Tropical Cyclone Intensity Estimation and Forecasting using Satellite Imagery and Deep Learning

submitted in partial fulfillment of the requirement
for the award of the Degree of

Bachelor of Technology
in
Computer Science and Engineering (Data Science)

by

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under the guidance of

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April 2024

Certificate

This is to certify that the Project entitled "Tropical Cyclone Intensity Estimation and Forecasting using Satellite Imagery and Deep Learning" has been completed to our satisfaction by Mr. Mohammed Saad Mukhtar Ahmed Belgi, Ms. Aditi Nilesh Bhutada and Ms. Janhavi Ram Deshmukh under the guidance of Prof. Jignesh Sisodia for the award of Degree of Bachelor of Technology in Computer Engineering from University of Mumbai.

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April 2024

Project Approval Certificate

This is to certify that the Project entitled "Tropical Cyclone Intensity Estimation and Forecasting using Satellite Imagery and Deep Learning" by Mr. Mohammed Saad Mukhtar Ahmed Belgi, Ms. Aditi Nilesh Bhutada and Ms. Janhavi Ram Deshmukh is found to be satisfactory and is approved for the award of Degree of Bachelor of Technology in Computer Engineering from University of Mumbai.

External Examiner	**Internal Examiner**
(signature)	**(signature)**
Name:	**Name:**
Date:	**Date:**

Seal of the Institute

Statement by the Candidates

We wish to state that the work embodied in this thesis titled "Tropical Cyclone Intensity Estimation and Forecasting using Satellite Imagery and Deep Learning" forms our own contribution to the work carried out under the guidance of Prof. Jignesh Sisodia at the Sardar Patel Institute of Technology. We declare that this written submission represents our ideas in our own words and where others' ideas or words have been included, we have adequately cited and referenced the original sources. We also declare that we have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in our submission.

Name and Signature:
1. Mohammed Saad Mukhtar Ahmed Belgi
2. Aditi Nilesh Bhutada
3. Janhavi Ram Deshmukh

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Contents

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List of Abbreviations

ADC	Analog to Digital Converter
ASIC	Application Specific Integrated Circuit
CC	Current Controller
DSP	Digital Signal Processor
FPGA	Field Programmable Gate Array
HIL	Hardware-In-the-Loop
IM	Induction Motor
ISR	Interrupt Service Routine
LQR	Linear Quadratic Regulator
LCL	Inductor-Capacitor-Inductor
PCC	Point of Common Coupling
PID	Proportional Integral Derivative
PLL	Phase Locked Loop
PWM	Pulse Width Modulation
SEQUEL	Solver for circuit Equations with User defined Elements
VSI	Voltage Source Inverter
VS-PWM	Voltage Source Pulse Width Modulation
SRF	Switching Ripple Filter

Abstract

Tropical cyclones pose significant threats to coastal regions, including the Indian Subcontinent, often resulting in substantial economic losses and profound impacts on communities. Accurately estimating and forecasting cyclone intensity, measured by maximum sustained wind speeds and central pressure, is critical for disaster relief agencies to plan effective evacuation and relocation efforts, ultimately saving lives and minimizing property damage. Satellite imagery provides vital data on a storm's structure, cloud patterns, eye structure, convective activity and evolution over time, and can be utilized for real time intensity estimation. Our project presents a deep learning based solution for this task, utilizing deep Convolutional Neural Networks (CNN) to extract meaningful information from satellite images. We have used a dataset consisting of more than 30,000 images (184 cyclones) to train and compare performances of ResNet-18, ResNet-34 and Resnet-50 architectures for regression of central pressure of the cyclone. Furthermore, we have experimented with Inception architecture with and without residual connections, as well as aforementioned models for the task of intensity grade classification. We plan to utilize sequential information for forecasting and develop a real-time forecasting module in the next stage of our project.

Chapter 1

Introduction

< Introduction of your project should be here>
This work is concerned with the issues of emulating different loads using power electronic converters. The scope of the problem as follows:

- To implement models of machine type loads.
- Study issues of modelling machine type loads under faulted condition.
- Study issues of modelling solid-state loads (thyristor converter).

