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An Overview of Various Strategies for Dealing With The Under-Frequency Load Shedding Problem in Power Systems

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ABSTRACT

It's essential to maintain a consistent and dependable energy supplies given the rising global demand for energy. When there is a crisis, such as a malfunction or an imbalance between energy production and load demand, the Frequency system becomes unstable. A load shedding scheme is an important key to recover frequency system and ensure the obtainability of electrical power for serious loads in a plant. Therefore, it is necessary to provide reliable technologies to quickly and accurately way to prevent breakdown in the system energy. Under Frequency Load SheddingUFLS is one of the important systems protection, and as is currently the case in many instances, it is the final step to prevent the system's collapse following an interruption or failure energy in the system. In this paper, the review of the literature is presented, along with a look at the various methods employed in the electrical power system and a comparison of traditional, adaptive, and intelligent load-shedding strategies. In order to clarify the intended function (entity) and preserve system stability, extra classification of additional elements is suggested. The various load shedding systems were addressed, along with their benefits and drawbacks, and a comparison between them was made with a list of the most significant justifications for doing so.

Keywords:

load shedding; under frequency; frequency stability; system capacity; UFLS; smart home applications

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1. INTRODUCTION

The main goal of the operators system is to ensure that the electric power system operates in a dependable and safe manner[1]. All systems of electrical power which contain generation are subject to various conditions of unusual operation such as the loss of some or every generation and damage the equipment within the system and other disturbances which can lead to reduced capacity of generation available to the system. Power outages affect on public utilities, refineries, mines, industrial processes, and all energy systems in the world [2], as shown in Figure 1. In these cases, if at all possible, the balance between the residual generation and the existing loads should be restored before the impact of the reduction in load frequency on the turbines and auxiliary producing equipment, which may eventually lead to a complete breakdown of the system [3].

The level of the system frequency has a significant impact on the reliability of the power systems, and in some cases, a frequency breakdown will occur. The danger of operating low frequency power systems is that it can lead to damage to steam turbines [4][5]. To avoid the main electrical system from failing, the proper commands must be given to return the system frequency to the permitted range [6]–[8].

One of the most crucial duties of the protection system is to provide stability. Different technologies, such as generator automatic controls (AGCs) and auto-generating governors, are used to maintain the nominal frequency's value. If the control system fails to return the frequency value back to its nominal value quickly, the protection system for the prevention of instability will be activated. So that, under frequency relays are used for this purpose [9][10].

The loss of the main system sources or critical transmission lines in power systems may cause an imbalance between the system load and the available generation, which is directly reflected in the frequency change in the system [11]. If the load and generation are imbalanced, the load shedding system will automatically operate depending on the power system's frequency to keep the system stable and give additional security for equipment and residual loads [6][12].

As soon as the frequency decreases to a level that indicates a loss of generation or an overload, these relays cut off the less critical loads [3][13].

This paper will hold value for future research endeavors, as it discusses the shortcomings and merits of the utilized methods. Additionally, it addresses the scarcity of recent reviews on this subject and proposes new classifications for the load-shedding topic.

The paper focus on the problem of generation/load imbalance in electric power systems and the problem of instability. Review various load-shedding plans to regain power balance and maintain the system's frequency within allowable bounds. The objective of this paper is to compile existing literature concerning optimization models designed to address the issue of load shedding. The main emphasis is placed on conducting a thorough assessment of these models, with the intention of clearly documenting the inherent pros and cons of each approach.

2. POWER SYSYTEM STABILITY

Frequency and voltage are crucial components in power systems for preserving system stability.

Power system stability is the ability of the system to maintain its integrity after a disturbance. Power system stability is essential for ensuring the reliability of the power grid.

In simultaneously with the increasing number of loads, keeping the system in synchronization after it has experienced a fault becomes more and more complex.

Therefore, control equipment in emergencies is necessary to ensure safe and reliable operation of the system of energy and avoid cessation of electricity. Generally, it can be found that the system is discontinued due to different forms of instability, either in the event of voltage unstability of the system or frequency unstability, or both together. . Power system stability is classified into three major groups, namely frequency stability, voltage stability and rotor angle stability [14][15].

2.1 Frequency Stability

A power system's frequency stability is defined as “the ability of a power system to maintain a constant frequency after a severe perturbation has occurred in the system that results in a significant imbalance between generation and load”. Issues with frequency stability are linked to significant generating losses and slow equipment response. Insufficient generation reserve and insufficient control and protection equipment coordination.

2.2 Voltage Stability

Voltage stability is characterised by “the ability of a power system to maintain an acceptable voltage in all generalities in the system under normal conditions and after exposure to disturbances”.

2.3 Rotor angle stability

Rotor angle stability is the capacity of synchronous machine units in a system to maintain angular divergence owing to variations in effective power flow.

Rotor instability is generally associated with changes in the effective energy flow that

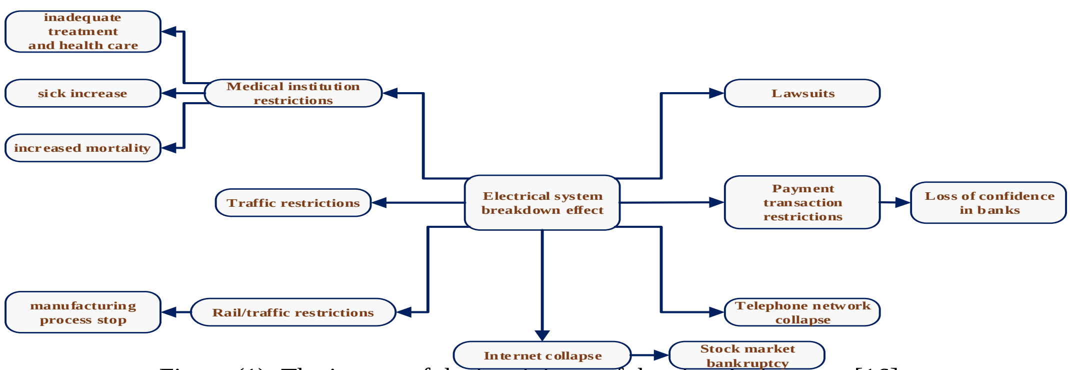

Figure (1): The impact of the breakdown of the electrical system [16] create angular displacements between the synchronous units in the system. The frequency of the power system decreases rapidly if a mismatch occurs between the generation and the load when a power disturbance occurs [17][18]. An abnormal frequency can directly affect the operation and reliability of the power system. A large frequency deviation can lead to damage to the equipment associated with the system. Deterioration of load capability can overload the transmission line, interfere with various safety systems, and, in extreme situations, bring about the system's collapse. Emergency control may require extra control, such as Load Frequency Control (LFC), depending on the severity of the frequency deviation [19], [20]. The power plant's ancillary services are more sensitive to the minimum permissible frequency. At a frequency of 47.5 Hz, it begins to malfunction. Asynchronous motors for auxiliary services are cut off by their protective mechanisms at a frequency of roughly 44–46 Hz [1], [21]. Steam turbines can manage up to 10 emergencies at 47.5 Hz simultaneously but are more sensitive to frequency drops. A frequency below 47.5 Hz should thus not be used [1].

The frequency of generators depends upon the occurrence of disturbances on the following factors:

• The rate of the initial frequency decrease is faster for the generator closest to the disturbance point [1], [11], [17],[22],[23]

• Generators with more constant inertia experience less frequency dipping [24],[25].

• The stability of the frequency following the appearance of a disturbance is significantly influenced by the damping factor. On the generator's initial frequency behaviour, though, it has no discernible impact [22], [25]. Figure 2 discusses the lowest frequency deviation factors.

The energy imbalance depends on the dynamical characteristics of the turbines, controllers, loads, and other controllers, and is proportional to the values of the frequency lowest and the new steady-state frequency obtained during the transient phase [26].

