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Article

Comprehensive overview of optimizing PV-DG allocation in power system and solar energy resource potential assessments

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Review Article

Comprehensive overview of optimizing PV-DG allocation in power system and solar energy resource potential assessments



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ABSTRACT

Distributed Generation based on Photovoltaic (PV-DG) injected in the power system is considered a highly promising solution due to the advantage of clean energy use. However, the investigation of the optimal PV-DG allocation (site and size) is a significant task for power system requirements and assessment of PV potentials. Recent research works on PV-DG allocation are reviewed from two viewpoints; (1) DG, optimization algorithms and objectives and (2) methodologies of PV potential assessments.

Due to the review of recent research works, the research gaps are identified and new methodology will be proposed. The authors strongly believe that this work can be helpful to mitigate power system challenges. Besides, it helps to maximize the PV harness within the power system in particular developing countries.

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Contents

1. Introduction.....	174
2. Overview of PV-DG	175
2.1. Definition of PV-DG	175
2.2. The benefit of PV-DG utilization.....	176
2.3. Grid connected PV system.....	176
2.3.1. PV-DG operation modes	176
2.3.2. Irradiance models of PV	177
2.4. PV-DG location in power system.....	177
2.4.1. Transmission and distribution systems	177
2.4.2. Transmission and distribution system with PV-DG differences	177
3. Constraints for optimal PV-DG	178
4. Impact of PV-DG on power system.....	178
4.1. PV-DG without optimization.....	179
4.1.1. Voltage rise	179
4.1.2. PPV-DG output fluctuation.....	179
4.1.3. Harmonics	179
4.2. PV-DG with optimization.....	180
4.2.1. Voltage profile with optimal PV-DG	180
4.2.2. Power factor with optimal PV-DG	181
4.2.3. Voltage sag with optimal PV-DG.....	181
4.2.4. Fluctuation output of optimal PV-DG	181
4.2.5. Harmonics with optimal PV-DG.....	181
4.2.6. Short circuit current with optimal PV-DG	181
4.2.7. Power system reliability with optimal PV-DG.....	182
4.2.8. Power system stability with optimal PV-DG	182
5. Optimization methods for PV-DG allocations.....	182
5.1. Analytical methods.....	182

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5.1.1.	2/3 rule.....	183
5.1.2.	Loss Sensitivity Factor (LSF).....	183
5.1.3.	Improved Analytical method (IA).....	183
5.2.	Meta-heuristic algorithms.....	183
5.2.1.	Genetic Algorithm (GA).....	183
5.2.2.	Artificial Bee Colony (ABC).....	183
5.2.3.	Backtracking search Optimization Algorithm (BSOA).....	185
5.2.4.	Krill herd algorithm (KHA).....	186
5.3.	Hybrid techniques.....	186
5.3.1.	Hybrid analytical methods.....	186
5.3.2.	Hybrid meta-heuristic algorithms.....	187
5.3.3.	Hybrid analytical and meta-heuristic algorithms.....	187
5.4.	Other optimization algorithms for DG.....	188
6.	Objectives within power system.....	189
6.1.	The impact of objectives on PV-DG in power system.....	189
6.2.	Optimization objectives in power system.....	189
6.2.1.	Technical power loss.....	189
6.2.2.	Voltage stability (V_{st}).....	190
6.2.3.	Voltage profile (V_{pro}).....	190
6.2.4.	Voltage deviation (V_d).....	190
6.2.5.	Minimization of total operational cost.....	191
6.2.6.	Emission.....	191
6.2.7.	Load margin (LM).....	191
6.2.8.	Other objective functions.....	191
7.	PV solar energy source.....	191
7.1.	PV potentials.....	193
7.2.	PV potential mathematical models.....	193
8.	Relative studies of PV potentials.....	193
9.	Interaction between PV-DG and grid.....	195
10.	Analysis and comparison for PV-DG allocation.....	196
10.1.	Optimization algorithms.....	197
10.2.	Objectives in power system.....	198
10.3.	Methodologies of PV potentials.....	198
11.	Discussion.....	198
11.1.	Site and size of PV-DG in power system.....	198
11.2.	PV potential assessments.....	199
11.3.	The gap in literature and solution.....	199
12.	Conclusion.....	201
	Declaration of competing interest.....	201
	Acknowledgments.....	203
	References.....	203

1. Introduction

Due to inexhaustible and non-polluting of Renewable Energy Sources (RESs) characteristics, the total global renewable power capacity for the last year 2018 reached up to 1246 GW where China (404 GW), United States of America (180 GW), and Germany (113 GW) are foregrounded of the top (REN21, 2019). Generator based on RESs is categorized into dispatchable (e.g. hydro, geothermal and biomass energies) and non-dispatchable (e.g. solar and wind energy source) generators (Foley and Díaz Lobera, 2013). A non-dispatchable generator is not controlled by the system operator. It cannot be turned on or off when it is required. The non-dispatchable generator is based on intermittent sources. On the other hand, the dispatchable generator is flexible and under control. Its output can be changed fairly due to the system demands. From Tromly (2001) and Hoogwijk and Graus (2008), Fig. 1 shows the all types of RESs and their main usages.

It is noteworthy that, solar PV (data are provided in direct current), CSP/STE (Concentrated Solar Power/Solar Thermal Electricity) and solar hot water (only data are for glazed and unglazed collectors) have significant increase for the last five years as depicted in Fig. 2 (REN21, 2019, 2018, 2017, 2016, 2015).

As in literature, the investigating optimal allocation (site and size) of PV-DG (Photovoltage Distributed Generation) is studied from two viewpoints individually. The first viewpoint is done

within power system. This achieves by using optimization algorithms, desirable objective function (single or multi-objective) and constraints of power system (Alinejad-Beromi et al., 2007; Salih et al., 2016). It is noteworthy that, unsuitable allocation of PV-DGs may limit the level of penetration by increasing active power loss (P_{loss}) and decreasing the voltage profile within the power system.

The second viewpoint is used to estimate PV resource potentials. Assessment of PV resource potentials have significant role for network-connected PV system and PV standalone system. There are mainly four interrelated potentials; (1) theoretical, (2) geographical, (3) technical and (4) economic potentials (Tucho et al., 2014). Each potential has its own parameters and mathematical models. PV potentials are also controlled due to country regulations and policy.

This work reviews some recent studies of PV-DG in power system (transmission and distribution systems) including optimizing algorithms, constraints, challenges and objective functions. In addition, it includes the existing work of sustainable PV resource potential assessments. Such work will help to find the gap among relative conducted studies and propose a new methodology. Authors strongly believe that power system capability and PV resource potential assessments should be considered at same time optimally.

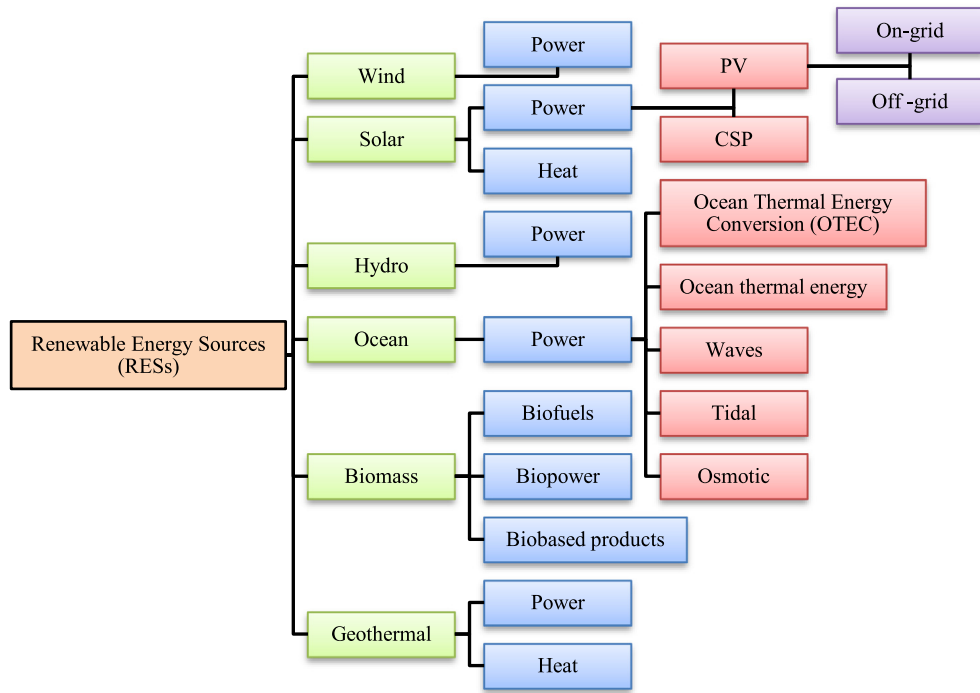


Fig. 1. Types and main usages of Renewable Energy Sources (RESs).

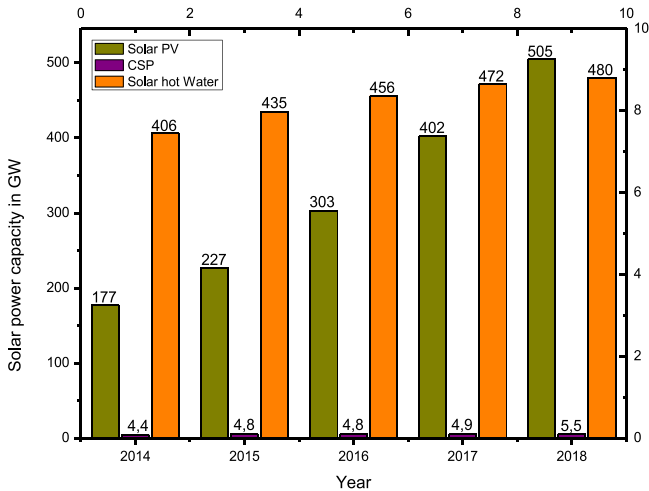


Fig. 2. Three different solar power capacity between 2014 and 2018.

2. Overview of PV-DG

First of all, the term DG has synonym names such embedded, decentralized, dispersed, district and local generation due to the country or region. As in literature, DG is injected to distribution system due to the improvement of power system performance and the flexibility of DG size (Rezaee Jordehi, 2016; Dinakara et al., 2016). DGs are classified based on diverse technology and source. There are mainly four types of DG as in Table 1. In some articles, reactive power source (type II) is excluded (Mozina, 2008, 2009; El-Fergany, 2016). Up arrowhead (\uparrow) means the DG type supplying power whilst down arrowhead (\downarrow) indicates to DG type consuming power. The high performance of power system depends on real and reactive power injections like DG type (III) (Reddy et al., 2017; Kayal and Chanda, 2013).

Table 1
The four classification of DG.

DG type	Real power (P)	Reactive power (Q)	Example
I	\uparrow	0	PV and fuel cell
II	0	\uparrow	Phase modifier circuit or synchronous condenser
III	\uparrow	\uparrow	Small hydro turbines, Cogeneration and gas turbine
IV	\uparrow	\downarrow	Induction machines e.g. Wind turbine (DFIG)

2.1. Definition of PV-DG

The definition of DG (same as PV-DG) does not have consensus. DG definition is swigged between site and size (Viral and Khatod, 2012). Herein, some definitions of DG are presented while size of DG is depicted in Fig. 3.

- 1- Electric Power Research Institute (EPRI) define DG as generation starts from a few kilowatts up to 50 MW (Ackermann et al., 2001). Herein, DG location is not defined
- 2- IEEE stands for the Institute of Electrical and Electronics Engineers defines DG as smaller unit than central generation so that permits to have interconnection at any close point in the power system (Pepermans et al., 2005). IEEE does not define the DG size and the DG location does not be specified in transmission or distribution systems.
- 3- DG is based on different technologies either renewable or fossil fuel resources, that generates electricity and used where it is needed. DG can serve single structure such homes or part of microgrid (EPA, 2018). This definition does not mention DG size or in which system should be installed.

In term of DG ratings, this depends on power system capacity and voltage level (El-Khattam and Salama, 2004). Meanwhile, the

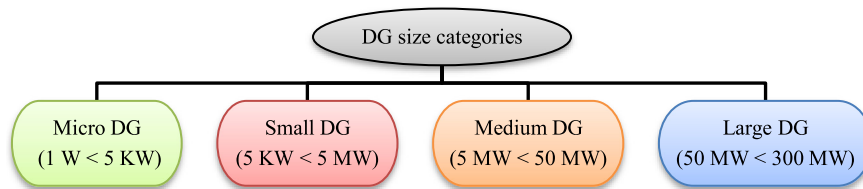


Fig. 3. Four different DG sizes.

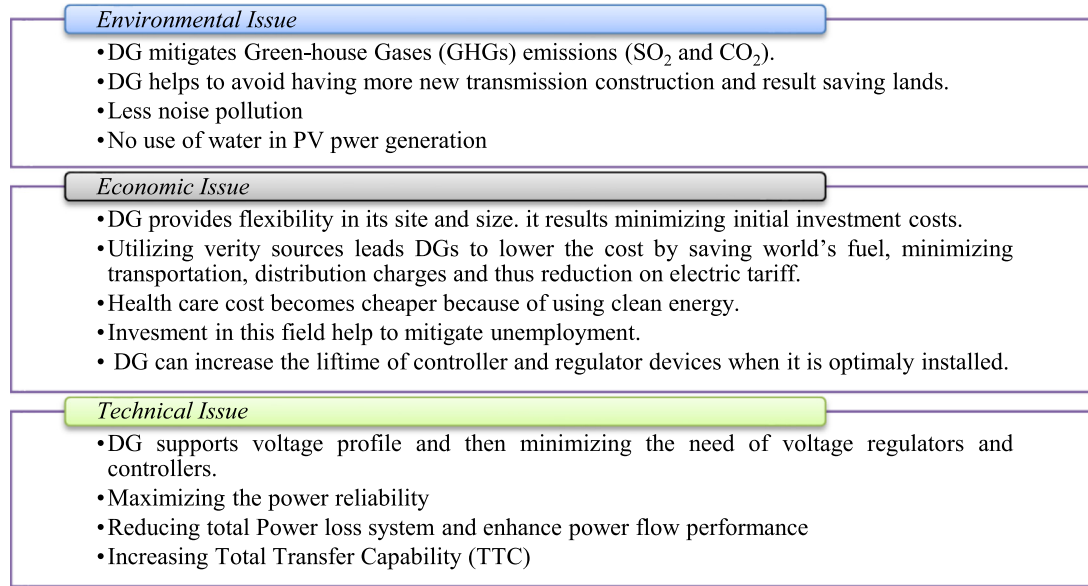


Fig. 4. The block shows the mutual benefit of DG-RES.

location of DG output is not necessary to be consumed in distribution system. As it happened in New Zealand where wind farm 3.5 MW is operated within distributed network. However, during nights at the low load and high wind speed, the produced power of wind farm is transferred to transmission system (Ackermann et al., 2001). This lead us to DG power can be installed in high and medium voltage systems.

2.2. The benefit of PV-DG utilization

The motivation of using PV-DG comes from three aspects. The mutual relationship of environment, economic and power network performance is strongly interrelated. Based on optimal allocation of DG, technical system issues can be very well handled. The some benefits of PV-DG which are also similar to DG-RESs are presented as in Fig. 4 (Viral and Khatod, 2012; Tan et al., 2013; Arya et al., 2012; Adefarati and Bansal, 2017; Al-Muhaini and Heydt, 2013; El-Khattam et al., 2004; U.S. Department of Energ, 2007; Singh et al., 2017; Rath et al., 2017; Elnozahy and Salama, 2013; Singh and Mishra, 2018).

2.3. Grid connected PV system

In PV system, solar radiations are trapped and converted into electric power. PV cells are exposed to sunlight, the interior construction of PV cells has the ability to absorb photons and then electrons are released. PV system can be either on-grid or off-grid (Hersch and Zweibel, 1982; Tan, 2004). The electric current by PV cells is always Direct Current (DC) in nature. It can be converted to Alternative Current (AC) by electronic device inverter. There are four different topologies of PV inverter to be connected to the grid; (1) multi-string topology, (2) centralized topology, (3)

string topology, and AC module topology (Sun et al., 2011). Fig. 5 is illustrated the PV system connection with mesh power system. In this section, the PV-DG is modeled in power system either PQ node or PV note. At the same time, it presents the modeling of output power of PV system based on solar irradiance.

2.3.1. PV-DG operation modes

Depending on the type, electric machine of DG and utility interface (direct or indirect) used for a connection to the power system, all DGs have to models either as PQ (power-controlled) node or PV (voltage-controlled) node power flow studies (Maya and Jasmin, 2015; Liu and Xu, 2016). PV-DG is installed to the power system via power electronic interface. Based on the control mode of electronic device, the PV-DG model is determined. The case of controlling P and V independently, PV-DG model is set to PV node. On other hand, the PV-DG model is PQ node when P and Q are controlled independently (Moghaddas-Tafreshi and Mashhour, 2009). In the case of the PQ node, the PV-DG behaves as a negative load which does not make any obstacle to power flow. Meanwhile, PV-DG can operate as the PV node which requires an iterative procedure to keep specified voltage magnitude and monitoring DG reactive power limits. Therefore, some means should be considered as follows Emmanuel and Rayudu (2017), Tong (2006) and Khushalani et al. (2007):

- 1- For zero reactive power and at iteration τ , the positive sequence voltage mismatch for each PV node is given by Eq. (1):

$$\Delta V_k^\tau = |V_k^{sc}| - |V_k^\tau| \leq \mathcal{U} \quad \forall k \in S = \{1, \dots, n\}, \quad (1)$$

where $|V_k^{sc}|$ is specified voltage magnitude at bus k .

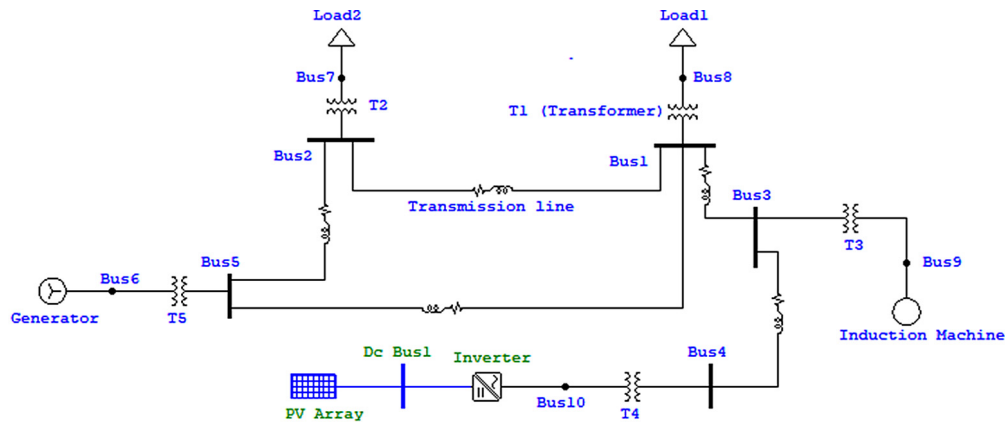


Fig. 5. Schematic diagram of grid-connected PV system.

- 2- If the positive sequence voltage ΔV_k^r mismatches exceeding the threshold μ , the reactive current injection for PV with the help of the positive sequence impedance sensitivity matrix is calculated by Eq. (2):

$$Z_{kS} * I_{kQ}^r = \forall V_k^r, \quad (2)$$

where Z_{kS} is a positive sequence constant real impedance matrix ($n \times n$), n is the number of PV nodes, I_{kQ}^r is the positive sequence reactive current injection.

- 3- Due to constraint of reactive power supplied from DG, it is required to compute this reactive power using the current injection and the voltage of PV node using Eq. (3). And then Q_{kG} is compared to the constraint as in Eq. (4). Out of the given maximum constraint, the DG reverts to a P-Q node.

$$Q_{kG}^r = \text{imag}(V_{ka} I_{ka}^{*r}) + (V_{ka} I_{kb}^{*r}) + (V_{ka} I_{kc}^{*r}), \quad (3)$$

where Q_{kG}^r is the total three-phase reactive power injected by the DG unit at node k .

$$Q_{kG}^{\min} < Q_{kG}^r < Q_{kG}^{\max} \quad (4)$$

2.3.2. Irradiance models of PV

DG has different mathematical models for PV type production. The output power of the PV model depends on several parameters such as fill factor and PV generation efficiency. The solar irradiance is the spine of this type of generation. In this paper, PV-DG models are listed in Table 2.

2.4. PV-DG location in power system

Generally, transmission and distribution (T&D) are distinguished based on the voltage level (von Meier, 2006). However, this classification is poor for worldwide because of the voltage overlap in T&D and modern system in developed countries such the highest voltage level in distribution network Italy 150 kV (a L'Abbate et al., 2007). Installing PV-DG can be located either transmission or distribution system. This study focuses to locate PV-DG in transmission system.

2.4.1. Transmission and distribution systems

Specifically, transmission lines in power system have two functions; (1) to transfer bulk power over long distance from high voltage to low voltage and (2) to connect power systems with each other based on economic and technological reasons such as nation grid in Japan and more complex grid (Europe, 0000; Kothari and Nagrath, 2003). As result, transmission system forms mesh network. This Bulk power is received by the distribution system through the substation and delivers to the loads. Distribution system has different topologies due to several factors such as

construction cost, design, operation, and desirable area. There are mainly three different form of network; (1) radial, (2) ring (loop) and (3) cross-loop (mesh) (Systems, 0000).

2.4.2. Transmission and distribution system with PV-DG differences

- 1- Distribution system is designed to receive power from transmission system in one direction like radial system (Kadir et al., 2014). Injecting DG to distribution system may require resetting fault protection system due to the changing in fault current (Dulau and Bica, 2017). Since the fault current will be supplied from DG and the distribution system (Borges and Falcão, 2006; Of et al., 2004).
- 2- Reverse Power Flow toward the substation can cause disturbance of protection and regulation devices in radial distribution system (Suh et al., 2017; Al-Sabounchi et al., 2011).
- 3- In distribution system, low voltage ends are usually not linked to the Supervisory Control and Data Acquisition (SCADA) system. Control system encounters difficulty to gather required data in particular from DG units. This is because of independent DGs operate due to the market needs (Ackermann et al., 2001).
- 4- Due to the most distribution network configurations either radial or loop networks, the reliability of such system is low compared to the transmission system which is mesh network. As result, the advantages of connecting DG directly to the distributed system are threatened to be lost (Kamal Kant Sharma, 2012).
- 5- The concept of Available Transfer Capability (ATC) in transmission system is applied unlike distribution system (NERC, 1996).
- 6- Allocation of DG in sub-transmission system has ability to reduce the total power loss and foster voltage profile compared to lower voltage in the meshed system IEEE 14 bus. The study proved that the lower total power reduction is with type (I) of DG where real P_L (for 69 kV) is between 50% and 75% compared with real P_L (for 13.8 kV) is between 25% and 50% (Ogunjuyigbe et al., 2016).
- 7- DG based on renewable energy source (RES) is depended on its geographical potentials. Meanwhile, the high level penetration of DG-RES is restricted to the capability of electrical system. For example, even though PV-DG with 3000 MW of total generation in nation grid of Egypt is investigated, the grid is able to maintain stable (Sultan et al., 2019). This may not be possible in distribution system.
- 8- Since the ratio of R/X in transmission system is less than in distribution system, this causes high effect in latter system based on power losses and poor voltage support compared

Table 2
PV-DG models based on solar irradiance.

Ref.	Model	Parameters
Salameh et al. (1995)	$P_a = \int P(S) \cdot f(S) \cdot dS$	where P_a is the average power output from a PV module, $P(S)$ is the output power of the module, $f(S)$ is the probability density function. S is value of irradiance.
Ruiz-Rodriguez et al. (2011)	$P_{PV} = \eta_{PVg} * A_{PVg} * G_t$	where η_{PVg} is PV generation efficiency, A_{PVg} is PV generator area (m^2) and G_t is solar irradiation in module plane (W/m^2).
Ali et al. (2017a)	$P_{PV} = \begin{cases} P_{PVr} \times \left(\frac{G}{G_r}\right) & 0 \leq G \leq G_r \\ P_{PVr} & G_r \leq G \end{cases}$	where G and G_r are the solar radiation (W/m^2) for the selected location and the rated radiation at the earth's surface ($1000 W/m^2$) respectively. P_{PVr} is the rated PV output power at solar radiation of ($1000 W/m^2$) and temperature of $25^\circ C$.
Swief et al. (2018)	$P_{PV} = \begin{cases} P_{rated-PV} \times \left(\frac{R^2}{R_{STD} \times R_C}\right), & R \leq R_C \\ P_{rated-PV} \times \frac{R}{R_{STD}}, & R_C \leq R < R_{STD} \\ P_{rated-PV}, & R \geq R_{STD} \end{cases}$	where P_{PV} is the PV output power (MW), R_{STD} signifies the solar irradiance in the standard conditions usually set to $1000 W/m^2$, R_C is a certain radiation point, usually set to $150 W/m^2$, and $P_{rated-PV}$ is the PV rated power (MW)
Kayal and Chanda (2013)	$P_{PV} = N_s * N_p * FF * V_{oc} * I_{sc}$ $V_{oc} = \frac{V_{Noc}}{1 + C_2 * \ln\left(\frac{G_N}{G_a}\right)} \left(\frac{T_N}{T_a}\right)^{c_1}$ $I_{sc} = I_{Nsc} \left(\frac{G_a}{G_N}\right)^{c_3}$ $FF = \left(1 - \frac{R_s}{V_{oc}/I_{sc}}\right) \left(\frac{\frac{V_{oc}}{nKT/q} - \ln\left(\frac{V_{oc}}{nKT/q} + 0.72\right)}{1 + \frac{V_{oc}}{nKT/q}}\right)$	where N_s and N_p are series and parallel PV modules respectively, V_{oc} and I_{sc} and FF are the open circuit voltage, short circuit current and fill factor of PV module respectively. G_N and G_a are the nominal and actual solar irradiance on module; T_N and T_a are nominal and actual module temperature, respectively. V_{Noc} and I_{Nsc} are nominal the open circuit voltage and short circuit current of PV module; R_s is the series resistance of module; c_1 , c_2 and c_3 are the three different constant which are introduced to show non-linear relationship between solar irradiance, photocurrent and cell temperature. n is density factor ($n = 1.5$), T is the PV module temperature, K is Boltzmann constant ($1.38 * 10^{-23} J/K$); and q is the charge of electron ($1.6 * 10^{-19} C$)
Rawat and Vadhera (2018)	$P_{PV} = N_s * N_p * FF * V * I$ $I = S_a [I_{sc} + K_i(T_c - 25)]$ $V = V_{oc} - K_v * T_c$ $FF = \frac{V_{mpp} * I_{mpp}}{V_{oc} * I_{oc}}$	K_i is current temperature, T_c is cell temperature coefficient, K_v is voltage temperature coefficient, S_a is average solar irradiance, I_{mpp} is current at maximum power point and V_{mpp} is voltage at maximum power point.

to transmission system (Moradi and Abedini, 2012a; Keane and O'Malley, 2005).