In developing motion control systems it is common practice to employ simulators to experiment with proposed designs and their effect on the performance of the system. These simulators are typically implemented on a digital computer using a high-level language program to solve a system of differential equations in a time-stepping fashion.

Due to the lack of accurate mathematical models of many physical systems, experiments cannot be completely eliminated in real-time. In an effort to fill in the gap between digital simulations in a computer and final experiments on the product, Hardware In- the Loop (HIL) has become a widely adopted technique. HIL typically refers to a system where some of the hardware or mechanical devices are replaced by controllers interfacing in real-time with sensors and actuators [1]. With a HIL system, one can finish most of the design and test iterations in a highly efficient highly flexible environment, as long as the HIL is an adequately realistic representation of the actual plant. The fidelity of the HIL system depends on how well it emulates the dynamics of the replaced components or subsystems. This is the motivation of dynamic load emulation. However in this research work a different approach is proposed for real-time load emulation using HIL system. The system uses the real controller running in its own processor, but rather than a real load connected to the converter, the controller acts on a simulation of load model and draws required currents of the actual system from the source.

For example, manufacturers of inverters will normally test prototype and preproduction equipment with a standard induction motor. This, motor may not always have the desired characteristics for a particular test, or may not be well matched to the intended application. The same arguments apply for generation applications which utilize power electronic conversion equipment. It is also the case that, in some testing situations, the manufacturer may wish to include characteristics of the mechanical load or prime mover. For instance, when testing an electric vehicle drive inverter, it would be useful to load the inverter with something which represents the characteristics of the vehicle during particular driving conditions. Similarly, a machine tool manufacturer may wish to test electric drive inverters with loads which characterize the dynamics, duty cycles and work piece variations of the machine tool. With these arrangements, long-term thermal tests can be carried out under realistic conditions. A similar benefit could be obtained in a generation application, for instance, in a variable speed wind generation system. Here, the generator is producing power in accordance with a randomly varying wind source. This subjects the power converter to randomly varying conditions, which are difficult to replicate in a test laboratory.

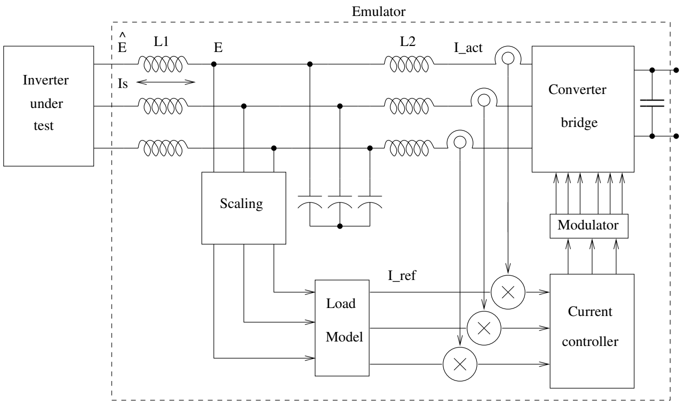

Figure 1.1: Load Emulation block diagram.

This report presents a new idea to overcome the above testing difficulties in the form of a 'virtual load'. The load emulation is composed of a bidirectional power converter, real-time digital system and a closed loop control system. The real time system is described below produce a programmable load/source, which can be connected directly to the power electronic inverter as a replacement for an electrical load. There may be some confusion between the inverter and the converters which form the virtual load, as shown in Fig. 1.1 'inverter' will be taken to mean the inverter being tested and 'converter' will be used to describe the power electronics in the virtual load. The virtual load is effectively a power level active impedance. It is important to realize that the virtual load is capable of bidirectional power flow and also transient and steady-state operation. These features allow it to emulate the characteristics of a wide range of electrical machines and their associated mechanical loads. The complexity of the emulation is limited only by the capability of the bidirectional power converter and the real-time simulation which controls it.

