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A multi-objective fuzzy-based procedure for maximal preventive reactive power dispatch problem

By

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Abstract:

This paper presents a proposed procedure depends on the multi-objective fuzzy linear programming (MFLP) technique to obtain the optimal reactive power reserve for generators and static switchable VAr sources, as a preventive control action to overcome any emergency condition. The proposed procedure is very significant to eliminate violation constraints and give an optimal reactive power reserve for multi-operating conditions. The proposed multi-objective functions are: minimizing the real transmission losses, maximizing the reactive power reserve at certain generator, maximizing the reactive power reserve at all generation system and/or switchable VAr devices. The proposed MFLP is applied to a 5-bus test system and the West Delta region system as a part of the Egyptian Unified network. The numerical results show that the proposed MFLP technique achieves a feasible real power loss with maximal reactive reserve for power systems.

Keywords:

fuzzy linear programming, optimal reactive power dispatch, preventive actions

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1. Introduction:

One of the major operating tasks of a power system is to maintain the load bus voltages within the limits for high quality consumer services. The electric power loads are not constant and varies from time to time. Any change in the power demand causes lower or higher voltages [1]. The loss minimization is one of the important objectives in operating the transmission networks [2].

In a typical power system, network losses account for 5 to 10% of the total generation in the power system, which would cost millions of dollars every year [3]. This objective can be achieved by achieving proper adjustments of control variables like generator bus voltage magnitude transformer tap settings and reactive power injected from switchable capacitor banks while satisfying the units and system constraints.

The ORPD problem is solved effectively by conventional optimization techniques such as Newton method [4], linear programming (LP) [5], dynamic programming [6], nonlinear programming [7], quadratic programming [8, 9] and interior point methods [10] and also by computational intelligence-based techniques such as genetic algorithm (GA) [11], particle swarm optimization (PSO) [12, 13] and differential evolution (DE), [14, 15].

Appropriate provision for reactive power is essential in power systems in order to ensure secure and reliable operation of power systems. Reactive power is tightly related to bus voltages throughout a power network, and hence reactive power services have a significant effect on system security. Insufficient reactive power supply can result in voltage collapse, which has been one of the reasons for some recent major blackouts [16]. The US-Canada Power System Outage Task Force states in its report that insufficient reactive power was an issue in the August 2003 blackout, and recommended strengthening the reactive power and voltage control practices in all North American Electric Reliability Council (NERC) Regions [16].

Availability of reactive power at sources is an important aspect, which should be considered while rescheduling of reactive power control variables. Power system network may have the transfer capability of reactive power but if reserve is not available and reactive power limit violation occurs than the static voltage stability limit may be inadequate [17]. Further reactive reserves available at sources will not be of much help in maintaining desired level of stability margin, if network transfer capability is limited. Nedwick et al. [18] have presented a reactive power management program for a practical power system.

E. Lobato et al. [5] proposed LP based optimal power flow for minimization of transmission losses and Generator reactive margins of the Spanish power system. Wu et al. [19] described an OPF based approach for assessing the minimal reactive power support for generators in deregulated power systems. He et al. [20] proposed a method to optimize reactive power flow (ORPF) with respects to multiple objectives while maintaining voltage security. The management of reactive power reserves in order to improve static voltage stability using a modified PSO algorithm is presented in [17]. Due to the ability of fuzzy logic to represent the sorts of qualitative statements employed by human, fuzzy logic has found favor among many engineers and its effectiveness in solving multi objective problems. Fuzzy systems have been increasingly used to develop more efficient schemes for the power system operation, planning, control, and management. The fuzzy system applications to power systems and future considerations of fuzzy system applications were presented in [21-23]. There are various types of membership functions which are commonly used in fuzzy set theory. The choice of shape depends on the individual application. A between different fuzzy models to solve the fuzzy-based optimal power dispatch problem have been presented in [24]. Reference [25] solved optimal power dispatch problem considering multi-objective FLP technique considering preventive action constraints. A multi-objective fuzzy linear programming method was presented [26] to obtain the optimal transmission loss with maximizing the voltage stability margin.

This paper presents a solution to the fuzzy security constrained ORPD problem with maximizing the preventive control actions. The overall objective is to minimize the real power losses, maximize the reactive power reserve, while satisfying all the variables within its limits.

2. Solution methodology

From an operational point of view, minimizing real power losses doesn't that a rigid minimum solution is achieved. It is more appropriate to state the objective of the optimal reactive power dispatch as: to reduce the real power losses as much as possible without moving too many control settings, while satisfying the soft constraints as much as possible and enforcing the hard constraints exactly. Here, the concepts of "as much as possible" and "not too many" are fuzzy in nature. The optimal reactive power dispatch is solved using multi-objective fuzzy linear programming (MFLP) technique to determine the optimal settings of control variables with efficient fine tuning of power system variables where the real power losses are minimized and the maximal of preventive control action is achieved by increasing the reactive power reserve of generators and switchable VAr sources.

