The Impact of Voltage Stability Constraint L-Index on Power System Optimization Base on Interior Point Algorithm by Considering the Integration of Renewable Energy

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Abstract. Renewable energy (RE) generation including wind and solar farms has experienced significant growth due to the challenge of climate and energy crisis. High penetration of RE affects system stability and generation cost optimization. In this paper, voltage stability L-index is proposed as the constraint of the primal-dual interior point method for optimal power flow by considering the integration of wind and photovoltaic cell power on system. L-index is used in this study to indicate the voltage security while renewable energy is prefixed into power system to build a new (REL-OPF) formulation that can consider the voltage stability margin and generation cost of the power grid. Weibull and Beta probability density functions are applied to determine the outputs of wind and photovoltaic power generation respectively. This model has the advantage that there is no need to calculate the critical point and could obtain the demanded voltage security level by adjusting the upper limits of indicator L constraints. The optimal solution can concurrently satisfy both the voltage security and the economical demand for power systems. The overall problem is simulated under coding written in MATLAB environment. The results obtained from regulating the upper limit of voltage stability constraint on IEEE30-bus has shown that the attention of RE generations into the system leads the fuel cost objective to decrease randomly as well as enlarge the distance of stability to a critical point with faster convergence.

1. Introduction

Optimal power flow (OPF) has become a powerful tool for power system planning, operation and power market. A voltage collapse is still the main issue for power system operators and it could happen at any time. Due to the limitation on the capacity of existing transmission facilities such as transmission lines and for strong economic incentives to be optimally operated by grid operators, many voltage instability incidents have occurred [1]. Renewable energy is an important power source for generating electricity. Many studies showed wind power systems could cause voltage stability fluctuation and the photovoltaic cells could enhance stability in strong light with the high temperature in daytime [2-4]. The increasing penetration levels of variable renewable generation, especially photovoltaic and wind, have been affecting power system optimization and security [5]. Thus, how to determine both the optimal and voltage stability in the environment of RE integration is a new OPF challenge for us.

The main goal of power system operator is not only to run the power system operation in a security condition without any voltage stability collapse but also at a low cost. To generate reliable electrical energy with a large scale of RE integration at minimum cost, the probabilistic optimal power flow
(POPF) analysis of wind and photovoltaic generations are presented in [6-9]. The authors in [10] proposed a static voltage stability by using fault screening and ranking method that includes the uncertainty of renewable energy generation output. By considering the random distribution of wind power and photovoltaic power generation, a voltage stability probability evaluation model under fault scenarios is established and using a random response surface method combined with the interior point method [11] to solve the cumulative probability distribution of the load margin for each failure scenario. The optimal wind farm capacity allocation to enhance and guarantee adequate voltage stability margin for an electricity market solution has been discussed in [12-13] while a multi-objective OPF approach that uses demand-responsive loads to improve steady-state voltage stability is proposed in [14-15]. To satisfy the voltage security along with the economical demand of power systems, the authors in [16] presented an optimal power flow (L-OPF) formulation taking in voltage stability constraints by embracing the L-index function which can reflect stability margin from the critical point. This indicator only focused on the traditional system and ignored the large-scale penetration of wind and photovoltaic generations into the modern power grid.

In this paper, a new proposed optimal power flow considering voltage stability constraint with RE grid-connected (REL-OPF) formulation is available to minimize generation fuel cost and demand security of the system with the combination of renewable energy into the power grid. Weibull probability density function (PDF) will be utilized in this study to get the highest density of wind speed to obtain the actual power output of wind power plants. At the same time, Beta distribution is also applied to calculate the density of irradiation as well as to compute the outputs of each solar farm. This work is also able to help power system operators to draw up the safety level of the system with the economic environment after the access of RE energy into power system.

The remaining of the paper is classified as follows. Section 2 introduces the deterministic model and solution of optimal power flow with the compound of voltage stability constraint L-index, wind and solar generation integration. The computation methodology and the practical test system is described in section 3. The study case and simulation result discussion are detailed in section 4 while the conclusion is presented in section 5.