Bidirectional power converters are now commonplace. The special feature of the converter used for the emulation role is that it must act at least as fast as the inverter being tested. A priori the assumption might be that the converter needs to be very fast, and that this might threaten the viability of the idea. In practice, the converter is used in conjunction with energy storage (i.e. inductors), which effectively slow changes down and reduce the bandwidth required.

1.1 Motivation

< Motivations for your project should be here>
This work was motivated by the need to emulate the loads which allows the user to test both the hardware and the software of the inverter. The virtual load can provide different load characteristics with which the control algorithms and inverter design can be tested. The flexibility of the load emulation allows the designer of the control algorithms to experiment with different designs safe in the knowledge that if something goes wrong expensive damage to the inverter and machine will not result. A rotating machine cannot be stopped instantly: it has inertia. The load emulation contains no rotating parts, it is made up of fast acting power electronics which can handle a fault situation and prevent unnecessary damage.

The load emulation system has regeneration capability, as the power flow from the inverter can be returned to the mains supply. When testing an inverter with an actual machine, the machine uses this power for rotation and it is therefore lost. As well as being a small energy benefit this also reduces the laboratory power supply requirements.

1.2 Objectives

< Objectives of your project should be here>

- To study various Real-time simulation methods.
- To study various current control methods.
- Detailed simulation of current controllers such as: 1. Synchronous reference PI regulator. 2. Hysteresis current controller. 3. Dead-beat current controller.
- To investigate the issues involved in the use of power electronic converter to emulate electrical loads.
- Design and implementation of experimental setup for virtual load emulation.
- Analysis, simulation and laboratory implementation of 'virtual Machine' in steady state as well in transient condition.
- Study issues of modelling machine loads under faulted condition.
- Study issues of modelling solid-state loads (thyristor converter).
- To study and simulation of interface impedance for various load models.
- To study and simulation of bidirectional power flow for AC to AC converter.

1.3 Problem Statement

< Problem Statement of your project should be here>

1.4 Contributions

< Contribution of your project for solving the stated problem should be here>

1.5 Layout of the Report

< Layout of your project report should be here>
A brief chapter by chapter overview is presented here.
Chapter 2: A literature review of different real-time simulation methods for load emulation is presented.
Chapter 3: Experimental setup, digital signal processor system, inverter, PWM generation will be described in this chapter.
Chapter 4: In this chapter, the most essential information on dynamical system model, Reference frame theory and basic equations for virtual machine are presented.
Chapter 5: Survey on current control methods are presented in this chapter. Investigation on the basic performance of current controller will be made using circuit simulation software SEQUEL. The results obtained from simulation are discussed.
Chapter 6: Some of the important design issues will be highlighted in this chapter. Being a non-ideal device, the inverter has many drawbacks. Dead-time between the IGBT switching, resistive voltage drop of the switching components and the DC-link voltage fluctuations have been identified as the most problematic non-idealizes. Analysis of the adverse effects of these problems and compensation methods will be the focus of this chapter.
Chapter 7: The problem of ripple output at the inverter legs and bidirectional power flow will be the focus of this chapter.
Chapter 8: Conclusions and discussion on future course of research work.

Chapter 2

Literature Survey

< Literature survey for your project should be here>
The main objective of the load emulation is to control the current drawn from the inverter to match the current, which would be drawn if it were connected to a real load. It achieves this by connecting the inverter to a power electronic AC/AC converter via an appropriate interface impedance. The power electronics of the virtual load simply consists of two back to back, three-phase, six-switch, bridge converters in conventional fashion. This arrangement allows bidirectional power flow to and from the inverter. The power electronics is then controlled by the real time system (DSP) to draw/source the currents to emulate the electromechanical system on an instant by instant basis.

