OPTIMAL PLANNING OF OPERATIVE RESERVE OF ACTIVE POWER IN POWER SYSTEM UNDER CONDITIONS OF UNCERTAINTY

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The necessity of optimal planning of active power's operative reserve's in power system and corresponding world experience is proved and studied. It's developed a general probabilistic assessment algorithm of the active power delay and based on fuzzy logic method worked out a assessment methodology of overall required reliability and accepted risk level of power system and individual load nodes. It's developed the algorithm for determining the amount of the hourly active power operative reserve of power system. Distribution of optimal operative reserve on parallel working generators and hourly power flow calculation in normal and emergency modes are done. Based on calculations if in power system at certain time interval there exists overloaded transmission line it's made optimization function with constraints and algorithm, which distributes and recalculates power flow in a way that in normal and emergency modes overloaded transmission line will be unloaded. For the practical testing of above created new method for example it's exemined power system and results are got.

Key words: power system, reserve, active power, fuzzy logic, algorithm, reliability, risk

Generation capacity reservation is one of the most important factors of power system's reliability improvement. Creation of the required amount of operative reserve capacity, the optimal structure and mobility is very difficult and complex calculation and operational task. Efficient solution of this problem enables power system in a timely manner to compensate unbalanced active power and carry out its basic function, continuous power supply of users with the proper quality of electricity.

In the normal and emergency modes realization conditions, the complexity and urgency of the capacity reservation problem for country's electric power system is due to major equipment antiquity of power stations and the networks, adverse changes in the structure of the fuel balance and by the level of complexity, also capacity reservation regulatory documents are improper.

Given the actuality of the problem over the last decade in the world for studies related with a variety of aspects of optimal operational planning of reserve power are performing with high intensity [4,5,6,7,8,9,10,11]. In these works it's proved a necessity of doing planned works of theoretical-likelihood analysis, statistical evaluation of operational concerns random processes characteristics and their inter-relationships of frequency and automatic control of active power and other problems, including energy-related issues of integration with other power systems.

It must be emphasized the fact that existing method of determination of active power reserve mobility and quantity of power systems can't completely meet requirement of practice because it is weakly driven by automated and operative control in time intervals.

In the practice of optimal planning of power system's operational reserve is widely used deterministic and probabilistic methods [7,8,8,10,11].

Power systems of different countries have different operating reserve requirement criterion, which are listed in Table # 1 - in [3,11].

As it's shown on table #7 power system active power operative reserve planning criterions are deterministic and they didn't consider random processes in power system. It's not shown solution ways of the operative reserve optimization problem. Optimal active

power operative reserve planning in power system requires complex solution to the problem, must be considered every factor which have influence on power system reliability.

Spinning reserve requirements in different power systems

Table 1

Power system	Criterion
Georgia	Minimum $10\% P_i^t$ (1)
Australia and New Zealand	$\max(P_i^t)$ (2)
BC Hydro (Canada)	$\max(P_i^{max})$ (3)
Manitoba Hydro (Canada)	$80\%\ \max(P_i^{max}) + 20\%(\sum_{i=1}^{n} P_i^{max})$ (4)
Yucon Electrical (Canada)	$\max(P_i^{max})+10\%(P_d^{max})$ (5)
Belgium	UCTE rules. Currently at least 460 MW
California (USA)	$50\% * \max\left(5\% P_{hydro} + 7\% P_{other\ generation}, P_{largest\ contingency}\right) + P_{non-firm\ import}$ (6)
France	UCTE rules. Currently at least 500 MW
PJM (Southern)	$\max(P_i^{max})$ (7)
PJM (Western)	$1.5\%(P_d^{max})$ (8)
PJM (Other)	1.1 % Of the peak + probabilistic calculation on typical days and hours
Spain	minimum $3(P_d^{max})^{1/2}$ maximum $6(P_d^{max})^{1/2}$ (9)
Holland	UCTE rules. Currently at least 300 MW
UCTE	No specific recommendation. The recommended maximum $(10P_{d,zone}^{max}+150^2)^{1/2}-150$ (10)

Where, P_i^t – t period i generator generation; P_i^{max} - t period biggest generation; P_d - Load.

To ensure required reliability level of power systems it's necessary in power system to be such capacity of active power's operative reserve, that in case of any transmission line and generator outage it will as much as possible meet electricity demand and will reduce to minimum customer's and power producer's expected losses. We believe that the most effective way to solve this problem in evaluation of power system's performance processes are using probabilistic method.This method enables us to analyze different scenarios of operative processes [6,7,8,11].

Analysis of research carried out by [4,5,6,7,8,11] shows, that in power system during the planning of active power's operative reserve by probabilistic method it's used only generator outage statistics and required reliability level for power system in certain time (day) is constant value. These circumstances may cause more or less than enough quantity operative reserve determination, what finally will influence on power system's reliability and security levels and will determine economically unjustified active power's operative reserve capacity.

The present work offers a new method of determining the value of the operational reserve, which is based on generator's outage statistics and in power system at certain time period (hour) different reliability level's characteristics. Research carried out by us shows, that for power system at certain time period (hour) acceptable risk (reliability) level determination depends on load points demands and their reliability (risk) levels.

