MSc Dissertation Daybook
MSc in Sustainable Energy Systems

Optimal Scheduling of Electric Vehicle Charging in Distribution Networks

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March to August 2017

Daybook – Table of Contents

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ID	Date	Commit Message
133ff87	Sat Aug 5 13:44:02 2017	evaluation in MATLAB
bd10f98	Fri Aug 4 21:08:11 2017	monte carlo evaluation
e340526	Thu Aug 3 10:10:42 2017	minor
4fdf037	Thu Jul 27 17:17:59 2017	minor
0696c7f	Tue Jul 25 19:55:03 2017	misc evaluation
f9a8c75	Sat Jul 22 12:07:03 2017	Data evaluation in MATLAB
38dd3d6	Mon Jul 17 13:36:11 2017	matlab figures
8e97a52	Mon Jul 17 11:41:10 2017	update TODOs/COULDDOs
6e012b3	Mon Jul 17 11:34:01 2017	organise imports
7c60d2f	Mon Jul 17 11:33:17 2017	enhanced log for multiple configurations (unique folders)
c4cfa54	Mon Jul 17 10:10:22 2017	document evalParams
00bcce0	Sun Jul 16 21:34:28 2017	test
8f8f00f	Sun Jul 16 21:07:14 2017	list of experiments
0c5d950	Sun Jul 16 21:05:45 2017	make voltage constraints optional + matlab evaluation
8a71abf	Sun Jul 16 19:49:23 2017	checked reference optimisation
29c1a70	Sun Jul 16 13:52:18 2017	full knowledge optimisation for evaluation. TO BE CHECKED!
3f16eb0	Sun Jul 16 11:51:55 2017	uncertainty demand by shift representation
6d3dcb8	Sun Jul 16 11:27:19 2017	demand uncertainty max implementation
8be39c4	Fri Jul 14 19:43:49 2017	availability uncertainty mitigation by penalty in LP
801b9fa	Fri Jul 14 18:42:31 2017	pep8 style adjustment
144041b	Fri Jul 14 18:04:46 2017	docstrings
e6f20ed	Fri Jul 14 15:55:18 2017	additional monitors
2418706	Fri Jul 14 15:31:02 2017	tidy
956364d	Fri Jul 14 14:40:31 2017	organise imports
3bb6fcc	Fri Jul 14 14:36:46 2017	Merge branch 'master' of https://github.com/orley-enterprises/ev_chargingcoordination2017.git
90e8de3	Fri Jul 14 14:36:11 2017	individual households in log in separate folder
9dc8511	Fri Jul 14 14:36:11 2017	individual households in log in separate folder
ac0d39b	Fri Jul 14 14:31:54 2017	clean commit (reorganisation, comments, reformat)
bd6773a	Thu Jul 13 17:49:19 2017	price_uncertainty difference per slot - sense?
7874be5	Thu Jul 13 12:25:19 2017	modify log
627a7b7	Thu Jul 13 12:15:51 2017	MC simulation log
1c6bdbb	Wed Jul 12 15:35:17 2017	comments
ffee496	Wed Jul 12 15:30:25 2017	thermal loading sensitivity incorporation
a55f05e	Wed Jul 12 11:15:34 2017	gurobi implementation LP with additional constraints and target
d53386b	Tue Jul 11 14:47:27 2017	2nd networkGREEDY with voltage sensitivities
b285f32	Tue Jul 11 14:47:04 2017	networkGREEDY with voltage sensitivities
6a6793c	Tue Jul 11 12:44:54 2017	voltage sensitivity matrix
7f90022	Sun Jul 9 18:26:57 2017	check

ef9408d	Sun Jul 9 17:56:36 2017	check
f7845a3	Sun Jul 9 15:54:20 2017	uncertainty mitigation prob, penalty, output availability prob
fa441b0	Fri Jul 7 19:15:09 2017	demand security margin
1e8b414	Fri Jul 7 18:09:22 2017	shift
2653c98	Fri Jul 7 17:53:17 2017	overload constraint NG, GA/PSO speed control, schedule on arrival impl.
3605b4b	Fri Jul 7 13:41:31 2017	documents
e47f2d7	Fri Jul 7 13:41:09 2017	minor
c27899e	Thu Jul 6 15:18:20 2017	clean commit
09246da	Thu Jul 6 12:26:14 2017	line thermal limits, vizualisation, red noise
6cd57da	Wed Jul 5 17:09:30 2017	closing commit for today
33efee8	Wed Jul 5 16:49:22 2017	delete
86f8c38	Wed Jul 5 16:47:53 2017	comparison adjustments
270f62d	Wed Jul 5 15:08:25 2017	manual urgency order (joint partial feeders in order)
6b172af	Wed Jul 5 14:11:54 2017	urgency by electrical distance (networkGREEDY)
27b77d1	Wed Jul 5 11:50:16 2017	accurate constraint observation in networkGREEDY
6fc4c5e	Wed Jul 5 10:04:35 2017	solved voltage inconsistencies
0a1fc2c	Tue Jul 4 18:33:45 2017	mileage multiplier added
c9f5c18	Tue Jul 4 16:48:24 2017	schedule reality adjustment
a166094	Tue Jul 4 16:00:26 2017	testing
0a47a98	Tue Jul 4 14:53:37 2017	avoid negative parameters mu & sigma for normal distributions
8d5dcda	Tue Jul 4 12:52:31 2017	sort logs
3491eb1	Mon Jul 3 16:44:14 2017	load multiplier for more challenging network state
92a2c78	Mon Jul 3 14:16:32 2017	progress display
904db29	Mon Jul 3 14:11:08 2017	multiple penetration levels possible
4b4266c	Mon Jul 3 12:09:36 2017	minor
0c86f9f	Mon Jul 3 11:49:31 2017	log extension, monte carlo simulations and PSO implementation
5dd94ba	Mon Jun 26 11:24:37 2017	comments / reorganise
de6f44f	Mon Jun 26 10:54:21 2017	first genetic algorithm
3e273a1	Sun Jun 25 14:23:13 2017	network based greedy optimisation implemented, voltage inconsistency
159a56c	Sat Jun 24 13:16:01 2017	timer added
08867bb	Sat Jun 24 12:52:27 2017	generate some new result files
c2904dd	Sat Jun 24 12:51:08 2017	minor
3f40254	Sat Jun 24 12:50:41 2017	added file export of result matrices
93a9017	Sat Jun 24 12:45:22 2017	some comments added
5448102	Sat Jun 24 12:42:45 2017	slotwise aggregate evaluation added
a7a4090	Sat Jun 24 10:16:48 2017	Set voltage base to 230V instead of 240V + add voltage and schedule logs
ad75df6	Fri Jun 23 22:47:16 2017	added voltage profile extraction and logs
1910878	Fri Jun 23 11:26:46 2017	Implement log outputs and introduce some calculations on results.
ac4fb3c	Thu Jun 22 17:28:34 2017	result handling started

4720c24	Thu Jun 22 13:40:58 2017	output formats
40cb342	Thu Jun 22 13:37:00 2017	As Fast As Possible Charging Routine
b4601f0	Wed Jun 21 19:38:15 2017	delete obsolete load profiles
1fdbe7a	Wed Jun 21 19:36:30 2017	household specifications
562527f	Wed Jun 21 17:52:45 2017	reordering
2921c65	Wed Jun 21 12:48:12 2017	readme
8a0af7f	Wed Jun 21 12:47:06 2017	forecast generation
61ce16f	Tue Jun 20 21:44:28 2017	gitignore
b94f14b	Tue Jun 20 21:43:55 2017	daily clean update
bb74b67	Tue Jun 20 21:41:52 2017	fitter for scipy format + vehicle specification class
a836640	Tue Jun 20 17:56:26 2017	scenario1
1cfdaa1	Tue Jun 20 17:54:47 2017	scenario
cc43f51	Tue Jun 20 10:02:48 2017	merge parameters and runner
24665cc	Tue Jun 20 10:01:19 2017	restructuring
d197cc4	Thu Jun 15 17:56:46 2017	seasonal sampled pv time series
e2e9182	Thu Jun 15 16:53:42 2017	price and demand time series
9089135	Thu Jun 15 12:19:13 2017	parameters first commit
1131800	Thu Jun 1 12:02:11 2017	network integration
51dbc6b	Thu Jun 1 10:07:59 2017	add network
06bb4f0	Thu Jun 1 09:33:57 2017	project files
733c258	Thu Jun 1 09:32:59 2017	First commit
9107451	Wed May 31 16:21:41 2017	Initial commit

Optimal scheduling of EV charging in distribution networks

Mission Statement

Student: Fabian Neumann Matric. No.: s1674190

Supervisor: Wei Sun

Summary and initial literature review

The transport sector accounts for a significant proportion of total energy consumption and is to date largely based on fossil fuels. With the objective to mitigate greenhouse gas emissions and become environmentally benign, the electrification of transport has progressed considerably by continuous development of hybrid and purely electric vehicles. However, conditions apply to achieve sustainability. First, the additional load of uncontrolled residential EV charging will negatively impact the low-voltage distribution network. Effects include excessive voltage drops and overloading of network components when many EVs charge simultaneously [1]. Second, a decarbonisation of electricity generation must accompany the expansion of electric vehicles. Consequently, increased intermittent renewable energy generation will add to the need for smart grid management.

