Evolutionary Multi-Objective Optimization of Micro Grids

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Motivation and Purpose

In order to design and simulate energy micro grids, a new simulation environment called *SMOOTH* (Simulation Model for Optimized Operation and Topology of Hybrid energy systems) is being developed at *RLI*. It allows the simultaneous simulation of integrated energy production units (e.g. photovoltaic, small scale wind turbines) as well as electric storage units and consumption loads (e.g. electric vehicles). An integral part of establishing *SMOOTH* as an effective planning tool is to develop an approach for optimizing a micro grid's design parameters regarding various objectives. Evolutionary algorithms (EA) were found to be along the most useful and promising methods in hybrid energy system design [1,2], so they are chosen as the principle optimization approach for *SMOOTH*. Since none of the existing EAs for hybrid energy systems optimization were capable of dealing with all of *SMOOTH*'s characteristics simultaneously it was necessary to compose a new multi-objective evolutionary algorithm (MOEA).

Approach and Research Object

Past and current research in the field of evolutionary optimization was reviewed, so that for each of the three main steps in the EA heuristic (selection, recombination, mutation) two candidate subroutines could be identified. Along with a newly developed approach for speeding up convergence of the optimization process, called tail band, the subroutines were cross-combined to form 16 MOEA variants. For comparison, a bi-objective test problem with *SMOOTH*'s characteristics was formulated. It represents an optimization problem in which 12 design parameters of a set of photovoltaic generators supplying a predefined load are to be optimized in such a way as to both minimize levelized cost of energy (LCOE) and maximize the system's self-sufficiency ratio (SSR), while satisfying a set of inequality constraints. To compensate for the semi-stochastic nature of EAs a sufficient number of optimization runs was conducted, so that the algorithm variants could be compared with statistical significance regarding ultimate optimization success, speed of convergence, scope of constraint violations and diversity within the MOEA's solution population.

In the following the algorithm variant identified as having superior performance, is called *SMOOTH-MOEA*