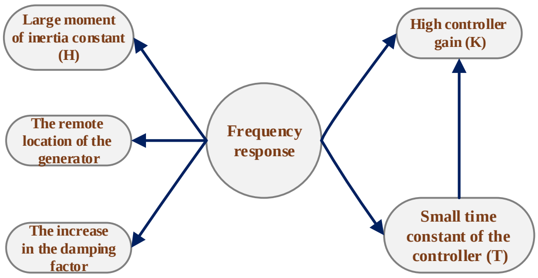

Figure (2): Ideal Factors Affecting Frequency Response of Generators [27]

3. THE POWER SYSTEM BEHAVIOR AFTER DISTURBANCES OCCURRENCE

Voltage and frequency decreases are the first signs of a systemic generation loss, whether complete or partial. However, since voltage decreases can also result from system issues, frequency drops are often seen as a more accurate indicator of generation losses. According to the amount of the ensuing overload and the system's inertial constant, the frequency will decrease suddenly in the system after the loss of generation [3].

Starting with the swing formula of a simple generator, one can obtain the relationship that dictates frequency shift over time following an unexpected shift in load and/or generation.

$$\frac{\mathrm{GH}}{\pi \mathrm{f_o}} \times \frac{\mathrm{d^2}\delta}{\mathrm{dt^2}} = \mathrm{P_A} \qquad (1)$$

Where:
G: MVA is the nominal apparent power of the machine.
H: Inertia constant (MWs/MVA = MJ/MVA).
δ: Torque angle of the generator.
f_o: Nominal frequency.
P_A: Net acceleration or deceleration in power (MW).

The following formula can be used to calculate the machine's speed at any time (W):

$$W = W_o + \frac{d\delta}{dt} = 2\pi f \qquad (2)$$

Where:
W_o: Synchronous speed, which is the nominal speed at the rated frequency.
By deriving equation (2) with respect to time, we will obtain

$$\frac{dW}{dt} = \frac{d^2\delta}{dt^2} = 2\pi\frac{df}{dt} \qquad (3)$$

Substituting equation (3) into equation (1), we get:

$$\frac{df}{dt} = \frac{P_A f_o}{2GH} \qquad (4)$$

Equation (4) specifies the rate of frequency change in Hz/sec, and can be applied to any specific machine or the total generation in the system. In such a case, the inertia constant can be calculated from:

$$H = \frac{H_1 MVA_1 + H_2 MVA_2 + \cdots + H_n MVA_n}{MVA_1 + MVA_2 + \cdots + MVA_n} \quad (5)$$

Where:

1, 2. . . n denotes the units of the individual generators.

It should be emphasized that the constant H in equation (5) is expressed in MVA base. Which is equal to the total generating capacity of the system.

The frequency change is caused by the accelerating power PA in equation (4), which may be computed by:

$$P_A = P_M - P_E \quad (6)$$

Where:

P_M: the input of mechanical powe into the generator.

P_E: Electricity produced by the generator.

There are no frequency variations and $P_A = 0$ in steady state. In a case of overload, P_E triumphs over P_M. Consequently, $P_A < 0$ and the system frequency will drop [3].

4. LOAD SHEDDING (LS) SCHEME

Load shedding relays (LS) are an important system protection tool, and are the only suitable means of preventing a power system from failing and causing serious damage and to limit the amount of load to match the available generation [4].

Basically, the load shedding relay is triggered when a condition that is classified as dangerous to the system is diagnosed. Diagnosing low or high frequency in electrical power systems is a historically traditional method for detecting imbalances in power [27]. Certain frequency values (underfrequency) or (overfrequency) are used as a threshold limit to start the load shedding process for the loads or generators to maintain the stability of the power system. Therefore, both excessively high and low frequencies must be prevented. Whereas, loads differences are considered as disturbances [28].

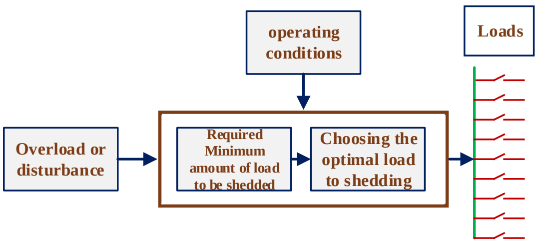

Figure (3): Topography of load shedding scheme [29]

To reestablish the power balance between the load and the available generation, several load-shedding (LS) techniques have been used. In addition, the LS load shedding algorithm has to detect the power deficit and calculate the minimum load value to be disconnected [27]. Each power system has its own load shedding system. For the UFLS scheme to function well with neighbouring power systems, it must be dependable, straightforward, efficient, quick, durable, and consistent [28].

On the other hand, the UFLS scheme should take into account the calculation of various Influential elements such as shifts in frequency, network architecture, the amount of disturbances, the voltage condition of the system, the spin reserve, etc., which leads to determining the number of steps, the amount of load disconnected in each step, and the delay time in each step. As shown in Figure (3). However, optimal load shedding during emergencies is one of the most important issues in planning, safety and operation of power systems [6][30].

The minimum frequency and amount of load to be disconnected is the main operating signal of the load shedding scheme and is related to the instantaneous frequency [4].

5. REQUIREMENTS FOR A SUCCESSFUL LOAD SHEDDING SCHEME

To ensure the success of the load shedding scheme in achieving its objectives and ensuring the stability of the system and increasing its reliability, there are several factors that must be taken into consideration, [31],[32],[33],[34].

1. The smallest permitted system frequency.

- The minimum acceptable operating frequency must be specified.
- The capacity of machinery to endure frequency variations has restrictions, such as steam turbines and generators. This apparatus has a very low frequency sensitivity.
- To prevent the equipment from operating below the allowed frequency, it is crucial to take the necessary precautions.

2. The appropriate amount of load to be disconnected

- To prevent an increase or decrease in disconnected loads, determine the proper imbalance ratio between power production and load demand.
- By taking into account the dynamic elements in the power system, simulation analysis must be used to evaluate the amount of load that needs to be disconnected.
- The amount of disconnected load should be as small as possible to recover the normal frequency and voltages after disturbances.

3. Value of the frequency threshold and the delay

- The brief duration of transient frequency and load shedding actions should be taken into account in the time delay.
- The procedure must be fast, so that the frequency drop can be stopped before severe crashes occur.

4. Determine the disconnected load and its location

- Steam generation takes priority over the electrical system (in steam power plant) and must be disposed of as soon as possible.
- The loads disconnection process should not interrupt other operations, and the necessary and important basic loads should be avoided.
- The location of the load to be disconnected for Under Voltage Load Shedding (UVLS) is determined by determining where the Overhead Voltage Dropped the Most.

5. The steps number and timing of disconnected loads

- The minimum time delay before UVLS is energized should be sufficient to prevent voltage breakdown in order to minimize unwanted trip signals in the transient time when load shedding is not essential.
- Delaying load shedding primarily serves to prevent excessive load shedding and determine the ideal load by ensuring that the system voltage or frequency is unstable.

6. LOAD SHEDDING SCHEME CLASSIFICATION

Under Voltage Load Shedding (UVLS) and (UFLS) are two broad categories for the load shedding plan [16].

6.1. Under-voltage load shedding scheme UVLS

According to this plan, load disconnection starts when the voltage reaches a specific level following a system disturbance. In this case, a UVLS scheme is applied to restore the system voltages to an acceptable level, thus avoiding large scale breakdown voltages. The concept of voltage collapse refers to a situation in which the voltage suffers a drop in a part of the power system [35].

6.2. Under-frequency load shedding scheme UFLS

According to this plan, load shedding is started when the system's frequency changes. The UFLS scheme ensures that the frequency of the system returns to the nominal value after it has experienced a perturbation in the system that leads to an unbalanced state of energy. When a minor fault occurs, the alternator's rotating reserve may be able to remedy the small misalignment by generating power from its additional generating capacity. But if the generator is already at its peak or the rotation reserve responses are too slow to inject power, a frequency recovery UFLS scheme must be used [36]. Accordingly, UFLS is applied to restore the system frequency to a satisfactory level after a major system emergency that can cause a generation failure condition, as well as prevent a complete collapse of the system, as well as help in achieving rapid recovery of all affected loads [34].

