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Electrical loads management in energy emergency conditions

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ABSTRACT

This paper presents an innovative proposal for the selection of electrical loads in intelligent networks when main power sources are limited or totally absent (in the following: in emergency conditions). The control strategy is based on the mathematical approach of the basis 0–1 Knapsack Problem. Results from three different algorithms are compared: Tabu Search, Greedy heuristic and dynamic programming. To verify correctness and accuracy in the solutions, a MatLab software have been developed. To evaluate the achieved results, a case study is shown in a true-life environment.

Introduction

Nowadays, the system model of future power generation, power consumption and related control systems is the *smart grid*. In general, this term refers to a network that, by means of the use of digital technology, acquires new features: higher efficiency and reliability, enhanced security of the service. Energy management in smart home environment is nowadays a crucial aspect on which technologies have been focused in order to save costs and minimize energy waste. This goal can be reached by means of an energy resource scheduling strategy provided by a suitable optimization technique [1]. Monitoring and metering processes are required to be performed in renewable energy conversion systems like smart grid applications of the conventional grid system [2]. It is also required that system is active, intrinsically stable and remotely *real-time* controllable [3]. This can lead to several advantages, depending on the technological solution in use [4]. These characteristic of smart grids are instrumental to ensure the functional coalescence of distributed generation; moreover, *Demand Side Management* (DSM) and management of storage systems allows load balancing [5]. Demand-Side Management can be defined as the implementation of policies and measures to control, regulate, and reduce energy consumption [6]. DSM is one of the most important functions in a smart grid, since it allows customers to perform choices regarding energy consumption, and supports energy suppliers to reduce the peak loads demand and reshape the loads profile. This leads to higher sustainability, as well as to a reduction of the overall operating costs and CO_2 emission [7]. The aim of the DSM is the dynamic systems control; future conventional energy system – thanks to the development of distributed power generation from renewable sources – must change and evolve in this direction [8]. The network patterns for production and dispatch electricity are still centralized [9]. Recently, there has been great interest in the integration of large numbers of small generation and storage systems at the distribution level [10]. In the closer past, the stimulation to a deep change and improvement of the electrical system became more and more strong. The main reasons that lead to some measures now being taken, are:

- the distributed generation [11];
- the economic crisis;
- the environmental objectives [12];
- the new legislative decrees.

To handle these new requirements, the development of smart grids that can accept two-way flows of energy – thus allowing integration of distributed generation from renewable sources and energy accumulation systems – is essential [13]. Energy storage based hybrid distributed power generation systems appear to be very promising for satisfying high energy and high power requirements of power quality problems in distributed generation systems [14]. The study of renewable energy sources led to the certainty that its enhancement may reduce losses and increase reliability, efficiency and safety of the dispatching service. Furthermore, the failure of components, the occurrence of accidents and natural disasters which cause disturbances to the network, can be foreseen using a supervision diagnosis and protection system [15]. This paper contains an innovative suggestion for the selection of electrical loads in emergency conditions, when the energy

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List of symbols

b	total volume of the instance of the problem considered
CoP_i	priority coefficient for the i-th load ($i = 1,n$)
ENE_d	energy delivered by the battery in 15 min (function of the SOC)
ENE_c	maximum battery power in a charging phase of 15 min
g	objective function
$k_{c\ i}$	contemporary coefficient for the i-th load
$k_{u\ i}$	utilization coefficient for the i-th load
l	number of sub-volumes in which volume b was divided
l_i	binary variable identification of the i-th load
M	sum of the n weights
n	total number of loads
$P_{avg\ i}$	average power absorbed by the i-th load
$P_{max\ t}$	maximum power available for the time period t
$P_{rated\ i}$	rated power of the i-th load
S	sets of objects placed in the Knapsack
SOC	battery state-of-charge
u_i	utility value of the i-th load
w_i	weight of the i-th object in the Knapsack Problem
X^*	optimal value of the objective function

provided by the public electricity supplier is totally or partially failing. The electric loads management is strictly linked to the overall reliability of the smart grids, since this limits the power service interruptions, allowing thus to achieve an excellent management and to improve the service quality.

