Srikanth Thummala, et. al. International Journal of Engineering Research and Applications
www.ijera.com
ISSN: 2248-9622, Vol. 11, Issue 2, (Series-I) February 2021, pp. 45-52

RESEARCH ARTICLE OPEN ACCESS

Power Quality Improvement ofUtility grid tiedDC/AC Micro Gridwith DGR and Converters using Metaheuristic Algorithms: A Review

Dr.A.S.Kannan, Srikanth Thummala*, Dr.B.M.Chandra
Associate Professor, Dept. of Electrical Engineering, Annamalai University, Chidambaram, Tamilnadu.
**Research Scholar, Dept. of Electrical Engineering, Annamalai University, Chidambaram, Tamilnadu.*
Professor, Dept. of EEE, QIS College of Engineering & Technology, Ongole, Andhra Pradesh

ABSTRACT:
Micro Grids are going to replace the traditional concept of electrical networks in order to satisfy the increasing needs in terms of flexibility, accessibility, reliability, and quality of the power supply. Economy and energy efficiency are the paradigms followed to exploit the available distributed energy resources (DERs), guaranteeing technical and environment-friendly standards. Obviously, the path to Micro Grids is complicated by the increasing heterogeneity of Micro Grid components, such as renewable, storage systems, fossil-fueled generators, and controllable loads [1]. Fortunately, the synergic interaction between DERs and information and communication technologies (ICT) foster the coordination among different infrastructures, promoting the development of Smart Grids at both theoretical and practical levels. The major highlights of utilizing micro grid are the capacity to self-heal from power quality (PQ) issues, efficient energy management, incorporation of automation based on ICT and smart metering, integration of distributed power generation, renewable energy resources, and storage units [2]. The advantages contribute to maintain good PQ and to maintain the reliability. In this regard, the concept of micro grid is brought to the stage as one of the main building blocks of the future smart grids [3].

Keywords: RES-Renewable energy sources, PQ-Power Quality, OT-Optimization Techniques

---

Date of Submission: 22-01-2021 Date of Acceptance: 06-02-2021

I. INTRODUCTION

Power quality refers to the ability of electrical equipment to consume the energy being supplied to it. A number of power quality issues including electrical harmonics, poor power factor, voltage instability and imbalance impact on the efficiency of electrical equipment. This has a number of consequences including: Higher energy usage and costs, higher maintenance costs and Equipment instability and failure. Electrical power is the main element that required in any function in the commercial and industrial sectors therefore it should be available at all times. Power quality is a set of parameters that define the characteristics of the power supply as delivered to the consumers in normal operating conditions in terms of continuity of supply and characteristics of voltage such as, frequency, magnitude, waveform and symmetry. Recently, power quality is not only a technical problem but also a problem that leads to financial issues. Many surveys have been shown that poor power quality causes large economic losses to industrial sectors.

PQ has emerged as a standout among the most essential issues of smart grid [4]. Although PQ has been a well-known concern of the conventional power grid, it has acquired exceptional concern in smart grids predominantly because of the following reasons: a) Expanding utilization of delicate loads and control forms as of late. b) Expansion of various nonlinear and single-stage loads which may antagonistically influence the PQ. c) Accessibility of cutting edge metering, detecting and control functionalities in smart grids which can be used to give an alluring PQ level for purchasers. The term power quality is used to describe the nonstationary disturbances, which cause the major malfunctioning of the electrical equipments. Operation of the electric loads without the proper power causes the electrical devices or loads to malfunction, fail prematurely, or not operate at all. Therefore, PQ analysis attracts many multidisciplinary researchers in this provocative field [5].

