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FREQUENCY DEVIATIONS CONTROL BASED ON EGYPTIAN STRATEGY USING PARTICLE SWARM OPTIMIZATION TECHNIQUE

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ABSTRACT

In this paper, optimal proposed procedures (OPP) for the frequency deviations control using particle swarm optimization (PSO) technique are presented to criticism the related Egyptian strategy. These procedures not only depend on the load balance constraints, but also depend on the security limits of power flows in the transmission lines; while the total generation fuel cost is minimized. The proposed procedures are examined on the actual system of the West Delta (WD) network, apart of the Egyptian network (EN), and IEEE 30-bus test system. Their results show the drawbacks of the Egyptian strategy applied for frequency deviations.

يقدم هذا لبحث أسلوبا مقترحاً باستخدام التقنية المثلى لأفراد السرب لمحاكه و نقد التقنية المتبعة فى النظام المصرى فى معالجة حالات التشغيل الطارئة و التى يمكن أن ينتج عنها انخفاض التردد و ذلك بالتحكم فى توزيع القدرة المولدة من الاحتياطى الساخن و الاحتياطى الجاهز وسياسة الفصل الاضطراري للأحمال مع الأخذ فى الاعتبار حدود متغيرات التشغيل وخصوصا حدود سريان القدرة فى خطوط النقل. تمت الدراسة على شبكة غرب الدلتا كجزء من شبكة جمهورية مصر العربية، بالاضافة الى نظام قياسى (IEEE 30-bus) و أبرزت الدراسة مواضع القصور فى التقنية المتبعة فى النظام المصرى فى معالجة حالات التشغيل الطارئة و التى يمكن أن ينتج عنها انخفاض التردد.

Keywords: *Spinning Reserve (SR), Load Shedding (LSH), Ready Reserve (RR), Security-Constrained Optimal Dispatch (SCOD), Particle Swarm Optimization (PSO) and frequency deviations.*

1. INTRODUCTION

Shortage of generation power in a network, i.e. increasing the load behind the generation, is invariably reflected in collapse of frequency. The activation of the spinning reserve (SR) may be successful to maintain the power system operation but in some cases, SR activation may fail. In such cases, automatic frequency-based electrical load shedding (LSH) is provided to restore the frequency under upset conditions. Then, the mounted ready reserve units (RR) must be activated to overcome the defect and restore the shedding loads. The analysis of power system reserve and the risk of LSH have to be examined in a method based on a balance between cost and security.

This paper deals with the composed problem of optimizing economic dispatch (ED) for fast spinning reserve (FSR), LSH and RR in order to withstand the frequency deviations due to major sudden generation loss to prevent collapsing by cascading effects.

1.1. Spinning Reserve

Utilities must maintain some generation capacity as SR to serve loads in the event of sudden or unexpected failure of operating generating units [1]. SR in a correct amount has an equivalent effect to LSH in controlling frequency excursions [2]. In this study, the SR is classified into:

Fast spinning reserve (momentary reserve), which includes power that can be delivered within a few seconds after a large frequency fall is detected and it is always available to be supplied automatically by the primary governor actions of the on-line generators through the interconnected system [3]. **Slow spinning reserve,** which can be defined as the remaining SR that could be obtained from the committed generating units by ramping up their output within specified time intervals [4].

1.2. Load Shedding

LSH is an effective corrective control action in which a part of the system loads are disconnected according to certain priority in order to steer the power system from the existing potential dangers with the least probability of disconnecting the important loads [5]. LSH is considered as the last-resort tool for use in that extreme situation and usually the less preferred action to be adopted, but in this kind of problem, it is vital to prevent the system from collapsing [2].

LSH strategy has been applied in the Egyptian network (EN) in steps. However, step one trips at 49.2 Hz while the last step goes at 48.5 Hz. This leaves a window of 0.7 Hz within six sequential steps of LSH are expected to operate. More importantly, the steps can be tripped simultaneously instead of sequentially, based on the frequency deviation values.

Ref. [6] presented a computational method for determining the settings of the under frequency relays (UFR) and the level of the available SR in power system by calculating an appropriate set of indices and distributions for comparing alternative strategies.

1.3. Ready Reserve

RR consists of the rapid start units, to accelerate the loads restoration to maintain the frequency at 50 ± 0.05 Hz, such as gas turbines and hydro-plants. It takes not more than 10-15 minutes for the gas units, while only 10 seconds for hydro units to produce a sufficient power to make up for the power defect [7].

The on-line determination of RR required for compensation of power deficit in power systems was introduced in Ref. [7] using artificial neural network (ANN) technique. Two methods for evaluating RR capacity were presented in Ref. [8], based on the stochastic-determination computation and the simulation procedure.

1.4 Security-Constrained Optimal Dispatch (SCOD)

The SCOD function replaces the traditional economic dispatch. The SCOD will allocate the real-time imbalance power among the generating units in such a way as to enforce generator schedules and minimize the system price while observing security constraints. Ref. [9] presented a solution of the SCOD problem using a modified GA.