2.1 Fuzzy based ORPD problem

The fuzzy ORPD problem is formulated as a fuzzified constrained optimization problem to minimize the real power losses. In This paper, the simple sensitivity parameters are used to represent the objectives and dependent variables in terms of the control variables [27].

$$\min \Delta F = \begin{bmatrix} \partial \tilde{F} / \partial \tilde{vg} & \partial \tilde{F} / \partial \tilde{QS} & \partial \tilde{F} / \partial \tilde{t}_{ij} \end{bmatrix} \begin{bmatrix} \tilde{vg} \\ \tilde{QS} \\ \tilde{t}_{ij} \end{bmatrix} \tag{1}$$

Subjected to

$$\Delta vg_i^{min} \le \Delta \tilde{vg}_i \le \Delta vg_i^{max} \qquad i \in Ng\text{-slack bus} \tag{2}$$

$$\Delta QS_j^{min} \le \Delta \tilde{QS}_j \le \Delta QS_j^{max} \qquad j \in Ns \tag{3}$$

$$\Delta t_{ij}^{min} \le \Delta \tilde{t}_{ij} \le \Delta t_{ij}^{max} \qquad i,j \in Nt \tag{4}$$

$$\Delta vl_i^{min} \le \Delta \tilde{vl}_i \le \Delta vl_i^{max} \qquad i \in Nb\text{-}Ng \tag{5}$$

$$\Delta QG_j^{min} \le \Delta \tilde{QG}_j \le \Delta QG_j^{max} \qquad j \in Ng\text{-slack bus} \tag{6}$$

$$\Delta Qf_k^{min} \le \Delta \tilde{Qf}_k \le \Delta Qf_k^{max} \qquad k \in Nl \tag{7}$$

Where ($\tilde{F}$) is the fuzzy real losses; ($\tilde{vg}, \tilde{vl}$) is the fuzzy bus voltage of generator and load respectively; ($\tilde{QS}$) is the fuzzy reactive output from the switchable bus; ($\tilde{t}_{ij}$) is the fuzzy tap point of the transformer tap changer; ($\tilde{QG}$) is the fuzzy reactive output from generators and ($\tilde{Qf}$) is the fuzzy reactive flow through lines.

Ng is the number of generators;

Ns is the number of switchable buses;

Nt is the number of transformer tap changer;

Nb is the number of buses; Nl is the number of transmission lines.

The symbols (min, max and Δ) refer to minimum, maximum and gradient of any variable, respectively. The dependent variables (y) are represented in terms of control variables (x) as:

$$y = C_{yx}.x \tag{8}$$

Where, C_{yx} is the sensitivity parameters of the dependent variables in terms of the control variables [27].

2.2 Reactive power reserve

The maximization of reactive reserve problem is formulated as an optimization problem whose objectives are (i) maximize the reactive power reserves as a preventive control action for any emergency can be occurred where the reactive power sources consist of synchronous generators and shunt capacitors and reactors on the transmission network and (ii) minimizing the real power losses margin with respect to current operating point. Reactive power reserve of the generators is the ability of the generators to support bus voltages under increased load or disturbance condition. How much more reactive power the system can deliver depends on present operating condition, location of the source, field and armature heating of the alternators. The availability of reactive power reserve of a generator is calculated using capability curves. For a given real power output the reactive power generation is limited by both armature and field heating limit [28]. The reactive power reserve of any generator can be represented as:

$$QG_{i,res} = QG_{i,max} - QG_i, \qquad i = 1,2,................Ng \tag{9}$$

Where, $QG_{i,res}$ is the reactive power reserve of a generator (i); $QG_{i,max}$ is the maximum limit of reactive power output of a generator (i) which is the maximum limit of reactive power that the machine can supply; QGi is the reactive power output of a generator (i) at current operating condition. The reactive power reserve of switchable VAr devices can be represented as:

$$QS_{j,res} = QS_{j,max} - QS_j \qquad ,i = 1,2,................Ns \tag{10}$$

Where, $QS_{j,res}$ is the reactive power reserve of a switchable VAr source (j); $QS_{j,max}$ is the maximum limit of reactive power output of a switchable VAr source (j); QSj is the reactive power output of a switchable VAr source (j) at current operating condition.

2.3 Fuzzy modeling

There are various types of membership functions are commonly used in fuzzy set theory. Different membership functions are used as fuzzy models to solve the optimal active power dispatch in power system [29]. One of the best membership functions to represent the control and dependent variables in power systems is the triangular shape.

