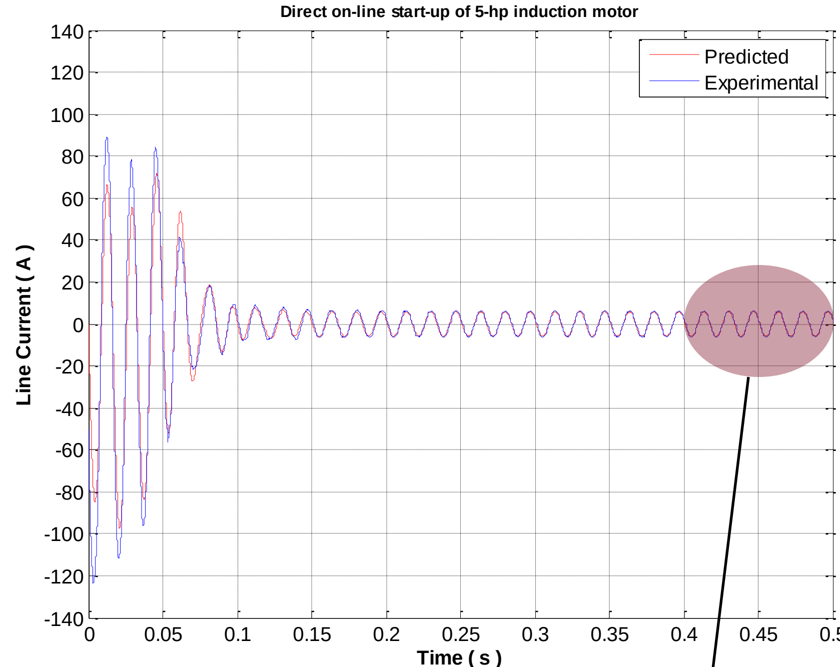


Fig. 7 Experimental and predicted current response during direct online start-up for 2–hp IM.



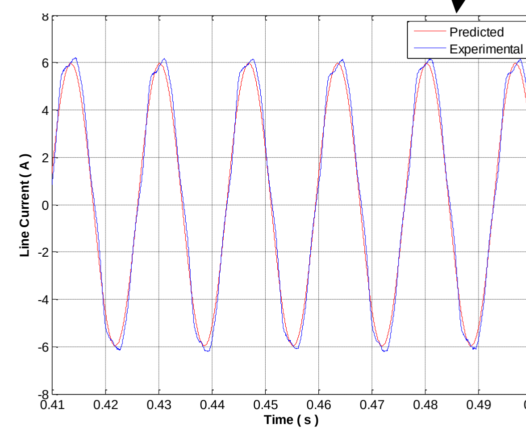


Fig. 8 Experimental and predicted current response during direct online start-up for 5–hp IM.