The PQ events which majorly occur in a distribution system can be classified into slow voltage variations, short duration under voltages, rapid voltage changes, harmonic distortions, and switching transients [6]. These are discussed to understand their effects in a smart grid. The PQ issues with the penetration of renewable energy sources integrated to the distribution system in terms of microgrids are explained. The microgrids which are classified into AC microgrids and DC microgrids are also discussed. The PQ concerns in each type of microgrids are discussed. The most common causes of disturbances at customers side are: Faulty equipment and Improper grounding to protect against surge, while the most common disturbances at utility side are caused by: Sags and swell is shown in figure.1

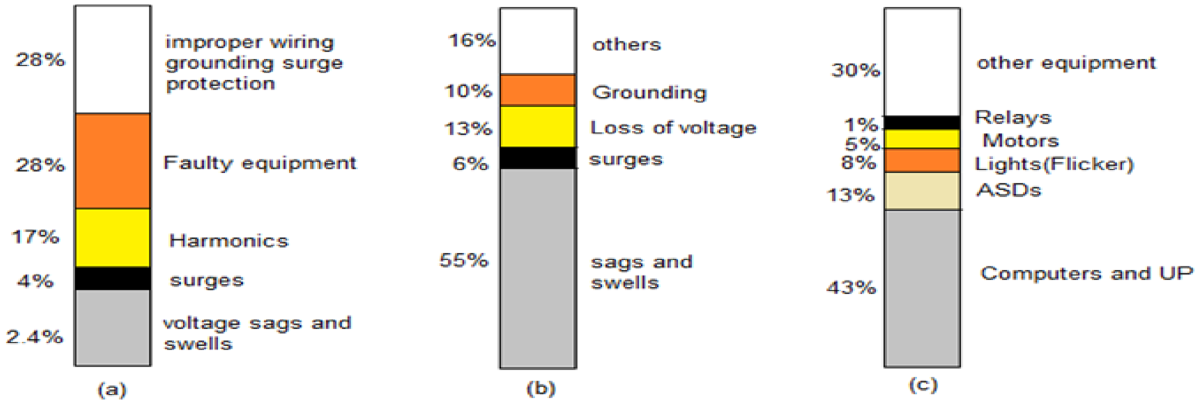


Fig.1 a) Customer side b) Utility side c) Affected Equipment

In past few decades, research in the metaheuristic and evolutionary domain has grown rapidly. Numerous literature have been published on popular approaches like genetic algorithms, memetic algorithms, simulated annealing, Tabu search, evolutionary algorithms, ant colony algorithms, particle swarm optimization, cuckoo search, etc. This book is a collection of these approaches in a single volume. Unlike deterministic methods initiating with one solution, the metaheuristic methods instigate with several feasible solutions (both for single- and multi-objective optimization problems) distributed randomly over the entire search space. These methods are also highly preferred for solving multi-objective optimization problems where more than one conflicting objective functions are involved. The method is expected to converge to a single optimum solution commonly referred to as global solution in literature for single-objective optimization problems and a set of solutions forming a Pareto optimal front for multi-objective optimization problems. The metaheuristic approach employed should congregate to the true Pareto front with high diversification in the solution set on the Pareto front. The choice for an apt approach for a given problem depends on several factors like the number and type of decision variables (continuous, discontinuous) and the nature of decision variable space; type of objective functions (minimization, maximization) and nature of objective space; nonlinearity and stiffness of model equations; type of constraints (equality and inequality); an ability of algorithm to handle the search spaces of objectives and decision variables. Metaheuristic approaches are classified into several categories based on the availability of data, values of variables, constraints involved, number of objective functions, online/offline, etc. Yet some common features clearly appear in most metaheuristics, such as the use of exploration (diversification) and exploitation (intensification). Exploration is the ability of an approach to investigate all promising regions of the solution space, whereas exploitation is the capability of improving the solution. Two being the cornerstones for a problem, initially, exploration is rigorous and in later epochs exploitation is more emphasized. Another similarity is the memory usage for archiving the best solutions over the iterations. One common shortcoming of most metaheuristics is the delicate tuning of numerous parameters; the theoretical results available are not adequate to help the user facing a new, difficult optimization problem.

