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# Representing an intelligent load shedding algorithm with utilization of frequency deviation integration

***Abstract**. In this paper, after a brief introduction to power systems' urgent need for a load shedding program, we attempt to optimize the frequency load shedding conventional method. This optimized method intelligently decides to shed appropriate system load proportional to the severity of power system disturbance. It is meant to prevent redundant load cut off by making a variety of choices in each load shedding step, a step that has been used in the conventional scheme up to now. The main idea behind using this intelligent load shedding scheme can be evaluated for applicability in Smart Grids. To prove the results, a few disturbances are simulated for the IEEE standard 9 bus system, and the grid defensive counteractions are analyzed within two situations. In the first situation, when the disturbances happen in the grid utilized with a conventional load shedding program, and the second situation uses the same disturbances with the intelligent load shedding scheme.*

***Streszczenie.** Przedstawiono program analizujący zmniejszanie obciążenia w sieci energetycznej w zależności od różnego rodzaju zakłóceń. Główną celem tego inteligentnego algorytmu jest zastosowanie w technologii Smart Grid. Przedstawiono symulacje zakłóceń i porównano proponowany algorytm z metodami konwencjonalnymi. (**Algorytm inteligentnego zmniejszania obciążenia sieci z wykorzystaniem zmiany częstotliwości**)*

**Keywords:** Conventional load shedding; Integrating *df/dt*; Intelligent algorithm.
**Słowa kluczowe:** zmniejszanie obciążenia, Smart Grid, sieci energetyczne.

## 1.Introduction

Power network stability has always been one of the main issues for system designers and system operators. Power systems have the duty to serve customers, and electricity plays a vital role in industrial and technological progress, therefore, continuity in load feeding and reliability are some of the fundamental expectations of each end user [1].

Also total black out or partial outages of service can impose heavy social and economical losses. So there are different points of view that explain the urgent needs for system reliability and stability.

Under normal power system operation conditions, feeding power nonstop to consumers should be a priority. And this is one of the fundamental principles of the power grid's creation. To satisfy this expectation, frequency preservation and frequency control become important as the main system quality criteria [1, 2].

But in an interconnected power system, one of the sensitive situations is collapsing the whole system following frequency decay due to outage of a large generating unit or extensive damage to a main tie line. In such a situation, shedding loads quickly is the best way to prevent cascading outages. This action of prevention is recognized as underfrequency load shedding (UFLS) [3].

## 2.Review of previous studies

In modern power systems with high adaptability, UFLS is known as an efficient way to stop fast frequency decay following great active power generation loss. Therefore, a good UFLS program can be used to stabilize a power network. Preliminary work on this issue started in 1950's. However it was accepted by most utilities after the 1965 blackout in the Northeast United States [4]. The load shedding objective is not to restore frequency to the exact nominal amount. Rather it should be attempted to reach proximity of nominal frequency, so remaining overloads can be controlled with generating units governors' action. To minimize the possibility of overshedding, designers often suggest load shedding programs in stepped form [5, 6].

The conventional schemes are designed for determining the amount of load to be shed based on the observed frequency deviation ($\Delta f$) following the system disturbances. In other words, in modern UFLS design, $\Delta f$ is used extensively [3]. For example, Table 1 represents the conventional UFLS algorithm of the union for the co-ordination of transmission of electricity (UCTE) based on TransmissionCode 2007 [7, 8].

Table 1. Five stages conventional UFLS plan

| | | |
|---|---|---|
| Stage 1 | 49.8 Hz | Alerting personnel and scheduling power station capacity not yet activated, according to the TSO's direction |
| Stage 2 | 49 Hz | Instantaneous load shedding of 10–15% of the system load |
| Stage 3 | 48.7 Hz | Instantaneous load shedding of another 10–15% of the system load |
| Stage 4 | 48.4 Hz | Instantaneous load shedding of another 15–20% of the system load |
| Stage 5 | 47.5 Hz | Disconnection of all generating facilities from the network |

But $\Delta f$ cannot give any information about amount of generation loss or rate of frequency decay. So the UFLS algorithm based on $\Delta f$ does not have good adaptability [3, 5, 9].

