Turkish Journal of Electrical Engineering and Computer Sciences

Volume 26 | Number 6 Article 30

1-1-2018

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FARID KARBALAEI

SHAHRIAR ABBASI

Turkish Journal of Electrical Engineering & Computer Sciences

http://journals.tubitak.gov.tr/elektrik/

Research Article

Turk J Elec Eng & Comp Sci
(2018) 26: 3156 – 3167
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doi:10.3906/elk-1805-11

L-index based contingency filtering for voltage stability constrained reactive power planning

Farid KARBALAEI[1*], **Shahriar ABBASI**[2]
[1]Faculty of Electrical Engineering, Shahid Rajaee Teacher Training University, Tehran, Iran
[2]Electrical Engineering Department, Faculty of Engineering, Razi University, Kermanshah, Iran

Received: 15.05.2018 • **Accepted/Published Online:** 12.10.2018 • **Final Version:** 29.11.2018

Abstract: One of the most important objectives in reactive power planning (RPP) is maintaining required voltage stability margin under normal and single-contingency situations. For this, an optimization problem must be formulated considering N-1 contingencies constrained for a set of predetermined contingencies. Traditionally, all these contingencies must simultaneously be addressed in the optimization problem. This can dramatically increase the problem dimension and decrease the convergence ability of its solution for large scale applications. This paper uses an L-index based contingency filtering strategy to select a small number of contingencies to be addressed in RPP problem. For this, the predetermined set of all contingencies is divided into some subsets wherein each subset of contingencies affects an especial part of power system. Then, only the worst contingency from each subset is selected and addressed in RPP problem so that the allocated VAr sources can cover all of contingencies. This method reduces the problem dimension and improves convergence ability of its solution for large scale applications, whilst the obtained results are similar to the ones taken from enumeration method of N-1 contingencies. The implemented simulations on the IEEE 39 and 118-bus test systems verify the capability of the proposed method.

Key words: Reactive power planning, VAr planning, voltage stability margin, L-index, contingency filtering

1. Introduction

Reactive power planning (RPP) deals with optimal allocation of new reactive power plants, considering location and size, wherein various objectives may be traced [1]. One of the important objectives is to improve the voltage stability margin with the minimum installation cost of new reactive power sources. Some works try to increase voltage stability margin for the normal state only [2–5], but the others aim to increase the stability margin under the both normal and contingency states of a power network [6–11]. For the sake of simplicity, in [7, 8] only the worst contingency is taken into account, but in [6, 9–11] all contingencies are addressed in the RPP problem.

In [2, 6], the voltage stability margin is not explicitly considered in the RPP problem, and in [3] a multi-objective optimization problem is formulated for RPP, wherein the voltage stability margin is treated as one of the objectives. The other objective is minimization of installation cost of new reactive power plants. In [7, 8], the voltage stability is respected as a constraint in a contingency constrained RPP and the VAr support requirements are determined for the worst contingency. With this determined VAr support, the feasibility of operation for all other contingencies is ensured simultaneously. It has been emphasized that the criterion of a

*Correspondence: F__karbalaei@sru.ac.ir

single worst contingency may not be appropriate for some systems. In [9], the RPP is formulated as a multi-objective optimization problem that voltage stability margin is incorporated as one of the objectives. The other objectives are improvement of voltage profile, minimization of active power losses, and installation cost of new VAr-plants. Static VAr sources (ex. switchable capacitors) are used for normal conditions and dynamic ones (ex. SVCs) are used for contingency cases. In [10], in addition to steady-state voltage instability, voltage dip time duration and maximum transient voltage dip are considered in the RPP problem. It uses the sensitivity information of the above criteria with respect to the reactive devices. The effect of new VAr sources obtained by sensitivity information is checked by using nonlinear simulations. In the method proposed in [11], first an initial VAr planning solution is obtained for each contingency. Then a penalty successive conic programming (PSCP) method is used to successively move the solutions to take a common value.