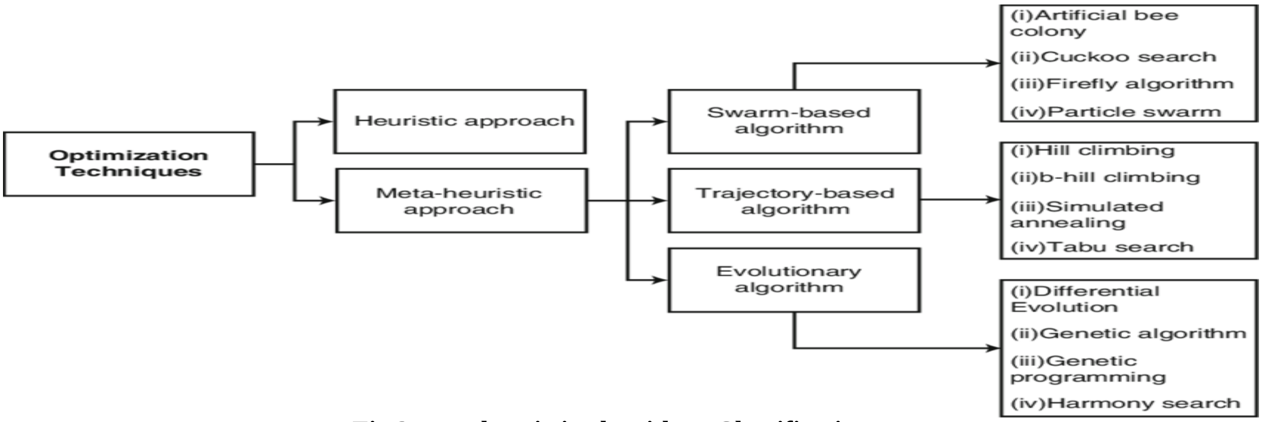
Optimization Techniques

An optimization problem consists of maximizing or minimizing a real function by systematically choosing input values from within an allowed set and computing the value of the function. The generalization of optimization theory and techniques to other formulations constitutes a large area of Applied Mathematics. More generally, optimization consists of finding best available values of some objective function given a defined domain including a variety of different types of objective functions and different types of domains.

One of the most significant trends in the field of optimization is the continually increasing emphasis on the interdisciplinary nature. Optimization has been a basic tool in all areas of Applied Mathematics, Engineering, Economics, Medical Science and other field of Sciences.

The majority of modern optimization techniques includes metaheuristic algorithms. Metaheuristicalgorithms such as Particle Swarm Optimization, Ant Colony Optimization, Artificial Bee Colony, Genetic Algorithm, Simulated Annealing, Cuckoo Search, Differential Evaluation, Biography Based Optimization and Harmony Search etc. are becoming very powerful in solving hard optimization problems and they have been applied in almost all major areas of science and engineering as well as industrial applications. The classification of the metaheuristic algorithms shown in the Figure 2.

.



. Fig.2: metaheuristic algorithms Classification

Application of metaheuristic algorithms in Microgrids

Power electronic converters and controllers contribute an important role in power transmission and distribution. The rising penetration of intermittent renewable energy systems into the grid further prompted not only the bulk use of power electronics converters in power system but also rise in several power quality issues. The switching operation of power converter devices and harmonic generated by the nonlinear load in power system raises the issues of power quality such as voltage distortion, poor power factor, voltage sag and swells, flicker, and voltage imbalance. restorer (DVR), unified power quality controller (UPQC), PWM controllers, multilevel inverters (MLIs) in distribution network of power system.

The interruption of power and transients in voltage hold the major share in PQ issues followed by voltage dip, harmonics and miscellaneous issues [6]. In India, some application such as traction, cement plants, casting plants, chemical industries are found major cause of harmonic pollution. The various metaheuristic techniques are being applied in solving PQ issues.

