OPTIMIZATION OF AGGREGATION PROCEDURES IN A SMART GRID ENVIRONMENT

Oihane ABARRATEGUI
UPV/EHU
Spain
oihane.abarrategui@ehu.es

Inmaculada ZAMORA
UPV/EHU
Spain
inmaculada.zamora@ehu.es

Dunixe Marene LARRUSKAIN
UPV/EHU
Spain
marene.larruskain@ehu.es

Araitz ITURREGI
UPV/EHU
Spain
araitz.iturregi@ehu.es

ABSTRACT

Aggregation will be one of the main features of the Smart Grid. A parallel ICT structure will have to be used in order to aggregate and handle a portfolio of DG, storage units, Electric Vehicles and even customers. In order to manage and control these procedures optimally, tools have to be developed.

This paper proposes the use Artificial Intelligence to automate these procedures, describing some metaheuristic techniques that can be used and identifying the applications they applied to within a Smart Grid environment.

INTRODUCTION

The evolution of the electric Power System into a Smart Grid makes necessary the development of new concepts in order to answer the needs of this highly automated and ICT based future network. One of these new concepts is the aggregation of a set of service providers and users that interact coordinately in order to increase the efficiency of the energy delivery process. A new stakeholder, the aggregator, manages the interaction of different participants as if they were a single entity. This participant portfolio can consist of Distributed Generators of different technologies, industrial or commercial customers or even a parquet of Electric Vehicles. It can consist of the combination of all these. Aggregation offers enhanced flexibility and a range of possible ancillary services. However, it is necessary to develop tools to handle all of these different stakeholders and optimize the aggregation procedures.

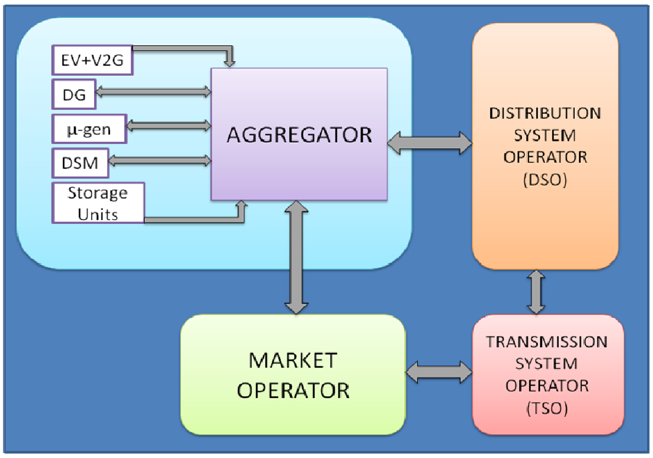
For this purpose, different optimization tools can be used. This paper proposes the use of Artificial Intelligence in the form of several metaheuristic techniques to approach the optimization problems that aggregation poses. These metaheuristic techniques are computational methods used to solve optimization problems iteratively, trying to improve a candidate solution. Natural evolution is an optimization process that can result in stochastic optimization techniques that can outperform classic methods. A wide range of metaheuristic techniques, eg., Genetic Algorithms (GA), Particle Swarm Optimization (PSO), Simulated Annealing (SA), Tabu Search (TS) and Ant Colony Optimization (ACO) can be used to approach the optimization problems that aggregation poses.

ARCHITECTURE OF THE AGGREGATION AND OPTIMIZATION PROCEDURES

Following, the optimization procedures that can help develop and enhance aggregation are identified:

Generation Scheduling: It is important for the aggregator to have advanced optimization tools to manage its generation portfolio. In a Smart Grid, the production will come from renewable sources and micro generation, intermittent source that introduce an uncertainty factor in the generation scheduling optimization procedures. The unpredictability can be balanced by using storage units, V2G and Demand Side Management to flatten existing peaks on the demand curve. Also geographically dispersed resources can be use to in order to avoid adverse meteorological situations.

Load forecasting: In an aggregation process, this is the complementary process to generation schedule. Load forecasting is necessary and also the first step towards an efficient Demand Side Management.



Demand Side Management: Efforts to flatten peak periods by controlling the demand response are generally done through price signals, time-of-use pricing (TOU), critical-peak pricing (CPP) and real-time-pricing (RTP). However, approaches that adapt to the current state of the grid and can predict supply and demand in the near future would be more flexible and useful.