In EN, the real-time control of some generating units can be performed automatically by the automatic generation control (AGC). The AGC will determine the unit set point values, which are the sum of a regulation component and an optimal base point component. Optimal base point values for participating units will be calculated using the SCOD.

1.5 Particle Swarm Optimization Technique

PSO technique is introduced to solve many power system optimization problems as, solving the multi-objective economic dispatch considering the generator constraints [10] and economic load dispatch [11]. In addition, there are more power system PSO-based applications as reported in [12-13].

PSO model

In PSO, each particle keeps track of its coordinates which are associated with the best solution that it has achieved so far. This solution is called personal best (**pbest**). The best value between **pbests** is commonly called the global best (**gbest**).

The basic concept behind the PSO technique, is presented in many research papers as [14], consists of changing the velocity of each particle toward its **pbest** and the **gbest** positions at each iteration. The velocity and position of each particle can be modified according to the distance between its current position and **pbest**, and the distance between its current position and **gbest** using the following equations:

$$v_{id}^{k+1} = w.v_{id}^{k} + c_1.r_1.(pbest_{id} - x_{id}^{k}) + c_2.r_2.(gbest - x_{id}^{k}) \quad (1)$$

$$x_{id}^{k+1} = x_{id}^{k} + v_{id}^{k+1}, \quad (2)$$

$i = 1,2,\ldots,n \qquad d=1,2,\ldots,m$

where,

n	number of particles in a population,
m	number of members in a particle,
v_i^k	current velocity of particle i at iteration k,
v_i^{k+1}	modified velocity of particle i at iteration k+1,
x_i^k	current position of particle i at iteration k,
x_i^{k+1}	modified position of particle i at iteration k+1,
r_1, r_2	random numbers between 0 and 1,
$pbest_i$	personal best of particle i,
gbest	global best of the population,
c_1, c_2	acceleration constants.
w	inertia weight factor often decreases linearly from 0.9 to 0.4 during a run.

The value of w can be set according to the following equation:

$$w = w_{max} - \frac{w_{max} - w_{min}}{k_{max}} * k \quad (3)$$

2. PROBLEM FORMULATION

A method to deal with a combined problem of FSR, LSH and RR in order to withstand the frequency deviations due to major sudden generation loss can be summarized in two major steps:

- ♦ determining the critical compensation of the system, "FSR, LSH and RR";
- ♦ minimizing the composed cost of that compensation "SCOD".

2.1. OPP to alleviate the frequency deviations for EN

Figure 2 shows the flow chart of the OPP to alleviate frequency deviations based on related Egyptian strategy.

2. INDUCTION MOTOR WITH STATOR WINDING TURN FAULT SIMULATION

The equations which describe the induction motor with stator winding turn fault can be written in vector/matrix form as follows:

$$[V_s]=[R_s][I_s]+\frac{d[\psi_s]}{dt} \quad (1)$$

$$[V_r]=[R_r][I_r]+\frac{d[\psi_r]}{dt} \quad (2)$$

$$[\psi_s]=[L_{ls}+M_{ss}][I_s]+[M_{sr}][I_r] \quad (3)$$

$$[\psi_r]=[M_{rs}][I_s]+[L_{lr}+M_{rr}][I_r] \quad (4)$$

where, for a squirrel-cage induction motor, $[V_r]=[0]$ and $[M_{rs}]=[M_{sr}]^T$ and

$$[V_s]=\begin{bmatrix} v_{as} \\ v_{bs} \\ v_{cs} \end{bmatrix} \quad [I_s]=\begin{bmatrix} i_{as} \\ i_{bs} \\ i_{cs} \end{bmatrix} \quad [I_r]=\begin{bmatrix} i_{ar} \\ i_{br} \\ i_{cr} \end{bmatrix}$$

are the stator voltage vector, stator current vector, and rotor current vector, respectively.

For the rotor circuits, the mutual inductance matrix $[M_{rr}]$, the resistance matrix $[R_r]$, and the leakage inductance matrix $[L_{lr}]$ are not influenced by the stator faults. These parameters can be written as follows:

$$[M_{rr}]=\begin{bmatrix} M & -0.5M & -0.5M \\ -0.5M & M & -0.5M \\ -0.5M & -0.5M & M \end{bmatrix}$$

$$[R_r]=\begin{bmatrix} r_r & 0 & 0 \\ 0 & r_r & 0 \\ 0 & 0 & r_r \end{bmatrix} \text{ and } [L_{lr}]=\begin{bmatrix} L_{lr} & 0 & 0 \\ 0 & L_{lr} & 0 \\ 0 & 0 & L_{lr} \end{bmatrix}$$

Clearly, the stator faults have a direct influence on the stator parameters (resistances, leakage inductances, and mutual inductances between phases) and on the mutual inductances between the stator and the rotor ($[M_{sr}]$ and $[M_{rs}]$).

