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OPTIMAL LOAD SHEDDING FOR MINIMUM UNDER FREQUENCY USING EXPERT SYSTEMS

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ABSTRACT

The under-frequency problem due to disturbances in large interconnected power systems, may lead - if not corrected -to an extensive serious damage. Disturbances in large power systems sometimes cause this interconnected systems to become separated into isolated subsystems, and this may lead to excess load, however, overloads the generating units causing the frequency to drop to levels that may cause permanent damage to steam turbines.

Load shedding are often applied throughout the system to avoid the turbine damage by restoring the frequency. It helps in restoring frequency in appropriate amount taking into consideration that there is no need in shedding excessive amounts of load. So minimum load shedding for under-frequency is needed which is the main aim of this paper with the help of an expert system.

This paper treats the under-frequency problem by using an adaptive traditional method for setting of the under-frequency relays. And an expert system is then suggested and developed as a perfect and fast method to accelerate the optimal shedding process for minimum frequency limit. These methods are implemented and applied on a simple power system. The obtained results are presented and discussed with a comparison between the traditional and suggested expert system methods.

KEYWORDS:

Under frequency , Load shedding , Power systems, Expert system , Minimum frequency limit.

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1.INTRODUCTION

Electrical power systems are always subjected to experiencing emergency conditions, which may result in a mismatching between generation and load. This may lead to isolated subsystems with either over or under frequency conditions. These subsystems are often suffer insufficient generating capacity to carry the load, and this condition almost lead to a decay of system frequency and may collapse within a short time, if measures are not taken, to restore the load-generation balance [1]. The problem of under-frequency and load shedding has been studied for many years [2-4]. It has been noted through these studies, that the power plants themselves are subject to failure at low frequencies since plant auxiliaries are unable to maintain normal output with the critical frequency being about 10 to 15% below normal frequency [5]. Several treatments of under-frequency load shedding have been presented in the past [6], [7].To maintain a load to generation balance during the system disturbance, practically

, automatic under-frequency relays were used to drop the load. In the past, system engineers began investigating the need for turbine protection and initiated an off-frequency study to review all aspects of system abnormal frequency protection [7].

In recent years, expert systems have been used at the inclusion of the operators experience in some areas. And it is certainly possible to bring the solution closer to the operator's routine.
The most recent development in expert systems for power system operation shows a number of concepts, which used for solving different power system problems [8-11]. One of these problems is the under frequency problem.

In this paper, a combination between a traditional analytical program and a rule-based program is made for the purpose of minimum under-frequency and load shedding problem. A comparison between results of these two programs is also made.

2-THEORETICAL FORMULATIONS

2.1 System Modeling and Frequency Analysis

As shown in fig.1, a linear system frequency response model is considered to represent the frequency performance of an isolated subsystem [5], [8].

From the block diagram shown in Fig.1, the frequency response in per unit (p.u.) can be computed as in the following equations:

$A_1 = D\,\Delta w$, where , $\Delta\omega$ indicate the per unit frequency deviation (1)

$$P_m = [\frac{K_m(1+F_H T_R S)}{R(1+T_R S)}]\Delta w \qquad (2)$$

$$P_a = P_{dist.} - P_m = P_{dist.} - [\frac{K_m(1+F_H T_R S)}{R(1+T_R S)}]\Delta w \quad (3)$$

$$\Delta w = (P_a - A_1)[\frac{1}{2HS}] \quad (4)$$

From eq. (1), and (3), eq. (4) can be rewritten as;

$$\Delta w = ((P_{dist.} - [\frac{K_m(1+F_H T_R S)}{R(1+T_R S)}]\Delta w) - D\Delta w)[\frac{1}{2HS}]$$

Rearrange this equation in S-domain;

$$\Delta w = [L][\frac{(1+T_R S)P_{dist.}}{S^2 + 2Mw_n S + w_n^2}]$$

Where,

$L = \frac{Rw_n^2}{DR+K_m}$, $w_n^2 = \frac{DR+K_m}{2HRT_R}$, and $M = [\frac{2HR + (DR + K_m F_H)T_R}{2(DR+K_m)}]w_n$