2.1 Characteristics of Real-Time Systems

As sequentially operating digital computers implement the control algorithm, it is crucial to provide appropriate computing power. The required computing speed depends on the time constants involved. power electronics systems operate in 'real time' which is a synonym of 'natural time'. Therefore, the control system must synchronize its operations to real time. The correctness of a real-time system depends not only on the logical result of the computation but also on the time at which the results are produced. Real-time systems have to respond to externally generated stimuli within a finite and specified delay. Whereas a deadline can be missed occasionally in 'soft real-time systems' such as on-line data banks, it is absolutely imperative for 'hard real-time systems' that responses occur within the specified deadline on each and every occasion [2]. This does definitely apply to power electronic control systems. Digital control systems constitute discrete-time sampled systems. With regard to power electronic systems, real-time operation typically involves control and sampling cycles in the range of 20 - 200 μs for normal operation. However, in case of fault situations, a reaction time of less than 1 μs might be required [3].

2.2 Classification of Real-Time Simulation

Testing and simulation of control algorithms is an important phase in the development of embedded control systems (ECS). Different types of simulation are possible during the design process of a controller [4] [5], ranging from simulation without time limitations, to partial real-time simulation in which only some parts of the complete control loop are simulated.

The initial functional evaluation of a control design is usually performed by off-line simulation of the control algorithm and the system. A successful evaluation leads to further tests and optimization under real-time conditions. These tests aim to improve the ability of a control design (1) to operate in real-time and (2) to interact with real equipment. Interaction with real equipment requires a large variety of interfaces. Currently the interaction with equipment relies increasingly on complex and powerful digital interfaces replacing analog interfaces to sensors and actuators. Digital interfaces generally yield a more noise immune data transfer and facilitate additional auxiliary features such as diagnostics.

A functional control prototype is required for the validation under real-time conditions. Usually the final control hardware is not yet available at this stage. Instead, rapid prototyping methods are used to provide an early functional real-time prototype of the control system. For this prototype, the functional behavior of the control system is reproduced by an emulator. The emulator requires flexible and powerful hardware structures in order to achieve real-time operation and interaction with either a real or a simulated environment.

Real-time simulation allows comprehensive and safe tests in the laboratory if tests in the real environment are not feasible or desirable. It simulates the entire load system under normal and fault conditions. Digital simulation offers several appealing advantages over analog simulation with regard to the dynamic range of variables, flexibility and reproducibility of results for each performance etc. Digital real-time simulation is much more challenging than control system emulation because it has to operate five or ten times faster than control systems to avoid delays which may generate artificial low frequency effects. Thus, digital real-time simulation demands very high performance of its underlying hardware structure. The use of parallelism inherent in large systems is inevitable and has to be reflected in a similar parallelism in the simulator hardware.

Chapter 3

Design

<Draw UML Diagrams and System Diagrams here>
To accurately implement the load emulation in real-time a multiple processor system may required. Fig. 3.1 shows the block diagram of closely coupled DSP system. In this system separate processors are employed to carry out data acquisition, communication and control for load emulation. This system is based on Texas TMS320vc33 DSP. In order to get flexible I/O interface and data acquisition, this system has two processors and a FPGA on single board. It provides interface between the USB controller and the DSP via Link Interface Manager (LIM) using Texas MSP430F168 Micro controller. Communication between PC's USB port and MSP 430F168 micro controller is done using Texas USB controller TUSB3210. DSP is used as a controller which executes the algorithms that control the converter via ASIC. Micro controller carries out data acquisition, storing real-time data, also can be used to transfer the data to PC for graphical display. The LIM is also interfaced to sensor unit for data acquisition. ASIC is used to carry out the pulse width modulation (PWM) for controlling the converter.

