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Renewable energy unit commitment, with different acceptance of balanced power, solved by simulated annealing

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ABSTRACT

This paper formulates a unit commitment optimisation problem for renewable energy sources distributed in a micro-grid formed by a complex of intelligent buildings of both office and residential characters, including a wide range of amenities. We present a description of the solution of this task using the simulated annealing heuristic optimisation technique. The simple experiment is performed in three different variants of acceptance of balanced power constraining condition. In one of the variants is used fuzzy model of mentioned constraining condition. The experiment was processed in the specialised computer programme.

1. Introduction

A building which is economically efficient, has low energy consumption and low impact on the (external/internal) environment, allows multi-purpose use and reconfiguration of its internal areas, provides the maximum amount of safety and comfort, and can reduce operating costs is called an intelligent building.

This article focuses on the optimisation problem of sorting renewable electrical energy sources distributed in an energy micro-network of a fictitious town comprising a complex of intelligent buildings, whereas the goal is to minimise the total costs for manufacturing a volume of electrical energy based on the prediction of its consumption during the considered period. Due to this reason, we need to also focus on the integrated and systemic solution of the external intelligence of intelligent buildings – i.e. the choice of renewable energy sources (RES) with respect to technical, operating and investment costs in relation to our problem. Last but not least, we will emphasise the significance of the present focus on centralised and distributed efficient production of electrical energy.

Renewable energy sources are renewable non-fossil-based natural sources of energy, specifically wind energy, solar energy, geothermal energy, hydro energy, soil energy, air energy, biomass energy, energy in landfill gas, energy in sewage gas and biogas energy. For completeness, we may extend these energy sources to also include the energy of oceans and seas, mining gas and lightning.

RES are renewable, ecologically harmless and can satisfy local energy needs. RES also have a firm position in the global energy supply system. They are especially a basic part of the solution of energy intensity of buildings and an essential prerequisite for low-energy, passive, zero-energy and plus-energy buildings. In our energy micro-network, we use the following types of RES (based on their merits): 1x cogeneration, 3x biomass, 3x wind, 3x hydro. Photovoltaic and geothermal energy is not accepted in the micro-network, as explained in the scenario specified in the “experiment” part. All applied RES implemented in the energy micro-network are designed so that their economical aspects, costs, economic and technical efficiency were advantageous (both economically and energetically) with respect to the users and realisation area.

A cogeneration unit (combined production of electrical and thermal energy – CPETE) simultaneously produces electrical and thermal energy. The basic financial characteristic of cogeneration units is a quick return on investments. In some economic and technical applications, a unit of high-capacity accumulators is used as an upgrade of cogeneration units.

The size of a cogeneration unit is chosen based on the user’s consumption diagrams. Specifically, at least 55% of the year must always be covered. Our experiment uses the values of consumption diagrams for two days in a week (a workday and a non-working day), whereas all installed RES are evaluated simultaneously. The

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values of the consumption diagrams were obtained from the actual operation of a selected area of users in our complex of intelligent apartment and office buildings, from the database of ČEZ a.s. Czech Republic. The results of the power consumption during these two days, which historically show little variance, are then used to compute the annual energy consumption. Based on the obtained values and distribution of their consumption during a day/year, the most advantageous choice turned out to be the installation of a cogeneration unit with an output of 200 kW_e/314 kW_t (electrical efficiency 32%, total CPETE efficiency 90%). The minimum annual coverage of the cogeneration unit was determined to be 50% of the year (4380 h), 365 days/12 h. However, the coverage is realistically expected to be higher. In our case, the cogeneration unit is first and foremost a source of electrical energy – which is also generated by hydro and wind power plants in the IB complex micro-network. In the case of such so-called island operations, with only limited connection to the distribution network (and only with partial or exceptional energy withdrawal from the distribution network), there are higher regulation costs.

From the environmental viewpoint, cogeneration units are more than acceptable. The chemical energy of biogas (which is used in our case) is transformed in the cogeneration unit into electrical energy at an efficiency of 30% and into thermal energy at an efficiency of up to 50%. This implies that the use of the cogeneration unit is only warranted when all of the produced thermal energy can be used at the place of its operation. In our case, this is possible thanks to the use of thermal energy in heating. An optimal consumption of electrical and thermal energy results in a total efficiency of up to 80%. Excess or lack of produced electrical energy requires the preparation of conditions for its accumulation via a control system based on a closed or open control system linked to exceptional withdrawal of energy from the distribution network into the intelligent building (IB) complex. A gradual increase of installed power in the area of the intelligent building complex may lead to problems in the cooperation of various RES, such as, e.g. cogeneration units, with the existing distribution network. Problems arise from the territorial configuration of the network and the local network in relation to the localisation of decentralised RES, which may also be present in areas where electrical energy was previously only supplied from the distribution network.