Based on possible scenarios of generator outages in power system for active power capacity outage assessment it's used capacity outage probability table (algorithm) [6,7,8,11], which is shown in table 2:

General algorithm of probabilistic assessment of the active power delay

Table 2

Scenario #	Generator			Available capacity P	Non-available (off) capacity	Individual probability of scenario	Total probability of scenario
	1	2	n				
1	1	1	1	$+P_{2max}+$	0	$P_{r1}=\sum_{i=1}^{n}(1-ORR_i)$ (11)	1
2	1	1	0	$+P_{2max}+$	P_{1max}	$P_{r2}=ORR_3*\sum_{i=1}^{2}(1-ORR_i)$ (12)	$\sum_{i=2}^{8}P_{r2}$ (15)
3	1	0	1	$+P_{2max}+$	P_{2max}	$P_{r3}=(1-ORR_1)*ORR_2*\sum_{i=1}^{2}(1-ORR_3)$ (13)	$\sum_{i=3}^{8}P_{r3}$ (16)
4	0	1	1	$+P_{2max}+$	P_{3max}	$P_{r4}=ORR_1*\sum_{i=2}^{3}(1-ORR_i)$ (14)	$\sum_{i=4}^{8}P_{r4}$ (17)
N	. .	. .	. .	. .	. .	. .	. .

Where, P_{r1}, P_{r2}, , P_{rn} - Individual probability of n scenario; $\sum_{i=2}^{8}P_{r2}$, $\sum_{i=2}^{8}P_{r3}$,..., $\sum_{i=2}^{8}P_{rn}$ Total probability of n scenario; ORR_i - Preparedness ratio of i generator; P – Available capacity of n scenario; P_{nmax} - Maximum power output of n generator.

Because of random nature and uncertainty of active power operative reserve variability in power system, for optimal determination of power system's t hour reliability (accepted risk) level by comparing with other methods fuzzy logic method is preferable [ ].

Research showed that for power system in certain period of time (hour) accepted Y_s reliability (risk) level should be assessed by two level fuzzy logic model. For creation of this model it must be selected such X_1, X_2,…X_n factors that will fully assess Y_s reliability level.

By analysis it is selected 2 factors: X_1 – Hourly load of each load point and X_2 – reliability level of each load point.

Based on X_1 and X_2 factors on the first level Y_1, Y_2,…, Y_i reliability evaluation is done.

Based on Y_1, Y_2,…, Y_i reliability (accepted risk) levels on the second level it is done final evaluation of Y_s whole power system reliability level.

Based on expert evaluation it is created X_1 and X_2 factor influence matrix on Y_1, Y_2,…, Y_i and Y_s reliability levels. Results are shown in table 3 and 4.

X_1 and X_2 factor influence on Y_1, Y_2,…, Y_i for first level

Table 3

Factor	X1	X2
	Increase	Increase
Y_1, Y_2,…, Y_i	Increasing	Increasing

$Y_1, Y_2,\ldots, Y_i$ reliability (risk) characteristics influence on Y_s for second level

Table 4

Factor	$Y_1, Y_2,\ldots, Y_i$
	Increase
Y_s	Increasing

For fuzzification of i load point's X_1, X_2, Y_1, $Y_2,\ldots$, Y_i და Y_s reliability level characteristics it is used triangular membership function and hourly characteristics are divided on 32 section, which has on figure 1 shown general form:

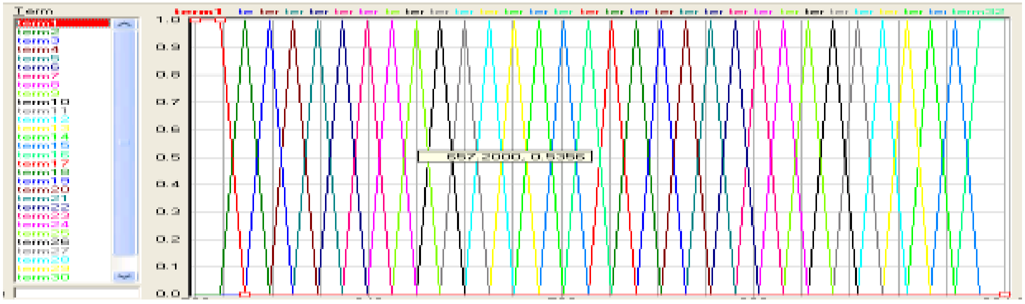


Fig. 1. General triangular membership function

Functional relationships of X_1, X_2 characteristics on $Y_1,Y_2,\ldots,Y_i$ and $Y_1,Y_2,\ldots,Y_i$ characteristics on Y_s reliability level are:

$$Y_1,Y_2,\ldots,Y_i = \psi_1(X_1, X_2), \quad (18) \qquad Y_s = \psi_2(Y_1,Y_2,\ldots,Y_i), \quad (19)$$

Where, ψ_1 and $\psi 2$ is procedure, which consists of rule base and it connects X_1, X_2, $Y_1,Y_2,\ldots,Y_i$ anda Y_s characteristics with each other.

Based on X_1 and X_2 characteristics influence matrix for i quantity load point according to n rule base it is determined X_1 and X_2 characteristics volatility influence on Y_t and $Y_1,Y_2,\ldots,Y_i$ volatility influence on Y_s characteristic. Description of this process is shown on figure 2.

#	IF dat1	THEN DoS	 risk1fin
1	term1	1.00	term32
2	term2	1.00	term31
3	term3	1.00	term30
4	term4	1.00	term29
5	term5	1.00	term28
6	term6	1.00	term27
7	term7	1.00	term26
8	term8	1.00	term25

Fig. 2. General rule base structure

Where, $term_i$ – Is i interval of X_1, X_2, $Y_1,Y_2,\ldots,Y_i$ and Y_s characteristics; Dos – Weight of rule of i interval;

For fuzzification of entering information and defuzification of final result taking into account different load points it is done fuzzy modeling process interaction block-scheme (model). See figure 3.

