Generator Capability Curve Constraint for PSO Based Optimal Power Flow

Mat Syai’in, Adi Soeprijanto, and Takashi Hiyama

Abstract—An optimal power flow (OPF) based on particle swarm optimization (PSO) was developed with more realistic generator security constraint using the capability curve instead of only $P_{\text{min}}/P_{\text{max}}$ and $Q_{\text{min}}/Q_{\text{max}}$. Neural network (NN) was used in designing digital capability curve and the security check algorithm. The algorithm is very simple and flexible especially for representing non linear generation operation limit near steady state stability limit and under excitation operation area. In effort to avoid local optimal power flow solution, the particle swarm optimization was implemented with enough widespread initial population. The objective function used in the optimization process is electric production cost which is dominated by fuel cost. The proposed method was implemented at Java Bali 500 kV power systems contain of 7 generators and 20 buses. The simulation result shows that the combination of generator power output resulted from the proposed method was more economic compared with the result using conventional constraint but operated at more marginal operating point.

Keywords—Optimal Power Flow, Generator Capability Curve, Particle Swarm Optimization, Neural Network

I. INTRODUCTION

THE recent development of optimal power flow method has adopted the artificial intelligence (AI) algorithm in gaining optimal solution of generator scheduling. The most popular intelligence optimization technique already applied were genetic algorithm, fuzzy, simulated annealing, expert system, neural network, PSO and the hybrid of them [1-12]. Among of these, PSO is the one received greatest attention caused by its capability in avoiding local optimal solutions. Most PSO papers stress on developing new techniques in effort to achieve optimal solution considering non linear power system characteristic [5-7]. Only view papers give attention in developing proper or more realistic constraint to the optimal power flow problem. As an example, more tight constraints such as Sudhakaran et.al, Pablo et.al and Gaing et.al [1-3] were used in solving economic dispatch problem. As a consequence, such tight constraint will result a pessimistic solution. Actually the optimum value of the objective function—in this case system operation cost—can still be reduced if we can alleviate the constraint especially generator security constraint. So far researchers used $P_{\text{min}}/P_{\text{max}}$ and $Q_{\text{min}}/Q_{\text{max}}$ to limit the generator output inside the secure operating condition. Matlab in its Power System Simulation Package used more realistic generator security constraint that is the generator capability curve which is approximated with five straight lines [4]. Although it is already better than $P_{\text{min}}/P_{\text{max}}$ and $Q_{\text{min}}/Q_{\text{max}}$ but the generator still can’t operate in the marginal area in order to get lower operation cost.

This research is aimed to develop neural network based generator capability curve and the security check algorithm that will be used as enhanced constraint of optimal power flow. The algorithm is very simple and flexible especially for representing non linear generation operation limit near steady state stability limit and under excitation operation area. Another constraint such as bus voltage limitation, equality and inequality of power is remains the same. The OPF solution is solved by PSO which already become a well established optimization method for generator dispatch. The inherent characteristic of PSO that is the capability to avoid local optimum point is pronounced by an enough widespread initial population. It is hoped that with the proposed additional constraint, generators can operate at their marginal operating point so that the most economic operation condition can be achieved. The simulation is conducted at 500 kV Java-Bali Power System. The simulation result will be compared with OPF solution using conventional ($P_{\text{min}}/P_{\text{max}}$ and $Q_{\text{min}}/Q_{\text{max}}$) constraint.

II. METHODOLOGY

A. Developing NN Model for Generator Capability Curve

In order to make generator capability curve possible as OPF constraint, a constructive back propagation NN Model for generator capability curve should be designed first. The algorithm is as follows:

1. Prepare a Neural Network with one input and one target. The number of hidden layer will be constructed automatically by constructive backpropagation (look at Fig. 1)

2. Use the angle $\theta$ and the related distance between origin and curve line $R$ as the input and target respectively (look at Fig. 2).

3. Sample a set of input-target data along the curve line and train the NN using the data set. The accuracy of the model resulted is depend on the number of input-target data used.
4. Test the resulting NN model with data other than already used at step 3. Compare the NN output with the related real distance between the origin and the curve line.

5. By entering the angle $\theta$ from $0^\circ - 180^\circ$ to the NN model and plotting the resulting input-output value, generate the whole curve. Compare the result with the original capability curve.