3. Constraints for optimal PV-DG

For the reliable and security transfer power from generation plant to load center in the interconnected network, the operational transfer may be restricted to the physical and electrical characteristics

- **Power Flow Balance and Generation:** total power loss and demands should be part form all total power generation including all DG units in the system. This output and input of the system is call Power Flow Balance limit (PFBL) (Duong et al., 2019; Devalalaji and Ravi, 2016).
- **Distributed generation:** should operate within their lower and upper limits (Ganguly and Samajpati, 2015).
- **Voltage Limits:** is also another constraint in power system. During injecting DG into the system, voltage level should maintain within the upper and lower limits acceptable range as in Eq. (5) (Abdmouleh et al., 2017; Abu-Mouti and El-Hawary, 2011). Most of electrical utility look to maintain $\pm 5\%$ range for voltage level. Maximum power can be transferred at minimum voltage limits without causing any damage to power system or customer facilities (NERC, 1996; Gomes and Saraiva, 2017).

$$V_i^{min} \leq V_i \leq V_i^{max}, \quad i = 1, 2, 3, \dots, n \quad (5)$$

- **Stability Limits:** interconnected transmission network must have the ability to survive under disturbances through transient. System disturbance itself can be categorized into two (1) small- disturbance or steady state stability which can be experienced in increment load and (2) large-disturbance

which can be happened in outage of line or generator and so forth (Chakrabarti, 2010).

- **Line Thermal Limits:** is defined as the maximum amount of electrical current that is conducted in transmission line or electrical unit for particular time before it cause damage by overheating (Moradi and Abedini, 2012b; Dong et al., 2014).
- **Total harmonic Distortion limits:** harmonic is usually generated from equipment with nonlinear voltage and current characteristics. THD limits were introduced in IEEE 519 standard. Due to the voltage at Point of Common Coupling (PCC), THD limits is given (IEEE, 2014; Ravikumar Pandi et al., 2013).
- **Phase angle limit:** This includes the maximum and minimum angle limits at bus- i as in Eq. (6) (Kumar and Gao, 2010; Alrashidi and Alhajri, 2011).

$$\delta_i^{min} \leq \delta_i \leq \delta_i^{max}, \quad i = 1, 2, 3, \dots, n \quad (6)$$

There are other inequality constraints which are not less important than aforementioned. Substation transformer capacity, short circuit level, traditional power generation, Number of DG, Intertie's delivery power, tap position, power factor and short circuit ratio should not also exceed the acceptable range (Zubo et al., 2017; Luo et al., 2018; Payasi et al., 2011).

4. Impact of PV-DG on power system

Power system based on renewable energy source encounters non-traditional problems such as voltage issues and more harmonics (Farhoodnea et al., 2013). In this section, it reviews the challenges of inserting PV-DG in power system with and without optimization based on location and size of PV-DG.

4.1. PV-DG without optimization

PV generation system is extremely dependent on environmental conditions, design of inverter systems, and control schemes in power convertor (Sarhan et al., 2006; Petrone et al., 2008). In power system, some problems raised with PV-DG connected system and traditional solutions are presented here.

4.1.1. Voltage rise

Power system is not completely designed to support high penetration of PV-DG. In transmission or distribution systems, the voltage problems at high voltage level has a little difference in nature than the voltage problems at low voltage level (POVLSEN and A/S, 2002). Therefore, increasing the level of PV-DG penetration associated with natural solar source characteristics can cause reverse power flow at low load and result to voltage rise (Eftekharijad et al., 2013; Kadir et al., 2014). Solar irradiance changes may not have high detrimental impact on network voltage level. The network voltage observed at 1.08 PM during the irradiation 1113 W/m^2 (at clean day) is 243.94 V. Meanwhile, the network voltage at 5.08 PM during irradiation 161 W/m^2 is observed 242.86 V (Ayub et al., 2014). This depends on the percentage of PV penetration to the system as outlined next (Karimi et al., 2016):

- 1- During low penetration level of PV output around 5%, at peak load PV inverter does have a little effect on voltage regulation on power line.
- 2- At medium penetration level of PV output around 10%, PV inverter can contribute to help reduction of the conventional voltage support capacitor size by approximately 40%.
- 3- During high penetration level of PV output around 30% to 50%, PV inverter might be able to support all voltage regulation on the power line.

Based on standard IEEE 1547–2003 introduced that, the PV-DG inverter acts as active power source and should not contribute to voltage regulation at the bus of connection (IEEE, 2002). This makes the grid responsible for reactive power support and voltage regulation. During high DG penetration, keeping voltage within specified limits can be maintained through several methods such as step voltage regulators, shunt capacitors, and transformer on-load tap changers (Shayani and De Oliveira, 2011; Survey et al., 0000; Alquthami et al., 2010). During short term of voltage variation due to insolation behavior, there is an extra burden on regulator devices and therefore, diminish the lifetime of equipment (Chidurala, 2016).

Nowadays, IEEE 1547–2018 imposes the inverter of PV-DG to contribute to reactive power and voltage regulation (Ropp, 2019; IEEE Standard Association, 2018). Localized PV-DG inverter controls can contribute to regulate voltages at low level, minimize power system losses and increase PV penetration in network capacity (Collins and Ward, 2015). Controlling and generating reactive power by PV inverter is cost-effective because there is no need to install supplemental device (Han et al., 2017). Another solution to mitigate the voltage rise caused by high PV-DG output is energy storage system used. Charging and discharging control based on an intelligent strategy is discussed to have high effective use of the storage capacity at low voltage (Alam et al., 2012).

4.1.2. PPV-DG output fluctuation

The output of PV-DG is fluctuated due to the intermittency nature of the solar source particularly inconstant irradiance and temperature as shown in Fig. 6. Therefore, PV system uses Maximum Power Point Tracking (MPPT) algorithm to obtain the maximum power point from PV panels (Chidurala, 2016). However,

Table 3

Various mod of storing energy by BSS.

Mode	Description
Load leveling mode	During exceeding grid power the required load, battery bank starts storing the surplus energy. This stored energy starts supplying into the grid when load demand becomes high.
Arbitrage mode	Battery bank starts storing energy (purchased off-peak) at cheap price and then the battery bank starts supplying grid at peak time where grid power is expensive.
Export curtailment mode	Battery bank located at customer premises can store the excess power from PV-DG. The stored power is not permitted to export it to the grid. As result, revers power flow is zero.

the power system still has to deal with two issues; to handle not only unsteady demand but also has to handle unsteady generators. This weakness can lead to lose the balance and reduce the reliability within the power system (Enslin, 2010; Zahedi, 2011).

Hybrid system by combining two or more power generation along with storage can help to improve power performance. High coordination, control and proper designing must be considered (Nehrir et al., 2011). The proposed configuration of hybrid PV-FC is introduced in Sun et al. (2011). PV is used as the main source, while FC is used to supplement the deficits of PV source during changes of insolation. Another method, proper Hybrid PV-DG and energy storage is recognized as a reasonable mitigation method at both small scale and large scale (Kocer et al., 2019). The results in Teng et al. (2013) presented that if the commitment between PV-GS and Battery Storage System (BSS) can be defined effectively, then the advantages of using BSS can be fulfilled. BSS have different applied modes as in Table 3 (Haque and Wolfs, 2016). Some times it is not practical to store all excess PV-DG output. Curtailed energy is proposed since PV-DG can be operated in off mode of maximum power point (MPP) lead to zero output (Kroposki, 2017).

Another way to mitigate the variability of PV output is to avoid large PV farm in one location. Even though PV farm is restricted to the geographical area, deploying smaller PV farms across wide region will help electrical utility to have smooth control on grid based on PV-DG (Nwaigwe et al., 2019).

4.1.3. Harmonics

Generally, power system is always affected by harmonics due to the non-linear equipment connected in the system. therefore, harmonics should not exceeds the permissible limits due to the standard (Bergen and Vittal, 2007). Total harmonic distortion (THD) either current or voltage is used as the common indices for measuring harmonic in the system. The harmonic detrimental impacts on the power system can be known by the following problems (El-Sayed et al., 2017; Bergen and Vittal, 2007).

- (a) Harmonics cause overheating in equipment which results to damage or failure of equipment.
- (b) Protection system in equipment can cause undesirable operation or failure.
- (c) Existing harmonics may lead to process disturbance or system malfunction of equipment.
- (d) In equipment of rotating harmonics causes pulsating and reduced torque.
- (e) In rotating and static of equipment, audible noise is increased.

Change in solar radiation can have a little difference on THD voltage compared to THD current (Ayub et al., 2014). Low solar irradiance leads to high THD current (Colque et al., 2019).

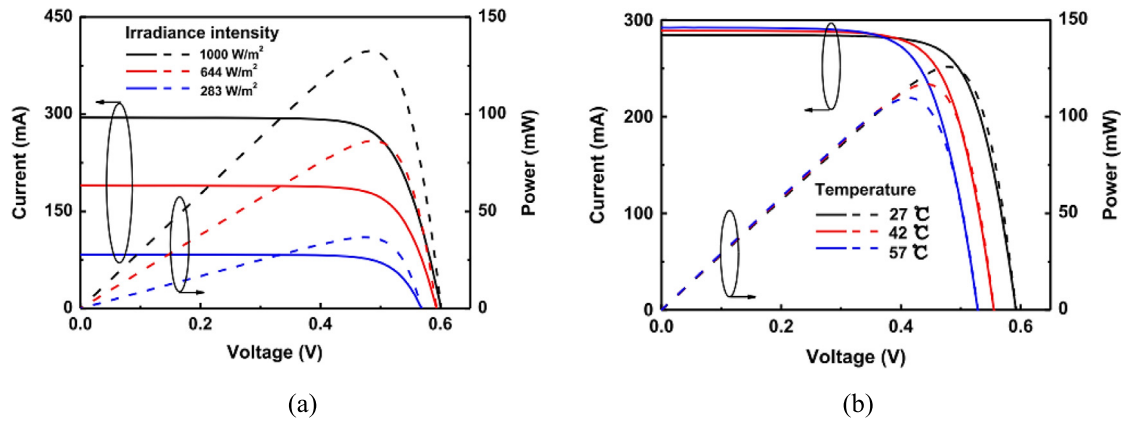


Fig. 6. Current-voltage (I-V) and power-voltage (P-V) characteristics of solar cells, (a) at constant 25 °C with various irradiance while (b) at constant the irradiance of 1000 W/m² with different temperatures (Xiao et al., 2014).

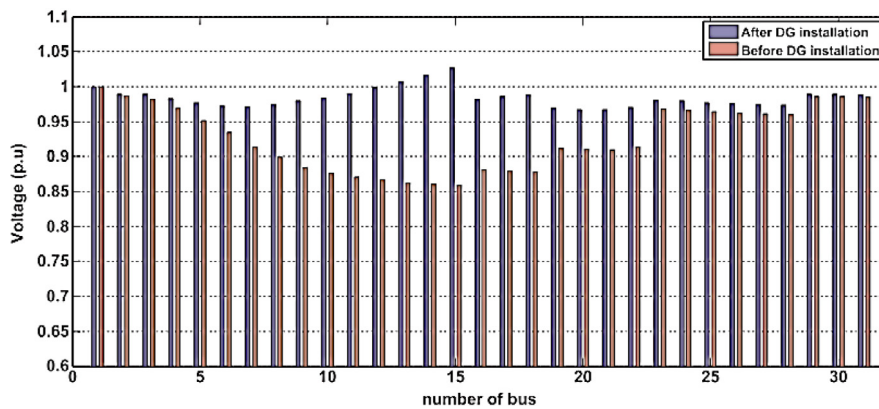


Fig. 7. The voltage profile before and after the optimal size and location of DG (HassanzadehFard and Jalilian, 2018).

Table 4
Divergence between three different filters.

Filters	Notes
L-filter	First order filter, attenuation 20 db/decade, required high value of inductor, non-cost-effective and causing voltage drop, using in such as high switching frequency converters.
LC-filter	Affected by nonlinear load harmonics (Rasul et al., 2017), second order filter, its resonant frequency relied on system impedance, attenuation 12 db/octave after cut-off frequency, less cost, large capacitor causing high inrush current and reactive power
LCL-filter	Attenuation 60 db/decade, reducing ripple current, non-cost-effective and improper design leads to resonance and instability in system.

Meanwhile, network-connected PV system is always associated with harmonics due to PV inverter contains semiconductor power switching devices such as IGBT, GTO, and diodes (Farhoodnea et al., 2013; Menti et al., 2011). The generated harmonics from PV inverters will be divergent due to three factors; (1) size of PV systems, (2) the type of control strategy and (3) on the network voltage harmonics (Chidurala, 2016). Based on the results, it emphasizes that THD current and THD voltage increase proportionally with the PV systems penetrations (Chidurala et al., 2016). Mitigating PV system harmonic can be done by different design of filters as in Table 4 (Gakhar and Gupta, 2019).

Another way of mitigation, converter with high quality and keeping the MPPT in all cells has been proposed. The distorted current can be mitigated in the multilevel-cascaded converters during different levels of solar radiation (Lashab et al., 2019).

4.2. PV-DG with optimization

It is very important to observe the impact of PV-DG connected system when optimal location and size are considered. Such PV-DG optimization can mitigate the dependence on the traditional solutions of using external devices to solve power system problems or improve the performance of this system.

4.2.1. Voltage profile with optimal PV-DG

Improving or maintaining voltage profile within the limits on power system is considered one of the most essential factors of power flow characteristics. An approach to improve voltage profile is implemented by optimal location and size of DG. In Ali et al. (2018), optimization algorithm is used to determine optimal allocation of single and double PV-DG in 69-bus distribution system. It is proved from the simulation, a minimum voltage in the base case 0.91 p.u. is improved up to 0.97 p.u. Similar study emphasizes that optimal allocation of DG contributes for improving voltage profile and the minimizing overloads in normal operation and under contingencies (Sanchez Mora et al., 2018). As depicted in Fig. 7, all the voltage values on system buses are improved.

Furthermore, under different type of load models (constant, industrial and residential loads) based on optimal allocation of DGs voltage profile keep improving for each model (El-Zonkoly, 2011). It is worthy noted that, even though optimal allocation of PV-DG based on only minimum active power loss (as objective function), voltage profile keep improving in the distribution and transmission power system (Karimyan et al., 2014; Mosbah et al., 2019). This is due to the mathematical relationship between voltage and resistance.

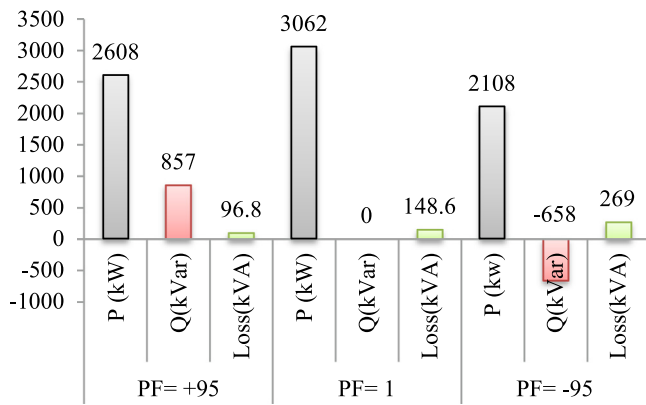


Fig. 8. PV-DG with different PF modes for 69 bus system.

4.2.2. Power factor with optimal PV-DG

Since the real power injection at unity power factor by PV may cause voltage rise and decreasing power factor (Agalgaonkar et al., 2014; Lewis, 2011). Therefore, the PV inverter act as active and reactive power source will play crucial role in term of changing installation point and then result in maximizing size, higher loss reduction and better voltage profile when optimization of location and size of PV is considered (Shahzad et al., 2016; Murty and Kumar, 2015). The power factor should be in range 0.95 lead/lag at maximum power output supplied at the bus of connection (Ellis et al., 2012). Table 5 and Fig. 8 is extracted from the obtained result in Kayal and Chanda (2013) and reformed to be in comparison form. It represents the different modes of PF which lead to varies power performance for PV-DG.

4.2.3. Voltage sag with optimal PV-DG

Voltage sag can be defined as a voltage in rms value decreasing in range 0.1 and 0.9 per unit at the power frequency for a period of 0.5 cycles to 1 min (Biswas et al., 2012). Optimal location of DG to enhance both power quality and real power loss within a distribution system is considered. Voltage sag is investigated based on the reliability index related to sag cost (Nasrolahpour et al., 2012). From the simulation result in Murthy et al. (2013), voltage sage index is enhanced from 36.00 to 46.00 when optimal allocation of DG is taking place in account. Similar work conducted to mitigate voltage sag using hybrid approach for DG installation. For one DG or two DGs connection, the voltage sag is mitigated in a short period of 0.06 s (Chandrasekhar Reddy et al., 2013). The good location of DG is found in the weak part of the power network. The results show the voltage sag is mitigated (Jahromi et al., 2007).

4.2.4. Fluctuation output of optimal PV-DG

In this work (Agarwal et al., 2015), random behavior of irradiance is model by Beta Probability Density Function (BPD). The collected data for each year is divided into four seasons. The season is presented by one typical day. Based on optimal allocation of PV-DG, the obtained results denotes all objective functions are achieved such minimum annual energy losses. For Prenc et al. (2013), a developed method is used to find the optimal location of PV-DG based on daily production and load dynamics in distribution network. the total daily apparent power loss is reduced from 190.53 kVA without PV-DG up to 133.96 kVA with PV-DG in 30-bus distributed system. The method takes in consideration both the time periods of maximum PV-DG output and peak power values to obtain the optimal location of PV-DG. Similar study is conducted in Hung et al. (2014). Combination of analytical expressions of active power loss, reactive power

loss and voltage deviation are used to allocate PV units while considering the time-varying load models and probabilistic PV generation. As result, the PV penetration is different between different time-varying load models. Authors in Ahmadi et al. (2018) used average winter solar radiation (as worse solar radiation) for Kabul city to analyze daily PV-DG and then to be injected to the distribution system in 21 optimized locations. This is carried out by GA based on minimum real power loss. The optimized allocations of PV-DG outputs are compared to average summer solar radiation and short-term cloud transient weather. As result of comparison, all cases overcome the issues like power quality and dependency on import power.

4.2.5. Harmonics with optimal PV-DG

Harmonics in power system can also be mitigated by optimal location and size of PV-DG. Based on PV-DG allocation for minimum power loss and harmonics, The voltage THD can be reduced from 6.0331% without PV-DG up to 3.9355% with PV-DG in 69-bus distribution system (Duong et al., 2019). In actual 51-bus medium distribution system (Hengsrirawat et al., 2012), voltage stability Index (VST) is used to find the proper location of PV-DG while probabilistic approach is used to obtain an optimal size of PV-DG. The results indicate that installing multi PV-DGs in power system have a little effect and does not violate the harmonic standards. However, considering background harmonics 35% can cause violation to voltage THD constraints exceeding 5%. In another study conducted on 13-bus Tehran distribution system (Alinejad-Beromi et al., 2008), optimal allocation of DG (Type III) is performed by PSO based on loss reduction, voltage profile improvement, THD reduction, and cost reduction. THD is reduced from 7.681% without DG up to 4.818% with DG. In Yakoub Yousef et al. (2019), a different location and size of PV-DG generate various amount of harmonics due to the impedance in the power system seen by inverter. In this reference, a methodology is applied to find the proper solutions such as suitable bus and the maximum permissible PV penetration level. This keep THD within standard limits. Similar study is conducted in Abdul kadir et al. (2013). Sensitivity Analysis (SA) is used to find the DG locations while Evolutionary Programming (EP) is used to find optimal DG sizes in 69-bus distribution system to minimize total real power loss and voltage THD. This algorithm EP is integrated with harmonics load flow analysis. It is worthy note that, the average voltage THD drops from 18.097% up to 1.097% due to optimal allocation of DGs.

4.2.6. Short circuit current with optimal PV-DG

The short-circuit levels (SCL) is increased after the installation of DGs and become highest with buses connected to DGs (Hosseini et al., 2013). PV-DG connected from bus to another in 13-bus distribution system has different SCL with different type of faults (Afifi and Darwish, 2014). There are many techniques to mitigate the increasing SCL. For instance, optimal location and size of solid state (SSFCL) is proposed to decrease the produced fault current by DG (Shahriari et al., 2009). Apart of using such device (SSFCL) to achieve single objective, optimal allocation of DG can be applied to minimize the SCL by considering it as one of the multi objective function (El-Zonkol, 2010). Increasing number of optimal allocation of DG units installed in smart distributed system will help to minimize fault level within the acceptable limit as in Fig. 9.

Similar study of multi-objective function is used to determine optimal allocation of multi-DG with different load models (El-Zonkoly, 2011). Even though SCL is considered as objective function, SCLs in both 38-bus radial system and an IEEE 30-bus meshed system has low maximum increase compare to base case. The maximum difference is 3.92% for 38-bus system and 2.3% for 30-bus system in the case of the industrial load model.

Table 5
Showing different PF modes of PV-DG for 69 bus system.

Type	PF mode	Bus number	Size		S_{Loss} (kVA)
			P (kW)	Q(kVar)	
PV-DG	+ 0.95	7 –16 –51 –54 –59 –61 –62 –65 –67 –68 –69	2608	857	96.8
	1	6 –8 –12 –26 –52 –53 –59 –61 –62 –65 –68	3062	0	148.6
	–0.95	8 –18 –51 –53 –59 –61 –62 –65 –66 –68 –69	2108	–658	269

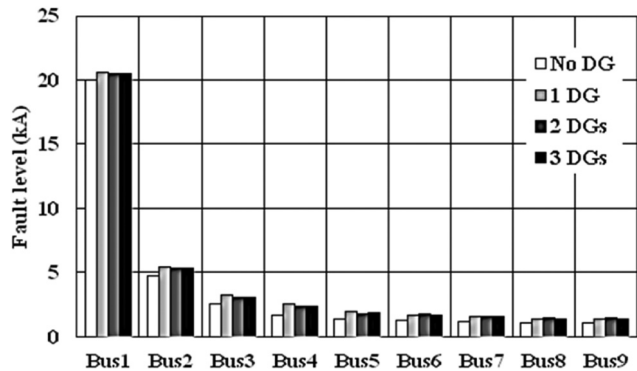


Fig. 9. Fault level at 9-bus smart distribution test system (Buaklee and Hongesombut, 2013).

4.2.7. Power system reliability with optimal PV-DG

The reliability of any power system always depends on the ingrained reliability of system components such as power generations, transmission lines and transformers (Pavani and Singh, 2014). There are many methods to ensure the reliability of power system performance such as network reconfiguration performed by switches in optimal manner (Badran et al., 2017; Civanlar et al., 1988) and Flexible alternating current transmission system (FACTS) controllers (Ashokrao et al., 2017; Bawazir and Wazir, 2014). On other hand, optimal placement and size of DG plays role to improve the power system performance. Cuckoo Search Algorithm (CSA) is used to determine allocation of optimal reclosers and DG based on minimizing Energy-Not-Supplied (ENS) index (Swief et al., 2018). In similar work, authors proposed a novel comprehensive approach to solve planning problem in a distribution system and to find the optimal allocation of DGs based on the reliability. The effectiveness of this method showed good impact on the system in term of reliability (Hasanvand et al., 2017). Based on optimal allocation of multi-DGs, distribution system, reliability and power losses using Differential Evolution algorithm are studied. The reliability indices; the system average interruption frequency index (SAIFI), the system average interruption duration index (SAIDI) and the expected interruption cost (ECOST) decreased from 0.289, 0.306 and 5,216.0 up to 0.046, 0.049 and 1,119.10 respectively (Chiradeja et al., 2017). On another study, the determining optimal DG locations to maximize the reliability are different due to time-varying loads. During different loading patterns in the circuits of a system, inserting a DG may yield the large enhancement for heavy load than light load (Zhu et al., 2006). The optimal placement of DG to improve reliability is examined. The factors such as DG based on renewable energy source and load curtailment scheme have impact on the sensitivity of reliability to changing location. However, the optimal location of DG remain the same (Banerjee and Islam, 2011).

4.2.8. Power system stability with optimal PV-DG

Voltage sensitivity analysis is used to propose the candidate buses for DG installation. Both probabilistic nature of loads and renewable DG (PV and wind) are considered. Simulation results

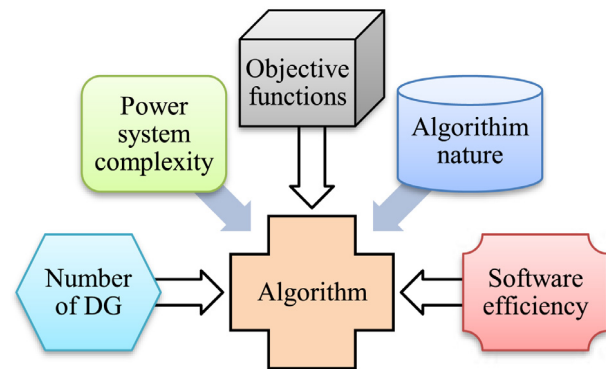


Fig. 10. Influence factors on algorithm performance for DG in power system.

shows that DG allocation can enhance the voltage stability margin Al Abri et al. (2013). In Aman et al. (2012), Power Stability Index (PSI) is used to find the most voltage sensitive bus and lowest power losses to place and size DG in distribution power system. It is proved that the voltage stability is improved after DG located. On other hand, DG with and without reactive limits have great effects on optimal location, size and number of DG. The optimal objective function based on Voltage stability and system power loss are performed by proposed method is much less than the case of no reactive limits (Esmaili et al., 2014). The authors proposed a new index to obtain the optimal allocation of DG. It is based on reduction of losses and improvement of voltage stability taking in account load variations (Poornazaryan et al., 2016). The obtain result indicates the voltage stability is kept improving below and above load base case after installed DG. In Roy et al. (2012), Q-laudability technique proposed to find suitable location for wind and solar generators. For improvement of voltage stability, authors recommends to locate the wind generator in the strong region and solar generator in the weak region in the power system.

5. Optimization methods for PV-DG allocations

The selecting algorithm is very sensitive task for PV-DG allocation. There are several factors which can indicate the most effective algorithm among others as in inspired Fig. 10 (Ayodele et al., 2015; Kayal and Chanda, 2013; Moradi and Abedini, 2012a).

Herein, algorithms can be divided into three categories. Each has its own characteristics and efficiency. They are presented as in Fig. 11.

5.1. Analytical methods

These analytical methods (AMs) are derived based on algebraic expressions. They are used to find the optimal DG allocation. Generally, these have ability to perform in fast and direct calculation (Viral and Khatod, 2012). It can handle a single objective in power system. Herein, some common analytical methods are presented.

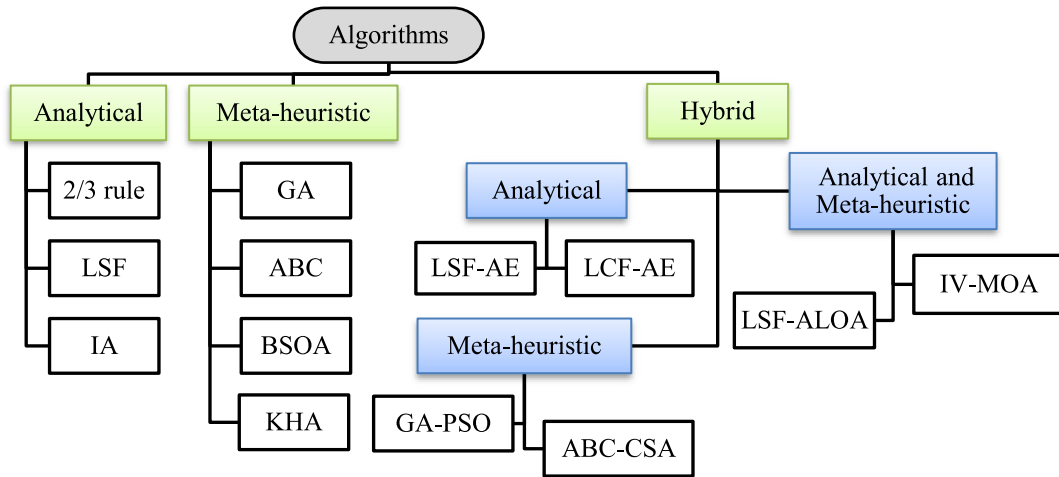


Fig. 11. Algorithm categories.

