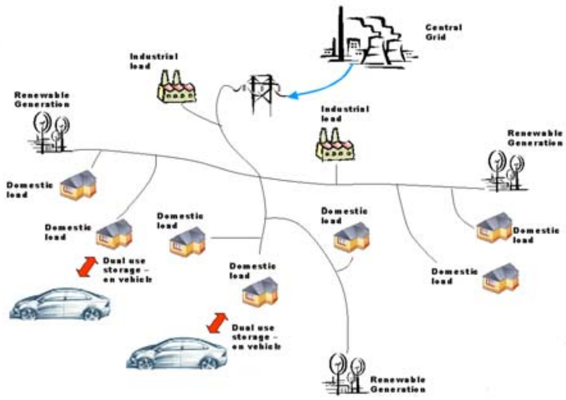
Multi-objective power network planning tool for high penetrations of Distributed Energy Resources with specific emphasis on Electric Vehicles

Steven Inglis (steven.inglis@strath.ac.uk), G.W.Ault, S.J.Galloway,
University of Strathclyde, Glasgow

Introduction: DER Planning

The integration of Distributed Energy Resources (DERs) in power systems presents substantial challenges to network planners. Assessing accurately the impact that DER will have is critical, as the specifics of the installed DER may affect: control of the network within limits; quality of supply; losses and financial objectives

To maximise benefits and minimise costs associated with the integration of DER, planning tools are required to indicate exactly where on the network controllable DER should be placed and how it should be operated. A modular and flexible planning methodology is required. This planning methodology should take into account the stochastic nature of power systems such as the fluctuations in DER production and electricity demand. This work investigates the effect that the inclusion of Electric Vehicles (EVs) will have on the distribution network when used as a responsive demand and dispatchable storage.



Approach

An existing network planning tool is extended with an extra module incorporating the stochastic and controllable nature of EVs. Results will illustrate optimal DER and EV integrations and network configurations with respect to chosen objectives. This planning tool offers network planners the most effective solutions to multi-objective problems.

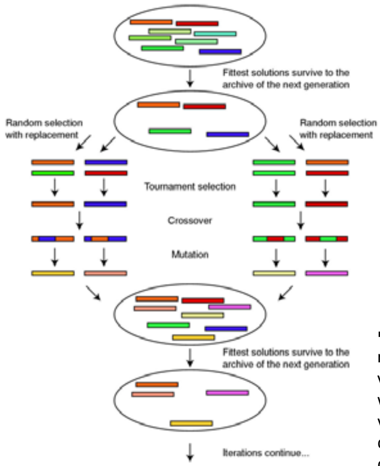
Multi-Objective DER Planning Problem with EV

- Use SPEA2 algorithm to optimise the following conflicting objectives:
  - **Minimise network investment and curtailment costs**
  - **Minimise carbon emissions**
  - **Maximise total annual benefits of all DER**
  - **Minimise cost of losses**
  - **Maximise DER network access (i.e. minimise curtailment)**
- Whilst adhering to the following technical constraints:
  - **Thermal line limits**
  - **Minimum acceptable battery state-of-charge**
  - **Maximum battery energy content (i.e. capacity)**
  - **Voltage limits**
- Other objectives could be added, such as **minimise voltage drop**, **minimise grid dependency**, **minimise electrical losses**, **maximise revenues for use of system**, **minimise curtailment payments**
- Optimal charging times could be communicated to the EV owner so charging occurs when electricity costs are low and power is taken from the battery to meet supply when costs are high.
- The multi-objective approach offers flexibility in terms of decision making and an insight into the benefits of EV energy storage with regards to the consumer and the network operator.
- Using an electric vehicle as a storage mechanism will **provide a means of supplying energy to the grid when the primary energy resources are not able to meet demand** – (for example during times of low wind) or when the consumer is informed via smart meter technology that the price of electricity will rise imminently.