When RPP problem is formulated under both the normal and contingency states, it is identified as a security-constrained optimal power flow (SCOPF) problem [12]. The SCOPF is classified into two modes: preventive (PSCOPF) and corrective (CSCOPF) [13]. In the CSCOPF, unlike the PSCOPF, the possibility of rescheduling control means in post-contingency states is considered. The major challenge of the SCOPF problem is the size of the problem [14]. Several approaches have been proposed for contingency filtering to reduce the number of contingencies to be included in the SCOPF problem [13, 15–19]. In [13, 15], an iterative approach was proposed to identify the smallest subset of the full contingency set, called binding contingencies, which provides the same optimal objective value as the full set. It is based on the value of the constraint violations in post-contingency states. This approach combines in [16] with a network compression method [20]. The compression method identifies an active region for each contingency based on the variations of nodal voltages and branch power flows in the post-contingency network. In [17], a DC SCOPF approximation is used inside the iterative AC SCOPF algorithm proposed in [13]. In PSCOPF mode, DC SCOPF is used to initially identify the binding contingencies. In CSCOPF mode, that determines the optimal set of corrective actions for each contingency. The algorithm proposed in [18] uses sequentially three filters. The first filter selects all contingencies that do not have a power flow solution. The second filter selects the contingencies that lead to operational constraints violation, and the third one selects the contingencies that lead to the largest reactive power response for each generator. In [21], a simplified model for the SCOPF is proposed to reduce the number of state variables instead of reducing the number of contingencies. In this model, only the variables of pre-contingency state appear and those of post-contingency states are expressed by pre-contingency variables using corresponding sensitivity values.

In the above mentioned papers, the contingency filtering methods are proposed for operation problems. In an operation problem, the objective function is minimized by rescheduling existing control means such as active generator powers, transformer ratios, shunt element reactances, etc. This paper uses L-index to filter contingencies for a voltage stability constrained reactive power planning problem. In a reactive power planning problem, some new reactive power sources (ex. switchable capacitors and/or reactors) are added to the power system. The main objective is to improve the voltage stability margin for contingency states by using the minimum value of new sources. In the proposed method, the predetermined set of all contingencies is divided into some subsets, wherein each subset of contingencies affects an especial part of the power system. Then, only the worst contingency from each subset is selected and addressed in the RPP problem. This method reduces the problem dimension and improves the convergence ability of its solution for large scale applications, whilst the obtained results are similar to ones taken from the enumeration method of N-1 contingencies.

The rest of this paper is organized as follows. The problem formulation is presented in Section 2 followed by some needed concepts explained in Section 3. The simulation results presented in Section 4 verify the capability of the proposed method, and finally the conclusions are drawn in Section 5.

2. Problem formulation

As mentioned several times in this paper, voltage stability constrained RPP problem must be formulated as an optimization problem. Here, we focus on the preventive mode. The objective function is to minimize the installation cost of new VAr-plants (switchable capacitors and/or reactors) as follows:

$$Minimize \sum_{i \in \alpha_L} (C_0 + C_1 Q_{ci}) u_i, \tag{1}$$

where $i \in \alpha_L$ represents the ith load bus, and α_L is the set of all load buses. Q_{ci} is the MVAr capacity of a new VAr-plant at bus i, and u_i is a binary variable that indicates whether or not to install a VAr-plant at bus i. $C_0(\$)$ and $C_1(\$/MVAr)$ are the fixed and unit costs for a VAr-plant, respectively. Installing the new VAr capacities, the required voltage stability margin must be maintained under normal state (without contingency) and when a single contingency from a set of possible contingencies occurred. At all normal and contingency states, subjected constraints and variables can be classified into three categories: the ones related to the base case, the ones related to the voltage collapse point, and the ones related to both the base case and the voltage collapse point. Hereafter, the variables related to the base case and the voltage collapse point are represented by superscripts b_k and c_k, respectively, where k denotes the contingency number. k=0 denotes the normal state. The variables and parameters that have the same values in two situations are shown with a superscript k that represents the contingency number. The variables and parameters that have the same values in all situations and contingencies are shown without superscript.

