Paper accepted for presentation at 2009 IEEE Bucharest Power Tech Conference, June 28th - July 2nd, Bucharest, Romania

Dynamic Analysis of Transition into Island Conditions of Slovenian Power System Applying Underfrequency Load Shedding Scheme

U. Rudez, *Student Member, IEEE*, and R. Mihalic, *Member, IEEE*

***Abstract*—Electricity blackout can be treated as critical situation of any country in economical, political, and security point of view. Therefore, underfrequency load shedding is one of the most important protection systems, as in many cases it is the last measure for preventing system blackout after serious disturbances occur in the power system. First, the static analysis of Slovenian power system has been performed to determine most probable islands in Slovenian system. Next, the dynamic analysis of one of these islands has shown, that the frequency gradient alone can give very misleading information about the active power deficit in an island. Several other variables must also be taken into account. Finally, a draft of a gradient based underfrequency load shedding scheme is presented, which highlights the gradient use problems and shows the potential of considering second frequency gradient as an indication of turbine governor response.**

***Index Terms*—Load shedding, frequency response, island operation, dynamic analysis.**

I. INTRODUCTION

TOTAL system collapse can in certain situations be avoided by isolating a certain part of the power system which finds itself in a so called island operation. Forming of an island can be a measure to avoid total blackout or it can be a consequence of undesirable events in a system, which cause transmission system elements outages.

In recent years terrorist attacks throughout the world are becoming more frequent. Electrical power system is expected to be one of the possible targets, as a tremendous damage on many fields can arise from total or even partial system collapse. Following these assumptions, appropriate measures have to be taken trying to avoid the worst. The main purpose of a power system is to power the consumers with quality electricity. Therefore the main effort in forming the appropriate underfrequency load shedding (UFLS) mechanism has to be the minimization of load tripping. The preservation of islands is preferred in order to achieve this goal.

During research study for Ministry of Defence in Republic of Slovenia first the static analysis of Slovenian power system was made in order to get enough information about the vulnerability of the system. Basic conclusions that arise from the analysis are presented in this paper, while more detailed information is given in [6].

The main subject of this paper deals with the dynamic transition into the island operation. As the lack of active power generation in an island causes rapid frequency decline, an automation procedure must be applied to shed load before frequency reaches the lowest acceptable limit.

While trying to define the most appropriate underfrequency load shedding scheme, the detailed analysis of parameters that influence the frequency trajectory has been performed. Frequency gradient was used in several papers ([1],[2]) to determine the initial active power deficit via frequency response model, presented in [3]. Our research has shown that certain other factors also can not be ignored or assumed to be constant, as frequency gradient can otherwise give very misleading information about the active power deficit in an island.

In the following chapter the results of the static analysis are briefly discussed. Next, the determination of initial active power deficit via simple formula given by frequency response model is analyzed. The overview of detected influential factors which effect the frequency decay rate is presented. A chapter containing proposed UFLS scheme follows, along with the test results of using it in a small island (containing four generating units). Finally the conclusions will be drawn.

II. STATIC ANALYSIS

Static analysis of Slovenian power system was performed in order to detect vulnerable points of Slovenian system and to make a list of possible islands, that might occur. The importance of predicting the island boundaries is discussed in chapter IV. In order to obtain the proper simulation results the whole Slovenian transmission system was modeled along with the 400 and 220 kV grid of the neighbouring countries. Many different combinations of undesirable events were simulated using load flow calculations. These events included most probable and also less probable outages in the circumstances of maintenance work on certain other system elements. In this way practically the worst case scenario was analyzed, as

---

This work was supported by a Slovenian Research Agency as a part of a research programme Electric Power Systems, P2-356.