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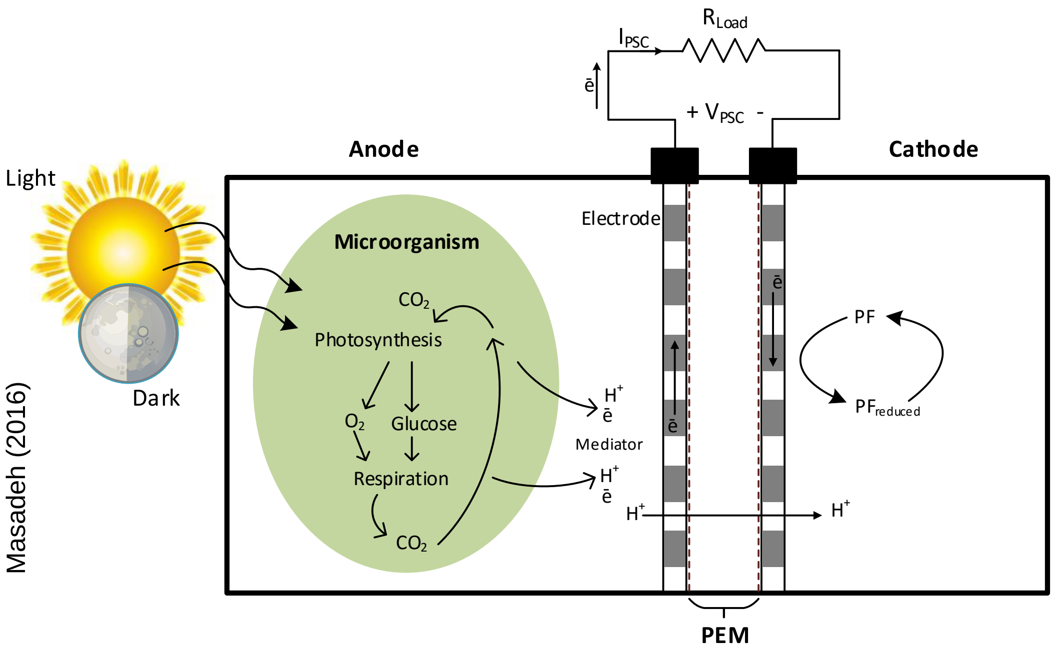
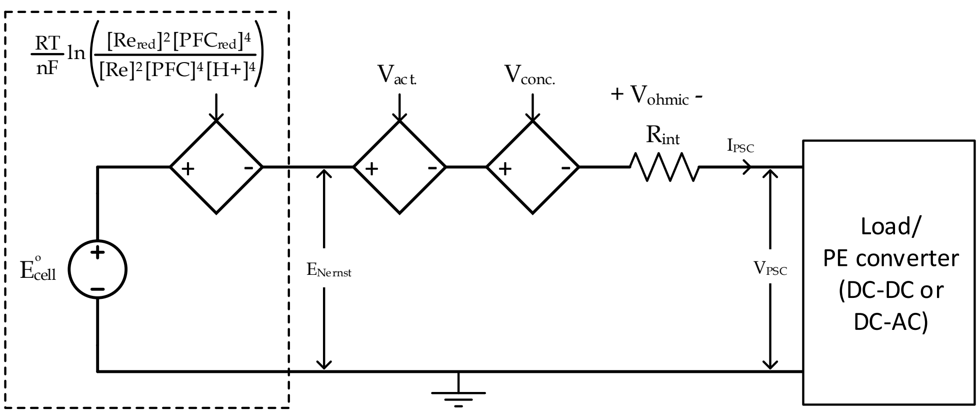
Photosynthetic Fuel Cells for Solar Energy Harvesting

Tamanwe Payarou



Masadeh (2016)

Figure 1:Schematic of micro-photosynthetic fuel cell



Masadeh (2016)

Figure2: Equivalent circuit of fuel cell

Background

- Photosynthesis and respiration in plants in presence of a mediator release electrons and protons.
- Selective membrane is used to provide a path to protons. Electrons are directed outside the cell via some wiring across a load.
- This process produces electric power. Unlike other renewable systems; Here energy is generated with and without the sunlight.

Modeling

- An equivalent circuit representation of the chemical and electrical processes is under development

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Photosynthetic fuel cell - characterization

