УДК 62-503.56

NETWORK PLANNING FOR NARROW-BAND POWER LINE COMMUNICATION IN SMART GRID

Ju.S.Yamnenko, doctor of science, **K.S.Osypenko**, **I.V.Neporozhnev,**
National Technical University of Ukraine "Kyiv Polytechnic Institute",
Ak. Yangelia Str. 16/9, Kyiv-56, 03056, Ukraine.

In the paper Smart Grid systems are investigated. Power Line Communication was used as communication technology for Smart Grid. System network planning and main steps of planning process were considered. On the stage of topological design Linear programming was used in order to solve equipment arrangement problem. Results for three different topographies: low, medium and mixed (low+medium voltage) are shown. At network realization Genetic algorithm was used energy-efficient control of electrical devices. References 7.
Key words: Narrow-band Power Line Communications, Smart Grid, Linear Programming, Genetic Algorithm.

INTRODUCTION. Modern tends in power networks development lead to their more interactivity and customer-orientation that involves a lot of changes in network design and control. These networks can be called Smart Grids. Power grids can be named "smart" for two reasons [1]: first, Smart Grids gives the customer an opportunity to take an active role in power supply; second, the efficiency of the system is increasing [1].

The ability to communicate is necessary requirement for devices in Smart Grid. One of the most promising and popular communication technologies is Power Line Communications (PLC) [2]. PLC is an alternative access technology which includes building of the network over the infrastructure of low-voltage grid.

There are two classes of PLC systems: narrow-band PLC system (NB-PLC) for which the bit rate does not exceed the 500 kbps, and broadband PLC (B-PLC) with bit rate of several Mbps. PLC systems use high frequency band on the energy cables where the signal is transported with 50Hz or 60Hz. Spectrum range for NB-PLC is from 9kHz to 148.5kHz and for B-PLC is from 2 to 30 MHz [3]. Some of the advantages to use narrow-band PLC systems for Smart Grid are that it is not very expensive and the transmitting distance is quite long. Also the advantage is that electricity supply companies already own the power cables so they don't have additional expenses on cable installation and system operation. NB-PLC network usually consists of two parts: low voltage (LV) and medium voltage (MV).

NETWORK PLANNING FOR NARROW-BAND PLC. In order to deploy the narrow-band PLC system network planning is used. The main condition of the network planning process is to ensure that a new network meets the needs of the user [4]. Three main steps of network planning are following: topological design, network-synthesis and network realization.

The aim of topological design is to identify where to place the components and how to connect them. The problem which appeared is equipment placement problem and it can be formulated in terms of Linear Programming. The role of Linear Programming for network planning is important, because it can solve the problem in exact way [9] using combinatorial programs to minimize or maximize linear function of variables subject under some constraints.

The main task is to place an optimal number of Access Points (APs) in the network. If one or more End Nodes are placed above a certain coverage distance (L_{max}) from their AP, one or several repeaters are placed, or some End Nodes are used as repeaters.

Objective function for this problem is the function of network costs, which has to be minimized [3,5]:

$$\min\ f_{Costs} = \underbrace{\sum_{j \in P_S^{(AP)}} C_{AP} a_j}_{AP\ costs} + \underbrace{\sum_{k \in P_S^{(R)}} C_R r_k}_{\text{Repeater costs}} .$$

Constraints are following:

1. Flow balance constraint - difference between output and input flow in the node should be equal to demand of this node plus demand of AP (if it is placed in this node) [5]:

$$\sum_{i,j \in Edges} x(i,j) - \sum_{j,i \in Edges} x(j,i) = d_i + d_i^{(AP)}.$$

2. Shortest-path constraint – the path between two points i and j should be minimal: assume that some point k exists between i and j, nearest to j, such that path from i to j is equal to path from i to k plus length between k and j; if path from i to j is more than L_{max}, a repeater is placed in point k, and second part of right expression is becoming equal to zero [5]: $p(i,j) = p(i,k) + l(k,j) r_k$

While solving equipment problem using Linear Programming methods it occurred, that repeater placement problem cannot be solved properly (no optimal solution can be found). The reason is that all these networks are vicious, and problem occurs while counting shortest paths. That is why only results for AP placement problem are shown.

In accordance to results that were obtained with Linear Programming for equipment placement problem for low-voltage network (220 end nodes) only one AP is needed; for medium-voltage network (50 end nodes) five APs are needed; for combined (low+medium voltage) network (600 end nodes) three APs should be placed with the costs of 100, 500 and 300 rated cost units respectively.

Network realization determinates how to meet capacity requirements, and ensure enough levels of signals in all points within the network. On this stage Genetic algorithm is used to solve the problem of determining the optimal switching points of loads in Smart Grid to minimize the excess of the critical level of electrical energy consumption [6].

