The 22nd International Conference on
Technical and Physical Problems of Engineering
ICTPE-2026
31 October 2026
International Organization of IOTPE

MACHINE LEARNING - ASSISTED UPS ENERGY MANAGEMENT AND XLPE CABLE HEALTH ASSESSMENT USING SMART METER DATA

S.M. Ahadzade, A.Y. Imanova, S.M. Ilyai, N.Z. Shahmuradov, E.R. Mammadzade

Institute of Physics, Ministry of Science and Education, Baku, Azerbaijan
Azerbaijan State Marine Academy, Baku, Azerbaijan
Azerbaijan State Oil and Industry University, Baku, Azerbaijan

Abstract - Modern distribution systems require reliable energy management due to the increasing integration of smart meters, sensitive electronic loads, and aging cable infrastructure. This paper presents an integrated framework that combines smart meter data acquisition, Artificial Neural Network (ANN)-based short-term load forecasting, uninterruptible power supply (UPS) operational management, and cross-linked polyethylene (XLPE) cable lifetime assessment. Smart meter measurements are processed to generate forecasted load profiles, which are subsequently used to support UPS control decisions and estimate cable thermal loading conditions. The proposed methodology links forecasted electrical demand with UPS operating strategy and XLPE insulation aging through a unified data-driven workflow. Harmonic analysis demonstrates the superior power quality performance of the three-level inverter compared with a conventional single-phase bridge inverter, while the cable lifetime assessment is based on the Arrhenius thermal aging model. The developed framework provides a practical methodology for improving the reliability, power quality, and predictive maintenance of modern smart distribution systems.

This study develops an integrated engineering framework that combines smart meter measurements, Artificial Neural Network (ANN)-based short-term load forecasting, predictive UPS operational management, and XLPE cable lifetime assessment. The forecasted electrical demand simultaneously supports UPS operational decision-making and cable lifetime evaluation, thereby establishing a direct functional relationship between energy management and predictive maintenance. Unlike previous studies that consider these problems separately, the developed framework utilizes a common information source to support multiple engineering functions within the same decision-making process. The main contribution of this work is the establishment of a unified engineering workflow that links smart meter data acquisition, ANN-based load forecasting, UPS operational control, and XLPE cable lifetime estimation. The proposed integration provides a practical methodology for improving power supply reliability, enhancing power quality, optimizing battery utilization, and supporting predictive maintenance in modern smart distribution systems. Although the present work focuses on the development of an integrated engineering methodology, the proposed framework also provides a solid basis for future implementation and experimental validation using real smart meter datasets and practical UPS installations.

The general relationship between the ANN input and the forecasted electrical load can be expressed as follows **:**

$$\hat{P}(t+\Delta t) = f(X_t, W)$$

where

- is the forecasted electrical load,
- represents the input feature vector obtained from smart meter measurements,

W - denotes the optimized neural network weights,

f - is the nonlinear mapping implemented by the ANN.

The prediction accuracy is evaluated using the Mean Absolute Percentage Error (MAPE), which is one of the most widely adopted performance indicators in electrical load forecasting studies [2,11]. where P_i and denote the measured and predicted electrical loads, respectively, and N is the number of observations.

$$MAPE = \frac{100}{N} \sum_{i=1}^{N} \left| \frac{P_i - \hat{P}_i}{P_i} \right|$$

where P_i and denote the measured and predicted electrical loads, respectively, and N is the number of observations.

Table 1. Input variables used for ANN-based electrical load forecasting .

Input Variable	Description
Voltage	RMS supply voltage
Current	Load current
Active Power	Instantaneous active power
Reactive Power	Reactive power demand
Frequency	Grid frequency
Energy Consumption	Historical energy usage
Time Index	Hour, day, season
Previous Load	Historical load values