2.1. Subjected constraints related to both the base case and voltage collapse point

A. Capacity limits of new VAr-plants:

$$0 \leq Q_{ci} \leq Q_{ci}^{max}; i \in \alpha_L \tag{2}$$

B. Physical limits on generator voltage magnitudes and transformer taps, that are the control variables:

$$V_i^{min} \leq V_i \leq V_i^{max}; i \in \alpha_G \tag{3}$$

$$t_i^{min} \leq t_i \leq t_i^{max}; i \in \alpha_t, \tag{4}$$

where α_G and α_t are the sets of generator buses and tap changing transformers, respectively.

C. Maintaining constant power factor at load buses.

$$\frac{P_{li}}{\sqrt{(P_{li})^2 + (Q_{li})^2}} = const_i; i \in \alpha_L \tag{5}$$

2.2. Subjected constraints related to the base case

A. Conventional equations of AC Load flow as:

$$P_{gi}^{b_k} - P_{li}^{b_k} = \sum_{j \in \alpha_L + \alpha_G} V_i^{b_k} V_j^{b_k} (G_{ij}^k \cos(\delta_{ij}^{b_k}) + B_{ij}^k \sin(\delta_{ij}^{b_k})); i \in \alpha_L + \alpha_G, k \in \alpha_C \tag{6}$$

$$-Q_{li}^{b_k} + Q_{ci} = \sum_{j \in \alpha_L + \alpha_G} V_i^{b_k} V_j^{b_k} (G_{ij}^k \sin(\delta_{ij}^{b_k}) + B_{ij}^k \cos(\delta_{ij}^{b_k})); i \in \alpha_L, k \in \alpha_C, \tag{7}$$

where α_C is the set of contingencies included in the optimization problem. The innovation of this paper is to select a small number of contingencies so that the allocated VAr sources cover all of the contingencies.

B. Limits on voltage magnitude at load buses as:

$$V_i^{min} \leq V_i^{b_k} \leq V_i^{max}; i \in \alpha_L, k \in \alpha_C \tag{8}$$

C. Real and reactive power generation limits:

$$P_{gi}^{min} \leq P_{gi}^{b_k} \leq P_{gi}^{max}; i \in \alpha_G, k \in \alpha_C \tag{9}$$

$$Q_{gi}^{min} \leq Q_{gi}^{b_k} \leq Q_{gi}^{max}; i \in \alpha_G, k \in \alpha_C \tag{10}$$

D. Line flow limit:

$$|LF_i| \leq LF_i^{max}; i \in \alpha_{tl}, \tag{11}$$

where α_{tl} is the set of transmission lines.

2.3. Subjected constraints related to the voltage collapse point

A. Inequalities of load flow equations as:

$$hP_{gi}^{b_k} - hP_{li}^{b_k} \geq \sum_{j \in \alpha_L + \alpha_G} V_i^{c_k} V_j^{c_k} (G_{ij}^k \cos(\delta_{ij}^{c_k}) + B_{ij}^k \sin(\delta_{ij}^{c_k})); i \in \alpha_L + \alpha_G, k \in \alpha_C \tag{12}$$

$$-hQ_{li}^{b_k} + Q_{ci} \geq \sum_{j \in \alpha_L + \alpha_G} V_i^{c_k} V_j^{c_k} (G_{ij}^k \sin(\delta_{ij}^{c_k}) + B_{ij}^k \cos(\delta_{ij}^{c_k})); i \in \alpha_L, k \in \alpha_C \tag{13}$$

In inequalities (12) and (13), h is excess loading factor related to stability margin (SM) as:

$$h = \frac{1}{1 - SM} \tag{14}$$

SM is traditionally defined as:

$$SM = \frac{S_{cp} - S_0}{S_{cp}}, \tag{15}$$

where S_0 and S_{cp} are the sum values of MVA loads at base case and voltage collapse point, respectively.