While investment in major network reinforcement is an intuitive measure to incorporate additional loads, it is deemed more economically efficient to encourage EV users to charge at off-peak times. Exploiting typical load flexibility of electric vehicles by controlled charge scheduling as means of demand-side management will allow substantial penetration levels in existing distribution networks and a mitigation of the network strains they evoke. This can be achieved by simple charge rate modulation with unidirectional power flow or additionally the provision of ancillary services to the system operator with bidirectional power flow [1]. The electric vehicle unites aspects of an energy consumer and a regulation provider simultaneously.

For users of electric vehicles to engage in coordinated charging and give up part of their flexibility, attractive monetary incentives and low acceptance barriers are essential.

Real-time electricity prices and time-varying regulation market clearing prices are both, a reflection of the general network state and a source of cost minimisation potential for consumers. For the small-scale capacities of individual electric vehicles to gain access to large-scale wholesale electricity and regulation prices an intermediary is necessary to which multiple consumers surrender charging control. This so-called aggregator optimises electricity bill savings and revenue from the provision of regulation services while observing network, equipment and demand constraints [3].

Whilst the commonly stated range anxiety of users of electric vehicles has been largely solved by the advent of modern Li-ion batteries, reliability and battery degradation remain major concerns besides high investment costs [1]. The latter may be solved by participation in power markets, whereas the former highlights the need for optimised charging schedules to avoid control sequences detrimental to battery life. Examples are the avoidance of large variations in charging rate over consecutive time steps, limitations on the depth of discharge or the minimisation of frequent charge and discharge cycles.

The availability of electric vehicles is often regarded as key determinant of load shifting potential and pre-set arrival/departure times are enforced by contractual obligations [2]. Although breaches of contracts occur, these are rarely considered during optimisation and may be penalised. Planning uses fixed arrival and departure times. Even if the arrival times are stochastic, EV owners are usually asked to specify their expected departure time and required battery charge to the aggregator for optimisation purposes. A relaxation of such constraints on users of electric vehicles would facilitate widespread adaptation of EV charging control, as besides flexibility of use it omits inconvenient latency and diligence in communication. However, it also permits further uncertainty to the optimisation [5]. To ensure a reliable battery charging processes, permitted uncertainty requires consideration by accurate prediction in conjunction with other, more inherent sources of uncertainty. Assessment of their impact on the performance of centralised charge control will be a principal contribution of this dissertation project.

Whilst on an aggregate scale consumer behaviour is quite accurately predictable, forecasts on an individual basis are prone to substantial deviations [2]. Inherent uncertainties besides the indeterminate arrival/departure times and locations are the battery state of charge upon arrival, residential load including the variability of possible local PV generation, and market prices for wholesale electricity from which cost savings are obtained and regulation services from which revenue is generated. Their negligence may entail severe economic losses to consumers and, thus, require accurate modelling. Other than multiple previous research works, likely deviations from market price forecasts will be considered for optimisation [4]. Furthermore, the coupling of vehicle-to-grid application and local generation as supplemental source of variability to residential loads is novel, but its significance must yet be determined depending on their level of coincidence.

In the light of newly introduced sources of uncertainty, previously utilised optimisation approaches will be implemented, adapted and tested for their performance in minimising EV charging cost and risk of load mismatch between forecasted and actual EV loads. Amongst others, receding optimisation horizons will be applied as means of uncertainty mitigation [2]. Dynamic programming, mixed-integer non-linear programming, heuristics, particle swarm optimisation, and genetic algorithms rank high among the most commonly applied optimisation techniques [1].

Main aims and objectives

- Develop a cost-minimising bidirectional scheduling algorithm for charging electric vehicles and supplying ancillary services. While observing network, equipment and demand constraints in a stochastic environment, the algorithm should combine consumer electricity bill savings with grid support. Academically, it should further enable the study of a potential trade-off between permitted uncertainty in terms of EV availability and low consumer acceptance hurdles of remote EV charging control.

- Characterise inherent and permitted uncertainties incurred with the optimal scheduling of EVs and evaluate their individual impact on optimisation at varying error margins.

- Analyse the implications of relaxing contractual obligations for the consumers' EV availability and the aggregator's allocation of final battery state of charge.

- Assess the performance of multiple optimisation methods under uncertainty and approaches to mitigate their sensitivity to prediction errors; that is to give an indication of the effectiveness and robustness of analytical, heuristic and artificial intelligence approaches.

- Evaluate the scalability of an aggregator not only in view of computational complexity but also of the interplay with varying degrees of uncertainty.

- Provide insights about the prospects of vehicle-to-grid technologies.

Interim targets

- Demonstrate the negative impact of uncontrolled EV charging on distribution networks, provide a review of electricity market mechanisms, make a case for demand-side management, and legitimate central control by an aggregator.

- Identify potential facilitators and prevalent barriers for EV owners' engagement with aggregators which require consideration in the analysed scenario.

- Compile and structure previously performed research on the optimal scheduling of electric vehicles and related research areas by summarising underlying assumptions, scenarios, approaches to system modelling, objective functions, enforced constraints, and applied optimisation methods.

- Learn or refresh methodological skills in the fields of stochastic programming, particle-swarm optimisation, genetic algorithms, dynamic programming, Markov chains and statistical applications for scenario reduction and time-series analysis.

- Decide on a suitable programming environment that equally satisfies requirements for and accurate representation of the reality and an efficient implementation of optimisation methods while maintaining a high degree of generalisability.

- Acquire empirical or representative data of mobility travel patterns, residential load, local PV generation, electricity prices, and regulation service prices.

- Build scenario via representative models of
  - a test distribution network defining network constraints allowing for variable penetration levels,
  - stochastic consumer behaviour including arrival/departure times as well as energy demand,
  - physical residential systems including electric vehicle attributes and local PV generation, and
  - electricity and regulation service markets providing information on the general network state.

- Define a fitting mathematical problem formulation.

Methodology and draft work plan

The dissertation will be an optimisation study based on a developed simulation model which forms the basis for project evaluation. It is yet to be decided which programming platform is deemed most suitable for the proposed undertaking. Because of the consecutive character of the project, the work programme builds naturally.

The main tasks will consist of

(a) a comprehensive literature review,	(0.5 weeks)	[after previous work]
(b) the mathematical problem formulation,	(0.5 weeks)	
(c) thoughtful system and behaviour modelling,	(2.5 weeks)	
(d) implementation of optimisation methods,	(2.5 weeks)	
(e) evaluation and critical analyses of results,	(1 week)	[without overlap]
(f) dissertation write-up,	(3 weeks)	
(g) final editorial works and time buffer.	(2 weeks)	

Of the tasks, only the literature review has been performed to date mostly in preparation of this mission statement. A multitude of journal articles has been reviewed and will be compiled insightfully upon commencement of the main project phase in mid-May. The sequence of subsequent activities following the exam period is outlined in the calendar on the next page.

1	Mo	15	May	Finalise literature review
	Tu	16	May	
	We	17	May	
	Th	18	May	Define setting/assumptions
	Fr	19	May	Problem formulation
	Sa	20	May	
	Su	21	May	
2	Mo	22	May	Modelling
	Tu	23	May	
	We	24	May	Torness plant visit
	Th	25	May	
	Fr	26	May	
	Sa	27	May	
	Su	28	May	
3	Mo	29	May	
	Tu	30	May	
	We	31	May	
	Th	1	June	
	Fr	2	June	
	Sa	3	June	
	Su	4	June	
4	Mo	5	June	
	Tu	6	June	
	We	7	June	
	Th	8	June	Implement optimisations
	Fr	9	June	Project presentation
	Sa	10	June	
	Su	11	June	
5	Mo	12	June	
	Tu	13	June	
	We	14	June	
	Th	15	June	
	Fr	16	June	
	Sa	17	June	
	Su	18	June	

6	Mo	19	June	
	Tu	20	June	
	We	21	June	
	Th	22	June	
	Fr	23	June	Scholarship seminar
	Sa	24	June	(tentative)
	Su	25	June	
7	Mo	26	June	
	Tu	27	June	
	We	28	June	Holiday
	Th	29	June	
	Fr	30	June	
	Sa	1	July	
	Su	2	July	
8	Mo	3	July	Evaluation / Analysis
	Tu	4	July	(extends into write-up)
	We	5	July	
	Th	6	July	
	Fr	7	July	Examiner interview
	Sa	8	July	Write-up
	Su	9	July	
9	Mo	10	July	
	Tu	11	July	
	We	12	July	
	Th	13	July	
	Fr	14	July	
	Sa	15	July	
	Su	16	July	
10	Mo	17	July	
	Tu	18	July	
	We	19	July	
	Th	20	July	
	Fr	21	July	
	Sa	22	July	
	Su	23	July	

11	Mo	24	July	
	Tu	25	July	
	We	26	July	
	Th	27	July	
	Fr	28	July	
	Sa	29	July	
	Su	30	July	
12	Mo	31	July	Submission of final draft
	Tu	1	August	Editorial and review
	We	2	August	
	Th	3	August	
	Fr	4	August	
	Sa	5	August	
	Su	6	August	
13	Mo	7	August	Poster design
	Tu	8	August	
	We	9	August	
	Th	10	August	
	Fr	11	August	Final review
	Sa	12	August	
	Su	13	August	
14	Mo	14	August	Dissertation printing
	Tu	15	August	Submission dissertation/poster
	We	16	August	Preparation of presentation
	Th	17	August	
	Fr	18	August	
	Sa	19	August	
	Su	20	August	
15	Mo	21	August	Poster printing
	Tu	22	August	Poster presentation

Required resources

None whatsoever.

