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A Placement and Sizing of Distributed Generation Based on Combines Sensitivity Factor and Particle Swarm Optimization: A Case Study in Bali's Power Transmission Networks

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Abstract— **Although many methods for optimizing DG placement and its size in a network with the target of reducing system power losses and voltage profile have already been commended, they still lack from several weaknesses. As a result much can be done about to happen with new algorithms. The proposed algorithms commonly have stressed their formulations on real power losses only and ignored the reactive power losses. Power systems reactive power injection plays an important role in voltage stability control, thus the reactive power losses need to be incorporated in optimizing DG allocation considering their voltage profile improvement. Whereas Particle Swarm Optimization (PSO) approach was proposed for finding the optimal size of DG. This study work intended to apply both real and reactive power flow, power loss sensitivity factors and PSO method in finding the candidate buses for DG placement and its size on Bali's 150 kV transmission networks. The experimental results show that the proposed algorithm is indeed capable of obtaining a good quality solution efficiently.**

Keywords— distributed generation, real and reactive power flow, power loss sensitivity factors, PSO, voltage profile improvement

I. INTRODUCTION

The goal of power system operation is to meet the demand at all the locations within power network as reliably and economically as possible. The conventional electric power generation systems apply the conventional energy resources, such as fossil fuels for electricity generation. Its operation is based on centralized control utility generators to meet the given demands of widely users. Currently, the rationalization for the large central-station plants is fading due to depleting conventional resources [1-2].

Distributed generation (DG) is small-scale power generation that is regularly connected to distribution system. The Electric Power Research Institute (EPRI) defines DG as generation up to 50MW [3]. Recently, Bali needs to develop DG to meet the electricity demand for its population. There are some reasons for this. First, tourism sector which always pays attention to green environtment and clean energy is the key driver of economic development in Bali. Then, Bali Province is a pilot project for the development and execution of renewable energy. The last, Bali Eco Smart Grid is a step towards a Bali Bersih as the province without carbon emissions resulting from energy such as electricity [4].

Usually, the DG when connected to network can offer a number of advantages. Some of the advantages are power losses reduction, energy undelivered costs reduction, preventing network expansion, and improved voltage profile and load factor [5-7]. On the other hand, DG can also have disadvantages on network, such as frequency deviation, voltage deviation and harmonics on network, and increase of power losses is another effect that may occur [8-9]. Thus, careful considerations need to be done when placing DGs in power systems.

The recognizing an appropriate placement of DG in radial along with loop systems to lessen losses has been offered as an analytical approach. But, in this method, optimal sizing is not considered [10]. Optimal placement of DG units for the various distributed load outlines is resoluted completely to minimize the total losses. A multiobjective optimization approach is presented in [11-13] for determining optimal location of DGs with an aim of improving the voltage profile and reducing the line losses. This approach united both power flow and power loss sensitivity factors in classifying the most appropriate zone and then optimized the solution by maximizing the voltage improvement and minimizing the line losses in the network. But, reactive power loss did not consider in optimization.

With the purpose of helping to broaden the knowledge about optimal allocation of DG on power system. Consequently, the placement of DG units should be cautiously resoluted with the attention of technical planning. The effect of placing a renewable DG on distribution network indices usually differs on the basis of its type, location, size, and load at the connection point [14-15].

This study presents a thorough study concerning the analytical approach of placement DG based on Combine Sensitivity Factor [16]. While, it sizing the DG is indeed complex problem. Practically, the heuristic methods are more suitable to resolve such complex problems rather than the analytical ones [17]. PSO is proposed to find solutions with faster convergence compared than other population-based algorithms. The advantages of PSO are easy to implement and there are few parameters to adjust [18]. The work is mainly carried out through nonlinear simulations under MATLAB [19-20].

This work is organized as follows. A research method is presented on Section 2. Section 3 presents research and analysis, whereas the conclusion followed by the references is presented on Section 4..

II. RESEARCH METHOD

*A. **The factors of power flow sensitivity***

The real power flow and reactive power flow in a line *l* connecting two buses, which are bus *i* and bus *j*, can be stated as:

$$P_{ij} = V_i V_j Y_{ij} \cos(\theta_{ij} + \delta_{ij}) - V_i^2 Y_{ij} \cos\theta_{ij} \tag{2.1}$$

$$Q_{ij} = V_i V_j Y_{ij} \sin(\theta_{ij} + \delta_{ij}) - V_i^2 Y_{ij} \sin\theta_{ij} - \frac{V_i^2 Y_{sh}}{2} \tag{2.2}$$

The power sensitivity is the change in real power flow (ΔP_{ij}) and reactive power flow (ΔQ_{ij}) in a transmission line-*k* connected between bus-*i* and bus-*j* due to unit change in the power injection (ΔP_n) and (ΔQ_n), respectively, at any bus-*n*. Mathematically, the power flow sensitivity can be written as $\frac{\Delta P_{ij}}{\Delta P_n}$ and $\frac{\Delta Q_{ij}}{\Delta Q}$.