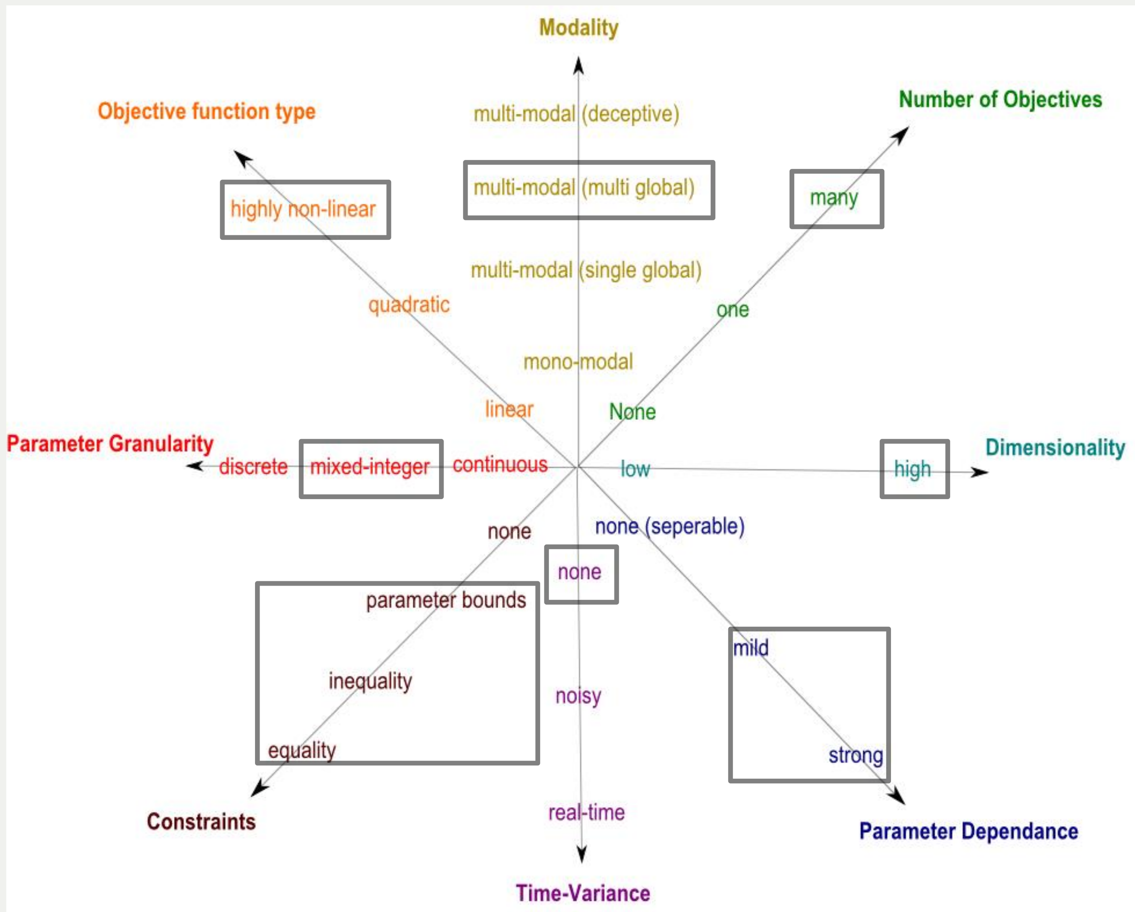

Figure 1: Optimization problem characterization; The micro grid model in *SMOOTH* can be characterized as a mixed-integer, non-linear, multi-modal, high-dimensional, and non-separable optimization problem with multiple objectives and various equality and inequality constraints.

Results

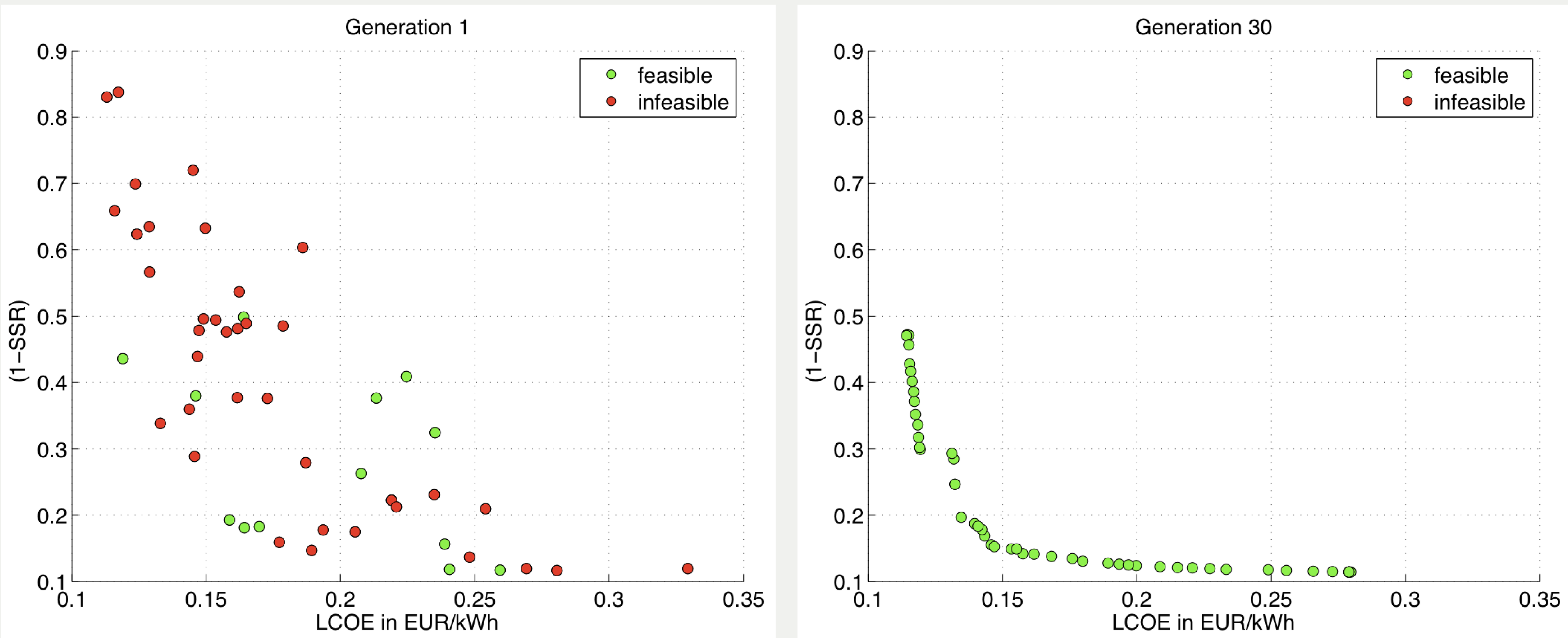

Figure 2: Evolution of the solution population, While in the first generation (left) the population mainly consists of infeasible solutions scattered across the objective space, the 30th generation (right) is completely feasible and has converged and lined up to form the pareto front. *SMOOTH-MOEA* ultimately generates the widest and most diverse pareto front with highest robustness of all variants while yielding comparable feasibility. The test problem demonstrates how multi-objective algorithms offer a better picture of optimality than any single-objective approach would have for either of the two objectives. For example, while the optimal solution for the maximization of SSR (minimization of 1-SSR) is close to 90%, it can be seen that a slight depreciation from this optimum down to an SSR of about 85% can reduce the LCOE by more than 40% (0.255 €/kWh to 0.150 €/kWh). Likewise, a slight increase of the minimum LCOE value permits a comparably large increase of the SSR.

