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Review of under Frequency Load Shedding Program of Kosovo Power System based on ENTSO-E Requirements

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ABSTRACT

Under-frequency load shedding (UFLS) is designed to protect the power system when the frequency drops below given thresholds by switching off certain amounts of the load aiming thus to balance generation and load. This paper presents a review of the existing UFLS (Under Frequency Load Shedding) program in compliance with recently revised Police-5 of Operational Handbook of ENTSO-e. The proposed review of the current UFLS program for Kosovo Power System has considered the main standards requirements and guidelines for UFLS set by ENTSO-E. This work examine system performance by conducting dynamic simulations of UFLS schemes subject to different imbalances between load and generation, and includes three power system island mode scenarios with different equivalent inertia of the system, respectively different size of the systems. With aim to define the best program of UFLS, which fits to the Kosovo Power System frequency behavior, two different UFLS programs are analyzed and results are compared. The proposed program is tested using a large scale PSS/E model which represents interconnected power system area of Southeast Europe.

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1. INTRODUCTION

Under-frequency load shedding (UFLS) is defined as a coordinated set of controls using under frequency relays which results in the decrease of electrical loads in the power system, with aim to recover the system frequency. Load shedding as the last resort to avoid a major power system breakdown has been utilized for a long time. It is mainly triggered by under-frequency or under-voltage protection relays and actuated by distribution system circuit breakers. Proper design of load shedding schemes which include proper settings of under-frequency protection is most relevant issue to ensure smooth load relief, in situations where the power system otherwise would go unstable. The current revised program requirements for UFLS are presented in Operational Handbook of ENTSO-E/Police-5.

Each TSO shall implement the ENTSO-E RG CE general UFLS scheme as followed:
Frequency in the range 49.0 to 48.0 Hz:

a. At least an amount of demand corresponding to 5% of the total load shall be disconnected at 49.0 Hz.
b. In total, an amount of demand corresponding to 45% +/- 7% of the total load shall be disconnected between 49.0 and 48.0 Hz.

The UFLS scheme shall be implemented stepwise taking into account following considerations:

a. The number of disconnection steps shall be minimum 6 (including the step triggered at 49.0 Hz),
b. For each step, an amount of demand corresponding to 10% of total load shall be disconnected at maximum.
c. Additional df/dt function in UFLS relays is allowed in the range 49.8 – 49.0 Hz.
d. No intentional time delay shall be set in UFLS relays.
e. Maximum disconnection delay shall be 150 ms including breakers operation time [1].

The existing UFLS program which is operational in Kosovo Power System, was established based on previous recommendation of ENTSO-E, including only four steps with different amount of load disconnections and with additional time delay included in under-frequency relays [2].

The main factors that ENTSO-E has initiated the UFLS review are:

a. System implementation ensures the affectivity of UFLS: it means a minimal necessary shedding of load,
b. Compensate disconnection of dispersed generation at unfavorable frequencies,
c. Avoid over frequency (overcompensation), overvoltage and power transients that can lead to an additional loss of generation.

1.1. Theoretical Background of under Frequency Load Shedding Protection (UFLS)

Each part of the power system can be unbalanced if the load exceed the generation. Such a change between the generated power and the load power is known as generator imbalance. In such cases generators automatically will increase the mechanical power on the turbine through the primary regulation (spinning reserve, if any), so that the frequency point would be kept near to the nominal value of 50 Hz. However, if the generators reach the regulation limits whereas the system remains in the island mode of work then the rapid frequency decline will occur. In these cases if the under-frequency protections are not activated for automatic switch off of the load, then under-frequency protection (47.5 Hz) of generators will carry out their tripping off, avoiding possible damage on the generator system.

The work of generators with the frequency below the critical values affects negatively the generator. Such effect in the cases of hydro-generators, even with a drop up to 10%, is not as great as in the cases of thermal generators as the latter are sensitive even for the values above 5%, as is illustrated in Figure 1. In order to avoid total decline of the system's isolated part, the under-frequency protections are applied in every power system in order to activate automatic load-shedding i.e. by switching off certain amounts of the power system load aiming thus to balance generation and load [3].

