My primary research interests focus on **Machine Learning and Optimization**, and their applications in **Energy Systems**. Being a graduate from **Indian Institute of Technology (IIT), Dhanbad** with majors in **Electrical Engineering**, I have always been driven towards working on innovations related to Smart-Grids. Besides this, the documentary on AlphaGo and its portrayal of how artificial intelligence (AI) can delve into the uncertain corners beyond what human minds can think of, hooked me to the fascinating **applications of reinforcement learning (RL)**. More recently, my research vision got shaped by the experience at **Microsoft Research (MSR), India** where my work revolves around building **"Technology for Emerging Systems"**. Although RL has several shortcomings in its real-world deployability, I believe working on defining safe policies and constrained action value pairs can potentially solve several complex problems in electrical energy sciences. Hence, through graduate studies at University of Cambridge , I plan to develop reliable and affordable AI-enabled solutions, robust-enough to drive sustainability goals in the next-generation energy system dynamics.

Research on Applied Reinforcement Learning and Optimization

In the recent past, with the evolution of artificial intelligence (AI), there has been a lot of interest in how to cater to the needs of modern Power Systems. At MSR, I work with Dr. Akshay Nambi, Tanuja Ganu and Dr. S. Kalyanaraman on applying machine learning for optimization and control in distributed energy resources. Specifically, my work explores various RL techniques, stochastic and traditional optimization algorithms that solve the physics-based constraints associated with power systems. To begin with, I worked on a **carbon arbitrage (CA) scenario** involving the reduction in carbon footprints of the customers of a **Microsoft's partner organization** in Ireland. Here, scheduling the batteries to charge and discharge accurately at the correct time periods plays a vital role. Thus I developed a **gym-compatible environment** that captures the dynamics of the battery, including the battery degradation process, updating the state of charge of the battery, and other configurations. Then, I compared the yearly carbon savings across various optimization algorithms alongside a simple percentile-based Heuristics model. Discrete RL algorithms accurately suited the problem because of the step-actions taken by the battery i.e. to charge, to discharge, or to stay idle. Through the results, I demonstrated that the neural network-based policy learners outperform the traditional algorithms in the presence of forecast errors with sufficient training data.

Energy operators face several challenges while applying classical RL to large-scale real-world environments because of its learning-by-doing nature. The amount of data collected online while interacting with the environment may also be limited, making it difficult for the RL agent to learn anything useful. Therefore, I worked on **OfflineRL** [1], namely on Conservative Q-learning (CQL) algorithm to solve the problem for CA scenario. I proposed to first use Model Predictive Control to solve the objective functions of the scenario by maintaining the constraints on the historically available datasets and then make our own Markov Decision Process based Datasets for the data-driven OfflineRL approach which is used as a supervised learning dataset. The performance boost of the OfflineRL approach compared to a simple RL agent trained from scratch showed the superiority of the procedure. This led to a **successful integration** of an example scenario to our Decision Management framework, **"EnCortex"**. More recently, my focus has been on developing the core energy abstractions, paired with modular and extensible optimization algorithms for "EnCortex". Also, my current vocation involves making the framework compatible enough to handle a range of use cases in the energy domain. It is now offered to a large global **energy partner of Microsoft** for wide scalability and is under **patent** review rights.

Getting a deployed agent to interact with the environment i.e. Learning from Demonstrations (LfD) for solving its exploration-exploitation trade-offs can prove to be detrimental in critical systems. Hence, to have the environment interactions performed as a pre-processing step, I experimented on **imitation learning** or more specifically **behaviour cloning**, where I used a trained RL expert to extend its learning to a new agent working on a similar environment. This benefits the energy operators to train the optimizers without having the need for large datasets. The results being promising, with "EnCortex" as a novel one-stop solution for Energy Management Operators, the work has been submitted for publication at a **top-tier Systems Conference** [1].

Research on Energy Systems

In my Sophomore year, I was introduced to an exciting line of research in **hybrid distributed generation systems**. Integration of advanced computing and communication technologies into these systems opened up an array of intriguing research directions to explore. To devise methods for enhancing efficiency and reliability of future power systems, I collaborated with the following academic research professionals to work on the front:

- I worked with Dr. Swades De as an intern at **IIT Delhi**. I carried out research in the areas of fault analysis in distribution systems and worked on **Synchro-phasor measurement units (PMU)** based anti-islanding mechanisms within micro-grids. With different types of faults, varying fault resistances, and location of fault inducement in the buses, I generated a **fault-detection Dataset** for later research.