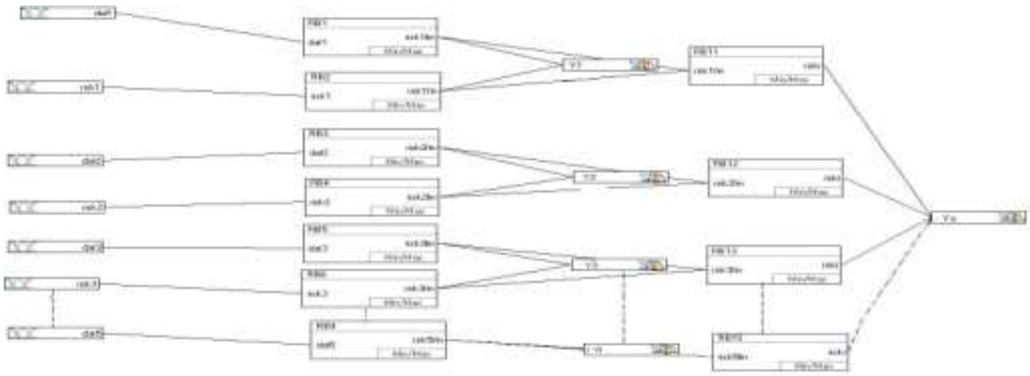


Fig. 3. Interactive block diagram of fuzzy modelling

Where, dat_i – Hourly load of I load point; $risk_i$ – Required reliability level of I load point; $RB_{i\ (dati)}$ – Rule base (I load point I load influence rules on Y_i reliability level); $RB_{i\ (riski)}$ – Rule base (I load point I reliability level influence rules on Y_i reliability level); Y_1,..,Y_i – Evaluated reliability level of i load point; Ys – Hourly reliability level of power system

Deffuzification of final results are done by using of minimax method [2,9,10].

Based on the results of researches algorithm for determining the amount of the hourly active power operative reserve of power system is made, which is described in table #5.

The algorithm for determining the amount of the hourly active power operative reserve of power system

Table 5

Start
Formation of # 1, 2, 3, . . N scenario
Formation of Fuzzy logic model and hourly t reliability level
$\sum_{i=2}^{8} P_{r2}$, **(20)** $\sum_{i=3}^{8} P_{r3}$, (21) $\sum_{i=4}^{8} P_{r4}$,(22) $\sum_{i=4}^{8} P_{rn}$ **(23) total probability and Y_t compare**
If Yt <= $\sum_{i=4}^{8} P_{rn}$, (24) than choose scenario related to $\sum_{i=4}^{8} P_{rn}$ (25) probability
Selection of the appropriate P avalaible capacity
For t hour minimum required operative reserve $R_t = D_t - P$ (26)
Formation of existing R_{a1}, R_{a2}, …, R_{an} reserve ($R_{an} = D_t - \sum_{i=1}^{n} P_g$) (27)
If $R_{an} >= R_t$, (28) than power system doesn't need addition operative reserve **Optimal operative reserve: $R_O = R_{an}$; (29)** **If $R_{an} < R_t$, than power system needs in addition $R_f = R_t - R_{an}$ (30) operative reserve** **Optimal operative reserve: $R_O = R_{an} + R_t^{\ 1}$ (31)**
By using of proportion method [1] distribution of R_O optimal operative reserve on parallel working generators
End

For the hourly distribution of generation and operative reserve on parallel working generators and in transmission lines based on newton-raphson method are done power flow calculation in normal and emergency modes [1,12].Based on calculations if in power system at certain time interval there exists overloaded transmission line it's made optimization function with constraints [1], which distributes and recalculates power flow in a way that in normal and emergency modes overloaded transmission line will be unloaded. Optimization function with constraints has following general form:

$$X \Rightarrow min \quad (32)$$

Subject to

$$D_i = \frac{\sum_{i=1}^{n}(B_i * C_i)}{\sum_{i=1}^{n} C_i}; \ (33) \ F_i = \frac{A_i * B_i * C_i}{D_i * \sum_{i=1}^{n} C_i}; \ (34) G_i = C_i - F_i; \ (35) \ H_i = -B_i * C_i * \frac{-J}{50} \ I_i$$

$$= G_i + H_i; \ (36) \ J = \frac{-G_{igam} * 50}{K_d * \sum_{i=1}^{n} G_i + M * \rho * (E - \sum_{i=1}^{n} C_i)}; \ (37)$$

$$\rho = \frac{\sum_{i=1}^{n}(C_i - C_{igam})}{\sum_{i=1}^{n} G_i}; \quad (38)$$

$$A_1 = A_2 = \cdots = A_i; \ (39) D_i = \sum_{i=1}^{n} G_i; \ (40) \ G_1 : G_2 : \ldots : G_i \le C_1 : C_2 : \ldots : C_i; \ (41)$$

$$I_1 : I_2 : \ldots : I_i \le C_1 : C_2 : \ldots : C_i \ (42) \ \sum_{i=1}^{n} F_i = R_{0i} \ (43) X = I_i \ (44) \ or \ I_1 + I_2 + \cdots + I_i \quad (45)$$

[1] - remark: Additional required active power's operative reserve is distributed among generators, also load deficit in algorithm is considered as import

Where,

- D_i – Is the coefficient of static tilt feature of power system;
- B_i - i generator's coefficient of static tilt feature,
- C_i - Rated power of I i generator;
- F_i - Reserve quantity distributed by proportion on i generator;
- A_i - Reserve capacity determined on parallel working generators;
- G_i - i generator's generation in normal mode;
- H_i - i generator's additional generation in emergency mode, during any G_{igam} generator outage;
- J - Frequency deviation during - G_{igam} generator emergency outage;
- I_i - i generator's total generation in emergency mode in G_i generator outage;
- G_{igam} - G_{igam} generator factual generation before it's outage;
- K_d - the coefficient of static tilt feature of load;
- M - the coefficient of static tilt feature in case of G_{igam} generator emergency outage;
- ρ – Power reserve ration;
- C_{igam} – Rated power of emergency outage generator;
- X – Feeding branch generation of overloaded transmission line;
- R_{0i} – At i hour optimal operative reserve capacity;
- D_i – At i hour load point demand; $i = 1, \ldots, n$;

Based on general optimization function it's created corrected algorithm for overloaded transmission lines unloading in power system, which is shown in table #6:

For the practical testing of above created new method of optimal planning of active power operative reserve in power system for example it's exemined power system with following characteristics. See table 7, 8, 9 and figure 4. On all busses voltage are 220 kV. For simplification reactive power loads on load points and losses on transmission lines are assumed as 0.

