1. Houria SADOUNI[1], 2. ABDELKADER RAMI[2]

Djillali Liabes University of Technology Sidi-Bel-Abbes,Algeria (1)
ORCID: 1. 0000-0002-4229-8883 2. 0000-0001-9599-6178

doi:10.15199/48.2022.02.49

Optimal economic dispatch of smart grid system

Abstract. *In this paper, we present the optimal economic dispatch (ED) strategy based on smart grid systems. We determine in this paper the minimum powers to be generated to satisfy a given load. Calculating minimum power amounts to calculating the minimum cost of electricity supplied to the consumer. The problem treated is an optimization problem with complex equality and inequality constraints requiring the use of an optimization method to solve it. We have considered the system in its steady state conditions.*

Streszczenie. *W niniejszym artykule przedstawiamy optymalną strategię ekonomicznej wysyłki (ED) opartą na systemach inteligentnych sieci. W tym artykule określamy minimalne moce, które mają być wygenerowane w celu zaspokojenia danego obciążenia. Obliczenie mocy minimalnej sprowadza się do obliczenia minimalnego kosztu energii elektrycznej dostarczonej do odbiorcy. Rozpatrywany problem to problem optymalizacji ze złożonymi ograniczeniami równości i nierówności, wymagający zastosowania metody optymalizacji do jego rozwiązania. Rozważaliśmy system w warunkach stanu ustalonego.*(***Optymalna ekonomiczna wysyłka systemu smart grid***)

Keywords: Smart Grid, Power System, Renewable Sources, Economic Dispatch, Optimization Problem.
Słowa kluczowe:. Smart grid, ekonomiczny rozsył energii

Introduction

Given the vast territories occupied by electric transmission system, major problems appear during its operation, and for a correct and economical operation, it is essential to monitor and control this system, in its entirety from a control center called dispatching.Hardware, software or organizational innovations, permitted in particular by information technologies smart grids offer solutions to these challenges. Numerous solutions have already been technically validated by an electrical system in different smart grids frameworks, participation of stakeholders in the methodological framework adapted to the evaluation of the socioeconomic value of smart grids solutions at the production-consumption-transport perimeter and to identify smart grids solutions that could be economically and environmentally promising[1-2] (Kayastha et al., 2014; Caballero et al., 2018), improving reliability of the power system to be controllable and automated [3–4] this modern technologies named Smart. (Bari et al., 2014; Miceli, 2013) [5-7] In this context, modern dispatching houses are called energy control centers. These last are equipped with computers processing real-time signals from a datum acquisition device (SCADA) (Bevrani and Hiyama, 2011). [8,9]. These computers carry out their data processing in a hierarchical structure, making it possible to coordinate and respond to the different requirements related to both the normal operation of the network and to emergencies. They control the levels of voltage and frequency settings, and they alert the operators, as soon as any abnormal operating situation is detected, thus allowing them to appreciate the event, and to take the appropriate measures, acting through the intermediary of their console on the elements of the network and thus to remedy the situations constraining for the electrical system. The human machine interface (HMI), the application servers, and the servers of communications are the main elements of the SCADA system. Data transmission, system monitoring, detection alarm, and control command transmission are common actions in an SCADA center. A mix of communications technologies such as radio, fiber optics and communications lines are a viable solution in a SCADA system. In many electrical systems, modern communications are already installed. Transmission and distribution substations are equipped with advanced protection measuring devices and new SCADA systems for monitoring and control. A SCADA system is software for power applications, typical hardware based on a computer. In general, SCADA system can be used in Oil & GAS dispatching, Railway systems (Metro & mainline) and power distribution application etc…The traditional electrical system has served well for the last hundred years. Modern societies demand that this intelligent system be more reliable, scalable, and manageable, while being cost effective, secure, and inter operable [10] (Gao et al., 2009). The new electrical system, called, “smart grid” (Wang et al., 2012)[11] revolutionizes the production, transmission and distribution of electricity by allowing benefit for electrical energy and information (Cespedes, 2013) [6]. In addition, it can complement current electricity grid by including renewable energy sources, such as wind power, solar energy and biomass, which are cleaner for the environment. A typical smart grid consists of numerous power generating entities and power consuming entity, all connected through a network.