5.1.1. 2/3 rule

The golden rule or 2/3 rule was introduced to find the optimal DG (in particular capacitor) location within distribution system with uniformly load. This technique locates approximately the DG at point of the line that corresponding to 2/3 of the entire length of the line. The size of DG is equal to 2/3 of the total load demand. The golden rule is simple and easy to be applied (Abdmouleh et al., 2017; Willis, 2000). The golden rule is simple and easy to be applied. However, it cannot be used directly for other types of loads (Mittal, 2012)

5.1.2. Loss Sensitivity Factor (LSF)

LSF is used either to find optimal allocation of DG or to reduce search space for sophisticated algorithms in power system. The technique is used based on the principle of linearization of the original exact loss formula at initial operating point. The LSF for a given system can be calculated by Eq. (7). List of buses with respect to highest LSF value is formed in descending order. The top ranked buses in the list are considered as the candidate locations (Hung et al., 2013). Fig. 12 shows the principle work of LSF.

$$LSF_i = \frac{dP_L}{dP_i} = 2 \sum_{j=1}^n (\alpha_{ij}P_j - \beta_{ij}Q_j) \quad (7)$$

where n is the number of bus, $a_{ij} = \frac{r_{ij}}{v_i v_j} \cos(\delta_i - \delta_j)$, $\beta_{ij} = \frac{r_{ij}}{v_i v_j} \sin(\delta_i - \delta_j)$ and $r_{ij} + jx_{ij} = Z_{ij}$ are the ij th element of [Zbus] matrix with [Zbus] = [Ybus]⁻¹.

Even though LSF does not need long processing time, it is noticeable, highest LSF value does not guarantee the lowest loss reduction (Acharya et al., 2006).

5.1.3. Improved Analytical method (IA)

Improved Analytical (IA) technique is used to optimize DG allocation. It is build based on analytical expressions. IA is mainly used to determine the optimal size at different buses by using Eq. (8). Meanwhile, the developed methodology is used to determine the optimal location of DG based on finding minimum real power loss (Hung et al., 2013, 2010). For optimal location, it is used approximate loss where the values α and β of base case based on Elgerd's loss formula is used. The flowchart in Fig. 13 shows the mainly steps for DG allocation:

$$P_{DG_i} = P_{D_i} + \frac{1}{\alpha_{ii}} \left[\beta_{ii}Q_i - \sum_{j=1, j \neq i}^n (\alpha_{ij}P_j - \beta_{ij}Q_j) \right] \quad (8)$$

where P_{DG_i} and P_{D_i} are the injection and demand of real power at bus i of the system respectively.

The power flow in this method runs two times; without DG to calculate the power loss based on base case load and with DG to calculate the minimum power loss. These make the approach fast in computational time.

5.2. Meta-heuristic algorithms

As in literature, most of existing researches consider meta-heuristic algorithms to optimize DG allocations. They are not restricted to solve one problem. By Multi Objective Optimization (MOO), meta-heuristic algorithms can handle contradictory objectives. The challenge in such algorithm, it can be trapped in local optimum either global optimum.

5.2.1. Genetic Algorithm (GA)

Genetic Algorithm (GA) is introduced by John Holland at 1975. GA is used in many applications of sciences. It has ability to handle single and multi-objective functions (Alinejad-Beromi et al., 2007; Pisica et al., 2009). In GA, set of gens are represented by chromosome or individual. Each individual represents a solution of the given problem and then group of different individuals create a generation (population). Every individual in the population gets an evaluation of its adaptation (fitness) to the environment. By means of evolutionary operators like selection, crossover and mutation, a new generation (offspring population) is created. The selection chooses the best gene combinations (individuals), which through crossover and mutation should drive to better solutions in the next population. Fig. 14 shows the frame work of GA (Samajpati, 2014; Popov, 2003).

Based on the result in Pisica et al. (2009), the proposed algorithm is effective when the number of DG is increased. It also achieves the objective functions. However, GA consume more time during operation.

5.2.2. Artificial Bee Colony (ABC)

Artificial Bee Colony (ABC) is method inspired by Dervis Karaboga in year 2005 (Karaboga, 2005). This technique is based on the principle of the activity of swarm of bees to look for food around their hive. In ABC, three groups of bees are formed: employee, onlooker and scout (Abu-Mouti and El-Hawary, 2011). ABC algorithm consists of four phases; (1) initialization phase, (2) employed phase, (3) onlooker phase and (4) scout phase. ABC just has two control parameters; (1) size of colony and (2) limit

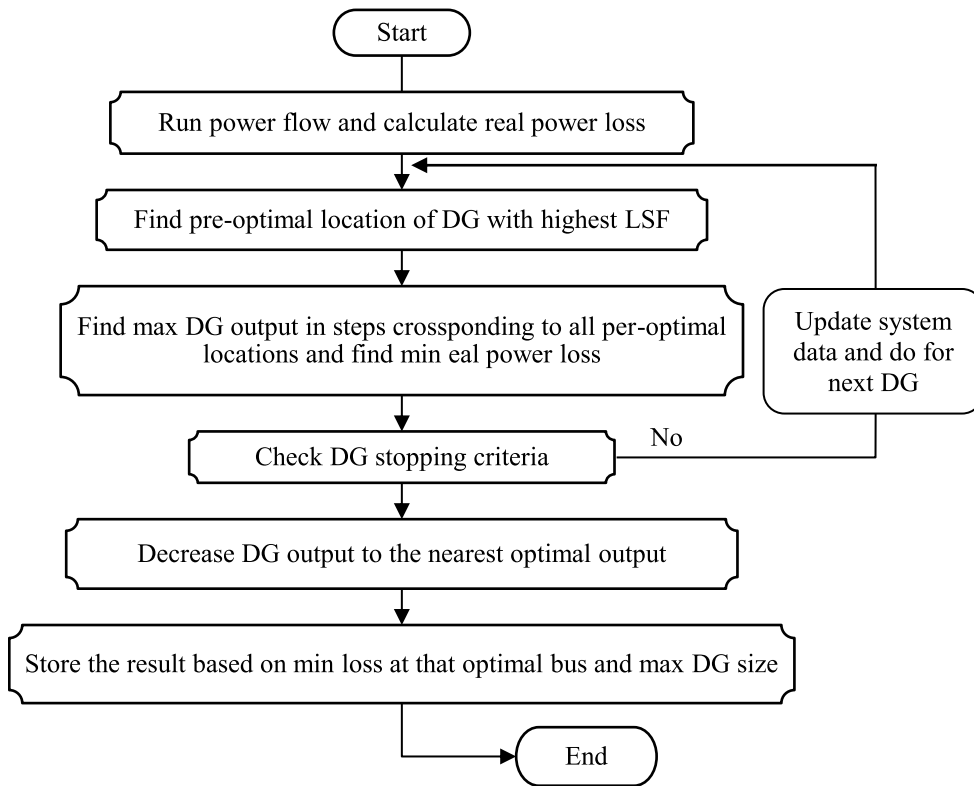


Fig. 12. Flowchart of LSF for DG allocation.

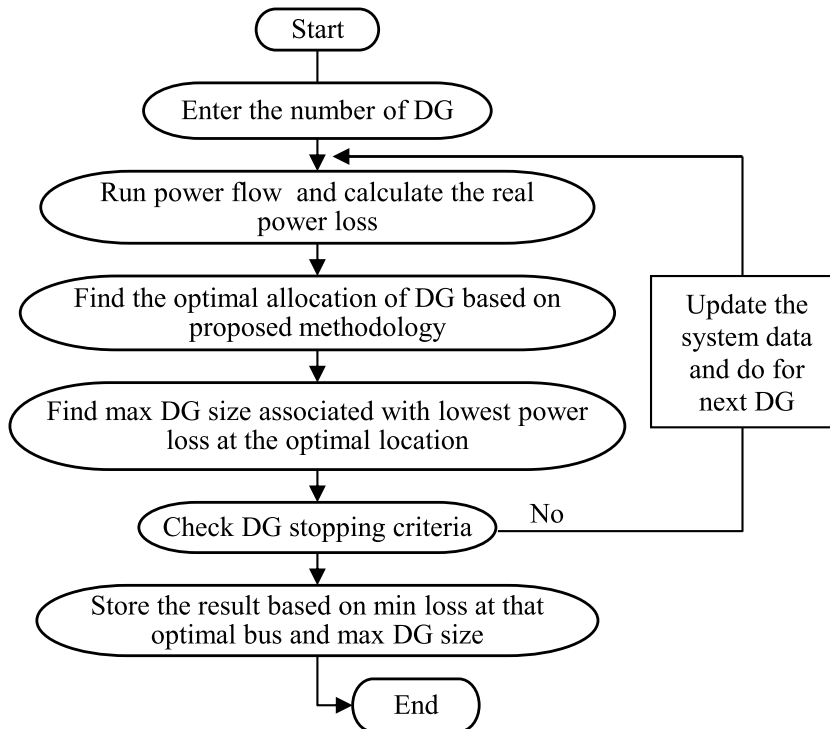


Fig. 13. Flowchart of DG allocation based on IA method.

or iteration number (MOHD NABIL BIN MUHTAZARUDDIN, 2014; Dixit et al., 2016b).

The initial location of food source is randomly determined by scout bees and then Eq. (9) is used to calculate the fitness function

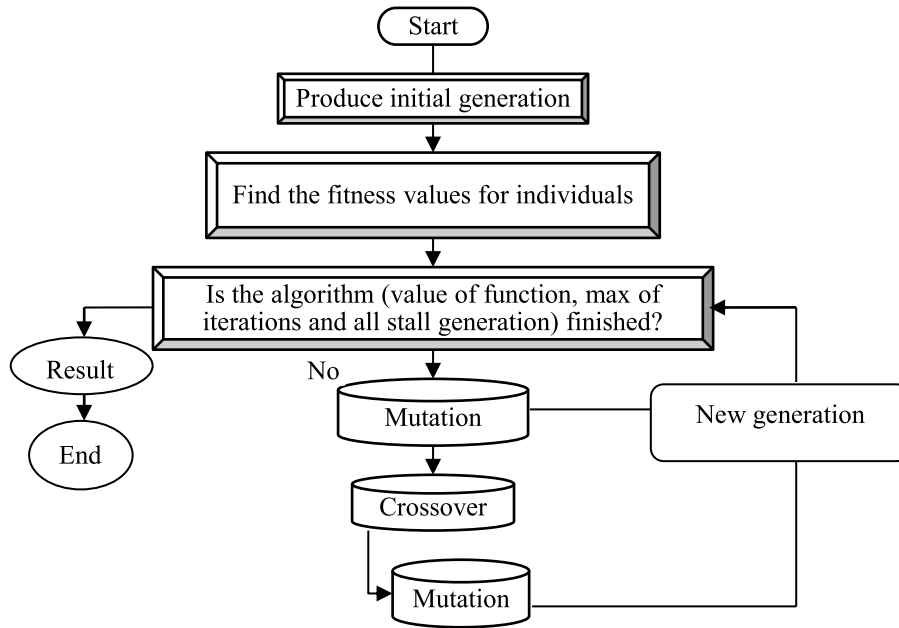


Fig. 14. Genetic Algorithm scheme.

(FV_i) within initial stage. The information of food location will transfer to employed bees. Latter bees will find another food source location near to the previous one by using Eq. (10) and then highest fitness value of new location is evaluated using greedy selection. The best fitness value will be kept in the memory and then used in onlooker' bees stage. Within this stage, the probability of available nectar is checked by using Eq. (11). Fig. 15 represents all stages of ABC algorithm.

$$FV_i = \frac{1}{1 + \text{objective function}_i} \quad (9)$$

$$x_{ij}^{new} = x_{ij}^{old} + \text{range}(0, 1) \cdot (x_{ij}^{old} - x_{ki}) \quad (10)$$

where x_{ij}^{new} and x_{ij}^{old} are the new and previous value of variable respectively. x_{ki} is a neighbor value that is selected randomly from j th dimension and range between (0,1) or [-1,1].

$$prob_i = \frac{FV_i}{\sum_{i=1}^N FV_i} \quad (11)$$

where $prob_i$ is probability value and N is the total number of employed bees.

ABC method is used to determine the optimal DG allocation. This algorithm is verified by comparing with other. It can perform the optimization of single and multi DGs in less time (Abu-Mouti and El-Hawary, 2011; Seker and Hocaoglu, 2013).

5.2.3. Backtracking search Optimization Algorithm (BSOA)

BSOA is originally used to find global minimum for a given problem. The BSOA can be explained by dividing its functions into five procedures: (i) initialization of the population (P) as in Eq. (12), (ii) selection-I which is used to find the old population ($oldP$) as in Eq. (13), (iii) mutation generates the initial form of the trial population mutant based on P and ($oldP$) using Eq. (14) (iv) crossover produces the final arrangement of the trial population T , and (v) selection-II, P is updated with individuals of T having better fitness as shown in Fig. 16 (Sheoran et al., 2015; El-Fergany, 2015). Unlike many search algorithms, BSOA has one control parameter that is used to control mutation in the

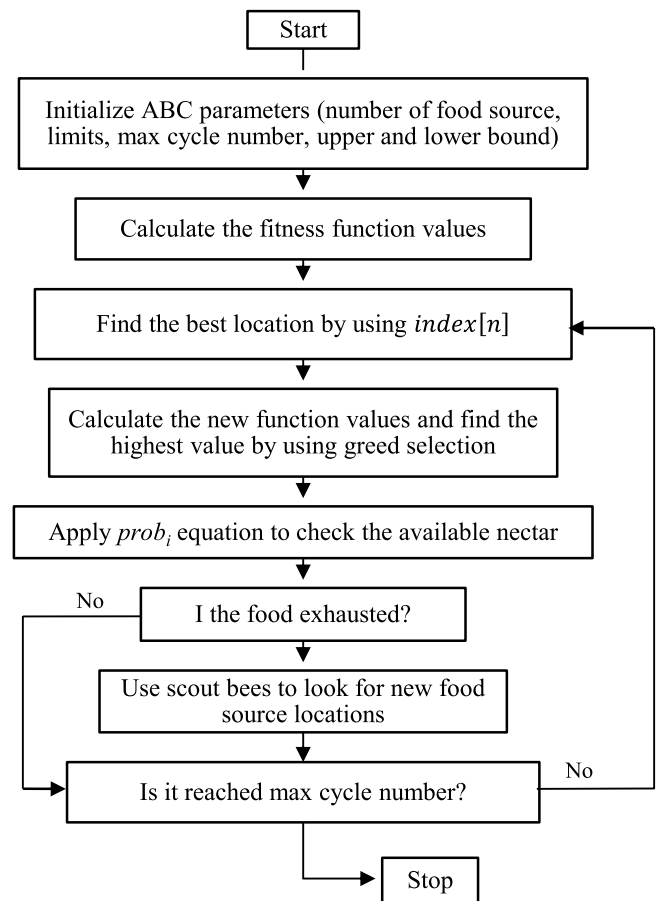


Fig. 15. The scheme of ABC.

crossover step and not be over-sensitive to it. BSOA's problem-solving performance is not over sensitive to the initial value of

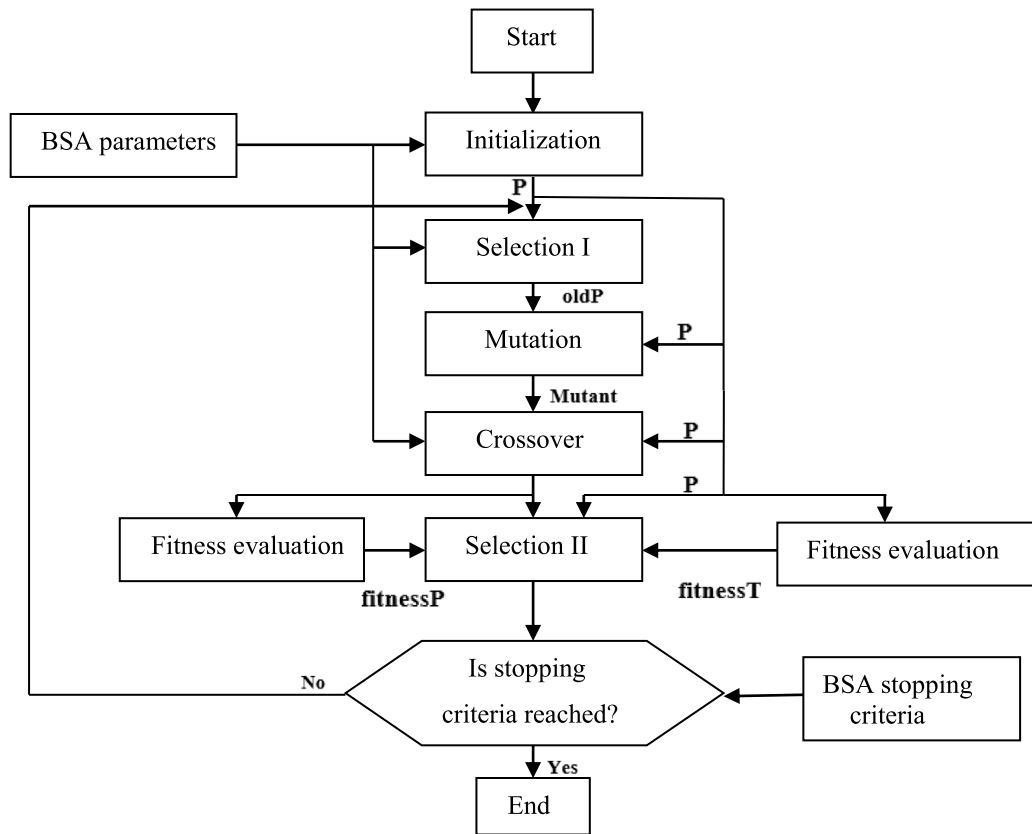


Fig. 16. The scheme of BSO (Sheoran et al., 2015).

this parameter (Civicioglu, 2013).

$$P_{i,j} = LB_j + rand(\dots) \cdot (UB_j - LB_j) \quad i \forall N \ \& \ j \forall D \quad (12)$$

where LB_j is lower bound of the optimized parameter j , UB_j is upper bound of the optimized parameter j , $rand(\dots)$ is a random number in the range 0 to 1, N is population size and D is problem dimension.

$$oldP = permuting(oldP) \quad (13)$$

$$mutant = P + F \cdot (oldP - P) \quad (14)$$

where $F = 3 \cdot randn$, and $randn$ generates a random number in the range [0,1] with normal distribution.

BSO is employed to determine the optimal location and size of DG in order to reduce real loss and enhance the voltage profile and voltage stability. This technique gives good performance to find allocation for different types of DG either single or multi-DG (El-Fergany, 2016, 2015; Gupta et al., 2015).

5.2.4. Krill herd algorithm (KHA)

krill herd (KHA) is optimization bio-technique used for many applications. KHA is developed by Gandomi and Alavi. The principle of such algorithm is based on herding behavior of individual krill due to searching for the food in multi directions as in Fig. 17. The lowest distances of each individual krill from food and from highest density of the herd are deemed as the objective function for the krill motion. The movement of individual krill is mocked in three steps; (1) Motion Induced, (2) Foraging Motion and (3) Random Diffusion. Regular KHA may be expressed by Lagrangian model in an n dimensional decision space, as presented in Eq. (15) (Gandomi and Alavi, 2012; Mukherjee and Mukherjee, 2016).

$$\frac{dx_i}{dt} = N_i + F_i + D_i, \quad i = [0, n_k] \quad (15)$$

where N_i is movement induced by other krill individuals (local), F_i is foraging motion (global), D_i is random physical diffusion and n_k is number of krill individuals.

KHA is used in power system to determine the optimal location and capacity of DG in power system. It last less time to solve the problem (Sultana and Roy, 2016; Ali et al., 2016b).

5.3. Hybrid techniques

Combination of different methods is also used to investigate the best location and size of DG for different scale systems. Hybrid methods can be categorized into (1) hybrid analytical methods, (2) hybrid meta-heuristic algorithms and (3) hybrid analytical and meta-heuristic algorithms. The hybrid methods can be done from same or different categories.

5.3.1. Hybrid analytical methods

1- Load Concentration Factor (LCF) and Analytical Expressions (AE) introduced in Shahzad et al. (2016) and Shahzad et al. (2017) is used to determine the optimal location, sizing for multiple DGs. Two approaches have been hybridizing; LCF is used to determine the locations as Eq. (16) Meanwhile, Derived analytical expression based upon exact loss formula is used to size the capacity for number of DGs simultaneously. Regard to number of desirable installing DGs, the topmost LCF's value of buses is considered for candidate locations. Fig. 18 represents the procedures of this method.

$$LCF_i = \sum_{j \in C_i} P_{Dj} \quad (16)$$

where P_{Dj} is the power demand connected at bus "j".

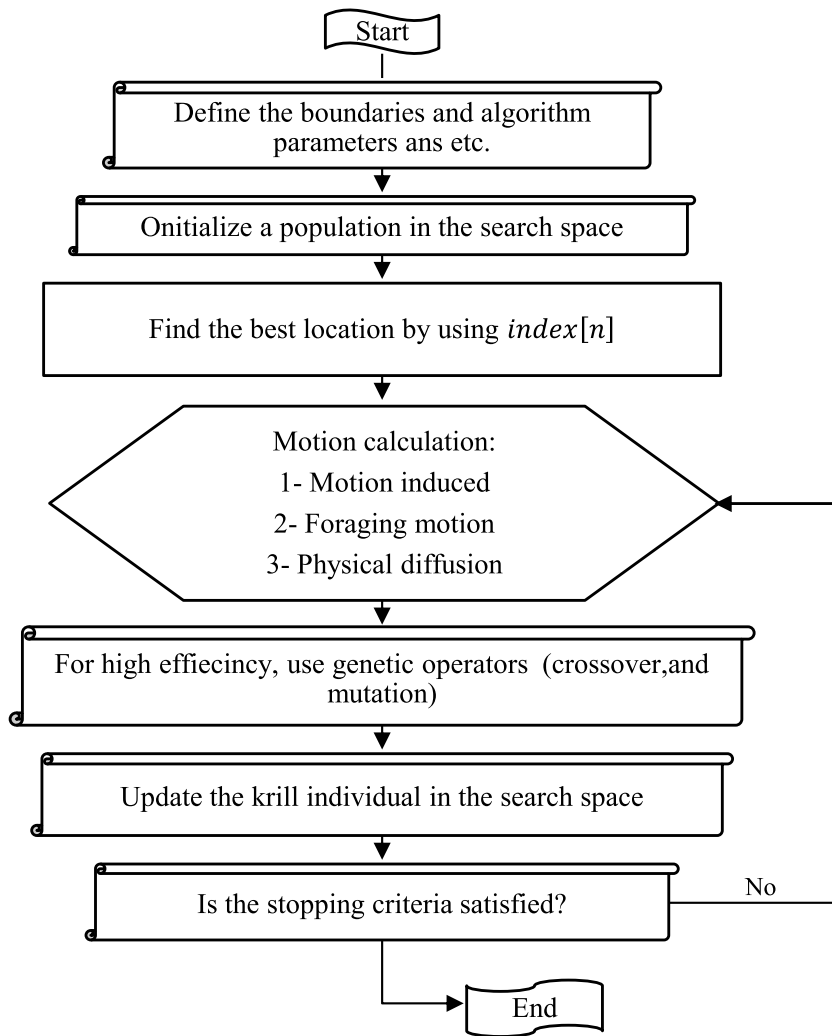


Fig. 17. The flowchart of KHA.

2- Another hybrid analytical method is based on LSF-AE proposed in [Elsaiah et al. \(2014\)](#) and [Dong and Shuhui \(2014\)](#) to minimize the power loss reduction of distribution system. LSF is applied to find the optimal location. Meanwhile, Analytical Expression (AE) is used to find optimal size and power factor for DG. LSF-AE is capable to handle medium distribution system of 69-bus.

5.3.2. Hybrid meta-heuristic algorithms

(a) Hybridizing two meta-heuristics methods Genetic Algorithm (GA) and Particle swarm optimization algorithm (PSO) for optimal allocation of DG is introduced. GA is utilized to determine the best location in the system due to its attractive quality. Meanwhile, PSO is used to find the maximum size of DG due to its fast convergence ability. The flowchart at [Fig. 19](#) represents the procedure to performance ([Moradi and Abedini, 2012a](#)).

The results showed that, the proposed combined GA/PSO method has good performance for voltage profile and voltage stability index ([Moradi and Abedini, 2012a](#); [Moradi and Abedinie, 2010](#)).

(b) The hybrid algorithm of artificial Bee Colony (ABC) and Cuckoo Search Algorithm (CSA) is used find the optimal location and size of DG ([Bhullar and Ghosh, 2018](#)). ABC was introduced in previous section of meta-heuristic algorithms. Meanwhile, CSA is optimization method introduced

by Yang and Deb in 2009. CSA has two major operators; direct search based on levy flights (first scenario), random search based on probability (second scenario) ([Yang and Deb, 2010](#)). A cuckoo egg represents a new solution while each host bird egg in a nest represents a solution. The aim is to replace a worst solution in the nests with the new and possibly better solutions ([Tan et al., 2012a](#)).

5.3.3. Hybrid analytical and meta-heuristic algorithms

(1) Another hybrid method is proposed to optimize DG in term of location and size. It consists of Whale Optimization Algorithm (WOA) (introduced by Mirjalili and Lewis) and Index Vector method (IV). WOA is inspired by hunting method of humpback whale kind of whale is fed by hunting small fishes or krills close to the sea surface. Humpback whale has unique method to hunt its prey. It is called bubble net feeding method ([Mirjalili and Lewis, 2016](#)). WOA is proposed to find optimal size of different modes of power factor for DG while optimal location is determined by IV as in Eq. (17). [Fig. 20](#) shows the procedure of this method ([Reddy et al., 2017](#); [Murthy et al., 2010](#)).

$$index [n] = \frac{1}{V(n)^2} + \frac{I_q(k)}{I_p(k)} + \frac{Q_{eff}(n)}{total Q} \quad (17)$$

$I_p(k)$, $I_q(k)$ are real and imaginary part of current in kth branch. $Q_{eff}(n)$ and $V(n)$ are effective load and voltage at nth bus respectively. Total reactive load is taken as *total Q*.