B. Real and reactive power generation limits:

$$P_{gi}^{min} \leq P_{gi}^{c_k} \leq P_{gi}^{max}; i \in \alpha_G, k \in \alpha_C \tag{16}$$

$$Q_{gi}^{min} \leq Q_{gi}^{c_k} \leq Q_{gi}^{max}; i \in \alpha_G, k \in \alpha_C \tag{17}$$

3. Contingency filtering for voltage instability

3.1. Voltage stability indices

It is well known that in a power system, the voltage collapse point (the voltage stability boundary) coincides with a saddle-node bifurcation point [22]. At this point, the minimum singular value and the minimum magnitude of the eigenvalues of the load-flow Jacobian matrix become zero, i.e. the Jacobian matrix becomes singular [23, 24]. Therefore, they have been proposed as indices to detect proximity to the voltage collapse point. Also, corresponding right and left eigenvectors can be used to identify weak buses and branch and generator participation factors [25]. The major drawback of the minimum singular value and the minimum magnitude of the eigenvalues is that they display nonlinear behavior and cannot predict the voltage collapse point. In addition to the minimum singular value and the minimum magnitude of the eigenvalues, some other indices based on the Jacobian matrix have been presented that show better behavior. One of them is the minimum singular value of the reduced load-flow Jacobian matrix. But this index displays also nonlinear behavior as the system approaches the voltage collapse point [23].

L-index first defined in [26] is calculated simpler than the eigenvalues of the load-flow Jacobian matrix. This index is determined for all load buses and can be used to identify weak buses. The L-index values at normal loading condition are close to zero, and tend to 1 when the system approaches the voltage collapse point. The higher the L-index is, the weaker the corresponding bus is. This index in [27] is used as an objective function in voltage/reactive power control problem to improve voltage stability margin. The L-index, similar to the minimum singular value and the minimum magnitude of the eigenvalues of the load-flow Jacobian matrix, displays nonlinear behavior and cannot be used to predict the voltage collapse point. But these indices, besides some sensitivity based methods [28, 29], have been proposed for voltage contingency ranking. In this paper, L-index is used for contingency filtering.

3.2. Contingency filtering

An iterative approach to quickly find the set of binding single-contingencies is presented. These contingencies will be respected in RPP problem. Solving the RPP problem with respect to either these contingencies or all predetermined contingencies leads to the same results. As the first step, initial binding contingencies are determined using the L-index known as a credible criterion to evaluate voltage stability margin. Then the optimization problem is solved by taking into account the initially determined binding contingencies. In the next step, all contingencies other than the ones included in the optimization problem are simulated. If none of them leads to violations, the computation will terminate. Otherwise, some additional binding contingencies will be identified from contingencies that violate the required voltage stability margin or other constraint types. For contingencies that lead to voltage stability margin violation, the new binding contingencies are determined using the L-index. For contingencies that violate other constraints, such as voltage magnitude and line flow limits, the method proposed in [13] is used to identify the new binding contingencies. For contingencies that violate both voltage stability margin and base case constraints, the new binding contingencies are determined using the L-index.

Let α_C be the set of contingencies considered and α_b be the set of binding contingencies included in the optimization problem. α_v is the set of contingencies which violate the required voltage stability margin and α_o is the set of contingencies which violate other constraint types. Also, α_{bv} is the set of binding contingencies from the set α_v, and α_{bo} is the set of binding contingencies from the set α_o. The steps of solving the optimization problem are as follows:

1) Identify the set α_{bv} using L-index. Let $\alpha_b \leftarrow \alpha_{bv}$.

2) Solve the optimization problem by including the set α_b.

3) Simulate all contingencies in $\alpha_C \setminus \alpha_b$. If none of them leads to violations, the computations terminate. Otherwise, identify new sets of $\alpha_{bv} \subset \alpha_v$ and $\alpha_{bo} \subset \alpha_o$. Let $\alpha_b \leftarrow \alpha_b \cup \alpha_{bv} \cup \alpha_{bo}$. Go to step 2.

