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OPTIMAL LOCATION OF MICRO-TURBINES IN A WATER SUPPLY NETWORK

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ABSTRACT

Micro-hydropower is currently expanding as a solution to improve the efficiency of water systems by using energy excesses which are typically lost. In the particular case of water supply systems, often excessive pressure exists in zones of the network connected to other areas situated at higher altitudes. Pressure reducing valves are commonly used as a mean for dissipation of this excess energy. In this work, the installation of micro-turbines in a closed water supply network is analyzed as a way to recover the existing surplus of energy by converting it into electricity. The flow in water supply systems is highly variable, with a direct impact on the efficiency of the turbine and, as most water-supply networks are meshed, the optimal location of the energy converters is not straightforward and needs assessment by simulation processes. For this purpose, an optimization tool based on the application of an evolutionary algorithm was developed to select the best location, model and runner size of a selected number of turbines to install in a network. Using the characteristic and efficiency curves of a micro-turbine and a database of flow demand given every hour, a simulated annealing process is applied to maximize the energy production while pressure restrictions imposed by regulation must be respected. The methodology was applied to a case study in a sub-grid of the water supply system of the city of Lausanne, Switzerland, and the considered micro-hydro converter was a five blade tubular propeller. This study is focused on the simulation problem and the convergence to optimal solution is analyzed under different restrictions and number of turbines to install.

Keywords: micro-hydropower; water supply systems; pipe network; optimization; simulated annealing.

1. EXTENDED ABSTRACT

The awareness that water, energy and food securities are linked, recently gained influence in political and economic decision making. This nexus implies the need for a more integrate management of these resources (Olsson, 2012), since choices made in one domain have direct and indirect consequences on the others (UNESCO, 2014). Considering this link as planning and policy making are made may lead to significant energy savings (Shrestha et al., 2012 and Vilanova et al., 2013).

As energy needs grow, water consumption will increase accordingly (Keeling and Sullivan, 2012). Furthermore, new solutions are being searched to decrease the dependence of the energy production on combustible fuels and nuclear power, either through the replacement of these sources by renewable energies or by improving the efficiency of the existent systems. In this scenario, such new techniques as hybrid installations, micro-hydro and optimization routines are emerging. This paper is focused on the utilization of micro-hydro in water supply systems (WWS) to produce electricity.

Generally, in a WSS, the pressure varies along the pipe profiles and with time. In addition, the pressure in some areas of the networks is higher than needed, as consequence of the links with other regions situated at higher geographic elevations. In certain cases, for example when the variation of the geodesic quotes is considerable, when there is a residual head at the end of a pipeline, or when there are lower head losses due to the smoothness of new pipes during the earlier stage of their life cycle (Carravetta et al., 2012), energy dissipation may have to be imposed to avoid pipe usage and leakages. In drinking pipe systems, pressure reducing valves are commonly used as a mean for excess energy dissipation (Jain and Patel, 2014; Ramos et al., 2010; Ramos and Ramos, 2010). A surplus of energy in the WWS may hence be recovered.

To that purpose, the installation of micro-turbines in water distribution networks is suggested in this study. These turbines allow to recover the excess of energy by converting it into electricity. However, the choice of the locations with enough potential for the installation of micro-hydro is often not obvious. The flow demand is highly variable, not only with a direct impact on the efficiency of the turbine but also on the direction and distribution of flows in a pipeline network. Furthermore, limitations of pressure often imposed by the regulator, for security and comfort reasons, must not be overpassed. In this study, a new technique with the use of a simulated annealing algorithm to optimize the energy production in these particular systems is proposed.

With the developed numerical model, the user is able to optimize the placement of a chosen number of turbines in a given network. Each solution for the optimization algorithm is obtained by the hydraulic solution of the state of the network for each hour, calculated using a commercial software linked to the optimization algorithm, and simulating the turbines as singular energy drops to which the head-loss coefficient is calculated recursively as a function of the turbine characteristics. The optimization tool is here tested for a real network of the city of Lausanne, Switzerland. This city was chosen for its topographic characteristics, ideal for the application of the proposed solution, as it possesses considerable topographic differences and high slopes.

To test the performance of the algorithm, a study was performed in a sub-grid of the Lausanne water supply network, with a database of hourly flows provided by *eauservice*, Lausanne, Switzerland. The partial network consisted on a closed network of 335 links and 312 nodes, where two of the nodes are a reservoir and a tank – Figure 1. While the tank is a regulation tank upstream the network, being hence the source of water in the sub-grid, the reservoir represents the network downstream the considered area, thus, the outlet.

Figure 1. Closed mesh for case study, sub-grid of the water supply system of Lausanne, Switzerland.