Based on table 7 and 8 data in power system it is determined generator's active power capacity outage table 10.

Corrective algorithm

Table 6

Start
Simulation of power flow in power system in normal and emergency modes by using of parallel working generators t hour generation and proportion method, according to R_i operative reserve (distributed on generators)
Comparing of simulation results of the maximum throughput of the transmission lines with the actual loads during normal and emergency modes: If $P_{line.facti} \leq P_{line.peri}$ (46) than i line is not overloaded, than go to step 7 If $P_{line.facti} > P_{line.peri}$ (47) than i line is overloaded and go to step 3
Formation of i=1,….n overloaded transmission lines
Determination of new quantity of R_i operative reserve with the use of corrective optimization function, parallel working generators t hour generation and proportion method
Simulation of power system's power flow in normal and emergency conditions
End

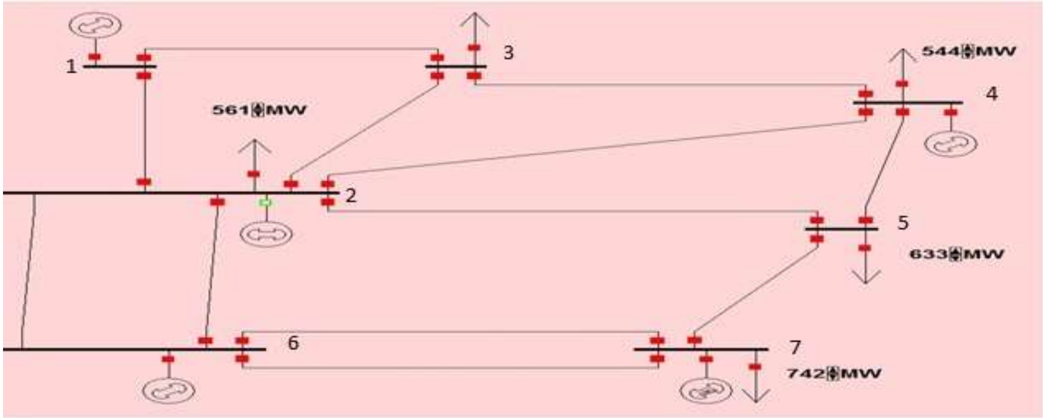


Fig. 4. Power system single-line diagram[2]

Power system's transmission lines maximum capacity

Table 7

Line #	From branch	To branch	Allowed throughput, MW
1	1	2	1000
2	1	3	1000
3	2	3	1000
4	2	4	1000
5	2	5	1000
6	2	6	750
7	2	6	750
8	3	4	1000
9	4	5	1000
10	5	7	1000
11	6	7	1000
12	6	7	1000

[2] Remark: For simplification on figure #4 represented power system's some generators are grouped in 1 generator

Technical characteristics of generators

Table 8

Characteristics	g-1	g-2	g-3	g-4	g-5	g-6	g-7	g-8	g-9	g-10	g-11	g-12	g-13	g-14	g-15	g-16	g-17	g-18	g-19	g-20	g-21	g-22	g-23	g-24	g-25	g-26	g-27	g-28	g-29	g-30	Total
Max. generation	30	30	30	30	30	30	30	30	30	30	30	50	50	100	100	100	100	100	100	100	200	200	250	250	300	300	300	350	420	420	4120
Min. generation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Emergency outage probability	0.01	0.02	0.03	0.02	0.04	0.01	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.02	0.01	0.03	0.01	0.02	0.02	0.01	0.02	0.03	0.01	0.01	0.04	0.01	0.02	0.03	0.01	0.01	-
The coefficient of static tilt feature	15	15	20	25	30	15	15	15	20	20	15	25	15	30	15	25	15	20	25	30	30	15	15	20	30	25	20	30	25	30	-

Techical data of load points

Table 9

Load point	Hr-1	Hr-2	Hr-3	Hr-4	Hr-5	Hr-6	Hr-7	Hr-8	Hr-9	Hr-10	Hr-11	Hr-12	Hr-13	Hr-14	Hr-15	Hr-16	Hr-17	Hr-18	Hr-19	Hr-20	Hr-21	Hr-22	Hr-23	Hr-24	Reliability level
#1	720	685.4	639.2	691.4	720.2	686.2	597	691	880.6	635.4	632.6	676.8	780.2	788.2	730.6	904.2	794	831.6	574.2	840.6	863	744.6	722	568	0.01
#2	544	683.4	702.2	584.4	665.2	716.2	668	674	629.6	661.4	724.6	675.8	796.2	637.2	895.6	735.2	721	630.6	612.2	784.6	897	759.6	672	802	0.02
#3	561	840.4	582.2	758.4	832.2	540.2	626	692	857.6	812.4	863.6	717.8	763.2	823.2	651.6	674.2	767	698.6	818.2	875.6	762	719.6	878	646	0.03
#4	633	649.4	561.2	652.4	713.2	679.2	790	723	678.6	806.4	770.6	785.8	658.2	742.2	644.6	886.2	645	891.6	847.2	658.6	712	638.6	797	649	0.01
#5	742	741.4	715.2	713.4	769.2	778.2	519	900	873.6	864.4	848.6	683.8	802.2	569.2	857.6	700.2	673	787.6	788.2	720.6	766	637.6	651	755	0.01
Total, MW	3200	3600	3200	3400	3700	3400	3200	3680	3920	3780	3840	3540	3800	3560	3780	3900	3600	3840	3640	3880	4000	3500	3720	3420	$K_d = 2$