By taking the expression of each parameter in function of the number of windings in each turn, considering the percentage of turn faulted μ_{as}, μ_{bs} and μ_{cs}, for phases a, b, and c respectively, while μ_{as}^*, μ_{bs}^* and μ_{cs}^*, are the percentage of turns unfaulted (i.e. healthy portion) for phases a, b, and c respectively, the stator parameter matrices can be written as:

$$[R_s]=\begin{bmatrix} \mu_{as}^* r_s & 0 & 0 \\ 0 & \mu_{bs}^* r_s & 0 \\ 0 & 0 & \mu_{cs}^* r_s \end{bmatrix}$$

$$[L_{ls}]=\begin{bmatrix} \mu_{as}^{*2} L_{ls} & 0 & 0 \\ 0 & \mu_{bs}^{*2} L_{ls} & 0 \\ 0 & 0 & \mu_{cs}^{*2} L_{ls} \end{bmatrix}$$

$$[M_{ss}]=\begin{bmatrix} \mu_{as}^{*2} M & -\mu_{as}^* \mu_{bs}^* \frac{M}{2} & -\mu_{as}^* \mu_{cs}^* \frac{M}{2} \\ -\mu_{bs}^* \mu_{as}^* \frac{M}{2} & \mu_{bs}^{*2} M & -\mu_{bs}^* \mu_{cs}^* \frac{M}{2} \\ -\mu_{cs}^* \mu_{as}^* \frac{M}{2} & -\mu_{cs}^* \mu_{bs}^* \frac{M}{2} & \mu_{cs}^{*2} M \end{bmatrix}$$

Using θ_r, the angle between stator phase and rotor phase, the mutual inductance matrices $[M_{sr}]$ and $[M_{rs}]$ are

$$[M_{sr}]=\begin{bmatrix} \mu_{as}^* Mc_1 & \mu_{as}^* Mc_2 & \mu_{as}^* Mc_3 \\ \mu_{bs}^* Mc_2 & \mu_{bs}^* Mc_3 & \mu_{bs}^* Mc_1 \\ \mu_{cs}^* Mc_3 & \mu_{cs}^* Mc_2 & \mu_{cs}^* Mc_1 \end{bmatrix}=[M_{rs}]^T$$

where

$$c_1=\cos(\theta_r)$$

$$c_2=\cos(\theta_r-\frac{2}{3}\pi)$$

$$c_3=\cos(\theta_r+\frac{2}{3}\pi)$$

The equations describing the mechanical part of the motor are:

$$T_e=[I_s]^T\frac{\partial[M_{sr}]}{\partial\theta}[I_r] \quad (5)$$

$$\frac{d\omega_r}{dt}=\frac{P}{2J}(T_e-T_l) \quad (6)$$

$$\theta_r=\int\omega_r dt \quad (7)$$

where, T_e is the electromagnetic torque, T_l is load torque, ω_r is the angular mechanical speed, J is the combined rotor-load inertia, P is the number of motor poles, and θ_r is the mechanical angle.

A signal processing algorithm is used to estimate the voltage and current phasors from the samples of waveforms. The signal processing algorithm is based on recursive discrete Fourier transform DFT [13]. Using the estimated phasor quantities, the fault signature can be extracted and fault detection can be estimated.

Figure 1. illustrates the current waveform of phase *A* for 5% of turns in phase *A* short-circuited. Fig. 2 depicts the estimated amplitude of the fundamental frequency component of the phase *A* current for the previous described fault.

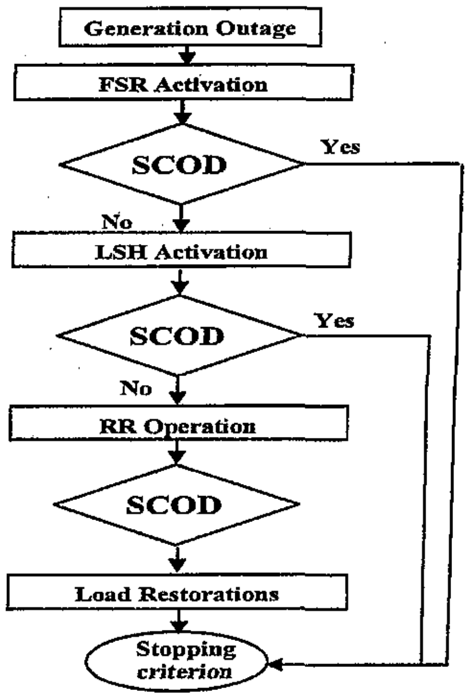

Figure 1 OPP Flow Chart

2.2 First stage, FSR optimization using PSO

Allocate the real-time imbalance power among the generating units to enforce generator schedules and minimize the generation fuel cost while observing security constraints. The mimicry of such stage can be carried out as:

2.2.1The objective function can be written as;

♦ Min $[(F_{SR})\,FSR]$ (4)

With,

$$F_{SR} = \sum_{i=1}^{N_G} (a_i.Pg_i^2 + b_i.Pg_i + c_i) \quad (5)$$

Where,

F_{SR} the total FSR fuel cost
FSR the total FSR
N_G total convention generation units number
Pg_i output power from generation unit i.
a_i, b_i and c_i the coefficients of the generation cost functions of the conventional units.