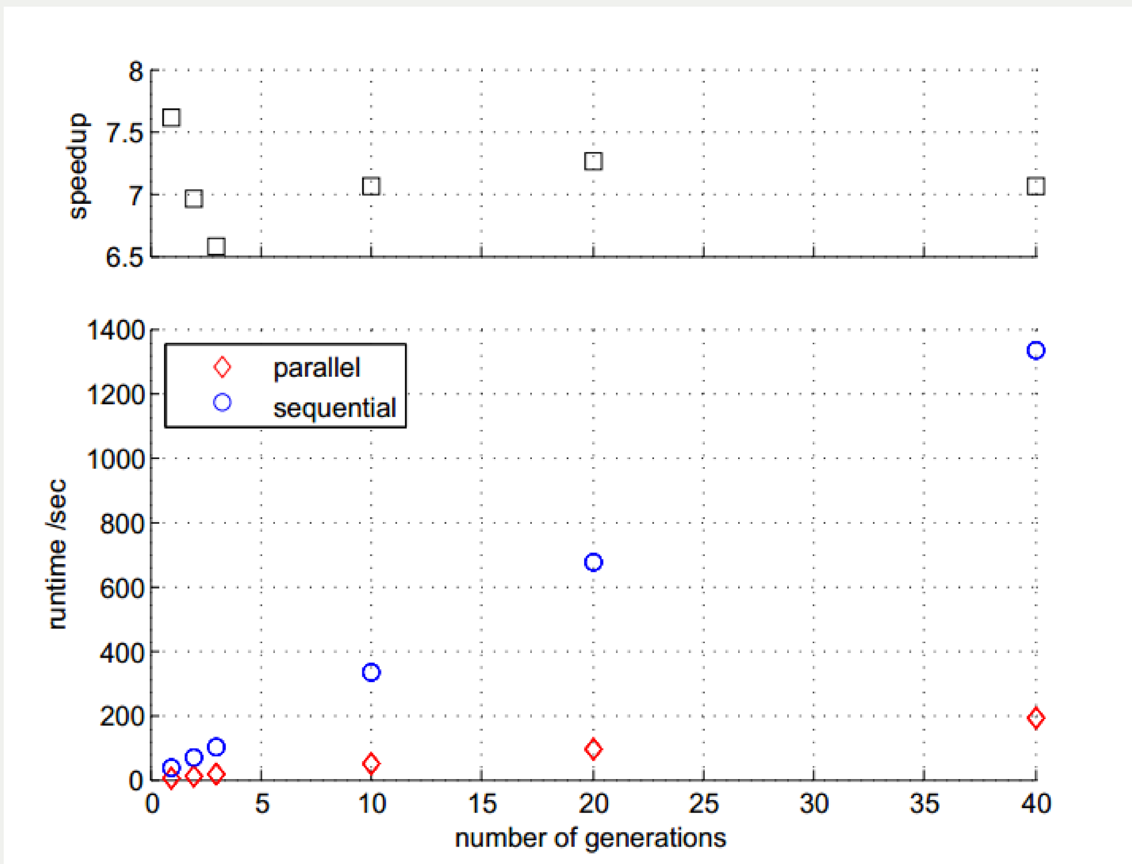

Figure 3: Speed of convergence and Parallelization, *SMOOTH-MOEA*'s selection scheme allows to parallelize optimization problem evaluations and thus the highest speed of convergence. Testing on eight workers compared sequential to parallel computation and showed that *SMOOTH-MOEA* achieves a speedup of around 7 which denotes a parallel efficiency of over 80%.