For a sudden disturbance, $P_{dist.}$ will be in the form of step function in s-domain, $P_{change} = P_{dist.}/s$, and the per unit frequency deviation in time-domain will be;

$$\Delta w(t) = (\frac{R}{Dr + K_m})(1 + Be^{-Mw_n t}\sin((w_n\sqrt{1-M^2})t + c))P_{change} \quad (5)$$

Where,

$B = \sqrt{\frac{1 - 2T_R M w_n + T_R^2 w_n}{1 - M^2}}$, and

$$c = \tan^{-1}(\frac{w_n T_R}{1 - Mw_n T_R}) - \tan^{-1}(\frac{\sqrt{1-M^2}}{-M})$$

Through these last equations, the value of frequency or speed can be computed for any $P_{dist.}$

2.2 Load Shedding Design

Generally, load-shedding design depends mainly on the frequency responses of the subsystem model according to many factors. These factors are, the frequency set points, number of frequency steps, and the amount of load shed per step. The minimum allowable operating frequency must be selected to a certain value.

Sufficient load should be shed to limit the frequency decline to above this selected minimum operating frequency value [7].

After setting the initial load shed frequency, load shedding is made in this paper in two protective plans. The first one, consists of four equal load-shedding steps for different values of power disturbance. And the second plan, consists of six load shedding steps of unequal size with the same value of total minimum load shed and for different values of load disturbance.

2.3 Expert System

Expert systems are computer programs that constructed to do the kinds of activities that human experts can do. Its programs are usually set up to operate in a manner that will be perceived as intelligent, as if there a human expert on the other side of the video terminal. The appearance of the expert system intelligence is enhanced to the extent that its program can accept free form input in simple English sentences and can state its conclusions in the same way. A program that can do this is said to have a natural language interface. Expert system programs are usually written in languages like LISP and PROLOG, [9], [10]. In this paper Prolog is used as a language for designing the suggested expert system.

Fig.2 presents the fundamental components of the expert system which are, [10], [11];
The database: which is composed of different data concerning the power system (the information of the system components).
The knowledge base: it contains the knowledge required to perform the expert system's tasks well, where the quality of the expert system relies on its knowledge base).
Inference engine: it is needed to perform the exploitation of the knowledge base in order to find solutions.

3. APPLICATIONS AND RESULTS

Frequency Response and Load Shedding Results

To compute the optimum settings of under-frequency relays, an under frequency turbine protection schemes are designed for a system with assumed sudden disturbance lead to a sudden load change of 0.6, 0.8, and 1.0 per unit. The minimum allowable operating frequency is selected to be 57 Hz. And the system parameters in per unit (p.u.) are [5];
K_m= 0.85, D=1.0, H=3.5, F_H=0.3, T_R=8.0, R=0.06.
All system parameters are estimated based on common knowledge of typical system designs

3.1 Scheme 1: Linear Frequency Response Model Applications and Results

Table 1, illustrates the frequency response of sudden load change of 0.6, 0.8, and 1.0 p.u . By using the linear system response model, fig.1,where the frequency response is obtained from Eq. (5), two protective plans are designed and compared. Plan1, for load shedding in 4-equal steps, and plan2 for load shedding in 6-steps. Since in large turbine-generator sets are not rated for continuous operation below about 59.5Hz [5], let the first step of load shedding frequency is set at 59.5 Hz.

Plan 1: As shown in Table 2, where for each load disturbance the corresponding minimum amount of load to be shed for four equal load shedding steps are tabulated, taking into consideration that the load shedding plan uses a time delay of 0.1 second for the first load shedding step.

Table 3, illustrates the frequency response after load shedding in four equal steps (plan1) for sudden disturbance equal 0.6, 0.8, and 1.0 p.u.

Fig. 3, (a, b, and c), shows the frequency response for 0.6, 0.8, and 1.0 p.u. load disturbance, respectively, before and after load shedding.

Plan 2: As shown in Table4, it consists of six load shedding steps of unequal size, for 0.6, 0.8, and 1.0 p.u. load disturbance. The load shedding steps are taken at closer steps than plan1. i.e. for load disturbance=0.6p.u.at frequency =59.5 Hz, load shedding is 0.046 p.u.(time delay=0.1second), then at frequency=59.3Hz, load shedding is 0.046p.u., then by step frequency equal 0.2 Hz, the frequency will reach 58.5Hz, at the sixth step and the load to be shed is found 0.036p.u. Note that, the total minimum load shedding for 0.6, 0.8, and 1.0p.u.load disturbance is the same as in plan1,0.24,0.48,and0.64, respectively.