2.3.1 Fuzzy modeling of constraints

The triangle fuzzy modeling for the control variables (x) is shown in Fig 1. These control variables are the voltage at generators buses (vg_i), reactive power output at switchable buses (QS_j) and transformer tap changer (t_{ij}). It is seen that a membership function equal to 1 is assigned to x_i^{med}. Each control variable is represented by two constraints for the upper and lower limits. The membership function for the lower limit of any control variable is described as:

$$\mu_1(x_i) = \begin{cases} 0 & x_i \le x_i^{min} \\ \left(x_i - x_i^{min}\right) \big/ \left(x_i^{med} - x_i^{min}\right) & x_i^{min} \le x_i \le x_i^{med} \\ 1 & x_i \ge x_i^{med} \end{cases} \tag{11}$$

And the upper limit membership function of any control variable is described as:

$$\mu_2(x_i) = \begin{cases} 1 & x_i \le x_i^{med} \\ \left(\dfrac{x_i^{max} - x_i}{x_i^{max} - x_i^{med}}\right) & x_i^{med} \le x_i \le x_i^{max} \\ 0 & x_i \ge x_i^{max} \end{cases}$$

$$i = 1,2,\ldots\ldots\ldots\ldots Ng + Ns + Nt - 1 \tag{12}$$

Where, x_i^{min} and x_i^{max} are the minimum and maximum limits of a control variable (x_i), respectively. While, x_i^{med} is a point between the minimum and maximum limits of the control variables, with a fine funning of the control variables especially the generators voltage to enforce it towards desired values to enhance voltage security .

Similarly, a triangle fuzzy modeling for the dependent variables (y_j) is shown in fig 2. It is seen that a membership function equal to 1 is assigned to y_j^{med}. Each dependent variable is represented by two linear constraints for the upper and lower limits. The membership function for lower limit of any dependent variable is described as:

$$\mu_3(y_j) = \begin{cases} 0 & y_j \le y_j^{min} \\ \left(\dfrac{y_j - y_j^{min}}{y_j^{med} - y_j^{min}}\right) & y_j^{min} \le y_j \le y_j^{med} \\ 1 & y_j \ge y_j^{med} \end{cases} \tag{13}$$

And the upper limit membership function of any dependent variable is described as:

$$\mu_4(y_j)=\begin{cases}1 & y_j \le y_j^{med} \\ \left(\dfrac{y_j^{max}-y_j}{y_j^{max}-y_j^{med}}\right) & y_j^{med} \le y_j \le y_j^{max} \qquad j=1,2,\ldots\ldots\ldots Nb+Nl \\ 0 & y_j \ge y_j^{max}\end{cases} \quad (14)$$

Where, y_j^{min} and y_j^{max} are the minimum and maximum limits of each dependent variable (y_j), respectively. While y_j^{med} is a point between the minimum and maximum limits of each dependent variable and it is less than the maximum limit of each one.