Economic Dispatch: The aggregation of the different stakeholders of the Smart Grid ahs also a commercial aspect. Decentralize Energy Management Systems and advanced economic dispatch can be use in order to take the aggregated to the markets and optimize their bids and prices.

Distribution network planning and operation: The flexible generation and demand will have an impact on the distribution network. The quality of service has to be guaranteed, thus reactive power control in order to keep the desired voltages a nodes is important. Also the placement of capacitor banks, Storage units, Distributed Generators can be planned to be contribute to an optimal network operation.

Electric Vehicles: The presence of the electric vehicles not only as a new load model but also as a storage mean will alter significantly the demand curve and the distribution network. Forecast of EV user habits and charging needs, designing a decentralized control to coordinate the movement of EVs and the application and cases for V2G demands the use of sophisticated optimization tools.

METAHEURISTICS FOR THE SMART GRID

In order to develop the optimization procedures mentioned in the previous section, metaheuristic techniques can be used. The advantage of using metaheuristics are the following: conceptual simplicity, broad applicability, outperforming classic methods on real problems, potential to use knowledge and hybridize with other methods, parallelism, robustness to dynamic changes, capacity to solve problems that have no known solutions.

Genetic Algorithms (GA)

Genetic algorithms (GAs) operate on a population of individuals (genotype). They use a coding (genotypic space) whilst other stochastic search methods solve the optimization problem in the original representation space (phemotypic). Each individual is a potential solution to a given problem and it is typically encoded as a fixed-length binary string (other representations have also been used, including character-based and real-valued encodings, etc.), which is an analogy with an actual chromosome. After an initial population is randomly or heuristically generated, the algorithm evolves the population (reproduction) through sequential and iterative application of three operators: selection, crossover and mutation. A new generation is formed at the end of each iteration.

Particle Swarm Optimization (PSO)

Artificial life research examines how natural creatures behave as a swarm, such as schools of fishes and swarms of birds. It uses three vectors as simple rules in the researches on boids (birdlike objects); Separation: step away from the nearest agent, Alignment: go toward the destination, Cohesion: go to the center of the swarm.

The behavior of each agent inside the swarm can be modeled with simple vectors. It uses the concepts of individual learning and cultural transmission:

- Individual Learning: people have tried the choices and know which state has been better so far, and they know how good it is.
- Cultural Transmission: people have knowledge of how the other agents around them have performed. They know which choices their neighbors have found most positive so far and how positive the best pattern of choices is.

Each agent takes its decision using its own experiences and the experiences of others. The position of each agent is represented by its 'x,y' axis position and also its velocity is expressed by 'vx' (the velocity of x axis) and 'vy' (the velocity of y axis). Modification of the agent position is made by the position and velocity information.

Tabu Search (TS)

Tabu Search consists of a procedure used to manage heuristic algorithms that perform local search. It carries out a number of transitions in the Search Space aiming to find the optimal solutions or a range of near-optimal solutions. The name tabu is related to the fact that in order to avoid revisiting certain areas of the Search Space that have already been explored, the algorithm turns these areas tabu (or forbidden). It means that for a certain period of time (the tabu tenure), the search does not consider the examination of alternatives containing features that characterize the solution points belonging to the area declared tabu.
These search algorithms are initialized with a configuration which becomes the current configuration. At every iteration of the algorithm, a neighbourhood structure is defined for the current configuration. Then, the algorithm switches to the fittest configuration, that is, the best configuration in this neighbourhood. Only the most promising neighbours are evaluated. The neighbourhood is updated dynamically and transitions to configurations with higher cost are allowed. An essential feature is the direct exclusion of search alternatives temporarily classified as forbidden (tabu). The use of memory becomes crucial in these algorithms.

Other mechanisms of Tabu Search are the intensification and diversification:

Intensification mechanisms: the algorithm does a more comprehensive exploration of attractive regions that may lead to a local optimal point.
Diversification mechanism: here the search is moved to previously unvisited regions, something that is important in order to avoid local minimum points.

Simulated Annealing (SA)

Annealing is the process of subjecting a solid to high temperature and then cooling it in order to obtain high-quality crystals. Simulated annealing emulates the physical process of annealing. During the cooling process, it is assumed that thermal equilibrium conditions are maintained. The cooling process ends when the material reaches a state of minimum energy, which, in principle, corresponds with a perfect crystal. The two main features of the process are the transition mechanism between states and the cooling schedule, in order to find an optimal configuration (or state with minimum "energy") of a complex problem.