Both load shedding in plan1 and plan2 use a time delay of 0.1 sec. for the first step. Note that the larger load shedding is taken first, followed by the smaller one. It is found that through this study, the results of the two plans are close, which indicates that the total amount of load is more important than the exact time of shedding.

3.2 Scheme 2: Expert System Applications and Results

Since it is important to detect the need for shedding very quickly and to complete all load shedding before the frequency can decay to a hazardous level, expert system is suggested and provided to help in this part of the problem. The simulation program has been developed to integrate the expert system module. As shown in Fig.4, a load shedding with frequency response program is used to simulate the power subsystem behavior. Hence the expert system module exchanges information with this program. The interface module takes care of the presentation of the solutions proposed by the expert system with the sequence of applied rules.

This expert system is applied on the two protective plans, i.e., it is used to identify very fast, 1- the total amount of minimum load to be shed for any load disturbance occurred as a first objective. 2- after the first objective is fulfilled, the second objective will be the identification of the amount of load to be shed at any step, 4-steps (plan1), or 6-steps (plan2). 3- identification of step frequency value corresponding to the amount of load shedding at this step.

3.2.1. Production rules

The following rules are proposed to determine the minimum amount of load shedding for any unknown load disturbance and also the amount of load to be shed at any step or frequency level for the two plans (see flow chart in Fig. 5).

Rule1 IF the frequency of the subsystem is declined under 57.0Hz
THEN this subsystem is subjected to under frequency problem
Rule2 IF the load disturbance is matched with that in database
THEN total minimum load shedding will identified

Plan 1:
Rule3 IF the study is for plan1
THEN load will be shed in four steps
Rule4 IF the number of steps is four
THEN load shedding is equal for all steps
Rule5 IF load shedding for plan1 is in step1
THEN set the initial frequency and frequency interval
Rule6 IF the load shedding for plan1 is in last step
THEN frequency must be 58Hz

Plan2
Rule7 IF the study is for plan2
THEN load will be shed in six unequal steps
Rule8 IF the number of steps is six
THEN the larger steps are taken first followed by smaller steps of load shedding
Ruler9 IF load shedding for plan2 is in step1
THEN set the initial frequency and frequency interval
Rule10 IF the load shedding for plan2 is in step six
THEN frequency must be 58.5Hz.

Results
Sequence of Rules

Rule1 : the subsystem is subjected to under frequency problem.
Rule2 : consider the subsystem is subjected to new load disturbances 0.70p.u, and 0.90p.u. If these values are not matched with those in database, they must be approximated

Plan1
Rule3 : for plan1, number of steps =4
Rule4 : total minimum load shed and load shed for each step;
for 0.70p.u load disturbance, total load shed=0.36p.u, load shed for each step=0.09p.u.
for 0.90p.u load disturbance, total load shed=0.56p.u,load shed for each step=0.14p.u.
Rule5 : initial frequency is set at 59.5Hz,and frequency interval is 0.5Hz

Rule6 : load to be shed at different frequency levels with 0.5Hz interval

step,	frequency(Hz.),	load to be shed(p.u)for load disturbance	
		0.70p.u	0.90p.u
1	59.5	0.09	0.14
2	59.0	0.09	0.14
3	58.5	0.09	0.14
4	58.0	0.09	0.14

Plan2

Rule7 : for plan2, number of steps=6

Rule8 : total minimum load shed is 0.36p.u for 0.70p.u load disturbance and 0.56p.u for 0.90p.u load disturbance.

Rule9 : initial frequency is set at 59.5Hz,and frequency interval is 0.2Hz

Rule10 : load to be shed at different frequency level with 0.2Hz interval

step,	frequency(Hz),	load to be shed(p.u)for load disturbance	
		0.700	0.900
1	59.5	0.069	0.106
2	59.3	0.069	0.106
3	59.1	0.057	0.089
4	58.9	0.057	0.089
5	58.7	0.054	0.085
6	58.5	0.054	0.085

Hint: If the new load disturbance value is mismatched with those in data base, this value is approximated to the nearest value in data base.

