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# Optimal Reactive Power Control Using Compensating Capacitor Based on Artificial Immune System

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## ABSTRACT

This paper presents the application of compensating capacitors for optimal power flow in transmission system. The compensating capacitors are placed at suitable locations in the transmission system and the size of reactive power to be injected by the capacitors to the system is obtained using artificial immune system (AIS) optimization technique. AIS will find the best value of reactive power of the compensating capacitors so that the total system loss is minimum. It is found that applying the AIS optimization technique is prospective approach for finding optimal reactive power output of the installed compensating capacitors in controlling reactive power of transmission system.

**Key words :** Optimal reactive power control, compensating capacitor, artificial immune system, optimization.

## 1. INTRODUCTION

One of the power system operation problems that becomes a concern is the control of voltage and reactive power. As certain loads especially large power consumers (LPCs) such as industrial loads are linked at the transmission system, which they produce varying demands of active and also reactive power. In order to transport active power adequately to the loads and to improve power factor in the system, reactive power has to be recompensed. A steady system operation is significant and requires that the bus voltages are preserved within assigned limits. Reactive power optimization is used to control voltage profile and to reduce active power loss of power systems [1]–[3]. As such, optimal reactive power control is important in power system operation. One of the methods to control the optimal reactive power in transmission system is by installing compensating capacitor to the transmission system. The compensating capacitor will give reactive power support to the transmission system to decrease the system loss, to uphold the capability of the system to sustain and to avoid voltage collapse.

Compensating capacitor also known as capacitor bank. It only capable to inject reactive power to the transmission system and cannot absorb the reactive power. Compensating capacitor can be divided into two types, which are shunt capacitors and series capacitors. Shunt capacitors are more frequently used in the power system compared to series capacitors. The benefits of using shunt capacitors are they can decrease the line current and system losses, improve the voltage and the power factor of the source. Furthermore, the capacitors can compensate the reduction in reactive current in the system.

For the past ten years, many optimization techniques have been introduced by researchers and electrical engineers for optimal reactive power control such as genetic algorithm [4]–[13], particle swarm optimization [14]–[18] and linear programming [19], [20], simulated annealing approach [21], self-directing evolutionary operation [12]–[15] and artificial bee colony (ABC) [22]–[26]. One of the meta-heuristic optimization techniques that have caught the attention of electrical engineers to solve power system problems is artificial immune system (AIS). AIS has been widely used in solving power system problems: economic dispatch problem, FACTs devices installation and distributed generation installation problem.

This paper proposes to use compensating capacitor to control reactive power flow in transmission system. Artificial immune system (AIS) optimization technique is used to find the optimal size of reactive power of the installed compensating capacitor. The optimal size of the reactive power is found from the objective of minimizing the total system loss. A few case studies are introduced to study the performance of the proposed AIS optimization technique in finding optimal size of the compensating capacitor. It is found that applying compensating capacitor with the integration of AIS optimization technique to find the optimal size of the capacitor is a prospective approach for solving optimal reactive power control problem.

## 2. METHODOLOGY

The application of compensating capacitor for optimal reactive power control starts by identifying the buses that have low voltage magnitude. This is because buses with low voltage magnitude are the suitable location for installing compensating capacitor as the low voltage magnitude is caused by the loss of reactive power at the buses. The buses with low voltage magnitude are found by solving the load flow of the test system. The IEEE 30-Bus reliability test system (RTS) is used in this study. From the load flow solution, then the number of compensating capacitor to be installed can be decided. Subsequently, the amount of injection is obtained using AIS optimization technique. The processes of AIS is as shown in Figure 1. And the 30-Bus system used is as shown in Figure 2.

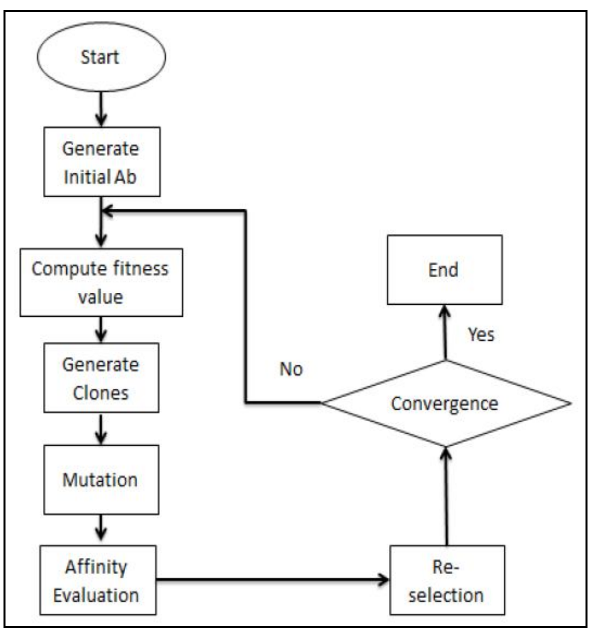


**Figure 1:** Flowchart of AIS

The steps of finding optimal injection of reactive power by compensating capacitor(s) using AIS are as follows:

Step 1: Randomize the size of reactive power injection of compensating capacitor(s). The size of injection will be used in computing the fitness value of system loss.

Step 2: Compute fitness value of system loss using equation (1) with the load flow solution of the 30-Bus system.

Step 3: The best twenty individuals that give the best values of system loss then undergo cloning process to generate their clones. They are cloned by ten to become two hundreds individuals.

Step 4: The cloned individuals then mutated using Gaussian mutation approach to produce new generation. This Gaussian mutation equation is as shown in (1).

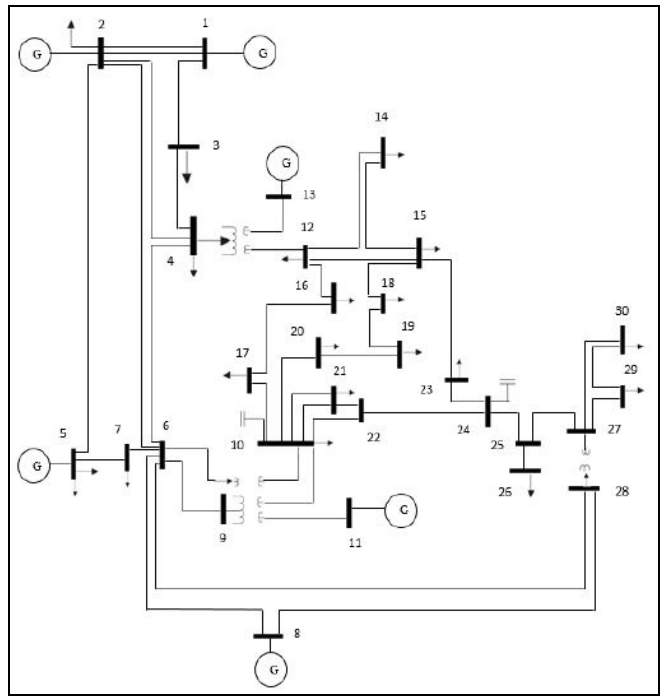

**Figure 2:** IEEE 30-Bus RTS

$$x_{i+m,j} = x_{i,j} + N\left(0, \beta\left(x_{jmax} - x_{jmin}\right)\left(\frac{f_i}{f_{max}}\right)\right) \qquad (1)$$

Where:

$x_{i+m,j}$ is mutated individual (new generation)

$x_{i,j}$ is cloned individual

$\beta$ is mutation scale, $0 < \beta < 1$

$x_{jmax}$ is maximum random number for every variable

$x_{jmin}$ is minimum random number for every variable

$f_i$ is fitness for *ith* random number

$f_{max}$ is maximum fitness

Step 5: The mutated individuals are again evaluated by computing the fitness value of system loss.

Step 6: From the affinity evaluation, the best twenty individuals are selected from ranking process where the individuals are sorted ascendingly based on the value of system loss produced by the new generation.

Step 7: The processes will be repeating until the algorithm converge. It can only converge when the difference between the first and the twentieth fitness values of the best twenty is 0.0001.

As previously mentioned, there are three case studies have been presented in this paper to study the performance of AIS in solving optimal reactive power control problem. The case studies are as shown in Table 1.

**Table 1:** Case Studies of Optimal Reactive Power Control Problem

| Case Study | Description |
|---|---|
| 1 | The first case study is also known as the base case. For this case study, no modification is made on the test system. |
| 2 | N-1 contingency |
| 3 | N-2 contingency |

Load flow problems for the all three cases are solved to find the location for installing compensating capacitor and to find the number of compensating capacitor to be installed in the system. Then, the size of reactive power injection by the capacitor(s) is optimally found using AIS with the objective to minimize system loss. The system loss is calculated using equation (2).

$$P_{loss} = \sum_{k=1}^{l} g_k [V_i^2 + V_j^2 - 2V_iV_j\cos(\delta_i - \delta_j), k \in \{1,2,\dots,l\} \quad (2)$$

Where,
$g_k$ is conductance of $kth$ line,
$V_i$ and $\delta_i$ are voltage magnitude and angle of bus $i$, respectively,
$V_j$ and $\delta_j$ are voltage magnitude and angle of bus $j$, respectively, and
$l$ is number of lines in the system.