2.2.2. The System constrains

FSR is limited by upper limit as:

$$\sum_{i=1}^{N_G} FSR_i \le \sum_{i=1}^{N_G} (Pg_i^{max} - Pg_i) \quad (6)$$

Where,

Pg_i^{max} maximum output power from generation unit i.

However, the maximum value of SR at generation bus i (SR_i^{max}) is constrained by:

$$SR_i^{max} \le \sum_{j=1}^{NL} PF_{i-j}^{max} + LD_i - Pg_i \quad \text{and}$$

$$SR_i^{max} \le (Pg_i^{max} - Pg_i) \quad (7)$$

Where,

NL the number of transmission lines connected to bus i.
LD_i the load demand at bus i.
PF_{i-j}^{max} the maximum power flow limit in line i-j.

The load balance constraint must be satisfied as:

$$\sum_{i=1}^{N_G} Pg_i = TLD \quad (8)$$

Where,

TLD the total load demand including the line losses

The limits of the generated power at bus i is described as :

$$Pg_i^{min} \le Pg_i \le Pg_i^{max} \quad (9)$$

The power flow in line k is restricted by its upper limit (PF_k^{max}) as:

$$PF_k \le PF_k^{max} \qquad k=1, 2...NL \quad (10)$$

2.3. Second stage, OPP for LSH optimization

The proper LSH strategy needs to know decision values, (frequency deviations, and generation- load imbalance).

*Unlucky, in EN these decision values have not on-*line certainty. However, based on the practical recordings for a certain period, it is recorded that 1500MW generation-load imbalance leads to one Hz frequency deviation (Δf). Therefore, a load frequency dependency correction factor (FC) equal to 1500 MW/Hz is used as AGC bias in the Egyptian national control center.

Moreover, this AGC bias is valid since three years ago in spite of the fact that there was a yearly incremental increase in the load demand and generations.

2.3.1 Proposed mathematical derivation

However, based on the above concepts, the frequency deviation (Δf) in the EN is considered proportional directly to the system generation-load imbalance. Therefore, the total load demand can be written as a function of the frequency deviations as follows:

$$\mathbf{TLD_0 - TLD = FC\,(f_0 - f)}$$

$$\text{or}\quad \mathbf{TLD = TLD_0 + FC\,(f - f_0)} \quad (11)$$

Where,

f_0 the nominal frequency, equal to 50 Hz,
f the defect system frequency, [Hz]
TLD_0 the total load demand at frequency f_0, [MW],

TLD the total load demand at frequency f, [MW],
FC the load frequency dependency correction factor in the system [MW/Hz].

If all loads are assumed to have the same linear frequency dependency, (pu/Hz), the load frequency dependency in the system will be affected by the amount of the load demand according to the following equation:

$$FC=TLD_o * K \quad (12)$$

Where

K the frequency dependency for all load demand [pu/Hz].

A combination between equations (11) and (12) results in the following equation:

$$TLD=TLD_0 + TLD_0 * K * (f-f_0) \quad (13)$$

Therefore, the incremental change in the load demand S_L, [MW/Hz], can be defined as:

$$S_L = \frac{dTLD}{df} = TLD_0 \cdot K \quad (14)$$

Similarly, the incremental change in the generation power S_G, [MW/Hz], can be defined as:

$$S_G = \frac{\Delta Pg}{\Delta f} = Pg_0 \cdot K \quad (15)$$

Where,

ΔPg the active power mismatch between the actual value and set-point value of the generators.

From equations (14) and (15), the frequency dependency for all loads (K) can be written as:

$$K = \frac{\Delta TLD}{\Delta f \cdot TLD_o} = \frac{\Delta P_g}{\Delta f \cdot P_{g_o}} \quad (16)$$

From equations (12) and (16), the load frequency dependency correction factor in the system (FC) can be written as:

$$FC = \frac{\Delta TLD}{\Delta f} = \frac{\Delta P_g}{\Delta f} \quad (17)$$

When FC equals to 1500MW/HZ, equation (17) cab be rewritten, for EN, as:

$$\Delta P_g = 1500 * \Delta f \quad (18)$$

Equation 18 can be rewritten to reflect the total demand of the EN, which is equal to 16500 MW, as:

$$\Delta P_g = 1500 * \frac{TLD0}{16500} * \Delta f \quad (19)$$

From equation (19), the frequency deviation (Δf) can be expressed as follows:

$$\Delta f = \frac{\Delta P_g * 16500}{TLD_0 * 1500} \quad (20)$$

Equation (20) yields the frequency deviation as a relation between a certain nominal load (TLD_o) and the generation-load imbalance based on the Egyptian strategy for frequency corrections.

Table 6.1 shows the LSH stages and the corresponding LSH percentage based on frequency deviations for EN.