The authors are with the Faculty of Electrical Engineering, University of Ljubljana, Ljubljana, 1000, Slovenia (e-mail: urban.rudez@fe.uni-lj.si; rafael.mihalic@fe.uni-lj.si)

978-1-4244-2235-7/09/$25.00 ©2009 IEEE

events that are not included in the contingency analyses are also simulated. Considering thermal limits of transmission elements, such as power transformers and transmission lines, a sequential outages were simulated with the repeated load flow calculations. The authors are aware that the dynamic analysis of such events is necessary to obtain more accurate results, but also the results of the static analysis gives enough indication of possible islands.

Five biggest islands, that are expected to arise, are depicted in Fig. 1. Smaller islands are also expected, most of them in the Gorenjska region. One of such islands is used as a test system for further analysis of dynamic transition into island operation.

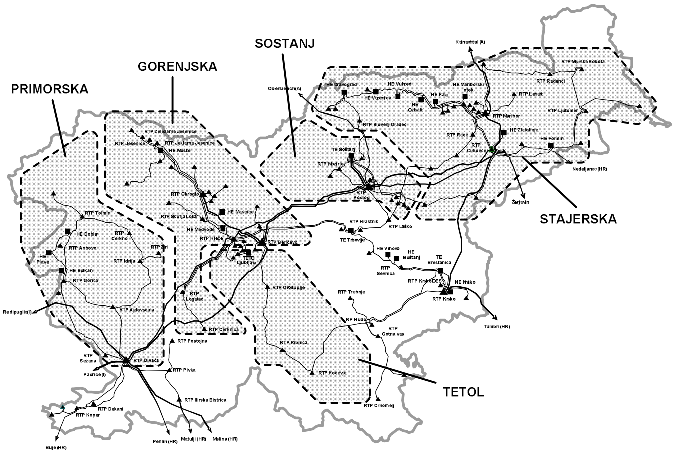

Fig. 1. Bigger islands expected in Slovenian power system

More detailed description of the analysis in question is given in [6].

III. Determination of Initial Active Power Deficit

The approximate frequency response of a power system can be calculated applying equation given in [3]. The formula is derived from introducing the equivalent generating unit. Its apparent rated power equals the sum of rated powers of individual units and the equivalent inertia constant is calculated as:

$$H_{eq} = \frac{\sum_{i=1}^{n} H_i \cdot S_{n,i}}{\sum_{i=1}^{n} S_{n,i}} \tag{1}$$

The quantities in (1) are:

H_{eq} - the inertia constant of an equivalent generating unit,

H_i - inertia constant of the i-th generating unit,

$S_{n,i}$ - apparent rated power of the i-th generating unit,

n - the number of all generating units replaced by an equivalent machine.

Considering the equivalent generating unit, various authors based their initial active power deficit determination on the following simple formula:

$$\left.\frac{d\Delta\omega}{dt}\right|_{t=0} = \frac{P_{STEP}}{2H_{eq}} \tag{2}$$

The formula itself determines that frequency gradient ($d\Delta\omega/dt$) at $t = 0$, where t denotes time, depends only on inertia constant (H_{eq}) in seconds and the active power deficit P_{STEP} in the system. In order to implement the use of (2) in practice, it is crucial to correctly recognize the quantities and their units.

The system frequency ω in (2) is in per unit values, based on the nominal system frequency ω_N. Converting from radians to Hertz, similar can be written for system frequency f, based on $f_N = 50$ Hz. P_{STEP} on the other hand is also defined in per unit, but based on the system voltampere base, which is said to be equal to the sum of the ratings $S_{n,i}$ of all generating units in the system, i.e. the rating of the equivalent generator (S_{eq}):

$$P_{STEP} = \frac{P_{def}}{\sum_{i=1}^{n} S_{n,i}} = \frac{P_{def}}{S_{eq}} \tag{3}$$

Considering above equations, the active power deficit in MW (P_{def}) can be written as:

$$P_{def} = \frac{2H_{eq}}{f_N} \cdot \frac{df}{dt} \cdot S_{eq} \tag{4}$$

Active power deficit P_{def} is determined by four factors:

- initial active power generation in the system (i.e. in the moment just before the system disturbance) P_{G0},
- initial active power consumption (load) in the system (i.e. in the moment just before the system disturbance) P_{L0},
- turbine governor reaction to a disturbance (depending on spinning reserve) ΔP_{tur},
- active power load changing ΔP_L due to voltage and frequency deviations from their prefault values.

