Optimal Reactive Power Flow using Fuzzy logic Controller Technique

T.Hariharan and Dr.M.GopalaKrishnan

Abstract: **Optimal reactive power flow is an optimization problem with one or more objective of minimizing the real power losses. The ancillary service for a generator has two components that have been recently recognized, i.e., one for sustaining its own real power communication and the other for providing reactive demand, enhancing system security, and scheming system voltage; and that only the next part should get financial compensation in aggressive power markets. In this paper planned incorporated technique will be united with fuzzy logic controller. This paper discusses the estimation of post-outage reactive power generation and flows using Linear estimation method for deregulated power system. One of the knowledge base intelligence techniques which will be utilized for verifying the generator reactive power operating limits and the power loss was the fuzzy logic. Representative results are presented using the IEEE 14 bus system by using MATLAB working platform and the ORPF presentation will be estimated.**

Keywords: **Optimum Reactive Power Flow (ORPF), Linear Estimates, Fuzzy Logic Controller (FLC)**

I. INTRODUCTION

Traditional power system security analysis includes the simulation of static as well as dynamic performance of a power system in response to a list of possible disturbances. In fact, in the vertically integrated utility structure and the competitive environment, the distribution entities have the obligation to serve all consumers at all times, i.e., provide a reliable service to all the loads. Operational reliability is normally checked using contingency analysis. Contingencies include the outage of system components and abrupt changes in loads.

The use full Newton power flow [1] for contingency analysis is Computationally expensive. To speed up the computations, fast approximate power flow methods were proposed, such as the decoupled power flow [2,3] and the iterative linear AC power flow [4].

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In the estimation of reactive power outputs and flows, the explicit consideration of reactive power limits is very important [5]. The estimation methods based on distribution factors and optimization discussed in the literature ignore equipment limits, thus increasing the estimation error [6]. An innovative, optimization-based method for post-line outage reactive flow and voltage computation is presented in [7].In this paper, the use of sensitivities for the estimation of post-contingency reactive generation and flows is discussed. No decoupling assumption is made in the derivation of the sensitivities. However, the method is flexible and the incorporation of decoupling is straightforward. Multiple outage contingencies and the redistribution of generation after a generation outage are easily handled. Employing linear estimates, the effect of devices' limits on the estimates is effectively captured. Representative results are presented on the IEEE 14 -bus test system. The numerical results show that by taking into account equipment limits, the estimation errors are significantly reduced.

II. POWER FLOW BACKGROUND

Consider an **N**-bus power system characterized by the admittance matrix **Y**. The *i, j* element Y_{ij} of **Y** is given by

$$Y_{ij} = -yij, i \neq j \quad (1)$$

$$Yii = \sum_j y_{ij} + y_{ig} \quad (2)$$

Where y_{ij} is the admittance of the line between buses *i* and *j*, and is the ground admittance of bus *i*. We denote the total active power generation and the total active load at bus *i* by P_i^g and P_i^l ,respectively, and their reactive power counterparts by Q_i^g and Q_i^l .The load terms P_i^l and Q_i^l are assumed to be fixed. The net power injections at bus i in terms of the load and generation are

$$P_i = P_i^g - P_i^l \quad (3)$$

$$Q_i = Q_i^g - Q_i^l \quad (4)$$

The net power injections at bus i satisfy [1]

$$P_i = \sum_{j=1}^{N} V_i V_j [G_{ij} \cos(\theta_i - \theta_j) + B_{ij} \sin(\theta_i - \theta_j)] \quad (5)$$

$$Q_i = \sum_{j=1}^{N} V_i V_j [G_{ij} \cos(\theta_i - \theta_j) - B_{ij} \sin(\theta_i - \theta_j)] \quad (6)$$

Where θ_i and V_i are the bus *i*'s voltage phase angle and magnitude, respectively.

The reactive power produced or consumed by a generator is limited, and depends on the active power being produced [5]. Assuming there is one generator at bus, and denoting the upper and lower limits for the reactive power generation by $\overline{Q_i^g}(P_i^g)$ and $\underline{Q_i^g}(P_i^g)$, respectively, the reactive power output is constrained by

$$\underline{Q_i^g}(P_i^g) \le Q_i^g \le \overline{Q_i^g}(P_i^g). \tag{7}$$

Let V_i^{sp} be the specified at the PV bus i. If $Q_i^g = \overline{Q_i^g}(P_i^g)$ then $V_i \le V_i^{sp}$, and we call the bus *max VAr constrained*. If $Q_i^g = \underline{Q_i^g}(P_i^g)$, then $V_i \ge V_i^{sp}$ and we call the bus *min VAr constrained*.