3.2.2 Comparisons and Discussions

For the first scheme, as a comparison between the two plans, it is obvious that, they both have a close view of the time frame when the load shedding is being initiated (time delay = 0.1second). And, since the amount of the total load shed is the same for the two plans, the comparison is based on the running time taken for the two programs. It is found that, for each step of the two plans, the execution time was 0.39seconds. Therefore, for plan1, the total time taken for running is 1.56 seconds, while for plan2, the running time was found 2.34seconds.

For the second scheme; beside the right and accurate action for using this expert system, the time taken for searching through this expert system, to make the decision, is found too small compared with that time for the first scheme (0.59 seconds for plan1, and 0.81seconds for plan2). Therefore expert system is considered simple, fast, and accurate in this area of study.

Both of the two scheme's programs would be executing in a computer with main processor is Intel Pentium Ш 733MHz., Cash memory is 256k, and 64MB Ram.

4.CONCLUSUIONS

Two schemes were proposed and suggested for determining the minimum amount of load to be shed for under frequency problem caused by a sudden load disturbance. The first scheme is based on the frequency detection by using a linear system frequency response model. This scheme is applied for two plans. The first plan deals with four equal load shedding steps, while the second plan consists of six load shedding steps of unequal size, and taken at steps that are closer together than the first plan but with the same total shed. As the size of the disturbance may increases, there will be greater need for rapid action. From this point of view, it is important to determine very quickly how much load shedding is required for a given disturbance. Expert system is suggested and introduced as a second scheme to solve this problem. It helps the operator to take his decision on a higher level without the need of applying the analytic programs and search for optimal total load shedding and load to be shed at every frequency level. A comparison between the two schemes is made and good results are obtained.

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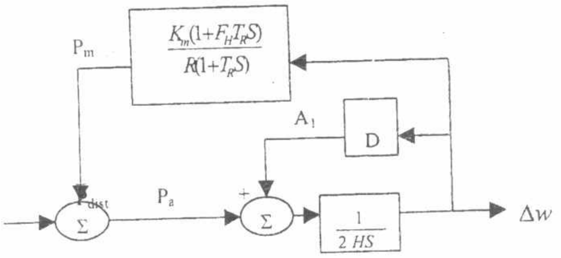


F_H: is the high-pressure power fraction of the reheat turbine.
K_m: is the gain
D : is the damping factor
H : is the inertia constant of the subsystem. constant.
T_R: is the reheat time

Fig.1 A linear system frequency response model for an isolated subsystem with $P_{dist.}$ as input.

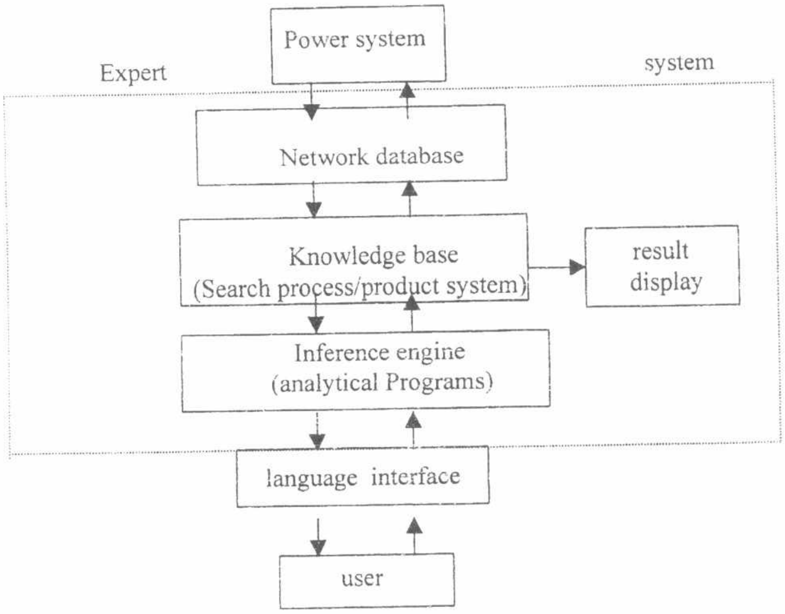
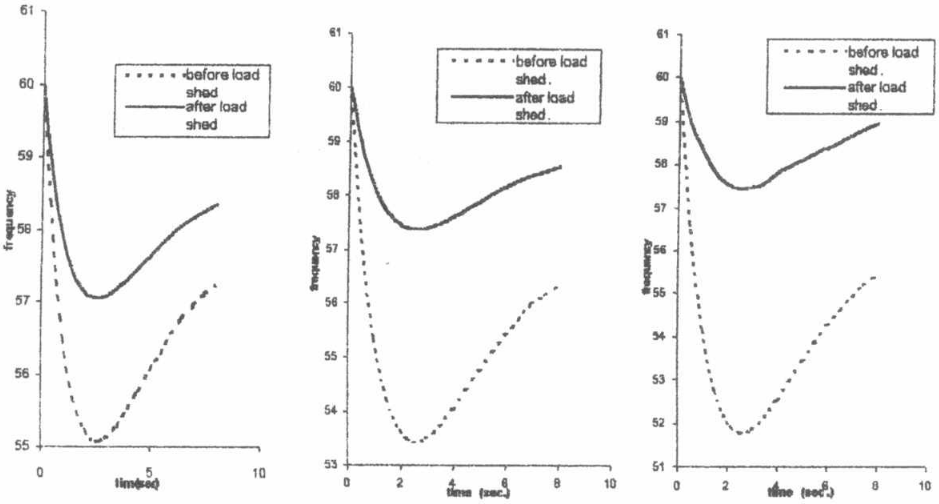