Health and safety implications

(a) A preliminary health and safety assessment anticipates no extraordinary risks involved in conducting the proposed project other than prolonged use of computers. Since no laboratory work is required and dissertation results will stem from computer simulations only, potential risks that deviate from ordinary office work are non-existent. This issue, however, was addressed in the General Risk Assessment Form RA1 as attached and further supplemented by the Display Screen Equipment Risk Assessment Form DSE.

(b) An actual implementation of the project outcomes is not expected to add major health and safety risks to the operation of low-voltage distribution networks. This is because no equipment with safety standards and risk implications deviating substantially from equipment in use is required. Naturally, failure of the proposed control scheme entails similar if not higher risk implications as ordinary distribution network failures. However, as under normal conditions intelligent control aims to mitigate detrimental impacts on the network, a decrease rather than an increase in hazards is anticipated overall. Nonetheless, at the current stage no informed statement on the change in reliability can be made.

References

[1] Kang Miao Tan, Vigna K. Ramachandaramurthy, Jia Ying Yong, "Integration of Electric Vehicles in Smart Grid: A Review on Vehicle to Grid Technologies and Optimization Techniques," in *Renewable and Sustainable Energy Reviews*, vol. 53, pp. 720-732, January 2016.

[2] A. O'Connell, D. Flynn and A. Keane, "Rolling Multi-Period Optimization to Control Electric Vehicle Charging in Distribution Networks," in *IEEE Transactions on Power Systems*, vol. 29, no. 1, pp. 340-348, Jan. 2014.

[3] S. Han, S. Han and K. Sezaki, "Development of an Optimal Vehicle-to-Grid Aggregator for Frequency Regulation," in *IEEE Transactions on Smart Grid*, vol. 1, no. 1, pp. 65-72, June 2010.

[4] Wenbo Shi and V. W. S. Wong, "Real-time Vehicle-to-Grid Control Algorithm Under Price Uncertainty," *2011 IEEE International Conference on Smart Grid Communications (SmartGridComm)*, Brussels, pp. 261-266, 2011.

[5] F. Soares, J. Lopes, P. Almeida, C. Moreira, and L. Seca, “A Stochastic Model to Simulate Electric Vehicles Motion and Quantify the Energy Required From the Grid,” in *Proc. 17th Power Systems Computation Conf.*, 2011.

Declaration

The supervisor and the student are satisfied that this project is suitable for performance and assessment in accordance with the guidelines set out in the course documentation.

Signed: 21 April 2017

Wei Sun – *Supervisor* Fabian Neumann – *Student*

General Risk Assessment

Form RA1

(Refer to Notes for Guidance before completing this form)

School Assessment No:	
Title of Activity:	MSc Dissertation
Location(s) of Work:	University accommodation, university library, supervisor's office for meetings.
Brief Description of Work: The dissertation is on the optimal charging control of electric vehicles in distribution networks. While the topic is based in electrical engineering, no laboratory work is required, but the project is solely based on computer simulations. Prolonged use of computers is anticipated.	

Hazard Identification: Identify all the hazards; evaluate the risks (low / medium / high); describe all existing control measures and identify any further measures required. Specific hazards should be assessed on a separate risk assessment form and cross-referenced with this document. Specific assessments are available for hazardous substances, biological agents, display screen equipment, manual handling operations and fieldwork. See http://www.ed.ac.uk/schools-departments/health-safety/risk-assessments-checklists/risk-assessments for details.

Hazard(s)	**Present Risk** **Evaluation** L/M/H	**Control Measures** (i.e., alternative work methods / mechanical aids / engineering controls, etc.)	**Risk** **Evaluation after control** L/M/H
Prolonged use of computer; work on computer screen.	M	- Daily check on time spent in front of computer screen. - Limit affected working hours to 8 hours per day. - cf. Display Screen Equipment Risk Assessment Form for more detailed assessment and mitigation proposals.	L

**Continue on separate sheet if necessary*

Engineering Controls: *Tick relevant boxes*

Guarding		Extraction (LEV)		Interlocks		Enclosure	
Other relevant information (incl. testing frequency if appropriate):							

Personal Protective Equipment (PPE): Identify all necessary PPE.

Eye / Face		Hand /Arm		Feet / Legs		Respiratory	
Body (clothing)		Hearing		Other (Specify)			
Specify the grade(s) of PPE to be worn:							
Specify when during the activity the item(s) of PPE must be worn:							

Non-disposable items of PPE must be inspected regularly and records retained for inspection

Persons at Risk: Identify all those who may be at risk.

Academic staff		Technical staff		P'Grad students	x	U'Grad students	
Maintenance staff		Office staff		Cleaning staff		Emergency personnel	
Contractors		Visitors		Others			

Additional Information: Identify any additional information relevant to the activity, including supervision, training requirements, special emergency procedures, requirement for health surveillance etc.

None required whatsoever.

Assessment carried out by:

Name:	Fabian Neumann	Date:	21/04/2017
Signature:		Review Date:	21/04/2017

Display Screen Equipment/Workstation Risk Assessment:

Introduction

The following checklist is designed to allow an assessment of individual Display Screen Equipment (DSE) workstations to be carried out, in terms of the Health and Safety (Display Screen Equipment) Regulations 1992, and associated guidance.

Users should be encouraged to carry out their own risk assessment, which will then be checked by the Local Safety Adviser. A new risk assessment needs to be carried out if there is a change of user, a change in equipment, or in location/set up.

Work through the checklist, ticking either the "yes" or "no" column against each risk factor:

- "yes" answers require no further action.
- "no" answers will require investigation and/or remedial action by the Local Safety Adviser. They should record their decisions in the "Action to take" column. Assessors should check later that actions have been taken and have resolved the problem.

Please note that, though a characteristic of the workstation may not precisely match the advice given in the Regulations and Guidance, remedial action will not require to be applied if the user in question is satisfied with the item, and desires no change.

Remember the checklist only covers the workstation and work environment. You also need to make sure that risks from other aspects of the work are avoided, for example by giving users health & safety training, and providing for breaks or changes of activity. Advice on these is given in the main text of the guidance.

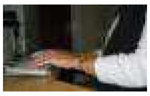
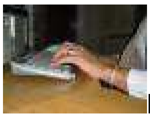
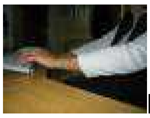
Record of Assessment

Workstation location: (School, Division, Unit etc., building, room no & floor)	*Primary: University accommodation* *Secondary: University libraries*
Name of User:	*Fabian Neumann*
Assessment completed by:	*Fabian Neumann*
Assessment checked by:	
Date of Assessment:	*21/04/2017*
Any further action needed? Yes / No Please specify action required.	*No*
Follow up action completed on:	

Assessment Checklist

Risk Factors	Yes / No		Things to Consider	Action to take
1. DISPLAY SCREENS				
Are the characters clear and readable?	X		Make sure the screen is clean and cleaning materials are made available. Check that text and background colours work well together.	
Is the text size comfortable to read?	X		Software settings may need adjusting to change text size.	
Is the image stable, i.e. free of flicker?	X		Try using difference screen colours to reduce flicker, e.g. darker background and lighter text, increase refresh rate of monitor setting. If problem persists, contact your IT.	
Is the screen's specification suitable for its intended use?	X		For example, intensive graphic work or work requiring fine attention to small details may require large display screens.	
Are the brightness and /or contrast adjustable?	X		Separate adjustment controls are not essential, provided the user can read the screen easily at all times.	

Does the screen swivel and tilt?	X		Swivel and tilt need not be built in; you can add a swivel and tilt mechanism. However, you may need to replace the screen if: - Swivel/tilt is absent or unsatisfactory - Work is intensive; and/or -The user has problems getting the screen to a comfortable position. The height of the screen should be roughly at eye level. A monitor stand may be required. If using an LCD screen, ensure it is adjustable in height, alternatively use a monitor stand.	
Is the screen free from glare and reflections?	X		Find the source of the reflections. You might need to move the screen or even the desk and/or shield the screen from the source of the reflections. Screens that use dark characters on a light background are less prone to glare and reflections.	
Is the user facing the screen.	X		Position the screen in front of the user, to avoid any twisting.	
Are adjustable window coverings provided and in adequate condition?	X		Check that curtains/blinds are in good working order. If not, report to Estates and Buildings. If these measures do not work, consider anti-glare screen filters as a last resort and seek specialist help.	
2. KEYBOARDS				
Is the keyboard separate from the screen?		X	This is a requirement, unless the task makes it impracticable (e.g. where there is a need to use a portable computer).	Use of portable computer and changing workplaces makes separate keyboard impracticable; primarily separate keyboard when university library monitor is used as secondary screen.