The impact of power electronics in modern power system is profound. The grid integration of distributed generations (DGs) including renewable energy systems (RESs) employs the power electronic converters. For the economic operation of power system, the optimization is required to reduce its number of components, complexity, installation cost, running cost, electrical losses, and harmonic contents etc. Several conventional iterative methods were applied in these optimization problems. However, they suffer to a large extent from various drawbacks such as convergence to local minima, complexity in programming, large computational time, requirement of proper initial guess and intuition etc. Although there are various methods proposed to solve the optimization problem, the metaheuristics on the other hand have proven their capabilities in solving the problems related to optimization in many engineering fields. In power electronics, the optimization is required in circuit design, filter design, intelligent controllers design, parameters computation, modeling of new topologies, harmonic mitigation, losses evaluation, finding of safe operating areas of power electronic components etc. In grid-connected applications, metaheuristics have also shown their excellence, as they enhance the quality of power along with optimization of cost, size, and efficiency of power system network.

Difficulties in Transmission and Distribution Using FACTS

In modern power system, the ever increasing electrical load demand has pushed the existing distribution and transmission networks to maximum limit. The use of FACTS and HVDC transmission system is preferred for ensuring dynamic and static stability. The FACTS controllers are conventionally used in regulation of voltage, steady and dynamic state control in power system, and optimization of power flow capability of transmission lines [2–4]. However, there are some issues as listed below:

a. Low-voltage ride-through (LVRT) capability in PV systems and wind power conversion systems.
b. Dynamic stability of power system.
c. Connection of converters to high-voltage network.
d. The problem of balancing the voltage of dc-link capacitors.
e. Precise control of active/reactive power for grid balanced/unbalanced conditions.
f. Application of new converter topologies.

Difficulties in Renewable Energy Systems

The renewable energy systems such as photovoltaic (PV) and wind energy conversion system (WECS) employ the power converters for conversion from dc to dc and ac to ac. Ocean energy, geothermal energy, nuclear energy, biomass, hydrogen fuel cells etc. are other major resources of renewable energy [6]. Following are the challenges in renewable energy systems.

1. To attain efficient maximum power point tracking (MPPT) in PV and WECS.
2. Intermittent nature of renewable energy resources.
3. High cost of maintenance and operation.
4. Injection of harmonics to grid.
5. Issue of stability of grid during grid fault condition.
6. Islanding effect.
7. Optimal placing and sizing of power electronic converters.
8. In ocean energy system, to maintain operation under harsh weather conditions.
9. To optimize the requirement of energy storage devices.

Difficulties in Energy Storage Systems

The examples of energy storage system are batteries, compressed air energy systems, fuel cells, flywheel energy storage systems, thermoelectric energy storage, and superconductive magnetic energy storage system etc. The power electronic converters are used in the energy storage systems [8]. The challenges in energy storage systems are as follows:

1. To facilitate the interconnected regional grids.
2. To match balance between load and generation.
3. The energy storage system should bring down the fuel cost in transportation sector. Also, environmental hazards should be reduced.
4. To monitor the impact of energy storage on stability of grid.
5. Development of grid integrated/standalone EVs/PHEVs.
6. Optimized utilization of renewable energy sources.

The rising share of intermittent renewable energy resources into grid has propelled the concept of microgrid. It comprises combination of distributed resources such as wind, solar, fuel cells, micro hydro, combined heat and power (CHP) etc. with superior control and coordination [9]. There are several parameters of microgrid like efficiency, allocation of sources, scheduling, cost, size, and location of components etc. which have to be optimized

.

Renewable Energy Systems (RES)

The contribution of RES in modern grid is increasing nowadays owing to their several environmental, technical, and economical benefits. Some of the benefits of RES to distribution networks are as follows:

• Reduced transmission loss.
• Voltage profile improvement.
• Increased efficiency.
• Reduction in electricity bills.
• Reduction in greenhouse gas emission.

To achieve the abovementioned advantages of RES systems, it is desirable tooptimize the sizing and allocation of generation units. Farh et al.[13] proposed theapplication of a crow search algorithm (CSA) based swarm optimization to solve forthe objectives such as:

• Minimization of cost and power loss,
• To find the optimum number of units required,
• To obtain the optimal allocation and sizing of RES,
• To find the optimum number of generation units.