Fig.2 The expert system configuration



(a) P_{change}=0.6 p.u. (b) P_{change}=0.8 p.u. (c) P_{change}=1.0 p.u.

Fig. 3 Frequency response, before and after load shedding for load disturbance, 0.6, 0.8, and 1.0 p.u.

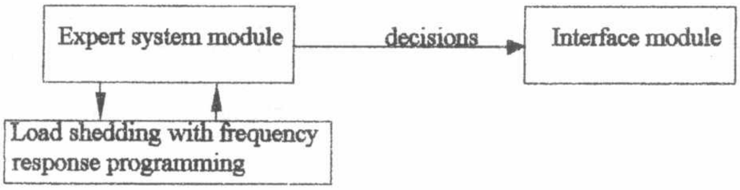


Fig. 4 Simulation program scheme.

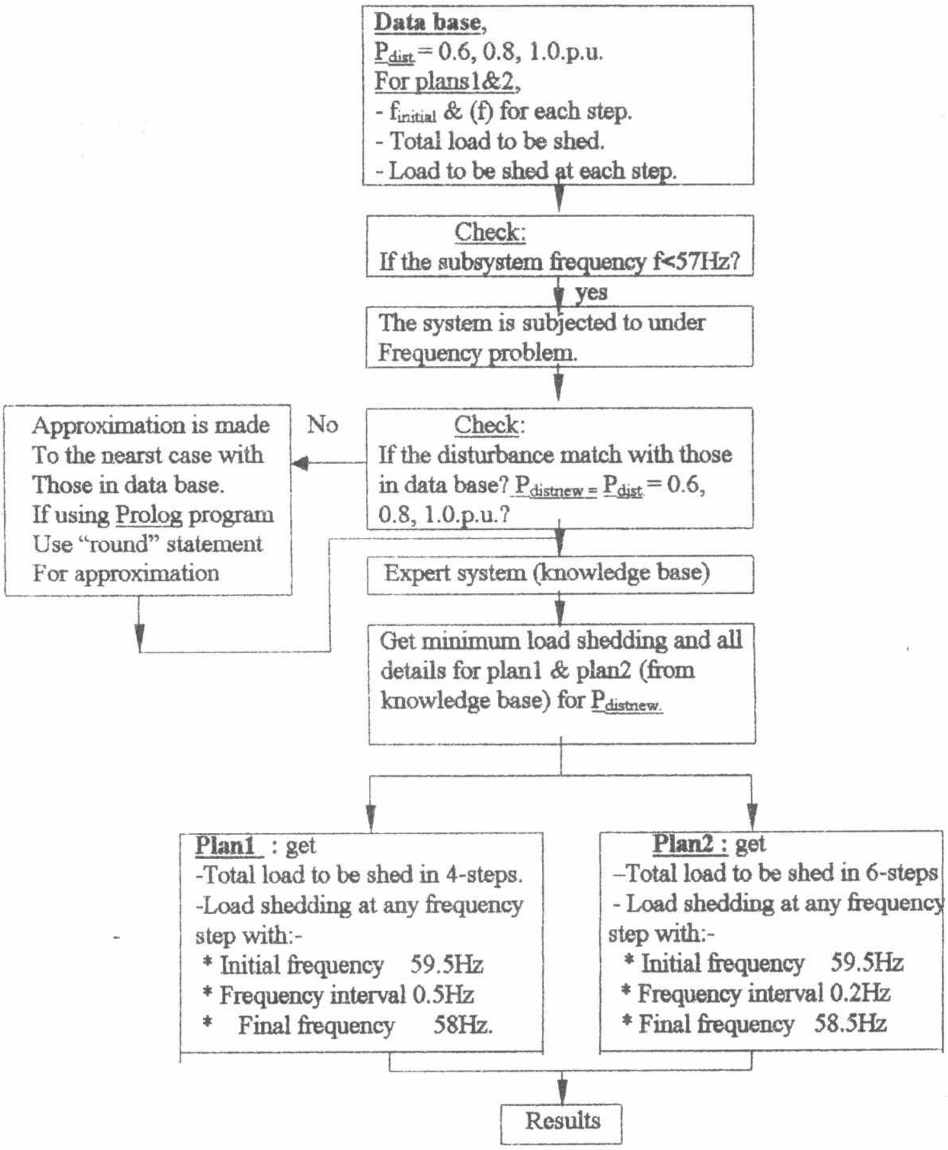


Fig.5 Flow chart of the suggested expert system.

Table1 Frequency response of sudden load change (P_{change}) of 0.6, 0.8,1.0 p.u.

Time (sec.)	frequency f (Hz)		
	Pchange=0.6 p.u.	Pchange=0.8 p.u.	Pchange=1.0 p.u.
0.0	60.00	60.00	60.00
0.5	57.87	57.16	56.45
1.0	56.48	55.31	54.14
1.5	55.65	54.20	52.75
2.0	55.22	53.62	52.03
2.5	55.07	53.43	51.79
3.0	55.12	53.49	51.86
3.5	55.28	53.71	52.14
4.0	55.52	54.02	52.53
4.5	55.78	54.38	52.97
5.0	56.06	54.74	53.43
5.5	56.26	55.09	53.86
6.0	56.56	55.41	54.26
6.5	56.77	55.69	54.62
7.0	56.96	55.99	54.93
7.5	57.11	56.15	55.19
8.0	57.24	56.32	55.4

Table2 Minimum load shedding and frequency settings of plan1

Step	frequency (Hz)	step load shedding (p.u.)		