Does the keyboard tilt?		X	Tilt need not be built in	Possibly achieved with lapdesk.
Is it possible to find a comfortable keying position?  YES NO NO	X		Try pushing the display screen further back to create more room for the keyboard, hands and wrists. Keep elbows close to the body, do not overstretch the arms. Users of thick, raised keyboards may need a wrist rest. Users may find the use of a compact mini-keyboard more comfortable.	
Does the user have good keyboard technique?	X		Training can be used to prevent: - hands bent up at wrist - hitting the keys too hard - overstretching the fingers	
Are the characters on the keys easily readable?	X		Keyboards should be kept clean. If characters still cannot be read, the keyboard may need modifying or replacing. Use a keyboard with a matt finish to reduce glare and/or reflection.	
3. MOUSE, TRACKBALL, ETC				
Is the device suitable for the tasks it is used for?	X		If the user is having problems, try a different device. The mouse and trackball are general-purpose devices suitable for many tasks, and available in a variety of shapes and sizes. Alternative devices such as touch screens may be better for some tasks (but can be worse for others). Check the device has been set to suit the user (for right or left hand user).	
Is the device positioned close to the	X		Most devices are best placed as close as possible e.g. right beside the keyboard.	

user?  NO  YES 			Training my be needed to: -prevent arm overreaching -tell users not to leave their hand on the device when it is not being used - encourage a relaxed arm and straight wrist. A compact keyboard will help the user to avoid overreaching.	
Is there support for the device user's wrist and forearm?	X		Support can be gained from, for example, the desk surface. If not, a separate supporting device (gel filled) may help. The user should be able to find a comfortable working position with the device.	
Does the device work smoothly at a speed that suits the user?	X		Check if cleaning is required (e.g. of mouse ball and rollers). Check the work surface is suitable. A mouse mat may be needed.	
Can the user easily adjust software settings for speed and accuracy of pointer?	X		Users may need training in how to adjust device settings.	
4. SOFTWARE				
Is the software suitable for the task?	X		Software should help the user carry out the task, minimise stress and be user-friendly. Check users have had appropriate training in using the software. Software should respond quickly and clearly to user input, with adequate feedback, such as clear messages.	

5. FURNITURE				
Is the work surface large enough for all the necessary equipment, papers etc?	X		Create more room by moving printer, reference materials etc elsewhere. Use multilevel trays for papers/documents. If necessary, consider providing new power and telecom sockets, so equipment can be moved. There should be some scope for flexible rearrangement.	
Can the user comfortably reach all the equipment and papers they need to use?	X		Rearrange equipment, papers etc to bring frequently used things within easy reach. A document holder may be needed, positioned to minimise uncomfortable head and eye movements.	
Are the surfaces free from glare and reflection?	X		Consider mats or blotters to reduce reflections or glare.	
Is the chair stable & suitable for the user? Does the chair have a working: - seat back height and tilt adjustment? - Seat height adjustment? - Swivel mechanism? - Castors or glides?	X		The chair may need repairing or replacing if the user is uncomfortable, or the adjustment mechanisms are faulty. Contact the University Furniture Office.	
Is the chair adjusted correctly?	X		The user must be familiar with the chair adjustments. Adjust the chair height to sit with elbows at approx. 90º & 2cm above the desk when touching the G & H keys.	

			The user should be able to carry out their work sitting comfortably. Consider training the user in how to adopt suitable postures while working. The arms of chairs can stop the user getting close enough to use the equipment comfortably. Consider chairs without armrests or alternatively, adjustable armrests. Move any obstructions from under the desk.	
Is the lower back supported by the chair's backrest?	X		The user should have a straight back, supported at all times by the chair, with relaxed shoulders.	
Are forearms horizontal and eyes at roughly the same height as the top of the screen?		x	Adjust the chair height to get the user's arms in the right position; adjust the monitor height/tilt if necessary.	Not achievable with laptop unless secondary screen used.
6. ENVIRONMENT				
Is there enough room to change position and vary movement?	x		Space is needed to move, stretch and fidget. Consider reorganising the office layout and check for obstructions. Cables should be tidy and not a trip or snag hazard.	
Is the lighting suitable, e.g. not too bright or too dim to work comfortably?	x		Users should be able to control light levels, e.g. by adjusting window blinds or light switches. Consider shading or repositioning light sources or providing local lighting, e.g. desk lamps (but make sure lights don't cause glare by reflecting off walls or other surfaces).	
Does the air feel comfortable?	x		VDUs and other equipment may dry the air. Green plants may help to increase moisture levels in the air.	

			Circulate fresh air if possible. As a last resort, if discomfort is severe, consider a humidifier.	
Are levels of heat comfortable?	x		Can heating be better controlled? More ventilation or air-conditioning may be required if there is a lot of electronic equipment in the room. Or, can users be moved away from the heat source?	
Are levels of noise comfortable?	x		Consider moving sources of noise, e.g. printers, away from the user. If not, consider soundproofing.	
7. ELECTRICAL				
Have you carried out a user check (visual inspection) of the visually accessible parts of the equipment and it's cable, plug and extension cable.	x		See http://www.docs.csg.ed.ac.uk/Safety/Policy/Part3.pdf for more information on user checks. Carry out a user check when the equipment has been relocated. Any faults or significant wear and tear, must be reported and repaired as soon as possible (contact your local computing support) Do not use any equipment if defective. Remove from operation and label 'DO NOT USE - EQUIPMENT FAULTY'.	

Final Questions to Users:

- Is a portable computer being frequently used? If so, reduce its use to a minimum. Alternatively, have a docking station (separate keyboard, separate screen or screen elevated, separate mouse or tracking device). More detailed guidance on working with laptop computers is available at http://www.docs.csg.ed.ac.uk/Safety/health/DSE.pdf.
    - Yes, but use of university library monitors as secondary screen.
- Has the checklist covered all the problems the user may have working with the DSE?
    - I find no extensions whatsoever.

- Has the user been advised of their entitlement to eye and eyesight testing, and advised to contact the Occupational Health Unit or the Health and Safety Office to arrange appropriate eye sight testing?
    - No, but I already get my eyesight checked regularly.
- Does the user take regular breaks working away from the DSE?
    - Yes, a sensible work-life balance is naturally kept.
- Has the user read the leaflet "Are you keying comfortably"?
    - Yes, I have seen it at the university library.

Who to Contact:

- For furniture replacement or repair, contact Furniture Office, Estates and Buildings 50 2077
- For Blinds, curtains, etc EBIS Repair, Works Division
- For Computing equipment / software contact Information Services (i.e. normal contact)
- For Electrical defects contact Works Division 50 2485
- For Work environment factors (ventilation, noise, etc) contact Occupational Hygiene Unit Occupational.Hygiene@ed.ac.uk
- Following implementation and trial of any changes - For on-going Health issues related to DSE use contact the Occupational Health Unit 50 8190 / Occupational.Health@ed.ac.uk

Optimal Scheduling of EV Charging in Distribution Networks

Initial Project Presentation

Fabian Neumann

Dissertation Project
MSc Sustainable Energy Systems
School of Engineering
The University of Edinburgh

June 19, 2017

Agenda

Impact of Electric Vehicles

Electrification of the transport sector
- additional loads in distribution networks
- voltage drops and overloadings when uncontrolled

For sustainability, decarbonisation of electricity
- variable generation calls for active network management
- EVs for demand side management as storable/deferrable load

Consensus

Existing networks can accommodate substantial penetration levels of electric vehicles if charging is coordinated.

Charging Coordination of Electric Vehicles

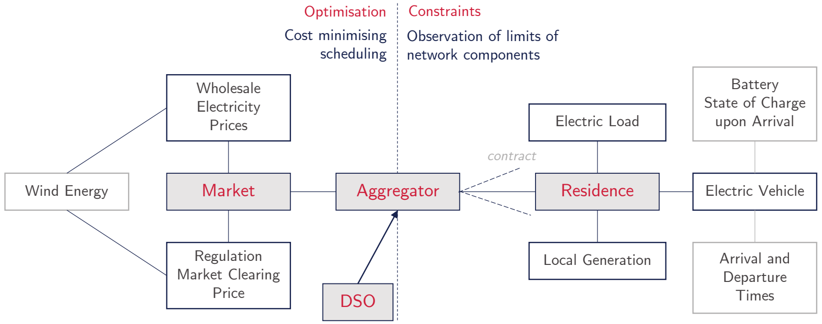
Typically, an aggregator acts as intermediary between multiple EV users and wholesale or ancillary service markets.

Vast amount of research was already conducted. Multitude of...
- optimisation objectives
- optimisation techniques
- optimisation hierarchies
- constraints
- scenarios / models
- uncertainty treatment

Market-based and network-based optimisation often disjunct. E.g.
- cost-minimising algorithm disregards network constraints or
- peak-shaving algorithm neglects potential economic benefits.

Uncertainties in Load Scheduling

Consideration of uncertainties about scenarios is more prevalent in academia than recognition of individual uncertainties in mobility patterns, residential demand and market prices.