Table 1, LSH Stages based the frequency deviation for EN

LSH Stage	Δf (Hz)	LSH (%)	Remaining load (TLD)
1st stage	$0.9 > \Delta f \geq 0.8$	5%	$0.95 * TLD_0$
2nd stage	$1 > \Delta f \geq 0.9$	9%	$0.91 * TLD_0$
3rd stage	$1.1 > \Delta f \geq 1$	13%	$0.87 * TLD_0$
4th stage	$1.2 > \Delta f \geq 1.1$	20%	$0.80 * TLD_0$
5th stage	$1.3 > \Delta f \geq 1.2$	40%	$0.60 * TLD_0$
6th stage	$1.5 > \Delta f \geq 1.3$	60%	$0.40 * TLD_0$
Emergency	$\Delta f \geq 1.5$	72%	$0.28 * TLD_0$

2.3.2. Objective functions

The first objective is related to minimize the total load shedding according to the load priority factor as:

- $$\text{Min } F_l = \sum_{j=1}^{N_L} P_j P_{shj} \quad (21)$$

Where,

P_j the priority of load to be shed at bus j,

P_{shj} the amount of load to be shed at bus j,

N_L the number of buses that contains loads.

The second objective function is to minimizing the amount of load to be shed as:

- $$\text{Min } F_2 = \sum_{j=1}^{N_L} P_{shj} \quad (22)$$

Where, ΔPg_i is the incremental changing in generation of unit i due to FSR.

2.3.3. System Constrains for LSH Optimization:

The amount of LSH must be within specified limit as shown in Table 1. In addition, all the system constrain, as shown in equations (6-10) must be satisfied.

2.4. Third Stage, RR Optimization using PSO

The total amount of RR, which is required to compensate the outage of generation unit j (RR_j), can be expressed as:

$$RR_j = Pg_j - \sum_{i \neq j}^{N_G} SR_i \quad (23)$$

Where,

$\sum_{i \neq j}^{N_G} SR_i$ the sum of SR for the remaining units.

The negative value of the required RR means that, there is no need to use the RR units.

2.4.1 Objective functions, for RR Optimization:

The first objective function is to minimize the cost of RR as:

♦ Min [(F_R) RR] (24)

Where,

$$F_R = \sum_{R=1}^{N_R} a_R . RR_R^2 + b_R . RR_R + c_R \quad (25)$$

Where, (a_R , b_R , c_R) are the coefficients of the cost function of the RR units; RR_R is the output power of RR unit R, and N_R is the total number of RR.

The load that has high priority will be restored firstly, Therefore, the second objective function can be formulated as follows:

$$\text{♦ Max } F_{RES} = \sum_{j=1}^{N_L} P_j . P_{restor\ j} \quad (26)$$

Where, $P_{restor\ j}$ is the amount of load to be restored at bus j which has priority P_j .

2.4.2 System constraints, for RR Optimization:

The load balance constraint must be satisfied as:

$$\sum_{i=1}^{N_G} Pg_{i,w/SR} + \sum_{R=1}^{N_R} RR_R = TLD \quad (27)$$

Where, $Pg_{i,w/SR}$ is the output active power of the conventional unit i after activation of spinning reserve SR.

The absolute value of active power flow in transmission line k must satisfy the following limit:

$$|PF_k| \le PF_k^{max} \quad (28)$$

The limits of the generated power at bus i is described as follows:

$$Pg_i^{min} \le Pg_i \le Pg_i^T \quad (29)$$

$$\text{Where, } Pg_i^T = Pg_i^{max} + RR_R^{max} \quad (30)$$

Where, RR_R^{max} is the maximum output power of RR unit R at bus i.

The injected power from each RR unit is limited by its upper limit (RR_R^{max}) as:

$$RR_R \le RR_R^{max}$$

$$\text{Where, } RR_R^{max} = \sum_{j=1}^{N_L} PF_{i,j}^{max} + TLD_i - Pg_{i,w/SR} \quad (31)$$

3. APPLICATIONS

3.1. Test systems

The standard IEEE 30-bus test system and the actual system of WD network are used for extensive study of optimal proposed procedures (OPP). The number of particles in the swarm equals 100; the program is terminated after 100 iterations.

3.2 Results and comments for the 30-bus system

The data of conventional generation units and RR units are listed in Table 2. However, the RR units are located at buses 1, 2, 8 and 11.

Table 2 Generation and RR data for 30-bus system

Generation Units						Mounted RR			
Bus No.	Pg_o MW	Pg^{max} MW	Cost Function ($/hr)			RR^{max} (MW)	Cost Function ($/hr)		
			a_i	b_i	c_i		a_R	b_R	c_R
1	41	80	0.02	2	0	30	0.05	3.5	0
2	77.7	80	0.02	1.75	0	30	0.03	3.1	0
5	35.6	40	0.03	3	0	-	-	-	-
8	44.5	50	0.06	1	0	20	0.02	3.25	0
11	30	30	0.01	3	0	20	0.02	3	0

Forced outage of generation unit

Table 3 shows the state of SR evaluation for the outage of generation unit at bus 1 (Pg_1) at various loading conditions. The optimal activation of SR is achieved using PSO that minimizes the total generation costs and satisfying the system constraints.