2. The mathematics model of (REL-OPF)

2.1. Voltage stability constraint L-Index

Voltage stability is one of the most important problems in modern electrical power grids. Voltage stability L-index was originally proposed in [17] by Kessel and Glavitch in 1986 and can easily be calculated from normal load flow data. The value of L-index changes between 0 (no load) and 1 (voltage collapse), which can intuitively reflect the load node's voltage collapse under the current operating mode. The advantage of the distance between points is that the stability can be judged without calculating the voltage collapse point.

\[
L = \frac{1}{1 + \frac{V_i}{V_x}}
\]

where, \( V_i = -\sum_{j \in S} F_{ij} V_j \) is the equivalent voltage formed by all generators in the system at the load bus \( i \); \( S \) is the set of all generator buses; \( F_{ij} \) is the corresponding element in the hybrid matrix \([H]\) of the sub-matrix \( F_{ii} \) in (2) which is generated by a partial inversion of nodal admittance matrix \([Y]\) and it describes the system structure as:

\[
\begin{bmatrix}
V_L \\
I_G
\end{bmatrix} =
\begin{bmatrix}
I_L \\
V_G
\end{bmatrix} =
\begin{bmatrix}
Z \mu & F_{LG} \\
K_{GL} & Y_{GG}
\end{bmatrix}
\begin{bmatrix}
I_L \\
V_G
\end{bmatrix}
\]

where, \( V_L, I_L \) is the vector of voltage and current of the load bus; \( V_G, I_G \) is the vector of voltage and current of the generator bus; \( Z \mu, F_{LG}, K_{GL}, Y_{GG} \) are the sub-matrix of hybrid matrix \( H \) which can be generated by the partial inversion from the bus admittance \( Y \) matrix.
$L_i$ could also be calculated by way of the nodal complex power $S_i$ as follow:

$$L_i = \frac{S_i^* Y_i^*}{Y_i^* V_i^2} \quad (3)$$

where,

* $*: \text{is the complex conjugate of vector,}$

$S_i^* = S_i + S_{i_{corr}}: S_i \text{ nodal complex power at bus } i ; \ S_{i_{corr}} = [\sum_{j \neq i} (Z_v / Z_r) (S_j / V_j)]V_i \text{ refers to the}$

contributions of the other load buses in the system to the index evaluated at the bus $i$; $S_i$ is the set of $Y_{i_{bus}} = 1 / Z_{i_{bus}}: \text{Mutual admittance of load bus } i$

The maximum value of the L-index ($L_{\text{max}}$) calculated at all load nodes can help to consider the overall voltage stability of the system, and this index can also be used as a quantitative method to estimate the voltage stability margin of the current operating point to the stability limit. In this study, therefore, the indicator $L$ is applied to constraint the optimal power flow.

2.2. The model of uncertainty photovoltaic

The uncertainty of the solar radiation intensity also makes the output power of the photovoltaic power generation system have strong randomness. The power output of PV is specifically related to the intensity of solar. The power generated by a photovoltaic module/cell can be calculated from the below equation:

$$\begin{cases} P_{S_i} = r_i A \eta \\ Q_{S_i} = P_{S_i} \tan \theta_{S_i} \end{cases} \quad (4)$$

where, $P_{S_i}, Q_{S_i}$ is the active and reactive power output of PV respectively; $r_i$ is the solar radiation intensity which will be calculated by (5); $A$ is the total area of the solar cell array; $\eta$ is the total photoelectric conversion efficiency; and $\theta_{S_i}$ is the power factor angle of photovoltaic power generation.

In this study, the uncertainty of the solar output is based on Beta probability density function. The Beta distribution is being utilized to create randomness and the probability density function $f(s_i)$ which is defined as:

$$f(s_i) = \frac{\Gamma(\alpha + \beta)}{\Gamma(\alpha)\Gamma(\beta)} s_i^{\alpha-1}(1-s_i)^{\beta-1} \quad (5)$$

where, $s_i$ is a variable which is calculated by $s_i = r_i / r_{max} \ ; \ r_{max}$ is the maximum of solar irradiation intensity; $\alpha, \beta$ are called shape parameters. And $\Gamma(\bullet)$ is the Gamma function.