The researchers gave a different classification of the loads. In [37], The researchers categorised load shedding as a cause-based strategy and an effect-based plan. Total load shedding is divided into two categories in [38]: basic load shedding, which is based on calculations of the generating deficiency, and gradual load shedding, which is based on power overload on system equipment. Load shedding can be carried out based on frequency or depending on load, claims [19].

- **Power-based load shedding (PLS)**

Calculates the power shortage and the amount of loads to be disconnected based on the instantaneous measurements.

- **Frequency-based load shedding (FLS)**

maintains a close eye on the frequency and its variation at predetermined thresholds. The load-shedding strategy has been divided into three categories [1]: conventional, semi-adaptive, and adaptive.

- **The traditional load shedding**

The cheapest and easiest option is this. If the frequency falls below a predetermined threshold, the typical approach disconnects a fixed amount of load.

- **The semi-adaptive scheme**

If the frequency threshold is achieved using this method, the load is cut off by measuring the df/dt.

- **The adaptive method**

The system frequency response model is employed. This work mainly classifies UFLS schemes into four categories:

• Conventional UFLS schemes.
• Adaptive UFLS schemes.
• Smart UFLS Scheme.
• UFLS scheme using smart home devices, smart meters, communication networks and the Internet of Things.

Figure 4 shows the main types of load shedding schemes.

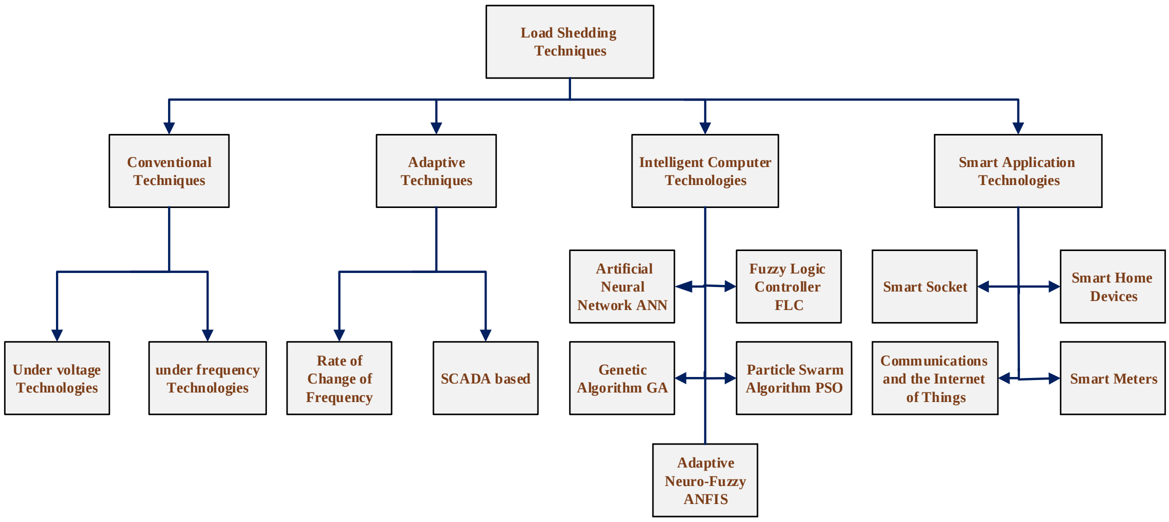

Figure (4): The main types of load shedding schemes

6.2.1. Conventional Under-frequency load shedding scheme

The UFLS relay mechanism was introduced in early 1967 to address the system's generation shortage. From this scheme, several factors involved were investigated to achieve optimal relay trip settings. The magnitude of the overload value is what determines the frequency drop rate at first. Next, depending on the allowed frequency limit value, the required quantity of load shedding is calculated. The quantity and magnitude of load shedding steps needed to disconnect the right amount of load are developed through a process of trial and error. The block diagram of the traditional load shedding programme is shown in Figure 5 [16] [39].

Conventional load shedding systems are designed to be set to disconnect a certain fixed amount of loads using a certain pre-determined number of gradients, and in this way, the system cannot operate perfectly.

Because they disconnect a set amount of load at specific frequency magnitudes, standard UFLS relays cannot implement an ideal load-shedding method. It is well known that this method can overshoot frequency and is unreliable at disconnecting the right amount of load [4].

Choosing the appropriate level of energy imbalance following perturbation is a crucial issue related to the traditional type. A specific quantity of loads is typically shed at a fixed frequency. In order to keep the frequency and voltage within the permitted ranges, load shedding may therefore be higher or lower than what the system dictates. This circumstance may lead to unintended equipment damage as well as significant system and load expenses [40].

Conventional methods of system load shedding are very slow and do not effectively calculate the correct amount of load to be eliminated [36]. The reason lies in the fact that the loads are not fixed because the load of the system may change and thus the load varies, which makes it difficult to accurately predict the amount of load that will be disposed at the specified time and place [41].

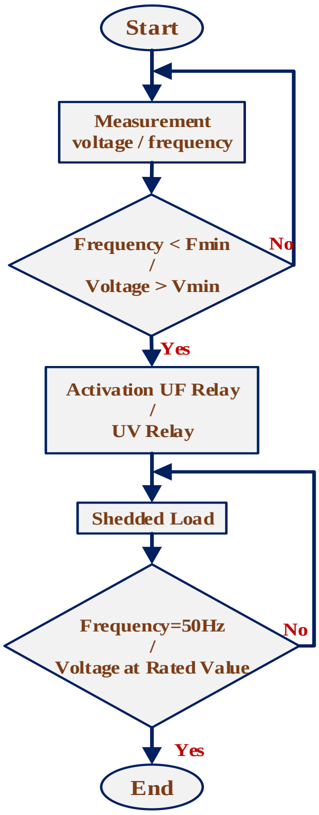

Figure (5): Conventional load shedding technology flowchart [39]

Traditional UFLS methods generally rely on evaluating an operational frequency against a specified frequency level on each stage, which may activate the following stage in accordance. Both fixed and variable amounts of loads that are detached in a single step are possible [42].

However, there is a major defect in the traditional techniques, as the calculations for the amount of loads to be removed are inaccurate, which leads to the disconnection of loads larger than required and unnecessary to be disconnected. Also, as well as the wrong determination of the time delay between successive stages may compromise system stability [43], [44].

Moreover, due to constraints imposed by development and evolution processes, modern power systems function even with lower power capacities and crucial stability margins [4]. In this situation, the UFLS scheme and other conventional power system security measures ought to be abandoned and decommissioned [4].

6.2.2. Limitations of Conventional Under-frequency load shedding scheme

Conventional load shedding schemes are designed using a static model of a power system that is set to disconnect a certain fixed amount of loads using a predetermined fixed number of gradients, and these schemes usually do not provide optimal settings for different system conditions[45]. Conventional UFLS schemes are conservative in terms of the amount of load being disconnected. The disadvantages of the traditional methods are illustrated in Table (1).

6.2.3. Adaptive under-frequency load shedding scheme

To more accurately estimate unbalanced energy and locate the unbalanced load from traditional methodologies, an adaptive load shedding method has been presented. The rate of frequency change (df/dt) has been used to create adaptive UFLS in order to assess disturbance [46].

Following the measurement of the system's rate of frequency change (ROCOF), an estimation of the size of the disturbance in the system's energy imbalance is made. The swing equation for the chosen generator has the following basic expression:

$$\Delta \mathrm{P} = \frac{(2\times H)}{f_n} \times \frac{df_c}{dt} = P_{m} - P_e \qquad (7)$$

Where:

f_c: is frequency (Hz)

f_n: is the nominal value of frequency (Hz)

df_c/dt: is ROCOF (Hz / s)

P_m: is the mechanical power per unit and P_e is the electrical power per unit [51], [52].

Table (1): the disadvantages and Limites of conventional scheme.