The type of cogeneration is selected based on media availability. The primary fuel for cogeneration units could be, e.g.: natural diesel gas, propane-butane, biogas, or other fuels based on consultation with the manufacturer (for instance wood-gas obtained in a wood-gas generation). In our case the fuel is gas-based and not steam-based. The energy conversion ratio from energy in the primary fuel to electrical energy is significantly higher than in the case of steam-based cogeneration, and is approximately 23–41%, while the thermal production efficiency is approximately 35–57%. The total energy utilisation ratio in the fuel ranges between 68% and 90%. We also need to consider other criteria related to the conditions in the IB complex: daily and annual schedules of thermal and electrical energy consumption; type of required warm-water medium; availability of gas fuel and the output of presently installed boilers and their thermal and pressure parameters.

To produce one kWh of electricity, our cogeneration unit uses, e.g. CZK 2.50/kWh worth of natural gas, with service costs amounting to approximately CZK 0.40–0.60/kWh. If the price of electrical energy from the distribution network exceeds CZK 3/kWh (which is true in the Czech Republic), it is advantageous to operate the cogeneration unit just to cover the complex's own electrical energy consumption and the additionally produced heat can be considered "free". In our experiment, electrical energy consumers pay for total connected electrical power consumption and for on-peak consumption, and a cogeneration unit can significantly reduce these costs.

Energy benefits of cogeneration. The goal of cogeneration, with respect to reducing the consumption of primary energy sources (PES) may be expressed by simple mathematical formulas, specifically: $Q_u = \frac{E}{\eta_{el}} + \frac{Q}{\eta_{vy't}} - \frac{E+Q}{\eta_{kj}}$ [GJ], where Q_u is the amount of saved thermal energy from fuel due to collective production of electricity and heat, E is the amount of electrical energy [GJ], Q is the amount of thermal energy [GJ], η_{el} is the total efficiency of a condensation power plant, η_{kj} is the total thermal efficiency of a condensation source and $\eta_{vy't}$ is the total efficiency of a heating plant. If we assume the efficiency of the cogeneration unit to be equal to that of a heating plant, the amount of heat saved in the fuel per unit of thermal energy delivered to the consumer may be computed as $\frac{Q_u}{Q} = \frac{E}{Q}\left(\frac{1}{\eta_{el}} - \frac{1}{\eta_{kj}}\right)$. In our case, we can express $e = \frac{E}{Q}$, which is the coefficient of the dependent electrical power (power/heat ratio). From the formula above we then get $\frac{Q_u}{Q} = e\left(\frac{1}{\eta_{el}} - \frac{1}{\eta_{kj}}\right)$. Based on this formula, we can say that if the total efficiency of the cogeneration unit is the same as the efficiency of a heating plant, then the amount of heat saved from PES is directly proportional to the power/heat ratio. The value of e depends on the type and make of the cogeneration source and its usual values can be obtained from the table of certain cogeneration units offered on the global market. When designing a cogeneration unit, it is always important to maximise its overall thermal efficiency. This is the only way to reach maximum savings of primary energy sources. We took this fundamental intent into account when designing the "Cogener" cogeneration unit. As a result, we will obtain maximum energy efficiency of the cogeneration unit implemented in our micro-network. We note that an in-depth calculation would exceed the scope of this article.

Biomass is created on Earth thanks to solar radiation and photosynthesis and may be divided to "dry" and "wet" biomass. If the biomass contains too much water, it is not suitable for combustion. Wet biomass, such as manure, slur and other agricultural and food waste, sorted communal biological waste, or some crops such as corn, may be successfully utilised in biogas stations. Biogas stations produce electricity in cogeneration units. Most frequently, they comprise adjusted piston engines which power a generator and are capable of transforming 30–40% of the energy in the biogas into electric power, while about one half of the biogas energy is transformed into heat.

Dry biomass may be identified with solid biomass, whereas the most frequently used materials for energy purposes are wood and specifically cultivated plants (quickly growing timber species, herbage). The fundamental advantage of dry biomass is that it accumulates energy well and may be easily stored for prolonged periods of time. One hectare of a field will produce a mass containing 40 to 90 MWh of energy, depending on the type of plant. It is only possible to extract energy from solid biomass by combustion, which produces both thermal energy and gases. The thermal energy produced in a biomass power plant may be used either for heating or for drying stored biomass. Gases from the combustion, e.g. wood-gas, may be used for the production of electric power by re-combustion.

Technical equipment for the utilisation of biogas still requires relatively steep investments, however it significantly contributes to the economics of agricultural businesses and also to environmental protection. High efficiency may only be reached when using all produced thermal energy.

Biogas produced in biogas stations (BGS) is used to power electric generators in cogeneration units. The combustion of pure biomass has the advantage of not harming the environment, since the amount of CO_2 produced in this way equals the amount of CO_2 the biomass captured/used during its growth. The only resulting air pollutant is NO_x. Biogas stations need not always produce only electricity. Today it is possible to transform biogas into bio-methane,