2.3. Probability model of wind speed

The output power of the wind power generation is determined by the wind speed. The actual wind speed of each wind farm can be expressed as an interval variable. The relationship between the output power of wind turbines and wind speed can be described as follows:

$$P_{W_i} = \begin{cases} 0 & v_i \leq v_{min}, v_i \geq v_{max} \\ a + bv_i & v_{min} < v_i < v_r \\ P_r & v_r < v_i < v_{max} \end{cases} \quad (6)$$
At the same time, each turbine of the wind farm running at constant power factor is considered, excluding the ability of the wind turbine to actively adjust the reactive power, the active power and reactive power of wind farm can be determined as follows:

\[
\begin{align*}
P_{W_i} &= N_{W_i} P_{W_i}^r \\
Q_{W_i} &= P_{W_i} \tan \theta_{W_i}
\end{align*}
\]  

(7)

where, \( v_{in} \) and \( v_{out} \) are respectively the cut-in wind speed and cut-out wind speed; \( v_r \) is rated wind speed; \( P_r \) is the rated output power of the turbine. These parameters are usually determined by the mechanical and electrical properties of the wind turbines; \( a = P_r v_{in} / (v_{in} - v_r) \); \( b = P_r / (v_r - v_{in}) \) can be defined as constants; \( v_r \) and \( P_{W_i} \) are the \( i \) bus actual wind speed and the actual active power of the wind turbines; \( N_{W_i} \) is the number of wind turbines in \( i \) wind farm, \( \theta_{W_i} \) is the power factor angle of the wind turbines.

The most widely used distribution function for analysing wind speed distribution is Weibull distribution density function. Weibull distribution is being utilized to create randomness and the probability density function \( f(v_i) \) is defined as:

\[
f(v_i) = \frac{K}{C} \left( \frac{v_i}{C} \right)^{K-1} \exp \left[ -\left( \frac{v_i}{C} \right)^K \right]
\]

(8)

where, \( v_i \) is \( i \) bus actual wind speed; \( C \) and \( K \) are scale and shape parameter respectively.

2.4. REL-OPF optimal power flow model

Optimal power flow is a special tool where an appropriate objective function (such as fuel costs, real power transmission losses, reactive power losses, pollutants emission, etc.) is minimized. The optimal condition is achieved by adjusting the available controls including generation outputs or reactive power sources to minimize an objective function subject to specified operating and security requirements. In this study, generation fuel cost is considered as the objective function. Voltage stability L-Index, wind and photovoltaic generation model from (1), (4), and (7) are applied into the interior point method for optimal power flow equations to construct a novel REL-OPF model. The power flow model of hybrid variables:

\[
\begin{align*}
\min f(x) &= \sum_{i \in S_q} (a_i P_{G_i}^2 + b_i P_{G_i} + c_i) \\
\text{s.t.} \quad V_i \sum_{j=1} Y_{ij} V_j \cos \delta_{ij} + P_{Di} - P_{G_i} - P_{v_i} - P_{l_i} &= 0; \ i, j \in S_q \\
V_i \sum_{j=1} Y_{ij} V_j \sin \delta_{ij} + Q_{Di} - Q_{G_i} - Q_{v_i} - Q_{l_i} &= 0; \ i, j \in S_q \\
V_{G_{min}} &\leq V_{G_i} \leq V_{G_{max}}; \ i \in S_q \\
P_{G_{min}} &\leq P_{G_i} \leq P_{G_{max}}; \ i \in S_q \\
Q_{G_{min}} &\leq Q_{G_i} \leq Q_{G_{max}}; \ i \in S_q \\
0 &\leq L_i \leq L_{max}; \ i \in S_L
\end{align*}
\]

(9)

where,

\( a_i P_{G_i}^2 + b_i P_{G_i} + c_i \) : generation cost coefficients of thermal plant \( i \)

\( Y_{ij} \) : transmission line admittance between buses \( i \) and \( j \)

\( V_i, V_j \) : voltage at bus \( i \) and \( j \)

\( \delta_{ij} = \delta_i - \delta_j - \alpha_{ij} \) : phase angle for corresponding elements
\[ P_{Gi} \cdot Q_{Gi} \] : dispatchable active and reactive power at node \( i \)
\[ P_{Di} \cdot Q_{Di} \] : active and reactive load at node \( i \)
\[ P_{si} \cdot Q_{si} \] : active and reactive power output of wind generations at bus \( i \)
\[ P_{si} \cdot Q_{si} \] : active and reactive power output of Solar PV generations at bus \( i \)
\( S_G \) : Set of generator buses
\( S_B \) : Set of buses in system
\( S_L \) : Set of load buses in system
\( S_R \) : Set of PV buses
\( (*)_{\min} , (\ast)_{\max} \) : lower and upper limits of variables or quantities
\( L_i \) : L index evaluated at load bus \( i \)
\( L_i^{\max} \) : the upper limit of the L-index in system at bus \( i \)

2.5. **Primal-dual Interior Point Method (PDIPM)**

Primal-dual interior point method leads to a good evaluation of the optimal solution after the first few iterations. It starts by determining an initial solution using Mehrotra’s algorithm, to locate a feasible or near-feasible solution. There are two procedures to be performed in an iterative aspect until the optimal solution has been found which first is the determination of a search direction for each variable in the search space by a Newton’s method and second is the determination of a step length normally assigned a value as close to unity as possible to accelerate solution convergence while strictly conserves primal and dual feasibility. A calculated solution in each iteration is to examine the optimal by the Karush-Kuhn-Tucker (KKT) conditions, which contain the primal feasibility, dual feasibility and complementary slackness.