Rate of frequency changes (*df/dt*) may be a suitable parameter to enhance the adaptability of UFLS program, but there is no practical scheme available today. The reason lies in the fact that the instant *df/dt* changes so violently that it cannot directly give any information about the severity of generation deficiency in the power system. These changes can cause either underestimating or overestimating at the time when the magnitude of generation loss should be assessed [9].

## 3.Proposed algorithm of the research

The main aim of this research is to present a new way for improving the conventional UFLS characteristic and then evaluating the advantages of the new algorithm through simulation.

In this paper, integrating surface between two load shedding steps will be used, which is called integrating *df/dt* and is represented with an "*h*" sign. With this new method, there will be different choices in each load shedding operational step that existed before.

As illustrated in Fig.1, the integral of downward and transient frequency trend should be calculated between two time points, 0 and $t_i$ , which respectively have the frequency value of $f_n$ (nominal amount) and $f_i$ (one of frequency steps).

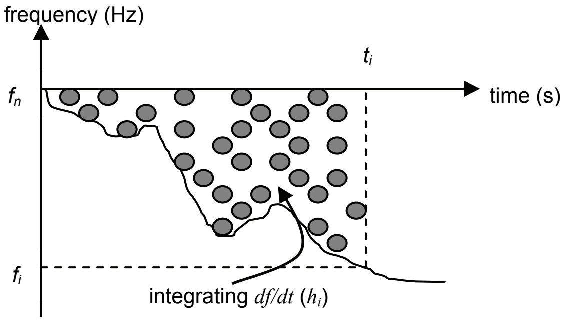



Fig.1. Integrating $df/dt$

Fig.1 implies that, regardless of existence of frequency oscillation, absolute value of $h$ grows with an approximately steady trend.

The value of integrating $df/dt$ can show the amount of power deficiency in some ways. Consider the illustrated time-frequency ($f$-$t$) diagram in Fig.2.

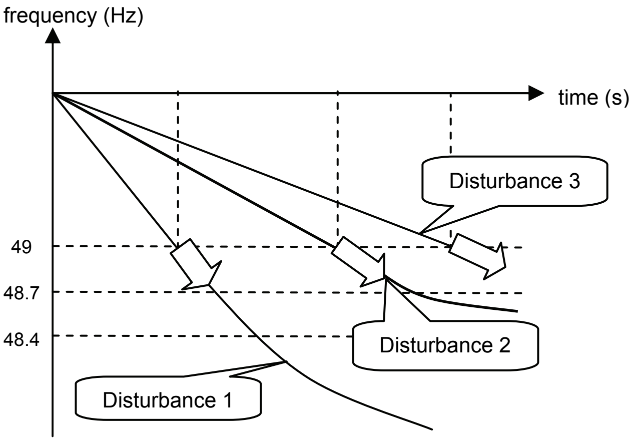



Fig.2. $f$-$t$ diagram and comparison of disturbances severity based on the integrating $df/dt$

As frequency curves imply, disturbance 1 is larger than 2, while disturbance 2 is larger than 3. Also, absolute value of surface under the curve 3 ($h_3$), which is enclosed between the time axis, right hand side vertical dot line, and frequency decay curve is the largest. Then state 2 ($h_2$) is smaller, and $h_1$ is the smallest. In other words, (considering the facts that all described surfaces are under the time axis) when minus sign is considered in integrating: $h_1 > h_2 > h_3$ . The obtained inequality is something independent from the frequency oscillation which created problems with using the rate of frequency changes for UFLS enhancement.

So if $P_i$ (i=1,2,3) describes load percentages that should be dropped to restore frequency, therefore: $P_1\% > P_2\% > P_3\%$.

Considering the above facts, the Intelligent UFLS algorithm is depicted in Fig.3.