Smart grid

Smart grids use renewable resources and reduce greenhouse gas emissions. However, while hydro power and bio energy can be produced and distributed at any time, wind and solar are intermittent resources, and therefore, unpredictable. A new report, entitled, “Boost energy efficiency through smart grids”, presents how information and communication technologies (ICTs) can mitigate the effects of climate change through a more efficient energy system that is better controlled. This report, commissioned by the ITU as a part of the “International Year of Sustainable Energy for All”, is part of the activities of the Telecommunication Standardization Sector (ITU-T) on ICT and climate changes. A smart grid is capable of controlling active grid intelligently to facilitate the integration of a different energy into the system [12].An intelligent electricity grid of which smart grid is one of the English-speaking denominations is an electricity distribution network that promotes the flow of information between suppliers and consumers to adjust the flow of electricity in the time real and enable more efficient management and integration of system in the grid. (Singer, 2009; Cai et al., 2012; Jenki et al., 2009) [13, 14, 15.16] Many definitions are given to explain what an intelligent grid is, Smart grids are electricity distribution grids that, through ICT, collect information from consumers and producers, and adjust their operation accordingly, all automatically This development will enable automated analysis of the stresses generated in the equipment. [17].

Smart grids are able to integrate energy from intermittent and unpredictable renewable sources, and to distribute electricity optimally. They provide electricity with improved profitability and lower emissions green house gas. They represent an exceptional opportunity to electrify developing countries where access to electricity is very limited. This definition is extended to include the means to transform the electric production from a centralized producer controlled network to a more consumer interactive one. (Ekanayake et al., 2012) [17,18] General of SG is presented in Figure1.

Fig. 1. General of the smart grid

Modeling pv panels

The electrical model of a photovoltaic cell is: Figure 2 PV electric model.

(1) $$I = I_{sc} - I_D - I_{Sh}$$

(2) $$I_{Sh} = \frac{V + IR_S}{R_{Sh}}$$

(3) $$I_D = I_0\left(e^{\frac{q(V+IR_S)}{nKT}} - 1\right)$$

where :*I* – output current of a solar cell (A),*Isc*- short circuit current (A),I_0 – saturation current (A) ,*q* – electron charge (1.6 x 10 - 19 (C)) ,*k* – Boltzmann constant (1.38 x 10 $^{-23}$ (JK $^{-1}$)) ,*T* – p - n junction temperature (K), t (^{o} C),*n* – junction constant,*V* – voltage across solar cell (V),*Rs* – series parasitic resistance for cell (Ω) ,*Rsh* – shunt parasitic resistance for cell (Ω)Basically, to provide a higher DC operating voltage, modules are connected in series. To provide a higher operating current, the modules are connected in parallel.

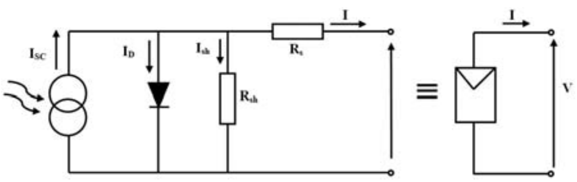

Fig. 2. PV electric model.

For an array of Ns × Nsh solar cells:

(4) $$V_{\text{mod}} = \sum_{i=1}^{N_s} V_i$$

NS – number of series connected panels

(5) $$I_{\text{mod}} = \sum_{i=1}^{N_{sh}} I_i$$

NSh – number of parallel connected panels

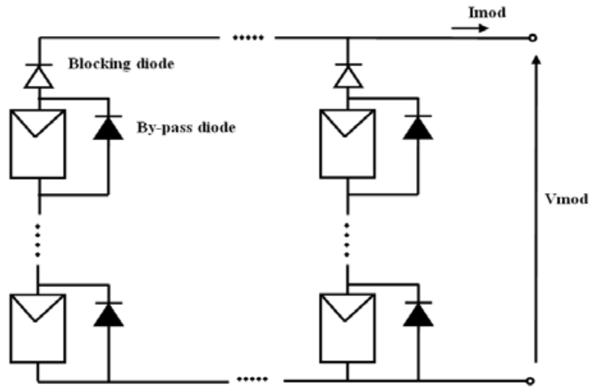

Fig.3.PV module association.

Output power and efficiency

The calculation of the output power of the cell depends on several factors including:

- Panel properties (construction technology)
- Environmental conditions (temperature, inclination, etc.)