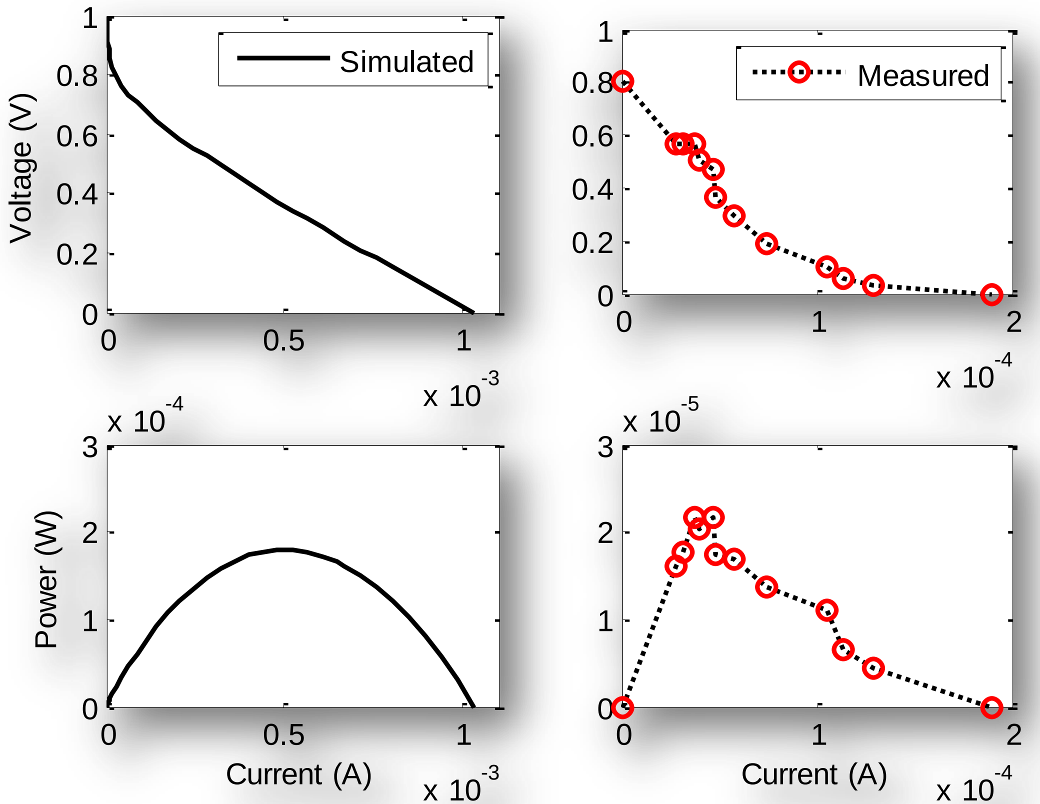

Figure4: Photosynthetic fuel cell characteristics

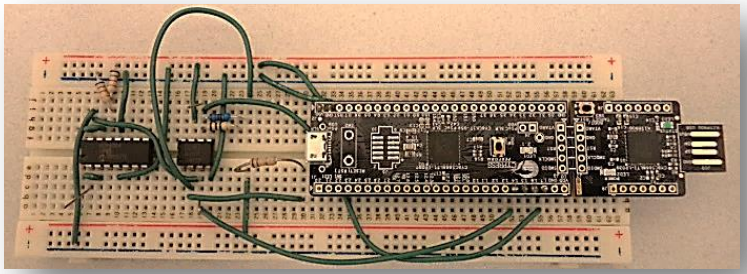

Figure3: Precision current sensing system
Range: 1 nA to 2 mA ±1%

➲ A 2cm x 2cm cell provides a maximum power of 200 uW

➲ Open circuit voltage: 0.8 V
Short circuit current: 20 uA

Future Work

- Circuit for efficient analysis and characterization of the photosynthetic cell
- Energy Harvester design and prototyping
- Dynamic Model of the photosynthetic cell

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Diesel-Hydrokinetic Energy Conversion System

Mohammad H. Ashourian

Background

- The local population, remote communities, often rely on their own diesel generators for energy. A diesel generator system (genset) causes air pollution and sometimes is costly.
- Hydrokinetic energy conversion systems (HKECSs) are clean, reliable alternatives, and more beneficial than other renewable energy sources and conventional hydropower generation system, but due to the stochastic nature of river speed and drastically variable load pattern of decentralized communities, the use of the diesel generator set is usually indispensable.

Challenges

- Hardware-in-loop (HIL) platform
  - How to emulate the diesel-hydrokinetic system?
  - How to test and develop dynamic models and evaluate new control schemes?
- Long-term conditions (steady-state)
  - How can HKECS power production meet systems' needs?
- Short-term conditions (transient)
  - How can HKECS contribute to voltage and frequency control?

Objectives

The objective of this research work are:

- Developing steady-state and dynamic models of the hybrid hydrokinetic-diesel system.
- Developing an electromechanical and power electronics based hardware-in-the-loop for the genset and HKECS.
- Proposing an approach to obtain the power-frequency characteristic to share power among generators and to operate at suitable operation point of the genset.