If the first UFLS operational threshold is triggered, this load shedding scheme would get ready to counteract (i=1). When the $h_1$ is compared with upper and lower described limits, the intelligent algorithm would select the appropriate choice between different available choices. Then at the time when the algorithm goes to second loop, (in other words, when the turn of the second UFLS step comes, if first condition was verified, meaning system frequency was lower than the frequency of second triggering step) integrating $df/dt$ should be compared with numerical ranges that are different from the ranges of first step[1]. Based on the number of conventional UFLS operating steps (which are optimized with the intelligent method), the repetition of the flow chart loop can be different (i=1,2,3,…). Another prominent note in illustrated flow chart is that the algorithm selects between just two different choices. Remember that the only purpose of drawing such a flow chart is to make basic idea clear. If not, in the SIMULATION RESULTS section for the grid under the study, the number of choices in each intelligent UFLS step (the same triggering steps that existed in conventional UFLS) can be different from the others. Details of the intelligent scheme will be clarified based on the requirement of the study grid.

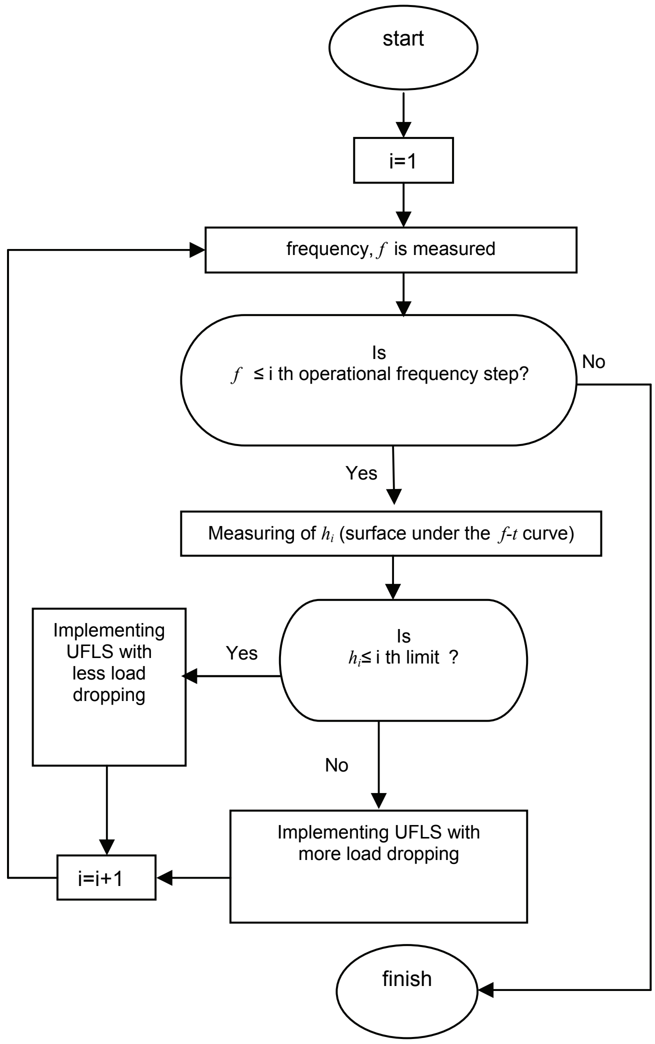



Fig.3. Intelligent UFLS algorithm flow chart

**4.Implementation of the proposed algorithm in the sample grid**

Fig.4 depicts the single line diagram of IEEE 9 bus standard system selected for simulation.

Table 2. Five stages conventional UFLS plan

| Stage of UFLS | Operational frequency step (Hz) | % Loads to be shed |
|---|---|---|
| 1 | 49 | 12.5 |
| 2 | 48.7 | 12.5 |
| 3 | 48.4 | 17.5 |

[1] Depending on the integrating method, this difference can be noticeable. In this paper, $h_i$ (i=1,2,3) is the result of integrating from the last time when frequency has had nominal value