Using, Taylor series approximation, change in line flows can be written by ignoring second and higher order terms as

$$\Delta P_{ij} = \frac{\partial P_{ij}}{\partial \delta_i}\Delta\delta_i + \frac{\partial P_{ij}}{\partial \delta_j}\Delta\delta_j + \frac{\partial P_{ij}}{\partial V_i}\Delta V_i + \frac{\partial P_{ij}}{\partial V_j}\Delta V_j \tag{2.3}$$

$$\Delta Q_{ij} = \frac{\partial Q_{ij}}{\partial \delta_i}\Delta\delta_i + \frac{\partial Q_{ij}}{\partial \delta_j}\Delta\delta_j + \frac{\partial Q_{ij}}{\partial V_i}\Delta V_i + \frac{\partial Q_{ij}}{\partial V_j}\Delta V_j \tag{2.4}$$

The coefficients appearing in (2.3) and (2.4) can be attained using the partial derivatives of real and reactive power flow with respect to variables δ and *V* as:

$$\begin{bmatrix} \frac{\partial P_{ij}}{\partial P_n} \\ \frac{\partial P_{ij}}{\partial Q_n} \end{bmatrix} = \begin{bmatrix} F_{P-P} \\ F_{P-Q} \end{bmatrix} = [J^T]^{-1} \begin{bmatrix} \frac{\partial P_{ij}}{\partial \delta} \\ \frac{\partial P_{ij}}{\partial V} \end{bmatrix} \tag{2.5}$$

$$\begin{bmatrix} \frac{\partial Q_{ij}}{\partial P_n} \\ \frac{\partial Q_{ij}}{\partial Q_n} \end{bmatrix} = \begin{bmatrix} F_{Q-P} \\ F_{Q-Q} \end{bmatrix} = [J^T]^{-1} \begin{bmatrix} \frac{\partial Q_{ij}}{\partial \delta} \\ \frac{\partial Q_{ij}}{\partial V} \end{bmatrix} \tag{2.6}$$

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*B. **The factors of power loss sensitivity***

The real power loss and reactive power loss in a line *l* connecting two buses, which are bus *i* and bus *j*, can be stated as:

$$P_{L(ij)} = g_{ij}\left(V_i^2 + V_j^2 - 2V_i V_j \cos\delta_{ij}\right) \tag{2.7}$$

$$Q_{L(ij)} = -b_{ij}^{sh}\left(V_i^2 + V_j^2\right) - b_{ij}\left(V_i^2 + V_j^2 - 2V_i V_j \cos\delta_{ij}\right) \tag{2.8}$$

From Eq. (2.7) and (2.8), the power flow sensitivity factors can be assessed using;

$$\begin{bmatrix} \frac{\partial P_{L(ij)}}{\partial P_n} \\ \frac{\partial P_{L(ij)}}{\partial Q_n} \end{bmatrix} = \begin{bmatrix} S_{P-P} \\ S_{P-Q} \end{bmatrix} = [J^T]^{-1} \begin{bmatrix} \frac{\partial P_{L(ij)}}{\partial \delta} \\ \frac{\partial P_{ij}}{\partial V} \end{bmatrix} \tag{2.9}$$

$$\begin{bmatrix} \frac{\partial Q_{L(ij)}}{\partial P_n} \\ \frac{\partial Q_{L(ij)}}{\partial Q_n} \end{bmatrix} = \begin{bmatrix} S_{Q-P} \\ S_{Q-Q} \end{bmatrix} = [J^T]^{-1} \begin{bmatrix} \frac{\partial Q_{L(ij)}}{\partial \delta} \\ \frac{\partial Q_{ij}}{\partial V} \end{bmatrix} \tag{2.10}$$

The factor of combined sensitivity (CSF) of individually bus is gained as follows

$$CSF_i = \left(F_{P-P_i} \times F_{Q-P_i}\right) + \left(F_{P-Q_i} \times F_{Q-Q_i}\right) + \left(S_{P-P_i} \times S_{Q-P_i}\right) + \left(S_{P-Q_i} \times S_{Q-Q_i}\right) \tag{2.11}$$

*C. **Particle Swarm Optimization***

PSO algorithm was first introduced by Kennedy and Eberhart in 1995. It has paying attention many scientists' attention and has been applied with countless achievement to extensive engineering studies. The method is based on a simple concept and can also be easily implemented by software codes.