The primal-dual interior point method will be summarized as the following steps:

**Step 0:** Initialization; Set \( k = 0, k_{\text{max}} = 50 \) centering parameter \( \sigma \in [0,1] \) and tolerance \( \varepsilon = 10^{-5} \)

Choose \( [l,u]^T > 0, [z > 0, w < 0, y = 0]^T \), where \( k, k_{\text{max}} \): Iteration count and its maximum.

**WHILE** \( (k < k_{\text{max}}) \)**

**Step 1:** Compute the complementary gap:

\[
C_{\text{gap}} \equiv \sum_{i=1}^{n} (l_i z_i - u_i w_i) \quad (10)
\]

If \( C_{\text{gap}} < \varepsilon \), then output optimal solution and stop. Otherwise:

**Step 2:** Compute the perturbed factor

\[
\mu \equiv \sigma \frac{C_{\text{gap}}}{2r} \quad (11)
\]

**Step 3:** Solve the correction equation for \( [\Delta x, \Delta y], [\Delta u, \Delta w], [\Delta z, \Delta w] \)

**Step 4:** Perform the ratio test to determine the maximum length in the primal and dual space:

\[
\begin{align*}
\text{step}_p &= 0.9995 \min_{i} \left\{ \frac{-l_i}{-\Delta l_i} : \Delta l_i < 0, \frac{-u_i}{-\Delta u_i} : \Delta u_i < 0, 1 \right\}, \\
\text{step}_d &= 0.9995 \min_{i} \left\{ \frac{-z_i}{-\Delta z_i} : \Delta z_i < 0, \frac{-w_i}{-\Delta w_i} : \Delta w_i > 0, 1 \right\} \\
&\quad i = 1, 2, \ldots, r
\end{align*}
\]

**Step 5:** Update the primal and dual variables by:
\[
\begin{bmatrix}
    x' \\
    l' \\
    u'
\end{bmatrix}
= \begin{bmatrix}
    x \\
    l \\
    u
\end{bmatrix} + \begin{bmatrix}
    \Delta x \\
    \Delta l \\
    \Delta u
\end{bmatrix};
\begin{bmatrix}
    y' \\
    z' \\
    w'
\end{bmatrix}
= \begin{bmatrix}
    y \\
    z \\
    w
\end{bmatrix} + \begin{bmatrix}
    \Delta y \\
    \Delta z \\
    \Delta w
\end{bmatrix}
\]

\(k = k + 1\)

END DO

Step 6: Print "Computation does not converge!" and Stop.

In this paper, OPF problem is solved by using the PDIPM algorithm for several thermal units' systems with determining the Lagrange, gradient, and hessien matrix. The hessien matrix is solved by both analytical and numerical methods using the KKT conditions. It proves to be more efficient than the analytical method through its fast convergence and computational efficiency.

3. Practical test system and computation methodology

3.1. IEEE30-Bus fuel cost and renewable energy

IEEE30-bus consists of 6 generators, 41 lines, and 21 load buses. Voltage stability constraint upper limit \(L_{\text{max}}\) is applied to evaluate all load buses in the system. The generation fuel cost coefficient and generation output limitations are obtained from paper [18]. All parameters of wind and photovoltaic farms [10] are described in Tables 2 and 3. The highest density of Weibull PDF and Beta PDF will be selected to compute the output of wind and solar generation respectively. Only thermal-power plants are used to calculate the minimum of the objective function. For renewable power plants such as solar and wind generation outputs are set to be zero fuel costs in this study. And the power factor angle of wind and photovoltaic outputs which is used in calculating reactive power outputs are supposed to equal 0.98 and 0.90 respectively. Moreover, each turbine in the same wind farm is determined to run at unity wind speed. All power demand in IEEE30-bus system is assumed to be constant.