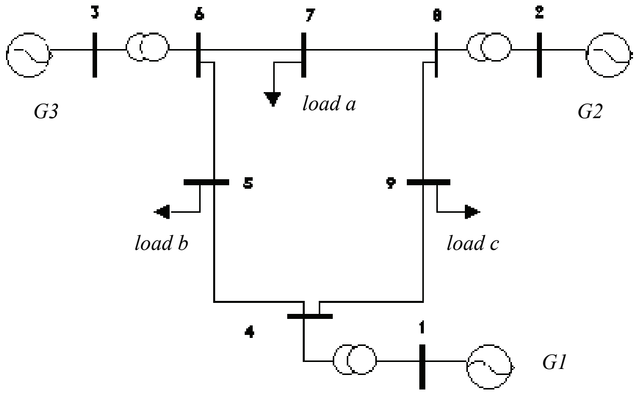



Fig.4. Single line diagram of 9 bus system

Table 2 shows the steps of the conventional UFLS scheme, which are used in this study. It needs to be explained that UFLS triggering steps have been selected according to the UCTE standard and are similar to the given information in Table 1. Also for Table 2, the average amount of shedding order in each Table 1 stage has been selected as the percentage of the loads that should be dropped in necessary situation.

Table 3 represents the intelligent UFLS scheme, which is the optimized version of the conventional UFLS scheme. The steps in Table 3 are adapted with the logic of the flow chart in Fig. 3. It means when the frequency tends to decrease following a disturbance, in each UFLS operational threshold, there will be various choices for shedding system loads. By taking the integrating *df/dt* into account, one of them will be selected.

Table 3. Five stages conventional UFLS plan

| Stage of UFLS | Operational frequency step (Hz) | Numerical ranges for analyzing *h* | % Loads to be shed |
|---|---|---|---|
| 1 | 49 | $h$<-0.35 | 16 |
| | | $h\geq$-0.35 | 17.3 |
| 2 | 48.7 | $h$<-0.53 | 7 |
| | | -0.53<$h\leq$ -0.46 | 9 |
| | | $h\geq$-0.46 | 17.3 |
| 3 | 48.4 | $h$<-0.76 | 7 |
| | | -0.76<$h\leq$ -0.63 | 9 |
| | | $h\geq$-0.63 | 17.3 |

When the information of two recent tables is evaluated, it is concluded that if a great disturbance happens and system frequency decay activates all the three predefined thresholds, the intelligent UFLS can implement 18 different scenarios while the grid always receives just one fixed type of load shedding order from the conventional UFLS program.

### 5.Simulation results

Before beginning any inspection in the obtained results, remember that due to the speed governor specification of the generating units of the grid, in all operating modes, system frequency starts to decrease from the nominal amount.

Fig.5 shows that the mentioned governor specification incurs the system frequency to be fixed at 49.6 Hz in normal operation mode.

Figs.6, 8, and 10 show *f-t* curves following the outages of generating units *G1*, *G2*, and *G3* respectively. And Figs.7, 9, and 11 depict the active power usage of *load a* due to the outages of generating units *G1, G2*, and *G3* respectively. All these figures compare the consequential results in two states:

a. for the grid utilized with the conventional UFLS scheme
b. for the grid utilized with the new intelligent UFLS program

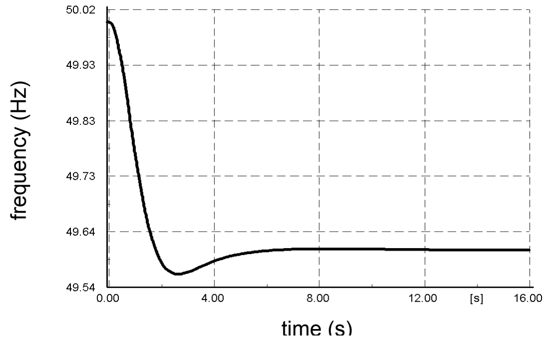
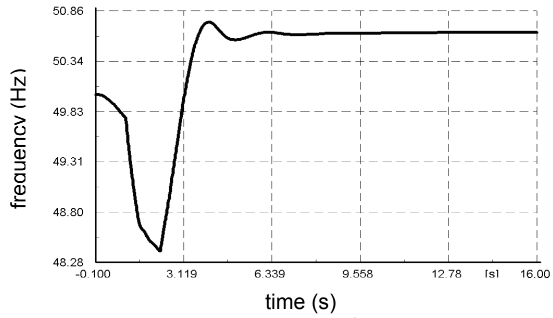
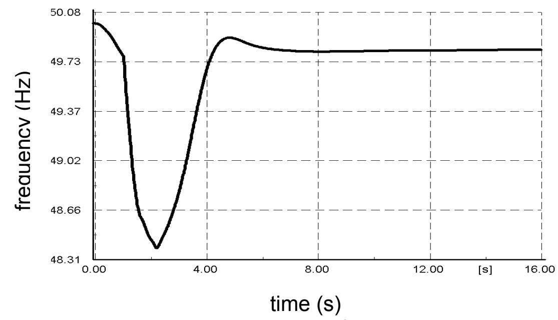



