

# Multi-objective Single DGPV Planning in Transmission System using Artificial Immune Systems Optimization Technique

Sharifah Azwa Shaaya, Ismail Musirin, and Shahril Irwan Sulaiman

**Abstract**— In this paper, a compensation scheme to impose an acceptable transmission system voltage profile and to minimise its active power loss while keeping a low cost was orchestrated. Loss and voltage of a power system are significant issues as they effect the power system quality of service. The installation of DGs has shown positive impacts to reduce system loss with some side-enhancement on the system voltage. This paper analyses the effect of installing DG to reduce the transmission system loss while at the same time ensuring the system voltage is within allowable operating limit with a DG cost constrained. The Optimal DG sizes and location were determined using Artificial Immune Systems (AIS). IEEE 30-Bus reliability test system was used as the transmission testbed. The results demonstrate that an optimal single real-power DG is able to ensure that the transmission voltage can be sustained within a recommended limit and at the same time reduce the system loss with minimal DG cost, which in turns would be beneficial to the power provider.

**Index Terms**— Distributed Generation, Real Power DG, voltage control, Loss Control, Artificial Immune Systems.

## I. INTRODUCTION

POWER loss and voltage deviation are two of the key issues in power system as they reduce the power transfer as well as causing under- or over-voltage phenomenon that can be interpreted as monetary loss to the power provider. Distributed generation (DG) technologies were found to be able to reduce power system loss while improving system voltage, especially when their sizes and placements are meticulously selected [1, 2]. In controlling the voltage profile of the power system, unified power factor controller (UPFC), as a flexible AC transmission systems (FACTS) devices, is suggested by ref. [3].

Plenty of studies were conducted to reduce power system loss by placing DG at the distribution side [4–7]. Very few studies investigated the effects of DG installation to the transmission network. The works however concluded that medium sized DGs are also able to reduce transmission network loss and improve voltage stability when DG location, DG size or both,

were optimally selected [8–10]. The determination of optimal DG location and/or size are important to ensure the attainment of the objective function. As such, a lot of researches were conducted to improve a power system by using various optimization techniques to determine the optimal DG to be installed in the system [11]. AIS are some example of classical optimization techniques. AIS are computational intelligence methods inspired by the biological immune systems. They have been applied to solve many engineering problems like generation scheduling, power dispatch and network reconfiguration [12–15].

Optimization can be performed to achieve a single objective function or multi-objective functions. Multi-objective optimization has drawn special attention from the computational intelligence society researchers due to its wide applicability in solving the science and engineering problem, although it cannot be treated as a universal problem solver [16].

In this paper, AIS is used to determine the optimal location and size of single DG with three objective functions. The multi-objectives are given proper weights and added to from a single objective. The DG to be used is a DG that deliver real power, such as photovoltaic or DGPV. Simulation was made on an IEEE 30-Bus reliability test system (RTS) to represent a small transmission power system.

## II. PROBLEM FORMULATION

The aim of this study is to observe the effect of single DG installation in power system to reduce the system loss while keeping the system voltage within an operating range with minimum DG cost. The DG power is limited to 50MW, based on the maximum PV output tabulated in [17].

The objective function is to minimize total system loss, represented mathematically as equation (1), to enhance the

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system voltage such that it is within  $\pm 5\%$  of ideal nominal value as in equation (2) and to minimize the DG capital cost as in equation (3).

$$O.F_1 = \text{Min} \sum_{i=1}^n P_{loss,i} \quad (1)$$

$$O.F_2 = 0.95 \leq V_{min} \leq 1.05 \quad (2)$$

$$O.F_3 = \text{Min} (DG_{cost}) \quad (3)$$

where  $n$  is number of bus in the system, and  $P_{loss}$  for each  $i$  line can be determined following equation (4) – (6)

$$P_{loss} = \sum_{i=1}^n \sum_{j=1}^n [\alpha_{ij}(P_i P_j + Q_i Q_j) + \beta_{ij}(Q_i P_j + P_i Q_j)] \quad (4)$$

where  $r_{ij}$  represents line resistance between bus  $i$  and bus  $j$ ,  $V_i$  and  $V_j$  represent voltage magnitude,  $\delta_i$  and  $\delta_j$  represent voltage angles while  $P_i$ ,  $P_j$ , and  $Q_i$ ,  $Q_j$  represent active and reactive power at bus  $i$  and  $j$  respectively.

The cost of the real power DG is taken from ref [18] as tabulated in Table 1.