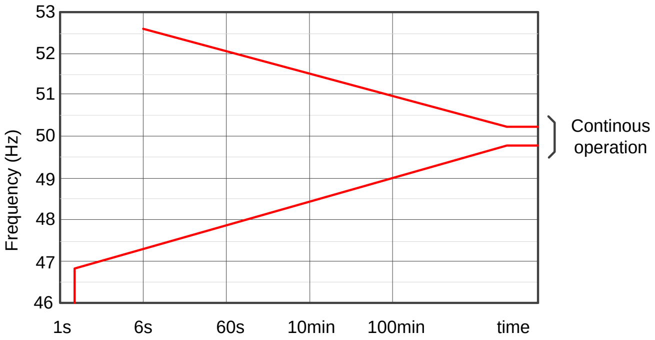

Figure 1.Steam turbine off-frequency limits

The dynamic behaviour of an individual synchronous turbine-generator i can be described using the swing equation of a rotating mass:

$$H_i \frac{df_i}{dt} = \frac{f_n^2}{2S_{ni}}(P_{mi} - P_{ei}) \tag{1}$$

where f_i is the frequency of generator i, f_n is the nominal frequency, P_{mi} is the mechanical power of turbine-generator i, and P_{ei} is the electrical power of generator i [4].

This non-linear differential equation defines the frequency change depending on the difference between the electrical and mechanical powers, respectively, from the unbalance between the generation and the load. The rate of change of frequency is defined by the imbalance and inertia of the turbine-generator.

The inertia constant is given in seconds and it can be interpreted as the time that energy stored in rotating parts of a turbine-generator is able to supply a load equal to the rated apparent power of the turbine-generator. System inertia constant plays e significant role on frequency behaviour after disturbance occurs in power system. The greater the inertia, the less acceleration will be observed and the less will be the frequency deviation. The inertia constant *H* describes the inertia of an individual turbine-generator and differs from type of generators. Inertia constant H for individual generators is represented by equation:

$$H = \frac{1}{2}\frac{J\omega_n^2}{S_n} \tag{2}$$

Where:

J is the moment of inertia of a generator and turbine [kg·m2],
ω_n is the rated mechanical angular velocity of the rotor [rad/s],
S_n is the rated apparent power of the generator [VA].

Real interconnected power systems usually operates in large scale synchronous zone, such a ENTSO-E and consist of a large number of generators and the network which connects the generators to loads. Hence, when an imbalance in the system arises, frequency is not uniform throughout the system.
The total equivalent system inertia constant is given by:

$$H_{sys} = \frac{H_1 S_{n1} + H_2 S_{n2} + \ldots\ldots + H_n S_{nn}}{S_{n1} + S_{n2} + \ldots\ldots + S_{nn}} = \frac{\sum_{1=1}^{n} H_i S_{ni}}{\sum_{1=1}^{n} S_{ni}} \tag{3}$$

Where:

S_{ni} is the rated apparent power of the generator *i* and H_i is the inertia constant of turbine-generator *i*

For example for Kosovo Power System the total equivalent system inertia constant is: H_{sys}=2.6 seconds

The equivalent system inertia constant variate based on the number of generations in operation and their characteristics. The lower the inertia, the high acceleration will be observed and the high will be the frequency deviation.

For wind and solar sources no effects of their inertia are considered since non-synchronously connected generation units, like modern wind turbine generators, PV solar units are connected via power converters. For wind turbines their rotational speed is isolated from the system frequency. They therefore do not deliver a natural inertial response and do not contribute to the system inertia. More RES, and less conventional generation the system will lose gradually the inertia which will have negative impact on system stability.

The system generation imbalance is calculated using equation:

$$\%(imbalace) = \frac{P_{load} + P_{losses} - G}{P_{load} + P_{losses}} \cdot 100 \tag{4}$$

It is very difficult to define the most probable level of system generation imbalance to be encountered particularly with high meshed systems having strong interconnections as are the individual power systems of SEE. This applies particularly in critical cases such as sudden disconnections from the interconnection. In these events certain elements of the system are overloaded to the critical values, which depend mainly on the level of system overload at the time of occurrence. If such overload element values exceed the range of normal overload levels then the current values enters in the range of over-current protection actuation (I>>) with a time delay being shorter than the time of frequency decline in the level of under-frequency protections actuation. Therefore the analysis is focused in cases where system is entirely isolated from the rest of synchronous zone.

The nature of the system frequency changes was analyzed in terms of the system generator imbalance level. Figure 2 presents four cases of frequency declines with different generation imbalances without acting of UFLS.

