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Varying Load Voltage Magnitude Impacts on Fault Level Constrained Optimal Power Flow

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ABSTRACT *:* *This paper mainly deals with OPF with fault level constraints (FLC) by using an iterative process. The OPF is to provide solutions in conditions where fault current levels at buses are within the specifications of switchgear. The aim of this paper is to consider the impacts of varying load voltage magnitudes to the bus impedance. This is done by formulating the bus impedance as a function of varying load voltages. FLC-OPF calculation was implemented by MATPOWER with corresponding modifications on its library source codes to cater non-linear constraints. The results showed that as FLC-OPF was imposed, the formulation considering the impact of varying voltage magnitude on the bus impedance have a better performance compared when the bus impedance is not considered to be a function of load voltage magnitude.*

Keywords - *Fault current, fault level constraints, MATPOWER, optimal power flow, voltage magnitudes*

I. INTRODUCTION

In recent years, the demand for electrical power has been increasing rapidly. Although this means adding of new generation and transmission, many researchers suggested that in the long run it will be more efficient if the increase in the generation capacity of the system will be integrated into the already existing electrical network [1-2]. For this kind of problem, the best solution is Optimal Power Flow (OPF). In an OPF problem, rather than just power flows, the optimal allocation of new generation capacity is determined to predefined connection points. Specifically, it aims to minimize the generation cost subject to demand constraints and the network physical constraints. This is how OPF had been used through the years. With this, we eliminate the need to install new generation units, which requires more intensive planning, hindered by environmental concerns, and may bring the network closer to its operational limits [3].

Furthermore, instead of just using OPF as an operation planning tool, it can be used as a generation planning tool that determines optimal locations and capacities of new generators that satisfy network constraints. The limits imposed by these constraints are crucial for system security. Such constraints include bus voltage limits, line thermal limits, and stability limits. Now as we desire for increased generation capacity, corresponding transmission expansion takes place. From the viewpoint of AC system analysis, transmission expansion causes the reduction in the magnitude of Thévenin impedances at important nodes in the load center. The reduction of Thevenin impedances, however, may result in the increase in short-circuit fault current level. If the fault currents at some locations are much greater than the breakable current level of the equipped circuit breakers, the section experiencing the applied faults might not be isolated and the circuit breakers can be thermally damaged. This led us to add the fault level constraints to the OPF as imposed by the circuit breakers. Hence, the Fault Level Constrained OPF (FLC-OPF). The FLC-OPF might enable the system operator to utilize the existing network infrastructures without sacrificing the investment condition for new generation.

In optimal power flow solution procedure, this paper deals with the formulation to consider the impact of varying load voltage magnitude which has effect on the calculation of the bus impedance. The formulation was implemented based on the fact that the bus impedance matrix can change as voltage varies because the load needs to be converted into the impedance for the procedure of bus impedance matrix construction for fault analysis and the corresponding bus voltage is involved in the conversion. Then the motivation of the study is that considering more accurate load impedance leads the better solutions in FLC-OPF. This paper reports the impacts before and after considering voltage magnitude on FLC-OPF solutions. The OPF function of MATPOWER[4] was utilized in order to implement the new formulation in this paper.

II. FLC-OPF

OPF is the process of dispatching the electric power system variables in order to minimize an operation criterion, while attending load and feasibility [2]. The unique feature of an OPF is that certain costs can be minimized while functional constraints such as line-flow voltage limits are respected [5-7]. The control variables, which are regulated during optimization, are usually the ones at the disposal of system operators. In this paper, we considered the generator active power as the control variables.

For the FLC-OPF problem, the fault level constraints are incorporated into the formulation and one of them can be expressed as follows:

$$\left|\frac{V_i}{Z_{ii}}\right| \le I_{CBi,\max} \tag{1}$$

where V_i is the voltage magnitude at bus *i* before the fault is applied; Z_{ii} is the Thévenin impedance at the faulted location; and $I_{CBi,\max}$ is the maximum fault current of the circuit breaker at bus *i*.

Z_{ii} is a function of the load voltages in the system, because in fault analysis, the equivalent load admittances are calculated from the constant power loads by dividing the corresponding voltage magnitude. The impact of changing voltage magnitudes on Thévenin impedance needs to be considered for more exact FLC-OPF calculation. The relation of Z_{ii} before and after switching on the load at bus *j* can be shown below:

$$Z_{ii,after} = Z_{ii,before} - \frac{Z_{ij}Z_{ji}(P_j - jQ_j)}{V_j^{\,2} + Z_{jj}(P_j - jQ_j)} \tag{2}$$

where $Z_{ii,before}$ and $Z_{ii,after}$ are Z_{ii} before and after switching on the load at bus *j*. In (2), V_j is the load voltage at bus *j*. Z_{ij} is the (*i*, *j*) component of bus impedance matrix before modification; P_j and Q_j are the active and reactive power consumed by the load *j*.

