ISSN 2348 – 9928
IJAICT Volume-1, Issue-1 May 2014 Doi:01.0401/ijaict.2014.01.04 Published Online 05 (05) 2014

MULTI OBJECTIVE OPTIMAL SITING AND SIZING OF INVERTER BASED DISTRIBUTED GENERATION UNITS CONSIDERING HARMONIC LIMITS IN MESHED ELECTRIC POWER SYSTEM

Asna.S.Asok
Department of Electrical and Electronics Engineering
Regional Centre Anna University,
Coimbatore, Tamilnadu, India.

***Abstract*— Distributed generation units (DGs), small generating units connected directly to the distribution networks are recently in growing attention as a solution to environmental and economical challenges caused by conventional power plants. In this study, a multi-objective framework is proposed for optimal placement and sizing of inverter based distributed generation units in meshed electric power system. The objective functions include maximizing the penetration level as well as minimizing power losses and total harmonic distortion subjected to various constraints such as power balance equations, bus voltage limits, individual harmonic distortion limit specified by IEEE-519 standard.. The DG penetration level could be limited by harmonic distortion because of the non linear current injected by inverter based DG units. This study is formulated as a nonlinear programming problem and tested on the IEEE-14 bus meshed distribution system with different DG scenarios. The problem is solved using particle swarm optimization algorithm due to its nonlinear and non convex nature. Simulation results show the effectiveness o the proposed approach. The best results have been obtained and is plotted and graphed.**

Keywords*— *Distributed generation, harmonic distortion, harmonic power flow, particle swarm optimization.

I. INTRODUCTION

The research and development on the distribution generation technology on renewable as well as non renewable resources has created an important role for DG in future. This is because of its improved performance, reliability and flexibility to achieve higher energy efficiency and reduced emission [1], [2]. According to the IEEE-1547 standard the DG units are interconnected with the utility grid [3], [4]. The location, type, and size of DG units are the three main factors that can affect the amount of DG penetration [5]–[7].

The DG units are of two types namely utility owned DG units and customer owned DG units [8], [9]. In the case of a utility owned DG installation, the utility has to optimally plan the location and size of the DG units in order to improve network benefits and reliability [10],[12]. In practice, one is not always able to site DG at the locations determined by an optimization algorithm; however it gives the planner an idea of where DG might be the most beneficial [13]. a new optimization problem is proposed to determine the maximum distributed generation (DG) penetration level by optimally selecting types, locations and sizes of utility owned DG units[14].

During the last decade, power electronic converters have undergone a fast evolution due to the development of fast semiconductor switches and also the introduction of real-time controllers that can implement advanced and complex control algorithms efficiently [15]. DG units of the inverter-based type end to have more impact on the system harmonic levels than synchronous- based DG.

The limitations on current and voltage harmonics, which can cause undesirable effects on various power system equipments and the measurement and equipment modeling for harmonic analysis, have been given in the IEEE-519 standard. The penetration level of photovoltaic generation in radial distribution system considering the limits on voltage magnitudes and conductor current flow is investigated. The maximum

In this paper, an optimization framework is proposed to maximize the DG penetration level, minimization of loss and minimization of total harmonic distortion in looped distribution systems taking into account power balance, voltage limits, harmonic limits and protection constraints.

In order to determine the harmonic distortion caused by inverter-based DG units, decoupled harmonic power flow (DHPF) is used. The problem is solved using the particle swarm optimization (PSO) algorithm due to the nonlinear and non convex nature. The problem is tested on the standard IEEE 14 bus distribution system.

II. PROBLEM FORMULATION

The proposed problem is to maximize the overall DG penetration level and to minimize the power losses and total harmonic distortion by optimally selecting the size of the inverter based DG units. The problem is solved using particle Swarm optimization (PSO). The constraints of the proposed problem include fundamental frequency real and reactive power balance, RMS voltage limits, individual harmonic

ISSN 2348 – 9928
IJAICT Volume-1, Issue-1 May 2014 Doi:01.0401/ijaict.2014.01.04 Published Online 05 (05) 2014

limits at each bus. The fitness evaluation sequence for each candidate solution is shown in Fig 1.