### 2.1 Case Study 1: Base Case

The first case study is also known as the base case. For this case study, no modification is made on the test system. From the load flow solution of 30-Bus system, it is found that bus 30 has the lowest voltage magnitude among other buses which is 0.9768 p.u. Although, it is greater than 0.95 which is the lower limit of the allowable voltage magnitude range, the voltage of the bus 30 can be improved to nearer to 1 p.u with an optimal size of compensating capacitor installed at the bus. There is only one compensating capacitor is installed for this case as the lowest voltage magnitude is still within allowable range.

### 2.2 Case Study 2: N-1 Contingency

In this case, one of the transmission lines in the system is randomly removed to demonstrate the line outage. This outage can be caused by the fault on the transmission line. Line 6-7 has been put on outage in this case. And bus 7 is the weakest bus in the system as it is the only bus that has voltage magnitude less than 0.95 p.u. Hence, only one compensating capacitor is decided to be installed, which is at bus 7.

### 2.3 Case Study 3: N-2 Contingency

For this N-2 transmission line contingency case study, two transmission lines are put on outage. The lines are line 6-7 and line 27-28. In this case, it is found that six buses have voltage magnitude less than 0.95 p.u with bus 30 has the lowest. There are six compensating capacitors to be installed in the system at bus 7, 25, 26, 27, 29 and 30.

## 3. RESULTS AND DISCUSSION

The results of optimal reactive power control in this paper are presented in case studies order. And for each case study, the pre-optimization values of system loss and minimum voltage are obtained from the load flow solution. It was ensured that the system loss is improved after the optimization process using AIS. Minimum voltage is not optimized in this study and only be recorded for comparison purpose.

### 3.1 Case 1: Base Case

As explained in the methodology section, bus 30 experienced the lowest voltage magnitude after the load flow is solved. However, the value is still within the allowable limits. Therefore, only one compensating capacitor is installed for this case. The optimization result for this case study is as shown in Table 2. AIS found the optimal reactive power to be injected at bus 30 is 3.5338 MVar. It can be seen from the table that after the implementation of AIS, the system loss has reduced 17.7396 MW to 17.6810 MW. Furthermore, minimum voltage also improved from 0.9768 p.u to 1.0037 p.u. This improvement can be clearly seen in Figure 3.

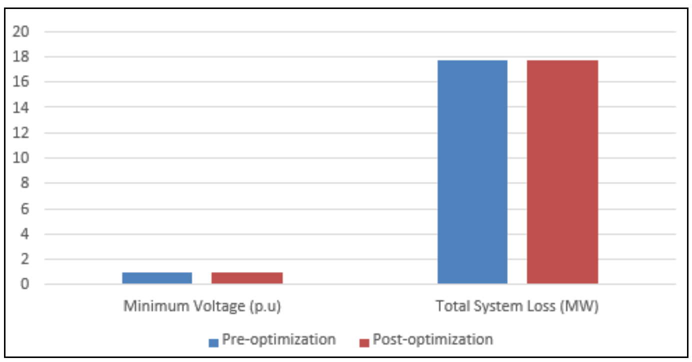


**Figure 3:** Comparison of Minimum Voltage and System Loss between Pre-optimization and Post-optimization (Case 1)

### 3.2 Case 2: N-1 Contingency

It can be seen from Table 3, when line 6-7 is on outage, the optimal size of compensating capacitor to be injected at bus 7 is 5.6081 Mvar. After the injection, system loss has improved from 19.4140 Mvar to 19.2712 Mvar. Even though, minimum voltage is not optimized, it still can be seen that post-optimization produced better minimum voltage which is 0.9636 p.u. This optimization result is illustrated in Figure 4.