Our conjecture is that by solving the optimization problem in iteration 1, all constraints are probably satisfied and the computation terminates. Because the optimization problem is formulated for a reactive power planning wherein, in addition to rescheduling control variables, some new reactive power sources are added. If only rescheduling control variables are considered, some post-contingency constraints satisfied at an iteration may be violated during the subsequent iterations. This necessitates some iterations before reaching the optimal solution. In spite of the above descriptions, step 3 has been presented to assure a credible and optimal solution.

3.3. Contingency filtering by L-index

In the method proposed in [13], non-dominated contingencies are selected as binding contingencies. Each non-dominated contingency may dominate some contingencies. In dominated contingencies, the values of constraint violations are smaller than those in the corresponding non-dominated contingency. All constraints violated by dominated contingencies must be also violated by the corresponding non-dominated contingency. So, the dominated contingencies and the corresponding non-dominated one must be located close to each other and affect the same area in the power system.

In this paper, the affected area by each contingency is identified using the L-index. Then, the contingencies are grouped according to the corresponding affected areas. After occurrence of a contingency, the affected area is the weakest bus i.e. a load bus with the maximum value of L-index. Contingencies with the same weakest bus are included in the same group. In each group, the worst contingency is selected as a binding contingency.

The L-index for load bus i is defined as follows [26]:

$$L_i = \left| 1 - \frac{\sum_{j \in \alpha_G} F_{ij} V_j}{V_i} \right|, \tag{18}$$

where V_i is the voltage phasor at bus i, and F is a submatrix of the matrix H. That, H is obtained from the admittance matrix and relates the vector of voltages at load buses and currents at generator buses to the vector of currents at load buses and voltages at generator buses, as:

$$\begin{bmatrix} V^L \\ I^G \end{bmatrix} = H \begin{bmatrix} I^L \\ V^G \end{bmatrix} = \begin{bmatrix} Z^{LL} & F^{LG} \\ K^{GL} & Y^{GG} \end{bmatrix} \begin{bmatrix} I^L \\ V^G \end{bmatrix} \tag{19}$$

4. Simulation results

In this section, some simulation on the IEEE 39 and 118-bus test systems are performed to verify the capability of the proposed method. The predetermined set of contingencies contains the base case in addition to any single line, transformer or generator outage with the exception of the contingency that cause bus isolation. The number of these contingencies in IEEE 39 and 118-bus systems is 44 and 231, respectively. All load buses are considered as candidates for installation of new VAr-plants, and maximum allowable VAr capacity at each bus is 200 MVAr with the step size of 5 MVAr. Let us assume, the fixed C_0 and unit C_1 costs for a VAr-plant are 100 \$ and 300 \$/MVAr, respectively, and the desired voltage stability margin is 30%. The genetic algorithm

(GA) is performed to search the optimal solution of the RPP optimization problem. GA is a capable tool to solve nonlinear and non-convex optimization problems and is frequently used in RPP literatures [30].

4.1. IEEE 39-bus test system

Initially, based on the proposed method in section 3.2, the set of binding contingencies is determined using the L-index. These contingencies and the corresponding voltage stability margins are tabulated in Table 1. After each contingency, the maximum value of L-index and the related bus are shown in the third column of this table; each bus denotes the affected part of the power system by a subset of contingencies that the binding one is shown in the first column. So, these 9 contingencies, as the first set of binding contingencies (α_{bv} in the first step), constitute the set α_b that must be respected in the RPP optimization problem to attain the first solution.

To attain a solution with high accuracy, the genetic algorithm is reiterated 30 times and the averaged values of new VAr capacities are calculated as the solution. The attained solution is presented in Table 2. It can be seen that the proposed method installs new VAr sources at 12 buses with the total capacity and investment cost of 415 MVAr and 0.126 M\$, respectively. The simulation of all contingencies in $\alpha_C \setminus \alpha_b$ with new VAr sources shows that none of them leads to constraint violation, so the computations terminate.