	Disadvantages and limitations of the conventional method	Ref
1	Conventional approaches do not account for changes in load level, system inertia, load design, or controller response characteristics.	[26]
2	Less shedded loads.	[40]
3	The process of returning the frequency to steady state is very slow and takes a while.	[41]
4	Conventional UFLS is unable to shed loads at the best sites or in the best volumes.	
5	The load is shedding without considering the amount of effective power imbalance that over-disconnection is likely to occur and the frequency rises above the acceptable maximum.	[42]
6	It causes unwanted damage and serious costs due to excessive or improper load shedding.	
7	The preset settings cannot provide adequate performance when the system deficiencies encounter large differences.	[43]
8	Small networks with little inertia and few measuring devices are not a good fit for using it.	
9	Economic losses	[44]
10	Unnecessary loads are disconnected as a result of the ineffective calculation of the proper amount of load to be shed.	[45]
11	Wrong determination of the time delay between successive stage	
12	The amount of shedded load is guessed in advance and is not an exact calculation	[46]
13	Lack of adaptability, as it does not distinguish between different frequency gradients.	
14	Optimization problems	[47]
15	Without sharing information, each relay responds with local frequency measurements and presets.	[48]
16	Frequency measurements and its variations can introduce significant errors due to the rapid variation in electrical grid conditions.	
17	Follow the pre-set and fixed frequency threshold for load shedding.	[49]
18	It does not take into account the size of the disturbance.	
19	It leads to non-optimal load shedding due to fixed load priority.	[50]

There are (N) steps that make up the load shedding approach, and each step is governed by the following variables [7], [31]:
• Under Frequency Level U.F (f);
• Rate of change in frequency (df / dt);
• Delay time (t);
• The load to be disconnected (p).

The studies carried out are to quantify the load to be shed and to evaluate the dynamic response of the system following perturbations [53],[54],[55]. However, there is no commonly accepted approach for establishing the settings for this protection [56]. Due to the significance of UFLS, the UFLS system must be implemented with great reliability. The flowchart for the adaptive load shedding technique is shown in Figure (6).

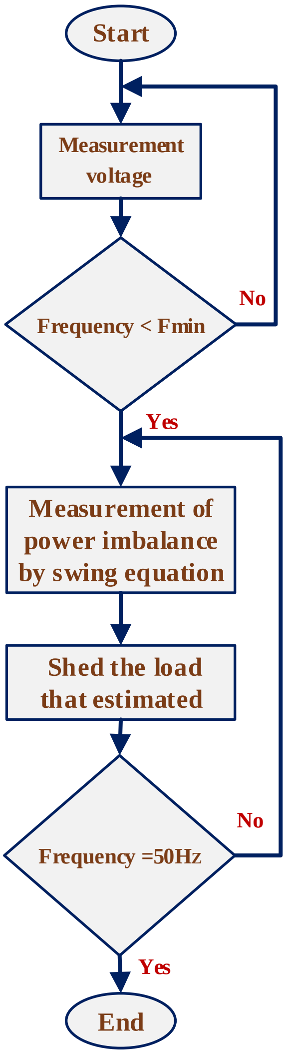

Figure (6): Adaptive load shedding technology flowchart [39]

The researchers believe in [57] that there are some problems that must be solved in the current UFLS schemes, as follows:
1) How to choose the frequency levels for load disconnections, as well as the levels and quantities of load that must be shed at each level.
2) How to handle many power system failures at once. When there are multiple failures in a row, the load cannot be disposed of again because it was disconnected after the first failure.

To reduce the minimum system load necessary under diverse conditions and to preserve system stability, adaptive load shedding techniques are advised. Scaling and the use of relevant indicators, such as the initial frequency gradient, are the foundations of adaptive schemes, which are used to calculate the active power deficit in an electrical power system [11].

Due to the disregard for the real system state and disturbance amplitude, the adaptive UFLS schemes' frequency deviation ranges are likewise broad. Additionally, it was discovered that the current technologies are insufficiently secure to keep the stability of power systems in situations including recent power failures [6].

6.2.4. Previous studies of adaptive load shedding technology

- In [11]the authors present a theoretically optimal under-frequency load shedding scheme and describe how any of the adaptive load shedding schemes can be tuned to take advantage of the greatest possible control over the base frequency. The plan must be able to prevent frequency drops in all situations and attempt to reduce the amount of disconnected load concurrently.
- In [26] the authors describe an adaptive method that overcomes known UF scheme problems by using communication between remote protection relays and a central UF device. This method continuously tracks dynamically changing load levels, system topologies, and load configurations.
- In [41] the proposed method is set to work in real time to estimate the amount of disturbance and to enhance the stability of frequency and voltage. The magnitude of the perturbation is determined using the swing equation. Load shedding is initiated by low frequency relays designed to shed the load based on disturbance rating and system condition including voltage levels.
- In [42], the two researchers proposed an adaptive scheme for load shedding at low frequency for using extensive measurements to examine the power system in the presence of solar photovoltaic plants. Load shedding is implemented in stages in selected buses taking into account any change in PV output and

load/generation at each step. When taking into account the priority of the pre-determined loads, the value of the loads in the bus that need to be disconnected depends on the constant voltage index of the buses at that precise instant.

-In [48] estimates the rate of change of frequency (RoCoF) of the Center of Inertia (CoI), and thus the Loss of Generation (LoG), using only in sites frequency measurements. The proposed UFLS relay determines the size of the LoG and the amount of load that must be shedded.

- In [58] the two researchers proposed to prevent frequency instability in the electrical power system during unusual disturbances in a large area, a new adaptive frequency load separation (UFLS) technique has been developed. To quickly and accurately check disconnect conditions, the devised approach uses online monitoring of third-zone distance relay resolutions for specific lines using WAMS and SCADA/EMS systems. And allow automatic load disconnection to maintain frequency stability of the power system.

In order to increase the stability of the power system following significant disturbances, the researchers developed three adaptive load shedding approaches in [59] to enhance the functionality of the conventional frequency load shedding system. To prevent such incidents, the suggested approaches employ site-measured frequency and voltage signals. The suggested algorithms start load shedding from areas with a bigger voltage drop and continue it for a longer time. Depending on the location of the disturbance, the system voltage condition, and the frequency drop rate, the speed, location, and amount of load shedding are altered adaptively.

- A two-unit large-scale adaptive load shedding strategy based on synchronous stations is presented in this study [60]. The first unit develops an adaptive System Frequency Response (SFR) model and determines the right number of load disconnects. The calculations are only slightly off when the adaptive SFR model includes both static and dynamic loads. The primary objective of the second unit is to select the best load drop site based on adequate voltage stability characteristics. These two components are run simultaneously.

- A novel adaptive dynamic load shedding system was put forth in [61]. The suggested methodology takes into account order outs of the load based on the voltage stability index, frequency sensitivity due to load damping, and real disturbance magnitude. In order to keep the system frequency within the defined acceptable limit, this method makes sure that the real load shedding is close enough to the necessary load shedding.

- In order to increase the frequency stability of small isolated networks, this research [62] introduces a new adaptive central controller that works in conjunction with a distribution-state estimator and frequency load shedding. In order to estimate the power consumption of a load, the new central control unit incorporates a distribution state estimator, which solves these problems. The actual active energy imbalance in the microgrid is estimated simultaneously by the system frequency and its rate of change. These two variables are used by the central control unit to calculate the appropriate amount of load that has to be sheaved.

- In [63] a new scheme for adaptive load shedding was proposed to overcome the disadvantages of existing schemes. The proposed scheme is adaptive to the power mismatch based on the local frequency measurement, and bypasses the problem of increasing the value of the sheded loads. The improved UFLS scheme incorporating frequency threshold and time delay is practical to implement and can be easily tuned using the proposed tuning method.

- In [64] the proposed method monitors negative sequence voltage, frequency and rate of change, which enables faster load shedding (high reliability) without unwanted triggering (high safety) when compared to conventional methods. Therefore, the new method avoids unwanted operation of the load shedding scheme when the substation (source) is out of service.