TABLE 1  
MEAN INSTALLED COST OF A REAL-POWER DG

Technology Type	Mean installed cost (\$/kW)
PV <10 kW	\$3,910
PV 10 - 100 kW	\$3,819
PV 100 - 1,000 kW	\$3,344
PV 1-10 MW	\$2,667

\*Unit cost is per kilowatt of the electrical generator, not the boiler capacity

The three objective functions were given a pre-fixed weightage each, namely  $w_1$ ,  $w_2$  and  $w_3$  and summed to be one single objective  $F_{multi}$  such that

$$F_{multi} = \text{Min} \sum_{i=1}^{n=3} w_i * O.F_i \quad (7)$$

$$\sum_{i=1}^{n=3} w_i = 1 \quad (8)$$

where  $w_1$ ,  $w_2$  and  $w_3$  are fixed to be 0.4, 0.3 and 0.3 respectively.

The objective functions are however subjected to power balance equality constraint defined by equation (9):

$$\sum_{i=1}^n P_i = P_{demand} + P_{loss} \quad (9)$$

where  $P_{demand}$  is total system load demand and  $P_{loss}$  is the total system loss. The inequality constraint as equation (10) is also considered:

$$P_{i,min} \leq P_i \leq P_{i,max} \quad (10)$$

where  $P_{i,min}$  and  $P_{i,max}$  are minimum and maximum real power output of  $i^{th}$  generator, respectively.

### III. ARTIFICIAL IMMUNE SYSTEMS

In this work, optimal DGs sizes are placed at optimal load buses of IEEE-30 RTS to compensate system loss while load increases. These optimal DG sizes and location were determined using Artificial Immune Systems (AIS) optimization

$$\alpha_{ij} = \frac{r_{ij}}{V_i V_j} \cos(\delta_i - \delta_j) \quad (5)$$

$$\beta_{ij} = \frac{r_{ij}}{V_i V_j} \sin(\delta_i - \delta_j) \quad (6)$$

technique. AIS technique is explained below.

#### A. Artificial Immune Systems (AIS) Technique

Flowchart for a general AIS optimization technique is shown in Fig. 1. The process is briefly explained:

- Step 1: Initialization process of AIS is conducted by generating the control variables representing optimal DG location,  $\lambda_n$  and size,  $s_n$  using a uniformly distributed random number generation.
- Step 2: Fitness of the transmission system, i.e. the total system's loss with optimal DG installation will be determined from load flow. Only individuals capable of reducing the total loss are selected into the pool, forming the initial population called parents.
- Step 3: Once the pool is full, the parents will be cloned by  $k$  to increase the population. The grown population is then mutated using the Gaussian mutation operator, generating new individuals, known as offspring. Load flow is then run to determine the fitness of the offspring.
- Step 4: The offspring will compete in a tournament process, where  $n$  individuals with best fitness will be transcribed to the convergence test process.

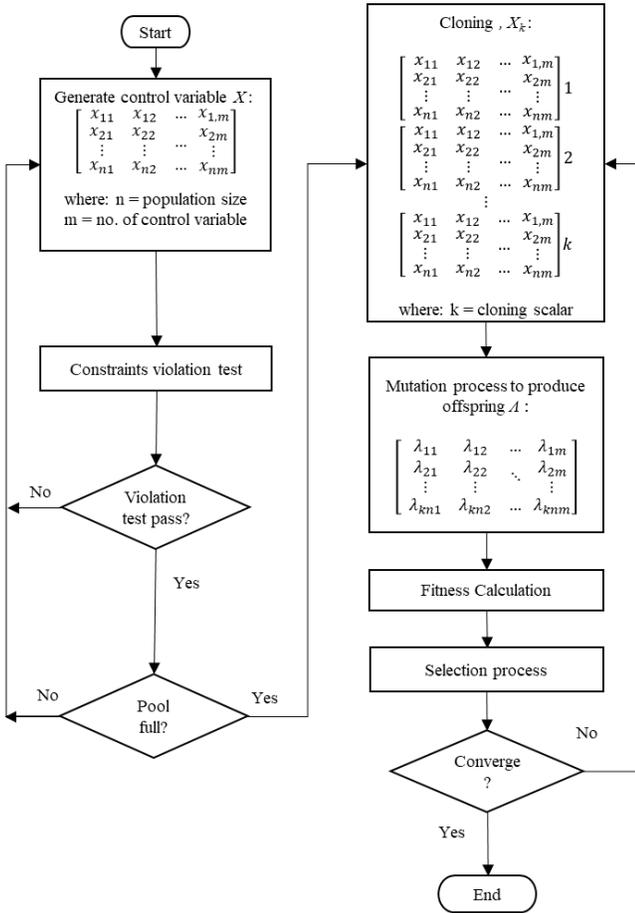


Fig. 1: Flowchart for AIS technique

Step 5: A convergence test will calculate the difference between the highest and lowest fitness such that

$$Loss_{max} - Loss_{min} \leq 0.00001 \quad (11)$$

Should this condition be met, optimal DG locations and sizes will be recorded. Otherwise, repeat Step 3 until Step 5.

