JOURNAL OF SCIENCE TECHNOLOGY AND EDUCATION 13(4), DECEMBER, 2025
E-ISSN: 3093-0898, PRINT ISSN: 2277-0011; Journal homepage: www.atbufstejoste.com

Load shading time control management scheme

A. E. Airoboman, S. A. Ibrahim, I. Ogbodick
Department of Electrical and Electronics Engineering,
Faculty of Engineering Technology, Nigerian Defence Academy, Kaduna

ABSTRACT

This paper presents a detailed exploration of load shedding, a critical last-resort practice in power system stability management. Moving beyond a mere definition, the analysis delves deeply into the evolution, operational principles, and comparative effectiveness of various load shedding time control schemes. The discussion begins with traditional under-frequency and under-voltage load shedding (UFLS/UVLS), examining their robust yet often non-discriminatory nature. It then progresses to more sophisticated, adaptive, and computational intelligence-based schemes enabled by modern Wide Area Measurement Systems (WAMS) and Phasor Measurement Units (PMUs). A significant portion of the analysis is dedicated to the socio-technical challenges of implementation, including fairness, economic impact, and public communication, arguing that a successful scheme is as much a policy achievement as an engineering one. Drawing on case studies and current research, the paper concludes that the future of load shedding lies in predictive, data-driven, and consumer-integrated approaches that transform it from an emergency blunt instrument into a precise grid management tool.

ARTICLE INFO
Article History
Received: August, 2025
Received in revised form: November, 2025
Accepted: November, 2025
Published online: December, 2025

KEYWORDS
Adaptive Load Shedding, Load Shedding, Phasor Measurement Units (PMU), Power System Stability, Wide Area Measurement Systems (WAMS),

INTRODUCTION

During my undergraduate studies, power systems were often presented as idealized, perfectly balanced networks where generation seamlessly matched load. It wasn't until I began my Master's degree and witnessed the real-world challenges in my home country that I fully grasped the fragility of this balance. Load shedding is the stark, practical embodiment of that fragility. It is the controlled, deliberate reduction of electrical load when the supply is insufficient, undertaken to prevent a far worse outcome: a total system-wide blackout. The consequences of a cascading blackout are monumental, leading to economic shutdowns, disruptions to essential services, and potentially taking days or weeks to restore a phenomenon tragically demonstrated by the 2003 Northeast blackout in the United States and Canada [1]. Therefore, load shedding, while disruptive, is a vital defense mechanism [2].

The core of this paper, and the focus of my recent research, is not on the need for load shedding, but on the intelligence embedded within its time control management and scheme the "how," "when," and "how much" of disconnection. The design of these schemes represents a complex optimization problem, balancing speed, precision, reliability, and fairness. A poorly calibrated scheme can be as damaging as no scheme at all, either failing to arrest a frequency decline or shedding excessive load, causing unnecessary economic and social hardship. This journal documents my journey through the technical layers, socio-economic implications, and future directions of these critical systems.

The Foundational Principles: Why Time and Rate of Change Matter

At the heart of any load shedding scheme is the fundamental relationship between power system frequency and the active power balance. The system frequency is a direct indicator of this balance: it increases when generation exceeds load and decreases when

Corresponding author: Sayyedi Aliyu Ibrahim
sayyedialiyut@gmail.com
Department of Electrical and Electronics Engineering, Faculty of Engineering Technology, Nigerian Defence Academy, Kaduna.

JOURNAL OF SCIENCE TECHNOLOGY AND EDUCATION 13(4), DECEMBER, 2025
E-ISSN: 3093-0898, PRINT ISSN: 2277-0011; Journal homepage: www.atbufstejoste.com

load exceeds generation. A significant loss of generation causes a rapid decline in frequency. If this decline is not arrested, it can lead to generator protection relays tripping (to prevent mechanical damage from operating at off-nominal frequencies), further exacerbating the generation deficit and accelerating the collapse.