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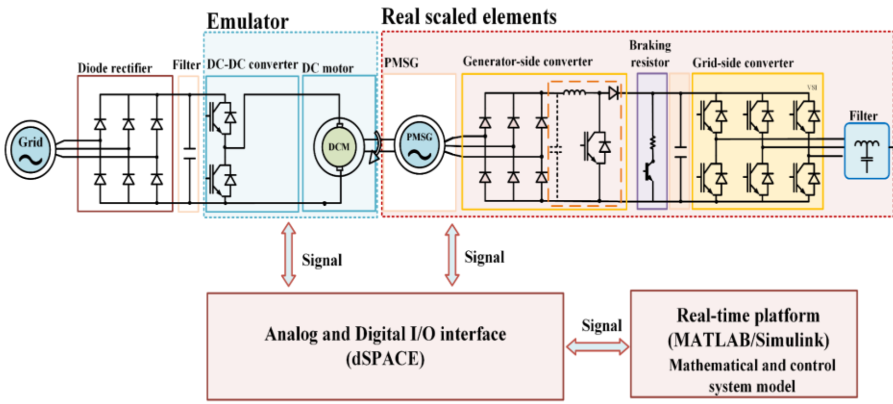
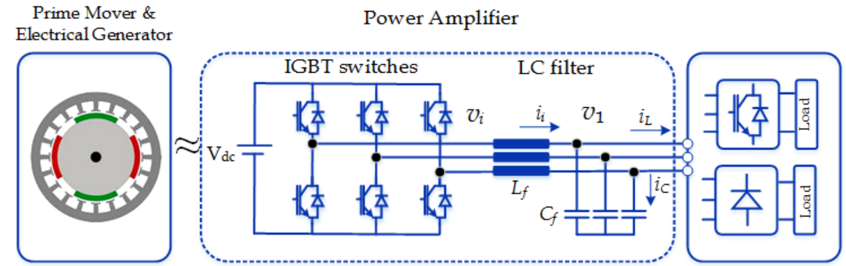
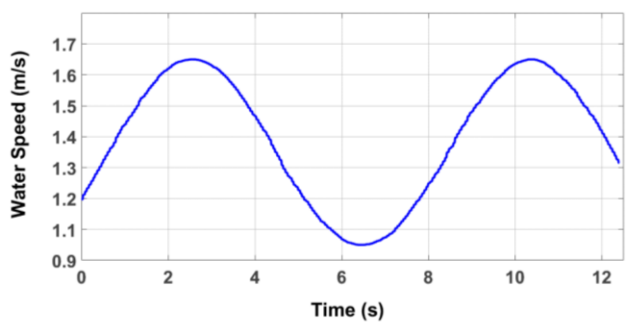
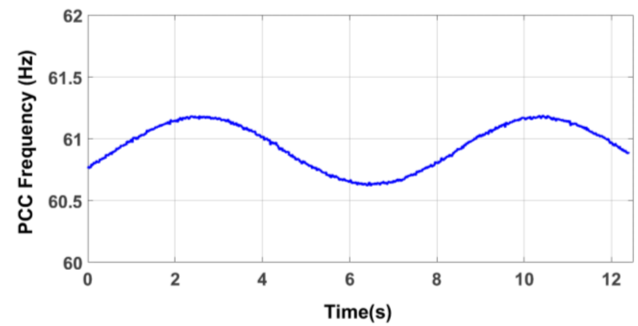


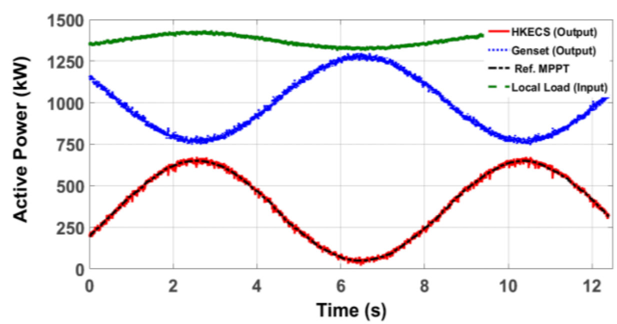
Electromechanical-based hydrokinetic energy conversion system emulator