The PSO algorithm is an adaptive algorithm based on a social–psychological metaphor [21]. Individuals in a population are adapted by recurring stochastically toward previously successful regions in the search space and are predisposed by the accomplishments of their topological neighbors. Every individual in particle swarm is called as a particle which represents a potential solution. Then every particle moves its position in search space and updates its velocity according to its own and neighbors' flying experience aiming to find a better position for itself.

Every particle in the population is treated as a mass-less and volume-less point in a *D*-dimensional space. A particle *i* is represented as $X_i = (x_{i1}, x_{i2}, \ldots, x_{iD})$. The position associated with the best fitness is regarded as its current best position. This position is recorded and represented as $P_i = (p_{i1}, p_{i2}, \ldots, p_{iD})$. Its corresponding fitness value which called the individual best P_{best_i} is also recorded. The overall best position of the population related with the current overall best fitness value *Gbest*, is recorded and characterized as $P_g = (p_{g1}, p_{g2}, \ldots, p_{gD})$. The velocity (the rate of the position change for particle *i*) is described as $V_i = (v_{i1}, v_{i2}, \ldots, v_{iD})$. Throughout the iteration procedure, the velocity and position of particle *i* are updated according to the following equations:

$$v_{id}^{(t+1)} = w.v_{id}^{(t)} + C_1.rand.(p_{best} - x_{id}) + C_2.rand.(g_{best} - x_{id}) \quad (2.12)$$

$$x_{id}^{(t+1)} = x_{id}^{(t)} + v_{id}^{(t+1)} \quad (2.13)$$

where the inertia weight w describes the weighting of previous velocity of a particle and the acceleration constans $C_1$and C_2 represents the weighting of stochastic acceleration terms that pull every particle toward the individual best position and overall best position. The range of $C_1$and C_2 are between 1 and 2.

The proposed analytical approach based method for placing DG units and optimazing its size in the *Bali*'s 150 kV transmission systems is as detailed in the following application steps, seen in Fig 2.1.

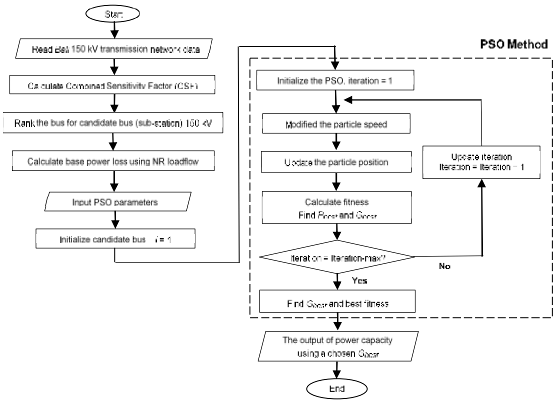

Fig. 2.1. Simulation flowchart

III. RESULTS AND ANALYSIS

In this case the DGs were presumed to be located in a *Bali*'s 150 kV transmission network, seen in Fig. 3.1. The potential of each type of DG size is predicted up to 10 MW [22].

The combined sensitivity factors of the buses were evaluated and the buses which contributed a combined sensitivity factor of more than 0.0900 were taken to be the candidate buses. So as to be able to choose the optimal locations of the DGs, results were obtained taking into attention all the candidate buses.

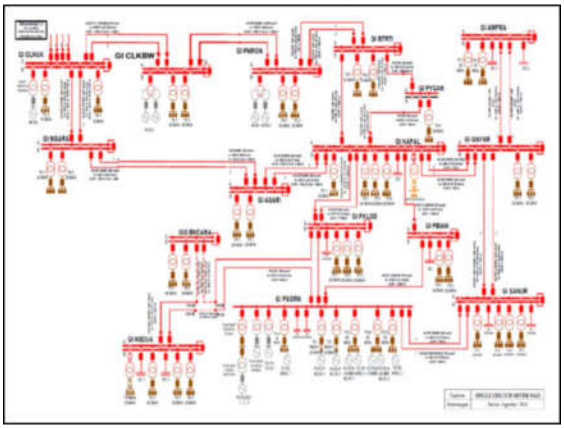

Fig. 3.1. Single diagram of *Bali*'s 150 kV transmission network [22]

