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A Review on Model of Integrating Renewable Distributed Generation into Bali's Power Distribution Systems: Issues, Challenges, and Possible Solutions

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Abstract

Spurred by a global energy crisis, the use of renewable distributed generation (DG) with solar photovoltaic (PV) energy, micro-hydro power, and biomass power are gaining momentum and play major role in Bali's distribution system as an alternative distribution system planning option. If distributed generation planning is optimal by selected optimization of multi-objective function under certain operating constraints and then their site and size are also selected optimally, the penetration of DGs is potentially beneficial. This paper would review techno-economic model objective, voltage profile improvement and power losses constraints as well as optimization based model using particle swarm optimization (PSO) algorithm application in Bali's distributed generation planning.

Keywords*: distributed generation, renewable energy, multi-objective function, techno-economic model, particle swarm optimization*

1. Introduction

Bali is is considering renewable energy resources like hydro, geothermal, solar, wind, and biomass as alternative for future energy needs. Although recently there have only been installed of renewable DG not more than 4 MW through PV, micro-hydro and biomass powers, Indonesian government declared that Bali was the area of clean energy [1].

Since most of the renewable DG are their early investment costs and investment risks compared to the other expansion planning scenarios are justly lower [2], therefore it becomes a stimulating task for integrating them into the power distribution networks. The great importance is the problem of DG location and sizing. The installation of DG units at non-optimal places and with non-optimal sizing can result in an increase in system losses, damaging voltage state, voltage flicker, protection, harmonic, and stability [3]. The accurately planning of renewable DG units should clearly suspend the new supports and installation of new units and components particularly in power distribution sector and also lead to some technical significances such as the enhancement of the system voltage profile and network losses [4-6]. The system reliability improvement and considerable reductions in the customer interruption costs are also among the other motivations followed on the growing implementation of the renewable DG units in power distributions systems [7-8].

On the opposing, lots of challenges and technical and economic concerns would be carried taking place in occurrence of renewable DG units in power distribution systems when designing the system [9]. In [10-11], the studies of integrating DG into power distribution networks have concerned only on technical aspects. Gaining the privatization process in electric industry into account and with the advent of deregulation trend, the economic factors also gain twice prominence and the renewable DG units have been then installed and operated not only with having the technical factors got run around, but also for the shake of lowering down the total amounts of cost and maximizing the benefits gained. Hence the emphasis on both aspects, technical and economic aspects, should be balanced. In [12], the increasing significance of the economic factors may occasionally lead to the degradation of the system technical performance.

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This paper describes the proposed model, namely techno-economic model, to integrate renewable DGs into Bali's distribution system. The suitable methodology has been chosen upon selected main criteria in the decision making problem from technical and economic aspects. A strong and well-proven optimization technique, namely PSO, has been proposed to be employed by which the proposed multi-objective formulation viz. techno-economic model has been applied on Bali's distribution system.

This paper is organized as follows: The literature review relating to the Bali's power distribution networks integration of renewable distributed generation is presented in Section 2. Whereas issues and challenges are presented in Section 3. Moreover, proposed solutions are described in Section 4. Finally, concluding remark followed by the references is described in Section 5.

2. Literature Review

Nowadays Bali has an electric power around 1500 MW. The electric power of 340 MW is supplied from outside of the island that is Jawa-Madura-Bali (Jamali) networks via Jawa-Bali 1,2,3,4 submarine cables, shown in Figure 1. While the rest is supplied by generators on the island itself, such as 280 MW, 130 MW, 80 MW, and 3x142 MW through Pesanggaran, Gilimanuk, Pemaron, and Celukan Bawang power stations, respectively. For the next ten years, Bali requires an additional 1500 MW in order that the activities of development, especially the tourism sector, are no longer constrained by an electrical problem in [13]. All of those energy sources have been extensively using the conversion of fossil fuels such as petroleum, coal and gas.