For the application of the algorithm the installation of a single model of turbine was considered, a five blade tubular propeller (5BTP) turbine developed during the EU-Project HYLOW, Hydropower converters with low head differences (HYLOW, 2012), whose performance curves were obtained by means of numerical simulation, using a Navier-Stokes commercial solver – FLUENT model, for a 100 mm runner.

The developed model used a simulated annealing process, which is a heuristic method based on the process of heating steel and ceramics (Bertsimas and Tsitsiklis, 1993). The method starts with an initial feasible solution and a small random change is applied to generate a neighboring solution with a different cost value. If the candidate solution is lower than the previous one, it is immediately accepted; if not, then it is accepted with a certain probability (Azizi and Zolfaghari 2004). This probability changes according to the cost function and with previously visited solutions (Van Laarhoven et al. 1992).

For each iteration of the algorithm, a placement of turbines is chosen. In these conditions, a full year is simulated using the commercial software EPANET 2.0 to calculate the turbinated flow, the head drop, the efficiency at each hour and, finally, the produced energy. A new solution is always generated from the previous one through a random pick between 0 and *k*, which represents the “distance” to the previous solution. To define this distance, the links are initially ordered by potential of energy production, obtained by an average production in each link with the maximum and minimum flows of the initial run, and the random pick is set to be the difference between the links’ indexes in this chain of potential.

The installation of one and two turbines without any restrictions in the network, apart from minimum pressure, was considered as reference for the calibration of the model in terms of initial point and generation of new solutions. The calibration of the algorithm with two turbines allowed to conclude that the following conditions gave the fastest convergence: use a high energy potential point for the beginning of the simulation; in the generation of a new solution there's always an augmentation of energy potential unless it's impossible; and in every 50 iterations the algorithm does not allow repetition when generating new solutions.

In Figure 2 are presented the results for 10 runs considering the installation of two turbines in these conditions, and for a maximum of 200 iterations In Table 1 the maximum and second maximum values for each run and the iteration of occurrence are shown.

Table 1. Caption heading for a table should be placed at the top of the table and within table width.

	BEST SOLUTION		**SECOND BEST SOLUTION**	
Run	**VALUE (MWH)**	**ITERATION**	**VALUE (MWH)**	**ITERATION**
1	128	60	116	1
2	128	40	116	1
3	116	1	101	81
4	128	122	116	1
5	128	96	116	1
6	128	59	116	1
7	128	149	116	1
8	116	1	116	143
9	128	101	116	1
10	116	1	110	65

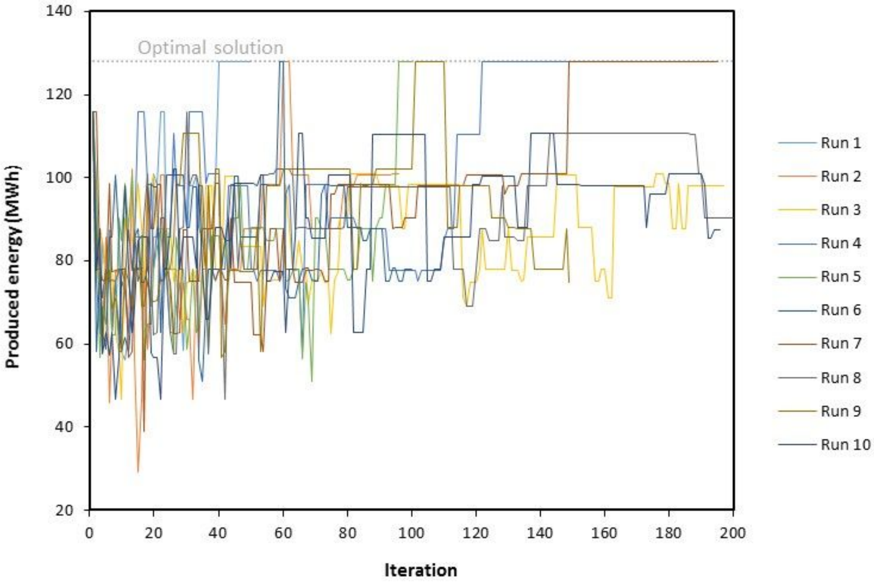

Figure 2. Progression of the 10 runs of the algorithm for the installation of two turbines without restrictions.

2. CONCLUSIONS

In this paper an algorithm to locate the optimal links in a meshed network to install micro-turbines was presented. The model uses a simulated annealing process with an hourly simulation of the produced energy in the network. The results herein showed proved through the application to a real case, that the implemented model converges when the installation of two turbines is envisaged. The algorithm proved to be robust, but improvements are still needed to verify the convergence with more than two turbines and with variable speed operations.

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