The transmission system loss and voltage before DG installation in the system will be compared with the system loss and voltage with the DG installation. Loss reduction percentage (LRP) due to DG installation will be calculated using equation (12).

$$LRP = \frac{Loss_{No\ DG} - Loss_{DG}}{Loss_{No\ DG}} \times 100 \% \quad (12)$$

where  $Loss_{No\ DG}$  and  $Loss_{DG}$  are the system loss without and with DG installation. Whereas, to examine the voltage improvement, the voltage enhancement percentage (VEP) is going to be used such that

$$VEP = \frac{Volt_{DG} - Volt_{No\ DG}}{Volt_{No\ DG}} \times 100 \% \quad (13)$$

where  $Volt_{No\ DG}$  and  $Volt_{DG}$  are the system voltage without and with DG installation.

#### IV. RESULTS AND DISCUSSIONS

Reactive load,  $Q_d$ , on Bus-30 of IEEE-30 RTS was incremented, from 0MVar to 30MVar. Table 2 shows the system losses and minimum voltage with and without single DGPV installation while reactive load  $Q_{d30}$  increases. When  $Q_{d30}=0$ MVar, the system loss was reduced from 17.56MW to 17.51MW while the system minimum voltage has no changes with the installation of the optimal DGPV. This loss reduction corresponds with 0.3% LRP. As the reactive load increases, the LRP become more significant. The LRP with DGPV installation when  $Q_{d30}$  is 10MVar, 20MVar and 30MVar are 9.85%, 9.20% and 8.58% respectively. Referring to the system voltage, the DGPV installation manages to enhance the voltage at all load, except at  $Q_{d30}=0$ MVar. But this is OK as the system voltage is in the desired range.

TABLE II  
IEEE-30 RTS LOSS AND LRP WITH SINGLE DGPV

$Q_{d30}$ (MVar)	Loss <sub>ini</sub> (MW)	VP <sub>ini</sub> (p.u)	Loss <sub>DG</sub> (MW)	VP <sub>DG</sub> (p.u)	LRP (%)	VE P (%)
0	17.6	1.004	17.51	1.004	0.3	0.0
10	18.1	0.933	16.33	0.968	9.9	3.8
20	19.6	0.844	17.75	0.950	9.2	12.6
30	23.4	0.707	21.43	<b>0.751</b>	8.6	6.2

It is noticeable from Table 2 that the system voltage decreases from 1.0036p.u to 0.7069p.u as  $Q_{d30}$  increases from 0MVar to 30MVar. Single DGPV installation managed to enhance the system minimum voltage from 0.9326p.u to 0.9681p.u and from 0.8438 to 0.9500p.u at  $Q_{d30}=10$ MVar and 20MVar respectively. However, at  $Q_{d30}=30$ MVar, a single DGPV installation was not able to increase the system voltage to the desired range of 0.95p.u to 1.05p.u as highlighted. For this reason, the following discussion will not consider the case with  $Q_{d30}=30$ MVar.

Table 3 presents the optimal multi-objective function  $F_{multi}$ , determined by AIS technique, together with the optimal DG location and size as well as the corresponding DG cost. Table 3 shows that the DGPV size increases as the reactive load increases. At  $Q_{d30}=20$ MVar, the DGPV is located at the weak Bus-30 with the size of 49.8MW, close to the maximum limit set at 50MW for the DGPV. With this DGPV size, the corresponding DG cost is \$133Mil and unsurprisingly the  $F_{multi}$  at this load is the highest among all reactive load as it is a function proportional to the cost. As such, the DG size and

location must be optimized so that a balance is achieved between the system loss, voltage and the DGPV cost.

TABLE III  
OPTIMAL SINGLE DGPV LOCATION AND SIZES

$Q_{d30}$ (MVar)	$F_{mult}$	DG <sub>cost</sub> (\$)	DG Loc. (Bus)	DG Size (MW)
0	0.42	1.27E+06	21	0.38
10	0.48	2.93E+07	30	10.77
20	0.79	1.33E+08	30	49.81

V. CONCLUSIONS

It can be concluded that as reactive load at a weak bus increases, so thus the DGPV size in order to reduce the system loss and enhance its voltage profile. The DGPV size increases as the reactive load increases and voltage decreases, but limited to a certain extent as it cannot enhance the voltage to the range suggested by IEEE standard at all reactive load. Should a power provider wish to increase the reactive load at a weak bus such as Bus-30 of IEEE 30-Bus RTS, it must limit the maximum loadability for a DGPV to compensate the system loss and voltage reduction.

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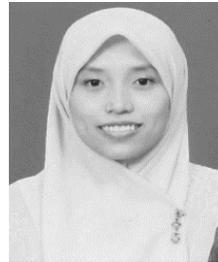
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