Probabilistic assessment of the active power delay

Table 10

Generator on outage	g-1	g-2	g-3	g-4	g-5	g-6	g-7	g-8	g-9	g-10	g-11	g-12	g-13	g-14	g-15	g-16	g-17	g-18	g-19	g-20	g-21	g-22	g-23	g-24	g-25	g-26	g-27	g-28	g-29	g-30	All on
Individual probability	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.740
Total probability	0.224	0.217	0.209	0.202	0.194	0.187	0.179	0.172	0.164	0.157	0.149	0.142	0.134	0.127	0.120	0.112	0.105	0.097	0.090	0.082	0.075	0.067	0.060	0.052	0.045	0.037	0.030	0.022	0.015	0.007	0.964
Available capacity	4090	4090	4090	4090	4090	4090	4090	4090	4090	4090	4090	4070	4070	4020	4020	4020	4020	4020	4020	4020	3920	3920	3870	3870	3820	3820	3820	3770	3700	3700	4120

According to table #9 data for 5 load points based on above mentioned methodology it's created fuzzy logic model, which is shown on figure 5.

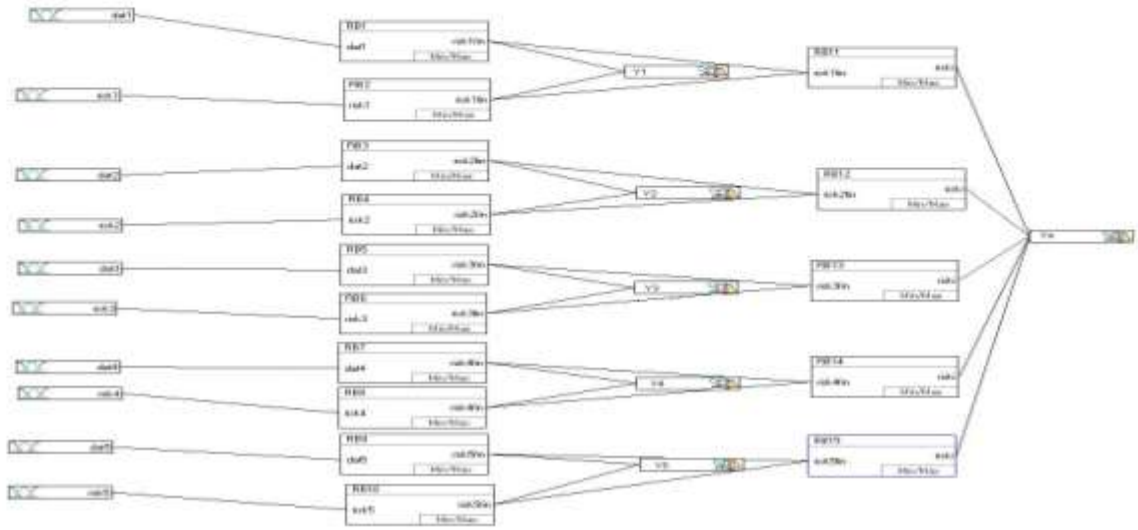


Fig. 5. Two level fuzzy logic model of hourly reliability level estimation

Based on Fuzzytech software calculations it's determined Y_1, Y_2, Y_3, Y_4, Y_5 reliability level of each load point and required Y_s reliability level for whole power system. Results of analysis is given in table 11.

Required hourly reliability level of power system

Table 11

Hour	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
Y_1	0.0156	0.0167	0.018	0.0165	0.0156	0.0166	0.0193	0.0165
Y_2	0.0248	0.0211	0.0205	0.0239	0.0216	0.0201	0.0215	0.0213
Y_3	0.0292	0.021	0.0286	0.0234	0.0212	0.0297	0.0273	0.0254
Y_4	0.018	0.0175	0.02	0.0174	0.0156	0.0166	0.0132	0.0153
Y_5	0.0143	0.0143	0.015	0.015	0.0136	0.0133	0.02	0.0103
Y_s	0.022	0.02	0.0222	0.0216	0.0191	0.02	0.0218	0.0207
Hour	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16
Y_1	0.0109	0.0181	0.0182	0.0169	0.0138	0.0136	0.0153	0.0103
Y_2	0.0226	0.0217	0.0199	0.0213	0.0179	0.0224	0.0152	0.0196
Y_3	0.0205	0.0218	0.0202	0.0246	0.0232	0.0215	0.0266	0.0259
Y_4	0.0166	0.0127	0.0138	0.0134	0.0172	0.0147	0.0176	0.0103
Y_5	0.0108	0.0111	0.0115	0.0158	0.0127	0.0188	0.0113	0.0154
Y_s	0.0195	0.0188	0.0189	0.0205	0.0189	0.0202	0.0201	0.0203
Hour	16-17	17-18	18-19	19-20	20-21	21-22	21-22	22-23
Y_1	0.0134	0.0123	0.02	0.012	0.0114	0.0149	0.0156	0.02
Y_2	0.02	0.0255	0.0231	0.0182	0.0152	0.0189	0.0214	0.0177
Y_3	0.0231	0.0252	0.0216	0.02	0.0233	0.0245	0.02	0.0267
Y_4	0.0176	0.0103	0.0115	0.0172	0.0156	0.0178	0.013	0.0175
Y_5	0.0161	0.0131	0.0131	0.0149	0.0137	0.017	0.0167	0.014
Y_s	0.0205	0.0194	0.0184	0.019	0.0183	0.0209	0.0202	0.0202