The conversion efficiency of solar cell is defined as:

(6) $$\eta = \frac{I \cdot V}{P_{radiative}} = \frac{FF \cdot I_{SC} \cdot V_{OC}}{P_{radiative}}$$

$I \cdot V$ – output power

$P_{radiative}$: radiative power falling on cell

(7) $$FF = \frac{I \cdot V}{V_{OC} \cdot I_{SC}}$$: fill factor

Cell efficiency is far from unity and in the best cases it approaches 18% (polycrystalline panels) and 24% (monocrystalline panels), in standard conditions.

Modeling wind turbines

Real power output of wind turbine is given by:

(8) $$P_m = \frac{1}{2} \cdot \rho \cdot \pi \cdot R^2 \cdot V^3 \cdot C_p$$

Where: ρ– the air density (kg/m3),R– the turbine radius (m),V– the wind speed (m/s),Cp– turbine power coefficient (power conversion efficiency of a wind turbine),

The electrical power output is given by:

(9) $$P_e = \eta_m \cdot \eta_g \cdot P_m = \eta_0 \cdot P_m$$

Where: η_m – efficiency of the turbine, η_g – efficiency of the generator

Economic dispatching problem and optimization

The problem of the economic distribution of energy has taken on considerable importance with the onset of the energy crisis were it caused more and more expensive fuels. It is therefore, necessary to plan the active and reactive powers of each power plant, so that the total cost of operation of the entire network is minimal. In another way, it is necessary to vary the active and reactive powers of the generators within certain limits to satisfy the particular demand of load with a minimum cost of the fuel. This process is called the optimal power flow, and sometimes it is known as the problem of economic dispatching

(Vanithasri et al., 2018). [19] To solve the problem of the routing of the power available on the scene of Consumption, it is necessary to determine the level of production of each group and the power transits in the network. We must meet the demand by respecting the technical and economic constraints of exploitation to minimize production costs (Younes et al., 2009) [20]). The use of intelligence techniques in power grids is a very wide and varied field of study and application for researchers who choose for a very secure, economical, and stable network. The production cost of a plant is generally modeled by a polynomial function of the second degree in P (active power generated by the plant) whose coefficients are constants specific to each plant: (5)

$$GC = c + bP_G + aP_G^2 \tag{10}$$

where:GC– generation cost,a– the cost of installing a MW in a generating unit [EUR/MWh2]; b– the cost of generating one MW in an hour [EUR/MWh]; c–the repair cost [EUR/h];PG- the power generated by the unit [MW]

Optimization problem

The optimization problem is specified as follows:

$$\min f(P_G) = \sum_{i=1}^{Ng} \sum_{j=1}^{Nl} GC \tag{11}$$

Considering the following constraints:
The power generated by source should not exceed its maximum

$$0 \le P_G \le P_{G\max}$$

All generated power is always equal to the demand and loses

$$\sum P_G = D$$

And for voltage:

$$V_{\min} \le V \le V_{\max}$$

Where: Ng – number of generating units; Nl – number of loads.

In this paper, we use harmony search (HS) optimization approach to solve this problem. In the next paragraphs we give an overview on this metaheuristic method.

The HS approach has been successfully applied to Bench-mark problems like the classical travelling salesman problem, Various mathematical functions (Vasebi et al., 2007). [21]. Rosenbrock's banana function and Six-hump camel back function.It's also applied in Real-world problems like : Combined heat and power economic dispatch (Mahdavi et al., 2007), [22]. Water distribution network design (Li et al., 2006; Baek et al., 2005), [23,24,25.26]. Structural design (Lee and Geem, 2004; [27]. Lee et al. 2005), [28.29]. Vehicle routing (Geem et al. 2005) [30,31,32]., Hydrologic parameter calibration (Kim et al., 2001; Paik et al. 2005), [33.34.35.36]. Aquifer parameters and zone structures (Tamer Ayvaz, 2007[37]. ; Paik at al. 2001), [36]. Pump switching (Geem, 2005; [28]. Tian et al., 2005) [38.39.40] Multiple dam scheduling (Geem, 2007), [41.42.43].Tour routing (Geem et al., 2005) [30,31,32].,, Music composition (Geem and Choi, 2007;. Geem, 2006) [42.43.44], Satellite heat pipe design, Offshore structure mooring, QoS based multicast routing and Sudoku puzzle solving

Approach and outline

Harmony search (HS) (Lee and Geem, 2005) [47]. is a new meta-heuristic optimization method (evolutionary algorithm) imitating the improvisation process of musicians.In the process, musicians improvise their instruments' pitches searching for a perfect state of harmony.The method consists of five basic steps (shown in the following lines). The detailed explanation of these steps can be found in (Geem, 2006) [45.46], which are summarized in the following (Mahdavi et al., 2007) [22]. :
Step 1. Initializing the problem and algorithm parameters.
Step 2. Initializing the harmony memory.
Step 3. Improvising a new harmony.
Step 4. Updating the harmony memory.
Step 5. Checking the termination criterion.
The detail of previous steps is given in the next five subsections.