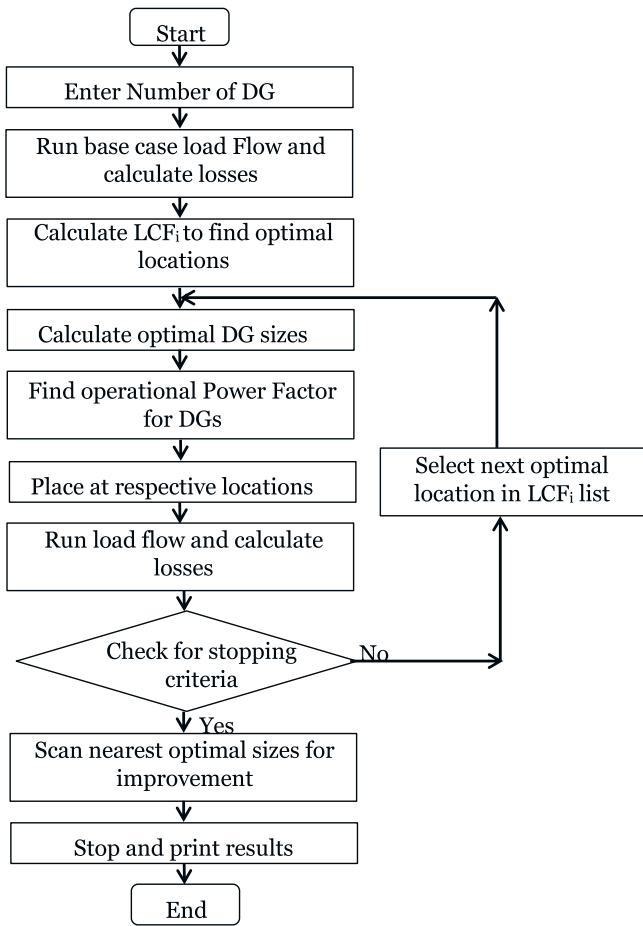


Fig. 18. Flowchart of optimal DG by using LCF-AE (Shahzad et al., 2016).

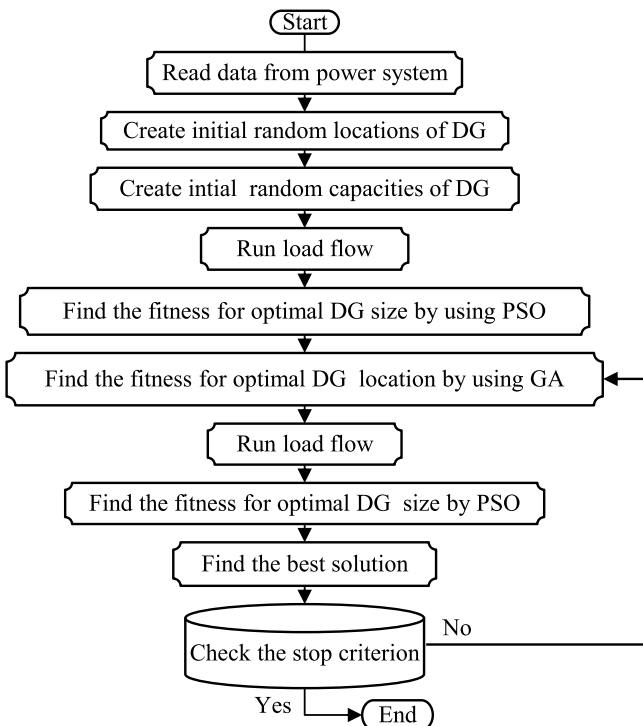


Fig. 19. The GA-PSO method for optimal location and size of DG.

LSF-ALOA: Loss Sensitivity Factor (LSF) is used to reduce the search space to present list of the candidate location for DG. Ant Lion Optimization algorithm (ALOA) is presented by Mirjalili in 2015 (Mirjalili, 2015). The principle work of this technique is to mimic between the most of ant lion life cycle (also called doodlebugs life cycle). It is ant lion larva (predator) and mainly ant (prey) in natural hunting mechanism. Fig. 21 is inspired from Dubey et al. (2016) to show the main steps of ALOA. This algorithm imitates the interaction between the predator and prey. The interaction model should include that, the requirement of the ants moves randomly in the search space while ant lion larva hunts ants and become fitter by using traps. The following matrices (18) and (19) present the stored sites of ants and ant lions and use them during optimization procedures:

$$M_{ant} = \begin{bmatrix} ant_{1,1} & ant_{1,2} & \dots & ant_{1,d} \\ ant_{2,1} & ant_{2,2} & \dots & ant_{2,d} \\ \vdots & \vdots & \ddots & \vdots \\ ant_{n,1} & ant_{n,2} & \dots & ant_{n,d} \end{bmatrix} \quad (18)$$

$$M_{antlion} = \begin{bmatrix} antlion_{1,1} & antlion_{1,2} & \dots & antlion_{1,d} \\ antlion_{2,1} & antlion_{2,2} & \dots & antlion_{2,d} \\ \vdots & \vdots & \ddots & \vdots \\ antlion_{n,1} & antlion_{n,2} & \dots & antlion_{n,d} \end{bmatrix} \quad (19)$$

n is the number of ants or ant lion and d denotes the ant or ant lion dimension. The objective function is employed during optimization and the following matrix (20) and (21) saves the fitness value for each ant and ant lion:

$$M_{oa} = \begin{bmatrix} F_t [ant_{1,1} \quad ant_{1,2} \quad \dots \quad ant_{1,d}] \\ F_t [ant_{2,1} \quad ant_{2,2} \quad \dots \quad ant_{2,d}] \\ \vdots \\ F_t [ant_{n,1} \quad ant_{n,2} \quad \dots \quad ant_{n,d}] \end{bmatrix} \quad (20)$$

$$M_{oal} = \begin{bmatrix} F_t [antlion_{1,1} \quad antlion_{1,2} \quad \dots \quad antlion_{1,d}] \\ F_t [antlion_{2,1} \quad antlion_{2,2} \quad \dots \quad antlion_{2,d}] \\ \vdots \\ F_t [antlion_{n,1} \quad antlion_{n,2} \quad \dots \quad antlion_{n,d}] \end{bmatrix} \quad (21)$$

In Ali et al. (2017a, 2016a), the authors work to develop ALOAA to optimize the DG allocation. ALOAA is proven to have good performance compared to other meta-heuristic algorithms (Mouassa et al., 2017; Hadidian-Moghaddam et al., 2017).

5.4. Other optimization algorithms for DG

There are other optimization algorithms which are not in categorization in Fig. 9. They are also used to find the optimal allocations associated with objective functions. Some of them are presented in this section and others are listed in Table 6.

- 1- ELF is also called Repeated Power Flow (RPF). It is single objective function used to optimize the allocation for DG. The principle operation of this technique is to install single DG at one time on bus. The DG output is increased in steps till stopped at specific value corresponding with real power loss (Elsaiah et al., 2014; Shahzad et al., 2016).
- 2- Revamp Voltage Stability Indicator (RVSI) method is used to identify the proper location of DG in the power system. RVSI is derived from quadratic equation of voltage for sending end of 2-bus system as in Rath et al. (2017). If RVSI value is approaching one for a given line, this line is considered as the critical line. Meanwhile, the line corresponding sending end bus is recognized as the weak bus (Singh et al., 2018).

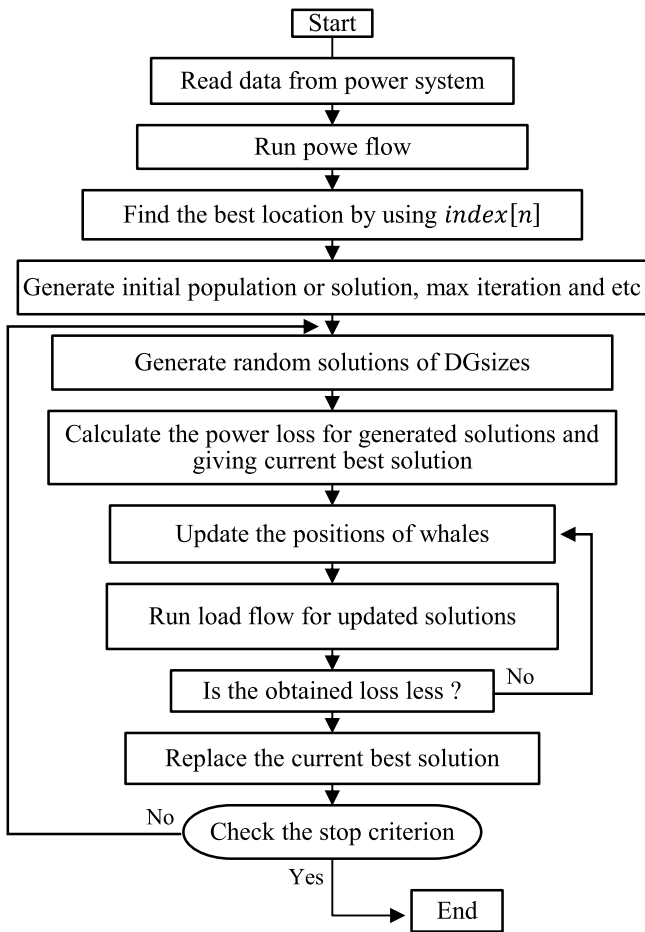


Fig. 20. IV-WOA method for optimal sitting and sizing of DG.

- 3- EA-OPF: Efficient Analytical (EA) method is based on applied the proposed Real Power Loss Reduction (RPLR) as an index when DG is installed. EA is used to find optimal location. Meanwhile, Optimal Power Flow (OPF) is used to find the optimal DG size for the defined (Mahmoud et al., 2016).
- 4- Differential Evolutionary Algorithm (DEA) is demonstrated to be one of the most excellent EAs to solve real-valued optimization problems (Lin et al., 2004). DEA is based on population of random parallel search evolutionary for optimization. It has the ability to handle nonlinear, multi-objective functions, and non-differentiable (Bulac et al., 2010).

5- Sequential Quadratic Programming (SQP) is optimization method based on numerical iterative. It handles the constrained minimization problem by solving a quadratic programming (QP) (Alhajri et al., 2010; AlHajri and El-Hawary, 2008). SPQ is used to optimal allocation of DG. It can handle single and multi-objective functions (Darfour, 2013).

6. Objectives within power system

Determination of optimal site and size for PV-DG or DG in general within power system is also influenced by the objectives functions such minimizing loss and improving voltage profile. In this section, the impacts and most recent objective are presented.

6.1. The impact of objectives on PV-DG in power system

It is noteworthy that, the location of DG can be also changed due to the selecting desirable single or multi objectives associated with weight factors. In Nasrolahpour et al. (2012), the best location of DG to minimize real power loss is found on bus 36 and the best location for mitigate voltage sag is on bus 24 of 45-bus distribution network. However, bus 29 is considered as best location to achieve the double objective functions. Similar study is also conducted on PV-DG. The below simulation result in Fig. 22 obtained from IEEE-14 bus system illustrates the optimal location of PV-DG based on three objective functions (Mosbah et al., 2016). The bus 9 presents the optimal location for stability margin (λ) at (a) and total power loss at (b). However, Critical Clearing Time (CCT Wang et al., 2016) of removal fault at (c) indicates the bus 7 is the optimal location.

However, considering all three objective functions is affected the optimal location. In the case where weighted factors are considered have the same value $w_1 = w_2 = w_3 = 1/3$, optimal PV-DG location is in bus 9.

6.2. Optimization objectives in power system

This subsection explores enormous of studies to optimize the PV-DG allocation based on single and multi-objectives. Herein, all objectives in Radial Distribution System (RDS) or mesh power system are presented mathematically. Furthermore, Table 6 represents different several power system objectives for all type of DGs. This is because of the most objectives are common in power system for each DG type.

6.2.1. Technical power loss

Basically, power system losses can be classified into technical losses causes by internal factors and non-technical losses cause by external factors (Anumaka, 2012). For a transmission line (l) connected between (i) as sending node and (j) as receiving node, the real and reactive power loss are P_{loss} and Q_{loss} respectively

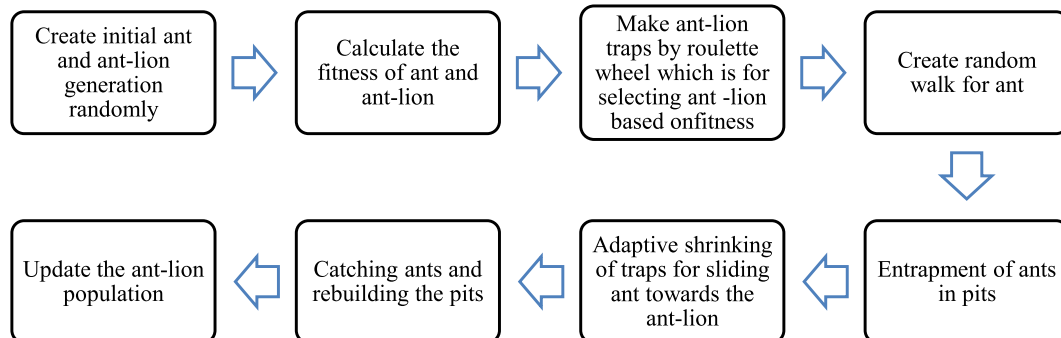


Fig. 21. The scheme of ALOA.

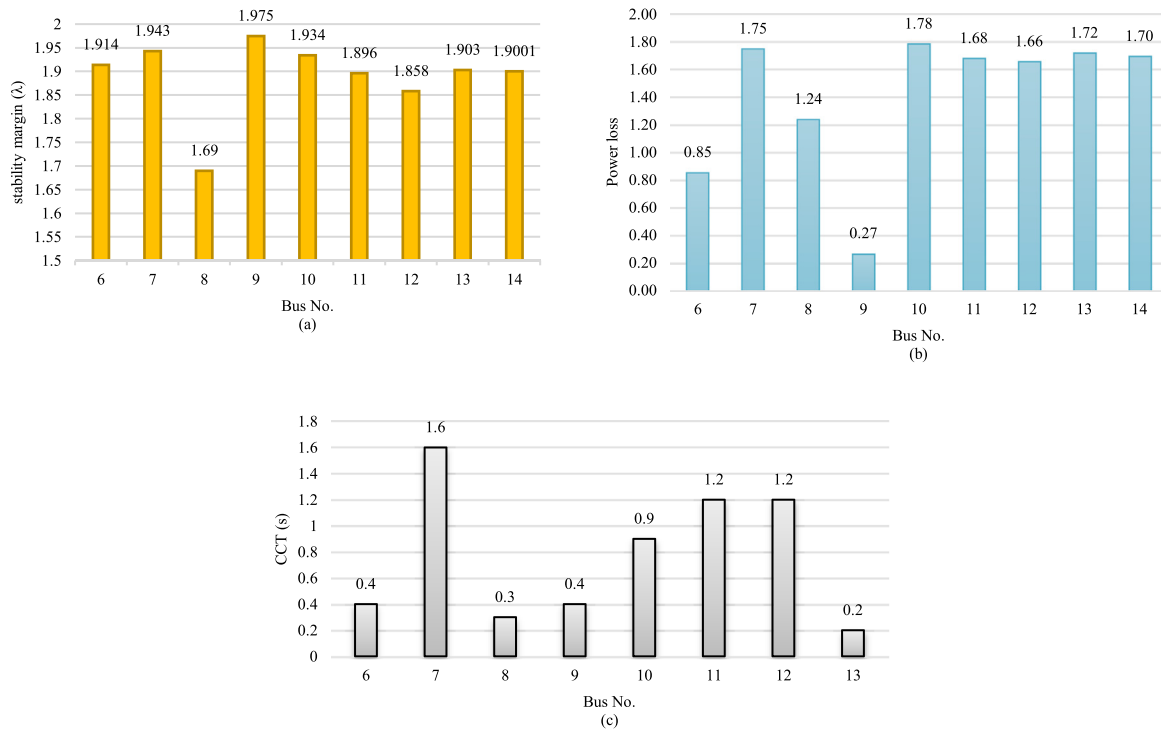


Fig. 22. (a) Represents the stability margin, (b) Showing minimum loss reduction and (c) Depicts the maximum CCT.

and presented mathematically as in Yuvaraj et al. (2017a) and Adefarati and Bansal (2016):

$$P_{loss} = \left(\frac{P_{ij}^2 + Q_{ij}^2}{V_i} \right) R_{ij} \quad (22)$$

or

$$P_{loss} = \sum_{i=1}^{n_n} I_{rel,ij}^2 R_{ij}, \quad (23)$$

where n_n is total number of buses in the given system, and R_{ij} $I_{rel,ij}$, are the resistance line and real current of power line respectively.

$$Q_{loss} = \left(\frac{P_{ij}^2 + Q_{ij}^2}{V_i} \right) X_{ij} \quad (24)$$

or

$$Q_{loss} = \sum_{i=1}^{n_n} I_{rect,ij}^2 X_{ij}, \quad (25)$$

where X_{ij} and $I_{rect,ij}$ are the reactance line and reactive current in that power line respectively. The power loss in a power system is also represented by an exact loss formula (Hung et al., 2013; Acharya et al., 2006; Hung and Mithulanathan, 2014):

$$P_{Loss} = \sum_{i=1}^{n_n} \sum_{j=1}^{n_n} [a_{ij} (P_i P_j + Q_i Q_j) + \beta_{ij} (Q_i P_j - P_i Q_j)] \quad (26)$$

$$Q_{Loss} = \sum_{i=1}^{n_n} \sum_{j=1}^{n_n} [\gamma_{ij} (P_i P_j + Q_i Q_j) + h_{ij} (Q_i P_j - P_i Q_j)], \quad (27)$$

where $a_{ij} = \frac{R_{ij}}{V_i V_j} \cos(\delta_i - \delta_j)$; $\beta_{ij} = \frac{R_{ij}}{V_i V_j} \sin(\delta_i - \delta_j)$, $\gamma_{ij} = \frac{X_{ij}}{V_i V_j} \cos(\delta_i - \delta_j)$; $h_{ij} = \frac{X_{ij}}{V_i V_j} \sin(\delta_i - \delta_j)$ and P_i , Q_i are net real and reactive power injections in bus i and P_j , Q_j net real and reactive power demand in bus j , and V , δ are the voltage magnitude and angle at

bus i and j . Furthermore, power loss also can be also expressed as (Moradi and Abedini, 2012a):

$$P_{loss} = \sum_{i=2}^{n_n} (P_{gni} - P_{dni} - V_{mi} V_{ni} Y_{ni} \cos(d_{mi} - d_{ni} + \theta_{ni})) \quad (28)$$

$$Q_{loss} = \sum_{i=2}^{n_n} (Q_{gni} - Q_{dni} - V_{mi} V_{ni} Y_{ni} \sin(d_{mi} - d_{ni} + \theta_{ni})), \quad (29)$$

where P_{gni} is real power output of the generator at bus ni , P_{dni} is active power demand at bus ni , V_{mi} and V_{ni} are voltage of bus at mi and ni respectively, and δ_{mi} and δ_{ni} are phase angles of voltage at bus mi and ni respectively, Y_{ni} is admittance between bus ni and bus mi , θ_{ni} is phase angle of Y_{ni} .

6.2.2. Voltage stability (V_{st})

VSI is one of the most indices that are implemented to investigate the level security in power system. It can be obtain from such mathematical model as below (Ali et al., 2017a; Tan et al., 2012b):

$$VSI(j) = |V_i|^4 - 4(P_j X_{ij} - Q_j R_{ij})^2 - 4(P_j R_{ij} + Q_j X_{ij}) \cdot |V_i|^2 \quad (30)$$

6.2.3. Voltage profile (V_{pro})

The power system voltages should maintain within specified limits because of the power quality requirements. Voltage profile (V_{pro}) can be expressed mathematically as (Moradi and Abedini, 2012b):

$$V_{pro} = \sum_{i=1}^{n_n} (V_{ni} - V_{ratd})^2, \quad (31)$$

where V_{ratd} are voltage of bus ni rated voltage in per unit.

6.2.4. Voltage deviation (V_d)

Due to the nature of radial distribution system, it can lead to voltage dips in case of heavy load and remote areas. Hence

minimize the voltage deviation is significant issue in power system. Voltage deviation can be mathematically presented as (Tolba et al., 2018b, 0000; Khoa et al., 2017):

$$\Delta V_d = \max \left(\frac{V_1 - V_i}{V_1} \right), \forall i = 1, 2, 3, \dots, n_n \quad (32)$$

or

$$V_d = \sum_{i=2}^{n_n} [(V_i - V_{max})^2 + (V_i - V_{min})^2] \quad (33)$$

or

$$\Delta V_d = \sum_{i=1}^{n_n} \left(\frac{V_{ref,i} - V_i}{V_{ref,1}} \right)^2, \quad (34)$$

where V_{ref} is a reference bus, V_{max} and V_{min} are maximum and minimum voltage.

6.2.5. Minimization of total operational cost

There are many factors to be considered to minimize the cost (Kansal et al., 2015; Kefayat et al., 2015a). Herein, minimization of total operational Cost is mathematically presented. The operational cost consists of two components. The first one is the real power received from the substation of power system. The second component is the cost of real power received from DG injected to the same system. The total operating cost (TOC) can be minimized by the following formula (Tolba et al., 2018b):

$$TOC = (C_1 P_{DG, total loss}) + (C_2 P_{T, DG}), \quad (35)$$

where, C_1 and C_2 are the cost coefficient of real power supplied by substation and DGs in \$/kW, $P_{T, DG}$ is the total real power drawn from installed DGs.

6.2.6. Emission

Reduction of emissions come from different supplied power sources in power system, it is another objective to be minimized. The most important pollutants are such as Carbon Dioxide (CO_2), Nitrogen Oxides (NO_x) and Sulfur Dioxide (SO_2) and mathematically modeled as Kefayat et al. (2015a). topically, PV-DG does not cause any of these emission components.

$$E = (CO_2 + NO_x + SO_2) P, \quad (36)$$

where E and P are design emissions produced and real power generation by the (k) energy sources.

6.2.7. Load margin (LM)

At a specific point of operation, the amount of extra added load that would give rise to a voltage collapse is called as the loading margin stability (LMS) or loading margin (LM) of the system. the modal participation factor analysis method is proposed in Thakur and Jjiang (2013). LM is can be also mathematically written as (Mahdad, 2019):

$$P_{new} = LM \times P_{norm} \quad (37)$$

$$Q_{new} = LM \times Q_{norm}, \quad (38)$$

where P_{new} and Q_{new} are the new real and reactive power to be satisfied, P_{norm} and Q_{norm} are the real and reactive power at normal condition.

6.2.8. Other objective functions

There are some other different objective function which are not covered in Table 6. They are presented mathematically as below:

- 1- Voltage sag mitigation and voltage quality improvement
Voltage quality has become a very important aspect of power delivery especially in the second half of the 1990s (Bollen, 2013). Voltage sag or dip is one of the severe forms of voltage quality problems in distribution network. In order to improve voltage quality, voltage sag should be mitigated as soon as possible for preventing the load from getting damaged. Voltage sag can be mitigated by several indices as in (Nasrolahpour et al., 2012):

$$SCI = \frac{\sum_{j=1}^{N_E} \sum_{i=1}^{SET_i} LSC_{ik}}{N}, \quad (39)$$

where SCI is loss cost of sag events index; LCS is loss cost caused by sag events for a customer, N_E is the number of customers affected by sag events, SET is sag event times per year of a customer. Another voltage sag index (VSI) is also mathematically presented as (Murthy et al., 2013):

$$VSI = \sum_{i=1}^{NPCC} \sum_{j=1}^{n_n} |V_{ij}^{sag}|^2, \quad (40)$$

where $V_{ij}^{sag} = \frac{Z_{ij} + Z_t}{Z_s + Z_{ij} + Z_t}$, NPCC is number of Point of Common Coupling, V_{ij}^{sag} is the sagged voltage at PCC during the fault at node j , Z_s is the source impedance at PCC, Z_{ij} is the impedance between PCC and fault location j and Z_t is the fault impedance

- 2- Frequency quality improvement
Power frequency characteristic is very important issue in power system. During severe disturbances happen on the power system, the frequency can be deviated from normal steady state performance temporarily. The deviation in frequency are caused by either severe blackouts and massive generation/load imbalances (Institute of Electrical and Electronics Engineers, 2011). Frequency should remain within standard limits (Reliability Panel Australian Energy Market Commission, 2017).
- 3- Harmonics
Typically, current distortions is caused by loads while voltage distortions is caused by generators. For generators such DG, two major issues of harmonic distortions include voltage Total Harmonic Distortion (THD_V) and Individual Harmonic Distortion (IHD_V). Such harmonics must be maintained within standard limits (Duong et al., 2019; Sasiraja et al., 2017; Sadeghi and Ghaffarzadeh, 2016). The total voltage harmonic distortion at each bus i is as follows:

$$THD_{V,i}(\%) = \frac{\sqrt{\sum_{h \neq 1}^h |V_i^h|^2}}{|V_i^1|} \times 100 \leq THD_V^{max} \quad (41)$$

$$IHD_{V,i}^h(\%) = \frac{|V_i^h|}{|V_i^1|} \times 100 \leq IHD_V^{max}, \quad (42)$$

where h is the harmonic order, THD_V^{max} is the maximum allowable total voltage harmonic distortion limit, and IHD_V^{max} is the maximum permissible voltage harmonic distortion level at harmonic order.

7. PV solar energy source

The clean energies are considered as promising solutions to tackle and mitigate tremendous of local and international outstanding. PV system is the method to convert solar energy to

Table 6
Summary of objective functions associated with their algorithms.