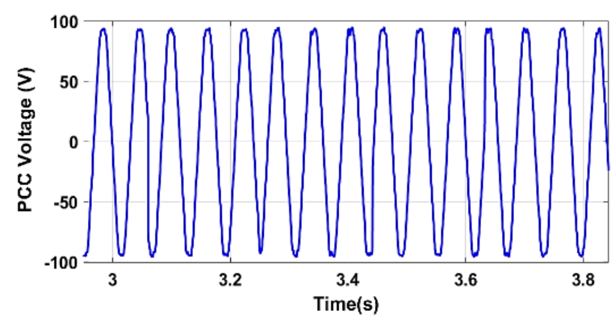


Converter-based hydrokinetic energy conversion system and genset emulator





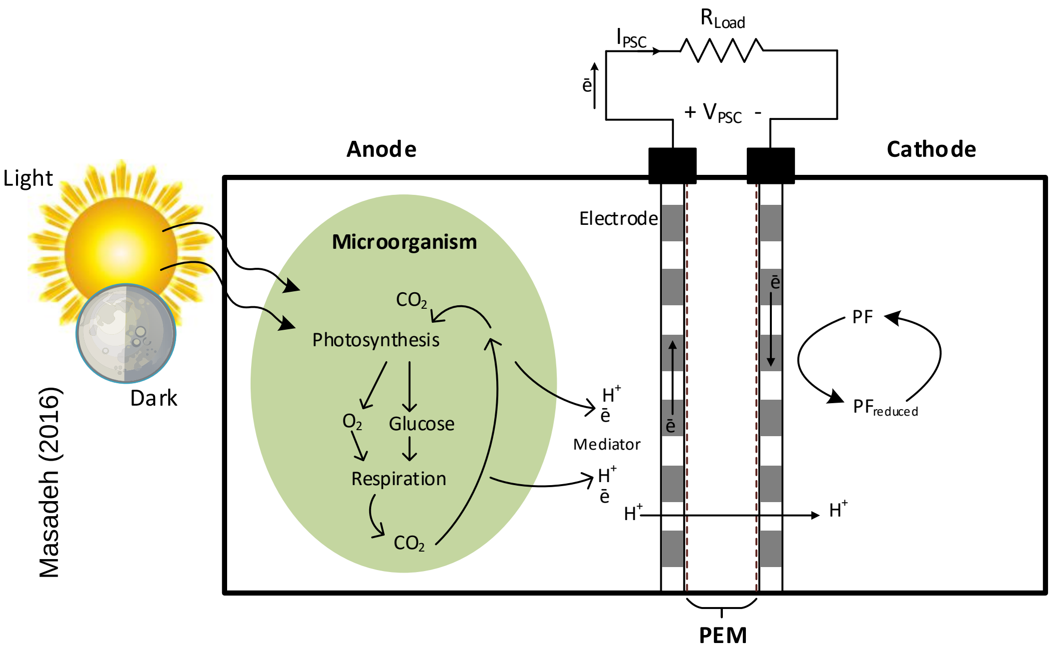




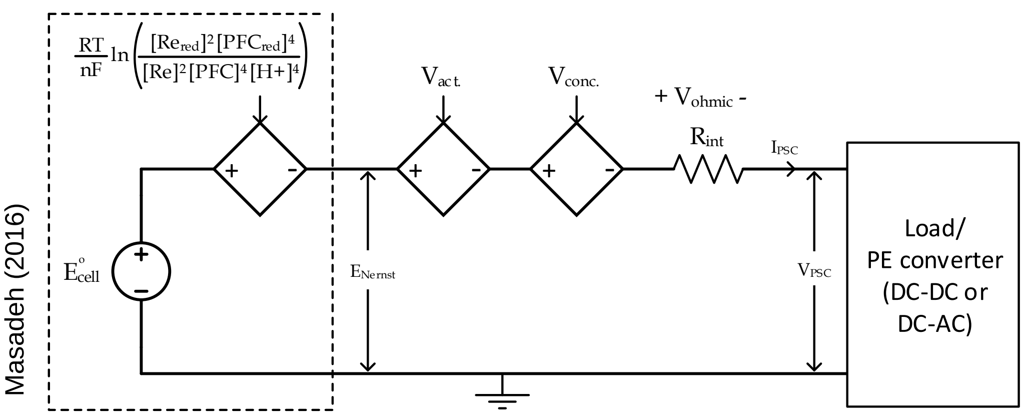
The test results for the storage-less hydrokinetic-diesel system; the genset is run with droop control mode operation. The frequency of no-load and droop derived gain are set at 62 Hz and 0.001052 Hz/W, respectively.

Photosynthetic Fuel Cells for Solar Energy Harvesting

Jonathan Maisonneuve



Schematic of micro-photosynthetic fuel cell



Equivalent circuit of fuel cell

Background

- During photosynthesis and respiration electrons and protons are released
- When this occurs in the presence of a selective membrane, protons will pass through the membrane while electrons are directed outside the cell and across some load.