The vector **x** is constructed with the voltage angles of the PV and PQ buses, and the voltage magnitudes of the PQ buses, and the vector $\tilde{x}$ is constructed with the voltage angles and magnitudes of all buses. Let $f(\tilde{x})$ be the vector of the PQ and PV buses' active power injections, and the PQ buses' reactive power injections, both as explicit functions of $\tilde{x}$. Let f^{sp} be the vector with the specified values for $f(\tilde{x})$. The power flow problem is to obtain $\tilde{x}$ such that

$$f(\tilde{x}) = f^{sp} \tag{8}$$

In the solution of the power flow problem, the Jacobian

$$J := \frac{\partial f(\tilde{x})}{\partial x} \tag{9}$$

is used.

The *full Jacobian J* is defined as

$$\tilde{J} := \frac{\partial \tilde{f}(\tilde{x})}{\partial \tilde{x}} \tag{10}$$

The power $S_{ij}=P_{ij}+jQ_{ij}$ flowing from *i* bus on the line that connects buses *i* and *j* is given by

$$P_{ij} = \sum_{j=1}^{N} V_i V_j [G_{ij}\cos(\theta_i-\theta_j) + B_{ij}\sin(\theta_i-\theta_j)] - V_i^2(G_{ij} - g_{ijg/2}) \tag{11}$$

$$Q_{ij} = \sum_{j=1}^{N} V_i V_j [G_{ij}\sin(\theta_i-\theta_j) - B_{ij}\cos(\theta_i-\theta_j)] - V_i^2(B_{ij} - b_{ijg/2}) \tag{12}$$

The focus of this paper is the estimation of post-contingency reactive power outputs Q_i^{gc} and flows Q_{ij}^c. The computation of these quantities under different contingencies requires the solution of (8) under each contingency.

III. LINEAR ESTIMATES

We linearly parameterize the occurrence of a contingency using the parameter K. Hence, we let all the quantities defined the previous Section be functions of K. Since the parameterization is linear, the specified quantity changes are proportional to changes in K. Consider, for example, the outage of the load and generation at bus *j*, and let K change from K^O to K^C. Then $P_j(K^O)$ and $Q_j(K^O)$ take their pre-contingency values P_j^O and Q_j^O, and the post-contingency values are $P_j(K^c)=0$ and $Q_j(K^c)=0$. For $K^O<K<K^c$

$$P_j(K) = (K^C-K)P_j^O$$

and $$Qj(K) = (K^C-K)\,Q_j^O.$$

The net active power injections at PV and PQ buses do not change with the contingency, and so $P_i(K) = P_i^O$ Also, the net reactive power injections PV at PQ buses do not change with the contingency, and so $Q_i(K) = Q_i^O$. we can obtain Q_i^g and Q_{ij} as functions of K for $K^O< K <K^c$. We use the Taylor series of these functions to express the post-contingency reactive power output Q_i^{gc} and the flow Q_{ij}^c as

$$Q_{ij}^c = Q_{ij}^o + \frac{dQ_{ij}}{dK}\Delta K + h.o.t \tag{13}$$

$$Q_i^{gc} = Q_i^{go} + \frac{dQ_i^g}{dK}\Delta K = h.o.t \tag{14}$$

Where we denote pre-contingency quantities with a superscript o. Whenever ΔK is sufficiently small, the h.o.t. can be neglected to obtain approximate values of Q_i^{gc} and Q_{ij}^c. To give K a physical interpretation, in the remainder of the paper we set K before the contingency equal to 0 and after the contingency equal to 1, so that $\Delta K=1$ for the occurrence of the contingency.

A. *Load and Generation Contingencies*

Consider contingencies where a change in K implies a change in the active and or reactive power injections/withdrawals, including generator and load outages. Using (4), the derivatives in (13)–(14) are

$$\frac{dQ_{ij}}{dK} = \nabla_X Q_{ij} \cdot \frac{dx}{dK} \tag{15}$$

$$\frac{dQ_i^g}{dK} = \nabla_X Q_i^g \cdot \frac{dx}{dK} + \frac{\partial Q_i^g}{\partial K}$$

$$= \nabla_X Q_i \cdot \frac{dx}{dK} + \frac{\partial Q_i}{\partial K} + \frac{\partial Q_i^l}{\partial K}. \tag{16}$$

The elements of $\nabla_X Q_{ij}$ are computed using (12). The gradient $\nabla_X Q_i$ is obtained from the full Jacobian.

The differential change in K leads to a differential change in the system state x. Changes in the system state are subject to (5) and (6), which in a differential sense are reduced to

$$df = Jdx \tag{17}$$

Thus

$$\frac{dx}{dK} = J^{-1}\frac{df}{dK} \tag{18}$$

In practice, for computational efficiency reasons (dx/dK) is obtained directly using factorization methods. Note that when the contingency involves the outage of generator *p*, there is a change in the reactive generation at bus. For this change to be enforced, bus *p* needs to be modeled as a PQ bus for the purpose of the computation of (dx/dK).