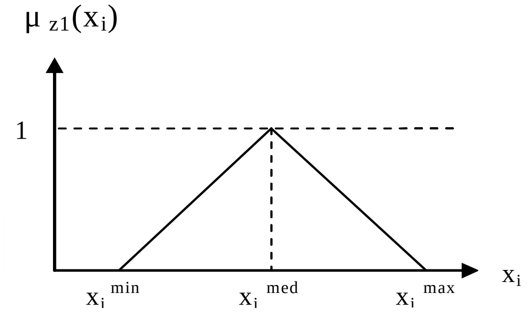

Figure 1: *Triangular membership model for control variables (x_i)*

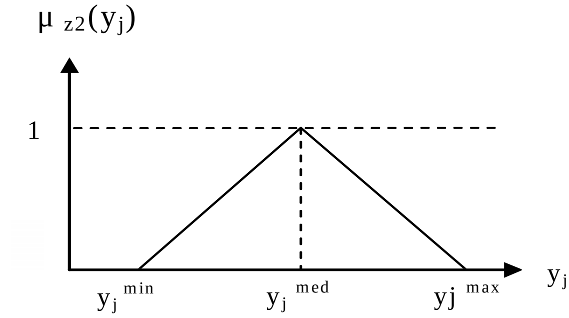

Figure 2: *Triangular membership model For dependent variables (yj)*

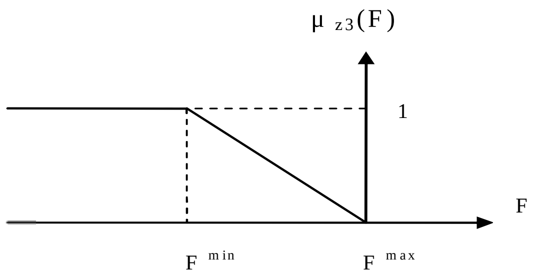

***Figure 3**: Fuzzy membership model for real power losses (F)*

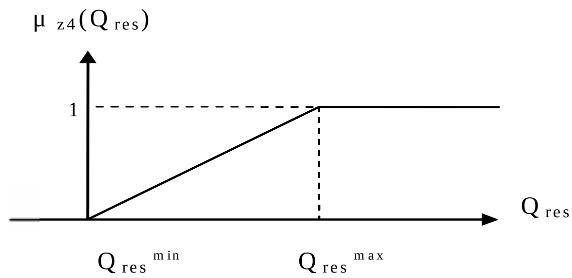

Figure 4: *Fuzzy membership model for reactive power reserve (Q_{res})*

2.3.2 Fuzzy modeling of objectives

Different objective functions are described in the proposed procedure. This objective s are minimizing the total real power losses and maximizing the reactive power reserve for generators and switchable VAR sources. The fuzzy modeling of the incremental of real power losses (F) is shown in fig 3. Eq (15) can be represented the fuzzy membership function of the losses which is less than or equal the permissible losses as:

$$\mu_5(F)=\begin{cases}1 & F\le F^{min}\\ \left(\dfrac{F^{max}-F}{F^{max}-F^{med}}\right) & F^{min}\le F\le F^{max}\\ 0 & F\ge F^{max}\end{cases} \tag{15}$$

Where, F^{min} and F^{max} are the minimum and maximum incremental of real power losses which, are related to the minimum and maximum reactive power dispatch of the power system, respectively at a certain reactive power demand. The fuzzy membership function for maximizing the reactive power reserve can be represented as Eqn (16) and as shown in Fig 4.

$$\mu_6(Q_{res})=\begin{cases}0 & Q_{res}\le Q_{res}{}^{min}\\ \left(\dfrac{Q_{res}-Q_{res}{}^{min}}{Q_{res}{}^{max}-Q_{res}{}^{min}}\right) & Q_{res}{}^{min}\le Q_{res}\le Q_{res}{}^{med}\\ 1 & Q_{res}\ge Q_{res}{}^{med}\end{cases} \tag{16}$$

Where, $Q_{res}{}^{min}$ and $Q_{res}{}^{max}$ are the minimum and maximum reactive power reserve for the generators and switchable VAR sources in the power system, respectively.

3. Proposed procedure for maximal reactive reserve

The proposed objectives to maximize the reactive power reserve either for all sources of static and dynamic reactive power or individually are incorporated to the fuzzy linear programming technique. Then, it is applied to the ORPD at an operating condition as shown in Section 2.1. These objectives are considered as various preventive control actions that may be taken into account of the operator to remove any violation limit, which may occur at the emergency condition.

3.1 Maximization of reactive reserve for each generation unit

The maximal effect of the preventive control action to maximize the reactive power reserve for each generation unit can be expressed as:

$$\begin{aligned}&\max\ QG_{i,res}\\ &\qquad QG_{io} - QG_i \le QG_{i,res}\end{aligned} \tag{17}$$

Where, QG_{io} is the initial reactive generation for unit (i); QG_i is the fuzzy reactive generation of new operating condition for generator (i); $QG_{i,res}$ is the maximal reactive reserve for generator (i) at certain operating condition which is defined in Eqn(9).

3.2 Maximization of reactive reserve for all generation units

Eqn (17) is restated, as multi-objective problem to obtain the maximal reactive power reserve for all generation units except the slack bus generator simultaneously, as:

$$\max \ QG_{i,res} \qquad (18)$$
$$QG_{io} - QG_i \leq QG_{i,res} \quad ,i = 1,2,...............Ng, \ i \neq \text{slack bus}$$

Where, QG_{io} is the initial reactive generation for unit (i); QG_i is the fuzzy reactive generation of new operating condition for generator (i); $QG_{i,res}$ is the maximal reactive reserve for generator (i) at certain operating condition which is defined in Eqn(9).

3.3 Maximization of reactive power reserve at switchable buses

The maximal reactive reserve for all switchable VAr devices can be expressed as:

$$\max \ QS_{j,res} \qquad (19)$$
$$QS_{jo} - QS_j \leq QS_{j,res} \quad ,j = 1,2...........,Ns$$

Where, QS_{jo} is the initial reactive output for all switchable buses (j); QS_j is the fuzzy reactive output of new operating condition for all switchable buses (j); $QS_{j,res}$ is the maximal reactive reserve for all switchable buses (j) at certain operating condition which is defined in Eqn(10).