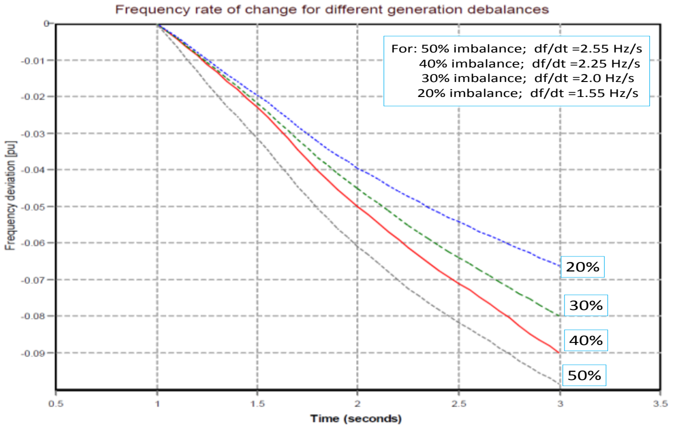

Figure 2. System frequency response from different value of generator imbalances

2. SELECTION OF THE POWER SYSTEM ISLAND MODE OPERATION REGARDING UFLS

In order to define the UFLS program for Kosovo Power System, based on ENTSO-E requirements and recommendations, three different simulation cases were created so that the behavior of frequency can be studied in different island mode scenarios:

a. Scenario-1 (referent): Large part of South-East European Power systems isolated from the rest of ENTSO-E
b. Scenario-2: Four Power Systems (Greece, Albania, Macedonia and Kosovo) isolated from the rest of ENTSO-E
c. Scenario-3: Kosovo Power System isolated

For each scenario, different imbalance levels are simulated: 50%, 40%, 30% and 20%. In Figure 3 is shown the first scenario when SEE power systems remain isolated from the rest of ENTSO-E. Scenario-2 and 3 considers smaller part of power systems operating in island mode.

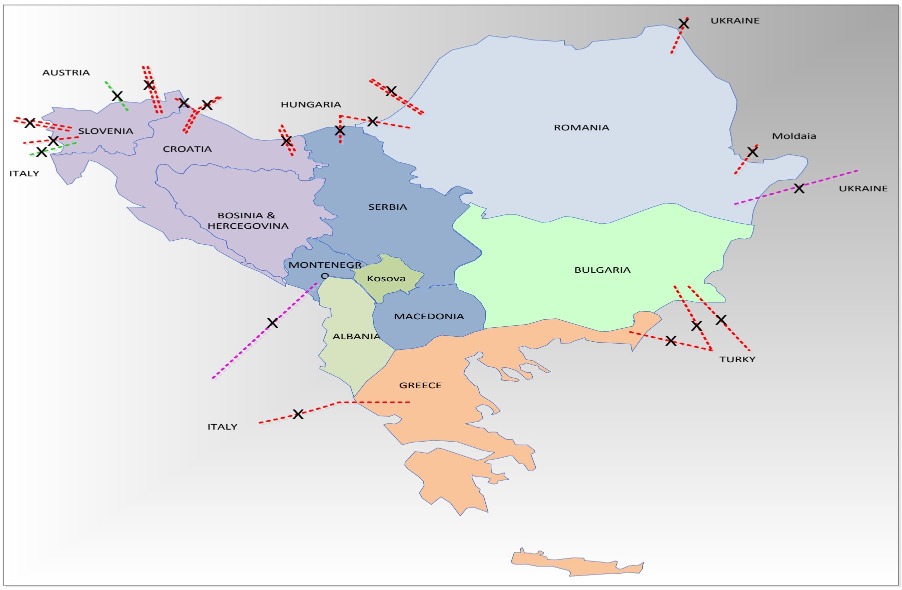

Figure 3. South-East European Power systems isolated from the rest of ENTSO-E (Scenario-1)

By means of system simulations, the following recommendations for System Operator of Kosovo will be determined for:

a. Optimal total shedding load in percentage of reference load,
b. Optimal frequency stepping for a system with dispersed frequency relays implemented,
c. Optimal number of load shedding stages in percentage of reference load.

3. SIMULATION MODEL

The power flow and dynamic simulations are carried out on a large scale PSS/E model having over 14 interconnected areas representing given countries of Southeast Europe (SEE) power systems, including the Kosovo Power System [5]. The load models with voltage and frequency dependence has been included in the design for UFLS in order to achieve accurate active power imbalance estimation.

Using large scale model the simultaneous opening of interconnection lines was simulated with the generator units under operation affected by different level of generation imbalances, considering three scenarios of isolated systems in winter regime of operation.