Fig.5. Preliminary frequency decay in normal operational mode




a. conventional UFLS scheme



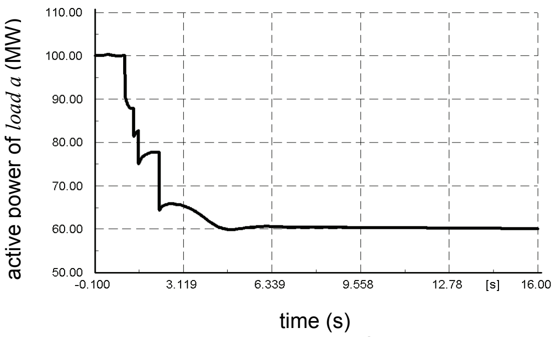

b. intelligent UFLS scheme

Fig.6. *f-t* curves following *G1* outage

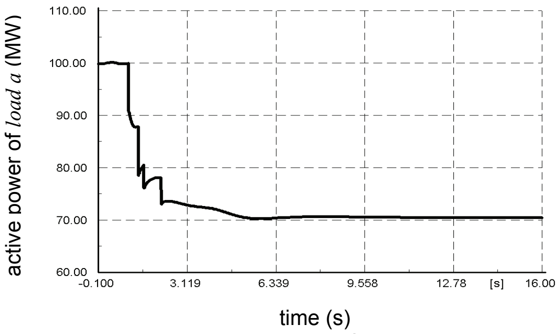
In both Fig.6-a and Fig.6-b before t=1 s (the time when generation deficiency happens), frequency drops with a primary gradient. This primary decay is the decay that was mentioned earlier in the Fig.5. From t=1 s, the frequency decline will be aggravated. In Fig.7-a, due to the frequency decrease, the conventional UFLS scheme cuts off the feeding of in increments of 12.5% , 12.5% and 17.5% of the system loads in three steps. It means 42.5% of the system loads are dropped totally, which results in stopping the frequency decay at 48.41 Hz and at the moment equal with 2.204 s. Therefore, the frequency decay is stopped during 1.2 s from the start time of the contingency. Then in a rising path, frequency reaches the maximum point 50.743 Hz at the moment 3.996 s.

Fig.6-b and Fig.7-b show that with similar disturbance, when *G1* is shut down in t=1 s, intensified frequency decay is sensed with the Intelligent algorithm, which respectively sheds 17.3%, 7%, and finally 7% further of the system loads. Thus, the intelligent algorithm succeeds to stop frequency at 48.388 Hz and put it in a restoration path, all

with 31.3% of network load dropping during a 1.175 s time span. Also at the moment of 4.767 s, frequency is observed in its peak value, equal to 49.898 Hz.