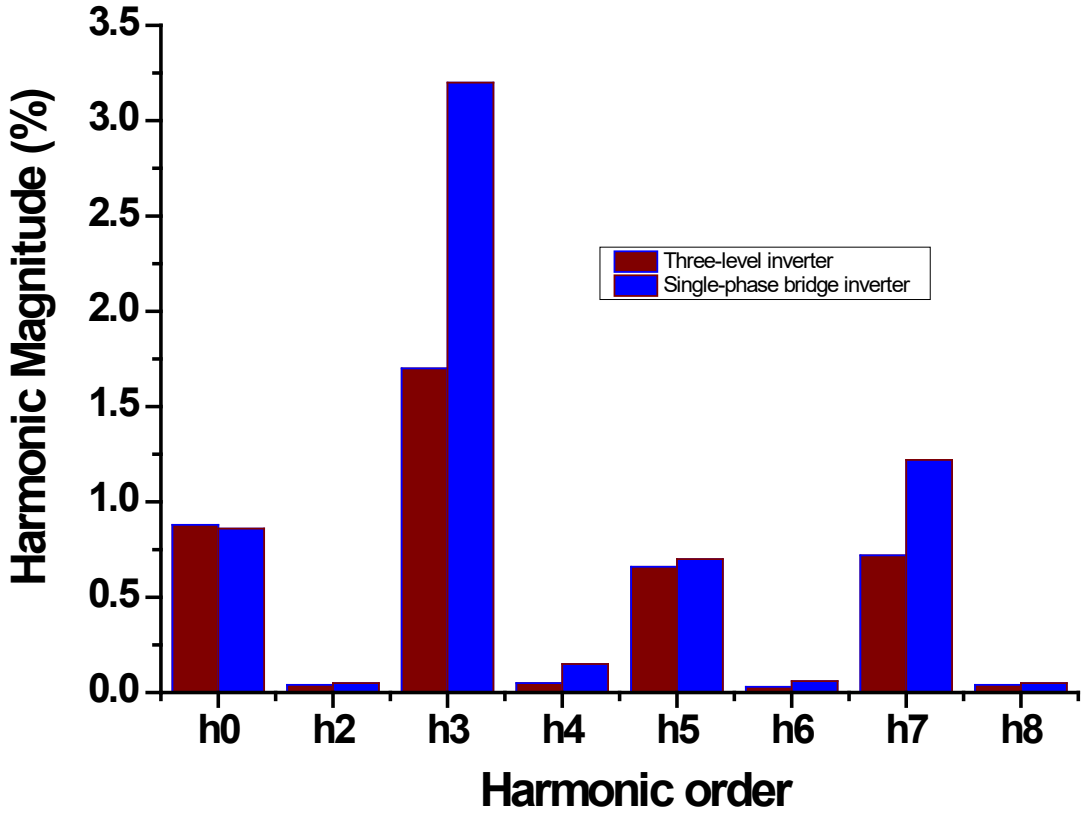


Figure 1. Harmonic Magnitudes under a Resistive–Inductive Load

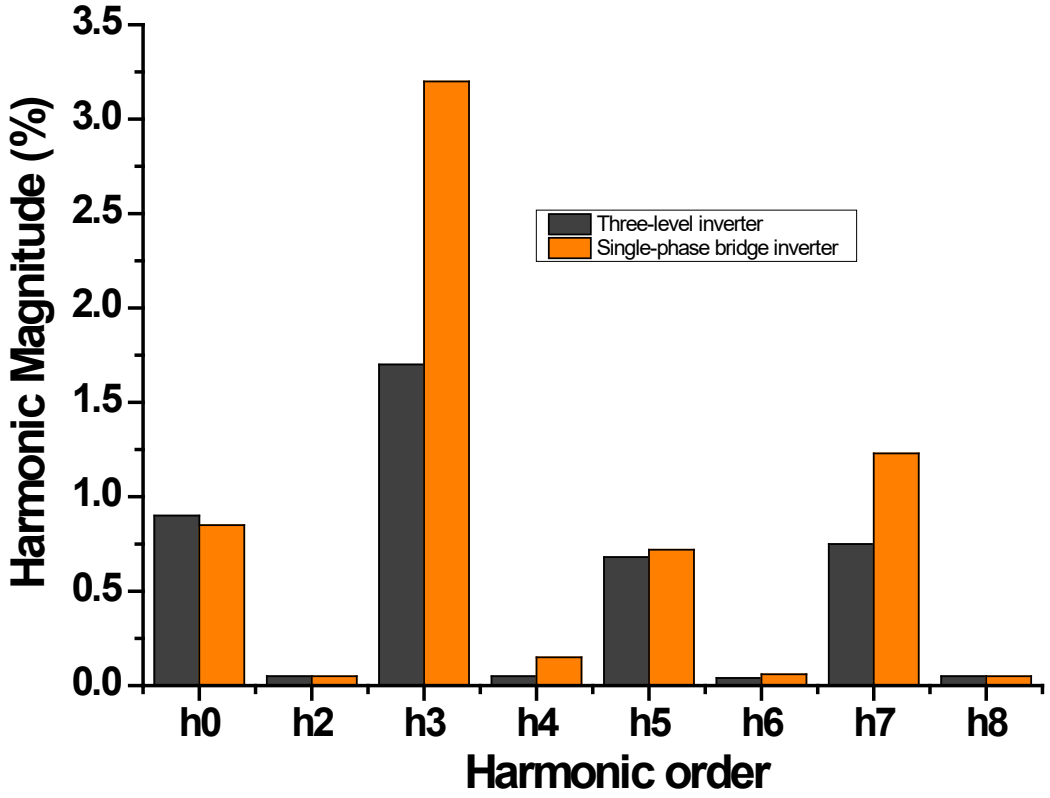


Figure 2. Harmonic Magnitudes under a Rectifier Load

CONCLUSIONS

This study developed an integrated energy management framework that combines ANN-based electrical load forecasting, predictive UPS operation, and remaining useful lifetime assessment of XLPE-insulated power cables within a unified smart distribution architecture. Unlike conventional approaches, which typically investigate these engineering functions independently, the developed methodology demonstrates how forecasted electrical demand obtained from smart meter measurements can simultaneously support operational control and predictive maintenance. The ANN-based forecasting model provides a common information source for both UPS management and cable lifetime assessment. Forecasted electrical demand is utilized to optimize UPS operation through predictive battery management and inverter control while simultaneously serving as the input for estimating conductor temperature and evaluating XLPE cable remaining useful lifetime using the Arrhenius thermal aging model. This unified data-processing chain establishes a direct engineering relationship between load forecasting, power quality improvement, and cable condition assessment. The harmonic analysis demonstrated that the selected three-level inverter provides superior output voltage quality under both resistive–inductive and nonlinear rectifier loading conditions. In particular, a significant reduction of the dominant third harmonic was achieved compared with the conventional single-phase bridge inverter, while the remaining lower-order harmonic components were also reduced or maintained at negligible levels. These results confirm that the selected inverter topology is well suited for UPS applications requiring high power quality and reliable operation. The integration of smart meter measurements, ANN-based forecasting, predictive UPS operation, and XLPE cable lifetime assessment demonstrates the feasibility of utilizing a common data source for multiple engineering functions without requiring additional measurement infrastructure. Consequently, the developed methodology contributes to improved power quality, enhanced operational reliability, optimized battery utilization, and more effective predictive maintenance of smart distribution systems.

The present work establishes a practical engineering framework for integrating intelligent energy management with cable condition assessment. Future research will focus on experimental validation using real smart meter datasets, optimization of ANN forecasting performance, development of more detailed electrothermal cable models, and incorporation of real-time cable condition monitoring techniques to further improve the accuracy of remaining useful lifetime estimation .