| Table 1. IEEE30-Bus Generation Cost Coefficients. |
|---|
| Unit | Cost Coefficients | Generation Constraint |
| | \(a_i\) | \(b_i\) | \(c_i\) | \(P_{\text{min}}\) [MW] | \(P_{\text{max}}\) [MW] |
| 1 | 37.5 | 200 | 0 | 50 | 200 |
| 2 | 175.0 | 175 | 0 | 20 | 80 |
| 5 | 625.0 | 100 | 0 | 15 | 50 |
| 8 | 83.0 | 325 | 0 | 10 | 35 |
| 11 | 250.0 | 300 | 0 | 10 | 30 |
| 13 | 250.0 | 300 | 0 | 12 | 40 |

| Table 2. Wind Generation. |
|---|
| Number | 1 | 2 | 3 | 4 |
| Access Node | 7 | 8 | 12 | 18 |
| Number of Turbines | 10 | 8 | 5 | 6 |
| Rated capacity (MW) | 1.4 | 1.6 | 1.3 | 1.4 |
| Cut-in wind speed (m/s) | 3.0 | 4.0 | 4.0 | 3.0 |
| Rate wind speed (m/s) | 14 | 15 | 14 | 14 |
| Cut-out wind speed (m/s) | 25 | 30 | 30 | 25 |
| Minimum wind speed (m/s) | 1.1 | 3.8 | 1.6 | 2.5 |
| Maximum wind speed (m/s) | 30.1 | 24.5 | 23.7 | 36.9 |
| Shape parameter \(K\) | 1.8 | 2.1 | 1.7 | 1.9 |
| Scale parameter \(C\) | 7.0 | 7.5 | 7.0 | 7.5 |

| Table 3. Photovoltaic Generation |
|---|
| Number | 1 | 2 | 3 |
| Access Node | 23 | 24 | 29 |
### Table

| Total Areas (m²) | 4000 | 3500 | 4000 |
|-----------------|------|------|------|
| Transfer efficiency (%) | 14   | 14   | 16   |
| Minimum Irradiation (W/m²) | 381.2 | 398.9 | 381.5 |
| Maximum Irradiation (W/m²) | 608.9 | 727.1 | 598.6 |
| Shape parameter $\alpha$ | 4    | 4.2  | 3.8  |
| Shape parameter $\beta$ | 2    | 2.1  | 1.9  |

3.2. Proposed Methodology

This paper proposes the optimal power flow by using primal-dual interior point algorithm with considering static voltage stability L-index and the integration of wind / photovoltaic power generation to the grid. The method of solving problem includes the following step:

- First, by assuming that the power demand of system is stable, the L-index is added to the traditional optimal power flow as an inequality constraint to form an optimal power flow model (L-OPF) with voltage stability constraints, which is solved by the primal-dual interior point method. After regulating voltage stability constraint $L_{max}$, the fuel cost optimization value result from each indicator $L_{upper}$ limit is computed.

- Secondly, considering the probability density distribution of wind power and photovoltaic power generation. Weibull distribution density function and Beta distribution density function are used to define the highest density of wind speed and solar irradiation. A certain output of RE generation is given. Afterward, adjusting the upper limit of $L_{max}$ in OPF is carried out to get the minimized generation cost of each variation in the L-index value by gradually reducing the upper limit $L_{max}$. The result of OPF solution will be provided and indicator L values versus the price of fuel cost generation (REL-OPF) are subsequently obtained.

- Finally, the comparison of voltage stability L-index margin for optimal power flow (L-OPF) with renewable energy access to the power system (REL-OPF) is given.

For more detail of REL-OPF calculation methodology is figured as:
Figure 1. The Methodology flowchart of REL-OPF

4. Simulation results and analysis
The proposed REL-OPF formulation is implemented to a Matlab computer program and test on IEEE30-bus system. Weibull probability density function of four wind farms and Beta probability function are simulated as illustrated in figure 2 and figure 3 respectively.

Voltage stability constraint upper limit \( L_{\text{max}} \) can be chosen by the system operators according to the practical operation experience to guarantee sufficient voltage stability margin for the system. \( L_{\text{max}} \) is the maximum one among all the L-index values evaluated at load buses and the bus corresponding to is the easiest one to lose voltage stability.