Now, for the sake of comparison, we use the method proposed in [13] for contingency filtering. To do this,

Table 1. The set α_{bv} determined using the L-index based contingency filtering, for IEEE 39-bus system.

Binding contingency[1]	SM(%)	Max. L-index (related bus)
8–9	10.9	0.2519 (8)
4–5	11.4	0.2348 (4)
28–29	14.1	0.3044 (28)
2–3	12.7	0.2870 (3)
6–7	12.3	0.2380 (7)
15–16	11.8	0.3162 (15)
21–22	13.6	0.2758 (21)
26–27	14.1	0.2744 (27)
3–18	14.1	0.2168 (18)

1: *i-j* denotes to outage of line or transformer *i-j*.

Table 2. The RPP solution based on the proposed method, for IEEE 39-bus system.

Bus no.	MVAr	Bus no.	MVAr
4	20	11	25
5	45	12	45
6	45	13	35
7	50	14	30
8	35	15	15
10	50	27	20
Total new VAr capacity: 415 MVAr			
Total investment cost: 0.126 M\$			

voltage stability margin is treated as a constraint and added to base case constraints. Then binding contingencies are selected based on the value of the constraint violations in post contingency states. Each binding contingency dominates some contingencies leading to equal or less violation than the corresponding binding contingency for all constraints. The selected binding contingencies are shown in Table 3. The averaged values of the obtained new VAr capacities by 30 times solving optimization problem using these selected binding contingencies are seen in Table 4. These new VAr sources also satisfy all post-contingency constraints in $\alpha_C \setminus \alpha_b$.

Comparing Tables 1 and 3 shows that the number of binding contingencies determined by the L-index based method is 7 less than those obtained by the method proposed in [13]. Some more important results are observed from the comparison of Tables 2 and 4. The proposed method reduces the total capacity and the investment cost of the required new VAr-plants, about 6% and 5%, respectively. Similar results are obtained when the proposed method is simulated on the IEEE 118-bus test system.

4.2. IEEE 118-Bus Test System

Filtering the predetermined set of contingencies by the proposed method, the set includes 14 contingencies in the first step, as tabulated in Table 5. The number using the proposed method in [13] is 61 (Table 6). Solving the RPP optimization problem, the calculated VAr capacities based on each method are presented in Tables 7 and 8. These tables allow straightforward comparison between the two methods. The proposed method installs the total capacity of 805 MVAr with 0.244 M$ at 20 buses, whereas by the proposed method in [13], the solution has a total capacity of 900 MVAr with 0.273 M$ at 30 buses. Thus, by the proposed method, both the total

Table 3. The set α_{bv} determined using the proposed method in [13], for IEEE 39-bus system.

Binding contingency	Binding contingency
2–3	13–14
3–4	15–16
5–8	21–22
6–11	23–24
8–9	26–27
9–39	G32
10–11	G33
10–13	G38

Table 4. The RPP solution based on the proposed method in [13], for IEEE 39-bus system.

Bus no.	MVAr	Bus no.	MVAr
3	15	10	50
4	45	11	55
5	35	12	45
6	45	13	30
7	45	14	25
8	35	15	15
Total new VAr capacity: 440 MVAr			
Total investment cost: 0.133 M$			

capacity and investment cost are reduced about 10%. Again, the simulation of all contingencies in $\alpha_C \setminus \alpha_b$ with new VAr sources represented in Tables 7 and 8 shows that none of them leads to constraint violation, so the computations terminate.

Table 5. The set α_{bv} determined using the L-index based contingency filtering, for IEEE 118-bus system.