Ant Colony Optimization (ACO)

Ant colonies are capable of finding the shortest path to food resources. They are also capable of adapting to changes, e.g. if the path the ants were using gets blocked by an obstacle, they are capable of finding an alternative one. Ant algorithms use a collective intelligence based on a communication system of pheromone trails. Ants explore the Search Space randomly. The explored path is marked with virtual pheromone. Thus, the most popular paths leading to good solutions are rich in pheromone whilst the randomness in the process ensures that other new paths are still explored.
So, ant colonies follow an autocatalytic process leading to the optimization of the problem at hand.

The following Table is a short relation of the existing contributions that have been done using the presented metaheuristic techniques in order to address the problems posed by aggregation.

	TS	GA	PSO	SA	ACO
Generation Scheduling & Load Forecasting	[27] [18]	[5] [9] [19]	[3]	[18]	[30]
Economic Dispatch & Decentralized Energy Management	[16] .	[22] [21]	[12] [25]	[26]	
Reactive Power optimization		[10] [15]	[29], [31]		[20]
Capacitor, PMU, DG & Storage Unit Placement	[28]	[4]		[7]	[17] [11]
EV & V2G		[8] [15]	[14] [23] [13]	[24]	
Demand Side Management			[6]	[2] [1]	

CONCLUSIONS

This paper analyzes how metaheuristic optimization can be used in this cases and the impact it has in facilitating aggregation in a Smart Grid environment and delivers a small state-of-the-art for this line of work.

REFERENCES

[1] Ahamed, T. P. I., S. D. Maqbool, E. A. Al-Ammar, and N. H. Malik. 2011. "A simulated annealing algorithm for demand response".*2nd IEEE PES International Conference and Exhibition on, Innovative Smart Grid Technologies*.

[2] Chang, Yung-Chung. 2006. "An innovative approach for demand side management—optimal chiller loading by simulated annealing". *Energy* 31 (12) (9): 1883-96.

[3] Chao-Ming Huang, Chi-Jen Huang, and Ming-Li Wang. 2005. "A particle swarm optimization to identifying the ARMAX model for short-term load forecasting". *Power Systems, IEEE Transactions on* 20 (2): 1126-33.

[4] Dan Jiang, and R. Baldick. 1996. "Optimal electric distribution system switch reconfiguration and capacitor control". *Power Systems, IEEE Transactions on* 11 (2): 890-7.

[5] Dasgupta, D., and D. R. McGregor. 1994. "Thermal unit commitment using genetic algorithms". *Generation, Transmission and Distribution, IEE Proceedings*- 141 (5): 459-65.

[6] Faria, P., Z. Vale, J. Soares, and J. Ferreira. 2011. "Demand response management in power systems using a particle swarm optimization approach". *Intelligent Systems, IEEE* PP (99): 1-.

[7] Gantz, J. M., S. M. Amin, and A. M. Giacomoni. 2012. "Optimal mix and placement of energy storage systems in power distribution networks for reduced outage costs". *Energy Conversion Congress and Exposition (ECCE)*, 2012 IEEE, .

[8] Grunewald, A., S. Hardt, M. Mielke, and R. Bruck. 2012. "A decentralized charge management for electric vehicles using a genetic algorithm: Case study and proof-of-concept in java and FPGA".

Evolutionary Computation (CEC), 2012 IEEE Congress on, .

[9] Hong-Tzer Yang, Pai-Chuan Yang, and Ching-Lien Huang. 1997. "A parallel genetic algorithm approach to solving the unit commitment problem: Implementation on the transputer networks". *Power Systems, IEEE Transactions on* 12 (2): 661-8.

[10] Iba, K. 1994. "Reactive power optimization by genetic algorithm". *Power Systems, IEEE Transactions on* 9 (2): 685-92.

[11] Jen-Hao Teng, and Yi-Hwa Liu. 2003. "A novel ACS-based optimum switch relocation method". *Power Systems, IEEE Transactions on* 18 (1): 113-20.

[12] Jong-Bae Park, Ki-Song Lee, Joong-Rin Shin, and K. Y. Lee. 2005. "A particle swarm optimization for economic dispatch with nonsmooth cost functions". *Power Systems, IEEE Transactions on* 20 (1): 34-42.