The generator and power network losses are not included, as they are not considered in further derivations.

A. Load's Dependence on Voltage Deviations

Equation (4) is theoretically relevant at $t = 0$. Neither frequency nor it's gradient can be measured so quickly after the disturbance to meet this requirement. First reason is a certain time delay of measuring instruments. Second, at the time of island forming, many transient phenomena occur in the system, which reflects in the distorted measurements. Third, the boundaries of the island also can not be detected without some time delay, that is determined by a communication link capabilities between protection relays and the SCADA system. Island configuration must namely be known in order to calculate H_{eq} and S_{eq}.

Even though the frequency can be correctly measured in a few voltage periods, the voltage drop in the meantime reflects on the load's active and reactive power. One example that confirms this statement is the use of voltage drop in the system for determining the location of the disturbance ([4]). An importance of the voltage dynamics while measuring frequency changing was stressed also in [9]. In addition, many other authors ([7],[8],[10]) draw the attention on considering especially load's voltage dependence. The load's frequency dependence on the other hand can be neglected, as frequency does not drop for more than 0.1 % during the measurement time delay. As already stressed, measurement should theoretically be made at $t = 0$ when the frequency does not deviate from its nominal value yet.

Due to slow response of mechanical turbine valves controlled by a turbine governor, compared to a frequency decay rate, it can be concluded that turbine output remains constant when (4) is relevant. Its influence on initial active power deficit can therefore be neglected.

One of possibilities to mathematically model the load's voltage dependence is:

$$P_L = \sum_{i=1}^{m} P_{L0,i} \cdot \left(\frac{U_i}{U_{0,i}} \right)^{\alpha_i} \qquad Q_L = \sum_{i=1}^{m} Q_{L0,i} \cdot \left(\frac{U_i}{U_{0,i}} \right)^{\beta_i} \tag{5}$$

where P_L and Q_L represent the current values of system load's active and reactive power, $P_{L0,i}$ and $Q_{L0,i}$ i-th load's initial active and reactive power just before the disturbance, U_i the current voltage on the i-th load bus, $U_{0,i}$ the voltage of the i-th load bus in the steady state just before the disturbance, m the number of load busses in the system, α_i the factor depicting active power dependence of the i-th load and β_i the factor depicting reactive power dependence of the i-th load on voltage deviations.

It is reasonable to assume that after load shedding is completed and the system stabilizes, the remained load to a great extent reaches its initial value of active and reactive power. Therefore, in the process of determining the initial active power deficit, the effect of voltage drop on P_{def} must be eliminated. Neglecting system losses, P_{def} can be written as:

$$P_{def} = P_{tur} - P_L \tag{6}$$

where P_L stands for current system load active power and P_{tur} for the sum of a pre-disturbance mechanical power on the turbine ($P_{tur,0}$) and the additional turbine power due to governor reaction ΔP_{tur} (it is said to be neglected at $t \approx 0$). Inserting the load characteristics (5) in (6) we retrieve the value that we consider as required total shedding amount in MW:

$$P_{tur} - P_{L0} = P_{def} + \sum_{i=1}^{m} P_{L0,i} \cdot \left[\left(\frac{U_i}{U_{0,i}} \right)^{\alpha_i} - 1 \right] \tag{7}$$

where

$$P_{L0} = \sum_{i=1}^{m} P_{L0,i} \,. \tag{8}$$

For practical reasons, it is more appropriate for underfrequency relays to have the information about the percentage of the total load that needs to be tripped. Therefore the deficit is expressed as a percentage of total loading in the system, just before the disturbance occurs:

$$P_{trip} = \frac{P_{tur} - P_{L0}}{P_{L0}} \cdot 100 = \frac{P_{def}}{P_{L0}} \cdot 100 + \sum_{i=1}^{m} P_{L0,i} \cdot \left[\left(\frac{U_i}{U_{0,i}} \right)^{\alpha_i} - 1 \right] \cdot \frac{100}{P_{L0}} \tag{9}$$