- This produces electric power with inputs of sunlight, water and CO_2 and outputs of O_2 and H_2O

Modeling

- An equivalent circuit representation of the chemical and electrical processes is under development

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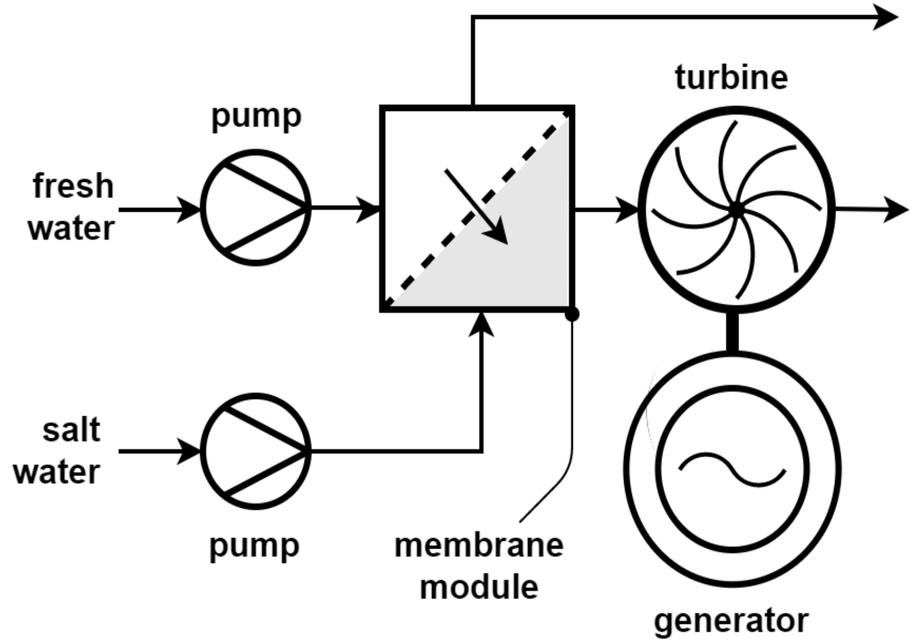
Osmotic Power for Remote Communities in Québec

Remote communities in Québec

Background

- There are 21 communities in Québec that are supplied by local diesel-generated electricity
- The electricity rate in some of these communities is > 1.00 $/kWh
- Power available in natural salt gradients represents a large untapped source of renewable energy, with potential for Quebec estimated at 12.5 GW