[1] also referred to as BatchRL

- For my Bachelor's thesis [2] at **IIT Dhanbad** under the supervision of Dr. K. Chatterjee and Dr. B. K. Naick, I extended the work done at IIT Delhi, to classify whether islanding has occurred or not by accurately shaping the rewards of **Asynchronous Advantage Actor-Critic (A3C)** algorithm and showed a net boost in the overall performance of the method as compared to the state-of-the-art neural network models. But, because the procedure was computationally expensive, along with the vulnerabilities of getting overfitted to a particular environment dataset and its incapability of transitioning to larger bus systems as compared to the other algorithms, it was decided not to progress with this approach.
- Continued to being motivated in solving the problem, I worked with Dr. Soham Dutta on hosting capacity (HC) amendment in the distribution system to achieve energy sufficiency. Here, firstly for noise cancellation, I use Spectral-Kurtosis (SK) to extract the features of the faulted transient signals. Then, based on the optimized feature importance values, I feed in the extracted features to Histogram-based Gradient Boosting (HGB) algorithm for accurately predicting the fault type and location with improved confidence. The work has been recently accepted to **Electric Power Systems Research Journal** [3].

Energy systems require managing physical and cyber variables to monitor, communicate and control the evolving complexities. This calls for solving a new challenge: detecting security threats in the Cyber-Physical systems (CPS). The availability of fewer training instances under zero-day attacks motivates me to explore reliable one-shot learning Deep RL techniques as one of my potential future research interests during my graduate studies.

Research on AI for Social Good

Having interests in solving challenges faced in the wide adoption of e-Mobility, I worked as a research intern at MSR on modeling energy consumption (EC) of batteries in electric vehicles (EV). EV owners are generally concerned about untimely battery drainage causing **"range-anxiety"**. To address this, I identified the challenges faced in real-world EC modeling and proposed the nature of data required to understand the phenomenon, and developed a two-stage approach (by extensive feature engineering using domain knowledge) to predict the EC of an EV before the start of the trip. The explainability and interpretability of the proposed models, alongside the boost in performance over non-explainable neural network models, led to a **successful collaboration** with a large e-bus company in India. Also, the work recently got published in **ACM COMPASS'22** [4].

In my Junior year, I participated in **Smart India Hackathon'20** where we designed a pipeline that realistically simulates a microgrid for **MathWorks**. My main contributions included formulating forecasting algorithms for predicting renewable energies, load demands, and market spot prices. Additionally, I designed a scheduler to optimize the total microgrid cost per day. The promising results were recognized by the panel and we were declared the winner of the specific problem statement. Later, we published the work in **IEMRE'21** [5].

As a part of the Global Finalists in **ASEAN India Hackathon'21**, I worked on enhancing maritime coastal security. The vessels which emit Automatic Identification System (AIS) data streams can be detected and identified whereas small vessels like some boats do not have an AIS system setup, so they can get past without getting detected. Therefore, I developed a system that accurately detects vessels or boats in satellite images and outputs the latitude and longitude coordinates. The work, later, was published in **INCET'21** [6].

Hence, through the research experience gained across domains specific to (i) applied RL, (ii) energy systems and (iii) AI for social good, I realize the need for a strong theoretical foundation to pursue advanced research. In this direction, I have always striven for academic excellence - during my Bachelor, I graduated as the **Silver Medalist** of my cohort. Working with research professionals has helped me to better interpret and address the reviews and comments in paper submissions. I believe that having valuable soft skills like time management and working in collaboration with others are vital for survival in challenging academic settings.

I am really excited to contribute to the fields of optimization and control along with its applications in energy systems. Having motivation in how to design safe RL techniques, I want to delve deeper into the theoretical aspects of RL and have a better understanding of the risk-averse, constrained and worst-case criteria to be included in the exploration process. I have a strong desire to work with **Dr. David Krueger** in this regard. His outstanding works on reward hacking [7] and objective robustness inspires me a lot to dig deeper into the foundations of RL so as to fruitfully apply it to energy systems. I also aspire to work with **Y** , **Z** in problems involving various aspects of optimization and machine learning. I believe gaining this theoretical background would help me push toward my future goal of building next-generation energy systems.

In summary, I believe I bring with me, research experience, industry-tested programming, and engineering skills, soft skills, and, most importantly, an unquenchable thirst for knowledge and excellence. Therefore, a Ph.D. in Engineering from University of Cambridge is the next significant achievement I eagerly anticipate in my life.

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