The focus of monitoring is the system frequency of Kosovo Power System in order to define the optimal program for UFLS. The frequency response of the system is analyzed with respect of ENTSO-E recently updates regarding UFLS, which is described in Police 5, of Operational Handbook.

3.1. Load shedding relay modeling

The maximum number of steps implemented into the model is equal to 8. For each step, a threshold and a percentage of disconnected load is associated, jointly with a delay that represent the relay computational time and time to execute and open the load feeder circuit breaker. Disconnection delay caused by circuit breaker switching time and relay operation time (without additional time delay) is taken to be 100 ms.

With aim to define the best program of UFLS, which fits to the Kosovo Power System frequency characteristics, two different UFLS programs are analyzed and results are compared:

a. 6 step UFLS with 6x8=48% of total load shed starting from 49.00 Hz and ending at 48.00 HZ
b. 8 step UFLS with 8x6=48% of total load shed starting from 49.00 Hz and ending at 48.00 HZ

The frequency range 49.00-48.00 Hz where the UFLS should act, is mandatory for each TSO-s operating in synchronous zone of ENTSO-E. The first step of load shedding is fixed at 49.0 Hz The reason is to reserve a range (1 Hz) between 50 Hz and 49 Hz where primary reserve is trying to recover the effect from the power deficit. This range of 1 Hz should control the under frequency transient by loads shedding. Below this frequency there is a certain margin (around 0.5 Hz) where generating units can operate and probably recover without trip. New ENTSO-E grid code for new generation units type D is more rigorously as previous national grid codes regarding time duration of island operation mode of generators, for example the generators should operate at least 30 min in under frequency regime 48.0 Hz-47.5 Hz. [6]

4. SIMULATION RESULTS

Figure 4 shows simulation result of system frequency response (400 kV bus bar at SS Kosovo B) after isolation of SEE Power system from the rest of ENTSO-E network, with 50 % generation imbalance. In this case the six step UFLS program is considered. All six steps are activated with 6x8%=48% of total load shed. Considering the time of 100 ms between under-frequency relay triggering and circuit breaker operating, it can be shown that for around 2.2 seconds the effects of UFLS on frequency recovery are visible and successful. The intervals between two load shedding blocks are 0.2 Hz. The minimum frequency decline is 47.9 Hz, with 0.4 Hz positive margin from critical system frequency of 47.5 Hz [7]. During the frequency decline in this case all primary power reserves from synchronous generators located in effected area will be automatically activated trying to recover the system frequency. Usually in such a circumstances effects of primary power regulation is not characterized as a fast response based on well-known speed governor characteristics of steam turbine generators. It can be considered that visible effects can be observed after 1 second from the initial trigger of speed governor. In this very short time frame and after the total system inertia constant plays e significant role on frequency behavior after disturbance occurs.

Figure 5 shows simulation result of system frequency response with same system condition as previous one, but with different UFLS program which consider eight steps with 8x6%=48% of total load shed. The intervals between two load shedding blocks are 0.1428 Hz, more close to each other than six step UFLS program. The minimum frequency decline is 47.85 Hz, with 0.05Hz higher than six step UFLS.

Figure 6 shows frequency response differences between two UFLS programs with same simulation condition considering 50 % generation imbalance.

As is shown in Figure 6, differences between two UFLS programs are relatively small, even we can be observed that 8 steps UFLS shows somehow better results but not so significantly.

Simulation with the same imbalance condition is performed also for smaller size of isolated power systems, scenario-2 (four remaining power systems) and scenario-3 with only Kosovo Power System in operation. Figure 7 shows simulation results of frequency response for three scenarios of different size of power systems remaining in operation in island mode.