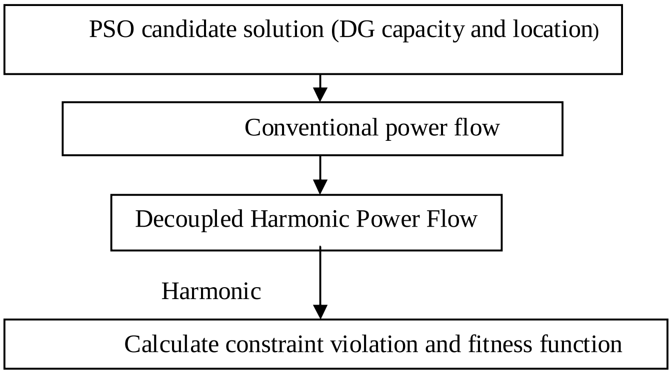

Fig 1: Framework showing fitness evaluation sequence

Initially, the Newton-Raphson based conventional power flow is conducted at fundamental frequency to calculate the fundamental voltage components considering inverter based DG units, taking into account the power balance constraints. The result of conventional power flow is used by the DHPF algorithm which estimates the higher order harmonic components with inverter-based DG units. The details of the proposed problem formulation are described in the following subsections.

A. Harmonic Power Flow Analysis

Harmonic power flow techniques are useful to estimate the system distortion due to the presence of nonlinear devices. Among various harmonic power flow formulations, the DHPF method is most commonly used due to its simplicity. The subroutine steps involving the decoupled harmonic power flow solution are shown in Fig 2. Initially, the results of conventional power flow, system data and DG location and capacity are inputted to DHPF subroutine. In higher order harmonic frequencies, the transmission lines shunt capacitors, synchronous machines, and linear loads are modeled as equivalent admittances using the results of the conventional power flow and then a new admittance matrix is formulated. Inverter-based DG units are modeled as harmonic current injecting sources in the DHPF method. On the other hand, the synchronous-based DG units are modeled as a source behind impedance. Nodal equations are solved for each individual harmonic order to obtain the harmonic voltage and the result is used to calculate the harmonic distortion.

The harmonic admittances of various components can be expressed as follows:

$$y_i^{(h)} = \frac{P_{L,i}}{\left|v_i^{(1)}\right|^2} - j\frac{Q_{L,i}}{h\left|v_i^{(1)}\right|^2} \quad (1)$$

$$y_{ci}^{(h)} = h y_{ci}^{(1)} \quad (2)$$

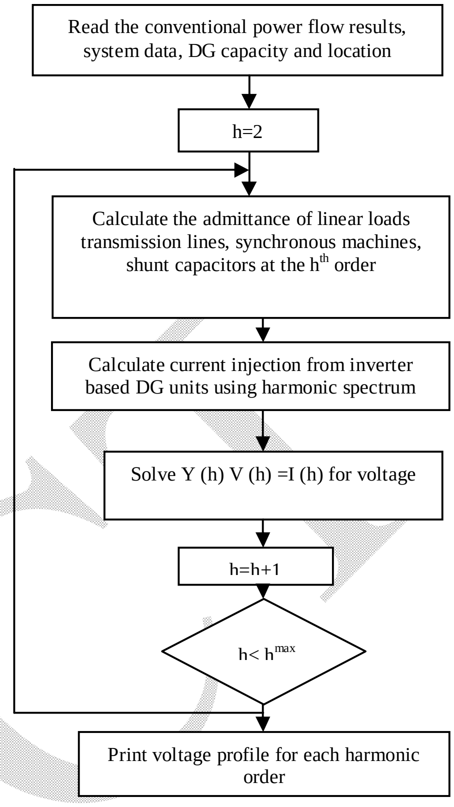

Fig 2 : Flow chart of the decoupled harmonic power flow

$$y_{i,i+1}^{(h)} = \frac{1}{R_{i,i+1} + jhX_{i,i+1}} \quad (3)$$

where

$P_{L,i}, Q_{L,i}$ fundamental real and reactive power

$\left|v_i^{(1)}\right|$ magnitude of fundamental voltage at buses *i*;

$y_{ci}^{(1)}$ fundamental frequency admittance of the capacitor connected at bus *i*;

$y_i^{(h)}$ admittance of load connected at bus *i* for *h* th order harmonic;

$y_{ci}^{(h)}$ shunt capacitor admittance at *h* th order;