They follow the other crows to theft the hiddenfoods from the hiding locations once the other crows left the places. The crows alsotake care of their food from being stolen which is based on the probability. To obtainbetter results, CSA was hybridized with PSO and was implemented on IEEE-30 bussystem to solve the problem of optimal power flowwith RES. The proposed algorithmshowed its excellent performance as compared to other metaheuristic methods forminimization of power loss and total cost of system.The incorporated the integration of tidal energy into a solar and windenergy based RES. For the economical operation of the proposed system, optimalsizing of generators, converters and other components is required. In this context,a novel CSA technique was proposed. The power extraction from the tides is moreanticipated and can be extracted with the help of tidal barrage or ocean current. Itsworking is similar to that of wind energy system. The important outcomes of theresearch work are as follows.

- CSA efficiently found the optimum size of components of PV/wind/tidalmicrogrid
- CSA holds the superiority in terms of better rate of convergence, accuracy, andtime saving as compared to PSO and GA.
- Optimum cost and high reliability of the system with battery storage.

In Yahiaoui et al. [14], the use of grey wolf optimizer (GWO) for theoptimization of design and total cost of hybrid RES. The proposed RES consistedof diesel generator, PV panels and energy storage devices. GWO algorithm imitatesthe hunting behavior of grey wolves. In the hierarchy, the α wolves lead the groupfollowed by β, δ, and ω wolves. The hunt for prey is steered by α, β and δ wolveswhileωwolves followthesewolves and change their positions according to positionsof their leaders. The important findings of the proposed strategy are as follows:

• GWO converges faster than the PSO.

• The optimal size of hybrid RESwas obtained using GWO.Number of componentsfor optimal operation were as follows: PV panels = 33, batteries = 90, dieselgenerators = 2. These numbers were found lower than that obtained by PSO,hence GWO resulted in least cost of the system.

• GWO minimized the annual cost of system.

InEltamaly et al. [15], the application of newbatalgorithm (BA) forMPPTconsidering partial shading inPVsystems. In this study, theoptimum number of agents were computed and found to be inversely proportional tothe number of maxima in power-volt curve of PV system.Ram et al. [16] emphasizedon the mixture of conventional P&O and bio-inspired metaheuristic method.The author proposed this idea to effectively utilize the robustness and simplicity ofP&O to enhance the reliability and efficiency ofMPPT. Flower pollination algorithm(FPA) mimics the biotic and abiotic transfer process of pollens. Steps involved inFPA-P&O are as follows:

1. Initialization of variables such as duty cycle, increment in duty cycle, probability.
2. Initialization of swarm position.
3. Find the best duty ratio corresponding to the global maximum power.
4. Update the duty cycle, if the criterion Gbest (t + 1)≈ • }0.05 Gbest (t) is not met,continue with FPA else switch to P&O.

Oshaba et al. [17] proposed the MPPT for PV system driven motor drive. In theirwork, authors implemented the use BAT algorithm for optimum tuning of parameters of PI controller. Simulation results showed the better performance as compared tothat of PSO.Nunes et al. [18]proposed the use of hybrid metaheuristic method. In the study, a combination of threemetaheuristics namely wind driven (WD), whale optimization (WO) and PSO wastested on PV systems for various scenarios including partial shading. The advantagesof this methodology is to utilize the beneficial characteristics of each algorithm forachieving global optimum solution.Raha et al. [19] proposedthe hybrid solution involving capacitors and superconductors together. CSA wasapplied for optimal sizing and optimal allocation of VAR compensators in the IEEE-118 bus system.Rahman.et al. [20] presented the review of metaheuristics used in electric vehicle (EV) andplug-in hybrid EVs.Touqeer Ahmed Jumani.et.al.[21] an efficient solution of the large voltage and power overshoots hence deteriorate the transient response and power quality issues is explored by developing an optimal microgrid (MG) controller using one of the most modern and intelligent artificial intelligence (AI) techniques named the salp swarm optimization algorithm (SSA).Khalil Gholami.et.al.[22] introduces a new methodof feeder reconfiguration is performed to decrease power loss, decrease the total harmonic distortion (THD), and improve voltage sag indices. Reconfiguration algebraic equations along with nonlinearities introduced by Diesel/PV/Battery standalone system are solved by means of Non-Dominated Sorting Differential Evolution Algorithm (NDSDEA). Thenpennaisivem Santhoshkumar.et.al.[23] established hybrid method denotes combined performance of both Whale Optimization Algorithm (WOA) and Ant Lion Optimization (ALO) algorithmit is named as AWOALO technique. The purpose of AWOALO technique is to optimize the controlparameters for regulate the changes occurred in the grid parameter such as voltage as well as frequencydepend on variations of inertia.