The evaluation of SR indicates that the SR is succeeded to cover the generation shortage problem in certain cases, while it is failed in other cases. However, at the loading conditions of 220 to 255 MW, the system has enough SR to cover the outage of Pg_1. While, SR activation is failed to cover the outage of Pg_1 at the loading conditions more than 255MW. In such cases, where the SR is failed to solve the generation-load imbalance problem, LSH should be activated.

Results and comments for LSH activation

It can be seen from Table 4 that, the system will be operated under low frequency without the LSH activation till the frequency is decreased to be 49.2 HZ. In these cases, the system is operated in critical mode, as it has not any available SR.

When the frequency deviation is increased more than 0.8 HZ, the amount of LSH is increased as follows:

Up to the 4^{th} stage, the amount of LSH is suitable to solve the generation-load imbalance problem and an acceptable amount of SR is available. As example, at a frequency of 49.018 HZ, this leads to activate the 3^{rd} LSH stage, the frequency to corrected to be 50HZ and a 9.46MW SR is available.

However, at the 5^{th} and 6^{th} stages there are unnecessary loads are shedding. This leads to more system deviations as the generation units may be out of step due to frequency increasing. As example, at a frequency deviation of 1.226 HZ, the 5[th] LSH stage is activated. This leads to unused generation of 82.8 MW.

Table 3 Generation with SR activation of the 30-bus

TLD MW	Generation units Pg_1	Pg_2	Pg_5	Pg_8	Pg_{11}	Pg_{13}	Total cost $/hr	Results
220	0	80	39.1	31.61	30	39	755.5	Successful activation of SR
230	0	80	40	34.28	30	46	806.5	
240	0	80	40	40.04	30	50	862	
250	0	80	40	50	25	55	939.1	
255	0	80	40	50	30	55	956.4	

Table 4 System results due to LSH activation for 30-bus

TLDo MW	f-f0 HZ	Stage	Output: Generation MW Pg_1	Pg_2	Pg_5	Pg_8	Pg_{11}	Pg_{13}	Total cost hr/$	TLD	LSH	SR	f
260	0.2115	Low Ferq	0	80	40	50	30	55	956	260	No LSH	No SR	49.79
265	0.4151		0	80	40	50	30	55	956	265			49.59
270	0.6111		0	80	40	50	30	55	956	270			49.39
275	0.8	1st	0	80	40	50	30	55	956	261	14		49.74
280	0.9821	2nd	0	80	40	50	30	55	956	255	25	0.2	50
282	1.0532	3rd	0	80	40	50	21	55	922	245	37	9.46	50
285	1.1579	4th	0	80	40	34	30	44	796	228	57	27	50
287	1.2265	5th	0	69	23	26	30	24	539	172	115	82.8	50
290	1.3276	Em.	0	46	10	20	30	10	325	116	174	139	50

Table 5 shows the OPP for LSH dependent on the loads priority at different loading conditions for 30-bus system. Where, LD_o is the nominal load value, while LD is the value of load bus after the LSH activation.

Results and comments for 30- bus RR activation

The optimal locations and amount of RR power are given in Table 6. For example, when the generating unit 1 is forced outage at load demand equal to 290 MW, the SR fails in solving the generation-load imbalance problem. In order to restore the load shed, the RR units at buses 2 and 11 must be operated with power equal 30 MW and 15 MW, respectively. In addition, the RR unit mounted at bus 8 does not need to be operated at the outage of generating unit Pg_1 for different loading conditions. The total generation costs are changed from case to another depending on the forced outage of generation unit and the value of loading condition.

3.3. Results and comments for WD network

The bus data for the WD network is shown in Table 7.

It can be seen from Table 8, that at the loading conditions of 1034 MW to 1200 MW, the system has enough SR to cover the forced outage of a generating unit Pg_1. The optimal activation of SR power is achieved using PSO that minimizes the total generation costs and satisfying the system constraints. However, SR activation is failed to cover unit outage at the loading conditions more than 1200 MW.