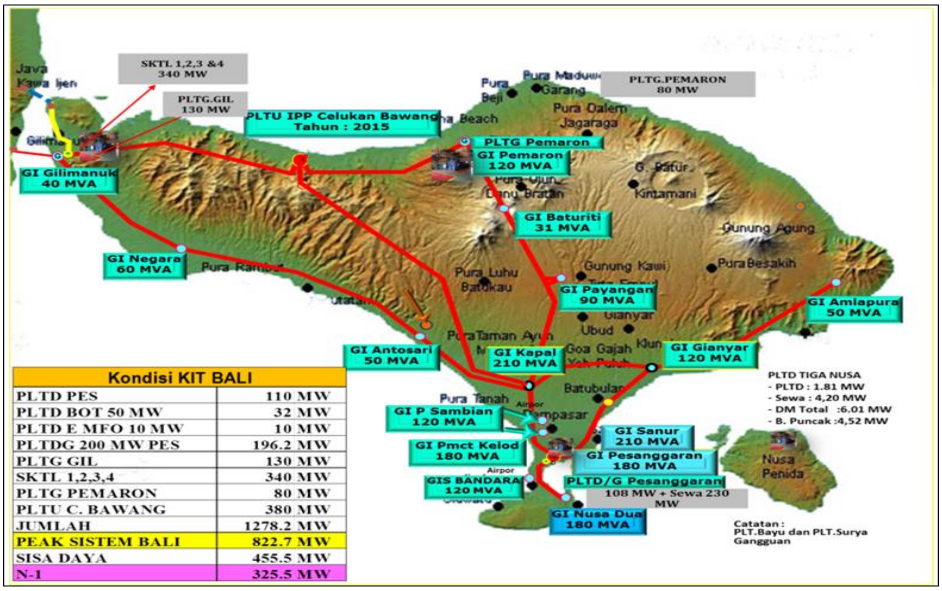

Figure 1. Single Line Diagram of Bali's 150 kV EHV Systems

These fossil energy resources are gradually reduced and the price continues to rise so it is necessary to look for other alternative energy sources that are such available abundantly in nature. This energy is renewable energy. Some renewable energy resources include hydro, geothermal, wind, solar and biomass. DG is well-suited to the use of these renewable energy technologies, because it can be located close to the user and can be installed in small units to match the load requirements of the customer. Some renewable DG have been installed in Bali with the power capacity exceeding more than 4 MW through PV, micro-hydro and biomass powers, shown in Figure 2. But their structures are off-grid [14-16].

In the past, renewable energy systems were not cost effective because of lower conversion efficiencies and uncontrollable electrical output. However, these key factors have contributed to increased opportunities for renewable energy systems. The first one is improvement in technologies including conversion efficiencies and power electronics for electrical power conditioning [17]. The second factor is changed interest in environmentally friendly power sources [18]. In the matter of environment, Bali makes serious efforts to fulfill its electrical demand using renewable DG that integrating them into the power distribution systems. And it leads to several technical and economic challenges.