Research Objectives

Optimisation study based on a developed simulation model

- Develop a robust cost-minimising (bidirectional) scheduling routine for charging EVs while observing network, equipment and demand constraints in a stochastic environment.
- Characterise inherent and conceded uncertainties incurred with the optimal scheduling of EVs. (esp. driving behaviour)
- Compare and assess the performance of multiple optimisation methods under uncertainty and approaches to mitigate their sensitivity to prediction errors.
  - greedy heuristic (benchmark optimisation)
  - metaheuristics (PSO or GA)
  - analytical (linear approximation)

Extract of Problem Formulation

$$\min_{\{P_{EV},\omega\}} \quad C = \sum_{t=1}^{T}\sum_{k=1}^{K}\sum_{d=1}^{D} \hat{\pi}_t \cdot \Delta t \cdot P^{EV}_{k,d,t} \quad - \quad \rho \cdot \eta \cdot P^{EV}_{max} \cdot \omega_{k,d,t}$$

$$\begin{array}{llcccl}
\text{s.t.} & & & \left(1-\hat{\alpha}^{EV}_{k,d,t}\right) \cdot P^{EV}_{k,d,t} & = & 0 \\
& 0 & \leq & P^{EV}_{k,d,t} & \leq & P^{EV}_{max} \\
& \beta_{min} \cdot B_{max} & \leq & \hat{B}^{arr}_{k,d} + \sum_{t=1}^{T} \eta \cdot P^{EV}_{k,d,t} \cdot \Delta t & \leq & B_{max} \\
& \gamma_{min} \cdot B_{max} & \leq & \omega_{k,d,t} \cdot \left(\hat{B}^{arr}_{k,d} + \sum_{\tau=1}^{t} \eta \cdot P^{EV}_{k,d,\tau} \cdot \Delta t\right) & \leq & B_{max} \\
& \Delta^{EV}_{max} & \leq & \left(\hat{\alpha}^{EV}_{k,d,t} \cdot \hat{\alpha}^{EV}_{k,d,t-1}\right) \cdot \left(P^{EV}_{k,d,t} - P^{EV}_{k,d,t-1}\right) & \leq & \Delta^{EV}_{max} \\
\text{PF} & V_{min} & \leq & V^{bus}_{k,d,t} & \leq & V_{max} \\
& 0 & \leq & S^{X}_{t} & \leq & S^{X}_{rated} \\
& 0 & \leq & I^{line}_{\ell,t} & \leq & I^{max}_{\ell}
\end{array}$$

$$\forall k \in \{1\ldots K\} \quad \forall d \in \{1\ldots D\} \quad \forall t \in \{1\ldots T\} \quad \forall \ell \in \{1\ldots L\}$$

Example: With 50 vehicles, 24 hour optimisation horizon and 15 minute resolution, the problem has minimum $2 \cdot 50 \cdot 96 = 9600$ decision variables.

Data Acquisition

Price time series

- UKPX Reference Price Data

Demand time series

- CREST demand model

Network topology

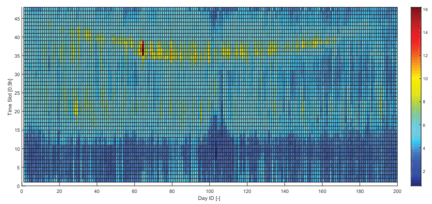
- European LV test feeder

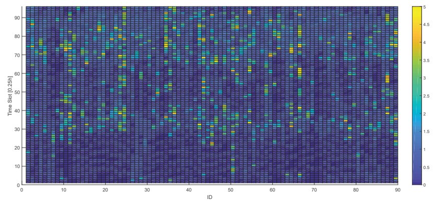
Mobility data

- National Travel Survey

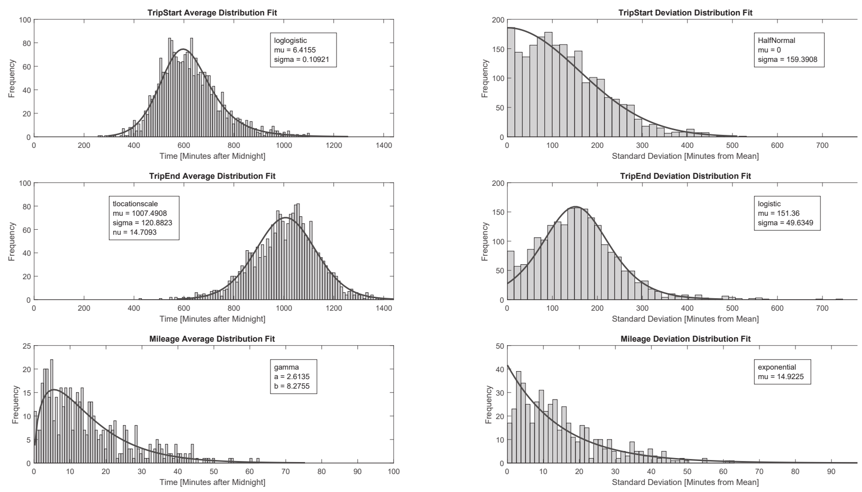
Other parameters

- vehicle specifications
- charging equipment
- ...

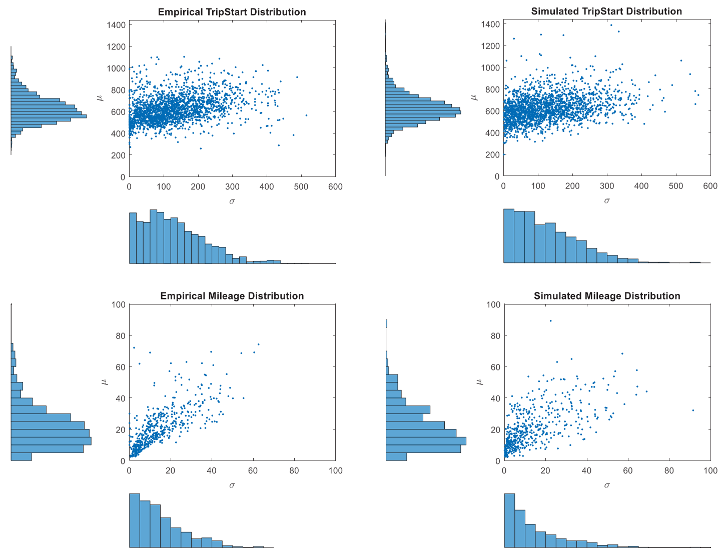




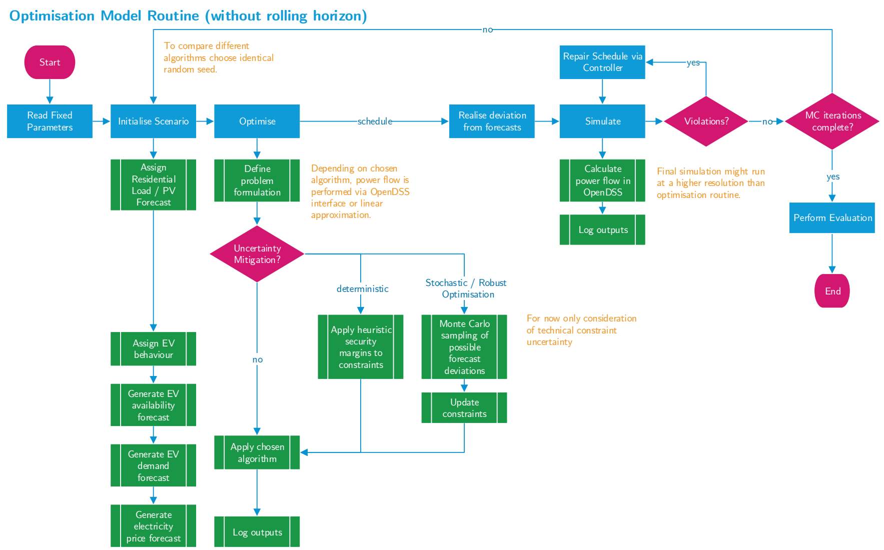
Travel Pattern Analysis



Travel Pattern Analysis



Optimisation Routine



Outlook on Upcoming Research

Implementation of...

- optimisation/model framework (Python, OpenDSS)
- optimisation algorithms
  - greedy heuristic (manual)
  - GA/PSO (DEAP)
  - LP (Gurobi, approximation)
- uncertainty mitigation
  - stochastic programming
  - rolling optimisation horizon
- reparation controller

Anticipated Difficulties

- thermal line limits data
- computational complexity
  - decision variables
  - power flow calculations
- incorporation of ancillary services (market structure)
- uncertainty modeling of demand, PV, and price
- information transfer and modelling forecast accuracy improvements (rolling opt.)
- linear power flow approximation

Summary

Scheduling Problem

- Cost Minimisation
- Physical Constraints
- Uncertainties
- 1-phase Connection
- Stochastic Programming
- Rolling Optimisation

Done

- Data Acquisition
- Travel Patterns
- Network Topology
- Parametrisation
- Power Flow in OpenDSS

To Do

- Framework Implementation
- Optimisation Algorithms
- Uncertainty Mitigation
- Real-time Controller
- Evaluation
- Write-up

HEALTH and SAFETY

General Risk Assessment

Form RA1

(Refer to Notes for Guidance before completing this form)

School Assessment No:	
Title of Activity:	MSc Dissertation
Location(s) of Work:	University accommodation, university library, supervisor's office for meetings.
Brief Description of Work: The dissertation is on the optimal charging control of electric vehicles in distribution networks. While the topic is based in electrical engineering, no laboratory work is required, but the project is solely based on computer simulations. Prolonged use of computers is anticipated.	

Hazard Identification: Identify all the hazards; evaluate the risks (low / medium / high); describe all existing control measures and identify any further measures required. Specific hazards should be assessed on a separate risk assessment form and cross-referenced with this document. Specific assessments are available for hazardous substances, biological agents, display screen equipment, manual handling operations and fieldwork. See http://www.ed.ac.uk/schools-departments/health-safety/risk-assessments-checklists/risk-assessments for details.

Hazard(s)	**Present Risk Evaluation** L/M/H	**Control Measures** (i.e., alternative work methods / mechanical aids / engineering controls, etc.)	**Risk Evaluation after control** L/M/H
Prolonged use of computer; work on computer screen.	M	- Daily check on time spent in front of computer screen. - Limit affected working hours to 8 hours per day. - cf. Display Screen Equipment Risk Assessment Form for more detailed assessment and mitigation proposals.	L

**Continue on separate sheet if necessary*

Engineering Controls: *Tick relevant boxes*

Guarding		Extraction (LEV)		Interlocks		Enclosure	
Other relevant information (incl. testing frequency if appropriate):							

Personal Protective Equipment (PPE): Identify all necessary PPE.