The harmonic admittances of various elements are used to formulate harmonic admittance matrix $Y^{(h)}$. The fundamental current injected by inverter-based DG units at bus $i(I_i^{(1)})$ and the *h*th harmonic order current $(I_i^{(h)})$ are given by

$$I_i^{(1)} = \left[\frac{P_{DG,i}^{in} + jQ_{DG,i}^{in}}{\left| v_i^{(1)} \right|} \right] \quad (4)$$

$$I_i^{(h)} = K(h)\, I_i^{(1)} \quad (5)$$

Where

$P_{DG,i}^{in}, Q_{DG,i}^{in}$ fundamental real and reactive power generated by inverter based DG units connected at bus *i*;

$K(h)$ Ratio of *h*th harmonic current to its fundamental value;

Finally, a set of nodal equations are solved for estimating the harmonic voltage profile values using (6)

$$Y^{(h)} V^{(h)} = I^{(h)} \quad (6)$$

B. Objective Functions

The objective is to maximize the DG penetration level with respect to the total system capacity, to minimize the losses and to minimize the total harmonic distortion. Since DG delivers only the reactive power as per standard IEEE-1547[3], the objective functions F and G are defined as follows:

$$\textit{Maximize} \quad F(\%) = \frac{\sum_{i=1}^{Nbus} P_{DG,i}^{in}}{\text{TotalMVA}} \times 100 \quad (7)$$

$$\textit{Minimize} \quad G(\%) = \sum_{i=1}^{N_{bus}} \frac{\sqrt{\sum_{h=2}^{h_{max}} \left| v_i^{(h)} \right|^2}}{v_i^{(1)}} \times 100 \quad (8)$$

$$\textit{Minimize} \quad P_L = \sum_{i=1}^{N} Loss_i \quad (9)$$

C. *Equality Constraints*

The real and reactive power balance constraints at fundamental frequency for each system bus *i* can be given as follows:

$$P_{G,i} + P_{DG,i}^{in} - P_{L,i} = \sum_{j=1}^{N_{bus}} \left| v_i^{(1)} \right| \left| v_j^{(1)} \right| \left| y_{i,j}^{(1)} \right| \cos\left(\theta_{i,j}^{(1)} - \delta_i^{(1)} + \delta_j^{(1)} \right) \quad (10)$$

$$Q_{G,i} + Q_{DG,i}^{in} - Q_{L,i} = \sum_{j=1}^{N_{bus}} \left| v_i^{(1)} \right| \left| v_j^{(1)} \right| \left| y_{i,j}^{(1)} \right| \sin\left(\theta_{i,j}^{(1)} - \delta_i^{(1)} + \delta_j^{(1)} \right) \quad (11)$$

Where

$P_{G,i}, Q_{G,i}$ Fundamental real and reactive power generation at bus *i*;

$y_{i,j}^{(1)}$ Magnitude of (*i*,*j*)th element of the Fundamental bus admittance matrix;

$\delta_i^{(1)}$ Angle of (*i*,*j*)th element of the fundamental bus admittance matrix;

D. Inequality Constraints

The inequality constraints consider here are bus voltage limits, total harmonic distortion limits and individual harmonic distortion limits.

Bus Voltage Limits:

The rms voltage magnitude at each bus is bound by a specified lower and upper limit as follows[31]:

$$v^{min} \le \sqrt{\left| v_i^{(1)} \right|^2 + \sum_{h=2}^{h_{max}} \left| v_i^{(h)} \right|^2} \le v^{max} \quad (12)$$

where v^{min} and v^{max} are the lower and upper rms voltage limits which are set at 0.9.p.u. and 1.1.p.u., respectively.

(1) Total Harmonic Distortion Limits:

The IEEE-519 standard imposes limits on the total voltage harmonic distortion at each bus *i* as follows:

$$\text{THD}_{v,i}(\%) = \frac{\sqrt{\sum_{h=2}^{h_{max}} \left| v_i^{(h)} \right|^2}}{\left| v_i^{(1)} \right|} \times 100 \le \text{THD}_v^{max} \quad (13)$$

where THD_v^{max} is the maximum permissible total harmonic limit which is usually set as 5%.

(2) individual Harmonic Distortion Limits:

The IEEE-519 standard imposes limits on the individual voltage harmonic distortion at each bus *i* as follows:

where $\text{IHD}_v^{max,h}$ the maximum allowable voltage harmonic distortion is level at harmonic order *h* and is considered as 3% .