The rate at which the frequency declines (df/dt) is a critical parameter. A steeper rate indicates a more severe power deficit. Traditional schemes primarily use frequency thresholds, but modern approaches leverage this rate-of-change information for faster and more accurate decision-making. The primary goal is to shed the minimum amount of load, in the shortest possible time, to stabilize the frequency and allow operators to restore normal operations.

TRADITIONAL LOAD SHEDDING SCHEMES: THE WORKHORSES OF GRID DEFENSE

Under-Frequency Load Shedding (UFLS)

The UFLS scheme is the most universally deployed and time-tested method. It operates on a simple, decentralized principle using frequency relays installed at various distribution substations. The scheme is pre-programmed with a series of escalating steps.

***Operational Principle: Each step has three key settings*:**

1. Frequency Threshold: The frequency level at which the step activates (e.g., 59.0 Hz, 58.8 Hz, 58.5 Hz on a 60 Hz system).
2. Time Delay: A brief intentional delay (e.g., 0.1 to 0.5 seconds) to prevent operation during transient swings and to allow other protective devices to act first.
3. Amount of Load to Shed: A predetermined block of load, typically a percentage of the total system load or the load at that substation.

When a generation deficit occurs, the frequency drops. The first UFLS step, set at the highest frequency threshold (e.g., 59.0 Hz), will activate after its time delay and disconnect its assigned load block. If the frequency continues to fall, the second step (e.g., 58.8 Hz) activates, and so on, until the frequency stabilizes or begins to recover.

Strengths and Weaknesses: The great strength of UFLS is its simplicity, reliability, and speed. It does not require complex communication infrastructure; each relay operates independently based on local frequency measurement. This makes it a robust last line of defense [3]. However, its weaknesses are significant. It is a "brute-force" method. The settings are static and calculated for a "worst-case" scenario, meaning they may shed more load than necessary for smaller disturbances. It is also "blind" to the location of the fault and the nature of the load being shed. Critical infrastructure like a hospital could be disconnected alongside non-essential load if they are on the same feeder, highlighting a major flaw in its lack of discrimination.

Under-Voltage Load Shedding (UVLS)

While frequency indicates the active power balance, voltage is closely tied to reactive power. Situations can arise where the system is stable in frequency but suffers from voltage collapse, often due to heavy reactive power loading on transmission lines after a contingency. UVLS schemes are designed to address this. They operate similarly to UFLS but are triggered by low voltage thresholds at key buses in the transmission network [4]. The combination of UFLS and UVLS provides a more comprehensive defense against different types of system instability.

THE PARADIGM SHIFT: ADAPTIVE AND COMPUTATIONAL INTELLIGENCE-BASED SCHEMES

The limitations of traditional schemes have driven research towards more intelligent, adaptive solutions. The advent of Wide Area Measurement Systems (WAMS) and Phasor Measurement Units (PMUs) has been a game-changer [5].

Corresponding author: Sayyedi Aliyu Ibrahim
sayyedialiyut@gmail.com
Department of Electrical and Electronics Engineering, Faculty of Engineering Technology, Nigerian Defence Academy, Kaduna.

JOURNAL OF SCIENCE TECHNOLOGY AND EDUCATION 13(4), DECEMBER, 2025
E-ISSN: 3093-0898, PRINT ISSN: 2277-0011; Journal homepage: www.atbufstejoste.com

The Role of WAMS and PMUs

PMUs measure voltage and current phasors (magnitude and phase angle) synchronized to a common time source, typically from the Global Positioning System (GPS). This provides a precise, real-time "snapshot" of the power system's state across a vast geographical area. In an adaptive load shedding scheme, data from multiple PMUs is streamed to a central control system. This system can calculate not just the frequency, but the actual power deficit in near-real-time by observing the rate of change of frequency and the power flows on critical corridors.