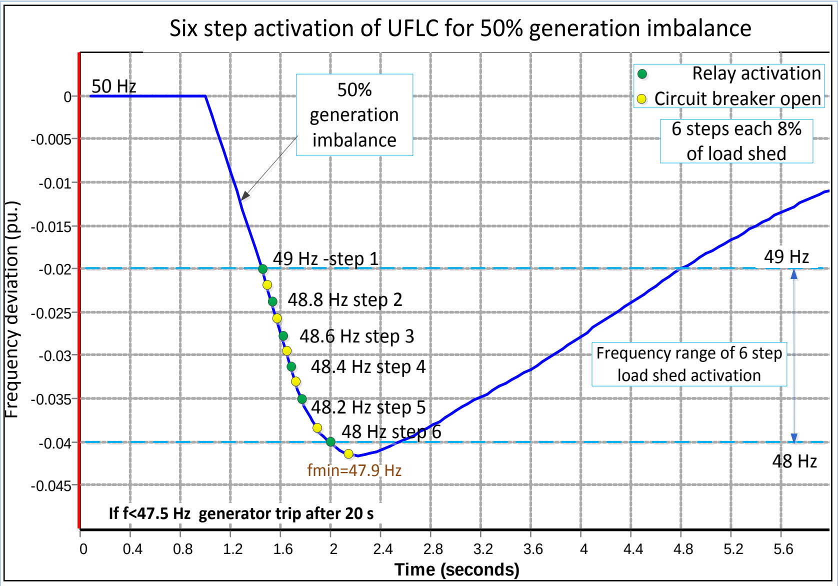

Figure 4.System frequency response with 50% generation imbalance and six step UFLS activation (Scenario-1)

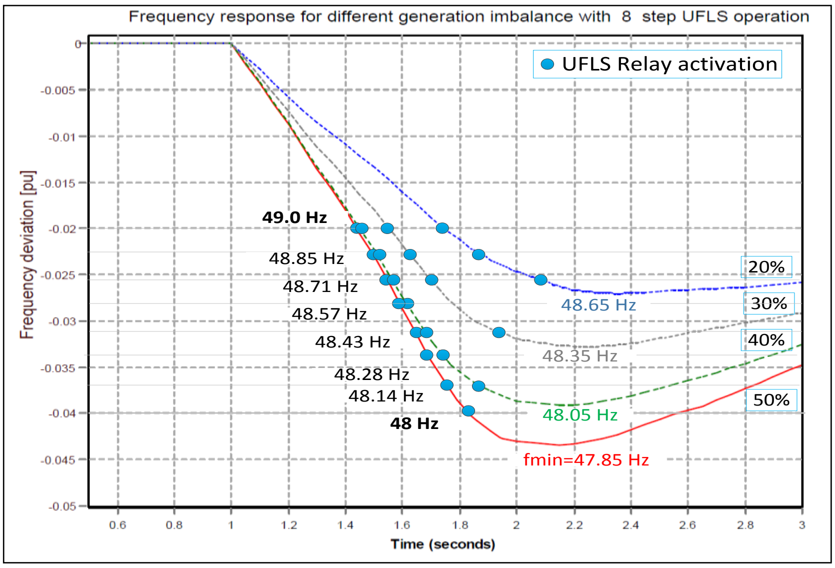

Figure 5. System frequency response with 50% generation imbalance and eight step UFLS activation (Scenario-1)

Larger the power system is, the lower frequency excursion will occurs. The frequency rate of change for different size of isolated power systems and different level of generation imbalances are shown in Table 1. As is shown in the table the frequency rate of change is lower when the size of isolated power system is larger. There are two factors influencing the value of frequency rate of change: the available of primary reserve and the inertia constant of the system. It can be expected that the large system will have more available primary power reserves and also larger total equivalent inertia constant because a high number of and high diversity of synchronous generation types with different parameters [8].

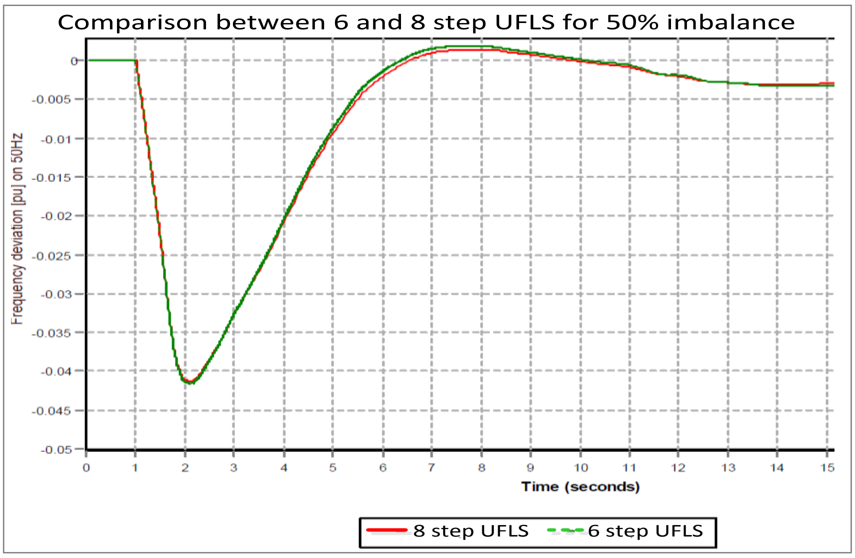

Figure 6. Frequency response comparison between six and eight step UFLS for 50% generation imbalance (scenario-1)