The paper presents the Knapsack Problem applied to electric loads case in Section 0-1 Knapsack Problem applied to an electric case. The description of the logic used by the algorithms within the software itself, not only by mathematical formulation, but also following the logical steps of the algorithms is illustrated in Section Algorithms of management selected for the resolution of the problem. Software architecture, outlined by a block diagram and illustrating several significant case studies, is described in Sections Software architecture and Case study. These case studies are based on a load control system in an existing school equipped with PV plant and a storage system. In order to evaluate the software efficiency, in different engineering solutions three tests are performed. In the first test, control of the plug to which the single electric user is connected is simulated. The second one involves the control of the individual backbone coming from electrical boards. In the last one, control on the panel board is hypothesized [16]. An analysis of computational complexity has been also made in order to compare and analyze the performances of the chosen algorithms.

0–1 Knapsack Problem applied to an electric case

The Knapsack Problem [17] is so called because of its help in solving *smuggler knapsack*'s problem, i.e. the problem of carrying a certain amount of selling items, each of different value when the total volume exceeds the one of an imaginary backpack, achieving the maximum total profit in connection with the selected items [18]. The problem is NP-hard (nondeterministic polynomial-time hard), exhibits easy formulation, but it is difficult to solve. The mathematical formulation, relative to the electric case, can be expressed through the following relation (1) [17,19]

$$\max g(x) = \sum_{i=1}^{n} CoP_i l_i \tag{1}$$

$$(x) = \sum_{i=1}^{n} P_{avg\ i} l_i \leqslant P_{\max t}$$

$$l \in \{0,1\}^n$$

$$1 \leqslant i \leqslant n$$

$$CoP_i > 0$$

$$P_{avg\ i} = P_{rated\ i} \cdot k_{u\ i} \cdot k_{c\ i} > 0$$

$$P_{\max t} > 0$$

This problem (and the relevant solution) found a wide field of application. Many techniques have been developed for logistics, financial investments, medical skin diagnosis, elaboration of DNA self-assembly model and neural networks, but has never been applied to electrical power system, or related scientific areas.

Algorithms of management selected for the resolution of the problem

To solve the problem, three algorithms have been used: Greedy, Tabu Search and dynamic programming. The Greedy algorithms [20] are said to be "heuristic" because they don't provide the optimum solution to the problem arisen. In the Knapsack Problem, an object is "good" when exhibits high u_i (CoP_i) and low w_i ($P_{avg\ i}$). In the considered Greedy algorithm, the objects are set by choosing the element $l_k \in n$ in order to maximize the ratio of utility and weight (2) among all n elements of the problem, after checking that constraint (3) is satisfied. It proceeds through a sort order descending in value resulting from the relationship between objects.

$$u_i/w_i \tag{2}$$

$$w_k \leqslant M - \sum_{i=1}^{n} w_i \quad \forall x_i \in s \tag{3}$$

where s is the set of objects placed in the knapsack until the current iteration is performed. The algorithm proceeds by evaluating, for each item, the ratio utility/power, and by sorting items of the basis of such parameter, in a decreasing order.

On the basis of the following positions:

$x_i = i$ is the generic load,
$v_i = u_i$ is the value of single load,
$y_i = l_i$,
$C = P_{\max}$,

Greedy transform function

$G{:}\{0,1\}^n \rightarrow \{0,1\}^n$ for any,

$X = x_1, x_2, \ldots, x_n$ set $G(X) = y_1, y_2, \ldots, y_{1n}$

where, $y_i (i = 1,2,\ldots,n)$ is defined as follows:

(1) for all the items $x_I = 1$, order them by their value density $v_i = w_i$ from the queue b(i), where b(1) is the serial number of the item with the first value density, b(2) is the serial number of the item with the second value density, and so on;
(2) set $k = 1$;