Eye / Face		Hand /Arm		Feet / Legs		Respiratory	
Body (clothing)		Hearing		Other (Specify)			
Specify the grade(s) of PPE to be worn:							
Specify when during the activity the item(s) of PPE must be worn:							

Non-disposable items of PPE must be inspected regularly and records retained for inspection

Persons at Risk: Identify all those who may be at risk.

Academic staff		Technical staff		P'Grad students	x	U'Grad students	
Maintenance staff		Office staff		Cleaning staff		Emergency personnel	
Contractors		Visitors		Others			

Additional Information: Identify any additional information relevant to the activity, including supervision, training requirements, special emergency procedures, requirement for health surveillance etc.

None required whatsoever.

Assessment carried out by:

Name:	Fabian Neumann	Date:	21/04/2017
Signature:		Review Date:	21/04/2017

1 March 2017 (Literature Review)

Notebook:	MA Journal		
Created:	01/03/2017 19:51	**Updated:**	08/08/2017 14:23
Author:	Fabian Neumann		
Tags:	lit		

First Literature Review

- Options to deal with additional load by EV
  - investment in major network reinforcement
  - encouraging EV users to charge at off peak times
  - devise controlled charging schemes
- Definition of smart grid
  - combination of enabling ICT technologies that jointly make the power delivery infrastructure more reliable, versatile, secure and more accommodating for the integration of distributed and intermittent resources
- Definition of demand side management
  - all intentional electricity consumption pattern modifications by end-use customers, that are intended to alter the timing, level of instantaneous demand, or total electricity consumption
- Why EV as demand side management?
  - rapid response to grid demand variations
  - EVs are already equipped with charging controllers that can implement different charging strategies given the available infrastructure

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- concepts
  - vehicle to home
  - vehicle to vehicle
  - vehicle to grid
- V2G services
  - ancillary services
    - power grid regulation
    - spinning reserve
  - active power support
    - avoid overloading and equipment aging
  - reactive power compensation
  - support for renewable energy resources
- justification for aggregator
  - intermediate system is necessary to deal with small-scale power of vehicles while providing the regulation service on large-scale power
  - bundles the technical and economic capacity of geographically concentrated EVs in order to control or set incentives to harness the demand flexibility of the vehicles
- organisational structures for aggregators
  - existing utilities with new financial contracts specific for PEV loads
  - for-profit entities participating in wholesale electricity market
- aggregator roles
  - fleet manager

    - retail EV customer aggregation
    - locational aggregation
- challenges to V2G
    - battery degradation
        - irreversible chemical reaction will increase internal resistance and reduce battery useable capacity
        - measure: equivalent series resistance (ESR)
    - high investment cost
    - social barriers
        - privacy
        - security

- location of charging (home charging will be important for achieving high rates of EV deployment, while public charging is for overcoming range anxieties)
    - home
    - car park
    - business / industry
    - roadhouse
- directions of power flow
    - unidirectional
        - inexpensive by adding simple controller to manage charge rate
        - requires attractive energy trading policy
        - only ancillary services
    - bidirectional
        - ancillary services plus functions such as peak load shaving, reactive power support, voltage regulation and frequency regulation
        - greater flexibility for power utility
- coordination / point of view / control architecture
    - system-wide
    - central /remote
        - direct load control (DLC)
        - requires high degree of information
        - poor scalability / high complexity
    - hierarchical / hybrid
        - schedule based
        - price based
    - distributed / local
        - price discrimination
        - requires more exchange of information, but the number of necessary parameters that need to be communicated is lower as the decision problem size is confined to one unit
        - parallel computing possible
- two-level optimisation
    - load scheduling -- determine purchase of energy in the day-ahead market based on forecasts
    - dynamic dispatch -- distributing purchased energy to PEVs on operating day (online)
- tariffs (endogenous / exogenous)
    - static
    - TOU (no provision of opportunity to dynamic reactions to system contingencies)

    - RTP (potentially spread)
        - locational marginal pricing (LMP)
        - spot market intra-day
    - Regulation market clearing price (RMCP)

- variables
    - charging sequence
    - charging duration
    - charging rate (continuous or binary)
    - energy purchase (slotwise)
- required knowledge
    - network topology
    - line impedances/admittances
    - nominal voltages
    - load profiles
    - expected departure time / allowable delay
- modeling
    - arrival times
        - normal distribution, white noise
- *objectives
    - minimise tap changing and energy losses / distribution network losses
    - minimise costs / maximise revenue - OFK14, HHS10, WAY12 (load scheduling), CTZ+12
        - from ancillary services
        - from energy trading -- WAY12
        - charging costs
        - discharging profit
    - maximise energy delivered to all EVs within a set period of time - RFK12
    - peak-shaving / valley filling / minimise deviation from target load - WW13, WAY12 (dispatch)
    - minimise emissions
    - weighting
        - prioritise batteries with a low SOC to generate more even distribution of charging - RFK12
- *constraints
    - EV
        - charging rates (continuous, discrete, fixed / upper and lower bounds) - OFK14, RFK12, CTZ+12
            - maximum charging power restricted by minimum of P_user, P_battery, P_charger
        - (almost) full charge/SOC at the end of charging period / user-specified departure time - OFK14, WAY12
        - EV availability / driving behaviour / arrival and departure times
        - general battery SOC/capacity limits
        - rate of change constraint (avoid large variations in charging rate over consecutive time steps) - RFK12
        - depth of discharge / minimise frequent dis/charging cycles
        - V2G connectivity needs to be cut off when the EV SOC is lower than an initially preset percentage -- TRY16
    - network

        - apparent power (residential + EV load) < network transformer rating - OFK14
        - current flowing through a particular phase of the mains cable < current rating - OFK14
        - total individual load < service cable capacity rating - OFK14
        - acceptable voltage range for LV network (upper and lower bounds), voltage change approximated linearly - RFK12
        - thermal loading of mains cable and transformer below maximum - RFK12
        - charging current should not surpass the acceptable charging current of EV battery
        - power balance
        - voltage limit
        - generation limit
        - line thermal limit
        - upstream supplier limit
        - system loading limit
- *methods / approaches
    - time coordinated optimal power flow
    - unit commitment (UC)
        - optimal dispatch generation schedule for available power grid generating resources
    - (mixed integer) nonlinear programming NLP, MINLP
        - sequential quadratic programming (SQP) - OFK14
    - linear programming - RFK12
        - approximately linear characteristics of both the network voltages and component loading sensitivities to the addition of EV load
    - dynamic programming - HHS10
    - Particle Swarm Optimisation (PSO)
    - Genetic algorithms
    - Fuzzy optimisation
    - ant colony optimisation (ACO)
    - heuristic - WW13, WAY12
        - price sorting
        - greedy
    - maximum likelihood strategy - WW13
    - Lagrangian relaxation (LR) - TRY16
    - Markov processes
    - Lyapunov optimisation - ZYYC16
        - no a-priori knowledge required
        - robust to non iid and non-ergodic processes
    - Alternating Direction Method of Multipliers (ADMM) - VAB14
        - global solution iteratively by individually solving local optimisation problems
        - information exchange between PEVs and aggregator at each iteration
    - uncertainty mitigation
        - probabilistic & stochastic / deterministic
        - rolling / receding time-horizon / day-ahead
- granularity
    - discrete (1min [model arrival of PEVs),5 min, 15 min, 30 min, 1h [minimum])
    - continuous
- horizon
    - 24 hours
    - overnight (9 hours, 10-7)

- sources of uncertainty (consider aggregation levels, absolute/ranking)
    - customer behaviour (breach of contract)
        - charging demand
        - utility function
        - arrival/departure dates
    - electricity prices (spot market / market bids)
    - local generation
    - renewable energy supply
- forecast sources
    - historical data
    - data by system operator
    - external
    - aggregator
- forecast methods
    - extrapolation
    - time-series
    - Gray theory
    - artificial neural networks ANN

- reference case
    - dumb charging / no control
- evaluation
    - required for one year to consider annual/seasonal variations in demand and generation
    - different kinds of customers (high, low, medium use)
    - MAPE
    - RMSE
    - euclidian distance
    - dynamic time warping (DTW) - SSW16
        - comparison of tim series while accounting for simple differences as time lags
    - standard deviation \sigma
    - coincidence factor: ratio of the maximum diversified demand divided by the maximum non-coincidental demand
    - fulfilment ratio: ratio of the actual energy charged by the deadline to the total energy requested by the customer
    - charging delay: expected vs actual time
- verification
    - sensitivity
    - robustness
- incentives
    - guaranteed life time battery warranty
- applicability
    - countries with mature electricity market environment
- relaxation
    - widening the range of departure SOC under customer agreement
    - disregarding uncertainty / assumption of perfect forecasts

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Buzz words

- V2G: buffer renewable energy sources by storing excess and feed in during high load periods stabilising intermittency of wind power
- V2G: control and management of EV loads by the power utility or aggregators via the communication between vehicles and power grid
- frequency regulation services
- battery management system
- deadline differentiated pricing: offers lower prices to customers who accept guaranteed job completion by a chosen deadline instead of demanding immediate job initiation
- Virtual Power Plants (VPP): One of the main candidates to help the reliability of the power grid is a virtual power plant (VPP). VPP structure is an accumulation of DGs, energy storage systems, as well as loads, that can be controlled locally. The entire system can be controlled by a central control entity; it works as an unique power plant. VPP not only deals with the supply side, but it also helps manage the demand and ensure grid reliability through demand response in real time.