Ref.	Algorithm	P_{loss}	Q_{loss}	V_{st}	V_{pro}	V_d	Cost	Emission	LM	Power systems
Salih et al. (2016)	SA	✓	x	x	x	x	x	x	x	IEEE 30 bus test system
Dinakara et al. (2016)	IV-FPA	✓	x	x	x	x	x	x	x	IEEE 15, 34 and 69-bus RDSs
Ali et al. (2017a)	LSF-ALOA	✓	x	✓	✓	x	x	x	x	IEEE 33 and 69-bus radial RDSs
Kayal and Chanda (2013)	PSO	✓	x	✓	x	x	x	x	x	IEEE 12, 15, 33 and 69-bus RDSs
Shahzad et al. (2016)	Proposed approach	✓	x	x	x	x	x	x	x	IEEE 37 and 119- bus RDSs
Hassan et al. (2017)	ALGA	✓	x	x	x	x	x	x	x	IEEE 33, 69 and 119-bus RDSs
Kefayat et al. (2015b)	ACO-ABC	✓	x	✓	x	x	✓	✓	x	IEEE 33 and 69- bus RDSs
Reddy et al. (2017)	IV-WOA	✓	x	x	x	x	x	x	x	IEEE 15, 33, 69 and 85- bus RDSs
Acharya et al. (2006)	Proposed approach	✓	x	x	x	x	x	x	x	IEEE 30, 33 and 69-bus RDSs
Hung et al. (2013)	Improved analytical	✓	x	x	x	x	x	x	x	IEEE 16, 33 and 69-bus RDSs
Yuvaraj et al. (2017b)	LSF-CSA	✓	x	x	x	x	x	x	x	IEEE 12, 34, and 69- bus RDSs
Sudabattula and Kowsalya (2016)	CSA	✓	x	x	x	x	x	x	x	IEEE 69 bus RDS
Tan et al. (2012a)	CSA	✓	x	✓	x	x	x	x	x	IEEE 69 bus RDS
Moradi and Abedini (2012a)	GA-PSO	✓	x	✓	✓	x	x	x	x	IEEE 33 and 69-bus RDS
Moradi and Abedinie (2010)	GA-PSO	✓	x	x	✓	x	x	x	x	IEEE 33-bus RDS
Rath et al. (2017)	RVSI	x	x	✓	x	x	x	x	x	IEEE 14 bus system
Ayodele et al. (2015)	GA	✓	x	x	x	x	x	x	x	IEEE 14 bus system
Ghosh et al. (2010)	Proposed method	✓	x	x	x	x	✓	x	x	IEEE 6, 14 and 30- bus systems
Mohan N and Kulkarni (2015)	WMOVI	✓	x	x	✓	x	x	x	x	Standard Civanlar16-bus and 12 bus Practical RDS
Pisica et al. (2009)	NOA and GA	✓	x	x	x	x	✓	x	x	IEEE 69 bus RDS
Seker and Hocaoglu (2013)	ABC	✓	x	x	x	x	x	x	x	IEEE 33, 69, 229 bus RDSs
Ali et al. (2016b)	KHA	✓	✓	x	x	x	x	x	x	IEEE 33 bus RDS
Devi and Geethanjali (2014)	MBFOA	✓	x	x	x	x	x	x	x	IEEE 12, 34, and 69-bus RDSs
Kayal et al. (2017)	DGSI	✓	x	✓	x	x	x	x	x	IEEE 12, 33, and 69-bus RDSs
Shahzad et al. (2014)	Proposed method	✓	x	x	x	x	x	x	x	IEEE 14 and 30 bus systems
Mohamed et al. (2017)	HPSO	✓	x	x	x	✓	✓	x	x	IEEE 33, and 69-bus RDSs
Mohamed and Kowsalya (2014)	LSF-BFOA	✓	x	x	x	✓	✓	x	x	IEEE 33, and 69-bus RDSs
Rathod and Adeshara (2014)	CPF	x	x	✓	x	x	x	x	x	IEEE 14 bus system
Manafi et al. (2013)	PSOs and DEs	✓	x	x	x	x	x	x	x	IEEE 33, and 69-bus RDSs
Abu-Mouti and El-Hawary (2011)	ABC	✓	x	x	x	x	x	x	x	IEEE 33, and 69-bus RDSs
Makhloufi et al. (2017)	CSA	✓	✓	✓	x	x	x	x	x	IEEE 9-bus RDS
Vadhera and Mahajan (2016)	Proposed method	✓	✓	x	✓	x	x	x	x	Modified IEEE 5, 14 and 30-bus systems
Al Ameri et al. (2015)	GA	✓	x	x	x	x	x	x	x	IEEE14, 30 and 57-bus system
Thakur and Jiang (2013)	Proposed method	✓	✓	x	x	x	x	x	✓	IEEE 14 bus system
Nabavi et al. (2011)	PSO	x	x	x	✓	x	✓	x	x	Modified IEEE 14 bus system
Singh and Parida (0000)	MINLP	✓	x	x	x	x	✓	x	✓	Standard 5 and IEEE 24-bus power system
Dulau et al. (2016)	N-R	✓	x	x	x	x	x	x	x	IEEE 14 bus system
Tolba et al. (2018b)	MFO	✓	x	x	x	✓	✓	x	x	15-bus of MEDN, 111-bus of Moscow region, IEEE 33, and 69-bus RDSs
Tolba et al. (2018a)	MFO	✓	x	x	x	✓	✓	x	x	IEEE 33-bus RDS
Yuvaraj et al. (2018)	BA	✓	x	x	x	x	x	x	x	IEEE 33-bus RDS
Ben Hamida et al. (2018)	Pareto optimality-based SPEA2	✓	x	x	x	x	✓	✓	x	IEEE 33-bus RDS
Biswas et al. (2017)	MOEA/D	✓	x	x	x	x	x	x	x	IEEE 33, 69, 119 and a practical 83-bus distribution networks
Mohsen et al. (2017)	GWO	✓	x	x	x	x	x	x	x	IEEE 33, and 69-bus RDSs
Khoa et al. (2017)	ORCSA	✓	x	✓	x	✓	x	x	x	IEEE 69-bus RDS
El-Fergany (2015)	BSOA	✓	x	x	✓	x	x	x	x	94- bus and IEEE 33-bus RDS
Dinakara Prasad Reddy et al. (2017)	PLI/WOA	✓	x	x	x	x	x	x	x	IEEE 15, 33, 69, 85 and 118-bus RDSs
Nawaz and Singh (2017)	PVSC	✓	x	x	x	x	x	x	x	IEEE 33 and real 130-bus RDSs
Ali et al. (2017b)	HGA	✓	x	x	✓	x	x	x	x	IEEE 34-bus RDS
Kansal et al. (2015)	PSO	x	x	x	x	x	✓	x	x	IEEE 33, and 69-bus RDSs
Mahesh et al. (2017)	MOPSO	✓	x	✓	x	✓	x	x	x	IEEE 33-bus RDS
Injeti (2017)	MOIDSA	✓	x	x	✓	x	✓	x	x	IEEE 33, and 69-bus RDSs
Peesapati et al. (2018)	FPA	✓	x	x	x	✓	✓	x	✓	IEEE 30, and 118-bus systems
Prakash and Lakshminarayana (2017)	WOA	✓	x	x	x	x	✓	x	x	IEEE-34 and 85 bus RDSs

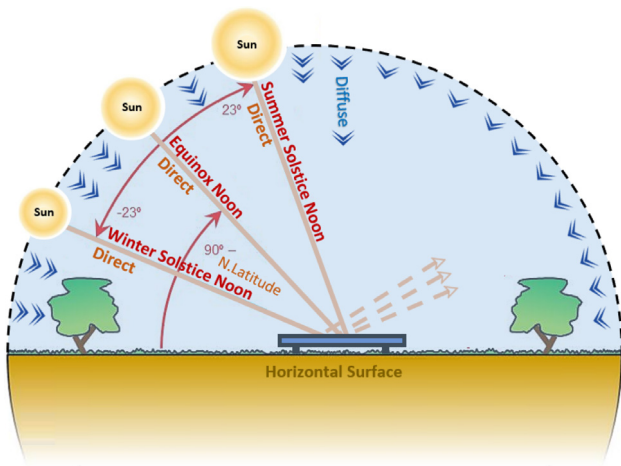


Fig. 23. Solar radiation on horizontal surface.

electric current directly. The global radiation is received by horizontal PV panels (H_h), consists of; (1) Beam or direct radiation (H_b), and (2) Diffuse irradiation (H_d) as in Eq. (43) and Fig. 23. In the case of tilted PV panel (H_t), reflected radiation ($H_{t,r}$) is presented as in Eq. (44) (Bawazir et al., 2016).

$$H_h = H_b + H_d \quad (43)$$

$$H_t = H_{t,b} + H_{t,d} + H_{t,r} \quad (44)$$

7.1. PV potentials

The second approach that can contribute to investigate the suitable location and proper size of grid connected PV system is based on PV potentials. Fig. 24 depicts the potentials in sequent manner (Tucho et al., 2014; Hoogwijk, 2004; Hermann et al., 2014). There are several parameters for each PV potentials either on-grid or off-grid. The flowchart in Fig. 25 shows the considered parameters that should be taken in account for potential assessments.

7.2. PV potential mathematical models

The theoretical potential model is usually integrated with the geographical potential in mathematical model. The potential models for PV are presented in Table 7. The Solar Home System (SHS) is not part of this work.

8. Relative studies of PV potentials

This section explores the recent researches to estimate the different potentials of PV solar energy. Most of the methodologies have common steps to evaluate the PV resource potentials.

In Hermann et al. (2014), The report introduce methodology to assess PV solar and other energy resource potentials in Africa. The analysis study is conducted on available GIS database. In Table 8, zones are excluded in geographical potential assessment. It shows the eliminated areas from the total geographical area. Fig. 26 depicts the framework for this report

In Bangladesh (Alam Hossain Mondal and Sadrul Islam, 2011), the authors estimated the potential of grid connected PV system. The estimation of potentials is done by using NASA SSE, GIS-based Geospatial Toolkit solar radiation data, HOMER and RETScreen simulation software. Several economic and financial indicators were calculated, such as the Internal Rate of Return (IRR), Net

Present Value (NPV), Benefit-Cost (B-C), Cost of Energy (COE) production and Simple Payback (SP). It is also studied the reduction potential of Greenhouse Gas (GHG) emission. Fig. 27 illustrates the process of this work methodology.

In Hoogwijk (2004), the global potentials are estimated for PV system by using grid cell approach as in Fig. 28. The yearly-averaged irradiance I (W m^{-2}) of cell (i) on the surface grid ($0.5^\circ \times 0.5^\circ$) is estimated to get theoretical potential. The measured database is in the period from 1961–1990 which is obtained from 4040 stations available in Climate Research Unit distributed over the world.

In this Ph.D. dissertation, geographical, technical and economic PV solar potentials are also estimated. The author divides the surfaces into two categories based on the capacity of PV generation and type of topology. Firstly, Centralized grid-connected PV system ($> 10 \text{ kW}_p$) consists of land surface where the PV system installation either tilted PV arrays (this was eliminated) or horizontal PV arrays. For centralized grid-connected PV system, the proposed values of suitability factors (f_i) by Sorensen are used as in Table 9 (Sorensen, 1999). Secondly, decentralized grid connected PV system ($< 10 \text{ kW}_p$) is considered representing top-roof (Hoogwijk, 2004). Technical potential is estimated. The efficiency of PV model influenced by temperature is neglected while the performance ratio is assumed by 0.75. Lastly the estimation of geographical potential is limited by considering the cost supply curve of PV which is combination of technical potential of grid connected PV electricity and Production cost of PV electricity.

Similar methodologies are also conducted in the Pakistan (Har-ijan et al., 2015) and Romania (Sebestyén, 2017). Theoretical, geographical and technical potentials are estimated for centralized, decentralized and standalone PV systems. The suitable factor (f_i) for centralized Solar PV is based on Sorensen (1999).

The study in Ayompe and Duffy (2014) is conducted for 33 locations in different regions of Cameroon. The focus of the study is to evaluate the energy production potential of PV system with respect to different PV modules. It is conducted in Solar GIS software. The long period satellite – derived data available in Solar GIS software is used. By using monthly average daily global horizontal, the energy output, PR and CF are calculated based on optimal tilted and horizontal surface of PV. The economic aspect is also undertaken where each of Simple Payback (SP) period and $LCoE$ are evaluated. Fig. 29 presents the flowchart of this work.

Another study evaluates solar potentials including economic analysis based on solar energy conducting in Fujian Province, China. It developed a framework of solar potential analysis based on GIS-based approach as depicted in Fig. 30 (wei Sun et al., 2013). The solar radiation for mentioned area is assessed by using the solar radiation analyst module of ArcGIS 9.3 (Clifton and Boruff, 2010; wei Sun et al., 2013). The major considered parameters to the model is spatial resolution of $90 \text{ m} \times 90 \text{ m}$ DEM derived from the Shuttle Radar Topography Mission (SRTM). The atmospheric transmissivity coefficient is also taken into account which define as a ratio between measured incoming solar radiation the extraterrestrial incoming solar radiation (Baigorria et al., 2004; wei Sun et al., 2013). The cost of PV generation is calculated based on the geographical distribution of technical potential. Moreover, geospatial supply curve (GSC) is employed to portray the evolution of available potential of photovoltaic (PV) generation with the increase of the generation cost.

In Adaramola (2014), the feasibility study of PV-DG on grid is conducted in Jos of Plateau state of Nigeria. Both technical and economic performance is examined with 80 kW. The PV grid-connected system is designed and analyzed by using HOMER optimization software (Al-karaghoul and Kazmerski, 2010). The economic analysis of the solar PV-grid connected system is assessed by the following indicators: LCOE and NPC of the system.

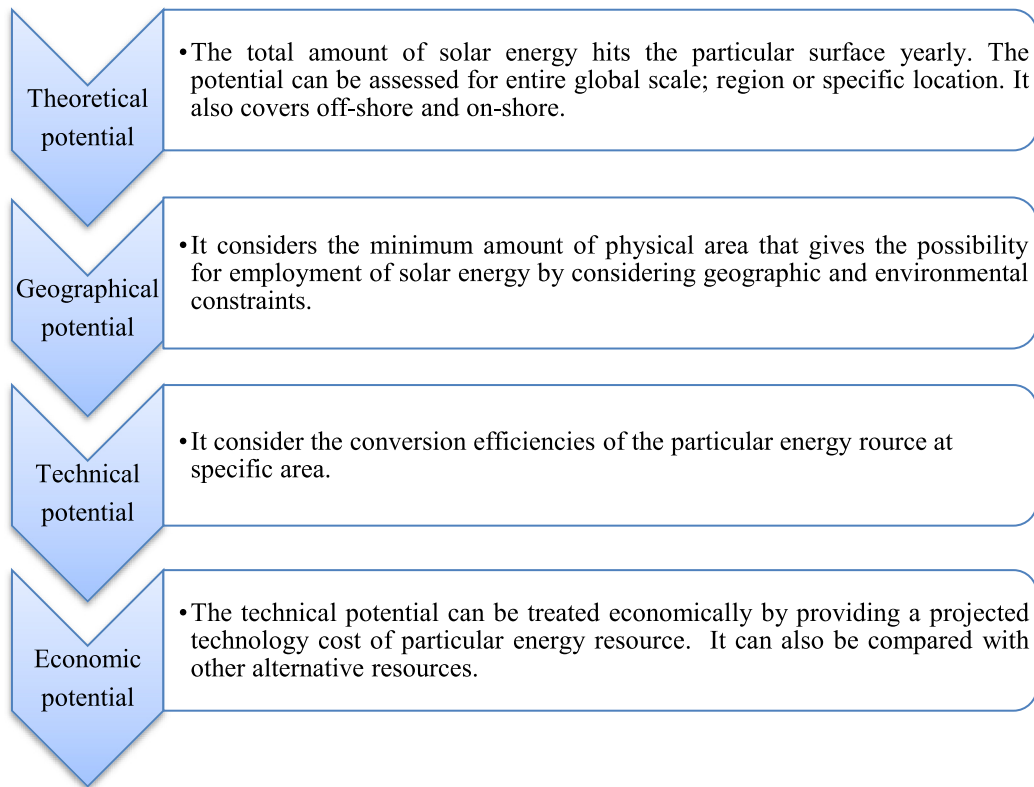


Fig. 24. The PV solar energy potentials.

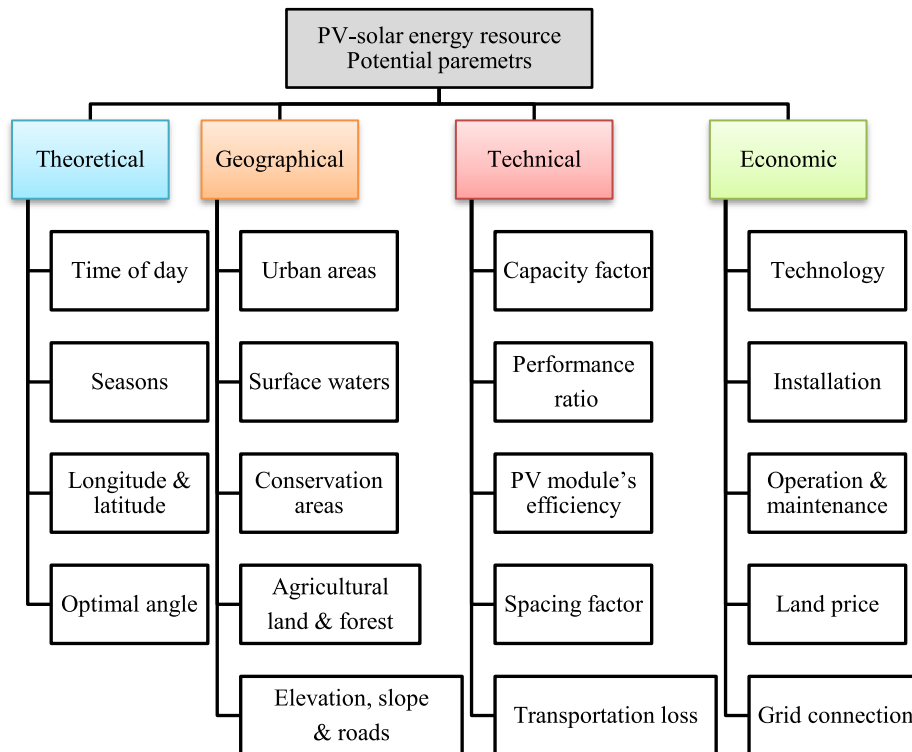


Fig. 25. The PV potential parameters.

Table 7
PV-solar potential models.

Potential	Model	Note
Geographical potential	<p>Hoogwijk (2004) Harijan et al. (2015) Sebestyén (2017)</p> $= I_i \cdot A_{s,i} \cdot h \quad A_{s,i} = A_i \cdot f_i$	<p>I_i ($W \text{ m}^{-2}$) is the time-averaged irradiance in cell i; $A_{s,i}$ (km^2) is the available suitable area in cell i. A_i is the available area while f_i is suitability factor; $h = 8760$ (h y^{-1}) is the number of hours in a year;</p>
Technical potential	<p>Hermann et al. (2014)</p> $= H_R \cdot \eta_m \cdot SF \cdot A$	<p>H_R solar resource availability in kWh y^{-1}, η_m is the PV module's conversion efficiency, SF is spacing factor.</p>
	<p>Hoogwijk (2004) Harijan et al. (2015) Sebestyén (2017)</p> $= G_{p,i} \cdot \eta_m \cdot PR$	<p>$G_{p,i}$ is the geographical potential and PR is the Performance Ratio of the PV system.</p>
	<p>wei Sun et al. (2013) Šúri et al. (2007)</p> $= p_i G_i PR / (1000 \text{ (W/m}^2\text{)})$	<p>p_i is the peak power of PV system installed in grid cell i, G_i is the annual total amount of global radiation on the horizon in grid cell i.</p>
	<p>Lopez et al. (2012)</p> $= A_{s,i} \cdot P_D \cdot CF \cdot 8760$	<p>P_D is power density (MW/km^2), CF is capacity factor.</p>
	<p>wei Sun et al. (2013)</p> $PC_i = \frac{L + C_{O\&M}}{E_i}$ $L = I \frac{r(1+r)^N}{(1+r)^N - 1}$	<p>PC_i is the cost of 1 kWh of electricity generated in a grid cell i, I is the initial investment cost depending on the PV system size, E_i is the energy yield in grid cells i, r is the nominal discount rate, N is the life time of the system. $C_{O\&M}$ is the operation and maintenance costs, L is the annual loan payment.</p>
Economic potential	<p>Hoogwijk (2004)</p> $C_i = \frac{a(M+B)C_{O\&M}(M+B)+L}{e_i}$ $a = \frac{r}{1-(r+1)^{-LT}} \text{ and}$ <p>Cost supply curve of PV</p>	<p>The production cost of PV electricity C_i ($\text{\\$ kWh}^{-1}$) in grid cell i, a (y^{-1}) is the annuity factor, L is the annual land rental price ($\text{\\$ m}^{-2} \text{ y}^{-1}$), M is the investment cost of the PV modules ($\text{\\$ m}^{-2}$), B cost ($\text{\\$ m}^{-2}$) is the Balance of System (BOS), The term and $C_{O\&M}$ is the annual O&M cost as percentage of the total investment costs ($\text{\\$ m}^{-2} \text{ y}^{-1}$). Finally, e_i is the specific annual electricity output ($\text{kWh m}^{-2} \text{ y}^{-1}$) of cell i, r is the interest rate, and LT the economic lifetime of the product.</p>
	<p>Kebede (2015)</p> $NPV = -C_o + \sum_{i=1}^T \frac{C_i}{(1+r)^i}$	<p>NPV is Net Present Value, C_o is initial investment, C is cash flow, r is discount rate, T is time.</p>
	<p>Ayompe and Duffy (2014)</p> $LCoE = \frac{CAPEX + \sum_{n=1}^N OPEX_n(1+d)^{-n}}{\sum_{n=1}^N G_n(1+d)^{-n}}$	<p>$LCoE$ is Levelized cost of electricity $CAPEX$ is capital investment cost, $OPEX$ is operation and maintenance cost, N is operating system life, n is operating year, G_n is net generation in operating year (kWh), d is annual discount rate.</p>

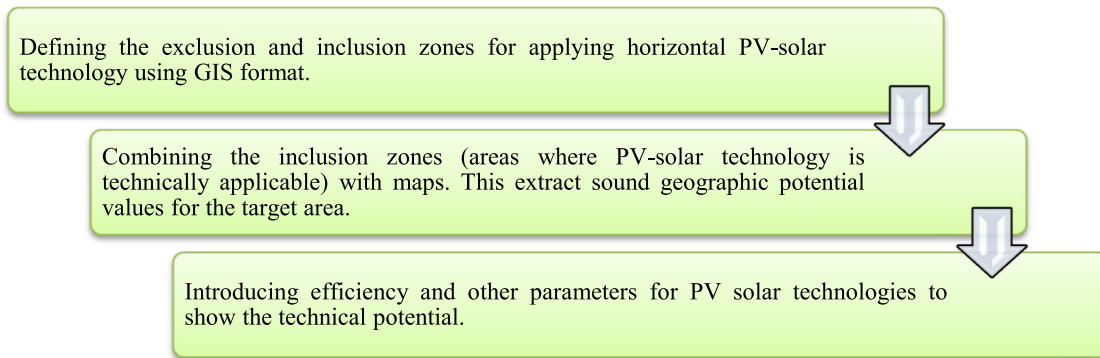


Fig. 26. General methodology for assessment PV-solar potential.

9. Interaction between PV-DG and grid

Fig. 31 depicts the proposed framework to determine the best sites and sizes of solar panels for long-term installations in selected areas using GIS, optimization, and simulation modules (Kucuksari et al., 2014). Given the suitable rooftops obtained from the GIS module, the optimization module then determines the optimal locations and the number of the PV systems to maximize the net profit of PV installations for the next two decades

Table 8
Exclusion zones.

Exclusion of areas					
Urban	Protected	Water bodies	slope > 45°	Agricultural land	Forest

using mixed-integer-linear programming approach implemented in General Algebraic Modeling System (GAMS (GAMS)).

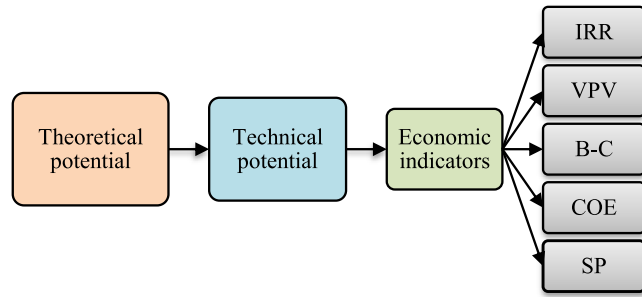


Fig. 27. Overview of the approach used to assess the potentials.

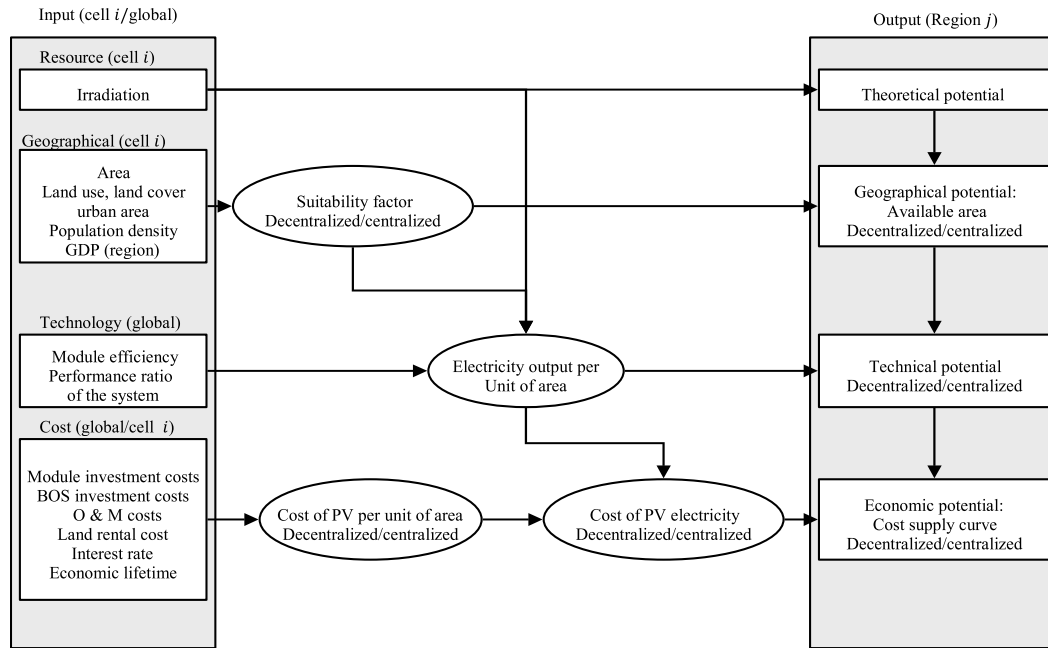


Fig. 28. Overview of the approach used to assess the global and regional potentials (Hoogwijk, 2004).

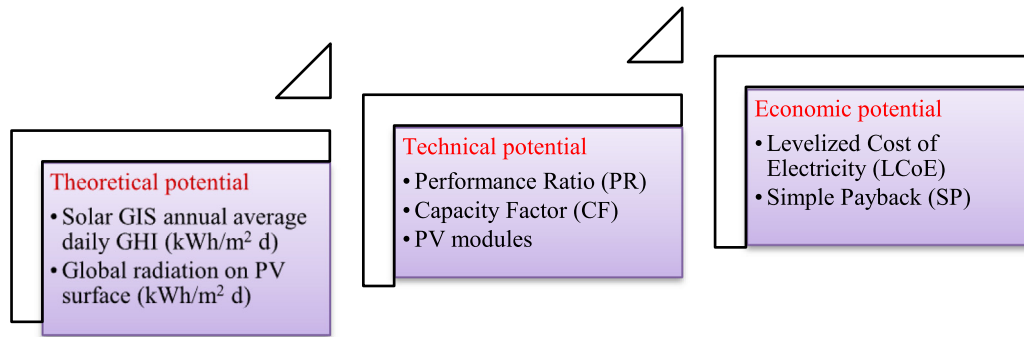


Fig. 29. Overview of the approach used to assess the potentials.

In the case of voltage limit violations and by the addition of intermittent PV generations or load fluctuations, two strategies; (1) reallocation of the PV system and (2) installation of local storage units are proposed. The first strategy is presented to find new locations for PV systems and power flow study is then performed again to verify voltage profiles. The second proposed strategy is the addition of storage units next to the PV generations. It does not cause voltage violations. It used to reduce power injection into the grid (Kucuksari et al., 2014).

10. Analysis and comparison for PV-DG allocation

Determination of optimal site and size for PV-DG within power system is influenced by optimization algorithm with desirable system objectives and other factors as depicted in Fig. 32. Power Factor (PF), configuration system, constraints and DG type can play role for optimal allocation of PV-DG or any other DG types. These factors are for both transmission and distribution systems. In this section, authors will focus on algorithms and objective function of the system based on analysis and comparison among the others in relative studies. Since the most of the reviewed

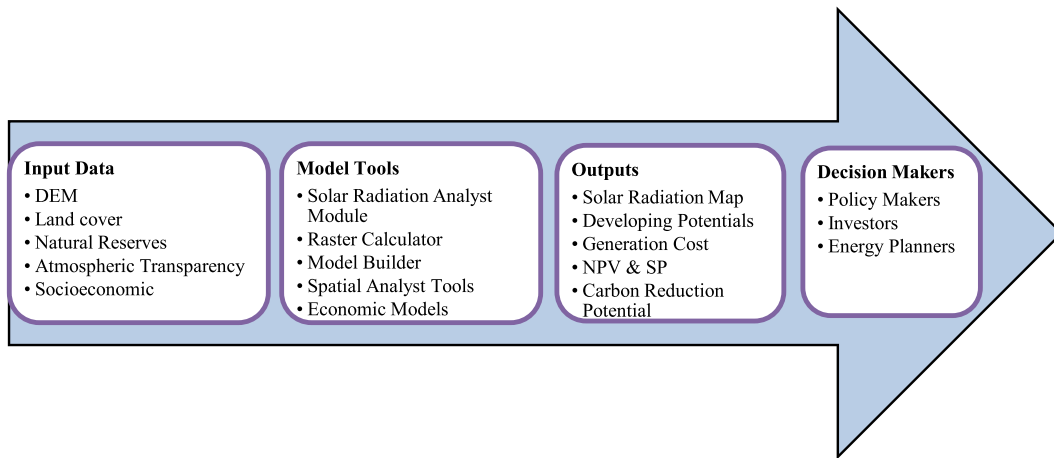


Fig. 30. Framework of the methodology for evaluating the feasibility of investments for solar energy (wei Sun et al., 2013).