In order to avoid exceeding the critical consumption level, it is necessary to set priorities for different groups of consumers. To reduce the total energy consumed in definite time interval some devices should be switched to a state with less consumption, and some of them should be even switched off.

The devices of high priority (e.g. providing protection and livelihoods) cannot be switched into other states and/or disconnected. Therefore, energy-efficient consumption control requires the distribution of the loads to some groups according to priority level and the possible working regimes.

Genetic algorithms allow calculation necessary data to control the devices within local power supply system and power systems within Smart Grid in order to reduce the excess of the critical consumption level.

Genetic algorithm determines the optimal moments of commutation [7]. The algorithm analyzes these characteristics in a time. When assigned consumption level is exceeded at some time interval, the algorithm changes the moments of commutation to minimize such exceeding. Thus, genetic algorithm indicates the optimal time for each device to turn on.

To avoid the situation when some load in Smart Grid is switched on in unplanned time, constraints for time interval of such potential load inclusion were assumed. When modeling of this algorithm has been imposed certain time limits at the time of switching on different objects.

CONCLUSION. Smart Grid can meet the needs of the today's grid. It incorporates latest technology to ensure network reliability and economy. Narrow-band PLC is the promising communication method for the devices in Smart Grid. The network planning can be effectively used to define optimal placement of equipment (access points and repeaters).

Network planning process consists of three main parts: topological design, network-synthesis and network realization. On the stage of topological design, which requires algorithms for equipment placing, Linear Programming was used in order to solve the equipment placement problem. Network realization determinates how to meet capacity requirements within the network. On this stage Genetic algorithm is used to solve the problem of determining the optimal switching points of loads.

1. *European Commission.* European SmartGrids technology platform: Vision and strategy for Europe's electricity networks of the future, 2006.
2. *Global Environment Fund/Global Smart Energy.* The electricity economy: New opportunities from the transformation of the electrical power sector, Aug. 2008.
3. *Haidine A.* Multi-Objective Combinatorial Optimization in Topology Planning of Wireline Broadband Access Networks – TU Dresden. – 2008. – Pp. 21–23, 57–59, 61–65, 100–101.
4. http://en.wikipedia.org/wiki/Network_planning_and_design
5. *Pioro M., Medhi D.* Routing, Flow and Capacity Design in Communication and Computer Networks. – Elsevier, 2004. – Pp. 105–112, 152–177.
6. *Sivanandam S.N.* Introduction to Genetic Algorithms – Springer-Verlag Berlin Heidelberg 2008. – 425 p.
7. *Randy L.* Practical Genetic Algorithms. – John Wiley & Sons, Inc. 2004. – 251 p.

УДК 62-503.56

ПЛАНИРОВАНИЕ УЗКОПОЛОСНОЙ *PLC* СЕТИ ДЛЯ СМАРТ ГРИД

Ямненко Ю.С., докт.техн.наук, **Осипенко К.С., Непорожнев И.В.,**
Национальный технический университет Украины «Киевский политехнический институт»,
ул. ак. Янгеля, 16/9, Киев-56, 03056, Украина.

Рассмотрено использование коммуникационной технологии PLC в Смарт Грид системах. Представлен процесс планирования сети и его основные этапы. На этапе топологического дизайна для решения задачи оптимального размещения оборудования применен метод линейного программирования. Приведены результаты для трёх различных топологий сети: низковольтной, среднего напряжения и смешанной. На этапе реализации сети применен генетический алгоритм для энергоэффективного управления подключением нагрузок. Библ. 7.

Ключевые слова: узкополосная *PLC* сеть, Смарт Грид, линейное программирование, генетический алгоритм.

УДК 62-503.56

ПЛАНУВАННЯ ВУЗЬКОПОЛОСНОЇ *PLC* МЕРЕЖІ ДЛЯ СМАРТ ГРІД

Ямненко Ю.С., докт.техн.наук, **Осипенко К.С., Непорожнєв І.В.,**
Національний технічний університет України «Київський політехнічний інститут»,
вул. ак. Янгеля, 16/9, Київ-56, 03056, Україна.

Розглянуто використання комунікаційної технології PLC в Смарт Грід системах. Представлено процес планування мережі та його основні етапи. На етапі топологічного дизайну для вирішення задачі оптимального розміщення устаткування застосований метод лінійного програмування. Наведено результати для трьох різних топологій мережі: низьковольтної, середньої напруги і змішаної. На етапі реалізації мережі був застосований генетичний алгоритм для енергоефективного управління підключенням навантажень. Бібл. 7.

Ключові слова: вузькополосна *PLC* мережа, Смарт Грід, лінійне програмування, генетичний алгоритм.

Надійшла 12.01.2012
Received 12.01.2012