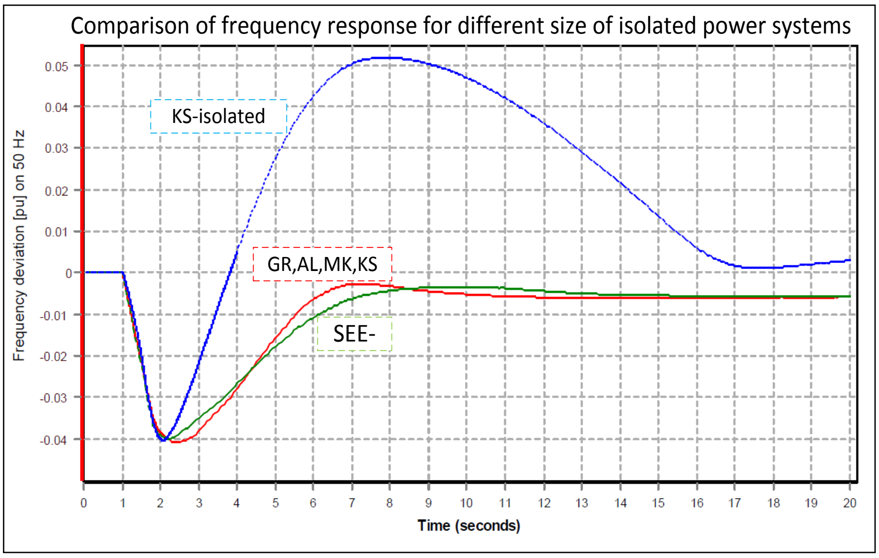

Figure 7. Frequency response for different size of isolated power systems for six step UFLS program.

Table 1. The frequency rate of change for different size of isolated power systems and different imbalances

	Frequency rate of change			
Imbalance Island mode	20% df/dt [Hz/s]	30% df/dt [Hz/s]	40% df/dt [Hz/s]	50% df/dt [Hz/s]
SEE	1.55	2.0	2.25	2.55
Gr, Al, Mk, Ks	1.2	1.65	2.15	2.45
Kosovo (Ks)	1.15	1.8	2.55	2.9

5. CONCLUSION

Comparison of simulation results between 6 step UFLS and 8 step UFLS with 48% of total load shed, shows no significant differences when they apply in Southeast Power System region of ENTSO-E. Even with the activation of all steps, the end frequency is never fully recovered. The 8 step UFLS shows some better performance regarding minimum frequency decay and end frequency. Furthermore 8 step UFLS has some significant disadvantages related to the narrow time intervals between two load shedding blocks in comparison with 6 step UFLS. When we consider that large number of circuit breakers in distribution network has different breakers operation time due to the technology and the age, there is a possibility of simultaneous triggering of two blocks when power system experiences frequency decay. While relay manufacturers provide set points in increments of 0.01Hz, there is typically 100-150 ms of time delay, including relay and circuit breaker operating times, from the relay triggering when the frequency reach setting point to the moment of load shed. During this delay, the frequency continues to drop, that is, the frequency at which load actually sheds is below the set point. If the spacing between the shedding stages is too close, the load shed initiated by a stage could actually shed the load while the frequency is in phase of recovery creating an unacceptable end frequency which can be too high. Therefore the recommendation for the System Operator of Kosovo is to adopt 6 steps, 6x8=48% load shed UFLS program, which fully complies with ENTSO-E requirements. The 6 step UFLS program is presented in Table 2 below:

Table 2. Six step, 6x8% UFLS settings

UFLS	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
Load shed	8%	8%	8%	8%	8%	8%
Initial frequency	49.0 Hz	48.8 Hz	48.6 Hz	48.4 Hz	48.2 Hz	48.0 Hz

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Gazmend Kabashi received his electrical engineering Degree from University of Prishtina, Kosovo in 2003. The Ph.D. degree received in 2013 in the same Faculty. Since 2003 he is with Transmission System and Market Operator of Kosovo (KOSTT) working on long term development of transmission network. He has authored over 20 papers in peer-reviewed journals. His research interests are in transient stability of power systems, and Wind Power energy.

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