MATPOWER is an open source Matlab based power system simulation package consisting of a set of Matlab m-files designed to give the best performance possible while keeping the code simple to understand and customize [4]. MATPOWER implements OPF by minimizing the generating costs subjected to power line flows and voltage limits. This study aims to add within MATPOWER's OPF functions the fault level constraints. This is done by revising the commands and corresponding algorithms in the MATPOWER file library. Specifically this includes the adding of the fault level constraints with its corresponding functions and revising the Jacobian and Hessian formulations.

III. RESULTS AND SIMULATIONS

This section describes the comparison of the performance of FLC-OPF with and without considering the impact of varying load voltages using the implemented FLC-OPF. The test system is the modified 23-bus system. Figure 1, 2, and 3 shows the comparison of their performance in terms of objective function value, feasibility error and optimality error as we increase the value of the FLC imposed. The choice of the starting value of 42 pu. is the minimum FLC that can be imposed to Bus 1, otherwise the solution diverges.

As seen from the figures, the performance of the formulation considering the effect of varying load voltages on the bus impedance is better than the performance without considering the effect of varying load voltages especially on the feasibility and optimality errors. In the simulation, the performance of our formulation was evaluated by imposing FLC on load buses simultaneously. The chosen load buses are bus 5, 6, 9, 11, and 18. It is noted that the load voltage magnitude becomes the bus voltage itself and therefore gives a significant impact on the bus impedance as given in (7). Table 1 summarizes the results of five cases. This is in ascending FLC value imposed.

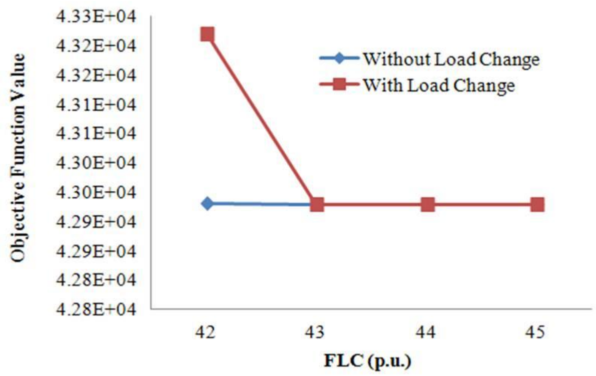

Fig. 1. Comparison of objective function values

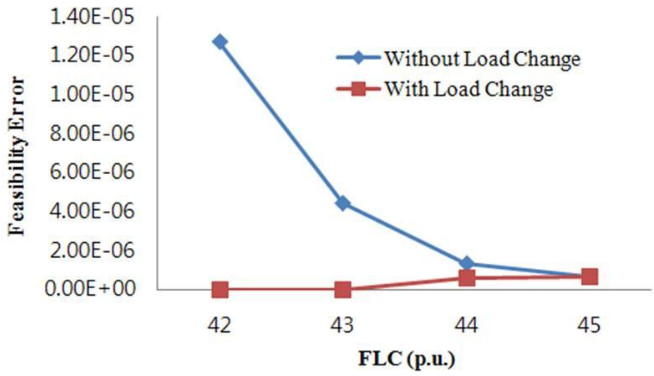

Fig. 2. Comparison of feasibility errors

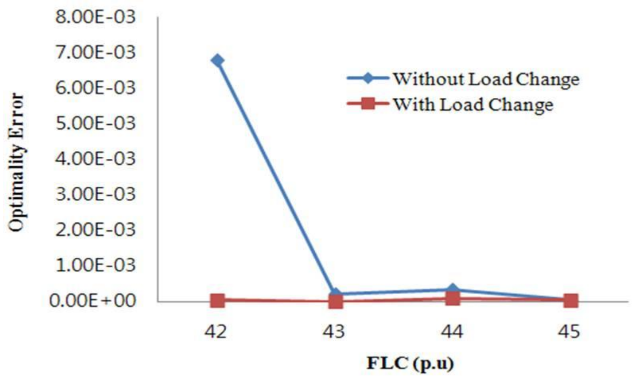

Fig. 3. Comparison of optimality errors

Table 1. FLC imposed on load bus at each case

Case No.	Bus 5 (FLC pu)	Bus 6 (FLC pu)	Bus 9 (FLC pu)	Bus 11 (FLC pu)	Bus 18 (FLC pu)
Case 1	48	55	43	57	45
Case 2	49	56	44	58	46
Case 3	50	57	45	59	47
Case 4	51	58	46	60	48
Case 5	52	59	47	61	49

The choice of the starting per-unit values on case 1, are also the most conservative FLC values that can give OPF solution to our test system. The performance with and without considering load voltage change on this five case are compared in terms of objective function value, feasibility error and optimality error, as in the following figures.