Table 5 Optimal LSH with load priority at various load conditions for 30-bus

Load Variable MW	Priority	75.5 load MW LD_o	LD	280 load MW LD_o	LD	282 load MW LD_o	LD	285 load MW LD_o	LD	287 load MW LD_o	LD	290 load MW LD_o	LD
PL20	1	2.89	0	2.94	0	2.96	0	2.99	0	3.01	0	3.04	0
PL29	2	3.15	0	3.21	0	3.23	0	3.26	0	3.29	0	3.32	0
PL18	3	4.2	0	4.28	0	4.31	0	4.35	0	4.39	0	4.43	0
PL23	4	4.2	0.71	4.28	0	4.31	0	4.35	0	4.39	0	4.43	0
PL26	5	4.6	4.6	4.68	0	4.71	0	4.76	0	4.8	0	4.85	0
PL16	6	4.6	4.6	4.68	0	4.71	0	4.76	0	4.8	0	4.85	0
PL10	7	7.62	7.62	7.76	6.65	7.81	0	7.9	0	7.95	0	8.04	0
PL14	8	8.15	8.15	8.29	8.29	8.35	3.77	8.44	0	8.5	0	8.59	0
PL4	9	9.99	9.99	10.1	10.1	10.2	10.2	10.3	0	10.4	0	10.5	0
PL15	10	10.7	10.7	10.9	10.9	11	11	11.1	5.39	11.2	0	11.3	0
PL24	11	11.4	11.4	11.6	11.6	11.7	11.7	11.8	11.8	11.9	0	12	0
PL17	12	11.8	11.8	12	12	12.1	12.1	12.2	12.2	12.3	0	12.4	0
PL19	13	12.4	12.4	12.7	12.7	12.8	12.8	12.9	12.9	13	0	13.1	0
PL30	14	13.9	13.9	14.1	14.1	14.2	14.2	14.4	14.4	14.5	0	14.6	0
PL12	15	14.7	14.7	14.9	14.9	15	15	15.2	15.2	15.3	15.2	15.5	0
PL3	16	16.3	16.3	16.5	16.5	16.7	16.7	16.8	16.8	17	17	17.1	0
PL21	17	23	23	23.4	23.4	23.5	23.5	23.8	23.8	24	24	24.2	0
PL7	18	29.9	29.9	30.5	30.5	30.7	30.7	31	31	31.2	31.2	31.6	30.4
PL8	19	39.4	39.4	40.1	40.1	40.4	40.4	40.8	40.8	41.1	41.1	41.5	41.5

Table 6 RR activation results for 30-bus system

TLDo	Generation Pg1	Pg2	Pg5	Pg8	Pg11	Pg13	Total cost $/hr
	0	80	40	37.5	50.00*	48.39	903.56
260	0	80	40	41.8	50.00*	48.2	925.66
265	0	110*	30	38.5	31.50*	55	958.05
270	0	110*	35	40	30	55	981.19
275	0	110*	40	40	30	55	1005.7
280	0	110*	40	45	30	55	1036.2
282	0	110*	40	47	30	55	1049.4
285	0	80	40	70.00*	40.00*	55	1061.3

*Ready reserve activation

Results and comments for LSH activation for WD network:

When Pg_1 is forced outage, the SR is failed to feed the system load over 1300MW. It can be seen from Table 8 that, the system will operate under low frequency without LSH activation until the frequency is decreased to 49.2 HZ. In these cases, the system is operated in critical mode, as it has not SR available.

For the frequency deviation is increased more than 0.8 HZ the amount of LSH is increased in the following manner:

Up to the fourth stage, the amount of LSH is suitable to the generation-load imbalance problem and an acceptable amount of SR is available. As example, at a frequency of 49.02 HZ, the 2nd LSH stage i.e. 5% load shed, is activate to correct the frequency deviation with a available SR equal to 41 MW. However, at the 5[th] and 6[th] stages shedding loads are more than required. As example, at a frequency of 48.19 Hz, the 5[th] LSH stage, i.e. 60% load shed, is activated. This leaves unused generation power of 440 MW.