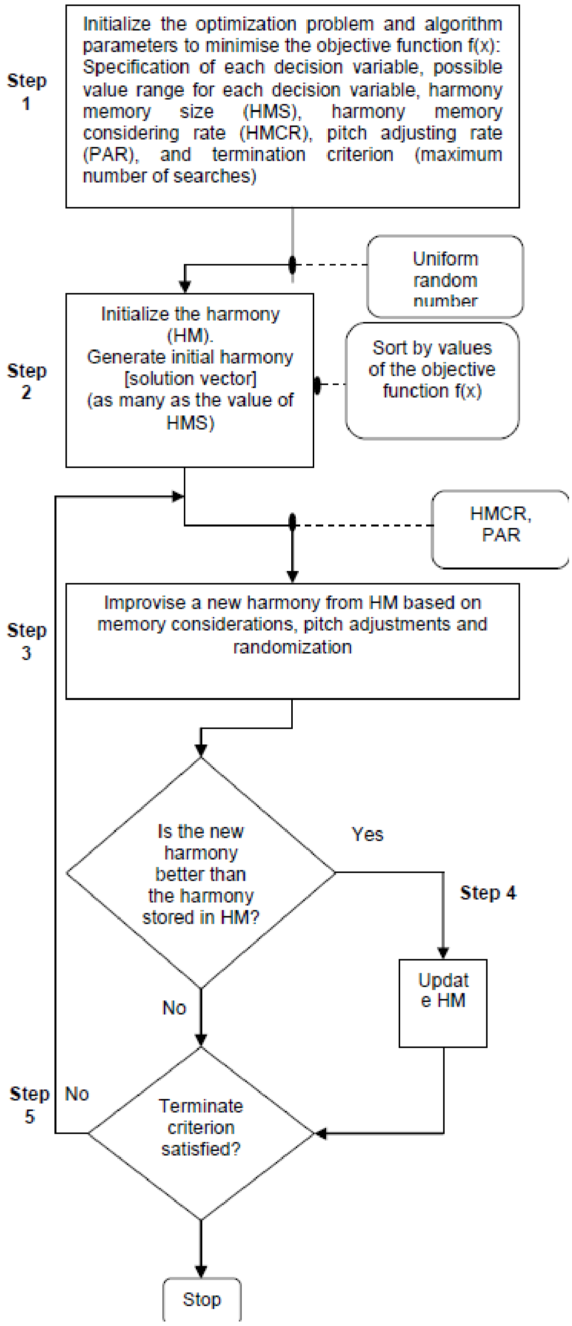

Fig. 4. Optimization procedure of the harmony search algorithm

Initializing the problem and algorithm parameters (Mahdavi et al., 2007) [22].

In Step 1, we make optimization problem definition as follows (Mahdavi et al., 2007):

Minimize $f(x)$ subject to (12)

(12) $x_i \in X_i, i = 1, 2, ..., N$,

Optimization, meaning find maximum or minimum of specified problem but generally the objective is minimization this why we have presented equation (12) with term 'Minimize'.

In the following:

$f(x)$ is an objective function;

x is the set of candidate solutions x_i belonging in the set of the possible range of values for each candidate solution X_i , the domain is limited by lower ${}_L x_i$ and upper ${}_U x_i$ value (${}_L x_i \le X_i \le_U x_i$).

N is the number of candidate solutions,

Initializing the harmony memory (Mahdavi et al., 2007) [22].

In Step 2, the harmony memory HM [50]. matrix is filled with randomly generated solution vectors of length (HMS) presenting the harmony memory size.

(13) $$HM = \begin{bmatrix} x_1^1 & x_2^1 & \cdots & x_{N-1}^1 & x_N^1 \\ x_1^2 & x_2^2 & \cdots & x_{N-1}^2 & x_N^2 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ x_1^{HMS-1} & x_2^{HMS-1} & \cdots & x_{N-1}^{HMS-1} & x_N^{HMS-1} \\ x_1^{HMS} & x_2^{HMS} & \cdots & x_{N-1}^{HMS} & x_N^{HMS} \end{bmatrix}.$$

Presentation of equation (13) is taken from (Mahdavi et al., 2007). [22].