P_{trip} represents the percent value of active power deficit in an island which directly determines the required total shedding amount, that would completely annul the imbalance between generation and consumption. The first summand in (9) represents the calculated active power deficit without considering load decrease ("Deficit - Part 1") and the second summand the modification ("Deficit - Part 2"), that eliminates the influence of voltage drop on calculated active power imbalance.

The change in frequency gradient due to voltage deviations is considerable, and depends also on the initial loading of the system P_{L0}. This can be seen from (10), that can be retrieved by considering (4) and (7).

$$\frac{df}{dt} = \frac{f_N}{2H_{eq} \cdot S_{eq}} \cdot \left[\left(P_{tur} - P_{L0} \right) - \sum_{i=1}^{m} P_{L0,i} \cdot \left[\left(\frac{U_i}{U_{0,i}} \right)^{\alpha_i} - 1 \right] \right] = f_1' + f_2' \tag{10}$$

Similar role as "Deficit - Part 2" has in (9), f_2' has in (10). It is evident that f_2' can not be determined without knowing the initial system loading $P_{L0,i}$, factor α_i and voltages on load busses.

The importance of considering f_2' has been shown using one of the small islands, expected to arise in the Slovenian power system in case of a serious blackout threat. This island, depicted in Fig. 2 was also used as a test system for proposed UFLS scheme.

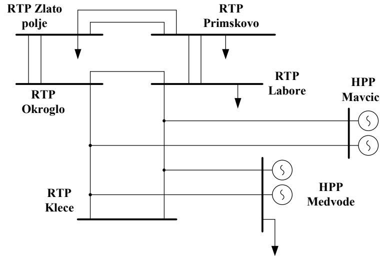

Fig. 2. Test system (island) with four generating hydro units and four load centers.

The test was performed in such a way, that the initial system loading P_{L0} was varied from 90 MW to 150 MW, while the active power deficit MW value (ΔP) was kept constant by increasing generation. As simulations were repeated for four different values of ΔP, columns of four different colors are depicted in Fig. 3.

From Fig. 3 it is evident, that not only ΔP, but also P_{L0} determine the frequency gradient. Higher the system loading, higher the gradient for the same ΔP value. For conditions with higher P_{L0} the value of f_2' can become a substantial part of the total value of frequency gradient (e.g. for $\Delta P = 80$ MW and $P_{L0} = 150$ MW f_2' represents almost 23 % of total frequency gradient). If the load was defined as a constant active and reactive power, the use of f_2' would no longer be needed. It is necessary to stress that in reality, factors α_i and β_i are usually different than zero and vary not only from one part of the system to another but also from time to time.

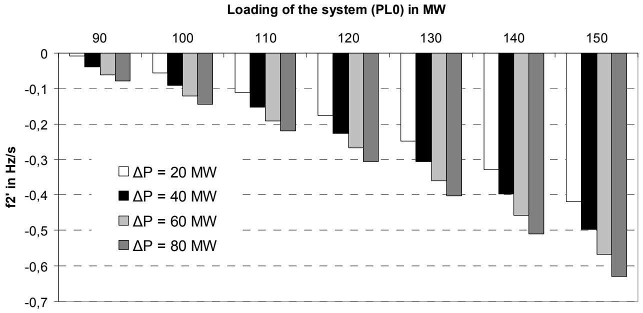

Fig. 3. Value of f_2', depending on initial system loading, and initial active power deficit in MW

IV. PROPOSED UFLS SCHEME

A. Gradient curves

From the derivations made so far it can be concluded that the following parameters of the island have to be known, if the frequency gradient is to be used for determination of the initial active power deficit:

- the boundaries of the island (connected generation units with their parameters and load busses in the island),
- island's load bus voltages,
- the characteristics of connected load (factors α_i),
- the pre-disturbance loading of the system in MW.