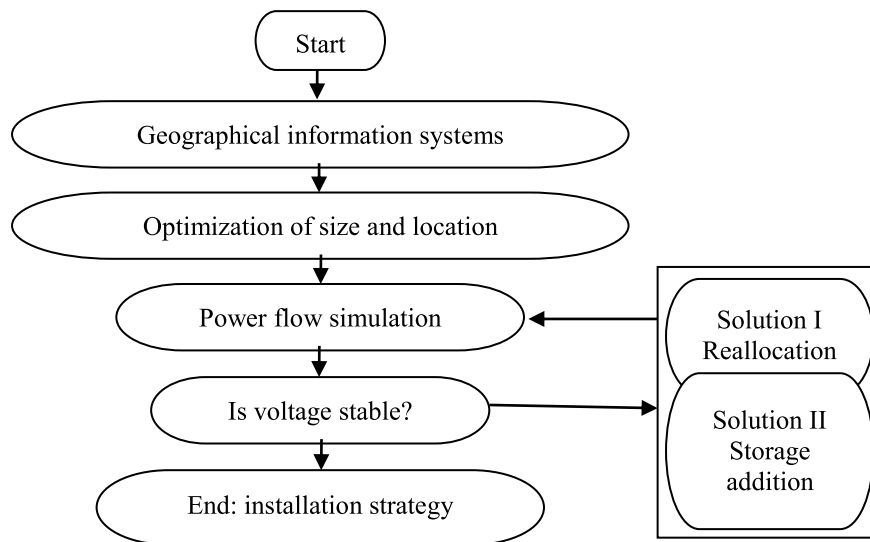


Fig. 31. Overview of the proposed modeling and analysis framework (Kucuksari et al., 2014).

Table 9
Suitability factors (f_i) for centralized solar PV.

f_i	0.05	0.05	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00
Area	Extensive grassland	Desert	Agriculture	Shrub land	Savannah	Tundra	Grassland	Urban area	Forest	Bio-reserve

papers in this work are applied on distribution system, they are taken as place for these comparisons. In addition, methodologies of PV potentials are presented.

10.1. Optimization algorithms

The comparison among different algorithms has sensitive indicator to find the optimal allocation of DG. In this comparison, reduction of P_{Loss} (kW) is considered as prevalent objective in almost all studies. Herein, CPU time is neglected. Even though time is important dynamic system, each algorithm was performed in different CPU capability. From Table 10, Figs. 33 and 34 based on 33-bus distribution system, LSF-ALOAA have the minimum P_{Loss} (kW) compared with others.

From Table 11, Figs. 35 and 36 based on 69-bus RDS; analytical methods have the minimum P_{Loss} (kW) compared with others

while KHA comes next. Even though they have minimum loss reduction, the base case P_{Loss} is lower than 225 (kW). By considering the difference in base case value, LSF-ALOAA is foregrounded.

In Fig. 37, analytical method and LCF-MM are presented. It is clear that, ELF is proved to be the best in reduction of P_{Loss} (kW) and longest CPU time (s) compared with other analytical methods which are performed at the same environment (Shahzad et al., 2016).

The hybrid GA-PSO depicts better result in term of minimum P_{Loss} (kW). However, this hybrid algorithm consumes longer time as compared to the case where either algorithm is applied alone as in Fig. 38, (Moradi and Abedini, 2012a).

Determination of the most suitable algorithm for PV-DG allocation is uneasy task. Table 12 gives overview comparison with three factors. Meta-heuristic algorithms either applied alone or combined with others have the priority to be used. However, the best performance based on the minimum P_{Loss} (kW) is obtained by LSF-ALOAA compared with others.

Table 10
Comparison of the results of different approaches for PV-DG in 33-bus RDS.

Method	Base case P_{loss} (kW)	1 PV-DG		2 PV-DG		CPU Time (s)	
		Bus No.	P_{loss} (kW)	Bus No.	P_{loss} (kW)	1 DG	2 DG
ELF (Hung et al., 2013)	211.20	6	111.10	12 and 30	87.63	1.06	2.03
ELF (Acharya et al., 2006)	211.20	6	111.1	–	–	–	–
LSF (Hung et al., 2013)	211.20	18	146.82	18 and 33	100.69	0.11	0.18
LSF (Acharya et al., 2006)	211.20	10	123.82	–	–	–	–
IA (Hung et al., 2013)	211.20	6	111.10	6 and 14	91.63	0.16	0.27
IA (Acharya et al., 2006)	211.20	6	111.24	–	–	–	–
GA (Hassan et al., 2017)	203.7	6	105.48	13 and 29	82.7	33.76	33.58
LSF-ALOA (Ali et al., 2016a)	210.98	6	103.05	13 and 30	82.6	–	–
ABC (Dixit et al., 2016a)	210.97	30	125.15	29 and 30	121.89	48.07	50.47
ABC (Abu-Mouti and El-Hawary, 2011)	210.98	6	109.31	–	–	–	–
KHA (ChithraDevi et al., 2017)	210.99	6	111.02	29 and 13	87.43	4.24	4.092
BSOA (El-Fergany, 2015)	210.84	8	118.12	13 and 31	89.34	20.40	23.54
IV-WOA (Reddy et al., 2017)	210.997	15	133.50	–	–	–	–

Table 11
Comparison of the results of different approaches for PV-DG in 69-bus RDS.

Method - 69	Base case P_{loss} (kW)	1 PV-DG		2 PV-DG		Time (s)	
		Bus No.	P_{loss} (kW)	Bus No.	P_{loss} (kW)	1 DG	2 DG
ELF (Hung et al., 2013)	219.28	61	81.33	61 and 17	70.30	7.75	15.53
ELF (Acharya et al., 2006)	219.28	61	81.33	–	–	–	–
LSF (Hung et al., 2013)	219.28	65	109.77	65 and 27	98.74	0.15	0.30
LSF (Acharya et al., 2006)	219.28	61	81.33	–	–	–	–
IA (Hung et al., 2013)	219.28	61	81.33	61 and 17	70.30	0.28	0.52
IA (Acharya et al., 2006)	219.28	61	81.44	–	–	–	–
GA (Pisica et al., 2009)	225	61	88.21	62 and 61	83.91	262.12	864.83
GA (Hassan et al., 2017)	224.6	61	83.18	0	0	85.097	–
LSF-ALOOA (Ali et al., 2016a)	224.94	61	81.776	17 and 61	70.750	–	–
ABC (Abu-Mouti and El-Hawary, 2011)	224.8	61	83.24	–	–	–	–
KHA (ChithraDevi et al., 2017)	220.534	61	81.6003	51 and 61	77.0354	11.2187	11.1014
IV-WOA (Reddy et al., 2017)	225.023	61	83.228	–	–	–	–

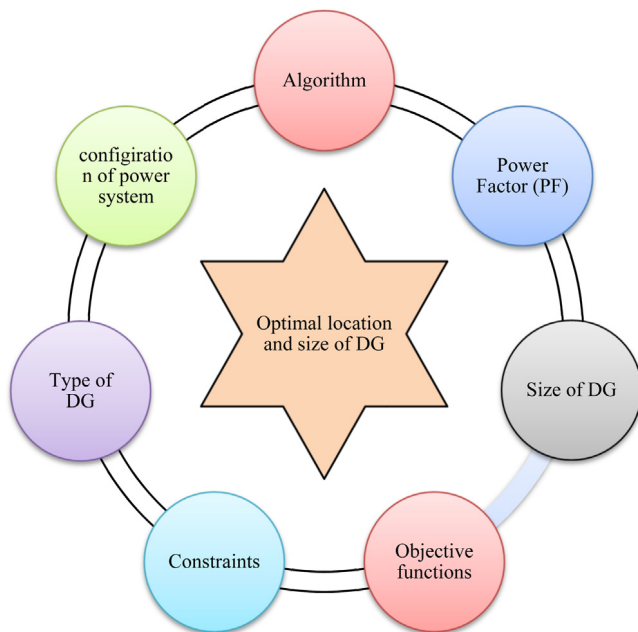


Fig. 32. Seven factors affect the optimal location of DG.

10.2. Objectives in power system

Most of the academic studies have common priority to minimize P_{Loss} (kW). The researchers also moved into multi objectives to find trade off. Fig. 39 is inspired from Table 6. As in literature, most of the existing work is based on static system performance.

10.3. Methodologies of PV potentials

According to PV potentials in literature, all of the reviewed works have similar methodology to estimate. Geographical potential takes the most attention due to finding the best location and size for PV-DG plant. The exclusive areas depend on country policy and environment. Technical PV potential depends on the available technology. Meanwhile, economic potential includes more than one parameter to decide if the implementation of the proposed project applicable or not from financial aspect.

11. Discussion

This review paper presents the recent works in this field. The conducted studies are either to investigate the optimization of PV-DG allocation within power system or to estimate the PV potentials. The latter is normally examined to meet the requirements of the power system as in Fig. 40. This usually happens for single DG. In this section, the weakness of previous relative works is presented.

11.1. Site and size of PV-DG in power system

Most of the studies are conducted based on a given optimization allocation of PV-DG in power system. Different algorithms, objective functions and power system constraints are used. However, these optimization findings may not meet the PV potential assessments. For example, electric utility based on optimization wants to install PV-DGs in three buses. Meanwhile, the second bus does not meet PV potential assessments. In this case, utility should do recalculation.

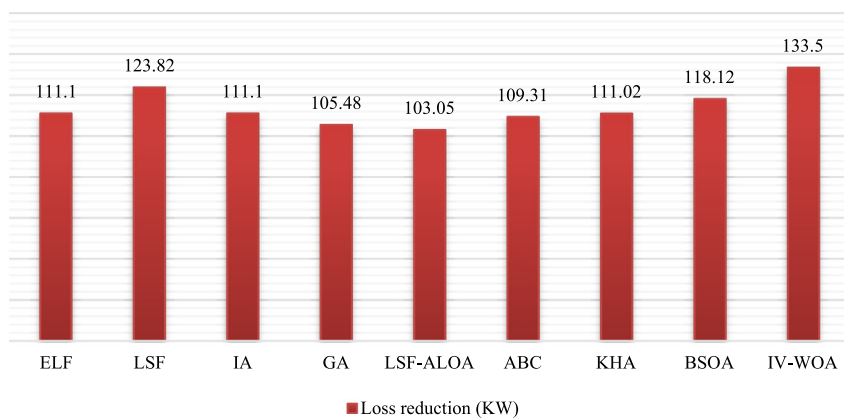


Fig. 33. Comparison of the results of different approaches for one PV-DG for 33-bus RDS.

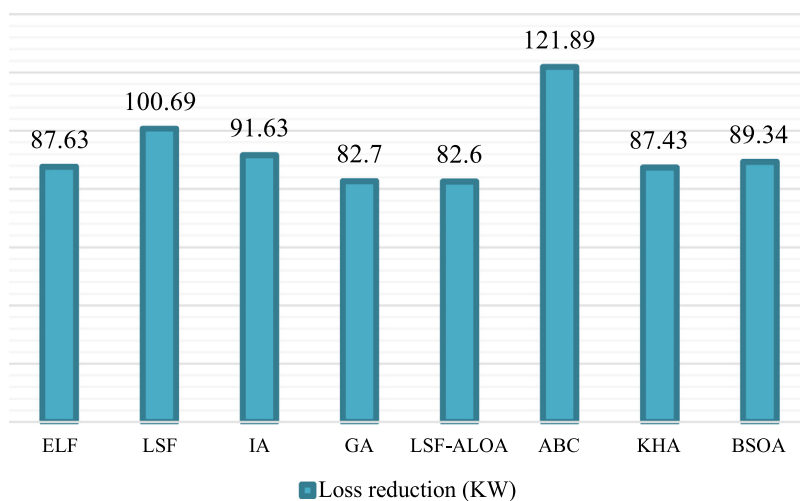


Fig. 34. Comparison of the results of different approaches for two PV-DG for 33-bus RDS.

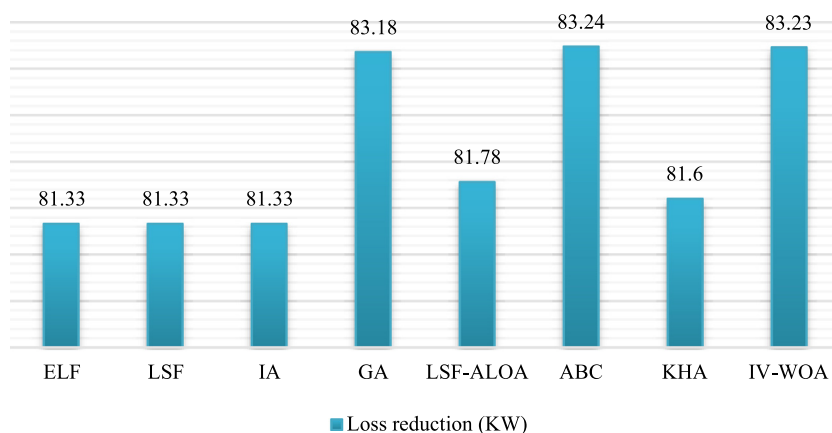


Fig. 35. Comparison of the results of different approaches for one PV-DG for 69-bus RDS.

11.2. PV potential assessments

The potential assessments can contribute to investigate the suitable location and proper size. This has significant role for grid connected PV system. However, this method is suffered from some issues. Firstly, the candidate location or size of PV-DG potentials may not be the best site and size for power system. Secondly, even if single PV-DG installed within power system meet the power system requirements, this is not sufficient for

power system to be improved without multi PV-DG. Lastly, time and effort by doing feasibility study based on PV potentials are not high effectively exploited.

11.3. The gap in literature and solution

This research mainly aims to overcome on the drawbacks from the last two subsections. So, this will help to exploit the PV energy resource with respect to the power system. To the best of

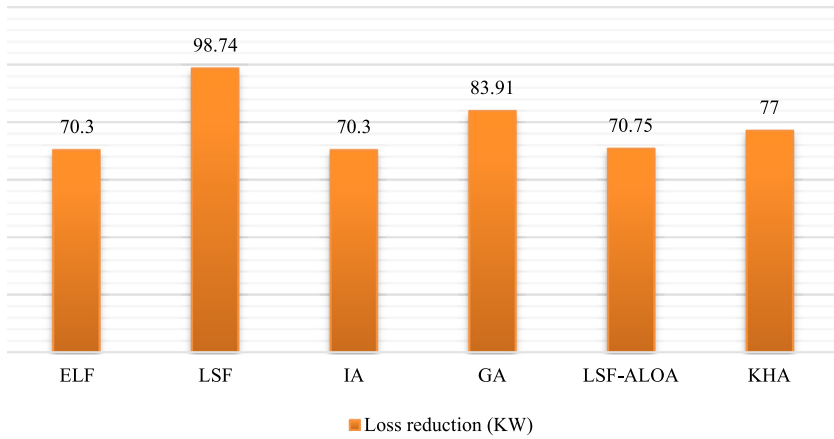


Fig. 36. Comparison of the results of different approaches for two PV-DG for 69-bus RDS.

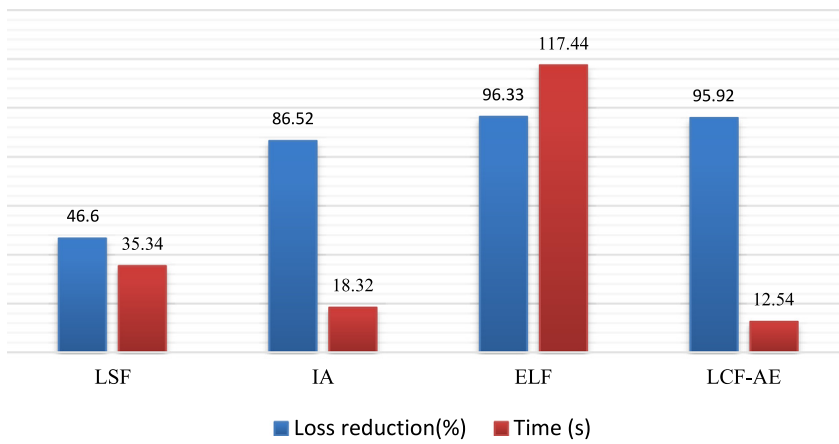


Fig. 37. Comparison among Analytical methods for four DGs with operational PF in 37-bus RDS.

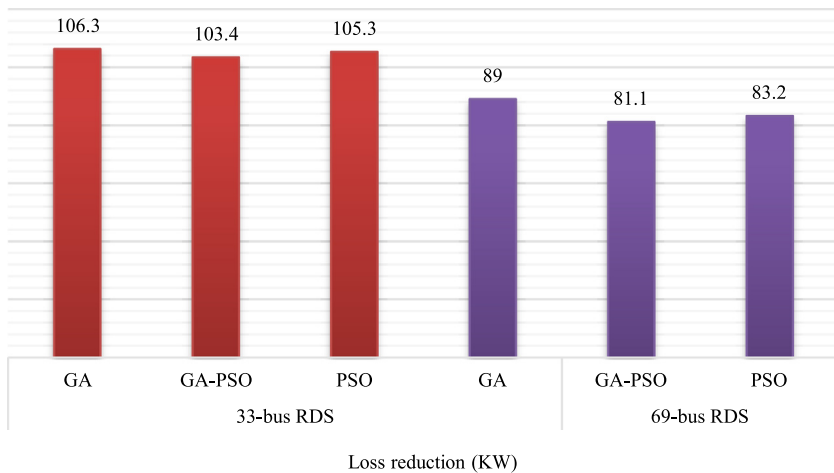


Fig. 38. Comparison among Algorithms for four DGs.

author’s knowledge, no study has attempted to evaluate and find the optimal locations and sizes of PV-DGs at the present of the two approaches simultaneously. Therefore, a strategy for the PV-DG allocation needs to be developed and at the same time taking into account the feedback of PV energy resource potentials.

Such methodology will help countries in particular those have very poor access to grid connected PV system. As a case study,

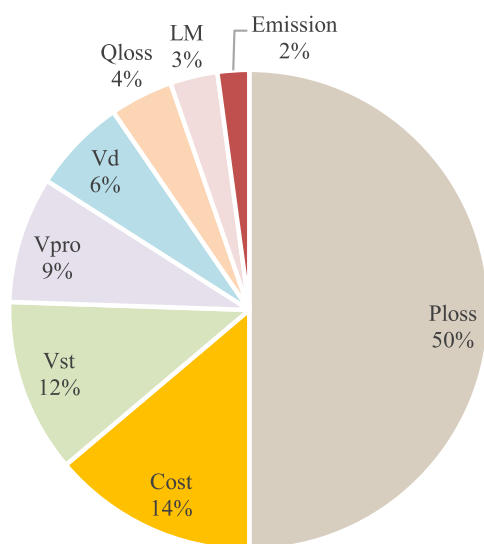
Yemen is one of undeveloped countries which its power system does not exploit much from RESs as in Fig. 41. In further study, Yemen power system will be considered as in Fig. 42.

The proposed methodology for this study is developed as in Fig. 43. It combines between two approaches to find optimization scenario of grid connected PV system.

Table 12

The overview comparison for the algorithms.

Algorithm	Multi-function	Location	Size	Note	
Analytical	2/3 Rule	✗	✓	✗	Fewer in literature. It is just used directly for uniformly load and does not support optimal solution.
	LSF	✗	✓	✗	Highest value of LSF may not give optimal location of DG.
	IA	✗	✗	✓	Analytical expressions are just used for optimal size.
Meta-heuristic	GA	✓	✓	✓	It consumes more time during operation and has slow convergence.
	ABC	✓	✓	✓	Fewer articles in literature, good performance compared.
	BSOA	✓	✓	✓	
	KHA	✓	✓	✓	It is very sensitive to the input parameters; unsuitable parameters lead into local convergence.
	LCF-AE	✗	✓	✓	Fewer in literature. It may miss the lowest loss reduction in large system.
	LSF-AE	✗	✓	✓	The location is determined by LSF which is not very accurate.
Hybrid	GA-PSO	✓	✓	✓	It demands more time for computation, slow convergence for finding global optimum solution
	ABC-CSA	✓	✓	✓	CSA has slow convergence (Tan et al., 2013).
	IV-WOA	✓	✓	✓	Fewer articles in literature. It may fail to find optimal allocation of DG for finding lowest power loss.
	LSF-ALOA	✓	✓	✓	Even though LSF is used to reduce searching area. As less number of candidate locations considered as less accuracy obtained

**Fig. 39.** Power system objectives in percentage.

12. Conclusion

Number of studies made attempts to obtain the high advantages of PV-DGs in all aspects for grid. This paper looks to PV-DG from two viewpoints, power system high performance and PV potential assessments. Configuration power system, optimization algorithms, constraints, power factors (PF) and desirable objectives have significant role for optimal allocation. The main findings of this review paper are listed as below:

- Meta-heuristic and the hybrid meta-heuristic algorithms are found more reliable optimization algorithms than others. LSF-ALOA algorithm performs better than all based on minimum power system loss which make it as a good proposed algorithm.

- Most of the previous works if not all are conducted in a distribution system. It is highly recommended to investigate transmission system with DG based on Renewable Energy Sources (RESs).
- Real power loss, cost and voltage stability index have more priority among power objectives.
- The impact of injecting PV to the power system can be mitigated by several measures.
- Almost, all PV potential assessment methodologies are similar. However, it depends on the country regulations and policy.
- All studies based on the power system are conducted apart of RES potential assessments. Similar, all previous works are done apart of power system. By integrating both of them, this will lead to:

- 1- Save effort and time.
- 2- Having plan for current and future of installing DG units.
- 3- Extending power system construction can consider all possible potential of RES.
- 4- Knowing the PV potential assessments for different geographical locations will help to give different potential output of DG. This will result to have more accuracy to DG limits.

By knowing the PV potentials, utility decision makers can resize and relocate the inserting number of DG based on obtained potential. This new proposed methodology is derived to have applicable PV-DG optimization in developing countries where heavy suffer from weak access to PV-DG grid connected system. As a case study, Yemen power system is considered.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

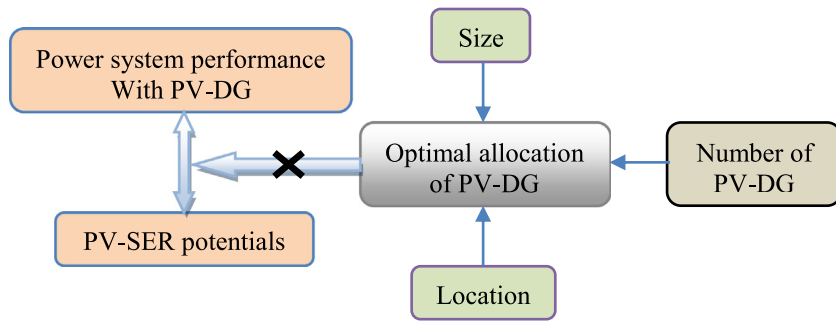


Fig. 40. The methodology of installing PV-DG.

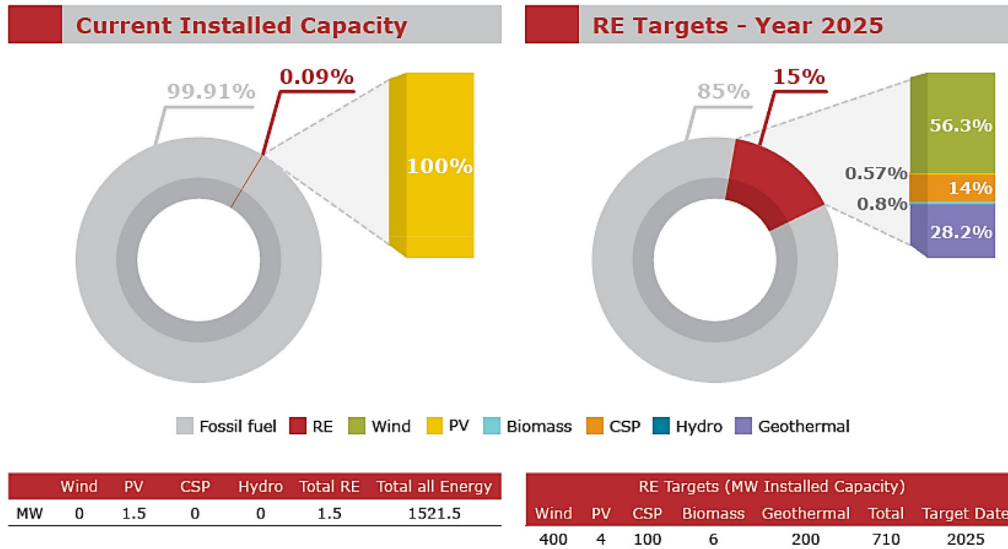


Fig. 41. Share of renewable energy in energy mix in Yemen (Regional Center for Renewable Energy and Energy Efficiency, 2012).



Fig. 42. Map of Yemen electric transmission system (Rawea and Urooj, 2018).

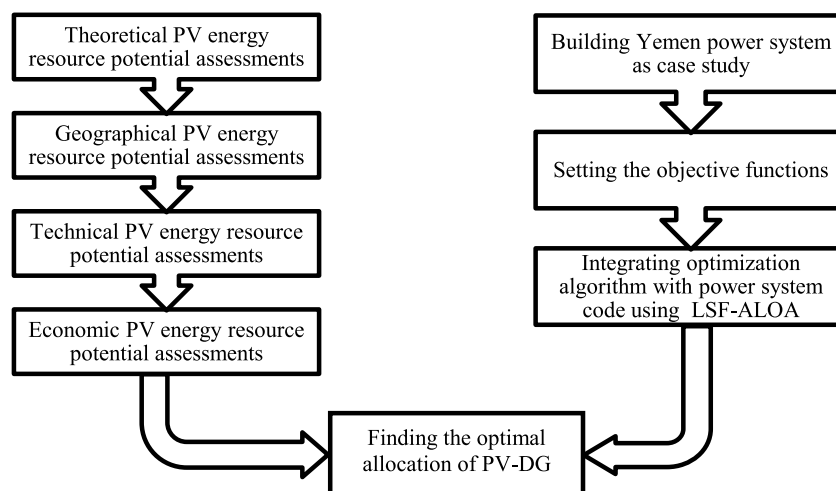


Fig. 43. The flowchart of the proposed methodology.