3.4 Multi-objective fuzzy linear programming technique

Since, the maximization of reactive reserve problem has multiple proposed objective function, the MFLP technique is performed by maximizing the minimum of all satisfaction parameters as maximize λ, where:

$$\lambda = \min \left\{\mu_{z1}, \mu_{z2}..............., \mu_{zi}\right\} \qquad (20)$$

Where, μ_{zi} is the membership functions of the constraints for control and dependent variables as well as the objectives constraints of real power losses and reactive power reserves, within range of [0-1] for all constraints. The fuzzy reactive dispatch presented in Eqs. (1)-(7) with maximizing reactive reserve objective can be expressed as:

$$\max$$

Subject to:

$$\lambda \leq \mu_{z1}(x_i) \qquad i = 1,2,........Ng + Ns + Nt - 1 \qquad (21)$$

$$\lambda \leq \mu_{z1}(y_j) \qquad j = 1,2,........Nk + Nb - 1 \qquad (22)$$

$$\lambda \leq \mu_{z1}(F) \qquad (23)$$

$$\lambda \leq \mu_{z1}(Q_{res,m}) \qquad m = 1,2,........Nm - 1 \qquad (24)$$

$$0 \leq \lambda \leq 1 \qquad (25)$$

Where, $\mu_{z1}(x_i)$ is the fuzzy membership function for control variables (i); $\mu_{z2}(y_j)$ is the fuzzy membership function for dependent variables (j); $\mu_{z3}(F)$ is the fuzzy membership function for the real power losses; $\mu_{z4}(Q_{res,m})$ is the fuzzy membership function for the reactive power reserve as another objective; Nm is the number of objective functions of reactive power reserve. Eqs (21)-(25) can be rewritten as follows:

$$-x_i + (x_i^{med} - x_i^{min})\lambda \le -x_i^{min} \qquad i = 1,2,.............Ng + Ns + Nt - 1 \tag{26}$$

$$-y_j + (y_j^{med} - y_j^{min})\lambda \le -y_j^{min} \qquad i = 1,2,.............Nk + Nb - 1 \tag{27}$$

$$x_i + (x_i^{max} - x_i^{med})\lambda \le x_i^{max} \qquad j = 1,2,.............Ng + Ns + Nt - 1 \tag{28}$$

$$y_j + (y_j^{max} - y_j^{med})\lambda \le y_j^{max} \qquad j = 1,2,.............Nk + Nb - 1 \tag{29}$$

$$F + (F^{max} - F^{min})\lambda \le F^{max} \tag{30}$$

$$-Q_{res,m} + (Q_{res,m}^{max} - Q_{res,m}^{min}) \le -{}_{res,m}^{min} \qquad m = 1,2,.............Nm \tag{31}$$

$$0 \le \lambda \le 1 \tag{32}$$

Eqs (26),(28) represent the fuzzy constraints of generators voltage, reactive power output at switchable buses, transformers tap setting, loads voltage, reactive power output from generators, reactive power flow through transmission lines, real power losses as objective function and the reactive power reserve as another objective function. The MFLP technique is computed to maximize λ, using these fuzzy constraints.

4. APPLICATIONS

4.1 Test systems

The 5-bus test system [30] and the West Delta region systems [31] are used for an extensive study to maximize the optimal reactive power reserve. The MFLP technique for minimizing the real transmission losses and maximizing the reactive power reserves is applied for the 5-bus test system (3-generation units, 7-lines). The one line diagram of the 5-bus test system is shown in fig 5. Table 1 and 2 show the transmission line data and bus-data for 5-bus test system, respectively. The West Delta region system is a part of the Unified Egyptian Network which consists of 52-bus and 8 generation buses [31]. These buses are connected by 108 lines. Figure 6 shows the one line diagram of the real power system at West Delta region. Shunt compensation limits at buses 18, 20 and 42 have been assumed between 0 p.u and 1 p.u (the base voltage is 66 kv, while the base MVA equals 100). OLTC limits between buses 4-25 and 11-28 have been assumed between 0.9000 and 1.1000.