Especially the latter is difficult to obtain and represents at the same time also the key factor for determination of the required shedding amount. This is the reason, why it is reasonable to estimate it in another way. It is suggested that a preceding analysis of the whole system in question is done, which would give as the result the list of most probable islands (as is briefly described in chapter II.). Even though authors in [1] express a certain concern about a feasibility of such studies, we find it necessary for using frequency gradient in order to improve the currently used UFLS schemes.

First, an estimated value of system loading should be acquired from the process of predicting the system load carried out by the system operator. Next, for each expected island and predicted system load, the so-called "gradient curves" are to be calculated. These curves give the linear relation between active power deficit in percent and the measured frequency gradient. As certain parts of the system could find themselves in different islands, a few different curves should be used by the same relays.

A gradient curve is a linear function of the frequency gradient, but is strongly dependent on the following parameters:

- loading of the system P_{L0}, which determines the steepness of the curve,
- voltage profile of the system and the load characteristics α_i, which together define the parallel location of the curve.

Mathematically, this can be written as:

$$P_{trip} = g_1 \cdot \frac{df}{dt} + g_2 \tag{11}$$

where $g_1 = g_1\,(S_{eq}, H_{eq}, P_{L0,i})$ and $g_2 = g_2\,(U_i, \alpha_i)$. Functions g_1 and g_2 can be derived from (4) and (9):

$$g_1 = \frac{2H_{eq} \cdot S_{eq}}{f_N \cdot P_{L0}} \cdot 100 \tag{12}$$

$$g_2 = \sum_{i=1}^{m} P_{L0,i} \cdot \left[\left(\frac{U_i}{U_{0,i}} \right)^{\alpha_i} - 1 \right] \cdot \frac{100}{P_{L0}} \tag{13}$$

The principle of determining the gradient curve is graphically depicted on Fig. 4.

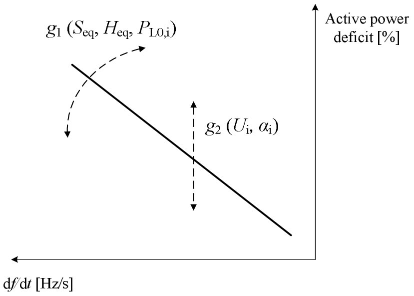

Fig. 4. The principle of a "gradient curve"

It can be observed that frequency gradient measurement alone can give misleading information about the active power deficit, as long as P_{L0}, bus voltages U_i and factors α_i are unknown. Therefore, the gradient curve should be defined according to the above mentioned parameters. This is one of the major concerns arising when using the frequency gradient for determination of initial active power deficit.

B. Load shedding

Once the initial active power deficit P_{trip} is calculated via gradient curve, the procedure of step-by-step load shedding must be applied. The load shedding is based on value of P_{trip} and follows listed guidelines:

- frequency must not drop under lowest acceptable value of 47.5 Hz,
- frequency overshoot is not desired,
- bigger shedding steps are scheduled prior to lower shedding steps (it is reasonable to lower the frequency decay rate as soon as possible in order to give the turbine governor enough time to react),
- total load shedding amount must be minimized (to keep supplied as much load as possible),
- monitoring the second frequency gradient gives us the information about the turbine governor, voltage control and load changing response,
- individual shedding steps should not interfere with one another (shedding steps should not be too close together).

It should be noted that not more than 20 % of the spinning reserve can be obtained in the first few seconds following the island formation ([5]). Shedding steps in the proposed scheme are adjusted accordingly.