Power Converters

The power conversion devices are principal component in power system which areused to interface RES to power grid. Koch et al. [24] presented a new procedure ofdesigning current controllers in grid connected application. GA was used to automaticallytune the parameters of controller, improve the dynamic response of controllerand to reduce the time in design stage. In Singh et al. [25], applied the firefly algorithmon the problem of power system stability. The firefly technique minimized the oscillations, overshoot and settling time of power system controller. Convergencerate of proposed controller was faster than that of conventional controller. Duman[26] presented the application of new moth swarm (MS) algorithm for the optimumpower flow control in HVDC system. The objectives achieved were as follows:

• Reduction in total cost of fuel,
• Improvement in the voltage regulation,
• Improvement in voltage stability.

Mohapatra et al. [27] applied GA based compensation technique for voltage andreactive power control. In Li et al. [28], discussed the role of metaheuristics in theoptimization of weight in aircraft's power converter design application. GA, PSOand simulated annealing (SA) were applied in the weight reduction of 2 kW inverterand the minimum weight was found to be 420 g only. Shayeghi et al. [29] proposedthe application of quantum PSO in UPFC for tuning the parameters of dampingcontroller. The results showed the improvement in the transient stability, effectivedamping of lowswitching frequencies, and superior performance as compared toPSObased power stabilizers. Sarkar et al. [30] proposed an ACO metaheuristic schemefor the control of switched shunt capacitors. Results showed that the proposed techniquewas superior from the point of view of memory required, time of response, anddynamics. ee et al. [31] discussed the application ofACOinwave energy conversionsystems. The ACO reduced the computation time which helped to reduce the oscillationsin output power. Abd-Elazim and Ali [32] applied the CSA for optimal design ofSTATCOM and finding their locations in distribution network. The proposed techniquereduced the damped oscillations and improved the voltage profile.Amirreza Naderipour.et.al.[33] method is applied to a cascade H bridge five-level inverter show that the salp swarm optimization algorithm (SSA) performs better in solving the harmonic analysis (FFT) of the inverter output voltage also indicates that the percentage of THD in the OSPWM method is lower than the SPWM method for different modulation coefficients. Therefore, using OSPWM method reduces harmonic distortion, improves switching frequency conditions, high output voltage quality and improves the power quality.

II. CONCLUSION

In the applications of metaheuristic algorithms in the various areas of power electronics were discussed. The merits of metaheuristics have emphasized their applicability in various power electronics applications such as in microgrids, in RES, and in power conversion devices. In general, metaheuristics are used in sizing, allocation, scheduling, cost and loss reduction, harmonics reduction, MPP tracking, voltage profile improvement, economic load dispatch problem, fast charging of batteries and numerous other problems. In the future, it is expected that several metaheuristics techniques may be used in solving the various complex problems related to power electronics.