Adaptive Load Shedding (ALS)

ALS schemes dynamically adjust the amount and location of load to be shed based on the actual measured severity of the disturbance. Instead of pre-defined, static blocks, an ALS algorithm might calculate that a 1200 MW generation loss requires shedding exactly 1100 MW of load (accounting for spinning reserve response) and will then send targeted commands to specific, pre-identified load blocks to achieve this. A key advantage is the ability to account for voltage stability margins. A scheme can use real-time voltage and phase angle data to identify areas of the network that are on the verge of voltage collapse and prioritize load shedding in those areas, a level of precision impossible with traditional UFLS (Kundur et al., 2004).

Computational Intelligence Techniques

Researchers are now embedding advanced computational techniques into load shedding logic. These include:

1. Artificial Neural Networks (ANNs): Trained on a vast dataset of simulated system disturbances, an ANN can learn to map specific system conditions (frequency, df/dt, voltage levels) to the optimal amount of load to shed, providing an ultra-fast response.
2. Fuzzy Logic: This method is excellent for handling the inherent uncertainty and non-linearity of power systems. Instead of crisp thresholds (e.g., "shed if frequency = 59.0 Hz"), fuzzy logic uses degrees of membership (e.g., "the frequency is very low"), allowing for a more nuanced and potentially more optimal control decision [6].

THE SOCIO-TECHNICAL DIMENSION: BEYOND THE RELAY SETTINGS

An engineer could design the most technically perfect adaptive load shedding scheme, but it would be a failure if it did not account for human and societal factors. This is a crucial lesson I've learned: power systems are socio-technical systems.

Fairness and Prioritization

A fundamental question is: whose power gets cut? A purely technical scheme might always shed residential load because it's easier to manage, but this would be socially and politically untenable. A robust management scheme must incorporate a load prioritization strategy. Critical loads hospitals, water treatment plants, emergency services, and key communication infrastructure must be identified and protected with dedicated feeders or backup generation [7]. After that, a fair rotational schedule among other customer classes (residential, commercial, industrial) is essential to distribute the inconvenience equitably.

Economic Impact and Communication

The economic cost of load shedding is staggering, affecting productivity, business operations, and foreign investment. Therefore, the economic sensitivity of different industrial and commercial loads should be a factor in advanced schemes. Furthermore, transparency and communication are vital. A utility that provides a public, predictable load shedding schedule (like Eskom in South Africa) allows businesses and individuals to plan, mitigating some of the economic and social disruption. The lack of a clear schedule breeds frustration, misinformation, and a loss of public trust.

Corresponding author: Sayyedi Aliyu Ibrahim
sayyedialiyut@gmail.com
Department of Electrical and Electronics Engineering, Faculty of Engineering Technology, Nigerian Defence Academy, Kaduna.

CASE STUDIES IN IMPLEMENTATION

Eskom's publicly available load shedding schedule, with its stages from 1 to 8, is a prime example of a managed, albeit traditional, approach. It combines technical UFLS principles with a pre-published, rotational schedule for different geographical "blocks." While the technical scheme may be conventional, the management of its implementation the public communication and the attempt at fairness is a critical part of its operational framework, even amidst its challenges.

North American Reliability Corporation (NERC) Standards

In North America, load shedding is governed by strict reliability standards set by NERC. Standards like PRC-006 and PRC-010 mandate specific performance requirements for UFLS and UVLS schemes, ensuring they are uniformly designed, tested, and maintained across all interconnected utilities [8]. This highlights the importance of a regulatory framework in ensuring the effectiveness of these last-line defense mechanisms.

FUTURE TRENDS: FROM LOAD SHEDDING TO DEMAND RESPONSE

The ultimate evolution of load shedding management is its integration with Demand Response (DR) and the Smart Grid. Instead of viewing load as a passive block to be disconnected, the future lies in treating it as a flexible resource. With smart meters and home energy management systems, utilities can establish programs where consumers voluntarily agree to have non-essential loads (electric water heaters, pool pumps, air conditioners with thermal inertia) remotely curtailed during system emergencies, in exchange for financial incentives. This "shedding" is seamless, often unnoticed by the consumer, and highly targeted. It represents a shift from a punitive, centralized control action to a collaborative, market-based partnership with consumers [9].