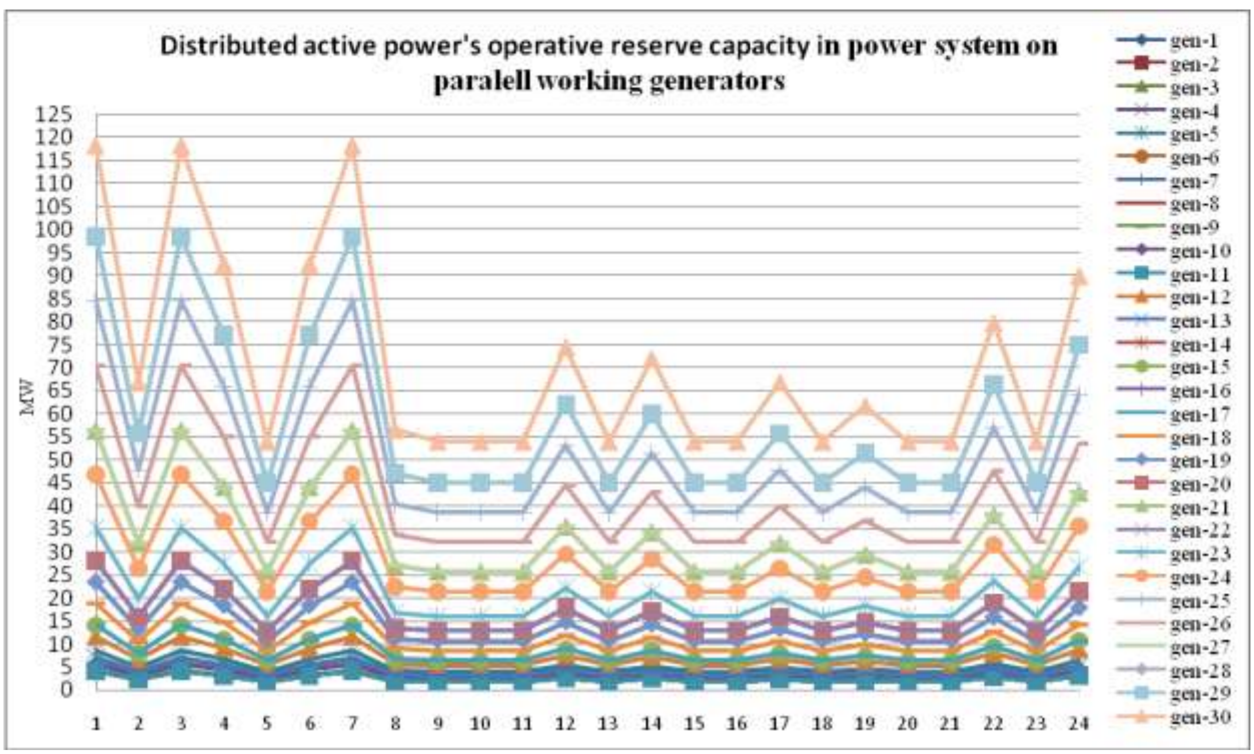
Based on table 8, 9, 10 data and table #5 given algorithm it's determined hourly optimal active power operative reserve of power system. Results are given in table 12

Hourly optimal active power operative reserve of power system

Table 12

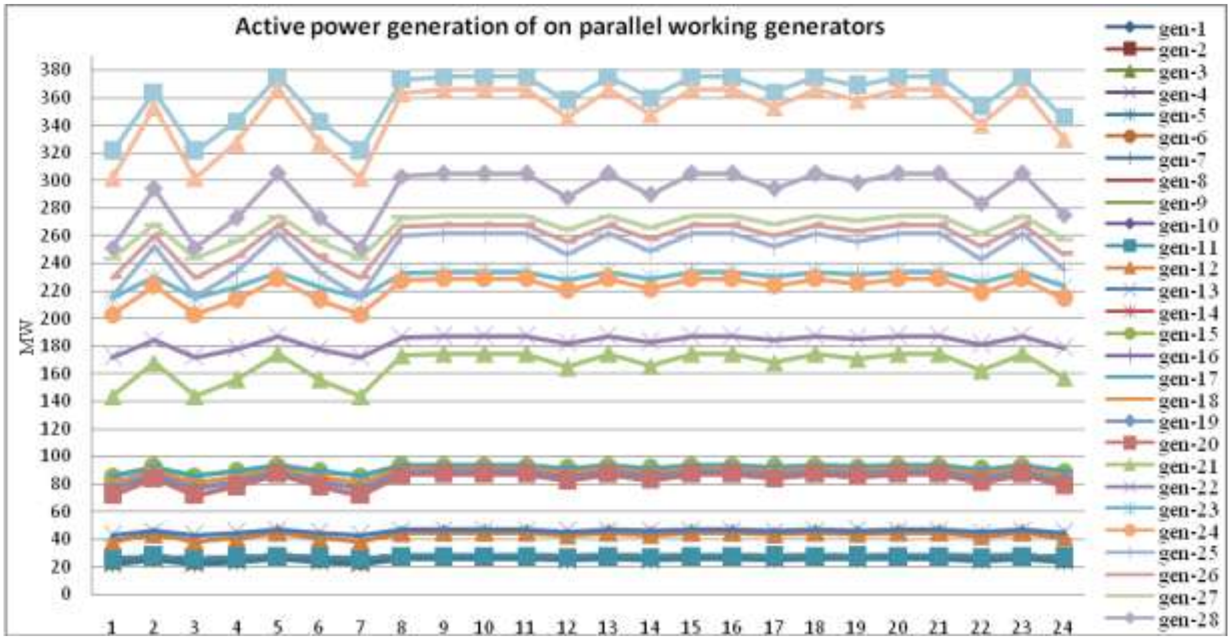
Hour	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
Existing operative reserve	920	520	920	720	420	720	920	440
Required additional operative reserve	0	0	0	0	0	0	0	0
Total operative reserve	920	520	920	720	420	720	920	440
% of demand	28.75	14.44	28.75	21.17	11.35	21.17	28.75	11.95
Hour	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16
Existing operative reserve	200	340	280	580	320	560	340	220
Required additional operative reserve	220	80	140	0	100	0	80	200
Total operative reserve	420	420	420	580	420	560	420	420
% of demand	10.71	11.11	10.93	16.38	11.05	15.73	11.11	10.76
Hour	16-17	17-18	18-19	19-20	20-21	21-22	21-22	22-23
Existing operative reserve	520	280	480	240	120	620	400	700
Required additional operative reserve	0	140	0	180	300	0	20	0
Total operative reserve	520	420	480	420	420	620	420	700
% of demand	14.44	10.93	13.18	10.82	10.5	17.714	11.29	20.46