Table 3.1. VHV line data of *Bali*'s 150 transmission system

NO	LINE BUS	TYPE	LINE (Kms)
1	*GH Gilimanuk – GH Ketapang 1*	OFC 3 PHASA	4,20
2	*GH Gilimanuk – GH Ketapang 2*	OFC 3 PHASA	4,20
3	*GH Gilimanuk – GI Gilimanuk 1*	ACSR.HAWK	1,72
4	*GH Gilimanuk – GI Gilimanuk 2*	ACSR.HAWK	1,72
5	*Gilimanuk – Negara 1*	ACSR.HAWK	43,69
6	*Gilimanuk – Negara 2*	ACSR.HAWK	43,69
7	*Gilimanuk – Pemaron*	2XACSR.HAWK	75,90
8	*Negara – Antosari 1*	ACSR.HAWK	44,40
9	*Negara – Antosari 2*	ACSR.HAWK	44,40
10	*Kapal – Antosari 1*	ACSR.HAWK	23,31
11	*Kapal – Antosari 2*	ACSR.HAWK	23,31
12	*Kapal-Baturiti*	T.ACSR 160 mm	38,17
13	*Kapal – Payangan*	T.ACSR 160 mm	21,48
14	*Kapal – Payangan*	ACSR.HAWK	5,20
15	*Kapal – Gianyar 1*	ACSR.HAWK	19,21
16	*Kapal – Gianyar 2*	ACSR.HAWK	19,21
17	*Kapal – Nusa Dua*	ACSR.PARTRIDGE	20,91
18	*Kapal – Nusa Dua*	OLEQ XLPE	0,96
19	*Kapal – Padang Sambian*	ACSR.HAWK	9,97
20	*Gianyar - Sanur 1*	ACSR.PARTRIDGE	16,50
21	*Gianyar - Sanur 2*	ACSR.HAWK	16,38
22	*Gianyar – Amlampura 1*	ACSR.HAWK	33,76
23	*Gianyar – Amlampura 2*	ACSR.HAWK	33,76
24	*Sanur - Pesanggaran 1*	ACSR.PARTRIDGE	7,74
25	*Sanur - Pesanggaran 2*	ACSR.HAWK	7,75
26	*Nusa Dua – Pesanggaran*	ACSR.PARTRIDGE	13,41
27	*Nusa Dua – Pesanggaran*	XLPE	1.2
28	*Baturiti – Pemaron 1*	T.ACSR	20,43
29	*Baturiti – Pemaron 2*	T.ACSR	20,43
30	*Pesanggaran – Padangsambian*	ACSR.HAWK	7,76
31	*Baturiti – Payangan*	T.ACSR	27,14
32	*Baturiti – Payangan*	ACSR.HAWK	5,20

Table. 3.2. Sub-station capacity

NO	NAME	TRAFO NO	CAPACITY (MVA)	KILO VOLT	AMPERE
1.	*Gilimanuk*	I	10	150/20	288.6 A
		II	10	150/20	288.6 A
2	*Negara*	I	15	150/20	433 A
		II	15	150/20	433 A
3.	*Antosari*	I	10	150/20	288.7 A
4.	*Kapal*	I	20	150/20	577.4 A
		II	20	150/20	577.4 A
		III	60	150/20	1732 A
		IV	60	150/20	1732 A

		V	50	150/20	3849 A
5.	*Padang Sambian*	I	60	150/20	1732 A
		I	30	150/20	866 A
6.	*Pesanggaran*	I	30	150/20	866 A
		II	30	150/20	866 A
		III	60	150/20	1732 A
		IV	60	150/20	1732 A
		V	60	150/20	1732 A
7.	*Nusa Dua*	I	30	150/20	866 A
		II	20	150/20	577.4 A
		III	30	150/20	866 A
		IV	20	150/20	577,4 A
8.	*Sanur*	I	30	150/20	866 A
		II	30	150/20	866 A
		III	60	150/20	866 A
9.	*Gianyar*	I	60	150/20	1732 A
		II	30	150/20	866 A
10.	*Baturiti*	I	16	150/20	462 A
11.	*Amlapura*	I	20	150/20	577.4 A
		II	10	150/20	866 A
12.	*Pemaron*	I	30	150/20	866 A
		II	30	150/20	866 A
13.	*Payangan*	I	30	150/20	866 A
14.	*Antosari*	I	10	150/20	288,7 A
15.	*Pemecutan Kelod*	I	60	150/20	1732 A

This was completed for DG and the obtained results tabulated as Table 3.3. The buses with CSF more than 0.0900 are *Payangan*, *Kapal*, *Gianyar*, *Amlampura*, *Pemecutan Kelod*, and *Sanur*, seen in Fig. 3.2. Whereas the optimal size of DG is seen in Table 3.4.