		Pchange=0.6pu	Pchange=0.8pu	Pchange=1.0pu
1	59.5	0.06	0.12	0.16
2	59.0	0.06	0.12	0.16
3	58.5	0.06	0.12	0.16
4	58.0	0.06	0.12	0.16
total min. load shedding		0.24p.u.	0.48p.u.	0.64p.u.

Table3 Frequency response after load shedding of plan1

	frequency f (Hz)		
time (sec.)	Pchange=0.6 p.u.	Pchange=0.8 p.u.	Pchange=1.0 p.u.
0.0	60.00	60.00	60.00
0.5	58.72	58.86	58.92
1.0	57.89	58.12	58.29
1.5	57.39	57.68	57.79
2.0	57.13	57.45	57.53
2.5	57.04	57.37	57.44
3.0	57.07	57.39	57.49
3.5	57.17	57.48	57.57
4.0	57.31	57.61	57.81
4.5	57.47	57.75	57.97
5.0	57.63	57.89	58.11
5.5	57.79	58.04	58.26
6.0	57.93	58.16	58.39
6.5	58.06	58.28	58.53
7.0	58.17	58.38	58.67
7.5	58.26	58.46	58.81
8.0	58.34	58.53	58.94

Table 4 Minimum load shedding and frequency settings of plan2.

step	frequency (Hz)	step load shedding (p.u.)		
		P_{change}=0.6pu	P_{change}=0.8pu	P_{change}=1.0pu
1	59.5	0.046	0.091	0.122
2	59.3	0.046	0.091	0.122
3	59.1	0.038	0.077	0.102
4	58.9	0.038	0.077	0.102
5	58.7	0.036	0.072	0.096
6	58.5	0.036	0.072	0.096
total min. load shed.		0.24p.u.	0.48p.u.	0.64p.u.