[13] Junqiu Yang, Jinghan He, Xiaojun Wang, Zhiqian Bo, and Wenqi Tian. 2012. "Optimal control strategy of electric vehicles based on the adaptive mutation of PSO algorithm". *Power and Energy Engineering Conference (APPEEC)*, 2012 Asia-Pacific, .

[14] Kachroudi, S., M. Grossard, and N. Abroug. 2012. "Predictive driving guidance of full electric vehicles using particle swarm optimization". *Vehicular Technology, IEEE Transactions on* 61 (9): 3909-19.

[15] Lee, K. Y., Xiaomin Bai, and Young-Moon Park. 1995. "Optimization method for reactive power planning by using a modified simple genetic algorithm". *Power Systems, IEEE Transactions on* 10 (4): 1843-50.

[16] Lin, W. M., F. S. Cheng, and M. T. Tsay. 2002. "An improved tabu search for economic dispatch with multiple minima". *Power Engineering Review, IEEE* 22 (1): 70-.

[17] Lingfeng Wang, and C. Singh. 2008. "Reliability-constrained optimum placement of reclosers and distributed generators in distribution networks using an ant colony system algorithm". *Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on* 38 (6): 757-64.

[18] Mantawy, A. H., Y. L. Abdel-Magid, and S. Z. Selim. 1998. "A simulated annealing algorithm for unit commitment". *Power Systems, IEEE Transactions on* 13 (1): 197-204.

[19] Orero, S. O., and M. R. Irving. 1998. "A genetic algorithm modelling framework and solution technique for short term optimal hydrothermal scheduling". *Power Systems, IEEE Transactions on* 13 (2): 501-18.

[20] Oumarou, I., Daozhuo Jiang, and Cao Yijia. 2009. "Optimal reactive power optimization by ant colony search algorithm". *Natural Computation, 2009. ICNC '09. Fifth International Conference on*, .

[21] Po-Hung Chen, and Hong-Chan Chang. 1995. "Large-scale economic dispatch by genetic algorithm". *Power Systems, IEEE Transactions on* 10 (4): 1919-26.

[22] Sheble, G. B., and K. Brittig. 1995. "Refined genetic algorithm-economic dispatch example". *Power Systems, IEEE Transactions on* 10 (1): 117-24.

[23] Siddiqi, U. F., Y. Shiraishi, and S. M. Sait. 2011. "Multi-constrained route optimization for electric vehicles (EVs) using particle swarm optimization (PSO)". *Intelligent Systems Design and Applications (ISDA)*, 2011 11th International Conference on, .

[24] Sousa, T., H. Morais, Z. Vale, P. Faria, and J. Soares. 2012. "Intelligent energy resource management considering vehicle-to-grid: A simulated annealing approach". *Smart Grid, IEEE Transactions on* 3 (1): 535-42.

[25] Sriyanyong, P. 2008. "Solving economic dispatch using particle swarm optimization combined with gaussian mutation". *Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology, 2008. ECTI-CON 2008. 5th International Conference on, .*

[26] Wong, K. P., and C. C. Fung. 1993. "Simulated annealing based economic dispatch algorithm". *Generation, Transmission and Distribution, IEE Proceedings* C 140 (6): 509-15.

[27] Xaiomin Bai, and S. M. Shahidehpour. 1996. "Hydro-thermal, scheduling by tabu search and decomposition method". *Power Systems, IEEE Transactions on* 11 (2): 968-74.

[28]Yann-Chang Huang, Hong-Tzer Yang, and Ching-Lien Huang. 1996. "Solving the capacitor placement problem in a radial distribution system using tabu search approach". *Power Systems, IEEE Transactions on* 11 (4): 1868-73.

[29] Yoshida, H., K. Kawata, Y. Fukuyama, S. Takayama, and Y. Nakanishi. 2000. "A particle swarm optimization for reactive power and voltage control considering voltage security assessment". *Power Systems, IEEE Transactions on* 15 (4): 1232

[30] Yu, I. K., and Y. H. Song. 2001. "A novel short-term generation scheduling technique of thermal units using ant colony search algorithms." *International Journal of Electrical Power & Energy Systems* 23 (6) (8): 471-9.

[31] Zhao, B., C. X. Guo, and Y. J. Cao. 2005. "A multiagent-based particle swarm optimization approach for optimal reactive power dispatch". *Power Systems, IEEE Transactions on* 20 (2): 1070-8.