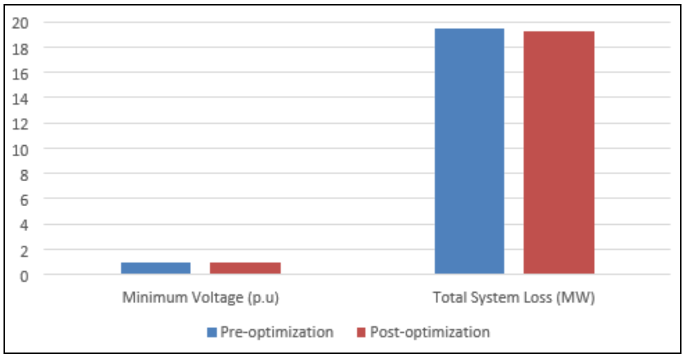


**Figure 4:** Comparison of Minimum Voltage and System Loss between Pre-optimization and Post-optimization (Case 2)

### 3.3 Case 3: N-2 Contingency

Unlike Case 1 and Case 2, there are six buses experienced low voltage magnitude less than 0.95 p.u when line 6-7 and line 27-28 are put on outage. The buses are 7, 25, 26, 27, 29 and 30. The optimal sizes of compensating capacitor to be used at the buses are 5.0490 MVar, 1.6158 MVar, 2.4923 MVar, 3.2237 MVar, 2.8074 MVar and 1.7232 MVar respectively. The minimum voltage of all these buses has also improved from 0.9464 p.u, 0.9252 p.u, 0.9057 p.u, 0.9005 p.u, 0.8776 p.u and 0.8643 to 0.9629 p.u, 1.0006 p.u, 0.9922 p.u, 0.9947 p.u, 0.9858 p.u and 0.9737 p.u respectively. Figure 5 shows in details the improvement of the voltage magnitude of all the six buses. After AIS implementation, the voltage magnitude of the six buses improved and within the allowable limits.

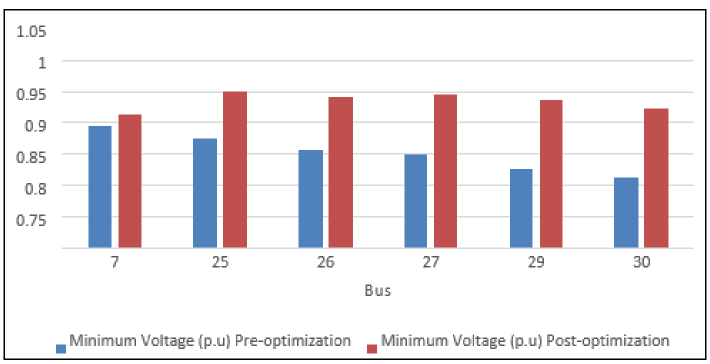


**Figure 5:** Comparison of Minimum Voltage and System Loss between Pre-optimization and Post-optimization (Case 3)

## 4. CONCLUSION

Overall, this project has presented the application of compensating capacitor in minimizing the system loss with optimal size of reactive power injection found using artificial immune system (AIS) optimization technique. It can also be seen that voltage stability of the system has also improved by the compensating capacitor installation. This approach of using AIS to find the optimal of reactive power injection of compensating capacitor is very useful for grid system operators (GSOs) in ensuring their system is operating in stable and optimal condition.

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**Table 2:** Optimization Result for Case Study 1

| Bus | Optimal Reactive Power Injection (MVar) | Pre-optimization | | Post-optimization | |
|---|---|---|---|---|---|
| | | System Loss (MW) | Minimum Voltage (p.u) | System Loss (MW) | Minimum Voltage (p.u) |
| 30 | 3.5338 | 17.7396 | 0.9768 | 17.6810 | 1.0037 |

**Table 3:** Optimization Result for Case Study 2

| Bus | Optimal Reactive Power Injection (MVar) | Pre-optimization | | Post-optimization | |
|---|---|---|---|---|---|
| | | System Loss (MW) | Minimum Voltage (p.u) | System Loss (MW) | Minimum Voltage (p.u) |
| 7 | 5.6081 | 19.4140 | 0.9464 | 19.2712 | 0.9636 |

**Table 4:** Optimization Result for Case Study 3

| Bus | Optimal Reactive Power Injection (MVar) | Pre-optimization | | Post-optimization | |
|---|---|---|---|---|---|
| | | System Loss (MW) | Minimum Voltage (p.u) | System Loss (MW) | Minimum Voltage (p.u) |
| 7 | 5.0490 | | 0.9464 | | 0.9629 |
| 25 | 1.6158 | | 0.9252 | | 1.0006 |
| 26 | 2.4923 | 21.6463 | 0.9057 | 20.8839 | 0.9922 |
| 27 | 3.2237 | | 0.9005 | | 0.9947 |
| 29 | 2.8074 | | 0.8776 | | 0.9858 |
| 30 | 1.7232 | | 0.8643 | | 0.9737 |