III. APPLICATION OF PSO TO MAXIMIZE DG PENETRATION TO MINIMIZE LOSSES AND TO MINIMIZE THD

Particle swarm optimization (PSO) is a population based stochastic search technique, well known among evolutionary paradigms, which optimizes a problem iteratively to improve a candidate solution. It is inspired by social behavior of bird flocking and fish schooling. Similar to genetic algorithms, it starts with a random population matrix X in the search space;

Corresponding Author: Asna.S.Asok, Regional Centre Anna University, Coimbatore, Tamilnadu, India.

however, PSO has no crossover and mutation operators. Each candidate solution, called particle, in the population travels with a velocity and it is bounded by its maximum velocity. At each time step, velocity of each particle is updated by its own flying experience *(pbest)* and the best particle's position in the swarm *(gbest)* and then particle position is also updated:

$$v_{i,d}^{k+1} = \omega v_{i,d}^{k} + c_1 r_1 \left(pbest_{i,d}^{k} - x_{i,d}^{k}\right) + c_2 r_2 \left(gbest_{d}^{k} - x_{i,d}^{k}\right) \quad (15)$$

$$x_{i,d}^{k+1} = x_{i,d}^{k} + v_{i,d}^{k+1} \quad (16)$$

Where

$v_{i,d}^{k+1}$ Velocity of *i*th particle's dimension *d* at iteration *k*;

$x_{i,d}^{k}$ Position of *i*th particle's dimension *d* at iteration *k*;

ω Inertia weight factor;

c_1, c_2 Cognitive and social coefficients equal to 2;

r_1, r_2 Random numbers in the range of [0,1];

$pbest_{i,d}^{k}$ Best position of *i*th particle at iteration *k*;

$gbest_{d}^{k}$ Global best position of the swarm at iteration *k*;

In order to have better balance between global exploration and local exploitation, the inertia weight ω is decreased linearly with the number of iterations [34]. The inertia weight is updated at each iteration as follows:

$$\omega = \frac{\omega_{\max} - \omega_{\min}}{iter_{\max}} \text{ x } k \quad (16)$$

Where

$\omega_{\max}, \omega_{\min}$ Minimum and maximum values of inertia weight set as 0.4 and 0.9 respectively

$iter_{\max}$ Maximum iteration number

The implementation of PSO algorithm to the optimal DG penetration and THD problem starts with the proper encoding of optimization parameter. The real power generation of inverter-based DG units connected to the set of candidate buses (N_{Cbus}) is considered as the parameter to be optimized; hence the particle structure is defined as:

$$X = [P_{DG,1}^{inv}, P_{DG,2}^{inv}, \ldots\ldots\ldots, P_{DG,N_{Cbus}}^{inv}] \quad (17)$$

Each candidate solution from PSO is passed to the conventional power flow followed by the DHPF. The various constraints on RMS voltage, harmonic distortion are verified for feasibility and if violation is found, those constraints are added to the objective using the penalty function method. The application of PSO algorithm for finding the optimal DG penetration level with harmonics and minimization of THD is shown in Fig 3.

IV. RESULTS AND DISCUSSION

The nonlinear optimization problem for maximizing DG penetration level and minimizing total harmonic distortion were implemented in MATLAB [30] and tested on IEEE 14 bus meshed distribution system. The constraint values of harmonic distortion are estimated using the DHPF.

A. *Case I*

In this case the objective is to minimize the losses. Here we consider only one inverter-based DG unit and tested on IEEE 14 bus meshed distribution system using PSO algorithm. After the implementation of PSO the real and reactive power loss is reduced from 13.5929 to 12.4775 and 56.9096 to 51.3351 respectively.

The optimal size and location of DG obtained is 10 and 13 respectively. The improvement in the voltage profile after optimally placing the DGs is shown in Fig 4.

B. *Case II*

The utility owned inverter-based DG units are considered to find the maximum DG penetration level. Since the inverter-based DG unit has minimal effect on the short circuit current, the protection coordination constraints are not considered.

The total system MVA rating is 150MVA.The capacity of inverter- based DG units is considered as the parameter to be optimized and also specified in (17).

The inverter-based DG units are considered as the source of harmonics and used in the DHPF subroutine. The harmonic spectrum of current injected by PWM inverter is considered to be the upper bound of the individual harmonic current limits (only odd order harmonics without the multiples of 3rd order harmonics) specified by IEEE-1547 standard.

An optimal DG penetration level of 47.1859% is obtained using the particle swarm optimization (PSO) algorithm by placing nine DG units at locations 4, 5, 7, 9, 10, 11, 12, 13 and 14 with a capacity of 7.3105 MW, 4.5878 MW, 4.8119MW, 4.9341MW, 2.5521MW, 1.6774MW, 5.4633MW, 1.6071MW and 14.2416MW respectively.