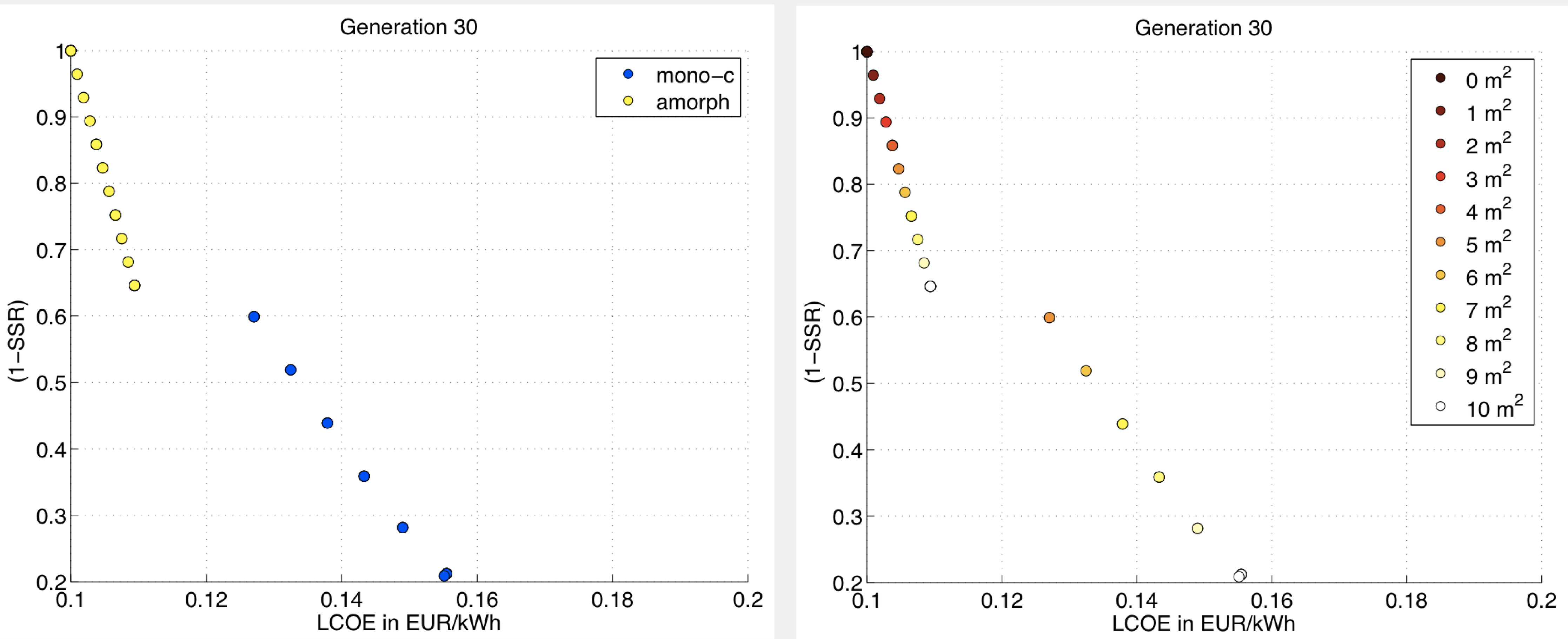

Figure 4: Pareto front of simplified PV problem colored according to parameters, Both azimuth and inclination angle are constant for all solutions (α ≈ 9° and γ ≈ 35°, respectively). The left graph demonstrates how a jump in the pareto curve correlates to a change in semiconductor quality. Low SSRs and low LCOE correlate with amorphous silicon technology. In order to increase SSR the PV generator's aperture is raised which increases LCOE at the same time (right). Once the maximum aperture of 10 m^2 is reached, the generator's peak power must be increased by switching to a technology of higher efficiency (here monocrystalline silicon), which causes a skip in the pareto front. *SMOOTH-MOEA* demonstrated effective and reliable convergence towards this sensible solution.

Conclusion

The algorithm variant identified as having superior performance, called *SMOOTH-MOEA*, demonstrated effective and reliable optimization behavior on the test problem. It converged the solution to a sensible tradeoff curve between the objectives of minimized LCOE and maximized SSR while satisfying the constraints 98% of the time. Due to its selection subroutine, *SMOOTH-MOEA* was found to be highly parallelizable, distributing the optimization function evaluations among separate workers with a parallel efficiency of over 80%. It can be expected that *SMOOTH-MOEA* is a suitable optimization algorithm for any other micro grid model exhibiting similar characteristics as *SMOOTH*. Its parallelizability allows reducing optimization time by a factor at the order of the number of available workers.

References
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[2] Banños R, Manzano-Agugliaro F, Montoya F, Gil C, Al-cayde A, Gómez J; Optimization methods applied to renewable and sustainable energy: A review; Renewable and Sustainable Energy Reviews; 15(4): 1753-1766; May 2011