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Household Energy Demand Predictions for IoT Systems

Leite, R.G., *P.G. Big Data Analytics, University of Liverpool*

***Abstract*—In modern societies, the ubiquity of computing devices highlights how data processing capabilities transitioned from revolutionary novelty to commodity. Lowering prices of smartphones, intelligent doorbells, or internet-enabled lightbulbs drive the creation of large software platforms responsible for the intensive computations requiring resources that would overwhelm more modest devices. Nonetheless, some use cases cannot cope with delays introduced by this type of distributed computation. For example, demand response proposals for smart electrical grids can expect millisecond-level thresholds. One possible way of mitigating this issue is by adding decision-making to the device itself. It is a case of edge computing that keeps a frequent communication channel with a large, distributed control plane always open. However, having a concise, deterministic algorithm that can handle cases like consumption forecasting seems beyond our current understanding of electrical engineering. This restriction points to the need for some form of pattern matching process constantly updated by a training feedback loop. The edge device would handle decisions by applying this model trained by the central platform. This document investigates the options available for proposals for time-series forecasting, including modern machine learning techniques. It investigated the feasibility and trade-offs expected to satisfy the technical challenges posed by this scenario.**

***Index Terms*—Machine Learning, Internet of Things, Edge Computing**

# I. INTRODUCTION

The importance of demand-side control of consumer-grade electrical systems has increased in popularity in the past decade. It is now discussed as an integral component of research areas such as Smart Electrical Grids and Distributed energy generation. The underlying motivation for bringing this topic to a more central position is the overdue modernization of electrical distribution systems worldwide. There is a departure from a centralized, unidirectional control system toward more fine-grained distributed models.

Some technological breakthroughs did not fit the legacy top-down communication model. For example, the introduction of Solar and Wind generation requires a much more agile response given the unpredictable nature of their availability. The operator started dealing with greater levels of variance that more slow-moving forecasting models could not reliably manage.

This landscape gave rise to energy aggregation services acting as coordinators independent coordinators. Industry players place bids on supply requirements advertised by system operators. It is the first step in decentralizing control. However, decentralizing the generation control still requires more fine-grained information dissemination.

This level of transparency enables proposals from the demand-side of the energy distribution equation. Research is often not tied to the same constraints imposed by routine business concerns. There are countless proposals for more radical communication architectures inspired by many disciplines, from Neighbourhood-level microgrids to multi-layered energy distribution cells, similar to cellular telephone zoning.

This restructuring shares the traits of similar past modernization endeavours. One often overlooked is moving consumers from passive receivers of information to active participants on updated digital platforms. These platforms moved from simple broadcasting to a much more immersive bidirectional channel. The advertisement industry was the first to exploit how to establish feedback loops to drive revenue increase.

There is no reason why Smart electrical systems could not follow this example. Updates in the distribution network require moving to the same digital planforms used by digital advertisement players. Therefore, there is little reason to reinvent consumer data extraction tools. Most importantly, this strategy enables leveraging tried and tested methods for handling privacy and cybersecurity.

This document explores the beginning of this journey. It aims to understand the best strategy for understanding consumer behaviour and its relationship to the energy distribution system. The focus is on developing a reliable tool for forecasting household demand as the first step toward fleshing out a fully digital, bidirectional communication medium.

It starts by disambiguating the acronyms involved in developing such systems. It must interact with newer iterations of older concepts, like Fog Computing. Moreover, it must also provide some guidance on terminology that seems well defined but still suffer from conflicting details. J. Kampars, et al., 2021, provide a comprehensive survey of the technological landscape. It explores the multiple overlapping concepts between the Internet of Things (IoT), Edge Computing, and Cloud Platforms.

Another relevant survey is B. Sudharsan et al., 2021. The authors present several options for energy demand forecasting on embedded platforms. While this document cannot reach the same level of depth, it is essential to understand the practical implications of connecting and distributing forecasting models across distributed networks.

Finally, A. T. Eseye and M. Lehtonen, 2020, discuss the standard machine learning techniques employed for this project. The document performs a comprehensive analysis of Artificial Neural Networks in roughly the same terms stated by this research's objectives. It also provides parallels with competing implementations using Support Vector Machines.

# I. METHODOLOGY

Multiple academic disciplines are involved in proposing a solid implementation for an ambitious Smart Grid system. A fully fleshed-out plan requires much more than examining candidate machine learning implementations. However, this study cannot spare the resources necessary to perform due diligence in all of the required aspects. Therefore, the focus will remain on the study of the decision-making process.

This focus on software implementation implies a primarily quantitative exploration of resource consumption. Since there is no candidate hardware platform, there are no expected limits. The scenario comes with extra tasks such as defining credible baselines so the researcher can reach some form of conclusion.

Nonetheless, some theoretical guidelines can form a comfortable guardrail. We are discussing a time-series forecasting problem that fits a well-established statistical mould. There are clear baselines for how effective a model can perform. Most importantly, this framework allows experiments to quantify each proposal's effectiveness level.

The intersection between computer science and statistical model evaluation defines the point where automated decision-making becomes a viable option. For example, inspecting the behaviour of a dataset will allow us to compute the error margins of doing nothing. Assuming that previous readings are close enough to the subsequent measurement, there is little reason to waste computing cycles.

With this baseline, we can look for algorithms to improve this score. This step lets us put computational costs in context and define a price-per-point accuracy boost. This evaluation can rely on well-established time and space complexity analysis. There is no point in discussing strategies for proper assignment of responsibilities of components in the distributed architecture of a Smart Grid system if we do not know the costs involved in each stage.

Space complexity will inform the memory capacity required to build adaptative models and evaluate decisions. The size of these artefacts also impacts the required network bandwidth to operationalise an appropriate response time. Finally, it will inform the storage requirements of the platform. Keeping a database of consumer profiles may allow more sophisticated inferences, but it can also be prohibitively expensive.

Time complexity will dictate the level of responsiveness of the system. We already discussed moving from a slow-moving, centralised forecasting plan to a distributed, fine-grained and responsive one. Generating and updating models can be a bottleneck that restricts response times. But also, forecasting times can hamper the agility of the solution.

# V. Conclusion

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Appendix

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References

A. T. Eseye and M. Lehtonen, "Short-Term Forecasting of Heat Demand of Buildings for Efficient and Optimal Energy Management Based on Integrated Machine Learning Models," in IEEE Transactions on Industrial Informatics, vol. 16, no. 12, pp. 7743-7755, Dec. 2020, doi: 10.1109/TII.2020.2970165.

B. Sudharsan et al., "TinyML Benchmark: Executing Fully Connected Neural Networks on Commodity Microcontrollers," 2021 IEEE 7th World Forum on Internet of Things (WF-IoT), 2021, pp. 883-884, doi: 10.1109/WF-IoT51360.2021.9595024.

J. Kampars, D. Tropins and R. Matisons, "A Review of Application Layer Communication Protocols for the IoT Edge Cloud Continuum," 2021 62nd International Scientific Conference on Information Technology and Management Science of Riga Technical University (ITMS), 2021, pp. 1-6, doi: 10.1109/ITMS52826.2021.9615332.

**Rodrigo Gonçalves Leite** (PG, University of Liverpool)

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