The convergence of particle swarm optimization algorithm and improvement of voltage profile is shown in Fig6 where the population size is set to 3 and the maximum number of iteration is set to 10.

Corresponding Author: Asna.S.Asok, Regional Centre Anna University, Coimbatore, Tamilnadu, India.

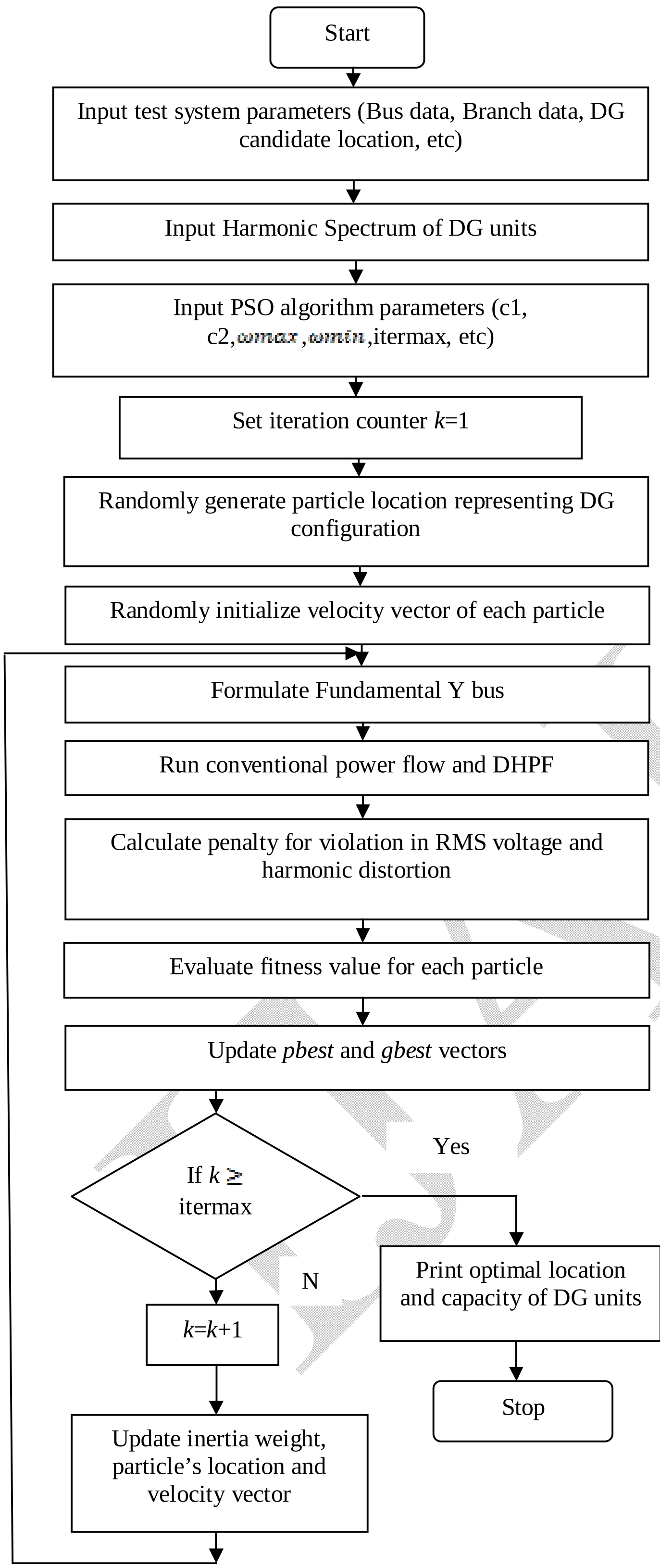

Fig 3 : Flowchart of PSO based optimal DG placement

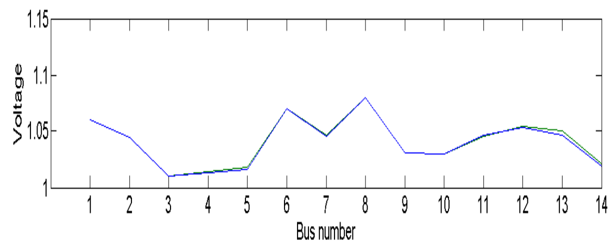

Fig 4 : Improvement in the voltage profile

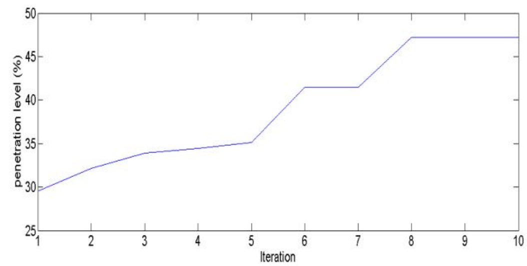

Fig 5 : Improvement of voltage profile and Convergence of the PSO algorithm

V. CONCLUSION

This method of placement of distributed generation of proper size using the particle swarm optimization has been implemented for the IEEE 14 bus meshed distribution system by placing three inverter based DG units and the results have been verified to be best. This takes very short time for the convergence. The results show that the maximum DG penetration level is limited by harmonic distortion level. The proposed optimization method can serve as a good planning tool for the utility operator to optimally allocate DG of different types in distribution systems to achieve better penetration level.

References

[1] N. Jenkins, R. Allan, P. Crossley, D. Kirschen, and G. Strbac, Embedded Generation, Institution of Engineering and echnology, 2008.

[2] M. H. Bollen and F. Hassan, Integration of Distributed Generation in the Power System. New York: Wiley-IEEE Press, 2011.

[3] IEEE Standard for Interconnecting Distributed Resources With Electric Power Systems, IEEE Std. 1547-2003, 2009, vol. 15.

[4] H. Puttgen, P. MacGregor, and F. Lambert, "Distributed generation: Semantic hype or the dawn of a new era?," IEEE Power and Energy Mag., vol. 1, no. 1, pp. 22–29, Jan.–Feb. 2003.

[5] C. Borges and D. Falcao, "Impact of distributed generation allocation and sizing on reliability, losses and voltage profile," in Proc. IEEE Bologna Power Tech Conf., 2003, Jun. 2003, vol. 2, p. 5.