6.2.5. Smart under-frequency load shedding scheme

Generally speaking, "computational intelligence techniques" refers to a collection of methods used to imitate human intellect [16].

“Smart Load Shedding” is a method that enables the improvement of power system stability, by providing adaptive real-time load control and load shedding, in situations where the power system is unstable [16].

The Smart UFLS scheme is a load shedding system that employs mathematical intelligence methods. When solving problems involving nonlinear difficulties, this scheme has significant benefits over the conventional approach [65], [66]. Since the late 1980s, the use of smart technologies in energy systems has grown. The load shedding strategy has also been subjected to a variety of intelligent procedures (intelligent algorithms) [65], [66].

Artificial intelligence (AI) techniques for UFLS applications provide superior performance compared to the conventional UFLS scheme in terms of adaptive step size and the greatest possible low swing frequency [67].

These algorithms are intended to provide support to the operating system during critical situations. Key aspects are the assessment of the appropriate magnitude and location of the energy response for a given perturbation, and the assessment of the appropriate expected temporal response in order to comply with an acceptable stabilization recovery [68], [69]. This temporal response is a major goal of suitable ICT networks to enable such reliable implementation [70].

No matter how disruptive, the standard UFLS system sheds a certain number of loads at each step, resulting in less-than-ideal load disconnection. UFLS adaptive and intelligent approaches, on the other hand, avoid needless load separation and, as a result, promote optimal shedding [16]. In general, the adaptive and computational UFLS based on artificial intelligence have methods for estimating the amount of disturbance and load shedding according to the extent of the fault [51][71]. As shown in Figure (7), which represents the block diagram of the smart load shedding technology.

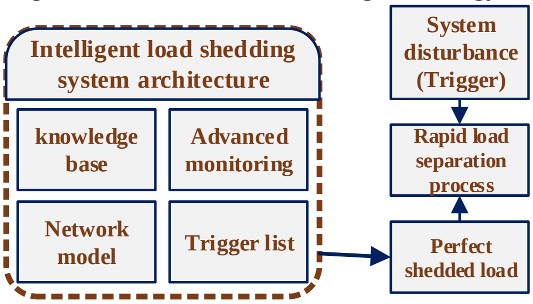

Figure (7): the block diagram of the smart load shedding technology

These technologies include artificial neural networks (ANN), adaptive neural fuzzy inference system (ANFIS), fuzzy logic control (FLC), genetic algorithms (GA), and particle swarm optimization (PSO) [72].

Fuzzy logic is one of the techniques of artificial intelligence, which requires precise identification of membership criteria and functions; if not, the solution deviates from the optimal value [67]. In comparison to fuzzy logic or traditional UFLS, Artificial Neural Networks (ANNs) offer a superior way for UFLS to function. ANNs, however, might not be appropriate in many error/disturbance circumstances. Additionally, ANNs require extensive training when dealing with complicated networked systems [73].

ANN-based load shedding scheme is proposed to analyze the transient stability of the actual power system, in order to find the minimum value of the loads shedded. However, there are some limitations to ANN, as it can achieve the satisfactory outcome for known cases. Thus, ANN fails to accurately predict unknown or variable states [65].

6.2.6. Previous research of Smart under-frequency load shedding scheme

- The researchers proposed in [56] an effective mathematical method that can be used to calculate the appropriate load-shedding strategy to protect power systems. A method based on a Monte Carlo series simulation method was developed to compare alternative strategies by taking into account the amount of load to be shedded and the related risks to system stability. The methodology developed uses artificial neural networks (ANNs) to determine the most appropriate load shedding strategy variables.
- A novel adaptive load-shedding technique based on energy flow tracking and artificial neural networks (ANN) is suggested in this research [73]. The frequency decrease of the equivalent center of inertia from the rated value to the threshold value is measured and utilized to calculate the total effective power misalignment using the ANN.
- The research [74] proposes an online method for predicting load shedding and correcting it by redistributing loads. This proposal uses artificial intelligence techniques, in particular neural networks, and special purpose power system simulation. The proposal of this paper is to find a solution to find the minimum adjustment for economic achievement to reduce load shedding.
- The study [75] suggests a novel approach to load-shedding emergency control that combines two artificial neural networks in order to implement load shedding. When an electrical system short circuit develops, the first artificial neural network (ANN1) instantly detects the situation (with or without load shedding). The selection of load-shedding solutions is defined and managed by the second artificial neural network (ANN2).
- The research [76] shows a smart strategy for load distribution in the electrical system of the college of Medicine at Selcuk University, which consists of different types and sizes of loads and is provided by distributed generation. The best load-shedding technique is used after sorting the loads based on importance and priority. For the best load shedding, fuzzy logic is employed. Based on actual data collected for PV generation and load demand, fuzzy logic is also used to determine the amount of loads to be shed.

In order of priority of importance, these loads are disconnected by the SCADA system.

- The research [77] presents a UFLS scheme characterized by increased effectiveness in the case of large disturbances and reduced shedded energy in the case of small and medium disturbances compared to the traditional load shedding system. These advantages are achieved by replacing the time-consuming cascading load shedding system with a synchronous load shedding mechanism and replacing ineffective system-state-independent fixed-frequency activation thresholds with implicit adaptive thresholds using fuzzy logic.
- An intelligent load-shedding plan based on mass learning particle crowding algorithm (CLPSO) and fuzzy logic control (FLC) has been presented for the isolated distribution system [78]. To calculate the amount of weight to be shed, FLC is suggested. System frequency and distribution system ROCOF are the entries on the fuzzy console. To achieve the ideal level of load shedding, another intelligent load-shedding strategy based on CLPSO is suggested.
- In [79], the researchers proposed a load shedding method based on Active Multilayer Fuzzy Logic (MLFLS) to improve the overall Micro Grid performance. Compared with the traditional UFLS scheme, the load is determined by the multilayer mechanism. Frequency deviation and steam pressure are specified as control inputs and output signal are control commands to maintain a given load in online or offline mode.

Optimization techniques, for example, genetic algorithm GA [80], ant colony [81], Monte Carlo [82], particle swarm PSO [83], bacteria forage BF [84], grasshopper algorithm [70] and various other algorithms, have been recently applied to load shedding. Generally speaking, these algorithms can minimise load shedding and keep swing frequencies as low as possible. On the other hand, in many situations convergence to a general solution cannot be ensured. Another disadvantage is that the majority of these algorithms depend on the original solution, have diverse computational needs, and are challenging to implement [85], [86].

To solve the optimal load shedding problem, several researchers developed an intelligent UFLS scheme based on Genetic Algorithms (GA).

The Genetic Algorithm (GA) was used with different objectives, either to reduce the amount of load shedding, and improve the condition of the voltages [68], or to reduce the load shedding while maximizing the minimum frequency swing and figure (8) shows the flowchart for the implementation of the load shedding scheme depending on the genetic algorithm [87].
- In [87] the two researchers determined the percentage of the load allowed to be disconnected and the critical variables, including the number of steps and the time delay of the frequency drop relays. A hierarchical genetic algorithm was used to minimize the amount of disconnected load and to maximize the lowest swing frequency. An isolated system with diesel generators and wind power generators is used to demonstrate the applicability of the proposed method.
- In [88], the researchers proposed the development of an adaptive UFLS method based on a genetic algorithm to automate the method of finding optimal variables to reduce repeated experimental true-false calculations. Simulations show that the method has better performance than previous methods and reduces the time and effort of repeated simulations.
- In [89] both researchers determined the amount of load shedded in each stage of the under frequency relay. A genetic algorithm (GA) was used to minimize the disconnected load and to maximize the minimum swing frequency. In GA, penalty functions and chromosomes of varying lengths are used to determine the optimal load shedding at all stages.