Note that great error usually happened at edge points caused by discontinuity of the curve. A simple technique to overcome this problem is by including the edge points as data in the learning process. Frequently, the under excitation operation limit (area under P axis) are more non linear than what is shown at Fig. 2. As will be shown the extremely useful characteristic of the proposed algorithm is its high flexibility to overcome the non linearity.

B. Developing Security Check Algorithm

The generator scheduling solution by proposed OPF should guarantee secure operation for all generators. A security check algorithm was developed as follows:

1. From the data of each generator power output (P and Q) resulted by PSO, the related angle $\theta$ and magnitude $R$ was computed.

2. By entering the angle data $\theta$ as an input of the NN Model resulted before, one can get a reference distance ($R_{ref}$) from the output.

3. The generator security was checked by comparing the value of $R$ and $R_{ref}$. If $R \leq R_{ref}$ the generator is secure but if $R > R_{ref}$ the generator is unsecure.

Fig. 3 gives a visual relationship between generator operating point (P,Q), $\theta$, R and $R_{ref}$. Fig. 4 shows the security check algorithm.

C. Overall Simulation Flowchart

Fig. 5 shows the overall simulation flowchart of PSO based OPF. As input data were network impedances and loads while the generator power will either be created randomly or regulated as initial population. A regulated widespread initial population is preferable to avoid local optimum solution.
algorithm will update power generator combination except the swing generator and repeat the process until all generators are secure. The other constraint such as system voltage level, equality and inequality of power were also processed at this step.

The optimal solution was founded by comparing the value of objective function of all possible generation combination via many iterations. The operation cost which is dominated by fuel cost was used as the objective function. At each iteration, the value of objective function of new individu should be compared with the old one and the lower operating condition cost was used as local best condition for the next iteration. Individu having the lowest cost among community should be used as global best condition for the next iteration. The PSO algorithm to update the generators operating point [1]:

\[ X_{i}^{k+1} = X_{i}^{k} + V_{i}^{k+1} \]  
(1)

\[ V_{i}^{k+1} = wV_{i}^{k} + c_{1} \cdot rand_{1} \cdot x(Pbest_{i} - X_{i}^{k}) + c_{2} \cdot rand_{2} \cdot x(Gbest - X_{i}^{k}) \]  
(2)

\[ w = \frac{w_{\text{max}} - w_{\text{min}}}{\text{Iter}_{\text{max}}} \cdot \text{Iter} \]  
(3)

with :

- \( V_{i}^{k} \) = individu velocity \( i \) at iteration \( k \)
- \( w \) = weight parameter
- \( c_{1}, c_{2} \) = acceleration coefficient
- \( rand_{1}, rand_{2} \) = random value between 0 and 1
- \( X_{i}^{k} \) = individu position \( i \) at iteration \( k \)
- \( Pbest_{i} \) = Pbest individu \( i \) until iteration \( k \)
- \( Gbest \) = Gbest community until iteration \( k \)
- \( w_{\text{min}}, w_{\text{max}} \) = initial and final weight
- \( \text{Iter}_{\text{max}} \) = maximum iteration number
- \( \text{Iter} \) = number of iteration now

III. SIMULATION AND ANALYSIS

A. Plant Data

The Plant used for simulation is the 500 kV Java-Bali Power System as shown in Fig. 6. The data of generator characteristics and cost, line impedances and an operating condition are shown at Tables I-III.