The threshold for the first load shedding step is determined to be at 49 Hz. Frequency of 47.5 Hz was used as the lowest frequency acceptable limit and 50.0 Hz as the overshoot milestone. For the first shedding step only 60 % of P_{trip} has been selected. Using this value, frequency gradient changed sufficiently in all simulated cases. If there is no spinning reserve available or it is less than 40 % of P_{trip}, additional checkpoints have to be introduced in the continuation. Locations of these checkpoints were selected corresponding to the frequency thresholds of the currently used UFLS scheme in the Slovenian power system (48.8 Hz, 48.4 Hz and 48.0 Hz) and can be reached only if the frequency decreasing continues.

In every checkpoint two conditions are examined:

- condition 1: gradient increase with regard to previous checkpoint has to exceed a certain predefined value (10 % is used in our case):

$$\frac{\left|df_{k-1}/dt\right|-\left|df_{k}/dt\right|}{\left|df/dt_{k-1}\right|}\geq 10\ \% \tag{14}$$

- condition 2: second frequency gradient has to exceed a certain positive constant ε (10^{-5} is used in our case):

$$\frac{d^{2}f_{k}}{dt^{2}}\geq\varepsilon \tag{15}$$

Denotations k and k-1 represent current and preceding checkpoint, respectively. If both conditions are satisfied, the shedding step at the current checkpoint is left out, otherwise it is executed. If conditions are not met in any of three checkpoints, the shedding is executed in a sequence 20 – 10 – 10 % of P_{trip}. In order the scheme to be reliable, another (final) shedding step is introduced at 47.5 Hz. It is executed only if frequency reaches this limit, while its amount is equal to the sum of all shedding steps left out during frequency fall.

In this manner frequency can not drop under 47.5 Hz, as the previous analyses have confirmed that P_{trip} is estimated in "better more than less" manner. The proposed scheme, graphically shown in Fig. 5, therefore crucially depends on the initial active power deficit estimation and consequently on a gradient curve determination.

V. EXAMPLE OF USING PROPOSED UFLS SCHEME

The examples presented in this chapter have been carried out applying software for simulating electric power system dynamics. As a test system, a dynamic model of a small island in Slovenia was built (Fig. 2). The effectiveness of the proposed UFLS scheme has been estimated by comparison to currently used UFLS scheme in Slovenian power system, which is based merely on measuring the value of frequency. Also, shedding in a predefined amounts takes place at certain threshold, which are summarized in Table I.

The results of different initial system loading P_{L0} are presented, namely P_{L0} = 152 MW (study case 1) and P_{L0} = 81 MW (study case 2). In Table II the results of the existing and the proposed UFLS scheme are presented. As can be noticed from the results on one hand the considerable amount of load can be prevented from tripping compared to existing UFLS scheme (in study case 1 up to over 40 % improvement compared to the currently used scheme - at P_{trip} = 40 % - time domain simulation is shown in Fig. 6). On the other hand, in all situations the system survives, i.e. no blackout occurs. The proposed UFLS scheme does not shed load in a predefined pattern, but according to the estimated value of deficit, which is done via gradient curve. In this way no "guessing" about the total shedding amount takes place.

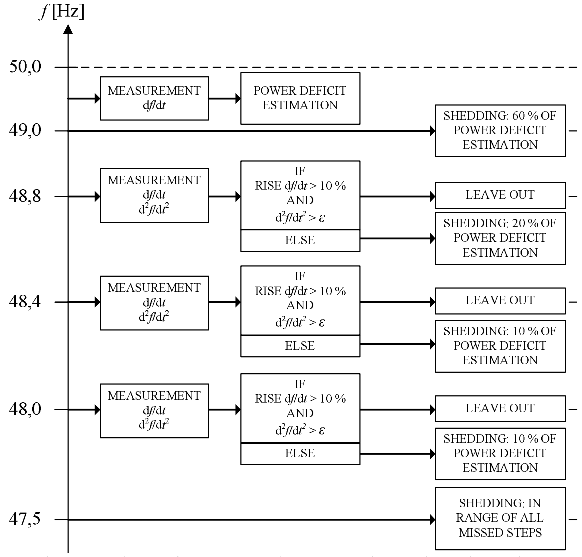

Fig. 5. The overview of a proposed UFLS scheme based on the preceding determination of island boundaries.