[6] J. Martinez and J. Martin-Arnedo, "Impact of distributed generation on distribution protection and power quality," in Proc. IEEE Power Energy Society General Meeting, PES'09, Jul. 2009, pp. 1–6.

[7] R.Walling, R. Saint, R. Dugan, J. Burke, and L. Kojovic, "Summary of distributed resources impact on power delivery systems," IEEE Trans. Power Del., vol. 23, no. 3, pp. 1636–1644, Jul. 2008.

[8] Smart connect Use Case: D9—Utility Manages Utility-Owned Distributed Generation. [Online]. Available: asset.sce.com/microsite/Documents/ ESC/D9_Use_Case_081223.pdf.

[9] A. Algarni and K. Bhattacharya, "Utility-owned DG units' impacts on distribution system operation," in Proc. IEEE/PES Power Systems Conf. Expo., PSCE'09, Mar. 2009, pp. 1–6.

[10] A. Schwarzenegger, "Renewable distributed generation assessment: Sacramento municipal utility district case study," Utility Project Report, 2005.

[11] R. Jabr and B. Pal, "Ordinal optimisation approach for locating and sizing of distributed generation," IET Gen., Transm., Distrib., vol. 3, no. 8, pp. 713–723, Aug. 2009.

[12] F. Abu-Mouti and M. El-Hawary, "Optimal distributed generation allocation and sizing in distribution systems via artificial bee colony algorithm," IEEE Trans. Power Del., vol. 26, no. 4, pp. 2090–2101, Oct. 2011.

[13] R. Dugan, T. McDermott, and G. Ball, "Planning for distributed generation," IEEE Ind. Appl. Mag., vol. 7, no. 2, pp. 80–88, Mar./Apr. 2001.

[14] V. Ravikumar Pandi, H. H. Zeineldin, and Weidong Xiao, "Determining Optimal Location and Size of Distributed Generation resources Considering Harmonic and Protection Coordination Limits", IEEE Transactions on Power Systems, vol. 1, no. 1, May.2013

[15] J. Carrasco, L. Franquelo, J. Bialasiewicz, E. Galvan, R. Guisado, M. Prats, J. Leon, and N. Moreno-Alfonso, "Power-electronic systems for the grid integration of renewable energy sources: A survey," IEEE Trans. Ind. Electron., vol. 53, no. 4, pp. 1002–1016, Jun. 2006.