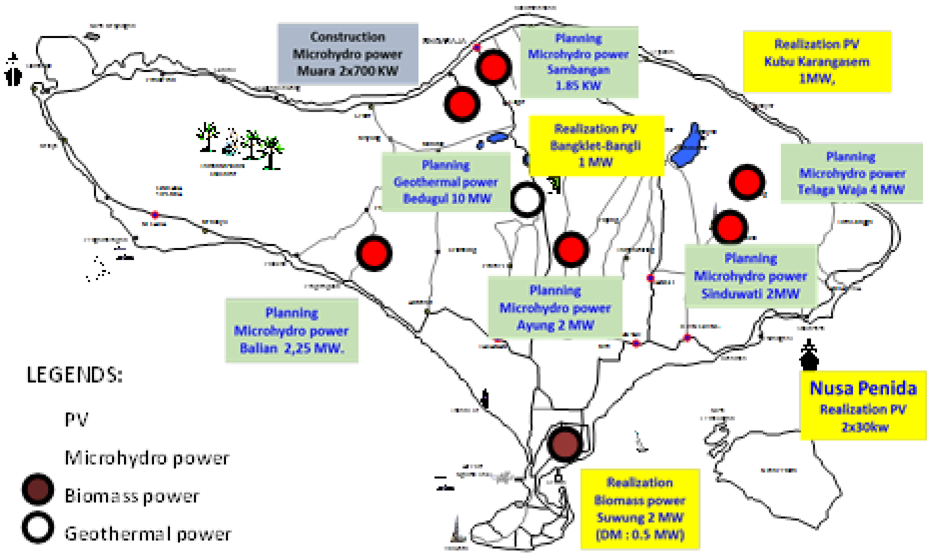

Figure 2. Planning and Realization of Renewable DG in Bali

Performance of renewable DG can be evaluated from technological and economic aspects. Effect on power quality, such as energy losses in [19] and sufficient power in [20], is one of the most important elements in nearly all DG evaluations, but is inadequate for comprehensive evaluations. In addition to the technology of renewable DG, investment cost is also crucial element in determining whether renewable DG should be installed [21]. Despite its potentials, installing the renewable DG to a power distribution grid is not as simple as “plug and play” problem. The problem becomes complex if different types of renewable DGs are considered.

The problems of renewable DG allocation can be expressed as an optimization problem with single objective function. The stability or reliability of system and losses of energy can be considered as objective functions respectively for the optimization studies [22-23]. Instead, the renewable DG allocation problems are modelled as a multi-objective problem. In [24-25], energy losses, voltage profile, fuel cost, and investment cost are regarded as objective functions and concurrently optimized by selected optimization technique. The multi-objective optimization has an advantage over single objective optimization i.e. it is that multi-objective optimization can offer a set of promising trade-offs rather than a crisp solution in single objective optimization. The popular multi-objective functions at recent is techno-economic model which combines both technical and economic aspects which been simultaneously optimized [26-29]. The selected optimizing method can be effectively determined as per the designer’s predominance without losing generality.

By considering of its multiple objectives, the optimal allocation and the size of renewable DG units in power distribution systems can be formulated as a non-deterministic optimization problem. The optimization problem not only involves non-linear and non-continuous objective functions but also involves discrete decision variables. In [30], it has been showed that the heuristic methods are more applied to solve such complex problems rather than the analytical methods. Particularly in [31-35], it has been observed that the population-based intelligent search methods have possible capabilities of gaining promising multi-objective solutions for these problems. Moreover, an algorithm named particle swarm optimization (PSO) in [36-39] is proposed to derive solutions with faster convergence compared to other population based algorithms. The advantages of PSO are that it is easy to implement and there are few parameters to adjust [40-41]. Both power flow and power loss sensitivity factors were utilized in identifying the candidate buses for renewable DGs allocations. This reduced the search space for the algorithm and also increasing its rate of convergence [42].

3. Issues and Challenges

The framework for proposed multi-objective distribution system expansion planning with renewable DG units should accomplish substantially both of technical and economic benefits. These benefits could be maximized by suitable planning i.e. sitting of renewable DGs at optimum locations with optimum size too. In this framework, the power suffiency and profitability index are considered as two main objectives [43], shown in Figure 3. Thus, it is a challenging assignment to model the integrating renewable DGs into Bali's power distribution systems. Further, these challenges are particularly categorized into technical and economic aspects that described below.