**Fig. 6 500 kv Java Bali power system**
TABLE III
OPERATING CONDITION

<table>
<thead>
<tr>
<th>No</th>
<th>Bus</th>
<th>P Load (MW)</th>
<th>Q Load (MVar)</th>
<th>P Gen (MW)</th>
<th>Q Gen (MVar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Suralaya</td>
<td>199</td>
<td>58</td>
<td>3,118</td>
<td>762</td>
</tr>
<tr>
<td>2</td>
<td>Cilegon</td>
<td>387</td>
<td>87</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>Kmbangan</td>
<td>638</td>
<td>200</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>Gandul</td>
<td>730</td>
<td>189</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>Cibinong</td>
<td>560</td>
<td>-47</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>Cawang</td>
<td>599</td>
<td>214</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>Bekasi</td>
<td>545</td>
<td>71</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>M. Tawar</td>
<td>1</td>
<td>-477</td>
<td>185</td>
<td>-</td>
</tr>
<tr>
<td>9</td>
<td>Cibatu</td>
<td>669</td>
<td>206</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>Cirata</td>
<td>612</td>
<td>323</td>
<td>650</td>
<td>313</td>
</tr>
<tr>
<td>11</td>
<td>Saguling</td>
<td>-</td>
<td>3</td>
<td>762</td>
<td>193</td>
</tr>
<tr>
<td>12</td>
<td>Bdg Sel.</td>
<td>638</td>
<td>-108</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>13</td>
<td>Maduracn</td>
<td>321</td>
<td>143</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>14</td>
<td>Ungaran</td>
<td>875</td>
<td>-211</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>15</td>
<td>Pedan</td>
<td>302</td>
<td>-386</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>16</td>
<td>Kediri</td>
<td>340</td>
<td>709</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>17</td>
<td>Gresik</td>
<td>176</td>
<td>231</td>
<td>454</td>
<td>200</td>
</tr>
<tr>
<td>18</td>
<td>Shy Barat</td>
<td>341</td>
<td>33</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>19</td>
<td>Grati</td>
<td>252</td>
<td>229</td>
<td>60</td>
<td>21</td>
</tr>
<tr>
<td>20</td>
<td>Paiton</td>
<td>493</td>
<td>435</td>
<td>3,099</td>
<td>606</td>
</tr>
</tbody>
</table>

The software used for simulation was Matlab and Newton Raphson was chosen as load flow algorithm. The neural network used was constructive back propagation and the PSO used was standard PSO. As many as fifty populations were selected as initial population.

B. Result and Analysis

The input and target data for developing NN model of generator capability curve were created by sampling the angle $\theta$ between $0^\circ - 180^\circ$ and the related distance $R$. As many as one hundred data for each generator were used for developing NN model. The procedure explained at IIA was applied to each generator. The curve resulted by NN-model together with the original curve are shown at Fig. 7 for generator Paiton. The other generators are left for simplicity. As can be seen, both curves are very similar except for a very view operating point. This means that the NN model can reconstruct exactly the original curve and ready used for OPF constraint.

The accuracy justification of generator security check algorithm is shown at Table IV and Fig. 8. Generator Suralaya is used as an example. The table show very accurate identification of security level of the generator. The Fig. 9 shows the convergence of the learning process of generator Cirata. It can be concluded that finally all population converge to the same value. The evolution of the objective function (cost/hr) is shown at Fig. 10. The optimal solution resulted was compared with the result using conventional constraint as shown at Table V. As can be seen, the proposed method give lower total operating cost but operates at more marginal operating point. Figs. 11-13 shows this phenomenon for three generators.
**Fig. 9b Convergent Process at iterations = 50**

**Fig. 9c Convergent Process at iterations = 150**

**Fig. 10 Trend of PSO to find minimum cost**

**Fig. 11 The P-Q position of Saguling generator**

**Fig. 12 The P-Q position of Gresik generator**

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**TABLE V**

<table>
<thead>
<tr>
<th></th>
<th>PSO with Constraint Curve</th>
<th>PSO with Constraint Min-Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>P(MW)</td>
<td>Q(MVar)</td>
<td>COST</td>
</tr>
<tr>
<td>2997.5</td>
<td>767.88</td>
<td>3.2348e+009</td>
</tr>
<tr>
<td>493.03</td>
<td>228.56</td>
<td>8.5192e+006</td>
</tr>
<tr>
<td>543.43</td>
<td>2.34e-005</td>
<td>271.72</td>
</tr>
<tr>
<td>804.23</td>
<td>0.75598</td>
<td>1105.8</td>
</tr>
<tr>
<td>502.65</td>
<td>0.47248</td>
<td>3.1838e+008</td>
</tr>
<tr>
<td>70.37</td>
<td>0.066148</td>
<td>1.0117e+006</td>
</tr>
<tr>
<td>3425.7</td>
<td>3011.22</td>
<td>3.6996e+009</td>
</tr>
</tbody>
</table>

**Total Cost** 7.2595e+009 **Total Cost** 7.2978e+009
IV. CONCLUSION

The proposed method containing capability curve constraint successfully reduces the operating cost compared with conventional constraint. The most additional valuable characteristic of the proposed method is its simplicity and flexibility in changing the constraint when there is a change in the curve limit especially related to under excitation operation limit. It is very useful to assist the engineer to minimize their power system operation cost as well as to maintain safety level of each generator connected to the system.

ACKNOWLEDGMENT

Thank you for the Indonesian Government Electrical Company and JICA-PREDICT for supporting all the data and financial needed in this research.

REFERENCES

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Fig. 13 The P-Q position of Paiton generator

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