Improvising a new harmony (Mahdavi et al., 2007) [22].

In this step, we generate (improvise) a new harmony vector, $x' = (x_1', x_2', ..., x_N')$, in which each value X'n is obtained by using three rules: harmony memory considering rate (HMCR); pitch adjusting rate (PAR); and random selection (Lee and Geem, 2005) [47.48]. .

Equation (14) illustrates how we take a memory consideration to obtain a new solution, equation (14) is a probabilistic model taking into account HMCR witch is the rate of choosing one value from the historical values stored in the HM and (1-HMCR) is the probability of generating a value randomly. HMCR is random value between 0 and 1 (uniform distribution).

(14) $$x_i' \leftarrow \begin{cases} x_i' \in \{x_i^1, x_i^2, ..., x_i^{HMS}\} \\ \text{whith probabilit y HMCR,} \\ x_i' \in X_i \text{ whith probabilit y } (1 - \text{HMCR}). \end{cases}$$

In the same manner in genetic algorithm (Geem et al., 2002), Pitch Adjusting Rate (PAR) is used to undergo a mutation of a selected value. PAR is a random rate used in mutation decision in the following equation (15):

(15) $$\text{Pitch adjusting decision for } x_i' \leftarrow \begin{cases} \text{Yes} \\ \text{whith probability PAR,} \\ \text{NO} \\ \text{Whith probability } (1 - \text{PAR}). \end{cases}$$

If probability is (1-PAR) nothing happed to selected element If probability is PAR the element should be pitch-adjusted as follow:

(16) $$x_i' \leftarrow x_i' \pm rand(\ )*bw,$$

where bw is an arbitrary distance bandwidth; $rand(\ )$ is a random number between 0 and 1

The three rules described previously are applied for each new generated harmony vector.

Updating harmony memory (Mahdavi et al., 2007) [22].

If the new harmony vector, $x' = (x_1', x_2', ..., x_N')$ is better than the worst harmony in the HM, judged in terms of the objective function value, the new harmony is included in the HM and the existing worst harmony is excluded from the HM.

From step 2, the new solution $x' = (x_1', x_2', ..., x_N')$ is evaluated in terms of the objective function value. If it yields a better fitness than that of the worst harmony in the HM, the new solution (harmony) will replace the worst harmony and in this manner always the best harmony will be included in and the worst one will be excludes from (eliminated) HM.

Checking termination criterion (Mahdavi et al., 2007) [21].

Similar to genetic algorithm [43], Harmony search algorithm need a stopping criterion (number of iterations) to terminate process. In this step if stopping criterion is not reached, Step 2 and Step 3 are repeated.

Optimization of smart grid

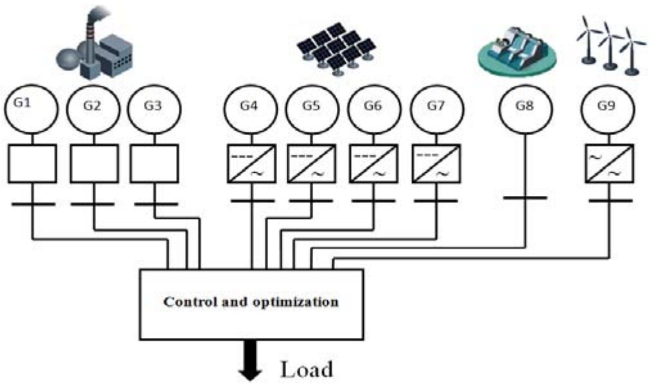

Fig.5. Diagram of the system

Data and specifications of each generator are presented in table 1.

Given values of PV panels and wind generator are those of stored power.

The curve below presents the level demand for the whole day

The max power demand is between 19h00 and 20h00, its value is 49.5 MW. Hence one dispatches our power system for this value.