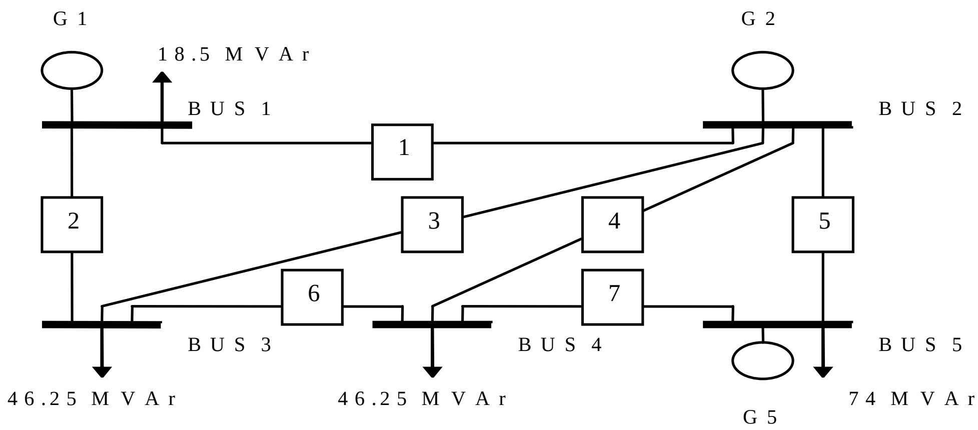

Figure 5: *The single line diagram for five bus test system*

Table 1: *Bus data*

Bus No	**Pg (MW)**	**Qg (MVAr)**	**Pd (MW)**	**Qd (MVAr)**	**QMAX (MVAr)**	**QMIN (MVAr)**	**V (P.U.)**	**Qinj (P.U.)**	**vmax (P.U.)**	**vmin (P.U.)**
1	89.57	89.57	65	50	120	-120	1.05	0	1.05	0.95
2	180	60	85	50	90	-90	1.02	0	1.05	0.95
3	0	0	75	45	100	0	0.97	0	1.05	0.95
4	0	0	75	45	0	0	0.96	0	1.05	0.95
5	140	40	150	100	150	-150	1.02	0	1.05	0.95

Table 2: *Transmission lines data*

Bus No	**nl (from)**	**nr (to)**	**R (P.U.)**	**X (P.U.)**	**BC (P.U.)**	**a (at nl side)**	**Max flow (MVA)**
1	1	2	0.02	0.06	0.030	1.0000	50
2	1	3	0.08	0.24	0.025	1.0000	50
3	2	3	0.06	0.18	0.020	1.0000	50
4	2	4	0.06	0.18	0.020	1.0000	50
5	2	5	0.04	0.12	0.015	1.0000	50
6	3	4	0.01	0.03	0.010	1.0000	50
7	4	5	0.08	0.24	0.025	1.0000	50

4.2 Results and comments

Five studied cases have been discussed as follows:

Case 1: The FLP technique is applied for the initial condition considering only the minimization of real power losses (Eqn. (1)) as an objective function.

Case 2: The MFLP technique is applied for maximizing the reactive power reserve of each generation unit, individually. Two objective functions are considered as constraints

(Eqs (1) and (17)).

Case 3: The MFLP technique is applied for maximizing the reactive power reserve of all generators except slack bus. Two objective functions are considered as constraints (Eqs (1) and (18)).

Case 4: The MFLP technique is applied for maximizing the reactive power reserve of switchable buses. Two objectives are considered as constraints (Eqs (1) and (19)).

Case 5: The MFLP technique is applied for maximizing preventive action of all generation units and switchable buses. Three objective functions are considered as constraints (Eqs(1), (18) and (19)).