Table 7 Bus data for WD network

Bus No.	Substation Name	Power Generation (MW)			MW LDo	Cost Function Coefficients		
		Min.	Max.	Initial		a $/MW2.hr	b $/MW.hr	c $/hr
1	Main Abu Al-Matamir	10	180	136	9	0.00921	2.9	0
2	Main Al-Bustan	10	180	52.2	2.5	0.00921	2.9	0
3	Mani As-Sadat	10	170	135	41	0.00921	2.9	0
4	At-Tahreer Badr	10	175	56	0	0.00617	2.5	0
5	Itay Al-Barud	10	250	200	38.5	0.00845	2	0
6	Damanhour PS	10	80	72.5	0	0.00522	1.8	0
7	Kafr Ad-Dwar PS	10	170	120.57	0	0.00921	2.9	0
8	Al-Mahmudyiah PS	10	200	196	0	0.00921	2.9	0
9	Banger El-Sokr*	—	—	—	17	—	—	—
10	El Sawra*	—	—	—	45	—	—	—
11	Abu Al-Matamir	—	—	—	1.7	—	—	—
12	Al-Nasr	—	—	—	47	—	—	—
13	Sub-Bustan	—	—	—	6.8	—	—	—
14	Shark Al-Bustan	—	—	—	3.62	—	—	—
15	Wadi An-Natrun Indust	—	—	—	6	—	—	—
16	Industrial Sadat	—	—	—	1.5	—	—	—
17	Sub-Sadat	—	—	—	9.36	—	—	—
18	Al Akhmas	—	—	—	18.68	—	—	—
19	Wadi An-Natrun	—	—	—	13	—	—	—
20	ABGHLB*	—	—	—	19	—	—	—
21	Shark As-Sahrawy	—	—	—	18	—	—	—
22	South Wadi An-Natrun	—	—	—	5	—	—	—
23	At-Tahady	—	—	—	10	—	—	—
24	Al-Entlak	—	—	—	1.75	—	—	—
25	MAGD	—	—	—	9.4	—	—	—
26	SHOHDA*	—	—	—	18	—	—	—
27	Interagro	—	—	—	19.5	—	—	—
28	An-Nubaryiah 200	—	—	—	25.75	—	—	—
29	An-Nubaryiah 100	—	—	—	10.85	—	—	—
30	Masrf Al-Umum	—	—	—	4	—	—	—
31	Ad-Dilingat	—	—	—	30.3	—	—	—
32	ABMAT	—	—	—	21.3	—	—	—
33	North Kafr El-Ziat*	—	—	—	39.24	—	—	—
34	Kom Hamada	—	—	—	21.13	—	—	—
35	Hosh Isa	—	—	—	22.45	—	—	—
36	Al Khairy	—	—	—	54.83	—	—	—
37	Shark Al-Bustan	—	—	—	30	—	—	—
38	Ar-Rahmanya				9.8		—	—
39	Abu-Ar-Reesh	—	—	—	43	—	—	—
40	Abu Hummus	—	—	—	21.5	—	—	—
41	Zarkoon	—	—	—	8.8	—	—	—
42	South Kafr Ad-Dawar	—	—	—	27.6	—	—	—
43	Kafr AdDwar As-Sarea	—	—	—	48	—	—	—
44	Al-Ghazl	—	—	—	30	—	—	—
45	Al Hareer	—	—	—	5	—	—	—
46	halk Al Gamal	—	—	—	20.38	—	—	—
47	Al-Mahmudyiah	—	—	—	19.6	—	—	—
48	Al Busayli	—	—	—	9.96	—	—	—
49	Rashid	—	—	—	21.5	—	—	—
50	Motobus	—	—	—	15	—	—	—
51	El-Atf	—	—	—	5.13	—	—	—
52	Fiwa*	—	—	—	47.13	—	—	—

Results and comments for RR activation for the WD network:

The optimal locations and amount of RR power are given in Table 9. However, for WD network, there is only an assumed RR unit at bus 50 [15]. When the generating unit Pg_1 is forced outage at load demand equal to 1265 MW, the SR is failed in solving the generation-load imbalance problem. In this case, the RR is used to remove the frequency deviation.

Table 8 Generations with SR activations for WD network

load MW	Generation units								Total cost $/hr	Results
	Pg_1	Pg_2	Pg_3	Pg_4	Pg_5	Pg_6	Pg_7	Pg_8		
1034	0	180	170	175	154.8	50	104	200	3350.6	Successful Activation of SR
1050	0	180	170	175	170.8	50	104	200	3471.3	
1150	0	180	170	175	250	70.8	104	200	4202.1	
1200	0	180	170	175	250	80	145	200	4400.1	

Table 9 System outputs due to LSH activation for WD network

TLD, MW	f_o HZ	Stage	Outputs												
			Generation MW								Total cost $/hr	TLD	LSH	SR	f
			Pg_1	Pg_2	Pg_3	Pg_4	Pg_5	Pg_6	Pg_7	Pg_8					
1300	49.37	--	0	180	170	175	250	80	170	200	5968	1300	0	-35	49.37
1325	49.17	1[st]	0	180	170	175	250	80	170	200	5649	1258.8	66.25	6.25	49.71
1345	49.02	2[nd]	0	180	170	175	250	80	169	200	5416	1224	121.1	41	50
1355	48.94	3[rd]	0	180	170	175	250	80	124	200	5163	1178.8	176.2	86.2	50
1365	48.87	4[th]	0	180	170	175	250	80	37	200	4783	1092	273	173	50
1375	48.19	5[th]	0	177.5	128	10	175.6	80	54.3	200	3487	825	550	440	50

Table 10 Ready reserve Activation for WD network

Generation units								Total cost $/hr	Results
Pg_1	Pg_2	Pg_3	Pg_4	Pg_5	Pg_6	Pg_7	Pg_8		
0	180	170	175	250	80	155	240 *	4638.2	* RR activation
0	180	170	170	250	80	170	240 *	4711.6	

4-CONCLUSION

In this paper, optimal proposed procedures have been successfully applied to imitate the frequency deviations problem for the Egyptian strategy, using PSO technique. From this paper:

1- A PSO-based procedure to imitate the Egyptian Strategy for the SR optimization problem is introduced in order to remove the effects of emergency conditions in case of the generation-load imbalance.

2- A PSO-based procedure to imitate the Egyptian Strategy for load shedding has been proposed in order to remove the effects of emergency conditions in case of shortage of the SR.

3- A proposed equation to determine the frequency deviation related to the generation-load imbalance has been efficiently applied.

4- PSO has been successfully applied to imitate the Egyptian Strategy for sitting and sizing the ready reserve units in order to remove the effects of emergency conditions in case of shortage of the SR.

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