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References

- Abdmouleh, Z., Gastli, A., Ben-Brahim, L., Haouari, M., Al-Emadi, N.A., 2017. Review of optimization techniques applied for the integration of distributed generation from renewable energy sources. *Renew. Energy* 113, 266–280.
- Abdul kadir, A.F., Mohamed, A., Shareef, H., Che Wanik, M.Z., 2013. Optimal placement and sizing of distributed generations in distribution systems for minimizing losses and THDv using evolutionary programming. *Turk. J. Electr. Eng. Comput. Sci.* 21 (SUPPL. 2), 2269–2282.
- Abu-Mouti, F.S., El-Hawary, M.E., 2011. Optimal distributed generation allocation and sizing in distribution systems via artificial bee colony algorithm. *IEEE Trans. Power Deliv.* 26 (4), 2090–2101.
- Acharya, N., Mahat, P., Mithulananthan, N., 2006. An analytical approach for DG allocation in primary distribution network. *Int. J. Electr. Power Energy Syst.* 28 (10), 669–678.
- Ackermann, T., Andersson, G., Söder, L., 2001. Distributed generation: A definition. *Electr. Power Syst. Res.* 57 (3), 195–204.
- Adaramola, M.S., 2014. Viability of grid-connected solar PV energy system in jos, Nigeria. *Int. J. Electr. Power Energy Syst.* 61, 64–69.
- Adefarati, T., Bansal, R.C., 2016. Integration of renewable distributed generators into the distribution system: A review. *IET Renew. Power Gener.* 10 (7), 873–884.
- Adefarati, T., Bansal, R.C., 2017. Reliability assessment of distribution system with the integration of renewable distributed generation. *Appl. Energy* 185, 158–171.
- Affifi, S.N., Darwish, M.K., 2014. Impact of hybrid renewable energy systems on short circuit levels in distribution networks. In: *Proceedings of the Universities Power Engineering Conference*, pp. 1–5.
- Agalgaonkar, Y.P., Pal, B.C., Jabr, R.A., 2014. Distribution voltage control considering the impact of PV generation on tap changers and autonomous regulators. *IEEE Trans. Power Syst.* 29 (1), 182–192.
- Agarwal, N., Verma, K., Niazi, K.R., Swarnkar, A., Gupta, N., 2015. Optimal penetration of renewable sources for distribution system performance improvement. In: *IEEE Power and Energy Society General Meeting*, Vol. 2015-Sept. pp. 1–5.
- Ahmedi, M., Lotfy, M.E., Shigenobu, R., Yona, A., Senjyu, T., 2018. Optimal sizing and placement of rooftop solar photovoltaic at Kabul city real distribution network. *IET Gener. Transm. Distrib.* 12 (2), 303–309.
- Al Abri, R.S., El-Saadany, E.F., Atwa, Y.M., 2013. Optimal placement and sizing method to improve the voltage stability margin in a distribution system using distributed generation. *IEEE Trans. Power Syst.* 28 (1), 326–334.
- Al Ameri, A., Nichita, C., Riouch, T., El-Bachtiri, R., 2015. Genetic algorithm for optimal sizing and location of multiple distributed generations in electrical network. 2015 *Mod. Electr. Power Syst.* (July), 1–7.
- Al-karaghoul, A., Kazmerski, L.L., 2010. Optimization and life-cycle cost of health clinic PV system for a rural area in southern iraq using HOMER software. *Sol. Energy* 84 (4), 710–714.
- Al-Muhaini, M., Heydt, G.T., 2013. Evaluating future power distribution system reliability including distributed generation. *IEEE Trans. Power Deliv.* 28 (4), 2264–2272.
- Al-Sabounchi, A., Gow, J., Al-Akaidi, M., Al-Thani, H., 2011. Minimizing line energy loss of radial distribution feeder with a PV distributed generation unit avoiding reverse power flow. In: *2011 2nd International Conference on Electric Power and Energy Conversion Systems, EPECS 2011*, no. 1. pp. 1–6.
- Alam, M.J.E., Muttaqi, K.M., Sutanto, D., 2012. Distributed energy storage for mitigation of voltage-rise impact caused by rooftop solar PV. *IEEE Power Energy Soc. Gen. Meet.* 1–8.
- Alam Hossain Mondal, M., Sadrul Islam, A.K.M., 2011. Potential and viability of grid-connected solar PV system in Bangladesh. *Renew. Energy* 36 (6), 1869–1874.
- Alhajri, M.F., Alrashidi, M.R., El-Hawary, M.E., 2010. Improved sequential quadratic programming approach for optimal distribution generation deployments via stability and sensitivity analyses. *Electr. Power Compon. Syst.* 38 (14), 1595–1614.
- AlHajri, M.F., El-Hawary, M.E., 2008. The effect of Distributed Generation modeling and static load representation on the optimal integrated sizing and network losses. In: *Can. Conf. Electr. Comput. Eng.* pp. 1543–1548.
- Ali, E.S., Abd Elazim, S.M., Abdelaziz, A.Y., 2016a. Ant lion optimization algorithm for renewable distributed generations. *Energy* 116, 445–458.
- Ali, E.S., Abd Elazim, S.M., Abdelaziz, A.Y., 2018. Optimal allocation and sizing of renewable distributed generation using ant lion optimization algorithm. *Electr. Eng.* 100 (1), 99–109.
- Ali, E.S., Elazim, S.M.A., Abdelaziz, A.Y., 2017a. Ant Lion Optimization Algorithm for optimal location and sizing of renewable distributed generations. *Renew. Energy* 101, 1311–1324.
- Ali, N.Z.M., Musirin, I., Khalidin, Z., Ahmad, M.R., 2016b. Optimal Location and Sizing of Distributed Generation using Optimization Technique, no. July. pp. 333–339.
- Ali, A., Padmanaban, S., Twala, B., Marwala, T., 2017b. Electric power grids distribution generation system for optimal location and sizing-a case study investigation by various optimization algorithms. *Energies* 10 (7).
- Alinejad-Beromi, Y., Sedighzadeh, M., Bayat, M.R., Khodayar, M.E., 2007. Using genetic algorithm for Distributed generation allocation to reduce losses and improve voltage profile. In: *Proceedings of the Universities Power Engineering Conference*, no. 1, pp. 954–959.
- Alinejad-Beromi, Y., Sedighzadeh, M., Sadighi, M., 2008. A particle swarm optimization for siting and sizing of distributed generation in distribution network to improve voltage profile and reduce THD and losses. In: *Proceedings of the Universities Power Engineering Conference*, pp. 1–5.
- Alquthami, T.S., Ravindra, H., Faruq, M.O., Steurer, M., Baldwin, T., 2010. Study of photovoltaic integration impact on system stability using custom model of PV arrays integrated with PSS/E. In: *North Am. Power Symp. 2010, NAPS 2010*. pp. 1–8.
- Alrashidi, M.R., Alhajri, M.F., 2011. Optimal planning of multiple distributed generation sources in distribution networks: A new approach. *Energy Convers. Manage.* 52 (11), 3301–3308.
- Aman, M.M., Jasmon, G.B., Mokhlis, H., Bakar, A.H.A., 2012. Optimal placement and sizing of a DG based on a new power stability index and line losses. *Int. J. Electr. Power Energy Syst.* 43 (1), 1296–1304.

- Anumaka, M.C., 2012. Analysis of technical losses in electrical power system (Nigerian 330Kv Network as a case study). *Int. J. Res. Rev. Appl. Sci.* 12 (August), 320–327.
- Arya, L.D., Koshti, A., Choube, S.C., 2012. Distributed generation planning using differential evolution accounting voltage stability consideration. *Int. J. Electr. Power Energy Syst.* 42 (1), 196–207.
- Ashokrao, Z.A., Machhindra, P.R., Padmanaban, S., Bhaskar, M.S., Martirano, L., Leonowicz, Z., 2017. Realization of 5-bus system using soft computing technique for flexible alternating current transmission system (FACTS) devices. In: *IEEE*. pp. 1–5.
- Ayodele, T.R., Ogunjuyigbe, A.S.O., Akinola, O.O., 2015. Optimal Location, Sizing, and Appropriate Technology Selection of Distributed Generators for Minimizing Power Loss using Genetic Algorithm, Vol. 2015.
- Ayompe, L.M., Duffy, A., 2014. An assessment of the energy generation potential of photovoltaic systems in cameroon using satellite-derived solar radiation datasets. *Sustain. Energy Technol. Assess.* 7, 257–264.
- Ayub, M., Gan, C.K., Kadir, A.F.A., 2014. The impact of grid-connected PV systems on harmonic distortion. In: 2014 IEEE Innovative Smart Grid Technologies - Asia, ISGT ASIA 2014. pp. 669–674.
- Badran, O., Mekhilef, S., Mokhlis, H., Dahalan, W., 2017. Optimal reconfiguration of distribution system connected with distributed generations: A review of different methodologies. *Renew. Sustain. Energy Rev.* 73 (January), 854–867.
- Baigorria, G.A., Villegas, E.B., Trebejo, I., Carlos, J.F., Quiroz, R., 2004. Atmospheric transmissivity: Distribution and empirical estimation around the central Andes. *Int. J. Climatol.* 24 (9), 1121–1136.
- Banerjee, B., Islam, S.M., 2011. Reliability based optimum location of distributed generation. *Int. J. Electr. Power Energy Syst.* 33 (8), 1470–1478.
- Bawazir, R.O., Chakchak, J., Cetin, N.S., Ulgen, K., 2016. Investigating the optimum tilt angle for solar receiver in Izmir. In: 3rd International Symposium on Environment and Morality, No. November. pp. 4–6.
- Bawazir, R., Wazir, M., 2014. The different performance of UPFC and STATCOM based on opti- mal location for enhancing voltage stability. p. 10.
- Ben Hamida, I., Salah, S.B., Msahli, F., Mimouni, M.F., 2018. Optimal network reconfiguration and renewable DG integration considering time sequence variation in load and DGs. *Renew. Energy* 121, 66–80.
- Bergen, A.R., Vittal, V., 2007. Power systems analysis.
- Bhullar, S., Ghosh, S., 2018. Optimal integration of multi distributed generation sources in radial distribution networks using a hybrid algorithm. *Energies* 11 (3).
- Biswas, S., Goswami, S.K., Chatterjee, A., 2012. Optimum distributed generation placement with voltage sag effect minimization. *Energy Convers. Manag.* 53 (1), 163–174.
- Biswas, P.P., Mallipeddi, R., Suganthan, P.N., Amaratunga, G.A.J., 2017. A multiobjective approach for optimal placement and sizing of distributed generators and capacitors in distribution network. *Appl. Soft Comput.* J. 60, 268–280.
- Bollen, M.H.J., 2013. Understanding power quality problems. p. 541.
- Borges, C.L.T., Falcão, D.M., 2006. Optimal distributed generation allocation for reliability, losses, and voltage improvement. *Int. J. Electr. Power Energy Syst.* 28 (6), 413–420.
- Buaklee, W., Hongesombut, K., 2013. Optimal DG allocation in a smart distribution grid using cuckoo search algorithm. *Trans. Electr. Eng. Electron. Commun.* 11 (2), 16–22.
- Bulac, C., Ionescu, F., Roscia, M., 2010. Differential evolutionary algorithms in optimal distributed generation location. In: ICHQP 2010-14th Int. Conf. Harmon. Qual. Power. pp. 1–5.
- Chakrabarti, S., 2010. Notes on power system voltage stability. pp. 1–16, Dept. EE, IIT, Kanpur [http// ...](http://...)
- Chandrashekar Reddy, S., Prasad, P.V.N., Jaya Laxmi, A., 2013. Hybrid approach for voltage sag mitigation in distribution system by optimal location and size of distributed generation. *J. Electr. Syst.* 9 (2), 150–166.
- Chidurala, A., 2016. High penetration of PV systems in low voltage distribution networks: Investigation of power quality challenges and mitigation.
- Chidurala, A., Saha, T.K., Mithulananthan, N., 2016. Harmonic impact of high penetration photovoltaic system on unbalanced distribution networks - Learning from an urban photovoltaic network. *IET Renew. Power Gener.* 10 (4), 485–494.
- Chiradeja, P., Yoomak, S., Ngaopitakkul, A., 2017. Optimal allocation of multi-DG on distribution system reliability and power losses using differential evolution algorithm. *Energy Procedia* 141, 512–516.
- ChithraDevi, S.A., Lakshminarasimman, L., Balamurugan, R., 2017. Stud Krill herd Algorithm for multiple DG placement and sizing in a radial distribution system. *Eng. Sci. Technol. Int. J.* 20 (2), 748–759.
- Civanlar, S., Grainger, J.J., Yin, H., Lee, S.S.H., 1988. Distribution feeder reconfiguration for loss reduction. *IEEE Trans. Power Deliv.* 3 (3), 1217–1223.
- Civicioglu, P., 2013. Backtracking search optimization algorithm for numerical optimization problems. *Appl. Math. Comput.* 219 (15), 8121–8144.
- Clifton, J., Boruff, B.J., 2010. Assessing the potential for concentrated solar power development in rural Australia. *Energy Policy* 38 (9), 5272–5280.
- Collins, L., Ward, J.K., 2015. Real and reactive power control of distributed PV inverters for overvoltage prevention and increased renewable generation hosting capacity. *Renew. Energy* 81, 464–471.
- Colque, J.C., Azcue, J.L., Ruppert, E., 2019. Photovoltaic system grid-connected with active power filter functions for mitigate current harmonics feeding nonlinear loads. In: 2018 13th IEEE International Conference on Industry Applications, INDUSCON 2018 - Proceedings. pp. 208–214.
- Darfoun, M., 2013. Optimal Distributed Generation Sizing and Placement Via Single- and Multi-Objective Optimization Approaches. Dalhousie University Halifax, Nova Scotia.
- Devabalaji, K.R., Ravi, K., 2016. Optimal size and siting of multiple DG and DSTATCOM in radial distribution system using bacterial foraging optimization algorithm. *Ain Shams Eng. J.* 7 (3), 959–971.
- Devi, S., Geethanjali, M., 2014. Application of modified bacterial foraging optimization algorithm for optimal placement and sizing of distributed generation. *Expert Syst. Appl.* 41 (6), 2772–2781.
- Dinakara, P., Reddy, P., Reddy, V.C.V., Gowri Manohar, T., 2016. Application of flower pollination algorithm for optimal placement and sizing of distributed generation in distribution systems. *J. Electr. Syst. Inf. Technol.* 3 (1), 14–22.
- Dinakara Prasad Reddy, P., Veera Reddy, V.C., Gowri Manohar, T., 2017. Optimal renewable resources placement in distribution networks by combined power loss index and whale optimization algorithms. *J. Electr. Syst. Inf. Technol.*
- Dixit, M., Kundu, P., Jariwala, H.R., 2016a. Optimal placement and sizing of DG in Distribution system using Artificial Bee Colony Algorithm. In: 2016 IEEE 6th International Conference on Power Systems, ICPS 2016.
- Dixit, M., Kundu, P., Jariwala, H.R., 2016b. Optimal placement and sizing of DG in Distribution system using Artificial Bee Colony Algorithm. In: 2016 IEEE 6th International Conference on Power Systems (ICPS). pp. 1–6.
- Dong, Z., Shuhui, L., 2014. Agent-based modeling and simulation of competitive electric power markets. In: 2014 Clemson Univ. Power Syst. Conf. PSC 2014. pp. 1–7.
- Dong, X., et al., 2014. Calculation of power transfer limit considering electro-thermal coupling of overhead transmission line. *IEEE Trans. Power Syst.* 29 (4), 1503–1511.
- Dubey, H.M., Pandit, M., Panigrahi, B.K., 2016. Ant lion optimization for short-term wind integrated hydrothermal power generation scheduling. *Int. J. Electr. Power Energy Syst.* 83, 158–174.
- Dulau, L.L., Abrudean, M., Bica, D., 2016. Optimal location of a distributed generator for power losses improvement. *Proc. Technol.* 22 (October 2015), 734–739.
- Dulau, L.L., Bica, D., 2017. Influence of distributed generators on power systems. *Procedia Eng.* 181, 791–795.
- Duong, M.Q., Pham, T.D., Nguyen, T.T., Doan, A.T., Van Tran, H., 2019. Determination of optimal location and sizing of solar photovoltaic distribution generation units in radial distribution systems. *Energies* 12 (1).
- Eftekharijad, S., Vittal, V., Heydt, G.T., Keel, B., Loehr, J., 2013. Impact of increased penetration of photovoltaic generation on power systems. *IEEE Trans. Power Syst.* 28 (2), 893–901.
- El-Fergany, A., 2015. Optimal allocation of multi-type distributed generators using backtracking search optimization algorithm. *Int. J. Electr. Power Energy Syst.* 64, 1197–1205.
- El-Fergany, A., 2016. Multi-objective allocation of multi-type distributed generators along distribution networks using backtracking search algorithm and fuzzy expert rules. *Electr. Power Compon. Syst.* 44 (3), 252–267.
- El-Khattam, W., Bhattacharya, K., Hegazy, Y., Salama, M.M.A., 2004. Optimal investment planning for distributed generation in a competitive electricity market. *IEEE Trans. Power Syst.* 19 (3), 1674–1684.
- El-Khattam, W., Salama, M.M.A., 2004. Distributed generation technologies, definitions and benefits. *Electr. Power Syst. Res.* 71 (2), 119–128.
- El-Sayed, M.M., Abou El-Ela, A.A., El-Sehiemy, R.A., 2017. Effect of photovoltaic system on power quality in electrical distribution networks. In: 2016 18th Int. Middle-East Power Syst. Conf. MEPCON 2016 - Proc.. pp. 1005–1012.
- El-Zonkol, A.M., 2010. Optimal placement of multi DG units including different load models using PSO. *Smart Grid Renew. Energy* 01 (03), 160–171.
- El-Zonkoly, A.M., 2011. Optimal placement of multi-distributed generation units including different load models using particle swarm optimization. *Swarm Evol. Comput.* 1 (1), 50–59.
- Ellis, A., et al., 2012. Review of existing reactive power requirements for variable generation. *IEEE Power Energy Soc. Gen. Meet.* 1–7.
- Elnozahy, M.S., Salama, M.M.A., 2013. Technical impacts of grid-connected photovoltaic systems on electrical networks - A review. *J. Renew. Sustain. Energy* 5 (3).
- Elsaiah, S., Benidris, M., Mitra, J., 2014. An analytical method for placement and sizing of distributed generation on distribution systems. In: 2014 Clemson Univ. Power Syst. Conf. PSC 2014.
- Emmanuel, M., Rayudu, R., 2017. The impact of single-phase grid-connected distributed photovoltaic systems on the distribution network using P-Q and P-V models. *Int. J. Electr. Power Energy Syst.* 91, 20–33.
- Enslin, J.H.R., 2010. Network impacts of high penetration of photovoltaic solar power systems. In: *IEEE PES Gen. Meet. PES, 2010*. pp. 1–5.
- EPA, 2018. Distributed generation of electricity and its environmental impacts. [Online] Available: <https://www.epa.gov/energy/distributed-generation-electricity-and-its-environmental-impacts>.

- Esmaili, M., Firozjaee, E.C., Shayanfar, H.A., 2014. Optimal placement of distributed generations considering voltage stability and power losses with observing voltage-related constraints. *Appl. Energy* 113, 1252–1260.
- E. Europe, Interconnection of electric power systems in the Arab world.
- Farhoodneha, M., Mohamed, A., Shareef, H., Zayandehroodi, H., 2013. Power quality analysis of grid-connected photovoltaic systems in distribution networks. *Prz. Elektrotech.* 89 (2 A), 208–213.
- Foley, A., Díaz Lobera, I., 2013. Impacts of compressed air energy storage plant on an electricity market with a large renewable energy portfolio. *Energy* 57, 85–94.
- Gakhar, P., Gupta, M., 2019. Harmonic mitigation in a transformer less grid connected solar PV system using modified LCL filter. In: 3rd International Conference and Workshops on Recent Advances and Innovations in Engineering, ICRAIE 2018, Vol. 2018, no. November. pp. 1–4.
- GAMS. [Online]. Available: <http://www.gams.com/>.
- Gandomi, A.H., Alavi, A.H., 2012. Krill herd: A new bio-inspired optimization algorithm. *Commun. Nonlinear Sci. Numer. Simul.* 17 (12), 4831–4845.
- Ganguly, S., Samajpati, D., 2015. Distributed generation allocation on radial distribution networks under uncertainties of load and generation using genetic algorithm. *IEEE Trans. Sustain. Energy* 6 (3), 688–697.
- Ghosh, S., Ghoshal, S.P., Ghosh, S., 2010. Optimal sizing and placement of distributed generation in a network system. *Int. J. Electr. Power Energy Syst.* 32 (8), 849–856.
- Gomes, P.V., Saraiva, J.T., 2017. Transmission system planning considering solar distributed generation penetration. In: *Int. Conf. Eur. Energy Mark. EEM*. pp. 2–7.
- Gupta, V., Donepudi, S.R., Subrahmanyam, N., 2015. Optimal placement of distributed generators in distribution system using backtracking search optimization for various load models. In: 2015 Int. Conf. Recent Dev. Control. Autom. Power Eng. RDCAPE 2015, Vol. 1, no. 3. pp. 350–354.
- Hadidian-Moghaddam, M.J., Arabi-Nowdeh, S., Bigdeli, M., Azizian, D., 2017. A multi-objective optimal sizing and siting of distributed generation using ant lion optimization technique. *Ain Shams Eng. J.* 1–9.
- Han, C.H., Ko, B.K., Song, S.Y., Jang, G., 2017. Application of PV Inverter on distribution system with high penetration of PV. *J. Int. Counc. Electr. Eng.* 7 (1), 263–268.
- Haque, M.M., Wolfs, P., 2016. A review of high PV penetrations in LV distribution networks: Present status, impacts and mitigation measures. *Renew. Sustain. Energy Rev.* 62, 1195–1208.
- Harijan, K., Uqaili, M.A., Mirza, U.K., 2015. Assessment of solar PV power generation potential in Pakistan. *J. Clean Energy Technol.* 3 (1), 54–56.
- Hasanvand, S., Nayeripour, M., Khooban, M.H., Fallahzadeh-Abarghouei, H., Doostizadeh, M., 2017. Power system distribution planning considering reliability and DG owner's profit. *J. Renew. Sustain. Energy* 9 (6).
- Hassan, A.A., Fahmy, F.H., Nafeh, A.E.-S.A., Abu-elmagd, M.A., 2017. Genetic single objective optimisation for sizing and allocation of renewable DG systems. *Int. J. Sustain. Energy* 36 (6), 545–562.
- HassanzadehFard, H., Jalilian, A., 2018. Optimal sizing and location of renewable energy based DG units in distribution systems considering load growth. *Int. J. Electr. Power Energy Syst.* 101 (April), 356–370.
- Hengsratawat, V., Tayjanant, T., Nimpitiwan, N., 2012. Optimal sizing of photovoltaic distributed generators in a distribution system with consideration of solar radiation and harmonic distortion. *Int. J. Electr. Power Energy Syst.* 39 (1), 36–47.
- Hermann, S.(KTH), Miketa, A.(IRENA), Fichaux, N.(IRENA), 2014. Estimating the renewable energy potential in Africa GIS-based approach.
- Hersch, P., Zweibel, K., 1982. *Basic Photovoltaic Principles and Methods*. United States, 1982.
- Hoogwijk, M.M., 2004. On the global and regional potential of renewable energy sources.
- Hoogwijk, M., Graus, W., 2008. Global potential of renewable energy sources: A literature assessment.
- Hosseini, S.A., Karimi Madahi, S.S., Razavi, F., Karami, M., Ghadimi, A.A., 2013. Optimal sizing and siting distributed generation resources using a multiobjective algorithm. *Turk. J. Electr. Eng. Comput. Sci.* 21 (3), 825–850.
- Hung, D.Q., Member, S., Mithulanathan, N., Member, S., 2013. Multiple distributed generator placement in primary distribution networks for loss reduction. *IEEE Trans. Indust. Electron.* 60 (4), 1700–1708.
- Hung, D.Q., Mithulanathan, N., 2014. Loss reduction and loadability enhancement with DG: A dual-index analytical approach. *Appl. Energy* 115, 233–241.
- Hung, D.Q., Mithulanathan, N., Bansal, R.C., 2010. Analytical expressions for DG allocation in primary distribution networks. *IEEE Trans. Energy Convers.* 25 (3), 814–820.
- Hung, D.Q., Mithulanathan, N., Lee, K.Y., 2014. Determining PV penetration for distribution systems with time-varying load models. *IEEE Trans. Power Syst.* 29 (6), 3048–3057.
- IEEE, 2002. IEEE standards c95.6. no. October.
- IEEE, 2014. IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems. IEEE Power and Energy Society.
- IEEE Standard Association, 2018. IEEE Std. 1547-2018. Standard for interconnection and interoperability of distributed energy resources with associated electric power systems interfaces.
- Injeti, S.K., 2017. A Pareto optimal approach for allocation of distributed generators in radial distribution systems using improved differential search algorithm. *J. Electr. Syst. Inf. Technol.*
- Institute of Electrical and Electronics Engineers, 2011. IEEE Std 1250 - IEEE guide for identifying and improving voltage quality in power systems.
- Jahromi, M.J., Farjah, E., Zolghadri, M., 2007. Mitigating voltage sag by optimal allocation of distributed generation using genetic algorithm. In: 2007 9th International Conference on Electrical Power Quality and Utilisation, EPQU.
- Kadir, A.F.A., Khatib, T., Elmenreich, W., 2014. Integrating photovoltaic systems in power system: Power quality impacts and optimal planning challenges. *Int. J. Photoenergy* 2014.
- Kamal Kant Sharma, D.B.S., 2012. Distributed generation- a new approach. *Int. J. Adv. Res. Comput. Eng. Technol. (IJARCET)* 1 (8), 313–318.
- Kansal, S., Tyagi, B., Kumar, V., 2015. Cost – benefit analysis for optimal distributed generation placement in distribution systems. *J. Int. J. Ambient Energy* 0750 (2015), 37–41.
- Karaboga, D., 2005. An Idea Based on Honey Bee Swarm for Numerical Optimization, no. TR06. Tech. Rep. TR06, Erciyes Univ., p. 10.
- Karimi, M., Mokhlis, H., Naidu, K., Uddin, S., Bakar, A.H.A., 2016. Photovoltaic penetration issues and impacts in distribution network - a review. *Renew. Sustain. Energy Rev.* 53, 594–605.
- Karimyan, P., Gharehpetian, G.B., Abedi, M., Gavili, A., 2014. Long term scheduling for optimal allocation and sizing of DG unit considering load variations and DG type. *Int. J. Electr. Power Energy Syst.* 54, 277–287.
- Kayal, P., Chanda, C.K., 2013. Placement of wind and solar based DGs in distribution system for power loss minimization and voltage stability improvement. *Int. J. Electr. Power Energy Syst.* 53, 795–809.
- Kayal, P., Chanda, S., Chanda, C.K., 2017. An analytical approach for allocation and sizing of distributed generations in radial distribution network. *Int. Trans. Electr. Energy Syst.* (October 2015), n/a-n/a.
- Keane, A., O'Malley, M., 2005. Optimal allocation of embedded generation on distribution networks. *IEEE Trans. Power Syst.* 20 (3), 1640–1646.
- Kebede, K.Y., 2015. Viability study of grid-connected solar PV system in Ethiopia. *Sustain. Energy Technol. Assess.* 10, 63–70.
- Kefayat, M., Lashkar Ara, A., Nabavi Niaki, S.A., 2015a. A hybrid of ant colony optimization and artificial bee colony algorithm for probabilistic optimal placement and sizing of distributed energy resources. *Energy Convers. Manage.* 92, 149–161.
- Kefayat, M., Lashkar Ara, A., Nabavi Niaki, S.A., 2015b. A hybrid of ant colony optimization and artificial bee colony algorithm for probabilistic optimal placement and sizing of distributed energy resources. *Energy Convers. Manage.* 92, 149–161.
- Khoa, T.H., Nallagownden, P., Baharudin, Z., Dieu, V.N., 2017. One rank cuckoo search algorithm for optimal placement of multiple distributed generators in distribution networks. In: *Proc. of the 2017 IEEE Region 10 Conference (TENCON)*, Malaysia, November 5-8, 2017, pp. 1715–1720.
- Khushalani, S., Solanki, J.M., Schulz, N.N., 2007. Development of three-phase unbalanced power flow using PV and PQ models for distributed generation and study of the impact of DG models. *IEEE Trans. Power Syst.* 22 (3), 1019–1025.
- Kocer, M.C., et al., 2019. Assessment of battery storage technologies for a Turkish power network. *Sustain.* 11 (13).
- Kothari, D.P., Nagrath, I.L., 2003. *Modern Power System Analysis*, third ed. Tata McGraw Hill Education private Limited, NEW DELHI.
- Kroposki, B., 2017. Integrating high levels of variable renewable energy into electric power systems. *J. Mod. Power Syst. Clean Energy* 5 (6), 831–837.
- Kucuksari, S., et al., 2014. An Integrated GIS, optimization and simulation framework for optimal PV size and location in campus area environments. *Appl. Energy* 113, 1601–1613.
- Kumar, A., Gao, W., 2010. Optimal distributed generation location using mixed integer non-linear programming in hybrid electricity markets. *IET Gener. Transm. Distrib.* 4 (2), 281–298.
- a L'Abbate, Fulli, G., Starr, F., Peteves, S., 2007. Distributed power generation in europe: technical issues for further integration.
- Lashab, A., Sera, D., Guerrero, J.M., 2019. Harmonics Mitigation in Cascaded Multilevel PV Inverters During Power Imbalance Between Cells, no. 12. pp. 1–6.
- Lewis, S.J., 2011. Analysis and management of the impacts of a high penetration of photovoltaic systems in an electricity distribution network. *Innov. Smart Grid Technol. Asia* 1–7.
- Lin, Y.C., Hwang, K.S., Wang, F.S., 2004. A mixed-coding scheme of evolutionary algorithms to solve mixed-integer nonlinear programming problems. *Comput. Math. Appl.* 47 (8–9), 1295–1307.
- Liu, W., Xu, H., 2016. Optimal distributed generator allocation method considering voltage control cost. *Dianwang Jishu/Power Syst. Technol.* 40 (10), 2998–3005.