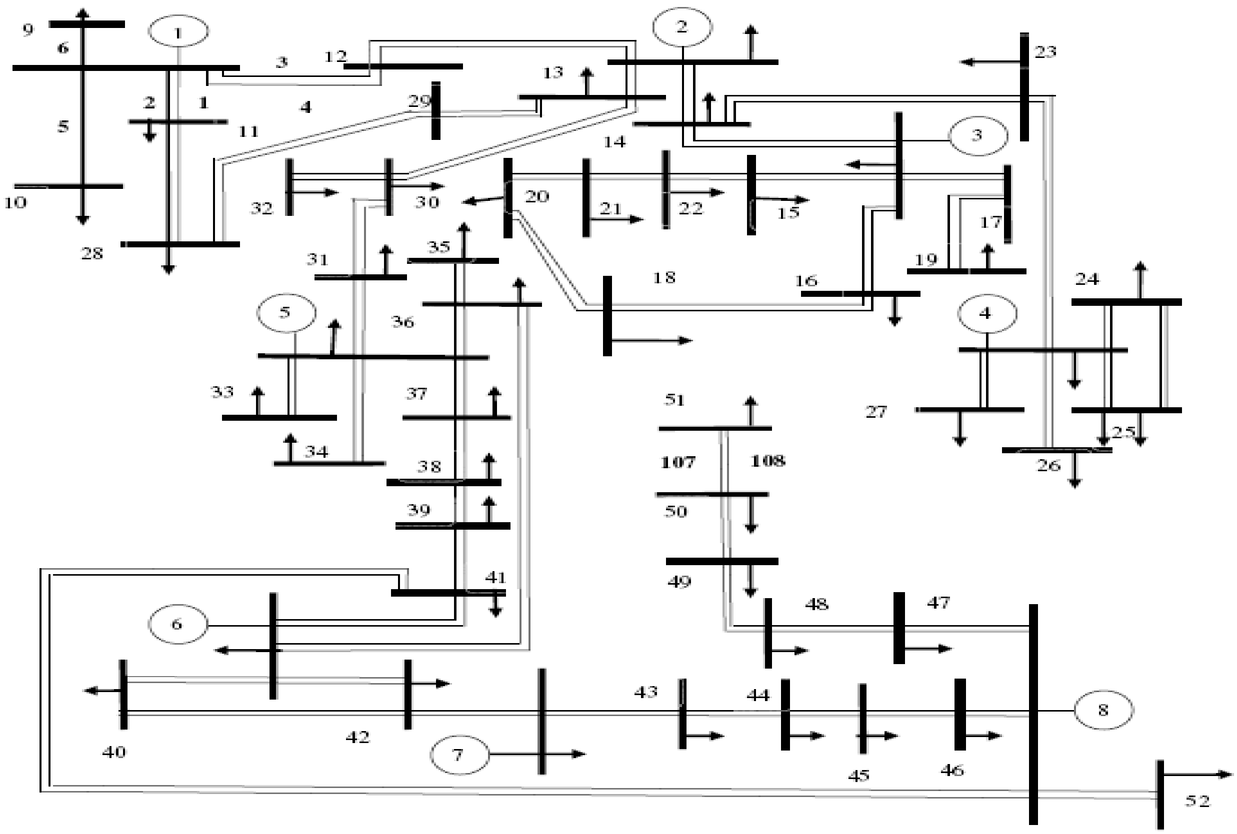

Figure 6: Single *line diagram for the 52-bus actual system of West-Delta region [29].*

4.2.1 5-bus system

Table 3 shows the results of the FLP technique (case 1) for the initial case of 5-bus test system and the MFLP technique for the other cases 2, 3, 4 and 5. However cases (2-A)-(2-B) represent the maximal effect of the preventive actions for maximizing the reactive power reserve for generators 2-5, respectively while, all the system constraints are satisfied. All the values in the table are per unit. In case 1, the real transmission losses are decreased from 6.6 MW to 4.32 MW by reduction percentage 34.5185%. In cases (2-A)-(2-B), the max Q_{res} has more reactive reserve for generators 2 and 5 compared with the FLP technique (case 1). However, the real power losses are slightly increased to 4.72 MW and 4.67 MW, respectively. In Case 3, the two generators 2-5 have more reactive power reserve compared with the FLP technique (case 1) while the real power losses are slightly increased to 4.62 MW with reduction percentage 30.023%. Also, the total reactive power reserve of all generators is maximized to 1.6535 p.u compared to all other cases. In case 4, the maximum reactive power reserve at switchable buses is achieved to 0.3986 p.u compared with all other cases. However, the real power losses are slightly increased compared with the FLP technique (case 1) to 4.47 MW with reduction percentage 32.3498%. In case 5, the reactive power reserve at generator 5 and switchable buses are increased. However, the real power losses are slightly increased compared to the FLP technique (case 1) to 4.42 MW with reduction percentage 32.9755%. While, the reactive power reserve at generator 2 isn't increased.

Table 3: *The maximization of reactive power reserve for 5-bus system*

	Initial case	**case 1**	**case 2-A**	**case 2-B**	**case 3**	**case 4**	**case 5**
QG_1	1.1554	0.3247	0.6386	0.5983	0.7589	0.3856	0.5602
QG_2	0.3670	0.4236	-0.1211	0.6415	0.0678	0.5721	0.5652
QG_3	1.2838	1.3438	1.5026	0.8687	1.1197	1.3912	1.0371
QS_3	1.1554	0.6441	0.7342	0.6361	0.8000	0.3986	0.5778
t_{3-4}	1.0000	1.0526	1.0526	1.0526	1.0526	1.0526	1.0526
Power losses	0.0660	0.0432	0.0472	0.0467	0.0462	0.0447	0.0442
% power losses Reduction		34.518	28.4837	29.3018	30.023	32.3498	32.9755
Total QG Reserve	0.7938	1.5079	1.5798	1.4916	1.6535	1.2511	1.4375

4.2.2 West Delta region system

Similar results have been obtained for West Delta region system. Table 4 and 5 represent the results of the FLP technique (case 1) for the initial case of West Delta region system and the MFLP technique for the other cases 2, 3, 4 and 5. However cases (2-A)-(2-B)-(2-C)-(2-D) represent the maximal effect of the preventive actions for maximizing the reactive power reserve for generators 4-5-7-8, respectively while, all the system constraints are satisfied. All the values in the table are per unit. The Newton Raphson load flow results are shown in Table 4 and 5 as the initial case. Load voltages at buses 18, 20 and 21 are violated. In case 1, the real transmission losses are decreased from 18.08 MW to 15.58 MW by reduction percentage 13.8335%. In cases (2-A)-(2-B)-(2-C)-(2-D), each selected generator has a maximal reactive power reserve compared to its value in the FLP technique (Case 1). However, the real power losses are slightly increased. Case 2-C gives the same solution of Case 1. In case 3, the reactive power reserve of all generators approximately except slack bus is maximized compared to the FLP technique (Case 1) while the real power losses are slightly increased to 16.28 MW with reduction percentage 9.9393%. Also, the total reactive power reserve of all generators is maximized. In case 4 and 5the real power losses are more increased compared to all other cases to 0.1717 MW and 0.1735 MW with reduction percentage 5.0244% and 4.0395%, respectively while, maximizing the reactive power reserve at switchable buses is achieved in case 4 and at all generators in case 5.

