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 ±5% of ideal nominal value as in equation (2) and to minimize the DG capital cost as in equation (3).

$$O.F_1 = Min \sum_{i=1}^{n} P_{loss,i} \tag{1}$$

$$O.F_2 = 0.95 \leq V_{min} \leq 1.05 \tag{2}$$

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

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

$$P_{loss} = \sum_{i=1}^{n}\sum_{j=1}^{n}\left[\alpha_{ij}\left(P_iP_j + Q_iQ_j\right) + \beta_{ij}\left(Q_iP_j + P_iQ_j\right)\right] \tag{4}$$

where r_{ij} represents line resistance between bus i and bus j, V_i and V_j represent voltage magnitude, δ_i and δ_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

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

$$\sum_{i=1}^{n=3} w_i = 1 \tag{8}$$

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):

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

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:

$$P_{i,min} \leq P_i \leq P_{i,max} \tag{10}$$

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 Artifical Immune Systems (AIS) optimization

$$\alpha_{ij} = \frac{r_{ij}}{V_iV_j}\cos\left(\delta_i - \delta_j\right) \tag{5}$$

$$\beta_{ij} = \frac{r_{ij}}{V_iV_j}\sin\left(\delta_i - \delta_j\right) \tag{6}$$

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, λ_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.

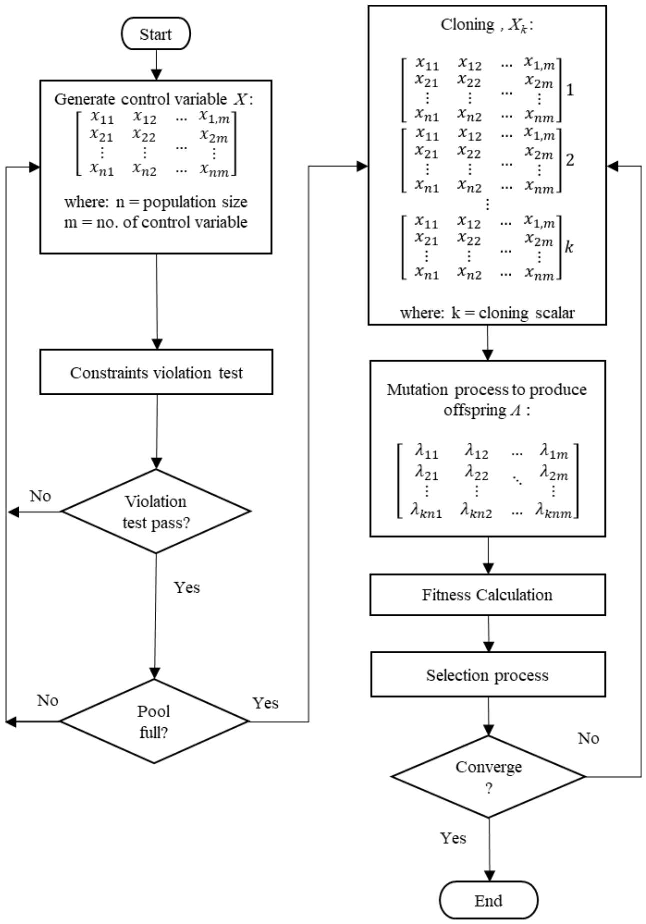

Fig. 1: Flowchart for AIS technique

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

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

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).

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

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

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

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}=0MVar, 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}=0MVar. 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)	$Loss_{ini}$ (MW)	VP_{ini} (p.u)	$Loss_{DG}$ (MW)	VP_{DG} (p.u)	LRP (%)	VEP (%)
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	**0.751**	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}=10MVar and 20MVar respectively. However, at Q_{d30}=30MVar, 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}=30MVar.

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}=20MVar, 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_{cost} ($)	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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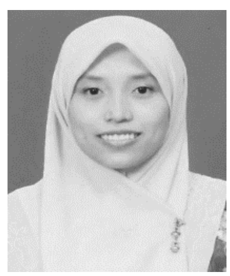

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