For optimal distribution of active power operative reserve on parallel working generators it's used method of proportion [1]. Results are shown on Curve 1.



Curve 1. Distributed active power's operative reserve capacity in power system on parallel working generators

Based on table 5 and curve 1 data in power system parallel working generators generation is shown on curve 2.



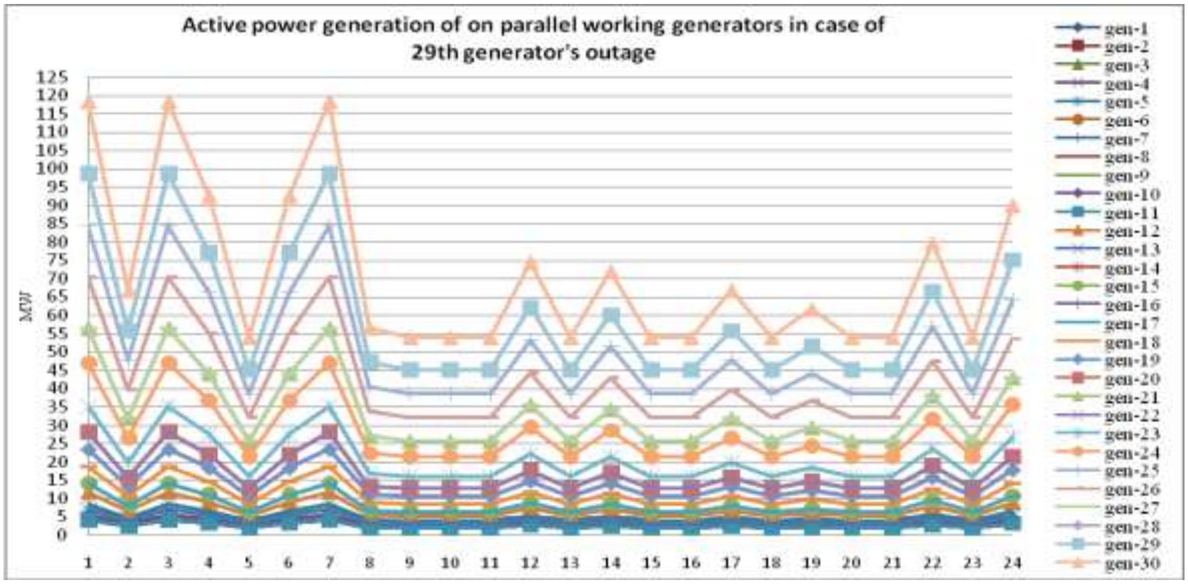
Curve 2. Active power generation of on parallel working generators

According to above mentioned methodology for checking optimality of determined active power operative reserve it's done emergency outage hourly simulation of the biggest generator #29 of power system. Results are filled in table #13 and shown curve 3.

29th generator's outage Simulation results

Table 13

Hour	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
Power system's remaining operative reserve, MW	620.44	183.43	620.44	401.86	74.23	401.86	620.44	96.04
Deviation of frequency	-0.171	-0.192	-0.171	-0.182	-0.198	-0.182	-0.171	-0.197
Total load reduction, MW	-22	-28	-22	-25	-29	-25	-22	-29
Total load reduction, %	0,68	0,77	0,68	0,73	0,78	0,73	0,68	0,78
Hour	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16
Power system's remaining operative reserve, MW	75.83	74.81	75.25	248.94	74.96	227.10	74.81	75.68
Deviation of frequency	-0.197	-0.197	-0.197	-0.189	-0.197	-0.190	-0.197	-0.197
Total load reduction, MW	-31	-30	-30	-27	-30	-27	-30	-31
Total load reduction, %	0,79	0,79	0,78	0,76	0,78	0,75	0,79	0,79
Hour	16-17	17-18	18-19	19-20	20-21	21-22	21-22	22-23
Power system's remaining operative reserve, MW	183.44	75.25	139.70	75.54	76.40	292.64	74.38	380.02
Deviation of frequency	-0.192	-0.197	-0.194	-0.197	-0.196	-0.187	-0.197	-0.183
Total load reduction, MW	-28	-30	-28	-31	-31	-26	-29	-25
Total load reduction, %	0,77	0,78	0,76	0,79	0,77	0,74	0,77	0,73