Table 4: *The maximization of reactive reserve of cases 1, 2 and 3 for West Delta system*

Variables	**Initial case**	**case 1**	**case 2-A**	**case 2-B**	**Case 2-C**	**case 2-D**	**case 3**
QG_1	0.6334	0.2988	0.2354	0.2354	0.2354	0.2988	0.2659
QG_2	-0.3790	0.1182	0.2779	0.2779	0.2779	0.1182	0.121
QG_3	0.8700	0.1692	0.1584	0.1584	0.1584	0.1692	0.1263
QG_4	0.9766	0.8565	0.8009	0.8009	0.8009	0.8565	0.8268
QG_5	0.3247	0.5408	0.3880	0.3807	0.3903	0.5408	0.4084
QG_6	0.7467	0.3974	0.4489	0.4829	0.4521	0.3974	0.357
QG_7	0.9321	0.7687	0.7070	0.6931	0.7039	0.7687	0.6195
QG_8	0.1697	0.2988	0.3626	0.3497	0.3604	0.2988	0.3368
QS_{18}	0.0000	0.1827	0.0000	0.0000	0.0000	0.1827	0.3199
QS_{20}	0.0000	0.3697	0.4575	0.4575	0.5000	0.3697	0.3199
QS_{42}	0.0000	0.0520	0.1945	0.1900	0.1934	0.0520	0.4256
t_{4-25}	1.0000	0.9950	0.9570	0.9550	0.9550	0.9950	0.9750
t_{11-28}	1.0000	0.9950	1.0144	1.0150	1.0150	0.9950	1.0147
vl_{18}	0.9313 *	1.0259	1.0080	1.0080	1.0080	1.0259	1.0405
vl_{20}	0.9191 *	1.0315	1.0222	1.0222	1.0222	1.0315	1.0407
vl_{21}	0.9252 *	1.0214	1.0125	1.0125	1.0125	1.0214	1.0304
Power losses	0.1808	0.1558	0.1631	0.1631	0.1631	0.1558	0.1628
% Power Losses Reduction		13.8335	9.7775	9.7631	9.8081	13.8335	9.9393
Total QG Reserve	16.9758	17.8066	17.8708	17.871	17.8706	17.8016	18.1883

* indicates to the violation of a variable

Table 5: *maximization of reactive reserve of cases 4 and 5 for West Delta system*

Variables	Initial case	case 1	case 4	case 5
QG_1	0.6334	0.2988	0.2673	0.2766
QG_2	-0.3790	0.1182	0.1884	0.1717
QG_3	0.8700	0.1692	0.8120	0.8134
QG_4	0.9766	0.8565	0.7708	0.7802
QG_5	0.3247	0.5408	0.4378	0.4067
QG_6	0.7467	0.3974	0.4956	0.5100
QG_7	0.9321	0.7687	0.7456	0.7672
QG_8	0.1697	0.2988	0.4410	0.4361
QS_{18}	0.0000	0.1827	0.0000	0.0000
QS_{20}	0.0000	0.3697	0.0000	0.0000
QS_{42}	0.0000	0.0520	0.0000	0.0000
t_{4-25}	1.0000	0.9950	0.9600	0.9750
t_{11-28}	1.0000	0.9950	1.0250	1.0250
vl_{18}	0.9313 *	1.0259	0.9724	0.9708
vl_{20}	0.9191 *	1.0315	0.9613	0.9596
vl_{21}	0.9252 *	1.0214	0.9674	0.9657
Power losses	0.1808	0.1558	0.1717	0.1735
% power losses Reduction		13.8335	5.0244	4.0395
Total QG Reserve	16.9758	17.8016	17.0914	17.0882

From these tables, the system operators can choice between taking more the preventive control actions from all system generation units or from switchable buses or from both of them, simultaneously.

5. Conclusions:

This paper presents an efficient procedure for the management of reactive power reserve using the MFLP technique in order to minimize the real power losses with enhancing the voltage security at all buses to overcome any emergency may occur in power system. The MFLP technique is successfully applied to achieve multi objective functions, which are required to obtain the optimal reactive power reserve in power system. When the optimal reactive power reserves are prepared, there are different constraints can be increased to avoid any emergency condition and to push the system to the normal state. With the use of the MFLP technique, a fine tuning of power system variables is valid and the objectives can be treated as constraints. Therefore, the proposed procedure allows the system operator to solve the emergency condition problem with minimum increase of real power losses.

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