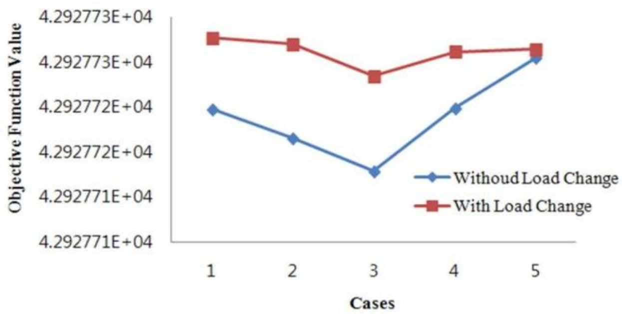

Fig. 4. Comparison of objective function values

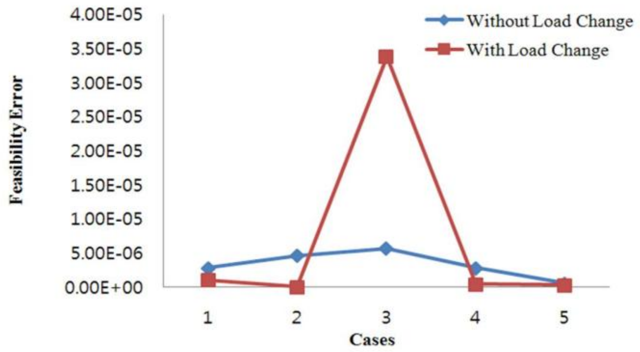

Fig. 5. Comparison of feasibility errors

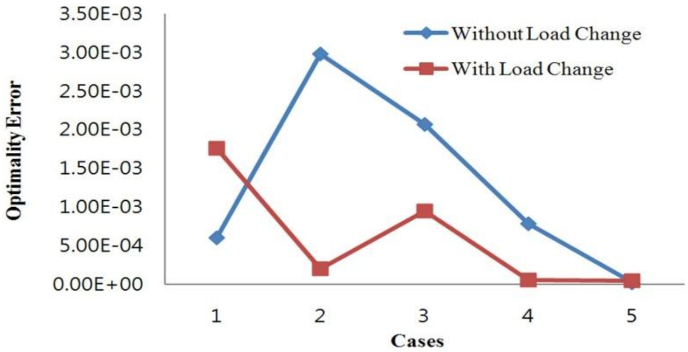

Fig. 6. Comparison of optimality errors

With regards to the objective function value comparison shown in figure 4, the difference between the two approaches is almost negligible. The feasibility shows a bigger difference between the two approaches. The performance of considering load voltage change on the feasibility error, figure 2, is better compared when load voltage change is not considered, although in case 3 the feasibility error of considering load voltage change is larger. The best performance of our formulation is on the feasibility error wherein it gives a much smaller amount, almost zero, compared when the load voltage change is not considered as seen on figure 6.

FLC-OPF calculation showed a good performance using our formulation considering the impacts of varying load voltages to the bus impedance. Our formulation did consistently better performance on non-load buses as shown on figures 3, 4, and 5. When imposing the FLC on load buses, its best performance is on the optimality error, where it gave much smaller values of almost zero compared when the load voltage changes is not considered. It is therefore imperative to say that in optimal power flow solutions constrained by fault level limits, the consideration of the load voltage magnitude impacts on the bus impedance is significant, especially when the faulted bus is a load bus. The formulation shows this relationship wherein the bus impedance is a function of load voltage magnitude. Correspondingly the change in bus impedance affects the fault level, the higher the bus impedance the lower the fault current is.

IV. CONCLUSION

Based on the results, the FLC-OPF considering the impacts of varying load voltage magnitude was implemented to minimize the generation costs while satisfying the line power flow, voltage and the fault level constraints, as an added feature. This paper describes the formulation to consider the impacts of voltage magnitudes on fault level constraints in OPF. The performance of the FLC-OPF considering voltage magnitudes impacts had shown to be better compared when the impact of load voltage magnitude is not considered in the calculation of bus impedance.

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