The harmony search algorithm parameters used to optimize our problem are:
Harmony Memory Size (HMS) = 30;
Harmony Memory Considering Rate (HMCR) = 0.95;
Pitch Adjusting Rate (PAR) = 0.7;
Maximum iterations (MaxIter) = 30000;
Optimization results are presented in table below:

Table 1 Data of sources

Source	Pmin (MW)	Pmax (MW)	a($/(MWh)^2)	b($/MWh)	c($/h)
G1	0	25	0.007	51.54	106
G2	0	35	0.07	61.15	49.8
G3	0	30	0.07	61.52	45.3
G4 (PV panels)	0	4	0.07	61.98	41.7
G5 (PV panels)	0	0.6	0.003	93.10	0.02
G6 (PV panels)	0	0.5	0.004	95.10	0.02
G7 (PV panels)	0	0.3	0.0045	96	0.03
G8 (small Hydro generator)	0	0.95	0.0025	45	0.015
G9 (Wind generator)	0	0.300	0.00458	58.59	0.0427

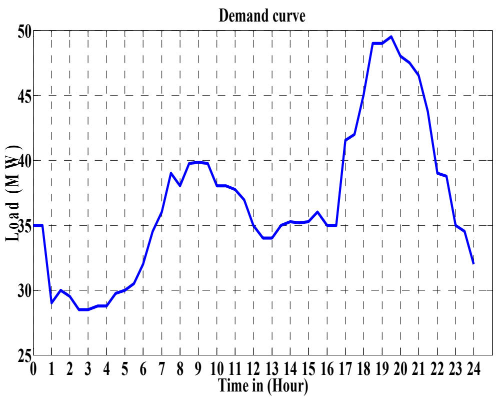

Fig.6. Full day load evolution.

Table. 2. Optimal values

Source	Optimal Power (MW)
G1	25.0000
G2	12.7465
G3	10.1035
G4 (PV panels)	0.4000
G5 (PV panels)	0.0000
G6 (PV panels)	0.0000
G7 (PV panels)	0.0000
G8 (small Hydro generator)	0.9500
G9 (Wind generator)	0.3000

From the table above, one can observe that in order to minimize the production and obtain the optimal cost, generators G1, G8 and G9 must supply their entire power to the load. Generators G5, G6 and G7 (PV panels) must be in rest because they have the highest cost coefficients.

conclusion

This paper consist the study of the smart grids. A smart grid is an alternative of a traditional network, it integrates energy sources of various natures (solar, wind, geothermic… etc). Our study based on the economic dispatch of a smart grid. Our network supplied a load during a full day. The optimal results obtained show that to satisfy a maximum value of 49.5 MW three generators G1, G8 and G9 must functioned at their maximum power values, on the other hand three solar generators G5, G6 and G7 must not supplied their powers to the load. Note that we have considered steady-state condition of the system.

***Authors**: Ph.D Houria.Sadouni, prof dr Abdelkader.Rami, Engineering Department, Réseaux-Convertisseurs–Machines (IRECOM), Djillali Liabes University, Sidi-Bel-Abbes,Algeria ; E-mail: sadounihouria@gmail.com*