CONCLUSION AND PERSONAL REFLECTION

My exploration of load shedding time control schemes has been a revealing journey from fundamental physics to cutting-edge data science and social policy. I began with the simple concept of a frequency relay and ended with a vision of a responsive, intelligent grid where consumers are active participants in maintaining stability.

The key insight is that there is no single "best" scheme. A layered defense is often the most prudent approach: traditional UFLS/UVLS provides a reliable, non-communicating safety net, while adaptive schemes using WAMS offer precision for a wider range of contingencies. Underpinning it all must be a robust, fair, and transparent management policy that considers the human impact of these necessary actions.

For my upcoming thesis, I plan to develop a detailed simulation model in a tool like DigSILENT Power Factory or MATLAB/Simulink. The objective will be to model a medium-voltage network and quantitatively compare the performance of a traditional UFLS scheme against a WAMS-based adaptive scheme for various disturbance scenarios, specifically measuring the amount of over-shedding and the time to recovery. Understanding these nuances is no longer just an academic requirement for me; it feels like a professional and civic responsibility to contribute to building the resilient, fair, and smart power systems of the future.

REFERENCES

[1] Ahmad, T. (2009). Social and economic impacts of load shedding on urban communities .Energy Policy Journal, 37(5), 1801-1808.

[2] Anderson, P. M., &Mirheydar, M. (1992). An adaptive method for setting under frequency load shedding relays. IEEE Transactions on Power Systems, 7(2), 647-655. https://doi.org/10.1109/59.141770

[3] Gungor, V. C., Sahin, D., Kocak, T., Ergut, S., Buccella, C., Cecati, C., &Hancke, G. P. (2011). Smart grid technologies: Communication technologies and standards.

Corresponding author: Sayyedi Aliyu Ibrahim
sayyedialiyut@gmail.com
Department of Electrical and Electronics Engineering, Faculty of Engineering Technology, Nigerian Defence Academy, Kaduna.

IEEE Transactions on Industrial Informatics, 7(4), 529-539.

[4] Hosseini, S. H., Khodabakhshian, A., &Fathi, S. H. (2006). A new fuzzy logic-based load shedding scheme. In 2006 International Conference on Power Electronic, Drives and Energy Systems (pp. 1-5). IEEE.

[5] Kundur, P., Paserba, J., Ajjarapu, V., Anderson, G., Bose, A., Canizares, C. &Vittal, V. (2004). Definition and classification of power system stability. IEEE Transactions on Power Systems, 19(2), 1387-1401.

[6] Momoh, J. A., Wang, Y., & Pater, R. (2007). Smart grid modeling and control for the prevention of cascading blackouts. In 2007 IEEE Power Engineering Society General Meeting (pp. 1-8). IEEE

[7] North American Electric Reliability Corporation (NERC). (2018). PRC-006-5: Automatic Under frequency Load Shedding. Retrieved from https://www.nerc.com/pa/Stand/Pages/PRC-006- 5.aspx

[8] [8] Phadke, A. G., & Thorp, J. S. (2008). Synchronized phasor measurements and their applications. Springer Science & Business Media.

[9] Taylor, C. W. (1994). Power system voltage stability. McGraw-Hill.

[10] U.S.-Canada Power System Outage Task Force. (2004). Final Report on the August 14, 2003 Blackout in the United States and Canada: Causes and Recommendations. Retrieved from https://energy.gov/oe/downloads/final-report-august-14-2003-blackout-united-states-and-canada-causes-and-recommendations.

Corresponding author: Sayyedi Aliyu Ibrahim
sayyedialiyut@gmail.com
Department of Electrical and Electronics Engineering, Faculty of Engineering Technology, Nigerian Defence Academy, Kaduna.