Osmotic power system

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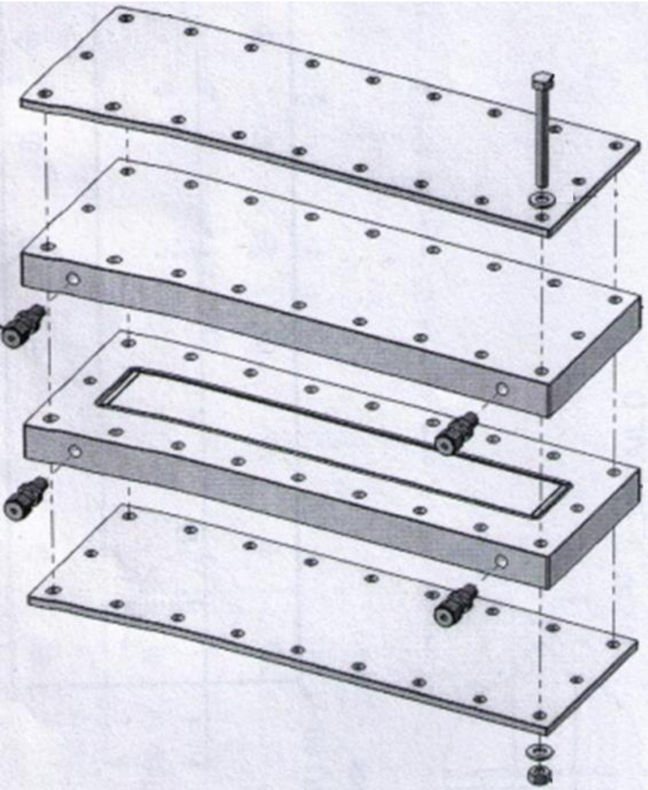
Experimental Set-Up

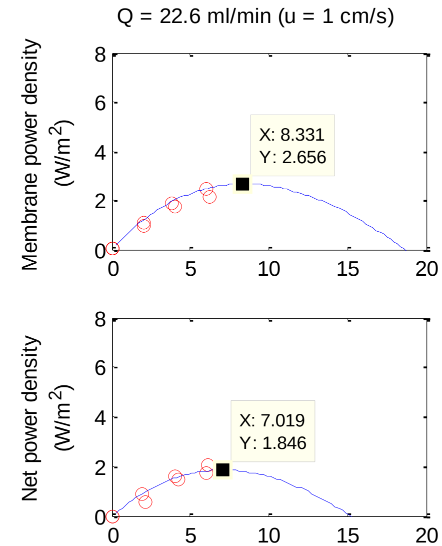


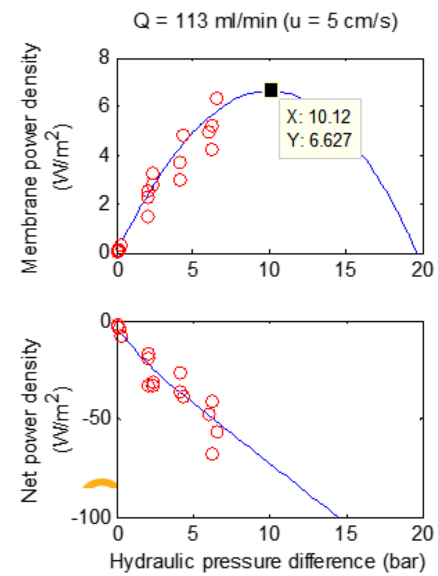
Custom cell for housing the membrane samples

Laboratory bench unit
at LTE Hydro-Québec

- **Membrane power densities of up to 7.1 W/m^2 were obtained under standard test conditions. These are the highest reported in the literature for a commercial membrane.**
- **The influence of flow rates through the membrane was shown to have a significant influence on membrane power and net power. By careful adjustment of these parameters it was demonstrated that net power can be maximized.**

Results





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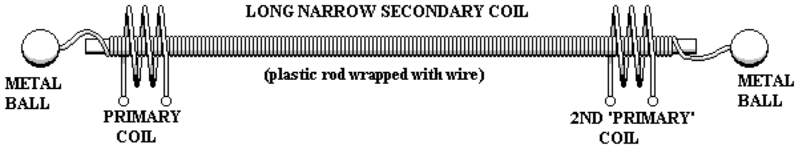
Experiments With Flat-spiral Coils for Single-Wire Non-Earth Return Power Transmission