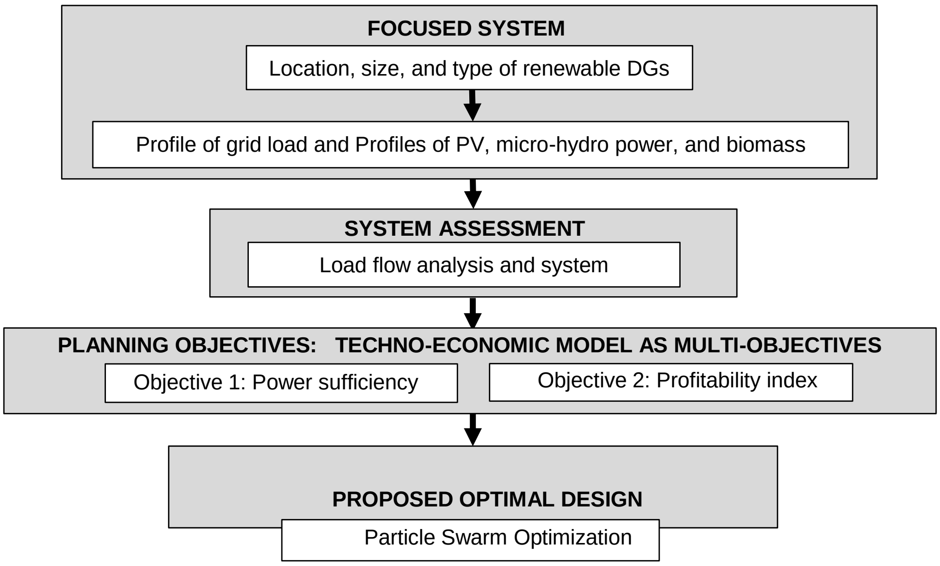

Figure 3. Framework of Design the Multi-Objective Distribution Systems with Renewable DGs

3.1. Technical Issues

The following are the technical issues are power quality which it is in the form of power sufficiency, power loss sensitivity factor, and optimal palcement of renewable DG [44-45].

3.2. Economic Issue

One of the most important economic issues is economic viability [46-47]. The economic viability of a distribution system project is reflected by its economy indicator. Net present value (NPV) is the highest aspect of the evaluation which identifies its economic indicator. NPV is calculated with the profitability index of the investment which is the ratio of the net present value to the total investment.

4. Ppoposed Solutions

The integrating renewable DGs, namely solar PV energy, micro-hydro power, and biomass energy power, into Bali's power distribution systems can provide an additional electric power to fulfill power demand. The increasing number of renewable energy sources and DGs requires new strategies to model the integrating of those DGs into electricity grid in order to maintain or even to improve the power-supply reliability and quality [48]. Keeping in view of the aforementioned, some of the proposed solutions are described as follows:

4.1. Power Loss Minimization and Voltage Profile Improvement of Distribution Power Systems

The real power loss reduction generally describes more consideration for the utilities as it reduces the efficiency of distributing energy to users. System loss reduction by optimally placed renewable DG along the grid feeder can be very useful if the designing do has to reduce losses and to improve network performance. On the other side, the distribution system is forced to maintain voltage level of each user bus within the required limit. To guarantee voltage profiles are satisfactory in distribution systems, the standard has been established to provide conditions or recommendations. Actually in practice, a voltage variation is trying to be controlled within the range of ± 6% [49]. By changing power flow configurations, the renewable DG units can improve voltage profiles. Proven to be the optimal locations and size of renewable DGs would have significant impacts on the effect of either power loss minimization or voltage profile improvement [50].

4.2. Power Flow Sensitivity Factors and Power Loss Sensitivity Factors of Distribution Systems

The sensitivity analysis is used to avoid recalculation of the power flow solution. The parameters used is the power transfer distribution factors and are defined as the changes in the line power flows due to a change in power injection at a specific bus. The sensitivities is to be found by searching the Jacobian matrix at a particular solution of the network and are only valid for small variations around the operating point [51].

The active and reactive power flow, *P* and *Q*, in a line *l* linking bus *i* and bus *j* can be described as:

$$P_{ij} = V_i V_j Y_{ij} \cos(\theta_{ij} + \delta_{ij}) - V_i^2 Y_{ij} \cos\theta_{ij} \quad (1)$$

