

MSc Thesis Proposal

Graph Neural Network-Augmented Deep Reinforcement Learning Maintenance Optimization of Energy Infrastructure Networks

- Context of the research

In recent years, Deep Reinforcement Learning (DRL) algorithms have been increasingly used for operation and maintenance (O&M) optimization of energy infrastructure, owing to its ability to learn optimal decision policies through direct interaction with the environment, without explicit modeling of system dynamics or prior knowledge of the underlying environment dynamics or optimal strategies. By framing maintenance optimization (MO) as a sequential decision problem (SDP), DRL enables adaptive and data-driven MO under uncertainty.

Despite these advantages, the application of DRL in MO of energy infrastructure networks is faced with a number of challenges related to temporal abstraction and delayed rewards; specifically, when the condition monitoring signals providing information on the health states of network components are collected at high temporal resolutions, whereas maintenance interventions can only be performed at operationally feasible intervals (e.g., weekly, or monthly intervals). Aligning the decision timesteps with these feasible maintenance windows inevitably results in loss of critical information regarding the intermediate system state transitions taking place within decision intervals. Additionally, component failures are less frequent in networks operating at high availability levels; while desirable from an operational perspective, this characteristic introduces a “sparse reward” problem. These different temporal dynamics and sparse reward signals may hinder the policy learning, leading to pre-mature convergence to suboptimal solutions.

- Objective of the research

The goal of this research is to propose a DRL-based framework for the maintenance optimization of energy infrastructure networks, whose components are subject to dependent competing failures, while considering the underlying uncertainties related to the operating conditions and their effects on network performance. The proposed methodology formulates the MO problem as a SDP, solved using DRL through the Proximal Policy Optimization (PPO) algorithm. Graph theory is used to model the network characteristics and interdependencies. Loss of information associated with intermediate state transitions is mitigated by developing a Graph Neural Network (GNN) model that learns informative features to, subsequently augment the environment state vector provided to the DRL agent, thereby, preserving the system degradation dynamics and improving temporal credit assignment problem. The research activities include:

- familiarization with graph theory and sequential decision problems
- literature review of DRL and GNN applications to O&M optimization of energy infrastructure
- development and evaluation of a GNN model for network performance analysis, and a DRL-based MO framework, integrating the developed GNN model
- applying the proposed DRL-based MO framework to a case study and evaluating the optimized maintenance policy against the conventional and condition-based policies
- analysis and interpretation of the obtained results.

- Required skills

- Interest in developing innovative algorithms to address real-world applications.
- Good knowledge of statistics/applied mathematics and AI/ML technologies and techniques.
- Good knowledge of Python and/or R programming languages, with a focus on DRL.

For further information, please contact:

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