Table 3.3. Results of CSF for candidate buses

NO	BUS	CSF
1	*Gilimanuk*	0.0000
2	*Celukan Bawang*	0.0034
3	*Pemaron*	0.0433
4	*Baturiti*	0.0808
5	*Payangan*	0.0986
6	*Negara*	0.0246
7	*Antosari*	0.0357
8	*Kapal*	0.1407
9	*Gianyar*	0.1534
10	*Amlapura*	0.0864
11	*GIS Bandara*	0.0862
12	*Pemecutan kelod*	0.1096
13	*Padang Sambian*	0.0815
14	*Nusa Dua*	0.0832
15	*Pesangggaran*	0.0376
16	*Sanur*	0.1175

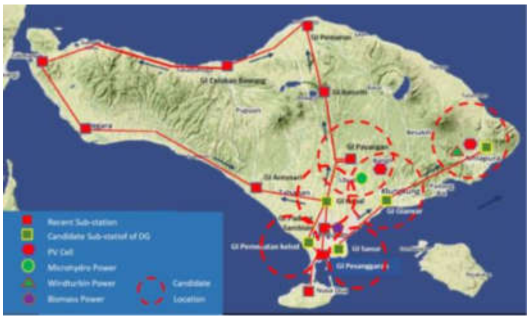

Fig. 3.2. Candidate locations of DGs on *Bali'*s VHV 150 kV transmission network

Table 3.4. The results for CSF, Fitness, and optimal of DG of candidate location of VHV 150 kV Bali

NO	CANDIDATE BUS	CSF	FITNESS	DG SIZE (MW)
1	*Payangan*	0.0986	0.9008	9.4332
2	*Kapal*	0.1407	0.9016	8.9808
3	*Gianyar*	0.1534	0.9039	7.7931
4	*Amlapura*	0.0864	0.9016	9.2438
5	*Pemecutan Kelod*	0.1096	0.9004	9.5985
6	*Sanur*	0.1175	0.9010	9.9179

With the chosen six DG sizes and its locations, a load flow assesment was accomplished using Newton Raphson method so as to determine the associated power losses and voltage levels. The result is given in the table below.

Table 3.5. The power losses results obtained using DG on *Bali's* VHV 150 kV system

SUB-STATION NAME	DG SIZE (MW)	POWER LOSSES (MW)	POWER LOSS REDUCTION (MW)	PERCENTAGE POWER LOSS REDUCTION (% MW)
Payangan *Kapal* *Gianyar* *Amlapura* *Pemecutan kelod* *Sanur*	9.4332 8.9808 7.7931 9.2438 9.5985 9.9179	49.473	3.428	6.7

Table 3.6. The voltage results obtained using DG on *Bali's* VHV 150 kV system

NO	SUB_STATION NAME	VOLTAGE WITHOUT DG (p.u)	VOLTAGE WITH DG (p.u)
1	*Payangan*	0.9041	0.9406
2	*Kapal*	0.8843	0,9006
3	*Gianyar*	0.8957	0.9100
4	*Amlapura*	0.9400	0.9500
5	*Pemecutan kelod*	0.8787	0.8908
6	*Sanur*	0.8800	0.8909

Table 3.5 shows that adding six DG into *Bali*'s VHV 150 kV system gave real power loss reduction more than 6.7 %, i.e. reducing from 52.901 to 49.473 MW. Furthermore, its optimal locations and their respective optimal sizes thus improved the voltage level, seen in Table 3.6.

IV. CONCLUSION

This paper gives the formulation and implementation of analytical and heuristical approach for system loss reduction in Bali's 150 kV transmmissionn network by optimal location of DGs and its size. Combined sensitivity factors were effectively utilized to come up with the candidate locations for DGs. For Payangan, Kapal, Gianyar, Amlampura, Pemecutan Kelod, and Sanur sub-stations which added DG around 0.9041 MW gave 6.7% real power loss reduction and thus improved the voltage level.

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