REFERENCES

[1]. J. Fivaz, W. Cronje, Application of evolutionary computation in power electronics, in IEEEAFRICON. 6th African Conference in Africa, George, South Africa, vol. 2 (2002), pp. 729–734.
[2]. C. Bulac, F. Ionescu, M. Roscia, Differential evolutionary algorithms in optimal distributedgeneration location, in Proceedings of 14th International Conference on Harmonics and Quality
[3]. of Power—ICHQP, Bergamo (2010), pp. 1–5.
[4]. P. Zanchetta, M. Summer, F. Cupertino, M. Marinelli, E. Mininno, On-line and off-line control
[5]. design in power electronics and drives using genetic algorithm, in *Proceedings IEEE IndustrialApplications Conference*, vol. 2 (2004), pp. 864–871.
[6]. D.V. Malyna, J.L. Duarte, M.A.M. Hendrix, F.B.M. Vanhorck, Multiobjective optimization of
[7]. power converters using genetic algorithm, in Proceedings of the International Symposium onPower Electronics, Electrical Drives, Automation and Motion (2006), pp. 713–714.
[8]. R.R. Chan, Y. Lee, S.D. Sudhoff, E.L. Zivi, Evolutionary optimization of power electronicsbased power systems. IEEE Trans. Power Electron. **23**(4), 1907–1917 (2008).
[9]. Y.A.I. Mohamed, E.F. El Saadany, Hybrid variable-structure control with evolutionaryoptimum-tuning algorithm for fast grid-voltage regulation using inverter-based distributedgeneration. IEEE Trans. Power Electron. **23**(3), 1334–1341 (2008).
[10]. S.E. De León-Aldaco, H. Calleja, J. Aguayo Alquicira, Metaheuristic optimization methodsapplied to power converters: a review. IEEE Trans. Power Electron. **30**(12), 6791–6803 (2015).
[11]. E.F.D. Arruda, N. Kagan, P.F. Ribeiro, Harmonic distortion state estimation using

anevolutionary strategy. IEEE Trans. Power Deliv. **25**(2), 831–842 (2010).

[12]. A. Askarzadeh, Electrical power generation by an optimised autonomous PV/wind/tidal/batterysystem. IET Renew. Power Gener. **11**(1), 152–164 (2017).

[13]. C. Gamarra, J.M. Guerrero, Computational optimization techniques applied to microgridsplanning: a review. Renew. Sustain. Energy Rev. **48**, 413–424 (2015).

[14]. B. Khan, P. Singh, Selecting a meta-heuristic technique for smart micro-grid optimizationproblem: a comprehensive analysis. IEEE Access **5**, 13951–13977 (2017).

[15]. J. Senthil Kumar, S.C. Raja, J.J.D. Nesamalar, P. Venkatesh, Optimizing renewable basedgenerations in AC/DC microgrid system using hybrid Nelder-Mead cuckoo search algorithm.Energy (2018).

[16]. H.M.H. Farh, A.M. Al-Shaalan, A.M. Eltamaly, A.A. Al-Shamma'a, A novel crow searchalgorithm auto-drive PSO for optimal allocation and sizing of renewable distributed generation.IEEE Access **8**, 27807–27820 (2020).

[17]. A. Yahiaoui, F. Fodhil, K. Benmansour, M. Tadjine, N. Cheggaga, Grey wolf optimizer foroptimal design of hybrid renewable energy system PV-diesel generator-battery: application tothe case of Djanet city of Algeria. Sol. Energy **158**, 941–951 (2017).

[18]. A.M. Eltamaly, M.S. Al-Saud, A.G. Abokhalil, A novel bat algorithm strategy for maximumpower point tracker of photovoltaic energy systems under dynamic partial shading. IEEE Access8, 10048–10060 (2020).

[19]. J.P. Ram, D.S. Pillai, A.M.Y.M. Ghias, N. Rajasekar, Performance enhancement of solar PVsystems applying P&O assisted flower pollination algorithm (FPA). Sol. Energy **199**, 214–229(2020).

[20]. A.S. Oshaba, E.S. Ali, S.M.A. Elazim, MPPT control design of PVsystem supplied SRMusingBAT search algorithm. Sustain. Energy Grids Netw. (2015).