Under these circumstances, the term $(\partial Q_p/\partial K)$ of (16) takes into account the reduction of reactive power generation at bus *p*. The term $(\partial f/\partial K)$ is the rate of change of real and reactive power injections with respect to a change in K, and is known for a specified contingency. For example, if after the contingency

- real load increased an amount k_i at bus *i*;
- reactive generation remained constant at bus j;
- active generation at bus *h* decreased by k_h; then

$(\partial P_i/\partial K)=-k_i$, $(\partial Q_j/\partial K)=-k_i$, and $(\partial P_h/\partial K)=-k_h$. Thus, the sensitivities in (16)–(18) can be computed for any change in load and corresponding generation response. Replacing (15)–(16) and (18) in (13)–(14), and neglecting the *h.o.t.*, we obtain

$$Q_{ij}^{c} \cong Q_{ij}^{o} + \nabla_X Q_{ij}.J^{-1}\frac{df}{dK} \qquad (19)$$

$$Q_i^{gc} \cong Q_i^{go} + \nabla_X Q_i.J^{-1}\frac{df}{dK} + \frac{\partial Q_i}{\partial K} + \frac{\partial Q_i^l}{\partial K}. \qquad (20)$$

Note that the linear estimation of all the desired quantities requires the solution of only one linear system of equations, (20). If the decoupling *P-V* and *Q-θ* of and holds, this linear system of equations can be decoupled into two subsystems, improving the solution speed. The linear estimates (19)–(20) have been applied to a variety of power systems problems.

IV. FUZZY LOGIC CONTROLLER

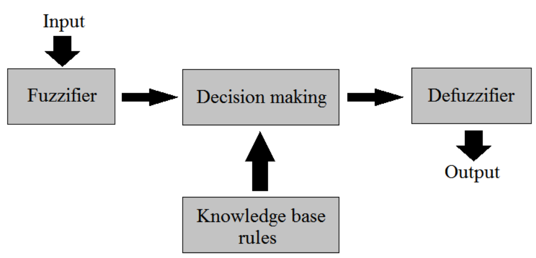

Figure.1. Structure of the proposed FLC

Fig 1 shows the structure of fuzzy logic controller. In this proposed system, the real power is the physical input of the fuzzy logic and the rules are generated depending on the real power input. The fuzzy rules has been generated by the three categories i.e., low, medium and high. These rules are used to assign the generator reactive power generation. In this generation limit is given to the optimization algorithm, it can be provide the minimized power loss of the system.

V. RESULTS AND DISCUSSION

The schemes presented have been applied to the estimation of post-contingency reactive power outputs and flows in various test systems. In this paper, representative results on the IEEE 14 -bus test system shown in fig.2 are presented to illustrate the capabilities of the proposed methods. The results for two contingencies for each test system are presented in detail. These contingencies have been chosen to allow the quick comparison of the results with other estimation methods in the literature. All generation limits are explicitly considered. Matlab and Power System Toolbox 2.0 were used in the implementation of the estimation methods.

For the IEEE 14-bus test system, the outages of line 2–4 and transformer 5–6 are presented in detail. The estimations were done using (19)-(20). The post-outage reactive power Outputs and flows are in Tables I and II, respectively. The outage of line 2–6 does not result in any generator becoming constrained.

TABLE I. POST-OUTAGE MVAR GENERATION FOR IEEE 14-BUS TEST SYSTEM

Line and Direction	Outage of Line 2-6		Outage of Transformer 4-7	
	Exact	Linear	Exact	Linear
1-2	-16.95	-16.83	-21.46	-20.93
1-5	6.18	5.54	1.30	-0.82
2-3	2.18	1.93	3.30	3.37
2-4	0.00	0.00	-1.48	-5.07
2-5	-0.36	-1.32	-1.22	-3.86
3-4	2.30	1.70	3.77	0.17
4-5	23.10	22.67	8.42	12.07
4-7	-12.13	-11.95	-4.83	-10.38
4-9	-1.37	1.30	3.22	-1.80
5-6	9.24	9.58	0.00	0.00
6-11	4.03	3.96	5.39	10.71
6-12	2.53	2.52	3.26	3.95
6-13	7.48	7.44	7.85	10.58
7-8	-19.87	-19.67	-21.52	-12.29
7-9	6.08	6.08	10.26	-2.80
9-10	3.82	3.88	4.90	-3.68
9-14	3.36	3.40	3.88	-1.69
10-11	-2.00	-1.94	-1.76	-9.67
12-13	0.78	0.77	1.59	2.29
13-14	1.99	1.94	3.53	7.17