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

And the power flow sensitivity factors F can be evaluated using above equations and expressed as:

$$\begin{bmatrix} \frac{\partial P_{ij}}{\partial P_n} \\ \frac{\partial P_{ij}}{\partial Q_n} \end{bmatrix} = \begin{bmatrix} F_{P-P} \\ F_{P-Q} \end{bmatrix} = [\ J^T\ ]^{-1} \begin{bmatrix} \frac{\partial P_{ij}}{\partial \delta} \\ \frac{\partial P_{ij}}{\partial V} \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} \frac{\partial Q_{ij}}{\partial P_n} \\ \frac{\partial Q_{ij}}{\partial Q_n} \end{bmatrix} = \begin{bmatrix} F_{Q-P} \\ F_{Q-Q} \end{bmatrix} = [\ J^T\ ]^{-1} \begin{bmatrix} \frac{\partial Q_{ij}}{\partial \delta} \\ \frac{\partial Q_{ij}}{\partial V} \end{bmatrix} \quad (4)$$

For the active and reactive power losses, P_L and Q_L, in a line *l* connecting bus *i* and bus *j* can be expressed as:

$$P_{L(ij)} = g_{ij} \left(V_i^2 + V_j^2 - 2 V_i V_j \cos\delta_{ij} \right) \quad (5)$$

$$Q_{L(ij)} = b_{ij}^{sh} \left(V_i^2 + V_j^2 \right) - b_{ij} \left(V_i^2 + V_j^2 - 2 V_i V_j \cos\delta_{ij} \right) \quad (6)$$

Based the active and reactive power losses, the power flow sensitivity factors *S* can be calculated using

$$\begin{bmatrix} \frac{\partial P_{L(ij)}}{\partial P_n} \\ \frac{\partial P_{L(ij)}}{\partial Q_n} \end{bmatrix} = \begin{bmatrix} S_{P-P} \\ S_{P-Q} \end{bmatrix} = [J^T]^{-1} \begin{bmatrix} \frac{\partial P_{L(ij)}}{\partial \delta} \\ \frac{\partial P_{L(ij)}}{\partial V} \end{bmatrix} \quad (7)$$

$$\begin{bmatrix} \frac{\partial Q_{L(ij)}}{\partial P_n} \\ \frac{\partial Q_{L(ij)}}{\partial Q_n} \end{bmatrix} = \begin{bmatrix} S_{Q-P} \\ S_{Q-Q} \end{bmatrix} = [\ J^T\ ]^{-1} \begin{bmatrix} \frac{\partial Q_{ij}}{\partial \delta} \\ \frac{\partial Q_{ij}}{\partial V} \end{bmatrix} \tag{8}$$

Finally, the combined sensitivity factor (CSF) for every bus is derived as follow [52]:

$$CSF_i = \left(F_{P-P_i} \times F_{Q-P_i}\right) + \left(F_{P-Q_i} \times F_{Q-Q_i}\right) + \left(S_{P-P_i} \times S_{Q-P_i}\right) + \left(S_{Q-P_i} \times S_{Q-Q_i}\right) \tag{9}$$

4.3. Multi-Objective Function

The main objective is to minimize the multi-objective function (MOF) i.e. techno-economic function as given below while meeting the network constraints [53].

$$f(x) = w_1 f_1(x_1) + w_2 f_2(x_2) \tag{10}$$

where $f_1(x_1)$ is the power suffiency of Bali's power distribution system and and $f_2(x_2)$ is profitability index (PI) of renewable DGs.

$$f_1(x_1) = \min\left((-1)\max\sum_{i=1}^{N_B} \Delta P_{D_i}^j\right) = \sum_{l=1}^{N_B-1} P_{L_m}^j - \sum_{=1}^{N_B-1} P_{L_{m_{DG}}}^j - \sum_{g=1}^{N_G} \Delta P_{G_g}^j - \sum_{k=1}^{N_L} P_{DG_k}^j \tag{11}$$

where $\Delta P_{D_i}^j$ is an increasing power demand in bus *i* at the level of *j* load and $P_{L_m}^j$ is system total loss in line *m* at the level of load *j*. $P_{L_{m_{DG}}}^j$ is DGs total loss in line *m* at the level of load *j*, $\Delta P_{G_g}^j$ is an increasing DG power demand at the level of *j* load, and $P_{DG_k}^j$ is power generation of DG unit.