OFK14

- majority of EV charging will take place on low voltage unbalanced networks
- use network sensitivity matrices
- optimisation horizon is 24h with optimisation every 30 min
- electricity price usually correlates closely with low system demand, meaning that EV charging may be allocated to those periods
- Charging rate depends on level -- single phase 0-4kW
- Batteries assumed 20kWh capacity
- Controlled charging without rolling optimization only delivers 80% of the required energy. The reason for the devicit is the assumed perfect forecasts for the EV availability and the BS_OC, which leads to charge allocated to times that EVs are not actually available.

HHS10

- vehicle batteries neither have a startup cost nor a shutdown cost while typical generators do
- systemwide optimality versus single-vehicle optimality
- The influence of each vehicle charging is a noise on the grid scale and hence does not affect the price of the power
- charging rate must be 0 or 1 -- proof available

RFK12

- effects include excessive voltage drops and overloading of network components occurring mainlz during periods of simultaneous charging of large numbers of electric vehicles
- The widespread adoption of EVs will introduce new customer demand patterns
- Existing distribution networks should be able to accommodate substantial penetration levels of EVs if the majoritz of charging is restricted to low charging rates at off-peak times
- Introduction of advance metering infrastructure (AMI) systems will aid the control/predictability of load patterns on residential networks

- maximize the total amount of energy that can be delivered to all EVs over a charging period while ensuring that network limits are never exceeded due to high levels of coincident charging
- due to the radial layout of the majority of LV residential networks optimisation tends to charge EVs connected near to the transformer at a higher rate than those located far from the transformer, which is due to the voltage levels being less sensitive to the addition of EV load near to transformer -- prioritise batteries with a low BSOC
- charging rate 4kW/1.5kW, BSOC 95%, 20kWh, 90% efficiencies, pf 0.95-0.97
- method neither computationally intense nor does it require storage of historical load data for subsequent use
- --> good modeling of behaviour!

WW13

- battery life is influenced by the depth of discarge, number of cycles, carge/discharge rates -- consider as constraints
    - prioritising system that considers the history of battery usage
- heuristic

WAY12

- aggregator has significantly large customer base so that it can purchase energy at wholesale market
- consider a risk-averse aggregator who would purchase the bulk of its electricity throuhg long-term bilateral contracts and by participating in the day-ahead market
- PEV driver might be hesitant to permit controlled charging
- the LMP absolute forecast is not critical, but for minimising cost the ranking of the hourly LMPs is critical
- more than 90% of vehicles are parket at home between 9pm and 6am
- assumption: aggregator does not engage in arbitrage

CTZ+12

- optimised charging pattern has great benefit in reducing cost and flatting the load curve if the peak and valley time periods are partitioned appropriately

TRY16

- the continual development of lithium ion battery and fast charging technology will be the major facilitators for EV roll out in the near future

VAB14

- Proposed approach is related to potential games in game theory for penalty term for deviation from previous consumer behaviour

ZYYC16

- day-ahead prediction errors for wind can easily exceed 20%
- many treated the scheduling as a static offline problem, in which the EV ownders are

required to submit their charging demand in advance and the needed future electricity prices and renewable supply are assumed known in advance
- dynamic online scheduling that is robus against inherent uncertainties
- achieves cost that is at most O(1/V) more than the optimal where V is a parameter that controls the tradeoff between cost and the average fulfilment ratio of requests

GoAn15

- price bidding not volume bidding on the day-ahead electricity market
- aggregator is assumed to potentially influence market prices
- Results show that agregator only has limited market power potential at moderate PEV penetrations
- But, assumption of exogenous prices leads to a suboptimal bidding strategy

Sch13

- long term forecasts are highly uncertaint, but hourly or daily forecasts are well within acceptable error margins of less than 10% of the actual value. Short term forecasts below four to two hours can even undercut the 5% value

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Questions

- What level of EV penetration would be sufficient to justify the implementation of a controlled charging scheme?
- What is the required penetration level such that a V2G system can replace other peak shaving and valley filling methods completely? (breakeven-point)
- Is the assumption that aggregators actions do not affect the relative ranking of hourly LMPs reasonable?
- V2G in combination with local generation and consideration of entailing additional uncertainty / coupling
- Often convexity is required for the problem to be solved. Why? What about convexification of power flow equations - VAB14
- How sensitive is the operator profit regarding PV generation forecast errors?
- Which share of renewable energy can be directly utilized by a fleet of EVs being scheduled according to different renewable generation patterns in comparison to an uncoordinated charging strategy?

Ideas

- Control of additional distributed energy resources (CHP, HP, micro-generation) -- pool optimisation
- difference of using intraday and day-ahead market --> hedging in the day-ahead market but ability to consider intra-day charging flexibility in the real-time market - Sch15
- division of chaging schedules into subsets / communication architecture
- Developed algorithms should be generalisable to several constraints / objectives)
- Market power of aggregators at varying penetration levels of PEVs?
- interaction with other flexible loads
- interaction with local generation capacity

Learn

- ZIP model
- Lyapunof-function
    - in the theory of ordinary differential equations (ODEs), Lyapunov functions are scalar functions that may be used to prove the stability of an equilibrium of an ODE. These are important to stability theory of dynamical systems and control theory. Similarity exists to general state space (finite) markov chains

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Empirical Data Acquisition

- Use Time Use Survey
- German Mobility Panel (MOP)
- European Power Exchange (EPEX)
- 50Hz TSO Zone (generation data)

TABLE IV
UNIDIRECTIONAL AND BIDIRECTIONAL CHARGER INFRASTRUCTURE COMPARISONS

	Power Flow and Switches	Situation	Power Level	Requirements and Challenges	Isolation and Safety	Control	Cost	Battery Effect	Distribution system	Benefits
Unidirectional Chargers and Infrastructure	One-way electrical energy flow, basic battery charge (G2V) Diode Bridge + Unidirectional converter	Available	Levels 1, 2 and 3	Power connection to the grid	Non-isolated or isolated	Simple. Active control of charging current. Basic control can be managed with time-sensitive energy-pricing.	Low price, no additional cost	No discharging degradation	No update or investment	-Provides services based on reactive power and dynamic adjustment of charge rates, even without reversal -Supplies or absorbs reactive power, without having to discharge a battery, by means of current phase-angle control -Voltage and frequency control
Bidirectional Chargers and Infrastructure	Two-way electrical energy flow and communication, charge/discharge (V2G) MOSFET (low power) IGBT (Medium power) GTO (High power level)	Not available	Expected only for Level 2	-Two-way power connection and communication -Suitable smart metering/sensors -Substantial information exchange -Extra investment and cost -Energy losses -Device stress	-Non-isolated or isolated. Non-isolated has advantages of simple structure, high efficiency, low cost, high reliability, etc. -Extensive safety measures -Anti-islanding protection Interconnection issues	Complex. Extra drive control circuits	High price	Degradation due to frequent cycling	Necessary updates and investment costs	-Ancillary services Voltage regulation Frequency regulation (down-up) -Spinning reserves -Reactive power Support -Peak shaving -Valley filling -Load following -Energy balance