Andrew Jensson

Background

- There are various methods to transmit power and signals over different media, some past experiments have been replicated with the intent to transmit power as a 'true' single-pole or single-phase topology.
- Current single-phase technology utilizes two-phases, commonly referred to as line and neutral; this is not a 'true' single-pole system such as designs produced by inventor Nikola Tesla but likely received the name from the single winding utilized of a three-phase generator.
- Transmitter and receiver coils are built as a resonant pair identical in construction except the winding direction is reversed in the receiver coil.
- Tests are performed to validate the characteristics of a the setup consisting of the transmitter and receiver coils connected with a single-wire on the outer end of their flat-spiral and an elevated spherical capacitor connected to the inner end.

- These experiments utilize are a down-scaled replication of a design patented by Nikola Tesla in 1900.



Similar system layout showing single-wire and spherical capacitor
Photos : http://amasci.com/tesla/tmistk.html

Objective

Develop characteristic model of flat-spiral coils in the application of single-wire power transmission without a separate return conduction path, I.e. earth, radiation propagation, etc

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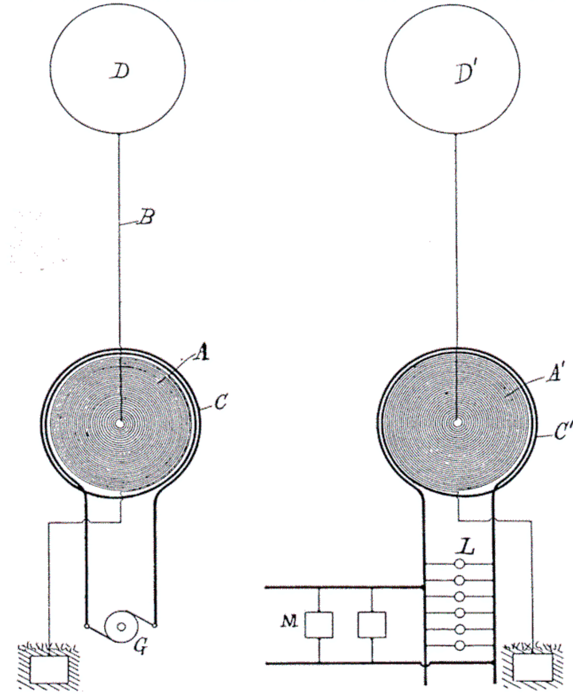
Proposed Experiments

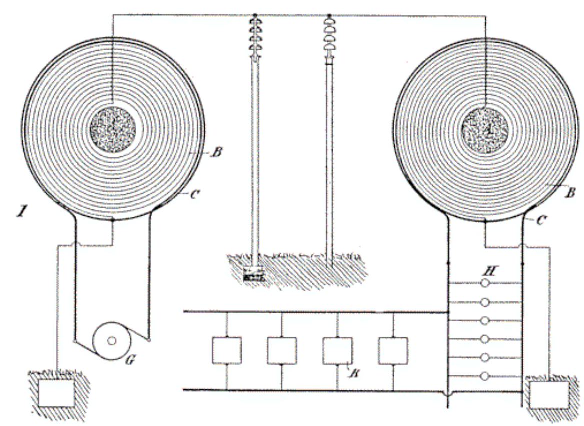
- Place transmitter and receiver at a fixed distance between them while increasing the single-wire length connecting them.
- Connect transmitter and receiver with a fixed single-wire length and move the receiver away from the transmitter at regular intervals.
- Set the distance and single-wire length at fixed value and sweep the frequency of the input generator.
- Each experiment above reveals important characteristics of the flat-spiral coil specifically in the application of power transmission over a single-wire.

Scientific Contribution

- There is not much known about the experiments of Nikola Tesla after his alternating current inventions. Greater understanding of some of his fundamental inventions may lead to new techniques to.utilize,transmit and generate electrical power.



Tesla 'wireless' transmitter patent drawing



Tesla single-wire transmission patent drawing

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Merci

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