$$f_2(x_2) = min(-PI) = \frac{\frac{(1+i)^n - 1}{i\,(1+i)^n}(R_a - C_{Total}) - PC_I}{PC_I} \tag{12}$$

where R_a is an annual revenue of selling price is, C_{Total} is total investment cost, *P* is generating capacity, and C_I is generating investment unit.

$$a = \frac{(1+i)^n - 1}{i\,(1+i)^n} \tag{13}$$

is the annuity index which came from both discount rate *i* and life cycle of renewable DG. Furthermore, provitability index of investment is the ratio net present worth (NPV) to total investment.

$$f(x) = w_1\left\{\sum_{m=1}^{N_B-1} P_{L_m}^j - \sum_{m=1}^{N_B-1} P_{L_{m_{DG}}}^j - \sum_{g=1}^{N_G} \Delta P_{G_g}^j - \sum_{k=1}^{N_L} P_{DG_k}^j\right\} + w_2\left\{\frac{\frac{(1+i)^n - 1}{i\,(1+i)^n}(R_a - C_{Total}) - PC_I}{PC_I}\right\} \tag{14}$$

where w_1 is the objective function weight of power sufficiency and w_2 is the objective function weight of provitability index.

4.4. Operational Constrains Formulation

The above formulated multi-objective function is minimized subject to various operational constraints, such as load balance constraint, real and reactive power generation limit, voltage limit, and DG's real and reactive power generation limit, so as satisfy the electrical requirements for the distribution network.

4.4.1. Load balance Constraint

For every bus, the subsequent load regulations should be satisfied:

$$P_{G_{ni}} - P_{DG_{ni}} - V_{ni}\sum_{j=1}^{N} V_{nj} Y_{nj} \cos\left(\delta_{ni} - \delta_{nj} - \theta_{nj}\right) = 0 \tag{15}$$

$$P_{G_{ni}} - P_{DG_{ni}} - V_{ni} \sum_{j=1}^{N} V_{nj} Y_{nj} \cos(\delta_{ni} - \delta_{nj} - \theta_{nj}) = 0 \quad (16)$$

4.4.2. Real and Reactive Power Generation Limit

This denotes to the upper and lower of active power and also the upper and lower of reactive power generation limit of generators at bus *i*.