Binding contingency	SM(%)	Max. L-index (related bus)
44–45	10.3	0.1081 (44)
11–13	16.7	0.1189 (13)
19–20	16.7	0.1542 (20)
20–21	15.0	0.0741 (21)
22–23	17.3	0.1059 (22)
34–43	20.0	0.1713 (43)
45–46	18.8	0.1162 (45)
51–52	17.7	0.1043 (52)
53–54	19.2	0.1512 (53)
77–78	16.3	0.1063 (78)
77–82	15.5	0.0680 (82)
84–85	17.5	0.0692 (84)
94–95	21.0	0.0876 (95)
80–97	19.1	0.0743 (97)

Table 6. The set α_{bv} determined using the proposed method in [13], for IEEE 118-bus system.

Binding contingency	Binding contingency	Binding contingency
3–5	49–54	78–79
3–12	55–56	77–80
11–13	50–57	79–80
15–17	51–58	68–81
16–17	56–59	91–92
23–24	55–59	94–95
17–31	60–61	82–96
29–31	59–53	98–100
15–33	63–64	99–100
35–36	61–64	106–107
35–37	64–65	17–113
33–37	49–66	32–114
37–39	49–66	76–118
37–40	65–66	G24
39–40	66–67	G85
40–41	69–70	G90
34–43	24–70	G91
47–49	71–72	G99
49–50	70–74	G116
52–53	69–75	-
53–54	69–77	-

For the sake of comparison, the total results taken from the proposed method, method of [13], and the complete enumeration method of N-1 contingencies are presented in Table 9. By the proposed method, the total investment costs are less than the ones calculated by the method of [13] for both test systems. Note that, for the IEEE 39-bus test system, the total investment costs in the proposed method and the enumeration method are approximately similar. However, the enumeration method is not converged for the 118-bus test system. The reason is that, in the enumeration method, all contingencies in α_C (231 contingencies in the 118-bus system) are addressed in the optimization procedure of GA algorithm; wherein, separate variables and parameters are considered for each contingency. This makes the optimization problem very complex and dimensionally intractable.

Table 7. The RPP solution based on the proposed method, for IEEE 118-bus system.

Bus no.	MVAr	Bus no.	MVAr
3	15	78	60
7	15	79	55
33	25	81	30
38	50	82	40
44	30	83	50
57	35	93	40
63	30	94	45
68	50	106	30
71	45	114	45
75	55	118	60
Total new VAr capacity: 805 MVAr			
Total investment cost: 0.244 M$			

Table 8. The RPP solution based on the proposed method in [13], for the IEEE 118-bus system.

Bus no.	MVAr	Bus no.	MVAr
3	25	71	45
7	20	75	40
20	20	78	50
21	15	79	40
23	35	81	20
33	30	82	35
38	25	83	25
41	15	93	45
43	30	94	40
44	35	96	20
51	30	101	20
57	35	106	15
58	20	108	30
63	35	114	35
68	25	118	45
Total new VAr capacity: 900 MVAr			
Total investment cost: 0.273 M$			

Table 9. The total results taken from the proposed method, method of [13] and the complete enumeration method of N-1 contingencies.

Test System	Total Value	The proposed method	The method of [13]	The enumeration method
IEEE 39-bus system	Investment cost (M$)	0.126	0.133	0.134
	CPU time (Min)	31	50	156
IEEE 118-bus system	Investment cost (M$)	0.244	0.273	Not converged
	CPU time (Min)	137	603	Not converged

5. Conclusion

Many number of contingencies must be addressed in the problem of the voltage stability constrained RPP. This makes the problem very complex and computationally large. Since, separate variables and parameters must be considered for each contingency. This paper focuses on selection of a small number of contingencies instead of all of them. To do this, an L-index based contingency filtering is proposed to divide the predetermined set of all contingencies to some subsets. Then, only one contingency from each subset, known as the binding contingency, is selected and addressed in the RPP problem. The case studies of IEEE 39 and 118-bus systems are used to try the capability of the proposed method and compare it with other methods. The attained results show, by the proposed method, the number of the addressed contingencies in the RPP problem is significantly reduced. In addition to that, total capacity and investment cost of the new VAr-plants are reduced.

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