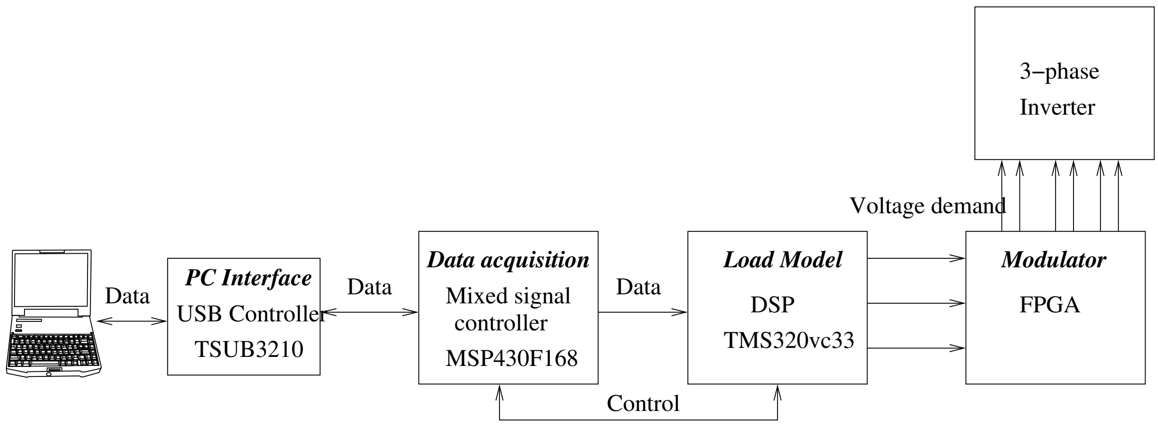

Figure 3.1: Block diagram of closely coupled DSP system.

The system requires the following I/O functions:
(a) Sampling of three line currents: Even if two line currents are sufficient due to the symmetrical nature of the load, it is important to have the third line current also sampled for the evaluation purposes. This requires three A/D converter inputs.
(b) Sampling of three line voltages: Even if two line voltages are sufficient due to the symmetrical nature of the load, it is important to have the third line voltages

also sampled for the evaluation purposes. This requires three A/D converter inputs.
(c) DC link voltage sampling: Since DC link voltage is used as a measured signal in the control algorithms, this will require another A/D converter input.

Chapter 4

Implementation

<Implementation Details should be here>

The table 4.1 is an example of referenced LaTeXelements.

Col1	Col2	Col2	Col3
1	6	87837	787
2	7	78	5415
3	545	778	7507
4	545	18744	7560
5	88	788	6344

Table 4.1: Table to test captions and labels

Chapter 5

Results and Discussion

< Results of your project should be here>
The previous chapters have been concerned with proving the machine modeling and elements of the process. The progression is made to the load emulation system, only by removing the real machine and replacing it with a bidirectional converter controlled by the real-time motor model. The real-time motor model effectively sets the current demands for the bidirectional converter. A measure of the success of this control is to compare the resulting currents to the virtual machine with the currents demanded by the real-time motor model.

Chapter 6

Conclusions

< Conclusion of your project should be here>
An load emulation environment has been presented which is capable of simulating a electrical load in real-time. In this research the fundamental objective of the load emulation is to provide a simulated electrical load to allow an inverter to be tested at real power levels without the requirement of an actual load. The load emulation replaces the actual load during the testing and development stages of the inverter design, thus providing a safer and more flexible development environment. The ability to simulate an electrical load in real time is one of the key elements which facilitates in the load emulation.

The primary analysis and results show that acceptable accuracy can be achieved in real time using a digital signal processor dedicated to this task. The second requirement of the load emulation is the ability to draw current from the inverter equal to that predicted by the real time load model. To do this, the load emulation incorporates its own internal bidirectional converter which acts as a controllable voltage source. A current control loop ensures that this converter together with three-phase line inductors draw the appropriate current from the inverter. The transient response of the current loops determines the tracking accuracy between the demanded and actual current drawn from the inverter being tested. The passive components in the load emulation (i.e. the line inductors) act to slow the response of the system.

The future course work will be focused on an industrial induction motor drive, and to simulate virtual machine. It will be at real levels of voltage and current, the behavior of the actual machine. The results of testing a standard ‘off-the-shelf inverter with the virtual machine will be compared with those obtained by testing the same inverter with the actual machine.

Chapter 7

Future Scope

<Future Scope of Your Project should be here>

Chapter 8

Research Publication

<Research Publication of Your Project should be here>

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