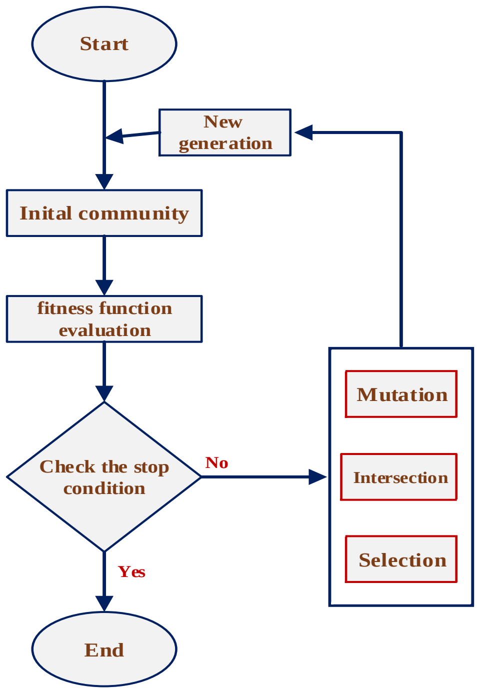

Figure (8): Genetic algorithm-based load shedding technique flowchart

- In order to recommend load-shedding solutions for power systems, this research [90] suggests using artificial neural networks (ANN) using the back propagation (BP) algorithm in combination or hybridization with genetic algorithms (GA). In order to increase backtracking capability, decrease mistakes, and shorten training time, back propagation neural networks (BPNN) are trained using the genetic algorithm. In addition, the amount of input variables for the neural network is decreased using a support method.

Genetic algorithms are used to optimize the weights of neural network structures to reduce drawbacks such as slow convergence rates and minimal local errors. The result is a network architecture that is able to learn faster and is able to predict with better accuracy.

- The Genetic Algorithm (GA) and the Exchange Market Algorithm (EMA), two optimization techniques, were utilized in [9] to tackle this optimization problem. This research introduces a new indicator for the distribution of load shedding among MGs based on total power generation and load demand.

An improvement issue and a new indicator for locating removable loads were introduced for the confidence of various MG owners.

- In this research [47] a hybrid method was used which is a combination of genetic algorithm (GA) and neural network (NN). GA is used through two stages, the first is to generate the optimization model and the other stage is to generate a dataset to develop the NN-based intelligent load shedding model.

-The particle swarming (PSO) algorithm has relatively good experience with advantages of convergence speed and robustness [83]. It is an optimization algorithm with a random search that has a parallel synthetic structure that has been exploited to improve the performance of the power system and increase the range of stability [91].

- In [92] the researchers present a new method to determine the value of the load to be disconnected and the delay time in each steage for UFLS load shedding relays in a marine power system near Taiwan. The load value to be shedded and the stages delay time are obtained by multi-objective programming based on particle swarm optimization. The proposed UFLS scheme ensures less load shedding and faster frequency response than the conventional UFLS scheme.

- In this paper [93] a particle swarm-swarming (PSO) algorithm based on Takagi-Sugeno (TS) was used to minimize the total shedded load and maximize the swing frequency. Two sets of fuzzy TS rules were developed to adjust the inertia weight and training factors in the proposed PSO to obtain the optimal settings.

-The paper [70] proposes an innovative, accurate, reliable and fast UFLS technology based on the grasshopper Optimization Algorithm (GOA). The objective function is to minimize the amount of shedded load while maximizing the minimum swing frequency in all steps. Bacteria Foraging (BF) Algorithm: The algorithm mimics the behavior of capturing E. coli bacteria, which is a natural behavioral occurrence. Similar to PSO, BF is a popular optimization technique [94].

Research has suggested hybrid optimization utilizing PSO and BF (HPSBF) for a variety of applications. For instance, researchers [95] suggested combining PSO with BF to address optimization delays and enhance the performance of the BF method when configuring a permanent magnet synchronous motor's PI-speed controller. HPSBF was also used to establish the parameters for solar modules [96]and decrease harmonics [97].

- To guarantee the security and stability of the system after failures and disturbances, the researchers introduced a hybrid optimization technique that combines PSO and BF (HPSBF) [50].

The objectives of the method are to reduce the load shedded by the relays while increasing the minimum swing frequency. The HPSBF technology optimises UFLS load shedding relays as a limited improvement with limits that correspond to the boundaries of system state variables. Comparing the HPSBF algorithm to the conventional PSO and BF methods, the viability of the HPSBF algorithm was confirmed.

Table (2) shows the most important advantages and disadvantages of the most popular and widely used artificial intelligence technologies.

6.2.7. Under frequency load shedding scheme based on smart home appliances, smart meters, communication networks and the Internet of Things

In this type of load shedding scheme, the active sharing of data from home appliances and smart meters is exploited for the purpose of rebalancing power between available generation and real load. In addition to the use of various telecommunication networks and the Internet, both wired and wireless, and the Internet of things technology in order to manage data and make load shedding decisions in a manner appropriate to the amount and location of the disturbance.

Table (2): Advantages and disadvantages of artificial intelligence

	Technology	Advantages	Disadvantages	Ref.
1	Artificial neural networks (ANN)	ANN has the capacity to provide the ideal level of load shedding.	Only known cases can receive satisfactory results via ANN, whereas unknown cases may not receive correct predictions.	[94]
2	Fuzzy logic controller (FLC)	Any scale power system can use load shedding by using FLC.	The FLC membership function needs a set up system. Otherwise, it might not offer the best load separation.	[95]
3	Adaptive neural fuzzy inference system (ANFIS)	ANN is used to optimise FLC parameters, which can result in precise load shedding.	Only systems of the Sugino kind can use it.	[67]
4	Genetic algorithms (GA)	The minimum level of load shedding is guaranteed by GA.	The shedded loads are difficult to estimate using GA.	[76]
5	Particle swarm optimization (PSO)	PSO is straightforward and capable of determining the ideal value.	Partial optimisation is easily disrupted by PSO.	[97]

Figure (9) shows the general structure of the potential load shedding scheme, it displays the smart equipment used, while figure (10) shows the utilities of loads and frequency control [29], [98], [99].

- An efficient wireless load shedding system for non-emergency situations is given in the study [29]. The suggested method offers a practical substitute that combines the use of current GSM microcontrollers to alert users via SMS messages to cut back on power usage before system capacity is reached and a regular power shutdown takes place.

- In [49] a smart UFLS/UVLS method based on the active participation of smart devices was proposed. The main contribution of this research lies in the use of smart devices under frequency and under voltage loads to restore system frequency and voltage in the emergency, reducing the amount of load disconnected compared with the traditional load shedding scheme, thus reducing the violation of user convenience and economic losses.

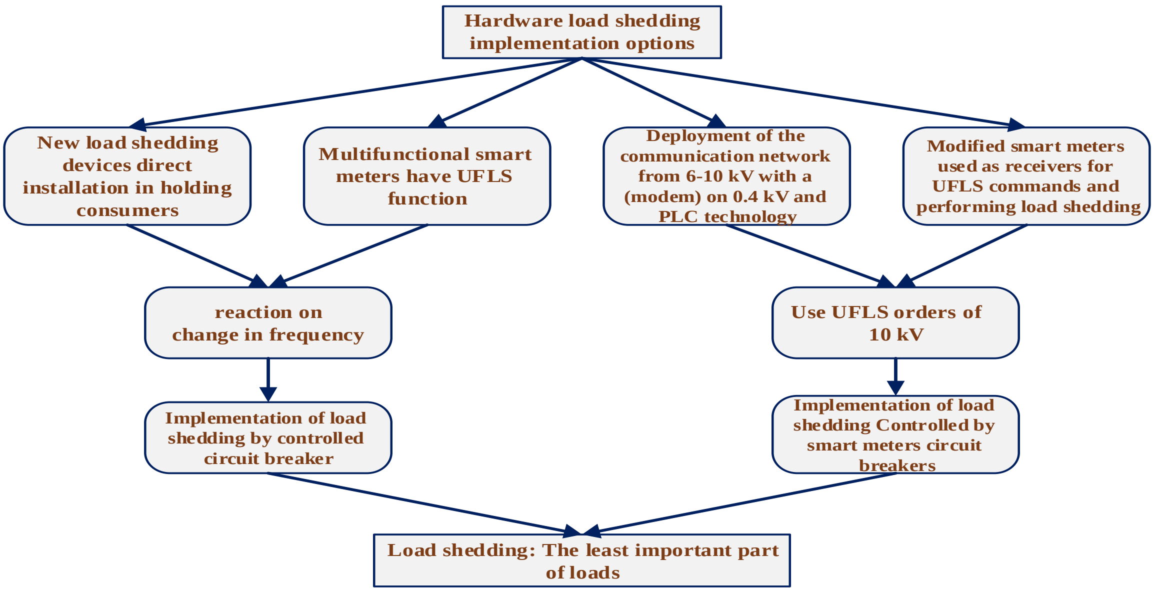

Figure (9): General structure of the possible organization of the load shedding scheme [98].