REFERENCES

1. N. Kayastha, D. Niyato, E. Hossain, Z. Han, Smart grid sensor data collection, communication, and networking: A tutorial, Wirel. Commun. Mob. Comput., 14, pp. 1055–1087 (2014).
2. V. Caballero, D. Vernet, A. Zaballos, G. Corral, Prototyping a web-of-energy architectrue for smart integration of sensor networks in smart grids domain, Sensors., 18, 2, pp. 1055–1087 (2018).
3. European Technology Platform (ETP) SmartGrids. Strategic Deployment Document for Europe's Electricity Networks of the Future. Available online: http://www.smartgrids.eu/documents/SmartGrids_SDD_FINAL_APPRIL2010.pdf (accessed on 2 June 2018).
4. United States Department of Energy, The Smart Grid: An Introduction,Available online: http://www.oe.energy.gov/SmartGridIntroduction.htm (accessed on 2 June 2018).
5. A. Bari, J. Jiang, W. Saad, A. Jaekel, Challenges in the Smart Grid Applications: An Overview, International Journal of Distributed Sensor Networks, 10, 2, pp. 1-11 (2014).
6. R. Cespedes, Planning the electrical energy system 2.0 with Smart Grids, IEEE Power and Energy Society General Meeting (PES), pp. 1–4, (2013).
7. R. Miceli, Energy Management and Smart Grids, Energies, 6, pp.2262–2290, (2013).
8. M. BOUDOUR, A. HALLAL, Basic Electrical Networks and Basic Concepts, Blue Pages, Algiers, (2010).
9. H. BEVRANI, T. HIYAMA, Intelligent Automatic Generation Control, CRC Press; KUMAMOTO UNIVERSITY, 2011, p. 298.
10. J. Gao, Y. Xiao, J. Liu, W. Liang, C. L. P. Chen, A survey of communication/networking in Smart Grids, Future Generation Computer Systems, 28, 2, pp. 391–404, (2012).
11. W. Wang, Y. Xu, M. Khanna, A survey on the communication architectures in smart grid, Computer Networks, 55, 15, pp. 3604–3629, (2011).
12. CEA, The smart grid: a pragmatic approach, Tech. Rep., Canadian Electricity Association, 2010, http://www.electricity.ca/ media/SmartGrid/SmartGridpaperEN.pdf.
13. Singer, J. (2009) 'Enabling tomorrow's electricity system: report of the Ontario Smart Grid forum', Independent Electricity System Operator, pp.1-50.
14. P. Murphy et al., "Enabling tomorrow's electricity system: report of the Ontario Smart Grid forum," Tech. Rep., Ontario Smart Grid Forum, (2010).
15. N. Cai, , N. T. T. Nga, J. Mitra, Economic Dispatch in Microgrids Using MultiAgent Systemǁ, Proceedings of North American Power Symposium (NAPS 2012), Champaign, IL, USA, 11, 9, pp. 1–5, (2012).
16. N. Jenki, J. B. Ekanayake, G. Strbac, Distributed Generation, London: The Institution of Engineering and Technology, 2009, p. 293.
17. Pawel Drzymala, Krzysztof Komeza, Henryk Welfle, Slawomir Wiak, Damian Kardas and Stefan Sieradzki, "Field analysis of end regions of stator windings of large turbo-generators", ISEF, 2009.
18. J. Ekanayake, N. Jenkins, K. Liyanage, J. Wu, A. Yokoyama, Smart Grid: Technology and Applications, Chichester: John Wiley & Sons, Ltd., 2012, p. 310.
19. European Commission, European Technology Platform for the Electricity Net works of the Future, (2015-12-02). http://www.smartgrids.eu/ETPSmartGrids1
20. M. Vanithasri, R. Balamurugan and L. Lakshminarasimman, Implementation of Radial Movement Optimization (RMO)

