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Module	EDRP402: Honours Project

A Comparative Analysis Of Different Modelling Paradigms For Real-Time Digital Twin Development: White-Box Vs Black-Box Modelling.

Introduction

A digital twin is a real-time virtual copy of a physical system that continuously receives data from sensors to replicate the actual system's behaviour and performance in a computer simulation. These virtual replicas have become essential tools in modern manufacturing and engineering, enabling companies to monitor equipment, predict failures, and optimize operations without interrupting actual production.

They range from:

- **Part-level**: A digital twin mimicking the performance of a unit part/component (e.g., a DC motor)
- **Asset-level**: A digital twin replicating the behaviour of a complete functional unit (e.g., a functional robot made up of multiple parts)
- **System-level**: A digital twin representing an entire operational system (e.g., an entire factory)
- **Network-level**: A digital twin modelling interconnected systems (e.g., networks of IoT connected factories at different locations)

Objective

The goal of this project is to investigate and find out which modelling paradigm between black-box and white-box is most suitable for efficient digital twin development. To figure this out, the project focuses on ‘part-level’ modelling, which is the fundamental building block of any complex system or network of systems. A 3-phase induction machine has been chosen as the part to be modelled as it is readily available, widely used in industry and sufficiently complex for a meaningful comparative analysis. The findings of the investigation might as well help inform decisions when developing digital twins for other electro-mechanical systems apart from induction motors.

30 July 2025

Deliverables

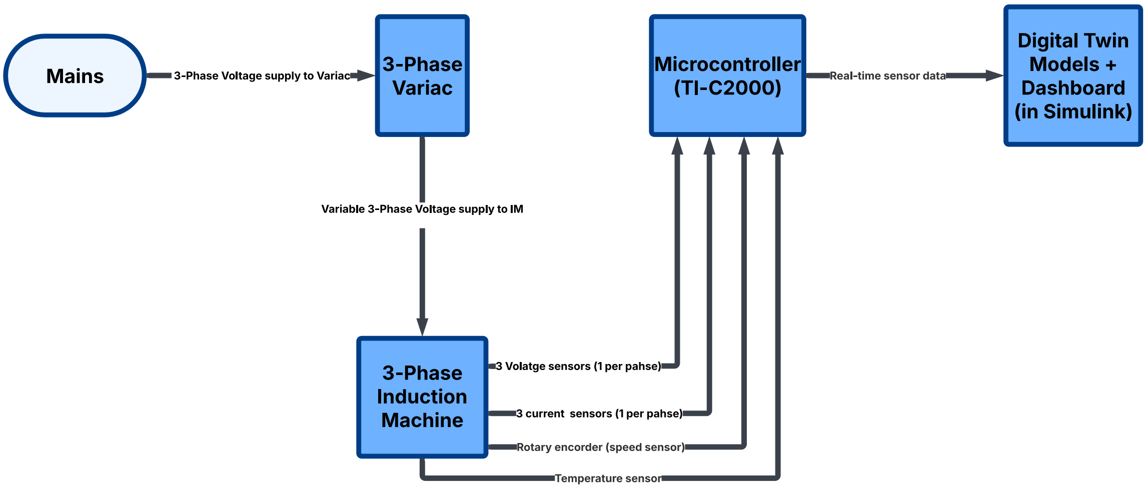

Figure 1: Project setup block diagram

The project aims to:

- Develop a physics-based analytical (White-box) model of a 3-phase induction machine
- Using the setup in Figure 1, acquire performance data to develop a data-based (Black-box) model of a 3-phase induction motor using System Identification
- Map both models into digital twins by real-time integration with the physical machine using the setup in Figure 1.

The performance of both digital twins is then analysed against the physical machine on the following benchmarks:

- **Accuracy**: Which model creates the most accurate digital twin compared to the physical system (at steady-state performance and transient response)
- **Real-time Performance**: How fast can the model handle data updates
- **Development Complexity**: Resource requirements and time investment for model creation and calibration