- The research [99] presents an application of the Internet of Things for smart devices for the automatic monitoring of the load shedding scheme at low frequency in the system coordination center. The purpose of this paper is to introduce Internet of Things (IoT) technology in AUFLS monitoring to develop a new load shedding system.
- In [100] the authors describe an intelligent load shedding scheme that monitors plant loads, generator, and generation/supply reserve for utilities to identify the lowest priority loads for shedding. Fast load shedding software uses the reliability and availability of modern Ethernet networks, and is described as simple compared to traditional systems.

control home appliances, which are connected to smart sockets.
- In the research [103] the system variables and time constants are determined through the online learning scheme using the actual frequency measurement. The system is then adaptively controlled based on these specific variables, providing the amount of load that should be shedded in a distributed and selective manner in order to maintain system frequency stability.
- In [104] an intelligent load shedding scheme for the Smart Load Management System (SLMS) was implemented in order to operate in isolated mode. The important functions of SLMS are shedding

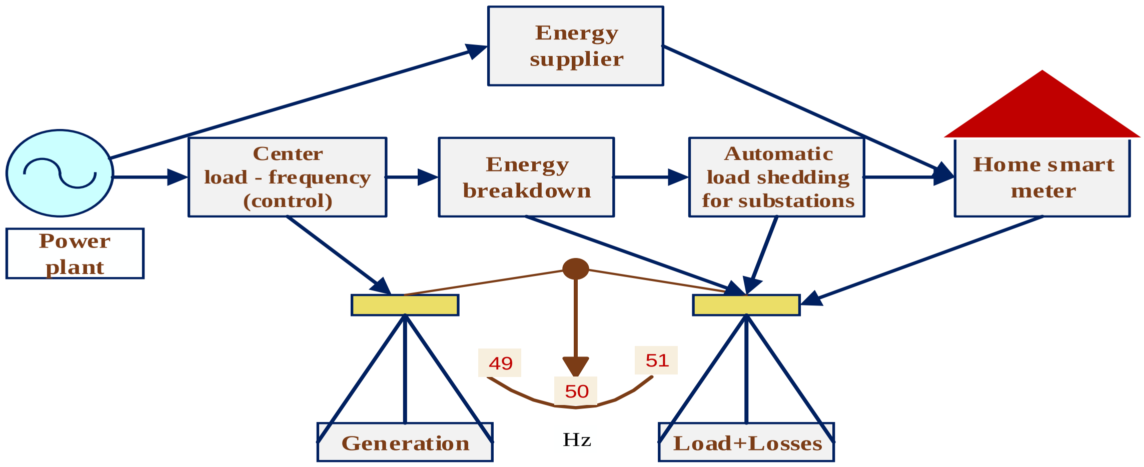

Figure (10): the utilities of loads and frequency control [98]

- To prevent power failures caused by rapid changes in network load and to lower the peak-to-average ratio (PAR), researchers in [101] suggested employing a new algorithm for direct intelligent load control and load shedding. The method makes use of prediction, shedding, and intelligent direct load control. Additionally, it has created a daily timetable for clients who have Intelligent Electronic Devices (IED) depending on their needs using IoT and data analytics to provide real-time load control.
- In [102] the researchers presented a hierarchical smart home control system that controls residential appliances. In this system there is a supervisor control device, a secondary control device, and some smart plugs. The supervisory controller is the power utility, which produces prompt electricity tariff and appropriate load shedding orders. The secondary controller, which is the central control unit of a smart home connected to a smart energy meter, produces on/off commands to perfectly and automatically

load under voltage and shedding load under frequency that can play a major role in power system stability. To keep the voltage and frequency within the permissible limit, the UVLS and UFLS functions are implemented in real time by means of PLCs (programmable logic controllers) and a power management system (PMS) in the real power station.
- In the paper [105], based on wide area measurements, the actual disturbance in the system is determined a few seconds before the load shedding procedure. Smart under frequency load shedding scheme is proposed with online disturbance estimation. Based on real-time measurements from PUM units, a system frequency response model was prepared and the extent of perturbation was estimated online before load shedding was implemented.
- The research [106] proposes an intelligent load shedding scheme that uses a regularly updated load shedding schedule to avoid deficiencies in the system currently in use. The proposed intelligent load shedding scheme (ILS) overcomes

these shortcomings by updating load shedding schedules online taking into account the actual loads borne by the selected feeders.

- Research [107] proposes an intelligent method for determining frequency stability when perturbation occurs, based on real-time measurements in the power system. The proposed scheme uses an improved energy flow tracking method to determine the amount and locations of load dips.
- In the research [108] reviews the current means and methods to reduce the load for eliminating the energy imbalance. There are ways to use modified power meters for load shedding, particularly when eliminating effective power imbalances and preventing frequency drops. The smart meter measures the electrical energy and transmits the data to the system operator's regional distribution center in real time. These devices can play a role in load shedding when necessary.
- In [109] a new method was proposed to define a UFLS strategy that includes smart devices to achieve coordinated control of rapid response resources and traditional control resources. In this way, smart hardware can be used to meet the regulatory requirements of the operating system and prevent a significant drop in frequency, thus improving the flexibility and stability of the system. It is able to mitigate the frequency decrease and reduce the amount of load shedding, Figure (11) shows the control strategy in the UFLS scheme, where: K is the response indicator, Fsm: reading the frequency of the smart meter, FLS: the starting frequency of the load shedding. Whereas, Figure (12) shows the smart device control units.
- In the paper [110] a platform is developed that illustrates the load control scheme that provides the initial frequency response. The platform uses a commercially available smart meter andremote-controlled smart sockets. A load controller is implemented in a computer that sends control signals to the smart sockets to turn on and off.
- In the research [111] smart measurements and control topography are used to develop traditional load shedding schemes. In addition, with the installation and application of smart meters, smart appliances and other smart home devices at the user's side, measurements and dynamic information can be obtained by these devices and used for the security and stability of the power system, thus obtaining a new intelligent load shedding system.