Figure 4 shows the test results of IEEE30-bus L-OPF and it defines that the fuel cost is increased while the upper limit of \( L_{\text{max}} \) is restricted and fuel cost is constant while its value is larger than 0.1356 (the optimal fuel cost will equal to the without voltage stability constraint OPF). When \( L_{\text{max}} \) is adjusted to 0.1320, the optimum fuel cost has reached the highest point. This means that the power system operator cannot find the optimal solution by more voltage stability demands. Moreover, it proves that the increase in grid security is proportional to the protection cost, hence it will be less economic. To enhance voltage stability requirements, more generations connected to the grid should be considered.
Figure 2. Weibull probability density function for wind speed.

Figure 3. Beta probability density function for solar irradiation.

Figure 4. The result of adjusting $L_{\text{max}}$ versus fuel cost (Non-RE).

Figure 5. The result of regulation of $L_{\text{max}}$ versus fuel cost (RE).

The influence of voltage stability constraint L-index and RE sources on power grid fuel cost optimum (REL-OPF) is resulted in figure 5. The attention of wind and solar energy has increased in a distance of system security from the current operating point to the critical point. The result of testing on IEEE30-bus shows that $L_{\text{max}} = 0.125$ is the highest point of the optimal solution while L-OPF is only $L_{\text{max}} = 0.132$. Thus, the power system operator could more demand the safety of the system if compare to the non-renewable energy integration system. Moreover, we mentioned that when the L-index value is set as the highest point, the total generation cost of REL-OPF is only 781.88$/h$ and the most security point is increased to 801.56$/h$. Without consideration investment cost on RE farms, the correlation of wind and solar generation output has reduced the total generation cost of power systems.

Table 4. Impact of L-Index on the objective function.

| IEEE30 L-OPF | $L$ | $L_{\text{max}}$ | Fuel Cost ($/h$) | $G1$ | $G2$ | $G5$ | $G8$ | $G11$ | $G13$ |
|--------------|-----|-----------------|-----------------|-----|-----|-----|-----|-----|-----|
|              | 1   | 0.1356          | 800.7219        | 176.88 | 48.68 | 21.31 | 21.35 | 12.25 | 12.00 |
|              | 0.1355 | 0.1355        | 800.8990        | 177.11 | 48.68 | 21.32 | 21.19 | 12.24 | 12.00 |
|              | 0.1350 | 0.1350        | 801.0462        | 177.21 | 48.68 | 21.32 | 21.14 | 12.23 | 12.00 |
|              | 0.1345 | 0.1345        | 801.1304        | 177.26 | 48.68 | 21.33 | 21.12 | 12.23 | 12.00 |
|              | 0.1340 | 0.1340        | 801.4180        | 177.46 | 48.68 | 21.33 | 21.02 | 12.22 | 12.00 |
|              | 0.1335 | 0.1335        | 803.3049        | 177.02 | 48.75 | 21.45 | 21.56 | 12.43 | 12.00 |
The results listed in table 4 revealed that when the system operator more demand system security by reducing $L_{max}$, the generator standing close to the weakest bus increased its output. In this simulation, IEEE30-bus system node 30 is recognized as the weakest bus in the whole system. Generator G2, G5, G8 and G11 which enclose the weakest bus are gradually increased their active outputs to compensate for voltage stability requirements. However, node number 30 is altered to be a stronger bus after a solar farm is connected at bus 29 and another bus will become the weakest bus in the system. As shown in table 5, after the access of RE into grid G5, G11 and G13 power outputs continue to soar and we can realize that these generators are located close to the new weakest bus in the system. This verification illustrates REL-OPF has a good effect on system security and economical demand.

According to figure 6, the iteration numbers of L-OPF consist of the difference between $L_{max}=1$ to $L_{max}=0.132$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$. However, REL-OPF has the same iteration numbers between $L_{max}=1$ and $L_{max}=0.125$ and $L_{max}=0.124$.
it proves that the integration of renewable energy offers a fast convergence for computation the optimal power flow.

5. Conclusion
The REL-OPF formulation is proposed in this paper to solve the optimal solution by considering the effect of voltage stability constraint L-index and the integration of RE. The impact of the incorporation of voltage security constraint into optimal power flow formulation on the active power dispatch and the output capacity of renewable generations problem is associated with guaranteeing adequate voltage security levels in power systems. The numerical results obtained by the IEEE-30 bus system showed that the distance of indicator L to the stability point \( L_{\text{max}} = 0 \) is better in case RE generations are connected close to the weakest bus in the power grid and it is proved to enhance both safety and economy. Besides, primal-dual IPM leads to a good convergence in the optimal solution especially after the integration of renewable generations.

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