TABLE I
CURRENTLY USED UNDERFREQUENCY LOAD SHEDDING SCHEME IN SLOVENIAN ELECTRIC POWER SYSTEM

Stage	Frequency [Hz]	Measure
I.	49.0	10 % of load shed
II.	48.8	additional 15 % of load shed
III.	48.4	additional 15 % of load shed
IV.	48.0	additional 15 % of load shed

By not shedding load at certain checkpoints, where the conditions 1 and 2 are satisfied, it is possible to shed less load, as the shedding criteria is determined in a way that tries to use as much turbine governor response as possible. The main contribution here is the use of a second frequency gradient. It namely reflects the velocity of changing frequency trajectory and directly reflects the impact of frequency and voltage regulation along with the load changing on frequency trajectory. In order to assure, that proposed shedding strategy would be more efficient than currently used scheme in all cases (from Table II it is evident that this is not the case at the moment), additional studies of second frequency gradient use are in progress and the current retrieved results are optimistic.

VI. CONCLUSION

After presenting the analysis results it is possible to summarize, that many factors influence the initial frequency gradient in the process of transition into island operation. Not only previously known inertia constant, rated power of connected generators and current MW deficit influence, but also initial system loading, voltage profile of the system and consequently the load voltage characteristics. Only by knowing all of these parameters it is possible to determine a gradient curve, that precisely defines the relation between initial frequency gradient and initial active power deficit. Without information just mentioned the gradient could provide strongly misleading information about the island active power deficit value.

TABLE II
COMPARISON OF SIMULATION RESULTS USING CURRENTLY USED UFLS SCHEME AND THE PROPOSED UFLS SCHEME

P_{trip} [%]	Shedding amount [%]			
	Currently used UFLS scheme Study case 1	**Proposed** UFLS scheme Study case 1	**Currently used** UFLS scheme Study case 2	**Proposed** UFLS scheme Study case 2
20	10.0	12.0	0.0	0.0
25	10.0	15.0	10.0	15.0
30	25.0	17.9	10.0	18.0
35	25.0	20.9	25.0	21.0
40	40.0	23.9	25.0	24.0
45	40.0	26.9	25.0	27.0
50	40.0	34.9	25.0	30.0
55	55.0	38.4	40.0	33.0
60	55.0	41.9	40.0	36.0
65	55.0	65.0	40.0	39.0
70	blackout	70.0	55.0	42.0
75	blackout	75.0	55.0	45.0
80	blackout	80.0	55.0	56.0

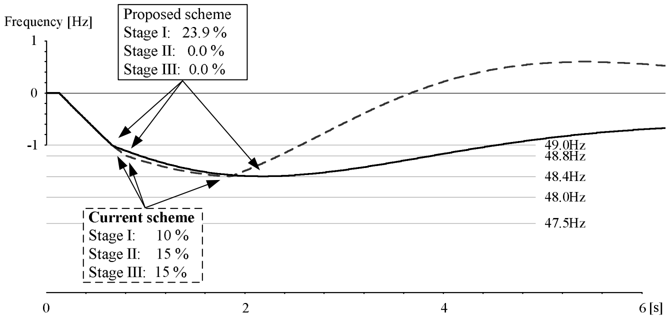

Fig. 6. The time domain simulation of currently used (dashed line) and proposed (solid line) UFLS scheme at $P_{\text{trip}} = 40$ %

Such dependence of frequency gradient makes it impossible to construct an universal UFLS scheme that would be suitable for every power system without certain parameters modification. Beforehand analyses are needed to correctly parameterize the underfrequency relays in order to shed the appropriate load amount for each predefined island.