TABLE II. POST OUTAGE MVAR FLOWS

Bus	**Outage Of Line 2-6**		**Outage Of Transformer 4-7**	
	Exact	**Linear**	**Exact**	**Linear**
1	-10.77	-11.29	-20.16	-21.75
2	36.38	34.83	42.82	35.72
3	29.28	28.30	25.37	21.48
6	17.15	16.64	24.00	32.73
8	20.49	20.27	22.25	12.48

The estimates are extremely accurate in this case. The average reactive generation absolute errors are reduced by 97% and 93%, respectively, compared to other technique. The reasons for the accuracy improvement is that we use exact sensitivities, while in there are approximations involved in the computation of the sensitivities. Generator 6 becomes max VAr constrained with the outage of transformer 4-7. Fig.3.shows that at K=0.51, i.e., the flows on transformer 4-7 are reduced by 51%, generator 6 becomes constrained. This is indicated with a O. Thus, for K > 0.51 the reactive output at bus 6 is fixed and the voltage magnitude at bus 6 decreases. The estimated K -distance to the change in status, indicated by *, is K=0.57.In any case, the average reactive flows absolute errors with the linear estimates are reduced by 37% and 85% respectively.

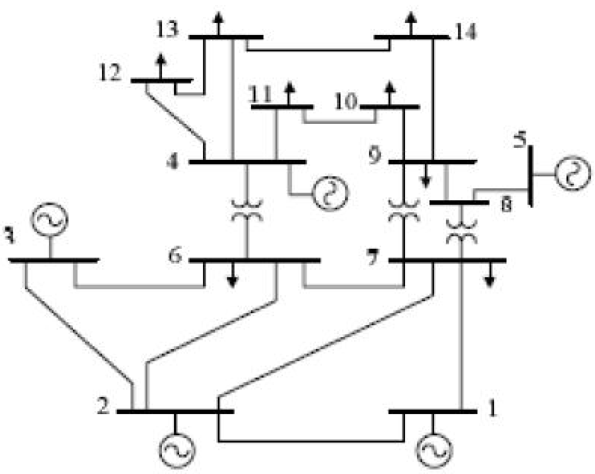

Figure.2. IEEE 14 bus system structure

In the IEEE 14-bus test systems, 23 contingencies were simulated. These consisted of all line and generation outages except for those resulting in load shedding. A summary of the estimation errors is presented in Table III, with the errors defined as the absolute value of the difference between the exact value and the estimated one. Note that the linear estimates are significantly more accurate for all three estimated quantities for IEEE 14-bus test system. For the linear estimation methods, the mean errors obtained are extremely small compared to the results presented in the literature.

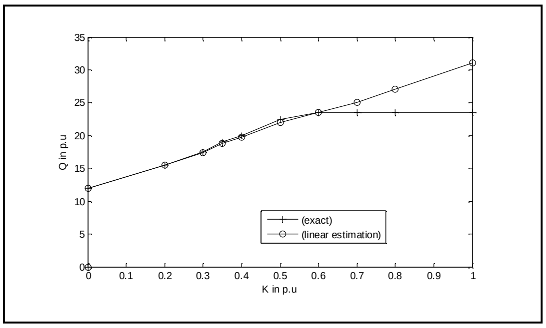

Figure. 3: Reactive power generation at bus 6 as a function of the per unit reduction in power flow.

The high maximum errors occur in few contingencies which lead to significant changes in the system, and in devices very close to those outaged. In these cases, V_i , Q_i^g and Q_{ij} are highly nonlinear functions of K, and so first-order estimates are not very accurate. For example, the maximum reactive power output error of 21.54 MVAr in the 14-bus test system occurs on generator 2 in the estimation of the effect of the outage of the slack generator 1. Generator 2 is the new slack generator for that contingency, and its post-contingency active power generation is 220MW higher than its pre-contingency active power output, a 570% increase. For the 14-bus test system, the total computation time was 43% of that taken by running power flows for the linear estimation method.

TABLE III. SUMMARY OF ESTIMATION ERRORS FOR IEEE 14-BUS TEST SYSTEM

Method	**Linear Estimation**		
Error	**Mean**	**St Dev**	**Max**
Gen[Mvar]	1.64	3.75	21.54
Flow[Mvar]	0.88	3.10	61.58

VI. CONCLUSION

The estimation of post-contingency reactive power generation and flows using sensitivities has been discussed. A linear estimation method and fuzzy logic controller has been proposed to capture the effect of equipment limit activation/deactivation on the estimates. The method is flexible and allows the representation of all type of contingencies. Representative results on the IEEE 14 bus test systems show that the estimation errors are significantly reduced with the proposed method, compared to the methods in the literature.

The estimation method proposed is useful in system reliability planning and operations, where contingency studies are intensively done.

Other direction for future work in the area is the comparison of the estimation accuracy using sensitivities with respect to flows and with respect to network admittances, for branch outage studies.

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