Methodology

An extra module will be added incorporating both the stochastic and controllable nature of the electricity storage capacity of electric vehicles. Influencing and managing the placement on the network of EVs will be crucial in receiving optimal benefits whilst minimising the effects the inclusion of EVs will have at (LV). Network configurations are represented within the outer loop investment optimisation problem to allow various network architectures to be selected to complement the DER portfolio

The Strength Pareto Evolutionary Algorithm 2 (SPEA2)



The network planning tool that will be used to optimise the inclusion of EV is based around the Strength Pareto Evolutionary Algorithm 2

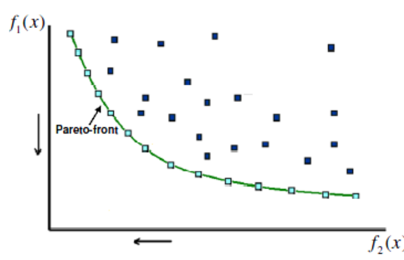
The SPEA2 is a highly regarded Multi-objective heuristic algorithm for use in a wide range of conflicting power system problems. SPEA2 is a type of Genetic Algorithm (GA) that is strongly based on the evolutionary theorem. Hence, the idea of the improvement in genes through survival of the fittest until a final optimal genetic solution is achieved, is a familiar one. SPEA2, like any other GA, aims to produce a final set of optimal solutions, for the Multi-objective problem, that represent the Pareto front.

- The **initial population** is created. Each chromosome representing a plan for optimal siting and sizing of electric vehicles when used as dispatchable storage. Each gene within each chromosome, representing an individual electric vehicle battery of a specific size at a specific node on the distribution network. The initial population is crucial for diversity and speed of convergence towards the final set of solutions.
- A **fitness value** is assigned to each chromosome relative to the success of the siting and sizing of the Electric Vehicles with respect to the chosen set of multi-objectives, detailed in the objective evaluation.
- SPEA2 is an **elitist** GA, allowing for the fittest individuals from the previous generation to survive into the next generation. Hence the fittest individuals are stored in an external archive.
- **Population variation**, to maintain **diversity**, is then achieved during each successive generation through Tournament selection, Crossover and Mutation.
- **Tournament selection** mimics the natural process of competition for mating, comparing chromosomes for the right to reproduce.
- **Crossover** swaps genes within good chromosomes to produce "offspring".
- **Offspring Mutation** is then carried out to maintain population diversity through exploration of previously uncharted decision space regions. The greater the diversity, the greater the chance of locating the optimal set of solutions.
- **Fitness assignment**, to be stored in the external archive for the next generation, is then carried out on the mutated offspring of the previous generation. The generation updating process is continued until the final set of solutions cannot be improved, or until a specified generation count has reached its limit.
- When comparing SPEA2 to other state of the art MOEA (NSGA-II, MOGA and VEGA) it has been shown that SPEA2 is **more accurate, computationally faster** and outperforms other MOEA in both theoretical and practical applications and is the most efficient, even in a small number of generations [1].

[1] Skolpadungket, P., Dahal, K. "Portfolio Optimization using Multi-objective Genetic Algorithms", Proceedings of the 2007 IEEE Congress on Evolutionary Computation, IEEE Press, Singapore, September 2007

Output

The expected output from the SPEA2 will resemble the diagram below. The final set of solutions that cannot be improved upon are represented by the Pareto front. Each square dot on the Pareto front represents a specific solution that is optimal in its own way.



A Pareto set for a two objective optimisation

Conclusion

A multi-objective planning method will obtain a set of Pareto Optimal DER and EV integrations and network configurations. The multi-objective approach will offer flexibility in terms of decision making and an insight into the benefits of EV energy storage with regards to the consumer and the network operator.

Electric Vehicle integration and operational configurations will be identified that offer the greatest value for the Distribution Network Operator.

This offers decision makers options relating to the optimal siting, sizing and operational management of electric vehicles. The ultimate aim of this planning approach is to offer network planners effective solutions to multi-objective problems.

The basis for this research is a methodology based upon a multi-objective planning tool that will analyse and optimise the integration of EV as dispatchable storage into the distribution network at LV with consideration of higher voltage level networks as well.