Curve 3. Active power generation of on parallel working generators in case of 29th generator's outage

For checking transmission lines overloading condition for 24 hour it's done power flow calculation with the use of PowerWorld software [12]. Results for 1 hour is shown below:

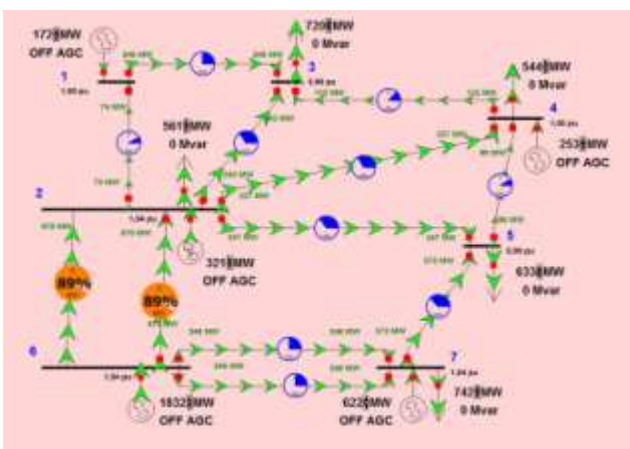


Fig. 1. Power flow calculation in normal mode in power system

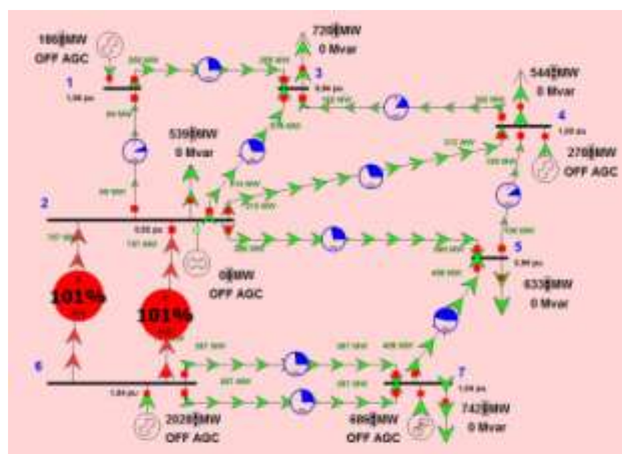


Fig. 2. Power flow calculation in power. system in emergency mode during# 29 generator outage

As it's shown on curve 2 in case of 29 generator emergency outage between 6-2 branches 2 transmission line are overloaded.

Calculations based in table 5 given corrected algorithm are given on figure 6 and 7:

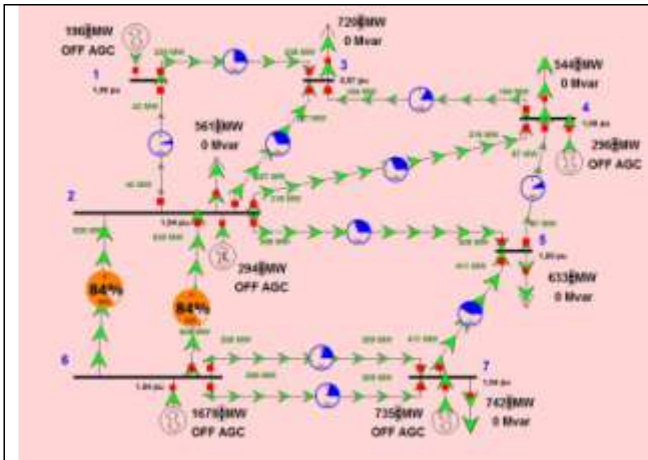


Fig. 3. Power flow calculation in normal mode in power system (corrected)

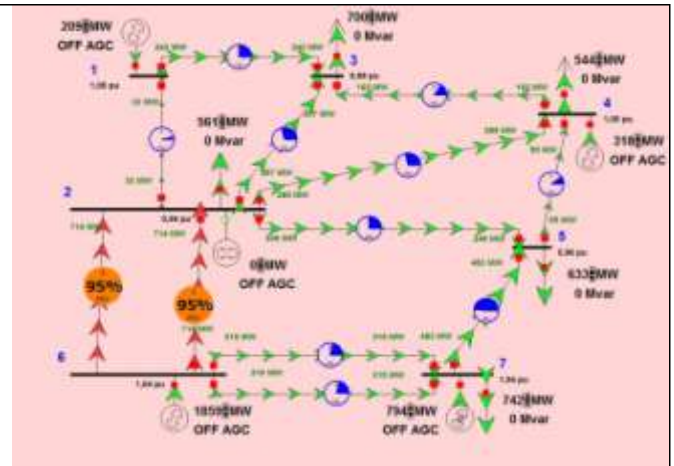


Fig. 4 Power flow calculation in power system in emergency mode during # 29 generator outage (corrected)

As it's shown from curve #3 and #4 in normal and emergency modes non of generators and transmission lines are overloaded. Also voltages on all busses are in acceptable ranges. Simulation results of corrected characteristics for 1 hour is given in table 14.

Table 14

Description			First	Corrected
Power system's remaining operative reserve, MW			620.44	518,62
Deviation of frequency			-0.171	-0,1556
Voltages on whole system	Min	Normal mode	211,2	213,4
		Emergency mode	202,4	206,8
	Max	Normal mode	231	231
		Emergency mode	231	231
Total load reduction, MW			-22	-19,9168

Conclusion

As a result of the research it's developed method of optimal planning of active power operative reserve in power system. This method enables power system based on generator's parameters, load point reliability characteristics, transmission lines capacities and hourly demand of electricity plan optimally active power operative reserve.

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