- Lopez, A., Roberts, B., Heimiller, D., Blair, N., Porro, G., 2012. U.S. renewable energy technical potentials: A GIS-based analysis. *Natl. Renew. Energy Lab. Doc. 1* (7), 1–40.
- Luo, L., et al., 2018. Optimal siting and sizing of distributed generation in distribution systems with PV solar farm utilized as STATCOM (PV-STATCOM). *Appl. Energy* 210 (August 2017), 1092–1100.
- Mahdad, B., 2019. Improvement optimal power flow solution under loading margin stability using new partitioning whale algorithm. *Int. J. Manag. Sci. Eng. Manag.* 14 (1), 64–77.
- Mahesh, K., Nallagownden, P., Elamvazuthi, I., 2017. Optimal placement and sizing of renewable distributed generations and capacitor banks into radial distribution systems. *Energies* 10 (6).
- Mahmoud, K., Yorino, N., Ahmed, A., 2016. Optimal distributed generation allocation in distribution systems for loss minimization. *IEEE Trans. Power Syst.* 31 (2), 960–969.
- Makhloufi, S., Koussa, S.D., Pillai, G.G., 2017. Cuckoo search algorithm for integration wind power generation to meet load demand growth. In: *Conference Proceedings - 2017 17th IEEE International Conference on Environment and Electrical Engineering and 2017 1st IEEE Industrial and Commercial Power Systems Europe, IEEEIC / I and CPS Europe 2017*, pp. 0–5.
- Manafi, H., Ghadimi, N., Ojaroudi, M., Farhadi, P., 2013. Optimal placement of distributed generations in radial distribution systems using various PSO and de algorithms. *Elektron. Elektrotehnika* 19 (10), 53–57.
- Maya, K.N., Jasmin, E.A., 2015. A three phase power flow algorithm for distribution network incorporating the impact of distributed generation models. *Procedia Technol.* 21, 326–331.
- von Meier, A., 2006. *Electric Power Systems*. John Wiley & Sons, Inc., Hoboken, New Jersey.
- Menti, A., Zacharias, T., Miliadis-Argitis, J., 2011. Harmonic distortion assessment for a single-phase grid-connected photovoltaic system. *Renew. Energy* 36 (1), 360–368.
- Mirjalili, S., 2015. The ant lion optimizer. *Adv. Eng. Softw.* 83, 80–98.
- Mirjalili, S., Lewis, A., 2016. The whale optimization algorithm. *Adv. Eng. Softw.* 95, 51–67.
- Mittal, M., 2012. Analytical approaches for optimal placement and sizing of distributed generation in power system. *IOSR J. Electr. Electron. Eng.* 1 (1), 20–30.
- Moghaddas-Tafreshi, S.M., Mashhour, E., 2009. Distributed generation modeling for power flow studies and a three-phase unbalanced power flow solution for radial distribution systems considering distributed generation. *Electr. Power Syst. Res.* 79 (4), 680–686.
- Mohamed, I.A., Kowsalya, M., 2014. Optimal size and siting of multiple distributed generators in distribution system using bacterial foraging optimization. *Swarm Evol. Comput.* 15, 58–65.
- Mohamed, A.A.Z.D., Tolba, A., Tulsy, Vladimir N., 2017. Optimal allocation and sizing of multiple distributed generators in distribution networks using a novel hybrid particle swarm optimization algorithm. pp. 1606–1612.
- Mohan N, A.T., Kulkarni, A.D., 2015. A weighted multi-objective index based optimal distributed generation planning in distribution system. *Proc. Technol.* 21, 279–286.
- MOHD NABIL BIN MUHTAZARUDDIN, 2014. Distribution network loss minimization via artificial immune bee colony.
- Mohsen, M., Youssef, A.-R., Ebeed, M., Kamel, S., 2017. 2017 nineteenth international middle east power systems conference (MEPCON). In: *Optimal Planning of Renewable Distributed Generation in Distribution Systems using Grey Wolf Optimizer GWO*, No. December. pp. 19–21.
- Moradi, M.H., Abedini, M., 2012a. A combination of genetic algorithm and particle swarm optimization for optimal DG location and sizing in distribution systems. *Int. J. Electr. Power Energy Syst.* 34 (1), 66–74.
- Moradi, M.H., Abedini, M., 2012b. A combination of genetic algorithm and particle swarm optimization for optimal DG location and sizing in distribution systems. *Int. J. Electr. Power Energy Syst.*
- Moradi, M.H., Abedini, M., 2010. A combination of genetic algorithm and particle swarm optimization for optimal DG location and sizing in distribution systems. In: *2010 9th Int. Power Energy Conf. IPEC 2010*. pp. 858–862.
- Mosbah, M., Khattara, A., Becherif, M., Arif, S., 2016. Optimal PV location choice considering static and dynamic constraints. *Int. J. Emerg. Electr. Power Syst.* 18 (1).
- Mosbah, M., Zine, R., Arif, S., Mohammedi, R.D., Bacha, S., 2019. Optimal power flow for transmission system with photovoltaic based DG using biogeography-based optimization. In: *Proceedings of 2018 3rd International Conference on Electrical Sciences and Technologies in Maghreb, CISTEM 2018*, pp. 1–6.
- Mouassa, S., Bouktir, T., Salhi, A., 2017. Ant lion optimizer for solving optimal reactive power dispatch problem in power systems. *Eng. Sci. Technol. Int. J.* 20 (3), 885–895.
- Mozina, C.J., 2008. A tutorial on the impact of distributed generation (DG) on distribution systems. In: *2008 61st Annu. Conf. Prot. Relay Eng.* pp. 591–609.
- Mozina, C.J., 2009. Impact of green power generation on distribution systems. In: *2009 IEEE Rural Electr. Power Conf.* pp. A3–A3–8.
- Mukherjee, A., Mukherjee, V., 2016. Chaos embedded krill herd algorithm for optimal VAR dispatch problem of power system. *Int. J. Electr. Power Energy Syst.* 82, 37–48.
- Murthy, K.V.S.R., Raju, M.R., Rao, G.G., Rao, K.N., 2010. Comparison of loss sensitivity factor & index vector methods in determining optimal capacitor locations in agricultural distribution. In: *National Power Systems Conference*, No. 6. pp. 26–30.
- Murthy, G.V.K., Sivanagaraju, S., Satyanarayana, S., Rao, B.H., 2013. Optimal placement of DG in distribution system to mitigate power quality disturbances. *Int. J. Electr. Electron. Sci. Eng.* 7 (2), 155–160.
- Murty, V.V.S.N., Kumar, A., 2015. Optimal placement of DG in radial distribution systems based on new voltage stability index under load growth. *Int. J. Electr. Power Energy Syst.* 69, 246–256.
- Nabavi, M.S.H., Hajforoosh, S., Masoum, M.A.S., 2011. Placement and sizing of distributed generation units for congestion management and improvement of voltage profile using particle swarm optimization. In: *IEEE PES Innov. Smart Grid Technol. ISGT Asia 2011 Conf. Smarter Grid Sustain. Afford. Energy Futur.* pp. 1–6.
- Nasrolahpour, E., Ghasemi, H., Monsef, H., Khoub, E., 2012. DG placement considering voltage sag and losses. In: *2012 11th International Conference on Environment and Electrical Engineering, IEEEIC 2012 - Conference Proceedings*. pp. 909–913.
- Nawaz, S., Singh, S., 2017. A novel approach for multiple DG allocation in distribution system of jaipur city. pp. 1–6.
- Nehir, M.H., et al., 2011. A review of hybrid renewable/alternative energy systems for electric power generation: Configurations, control, and applications. *IEEE Trans. Sustain. Energy* 2 (4), 392–403.
- NERC, 1996. Available transfer capability definitions and determination.
- Nwaigwe, K.N., Mutabilwa, P., Dintwa, E., 2019. An overview of solar power (PV systems) integration into electricity grids. *Mater. Sci. Energy Technol.* 2 (3), 629–633.
- Of, I., et al., 2004. Institution electrical hills. In: *Eighth IEE Int. Conf. Dev. Power Syst. Prot. Vol. 2004*, no. Mv. pp. 315–318.
- Ogunjuyigbe, A.S.O., Ayodele, T.R., Akinola, O.O., 2016. Impact of distributed generators on the power loss and voltage profile of sub-transmission network. *J. Electr. Syst. Inf. Technol.* 3 (1), 94–107.
- Pavani, P., Singh, S.N., 2014. Placement of DG for reliability improvement and loss minimization with reconfiguration of radial distribution systems. *Int. J. Energy Sect. Manag.* 8 (3), 312–329.
- Payasi, R., Singh, A., Singh, D., 2011. Review of distributed generation planning: objectives, constraints, and algorithms. *Int. J. Eng. Sci. Technol.* 3 (3), 133–153.
- Peesapati, R., Yadav, V.K., Kumar, N., 2018. Flower pollination algorithm based multi-objective congestion management considering optimal capacities of distributed generations. *Energy* 147, 980–994.
- Pepermans, G., Driesen, J., Haeseldonckx, D., Belmans, R., D'haeseleer, W., 2005. Distributed generation: Definition, benefits and issues. *Energy Policy* 33 (6), 787–798.
- Petrone, G., Spagnuolo, G., Teodorescu, R., Veerachary, M., Vitelli, M., 2008. Reliability issues in photovoltaic power processing systems. *IEEE Trans. Ind. Electron.* 55 (7), 2569–2580.
- Pisica, I., Bulac, C., Eremia, M., 2009. Optimal distributed generation location and sizing using genetic algorithms. In: *2009 15th International Conference on Intelligent System Applications To Power Systems*, no. 1. pp. 1–6.
- Poornazaryan, B., Karimyan, P., Gharehpetian, G.B., Abedi, M., 2016. Optimal allocation and sizing of DG units considering voltage stability, losses and load variations. *Int. J. Electr. Power Energy Syst.* 79, 42–52.
- Popov, A., 2003. Genetic algorithms for optimization – application in controller design problems.
- POVLSEN, A.F., A/S, E., 2002. Impacts of power penetration from photovoltaic power systems in distribution networks.
- Prakash, D.B., Lakshminarayana, C., 2017. Optimal siting of capacitors in radial distribution network using Whale Optimization Algorithm. *Alexandria Eng. J.* 56 (4), 499–509.
- Prenc, R., Škrlec, D., Komen, V., 2013. Optimal PV system placement in a distribution network on the basis of daily power consumption and production fluctuation. In: *IEEE EuroCon 2013*, no. July. pp. 777–783.
- Rasul, M.J.M.A., Khang, H.V., Kolhe, M., 2017. Harmonic mitigation of a grid-connected photovoltaic system using shunt active filter. In: *2017 20th Int. Conf. Electr. Mach. Syst. ICEMS 2017*.
- Rath, A., Ghatak, S.R., Goyal, P., 2017. Optimal allocation of distributed generation (DGs) and static VAR compensator (SVC) in a power system using Revamp Voltage Stability Indicator. In: *2016 National Power Systems Conference, NPSC 2016*.
- Rathod, M.D., Adeshara, A.S., Optimal & Fast Placement of DG Unit CPF Method Using MATLAB Toolbox PSAT. 2 (2) (2014) 1887–1894.
- Ravikumar Pandi, V., Zeineldin, H.H., Xiao, W., 2013. Determining optimal location and size of distributed generation resources considering harmonic and protection coordination limits. *IEEE Trans. Power Syst.* 28 (2), 1245–1254.

- Rawat, M.S., Vadhera, S., 2018. Impact of photovoltaic penetration on static voltage stability of distribution networks: A probabilistic approach. *Asian J. Water Environ. Pollut.* 15 (3), 51–62.
- Rawea, A.S., Urooj, S., 2018. Strategies, current status, problems of energy and perspectives of Yemen's renewable energy solutions. *Renew. Sustain. Energy Rev.* 82 (August 2016), 1655–1663.
- Reddy, P.D.P., Reddy, V.C.V., Manohar, T.G., 2017. Whale optimization algorithm for optimal sizing of renewable resources for loss reduction in distribution systems. *Renew. Wind Water Sol.* 4 (1), 3.
- Regional Center for Renewable Energy and Energy Efficiency, 2012. Renewable energy country profile.
- Reliability Panel Australian Energy Market Commission, 2017. The frequency operating standard.
- REN21, 2015. Renewables 2015 global status report.
- REN21, 2016. Renewables 2016 global status report.
- REN21, 2017. Renewables 2017: global status report.
- REN21, 2018. Renewables 2018 global status report.
- REN21, 2019. Renewables 2019: Global status report.
- Rezaee Jordehi, A., 2016. Allocation of distributed generation units in electric power systems: A review. *Renew. Sustain. Energy Rev.* 56, 893–905.
- Ropp, M., National Rural Electric Cooperative Association, 2019. Guide to the IEEE 1547-2018 standard and its impacts on cooperatives.
- Roy, N.K., Pota, H.R., Anwar, A., 2012. A new approach for wind and solar type DG placement in power distribution networks to enhance systems stability. In: 2012 IEEE International Power Engineering and Optimization Conference, PEOCO 2012 - Conference Proceedings, no. June. pp. 296–301.
- Ruiz-Rodriguez, F.J., Gomez-Gonzalez, M., Jurado, F., 2011. Binary particle swarm optimization for optimization of photovoltaic generators in radial distribution systems using probabilistic load flow. *Electr. Power Compon. Syst.* 39 (15), 1667–1684.
- Sadeghi, H., Ghaffarzadeh, N., 2016. A simultaneous biogeography based optimal placement of DG units and capacitor banks in distribution systems with nonlinear loads. *J. Electr. Eng.* 67 (5), 351–357.
- Salameh, Z.M., Borowy, B.S., Amin, A.R.A., 1995. Photovoltaic module-site matching based on the capacity factors. *IEEE Trans. Energy Convers.* 10 (2), 326–332.
- Salih, Q.A., Soomro, D.M., Saeh, I.S., 2016. Optimal distributed generators location for power losses improvement using sensitivity based method. In: 2015 IEEE International Conference on Smart Instrumentation, Measurement and Applications, ICSIMA 2015, no. November. pp. 24–25.
- Samajpati, D., 2014. Distributed Generation Allocation for Power Loss Minimization and Voltage Improvement of Radial Distribution Department of Electrical Engineering Loss Minimization and Voltage Improvement of Radial Distribution Systems using Genetic Algorithm. National Institute of Technology, ROURKELA.
- Sanchez Mora, M.M., Tamayo, C.A., Lopez-Lezama, J.M., 2018. Optimal allocation of distributed generation for improving chargeability and voltage profile under different operative scenarios. *Contemp. Eng. Sci.* 11 (51), 2503–2511.
- Sarhan, W.M., Alkhateeb, A.N., Omran, K.D., Hussein, F.H., 2006. Effect of temperature on the efficiency of the thermal cell. *Asian J. Chem.* 18 (2), 982–990.
- Sasiraja, R.M., Muthulakshmi, K., Kumar, V.S., Abinaya, T., 2017. PSO based optimal distributed generation placement and capacity by considering harmonic limits. *Teh. Vjesn. - Tech. Gaz.* 24 (Supplement 2), 391–398.
- Sebestyén, T.-T., 2017. Assessment of solar PV power generation potential in centre development region of Romania. *J. Clean Energy Technol.* 5 (4), 5.
- Seker, A.A., Hocaoglu, M.H., 2013. Artificial Bee Colony algorithm for optimal placement and sizing of distributed generation. In: 2013 8th International Conference on Electrical and Electronics Engineering (ELECO). pp. 127–131.
- Shahriari, S.A.A., Yazdian, A., Haghifam, M.R., 2009. Fault current limiter allocation and sizing in distribution system in presence of distributed generation. In: 2009 IEEE Power and Energy Society General Meeting, PES '09. pp. 1–6.
- Shahzad, M., Ahmad, I., Gawlik, W., Palensky, P., 2016. Load concentration factor based analytical method for optimal placement of multiple distribution generators for loss minimization and voltage profile improvement. *Energies* 9 (4).
- Shahzad, M., Gawlik, W., Palensky, P., 2017. Voltage Quality Index based method to quantify the advantages of optimal DG placement. In: 2016 18th International Middle-East Power Systems Conference, MEPCON 2016 - Proceedings. pp. 759–764.
- Shahzad, M., Ullah, I., Palensky, P., Gawlik, W., 2014. Analytical approach for simultaneous optimal sizing and placement of multiple distributed generators in primary distribution networks. In: IEEE International Symposium on Industrial Electronics. pp. 2554–2559.
- Shayani, R.A., De Oliveira, M.A.G., 2011. Photovoltaic generation penetration limits in radial distribution systems. *IEEE Trans. Power Syst.* 26 (3), 1625–1631.
- Sheoran, Y., Kumar, V., Rana, K.P.S., Mishra, P., Kumar, J., Nair, S.S., 2015. Development of backtracking search optimization algorithm toolkit in LabVIEW???. *Procedia Comput. Sci.* 57, 241–248.
- Singh, A., Ghatak, S.R., Dey, S., 2018. Strategic deployment of distributed generation and DSTATCOM in radial distribution system considering reliability aspect. In: 2018 2nd International Conference on Electronics, Materials Engineering and Nano-Technology, IEMENTech 2018, No. September.
- Singh, B., Mishra, D.K., 2018. A survey on enhancement of power system performances by optimally placed DG in distribution networks. *Energy Rep.* 4, 129–158.
- Singh, B., Pal, C., Mukherjee, V., Tiwari, P., Yadav, M.K., 2017. Distributed generation planning from power system performances viewpoints: A taxonomical survey. *Renew. Sustain. Energy Rev.* 75 (September 2015), 1472–1492.
- Singh, A.K., Parida, S.K., Optimal Placement of DGs Using MINLP in Deregulated Electricity Market, System.
- Sorensen, B., 1999. Long-Term Scenarios for Global Energy Demand and Supply: Four Global Greenhouse Mitigation Scenarios. Roskilde Universitetscenter (Denmark).
- Sudabattula, S., Kowsalya, M., 2016. Optimal allocation of wind based distributed generators in distribution system using cuckoo search algorithm. *Procedia Comput. Sci.* 92, 298–304.
- Suh, J., Hwang, S., Jang, G., 2017. Development of a transmission and distribution integrated monitoring and analysis system for high distributed generation penetration. *Energies* 10 (9).
- Sultan, H.M., Zaki Diab, A.A., Kuznetsov, O.N., Ali, Z.M., Abdalla, O., 2019. Evaluation of the impact of high penetration levels of PV power plants on the capacity, frequency and voltage stability of Egypt's unified grid. *Energies* 12 (3), 1–22.
- Sultana, S., Roy, P.K., 2016. Krill herd algorithm for optimal location of distributed generator in radial distribution system. *Appl. Soft Comput.* 40, 391–404.
- wei Sun, Y., Hof, A., Wang, R., Liu, J., jie Lin, Y., wei Yang, D., 2013. GIS-based approach for potential analysis of solar PV generation at the regional scale: A case study of Fujian Province. *Energy Policy* 58 (2013), 248–259.
- Sun, K., Zhang, L., Xing, Y., Guerrero, J.M., 2011. A distributed control strategy based on DC bus signaling for modular photovoltaic generation systems with battery energy storage. *IEEE Trans. Power Electron.* 26 (10), 3032–3045.
- Survey, P.S.A., Rakhshani, E., Rouzbehi, K., Adolfo, J.S., Tobar, A.C., Integration of Large Scale PV-Based Generation into. In: *Energies* 2019, MDPI, Vol. 12, no. 1425.
- Swief, R.A., Abdel-Salam, T.S., El-Amary, N.H., 2018. Photovoltaic and wind turbine integration applying cuckoo search for probabilistic reliable optimal placement. *Energies* 11 (1), 1–17.
- D. Systems, Distribution systems – General, pp. 300–309.
- Tan, Y.T., 2004. Impact on the power system with a large generation of photovoltaic generation. *Electr. Eng. Electron.* PhD (February), 1–8.
- Tan, W.S., Hassan, M.Y., Majid, M.S., Abdul Rahman, H., 2013. Optimal distributed renewable generation planning: A review of different approaches. *Renew. Sustain. Energy Rev.* 18, 626–645.
- Tan, W.S., Hassan, M.Y., Majid, M.S., Rahman, H.A., 2012a. Allocation and sizing of DG using cuckoo search algorithm. In: PECon 2012-2012 IEEE International Conference on Power and Energy, No. December. pp. 133–138.
- Tan, W.S., Hassan, M.Y., Majid, M.S., Rahman, H.A., 2012b. Allocation and sizing of DG using cuckoo search algorithm. In: PECon 2012-2012 IEEE International Conference on Power and Energy.
- Teng, J.H., Luan, S.W., Lee, D.J., Huang, Y.Q., 2013. Optimal charging/discharging scheduling of battery storage systems for distribution systems interconnected with sizeable PV generation systems. *IEEE Trans. Power Syst.* 28 (2), 1425–1433.
- Thakur, D., Jiang, J., 2013. Optimal location and size of DG for enhancing loading margin and reducing system loss. *IEEE Power Energy Soc. Gen. Meet.*
- Tolba, M.A., Diab, A.A.Z., Tulsy, V.N., Abdelaziz, A.Y., 2018a. LVCI approach for optimal allocation of distributed generations and capacitor banks in distribution grids based on moth-flame optimization algorithm. *Electr. Eng.*
- Tolba, M.A., Rezk, H., Tulsy, V., Zaki Diab, A.A., Abdelaziz, A.Y., Vanin, A., 2018b. Impact of optimum allocation of renewable distributed generations on distribution networks based on different optimization algorithms. *Energies* 11, 1–33.
- Tolba, M.A., Zaki Diab, A.A., Tulsy, V.N., Almoataz, Abdelaziz, Y., Abdelaziz, A.Y., LVCI approach for optimal allocation of distributed generations and capacitor banks in distribution grids based on moth-flame optimization algorithm.
- Tong, S., 2006. Slack Bus Modeling for Distributed Generation and its Impacts on Distribution System Analysis, Operation and Planning. Drexel University.
- Tromly, K., 2001. Renewable energy: An overview. p. 8.
- Tucho, G.T., Weesie, P.D.M., Nonhebel, S., 2014. Assessment of renewable energy resources potential for large scale and standalone applications in Ethiopia. *Renew. Sustain. Energy Rev.* 40, 422–431.
- U.S. Department of Energ., 2007. The potential benefits of distributed generation and rate-related issues that may impede their expansion.
- Vadhera, S., Mahajan, S., 2016. Optimal allocation of dispersed generation unit in a network system. *Int. Conf. Microelectron. Comput. Commun. MicroComput.* 2016, 0–4.

- Viral, R., Khatod, D.K., 2012. Optimal planning of distributed generation systems in distribution system: A review. *Renew. Sustain. Energy Rev.* 16 (7), 5146–5165.
- Šúri, M., Huld, T.A., Dunlop, E.D., Ossenbrink, H.A., 2007. Potential of solar electricity generation in the European Union member states and candidate countries. *Sol. Energy* 81 (10), 1295–1305.
- Wang, Y., Ravishankar, J., Phung, T., 2016. A study on critical clearing time (CCT) of micro-grids under fault conditions. *Renew. Energy* 95, 381–395.
- Willis, H.L., 2000. Analytical Methods and Rules of Thumb for Modeling Dg-Distribution Interaction, no. C, pp. 1643–1644.
- Xiao, C., Yu, X., Yang, D., Que, D., 2014. Impact of solar irradiance intensity and temperature on the performance of compensated crystalline silicon solar cells. *Sol. Energy Mater. Sol. Cells* 128, 427–434.
- Yakoub Yousef, M., Mahmoud Ismail, M., Mohamed El Masry, S., 2019. The effect of grid connected photovoltaic location and penetration level on total harmonic distortion. In: 2018 20th Int. Middle East Power Syst. Conf. MEPCON 2018 - Proc., pp. 141–145.
- Yang, X.-S., Deb, S., 2010. Cuckoo search via levy flights. pp. 210–214.
- Yuvaraj, T., Devabalaji, K.R., Ravi, K., 2018. Optimal allocation of DG in the radial distribution network using bat optimization algorithm. In: Garg, A., Bhoi, A.K., Sanjeevikumar, P., Kamani, K.K. (Eds.), *Advances in Power Systems and Energy Management: ETAEERE-2016*. Springer Singapore, Singapore, pp. 563–569.
- Yuvaraj, T., Ravi, K., Devabalaji, K.R., 2017a. Optimal allocation of DG and DSTATCOM in radial distribution system using cuckoo search optimization algorithm.
- Yuvaraj, T., Ravi, K., Devabalaji, K.R., 2017b. Optimal allocation of DG and DSTATCOM in radial distribution system using cuckoo search optimization algorithm. *Hindawi Publ. Corp. Model. Simul. Eng.* 2017.
- Zahedi, A., 2011. Maximizing solar PV energy penetration using energy storage technology. *Renew. Sustain. Energy Rev.* 15 (1), 866–870.
- Zhu, D., Broadwater, R.P., Tam, K.S., Seguin, R., Asgeirsson, H., 2006. Impact of DG placement on reliability and efficiency with time-varying loads. *IEEE Trans. Power Syst.* 21 (1), 419–427.
- Zubo, R.H.A., Mokryani, G., Rajamani, H.S., Aghaei, J., Niknam, T., Pillai, P., 2017. Operation and planning of distribution networks with integration of renewable distributed generators considering uncertainties: A review. *Renew. Sustain. Energy Rev.* 72 (October 2016), 1177–1198.