$$P_{G_i}^{min} < P_{G_i} < P_{G_i}^{max}, i = 1, 2, \dots, N_G \quad (17)$$

$$Q_{G_i}^{min} < Q_{G_i} < Q_{G_i}^{max}, i = 1, 2, \dots, N_G \quad (18)$$

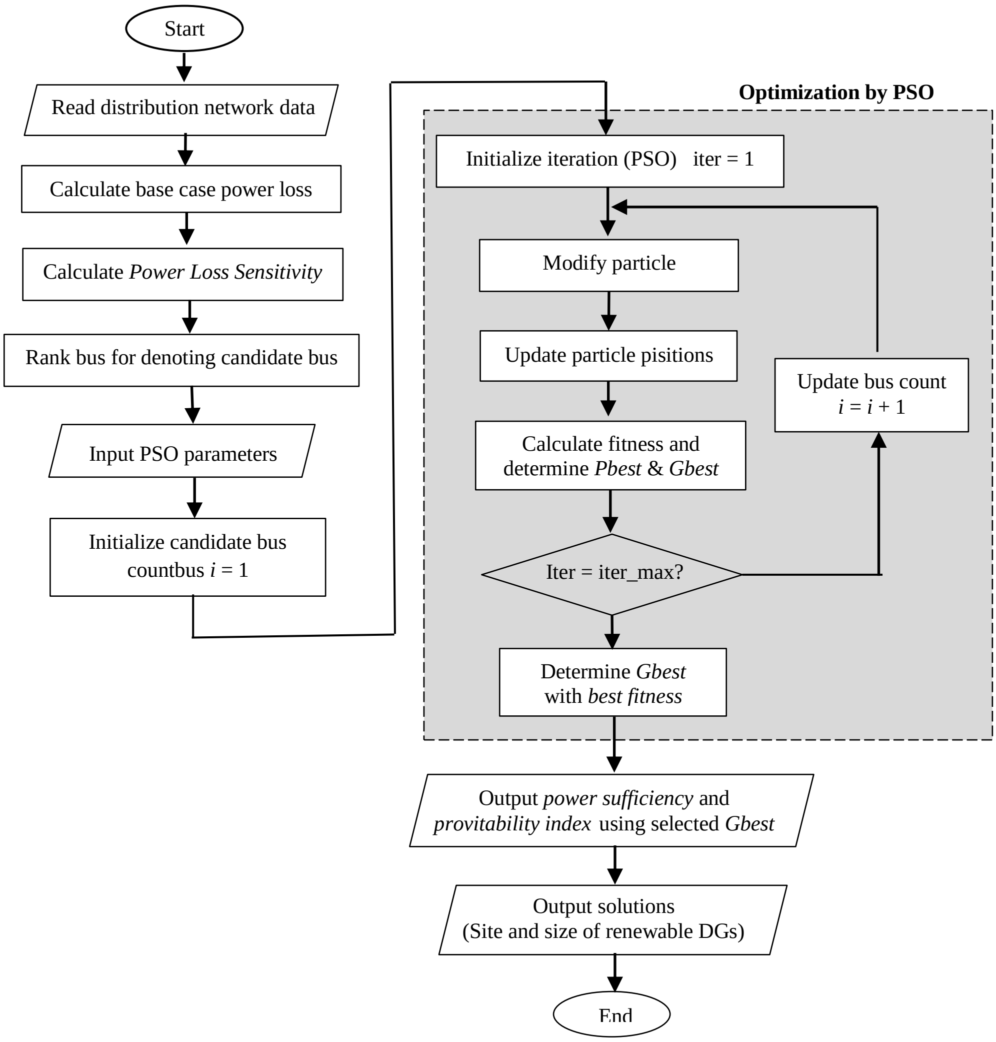

Figure 4. A Flow Chart of the Proposed Algorithm

4.4.3. Voltage Limit

The voltage must be retained within standard limits at every bus.

$$V_i^{min} < V < V_i^{max}, i = 1, 2, \dots, N_G \quad (19)$$

4.4.4. DG real and Reactive Power Generation Limit

This comprises the upper and lower active power and also the upper and lower reactive power generation limit of distributed generators connected at bus *i*.

$$P_{DG_i}^{min} < P_{DG_i} < P_{DG_i}^{max}, i = 1, 2, \dots, N_G \quad (20)$$

$$Q_{DG_i}^{min} < Q_{DG_i} < Q_{DG_i}^{max}, i = 1, 2, \dots, N_G \quad (21)$$

4.5. Flow chart for Proposed Algorithm

The proposed PSO multi-objective optimization problem formulation used to find optimal size and site of renewable DG units in Bali's distribution systems is shown as detailed in Figure 4.

4.6. Selection of Weights Values for PSO Multi-Objective Function

The allocation of the various weights in a given multi-objective function vary according to the technical concern. The power sufficiency is given more stresses since these results to a substantial reduction in total cost of operation. Though, this is not to mean that the other factor i.e. provitability index is not important. Therefore taking this into concern a study of the effect of the weights on the fitness was done so as to determine the best weights combination to adopt in impending with the multi-objective function. The values of the weights were assumed positive. It is also important to note that the condition $|w_1| + |w_2| = 1$ has to be satisfied in every case.

5. Conclusion

This paper concisely presents some issues related to integration of renewable energy resources or DG in Bali's distribution systems and their possible solutions available in the literature. The selected renewable energy resources were solar PV energy, microhydro power, and biomass power. The objective functions considered to be proposed were maximisation the system power sufficiency as well as provitability index. Both power sufficiency and provitability index is the base of techno-economic model. Moreover, in literature, PSO multi-objective optimization is the most easiestly used technique to find optimal size and site of renewable DG units in distribution systems. The power loss sensitivity a factor is used to avoid recalculation of the power flow solution during identifying the candidate buses for DGs allocations.

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