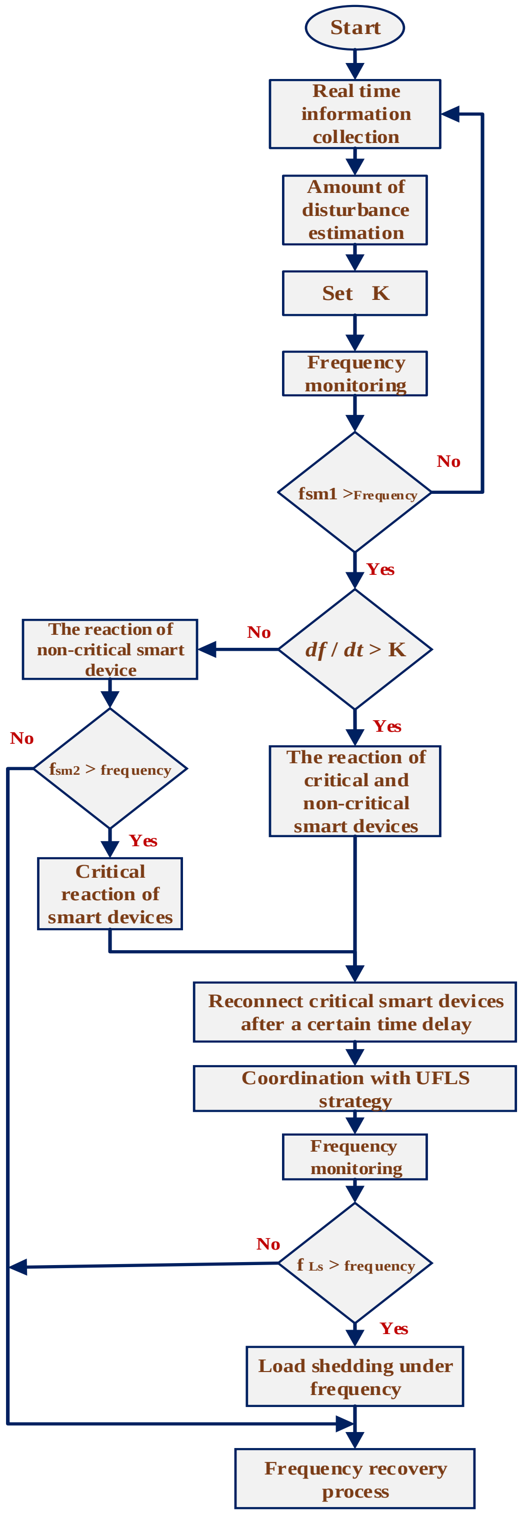

Figure (11): UFLS scheme control strategy in the context of smart devices [109]

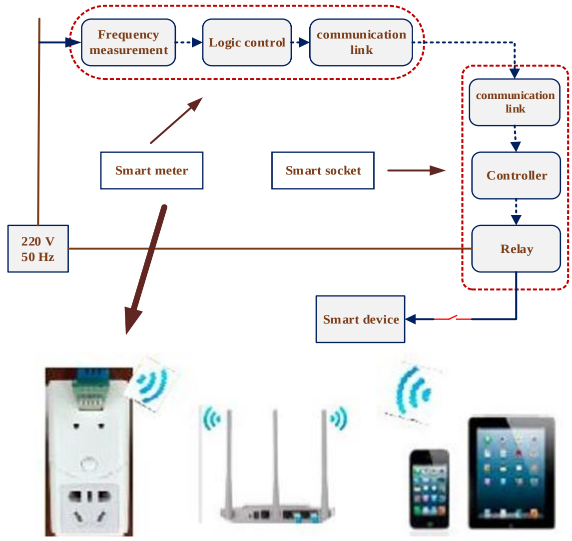

Figure (12): Control units for smart devices [109]

7. COMPARISON OF DIFFERENT LOAD SHEDDING TECHNOLOGIES

All of the above discussed UFLS techniques have their own advantages as well as their limitations. To select a particular technology to implement it needs a lot of attention regarding operating conditions, high disturbance level, frequency drop value and other variables. Table No. (3) Shows a summary of the comparison between the different types of load shedding techniques.

8. CONCLUSIONS

A significant discrepancy between generation and load demandcan happen in an interconnected energy system. This calls for efficient methods for quick and precise load shedding. Discussed are variables affecting frequency drop situations and their impact on system hardware, which can harm the entire network. Traditional load-shedding plans remove a predetermined number of loads in fixed blocks, which could result in insufficient load-shedding.

Adaptive metods take into account the rate of frequcy change and load shedding is done based on simple formulas because of the drawbacks inherent in traditional and adaptive approaches, computational intelligence techniques are required, while smart home applications and online monitoring can provide solutions to energy management and power balance issues. This paper reviews traditional, adaptive, computational methods (artificial intelligence technologies) and smart devices with communication networks in load-shedding and discusses the relative advantages and disadvantages.

Intelligence techniques in load-shedding are more efficient than other methods in terms of quick response, accurate load shedding amount and priority list updated load, while smart applications can be used in medium disturbances and network isolation cases. However, further improvement and development of these modalities are still required. A complete summary and comparison of the advantages and disadvantages of load-shedding methods werepresented.

Table (3): Comparison between different types of load shedding techniques.

Technology	Advantages	Disadvantages	Ref.
Conventional	-Simple - Easy to implement	- Lack of information on the extent of the disturbances -Unable to estimate the actual value of the energy imbalance. - Shedding of a fixed amount of loads during disturbances - Not suitable for application in modern and complex power systems	[45]
Adaptive	- An accurate method for determining the quantity of shedded loads - Reliable -active	- Optimum load shedding cannot be implemented due to frequency difference	[112]
Smart	- Has the ability to determine the optimal value of the shedded load. -It is efficiently applied in modern and complex energy systems	- It does not guarantee adaptation to a combination of frequency and voltage instability in the system.	[16]
Smart devices and equipment	- Usually used in cases of small and medium disturbance - Practical and suitable for implementation in cases of network isolation	- You need real-time communication networks, and this reduces their reliability - It cannot be applied to all facilities because it reduces consumer comfort	[98]

9. FUTURE DIRECTIONS

The previously mentioned schemes can be improved in the future according to the following recommendations.

1. The load shedding schemes controller is possible to be combined with load restoration procedure to automatically perform the reconnection of disconnected loads.
2. It can suggest that the scheme to consider inverter-based DG such as Photovoltaic and Wind energy. This includes the modeling of inverter controller, and the photovoltaic and wind energy of DG model. The voltage and current control should be considered to control the intermittent parameters for solar and wind energy.
3. Improvement of power deficiency estimation. In some situations, the error can be up to 9%. Since there are other factors that can affect the estimation process such as the load voltage dynamic time constant, they can be involved to enhance the accuracy.
4. Improvement of the topology-oriented schemes. It is can that the considered topology-oriented schemes do not sufficiently deal with the hidden assumption that the shedding amount of a load cannot be larger than its maximum power consumption. Thus, it may cause the actual shedding amount less than the planned value.
5. Other decision-making techniques such as Topsis-AHP, Fuzzy-AHP, Fuzzy-Topsis and other optimization methods can be explored in determining load shedding selectivity.

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نظرة عامة على الاستراتيجيات المختلفة للتعامل مع مشكلة فصل الأحمال عند اخفاض التردد في منظومات القدرة الكهربائية

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الخلاصة

من الضروري الحفاظ على إمدادات طاقة متسقة ويمكن الاعتماد عليها في ضوء الطلب العالمي المتزايد على الطاقة. عندما تكون هناك أزمة ، مثل عطل أو عدم توازن بين إنتاج الطاقة والطلب على الحمل ، يصبح نظام التردد غير مستقر. يعد مخطط فصل الأحمال مفتاحًا مهمًا لاستعادة نظام التردد وضمان إمكانية الحصول على الطاقة الكهربائية للأحمال الخطيرة في المحطة. لذلك ، من الضروري توفير تقنيات موثوقة لمنع حدوث عطل في طاقة النظام بسرعة وبدقة. UFLS هي إحدى الحماية المهمة للنظام ، وكما هو الحال حاليًا في كثير من الحالات ، فهي الخطوة الأخيرة لمنع انهيار النظام بعد انقطاع أو فشل الطاقة في النظام. يتم تقديم مراجعة للأدبيات ، جنبًا إلى جنب مع نظرة على الطرق المختلفة المستخدمة في نظام الطاقة الكهربائية ومقارنة الاستراتيجيات التقليدية والتكيفية والذكية لفصل الأحمال. من أجل توضيح الوظيفة المقصودة (الكيان) والحفاظ على استقرار النظام ، يُقترح تصنيف إضافي للعناصر الإضافية. تمت مناقشة مختلف أنظمة فصل الأحمال ومزاياها وعيوبها ، وتم إجراء مقارنة بينها بقائمة من أهم المبررات للقيام بذلك..

الكلمات المفتاحية

فصل الاحمال; انخفاض التردد; استقرارية التردد ; نظام القدرة; التطبيقات المنزلية الذكية; UFLS.