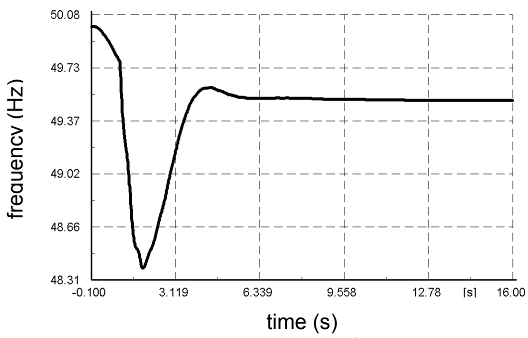



a. conventional UFLS scheme

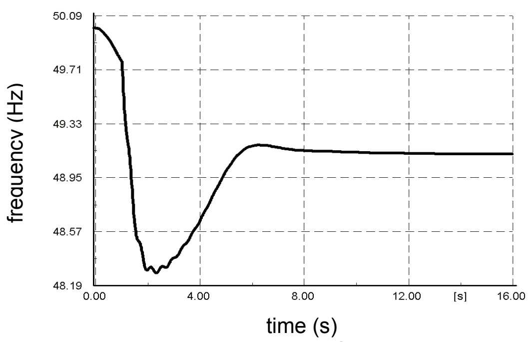



b. intelligent UFLS scheme

Fig.7. active power of *load a*, following *G1* outage



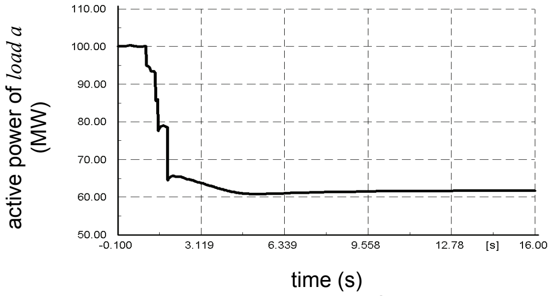

a. conventional UFLS scheme



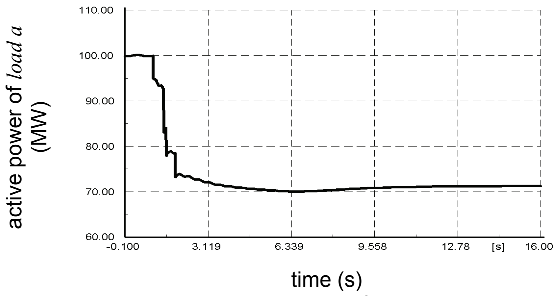

b. intelligent UFLS scheme

Fig.8. f-t curves following *G2* outage

As Fig.8-a shows, This time with counteraction of the conventional UFLS scheme following the outage of the *G2* generating unit, frequency decay is stopped at 48.387 Hz at the moment of 1.856 s. In the restoration path, maximum system frequency is 49.59 Hz, which happens at the time equal with 4.403 s. All these scenarios took place via the shedding load of 42.5% (Fig.9-a).



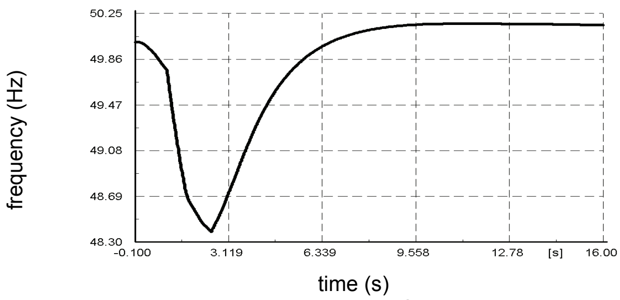

a. conventional UFLS scheme



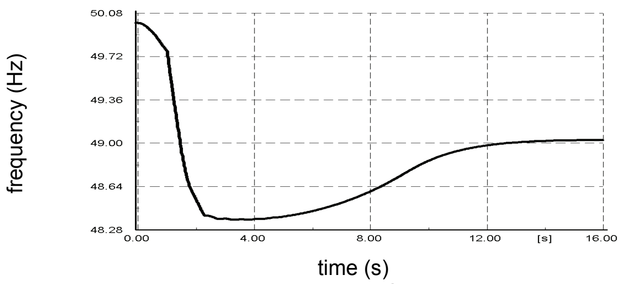

b. intelligent UFLS scheme

Fig.9. active power of *load a*, following *G2* outage

From the inspection of Figs.8-b and 9-b, it is deduced that during 3 stages of load shedding with a total dropped load of 32%, system frequency decay reaches the point of 48.28 Hz at the moment of 2.31 s and maximum frequency is 49.18 Hz at 6.187 s.