The proposed UFLS scheme takes advantage of the information that is accesible via measuring second frequency gradient, namely the level of different regulation influense on frequency trajectory (i.e. turbine governor, voltage control). The scheme has been tested on a small test system and shows considerable improvements compared to shedding amount of currently used scheme in the Slovenian power system. Besides, by using the proposed scheme power system blackout can always be avoided. Further work on the subject will include mostly more detailed analysis of the second frequency gradient and its use in further reduction of load shedding amount.

VII. REFERENCES

Periodicals:

[1] P. M. Anderson, M. Mirheydar, "An Adaptive Method for Setting Underfrequency Load Shedding Relays," *IEEE Transactions on Power Systems*, Vol. 7, No. 2, May 1992.

[2] V. V. Terzija, "Adaptive Underfrequency Load Shedding Based on the Magnitude of the Disturbance Estimation," *IEEE Transactions on Power Systems*, Vol. 21, No. 3, August 2006.

[3] P. M. Anderson, M. Mirheydar, "A Low-Order System Frequency Response Model," *IEEE Transactions on Power Systems*, Vol. 5, No.3, August 1990.

[4] D. Prasetijo, W. R. Lachs, D. Sutanto, "A new load shedding scheme for limiting underfrequency," *Power Systems, IEEE Transactions on*, Vol. 9, Issue 3, pp. 1371-1378, August 1994.

[5] H. E. Lokay, "Application of underfrequency relays for automatic load shedding," *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-87, Issue 3, pp. 776-783, March 1968.

Papers from Conference Proceedings (Published):

[6] U. Rudež, V. Ažbe, R. Mihalič, "Minimizing of Load Shedding During Islanding of Slovenian Power System Applying Gradient Function of Underfrequency Relays," In *International Conference on Deregulated Electricity Market Issues in South-Eastern Europe, DEMSEE 2008*, Nicosia, Cyprus, September 22-23, 2008.

[7] A. Li, Z. Cai, "A method for frequency dynamics analysis and load shedding assessment based on the trajectory of power system simulation," *Electric Utility Deregulation and Restructuring and Power Technologies, 2008. DRPT 2008. Third International Conference on*, pp. 1335-1339, 6-9 April 2008.

[8] M. S. Pasand, H. Seyedi, "New Centralized Adaptive Under Frequency Load Shedding Algorithms," *Power Engineering, 2007 Large Engineering Systems Conference on*, pp. 44-48, 10-12 October 2007.

[9] B. Shi, X. Xie, Y. Han, "WAMS-based load shedding for systems suffering power deficit, " *Transmission and Distribution Conference and Exhibition: Asia and Pacific, 2005 IEEE/PES*, pp. 1-6.

[10] M. Etezadi-Amoli, "On underfrequency load shedding schemes, " *Power Symposium, 1990. Proceedings of the Twenty-Second Annual North American*, pp. 172-180, 15-16 October 1990.

VIII. BIOGRAPHIES

Urban Rudez received his B.Sc. degree from the University of Ljubljana, Slovenia in 2005. After finishing graduate study he worked with Korona company in Ljubljana for 2 years as a system engineer in a Department for power engineering. In 2007 he joined the Department of power systems and devices at the Faculty of electrical engineering, where he still works as a junior researcher. His area of interest includes mainly power system analysis and FACTS devices.

Rafael Mihalic received the Dipl. Eng., M.Sc. and Dr.Sc. degrees from The University of Ljubljana, Ljubljana, Slovenia, in 1986, 1989, and 1993, respectively. He became a Teaching Assistant in the Department of Power Systems and Devices, Faculty for Electrical and Computer Engineering, The University of Ljubljana, in 1986. Between 1988 and 1991, he was a member of the Siemens Power Transmission and Distribution Group, Erlangen, Germany. Since 2005 he has been a Professor at the University of Ljubljana. His areas of interest include system analysis and FACTS devices. Prof. Mihalic is a member of Cigre (Paris, France).