[21]. H.G.G. Nunes, J.A.N. Pombo, P.M.R. Bento, Collaborative swarm intelligence to estimate PVparameters. Energy Convers. Manag. **185**, 866–890 (2019).

[22]. S. B. Raha, K. K. Mandal, N. Chakraborty, Hybrid SMES based reactive power dispatch by cuckoo search algorithm. IEEE Trans. Ind. Appl. **55**(1), 907–917 (2019).

[23]. I. Rahman, P.M. Vasant, B. Singh, M. Singh, M. Abdullah-al-wadud, N. Adnan, Review of recent trends in optimization techniques for plug-in hybrid, and electric vehicle charging infrastructures. Renew. Sustain. Energy Rev. **58**, 1039–1047 (2016).

[24]. Touqeer Ahmed Jumani ,Mohd Wazir Mustafa Madihah Md. RasidZeeshanAnjumMemon, Dynamic response enhancement of grid-tied ac microgrid using salp swarm optimization algorithm, Int Trans ElectrEnerg Syst.,1–19(2019).

[25]. Khalil Gholami, Saeed Jazebi, Energy demand and quality management of standalone diesel/PV/battery microgrid using reconfiguration, Int Trans ElectrEnerg Syst.,1-21(2020).

[26]. Thenpennaisivem Santhoshkumar ,V. Senthilkumar, Professor, Transient and small signal stability improvement in microgrid using AWOALO with virtual synchronous generator control scheme., ISA Transactions, 1-12(2020).

[27]. G.G. Koch, C.R.D. Osório, H. Pinheiro, R.C.L.F. Oliveira, V.F. Montagner, Design procedure

[28]. combining linear matrix inequalities and genetic algorithm for robust control of grid-connected converters. IEEE Trans. Ind. Appl. **56**(2), 1896–1906 (2020).

[29]. M. Singh, R.N. Patel, D.D. Neema, Robust tuning of excitation controller for stability enhancement using multi-objective metaheuristic firefly algorithm. Swarm Evol. Comput. **44**, 136–147,(2019).

[30]. S. Duman, A modified moth swarm algorithm based on an arithmetic crossover for constrained optimization and optimal power flow problems. IEEE Access **6**, 45394–45416 (2018).

[31]. A. Mohapatra, P.R. Bijwe, B.K. Panigrahi, An efficient hybrid approach for volt/var control in distribution systems. IEEE Trans. Power Deliv. **29**(4), 1780–1788 (2014).

[32]. Q. Li, R. Burgos, D. Boroyevich, Hierarchical weight optimization design of aircraft power electronics systems using metaheuristic optimization methods, in AIAA/IEEE Electric Aircraft Technologies Symposium (2018).

[33]. H. Shayeghi, H.A. Shayanfar, S. Jalilzadeh, A. Safari, Tuning of damping controller for UPFC using quantum particle swarm optimizer. Energy Convers. Manag. **51**(11), 2299–2306 (2010).

[34]. P. Sarkar, A. Baral, K. Das Bhatacharya, P. Syam, An ant colony system based control of shunt capacitor banks for bulk electricity

consumers. Appl. Soft Comput. J. 1–15 (2016).

[35]. P.C. See, V.C. Tai, M. Molinas, Ant colony optimization applied to control of ocean wave energy converters. Energy Procedia**20(**1876), 148–155 (2012).

[36]. S.M.Abd-Elazim, E.S. Ali, Electrical power and energy systems optimal location of STATCOM in multimachine power system for increasing load ability by cuckoo search. Int. J. Electr. Power Energy Syst. 80, 240–251 (2016).

[37]. AmirrezaNaderipourZulkurnain Abdul-Malek, Zulkarnain Ahmad Noorden, IrajFarajiDavoudkhani, Saber ArabiNowdeh, HesamKamyab , ShreeshivadasanChelliapan , Seyyed Mohammad, SadeghGhiasiCarrier wave optimization for multi-level photovoltaic system to improvement of power quality in industrial environments based on Salp swarm algorithm, Environmental Technology & Innovation,1-13(2020).