a. conventional UFLS scheme

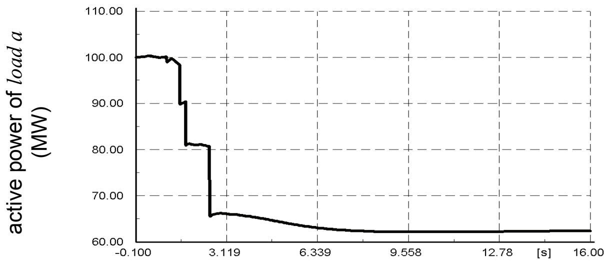



b. intelligent UFLS scheme

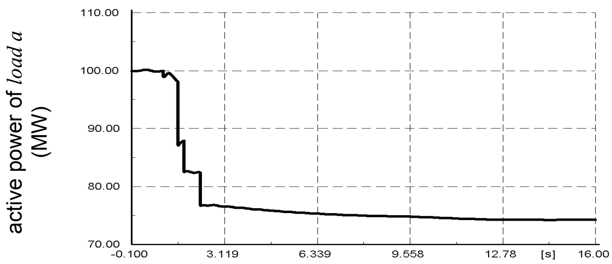
Fig.10. f-t curves following *G3* outage

In Fig.10-a, preliminary frequency gradient becomes steeper due to an outage of the *G3* generating unit. Following the frequency drop, the conventional UFLS scheme counteracts with the dropping of 42.5% of system loads in three stages. So frequency decay is stopped at 2.516 s and starts to restore. With this process, minimum frequency reaches 48.395 Hz while maximum frequency is

50.158 and transition time between the maximum and minimum points is 8.786 s. Fig.10-b depicts behavior of the system frequency following the *G3* outage while the network has been utilized with the intelligent algorithm. Inspection shows that the intelligent algorithm identifies three steps of load shedding for the network under its command, respectively 16%, 7%, and 7% (Fig.11-b). With fulfilling these three steps, the frequency decay stops at 48.361 Hz at the instant of 3.264 s. While frequency has the value of 48.361 Hz, its restoration takes about 10.864 s to reach its maximum point at 49.02 Hz.



a. conventional UFLS scheme



b. intelligent UFLS scheme

Fig.11. active power of *load a*, following *G3* outage

Load cut off statistics due to three different system disturbances following the intelligent UFLS and the conventional UFLS counteraction are compared in Table 4. Each number of the table cells describes the total portion of all system loads that will be dropped, following the order of UFLS plan.

Table 4. Load cut off statistics due to UFLS counteraction

| Disturbance | % shed load using intelligent UFLS | % Shed load using conventional UFLS | % Prevention of unnecessary Load shedding |
|---|---|---|---|
| Outage of *G1* | 31.3 | 42.5 | 11.2 |
| Outage of *G2* | 32 | 42.5 | 10.5 |
| Outage of *G3* | 30 | 42.5 | 12.5 |

The information in Table 4 confirms the decrease in unnecessary load shedding. This decrease is an important virtue of the new intelligent UFLS algorithm.

## 6.Conclusions and recommendations

As mentioned in this paper, some steps were attempted to move forward in order to fulfill fundamental power system principles and to increase the quality of serving energy.

Reducing the load shedding extensiveness in situations when there is no other solution to restore stability of a damaged power network, justifies more studies to correct the probable difficulties of the new intelligent algorithm. These corrective actions may differ due to understudy grids, but attenuating the numerical ranges for the comparison of integrating df/dt through increasing the number of choices in each UFLS triggering step could be an effective method.

The main idea behind using this modern load shedding scheme can be evaluated for applicability in Smart Grids. As this paper demonstrates, the optimized method avoids shedding a portion of loads in a way that allows the other power system principles to be met again. Therefore, the new intelligent method increases reliability and reduces operational cost concurrent with energy economy. All these consequential effects are the main objectives of Smart Grids.

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