Algorithm for Solving Economic Dispatch and Fixed Head Hydrothermal Generation Scheduling, 2018, p. 63–97.
21. M. YOUNES, S. HADJRI, H. SAYAH, Economic Dispatching by an Artificial Method, ACTA ELECTROTEHNICA, 50, 2, (2009).
22. Vasebi, A., Fesanghary, M., and Bathaee, S.M.T. (2007) 'Combined heat and power economic dispatch by harmony search algorithm', International Journal of Electrical Power and Energy Systems, Vol. 29, No. 10, pp.713-719.
23. Mahdavi, M., Fesanghary, M., and Damangir, E. (2007) 'An Improved Harmony Search Algorithm for Solving Optimization Problems', Applied Mathematics and Computation, Vol. 188, No. 2, pp.1567-1579.
24. Li, L., Chi, S. and Lin, G. (2006) 'Chaos Harmony Search Method and its Application to Local Factor of Safety Method for Soil Slopes', Chinese Journal of Rock Mechanics and Engineering, Vol. 25, No. 1, pp. 2763-2769.
25. Li, L., Chi, S. and Lin, G. (2006) 'Improved Harmonic Search Algorithm and Its Application to Soil Slope Stability Analysis', China Civil Engineering Journal, Vol. 39, No. 5, pp.107-111.
26. Li, L., Chi, S.C. and Chu, X.S. (2006) 'Location of Non-Circular Slip Surface Using the Modified Harmony Search Method Based on Correcting Strategy', Rock and Soil Mechanics, Vol. 27, No. 10, pp. 1714-1718.
27. Baek, C.W., Kim, E. S., Park, M.J. and Kim, J.H. (2005) 'Development of Optimal Decision-Making System for Rehabilitation of Water Distribution Systems Using ReHS,' J. of Korea Water Resources Association, Vol. 38, No. 3, pp.199-212.
28. Lee, K.S. and Geem, Z.W. (2004) 'A New Structural Optimization Method Based on the Harmony Search Algorithm', Computers & Structures, Vol. 82, No. 9-10, pp.781-798.
29. Lee, K. and Geem, Z. (2005) 'A new meta-heuristic algorithm for continuous engineering optimization: harmony search theory and practice', Computer Methods in Applied Mechanics and Engineering, Vol. 194, No. 36-38, pp.3902–3933.
30. Lee, K.S., Geem, Z.W., Lee, S.H. and Bae, K. W. (2005) 'The Harmony Search Heuristic Algorithm for Discrete Structural Optimization', Engineering Optimization, Vol. 37, No. 7, pp.663-684.
31. Geem, Z. W. (2005) 'Harmony Search in Water Pump Switching Problem', Lecture Notes in Computer Science, 3612, pp.751-760.
32. Geem, Z.W., Lee, K.S., and Park, Y. (2005) 'Application of Harmony Search to Vehicle Routing', American Journal of Applied Sciences, Vol. 2, No. 12, pp.1552-1557.
33. Geem, Z.W., Tseng, C.L., and Park, Y. (2005) 'Harmony Search for Generalized Orienteering Problem: Best Touring in China', Lecture Notes in Computer Science, Vol. 3612, 741-750.
34. Kim, J.H., Geem, Z.W. and Kim, E.S. (2001) 'Parameter estimation of the nonlinear Muskingum model using harmony search', Journal of the American Water Resources Association, Vol. 37, No. 5, pp.1131–1138.
35. Kim, S.H., Yoo, W.S., Oh, K.J., Hwang, I. S. and Oh, J. E. (2006) 'Transient Analysis and Leakage Detection Algorithm using GA and HS Algorithm for a Pipeline System', Journal of Mechanical Science and Technology KSME, Vol. 20, No. 3, pp.426-434.
36. Paik, K., Kim, J.H., Kim, H.S. and Lee, D.R. (2005) 'A Conceptual Rainfall-Runoff Model Considering Seasonal Variation', Hydrological Processes, Vol. 19, No. 19, pp.3837-3850.
37. Paik, K.R., Jeong, J.H. and Kim, J.H. (2001) 'Use of a Harmony Search for Optimal Design of Coffer Dam Drainage Pipes', J. of Korean Society of Civil Engineers, Vol. 21, No. 2-B, pp.119-128.
38. Tamer Ayvaz, M. (2007) 'Simultaneous determination of aquifer parameters and zone structures with fuzzy c-means clustering and meta-heuristic harmony search algorithm', Water Resources, Vol. 30, No. 11, pp.2326-2338.
39. Tian, Y.H., Bo, Y.M. and Gao, M.F. (2004) 'Harmony Annealing Algorithm for Multi-Dimentional Function Optimization', Computer Simulation, Vol. 21, No. 10, pp.79-82.
40. Tian, Y.H., Bo, Y.M. and Gao, M.F. (2005) 'Parameters Choice Criteria in Harmony Annealing for Function Optimization,' Computer Simulation, Vol. 22, No. 4, pp.70-74.
41. Tian, Y.H., Bo, Y.M. and Gao, M.F. (2005) 'The Application of Harmony Annealing Algorithm for Predictive Control of Nonlinear Systems', Automation in Petro-Chemical Industry, No. 2, pp.39-42.
42. Geem, Z.W. (2007) 'Optimal Scheduling of Multiple Dam System Using Harmony Search Algorithm', Lecture Notes in Computer Science, Vol. 4507, pp.316-323.
43. Geem, Z.W. and Choi, J.Y. (2007) 'Music Composition Using Harmony Search Algorithm', Lecture Notes in Computer Science, Vol. 4448, pp.593-600.
44. Geem, Z.W. and Geem, W.B. (2007) 'Cutting-Edge Optimization Technique and its Applications to the Civil Engineering', The Magazine of the Korean Society of Civil Engineers, Vol. 55, No. 2, pp.155-171
45. Geem, Z.W. and Choi, J.Y. (2007) 'Music Composition Using Harmony Search Algorithm', Lecture Notes in Computer Science, Vol. 4448, pp.593-600.
46. Geem, Z. W. (2006) 'Optimal Cost Design of Water Distribution Networks using Harmony Search', Engineering Optimization, Vol. 38, No. 3, pp.259-280.
47. Geem, Z.W. (2006) 'Improved Harmony Search from Ensemble of Music Players', Lecture Notes in Artificial Intelligence, Vol. 4251, pp.86-93.
48. Lee, K.S. and Geem, Z.W. (2005) 'A New Meta-Heuristic Algorithm for Continuous Engineering Optimization: Harmony Search Theory and Practice', Computer Methods in Applied Mechanics and Engineering, Vol. 194, No. 36-38, pp.3902-3933.
49. Yu, L. and Xin, K. (2007) 'Harmony Search Optimization for Design of Water Distribution Systems', Paper Online (http://www.paper.edu.cn/).