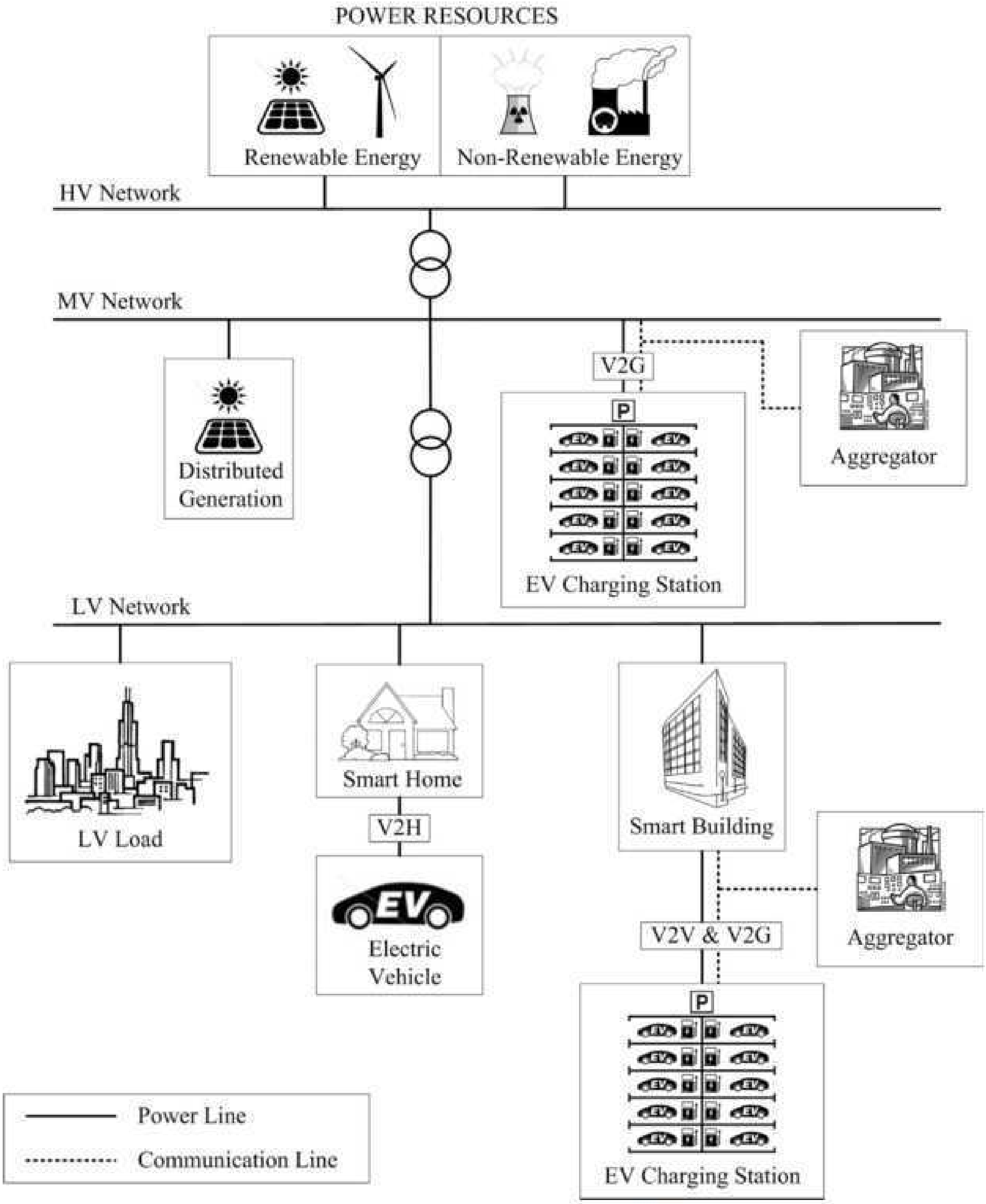

Fig. 1. V2H, V2V, and V2G framework [15].

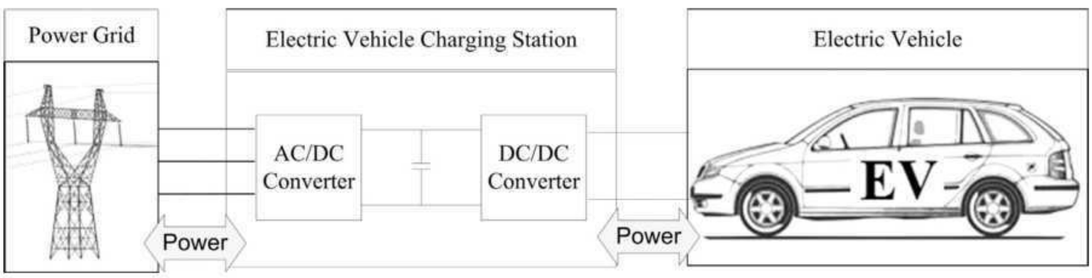

Fig. 2. Power flow diagram for V2G [13,14,29,30].

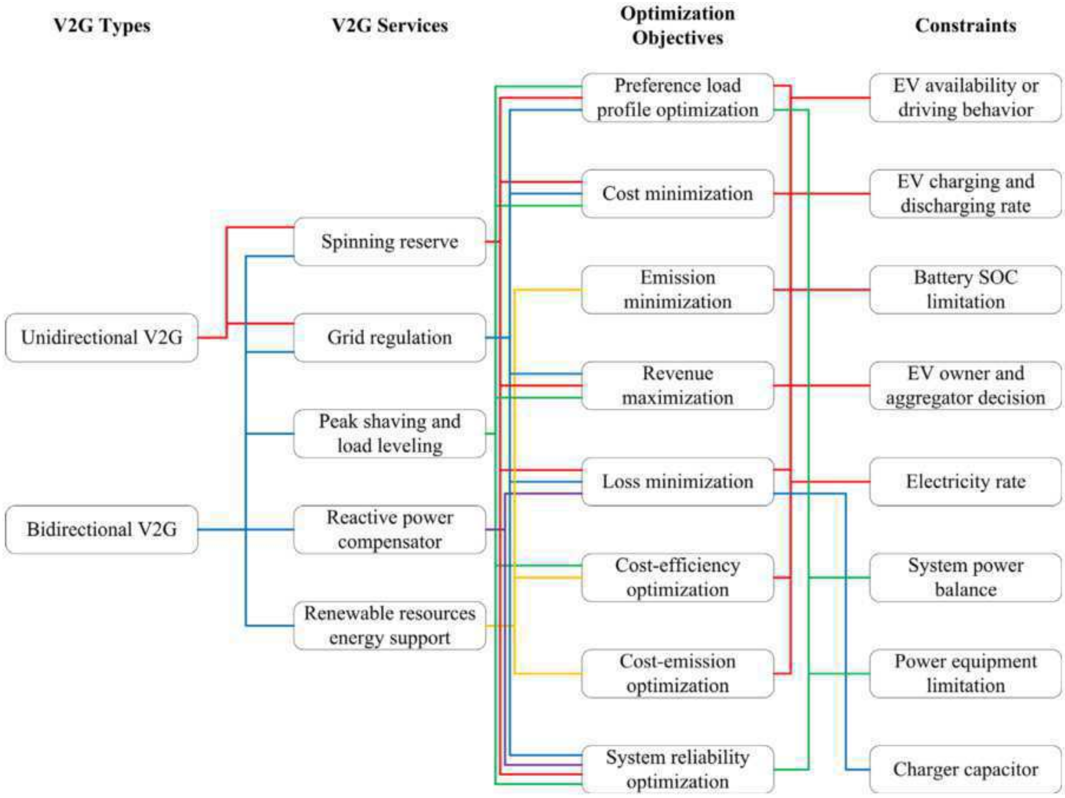

Fig. 6. Relation diagram for V2G types, V2G services, optimization objectives and constraints [17–19,28,31,51,68,82–88,90,91].

13 March 2017 (Research Questions)

Notebook:	MA Journal		
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Author:	Fabian Neumann		
Tags:	rq, schuller		

Electric Vehicle Charging Coordination - Alexander Schuller

Research Questions

- Avoiding new peaks due to low price signals in distributed optimisation --> physical generation constraints?
- find optimal optimisation horizon
- development of the regulatory framework needs to support more decentralized decisions and system operation, and must potentially be adapted to respond to structural changes imposed by the large numbers of distributed energy resources and adaptive loads like EVs
- decentralized coordination mechanisms must be further investigated and validated in regional markets under consideration of the inherent uncertainty in this environment (Ramchurn, 2012)

- RQ 2 - Economic Evaluation under Consideration of Storage Costs: What are the individual costs, including battery degradation, of charging electric vehicles employing a cost minimizing charging strategy while still fulfilling the given mobility profile, for the sociodemographic groups of employees & retired?
- RQ 2.1 - Economics of V2G under Consideration of Storage Costs: Which additional profits can be generated for the two groups if electricity can be sold back to the grid in a V2G operation strategy, while driving needs are still fulfilled and battery degradation is accounted for?

- RQ 3 - Scheduling for Renewable Energy Utilization Which share of renewable energy can be directly utilized by a fleet of EVs being scheduled according to different renewable generation patterns in comparison to an uncoordinated charging strategy?
- RQ3.1 - Source, Charging Power, Location Sensitivity: Which effect do different portfolios of renewable sources, in particular wind and solar, charging powers and locations and driving profile characteristics have on the utilization ratio?
- RQ 3.2- Shorter Optimization Horizon: What is the impact of a shorter optimization horizon with respect to the driving profile energy requirements and the utilization ratio of renewable energy?

- RQ 4 - Price Based Renewable Energy Utilization: Which percentage of renewable energy can be utilized by a fleet of EVs if charging is coordinated via a price signal mapping the scarcity of these intermittent sources?
- RQ 4.1 - Sensitivities: What is the impact of differing maximum charging powers, generation portfolios and EV driving patterns on the ability to use renewable energy for charging?
- RQ4.2 - Individual Costs: Which individual costs do EV-owners incur on average, given a

full cost assessment of their renewable energy usage?

Other notes

- in continuous systems the state variables change continuously with respect to time, which requires and adequate formal representation (e.g. differential equations) --> discrete!
- Following the description above, the simulation based analysis in this work is a dynamic, discrete event based deterministic simulation mapping and analyzing the individual objective of EVs and other relevant roles from the power system.
- generation and load data of different TSO-control zones in Germany
- Agent Based Computational Economics (ACE)
- group based evaluation: employees, retires, part-time employees, unemployed
- scaling of wholesale electricity prices to correspond to end-consumer price level
- generation input: wind + solar (also scaled to current capacity)
- investigate the bahavior of economically rational and thus highly price responsive EV-owners that receive a variable pricing scheme
- model considers the trips as mandatory constraints
- ideally one week optimisation horizon
- demonstrate the relevance of charging coordination for EVs. The Residual charg- ing strategy offers an interesting combination of different optimization objec- tives.
- The coordination approach based on ex ante known information can lead to unwanted effects as EV customers jointly start shifting their charging times ac- cording to the given objective criteria. This behavior in turn can lead to new peaks in the power system especially when high power connection ratings (in this approach 10.5 kW) are assumed and EVs are not spatially dispersed.
- In order to address the high load concentrations in the coordinated charging approaches, dynamic charging signals which are adapted according to the lo- cal distribution network situation in addition to the availability of RES and low energy prices could be introduced.
- upper case benchmark due to assumption of perfect information
- The aggregator needs to take decisions about which generation capacity from fluctuating renewable sources is needed in order to guarantee a sufficient supply of his customers.
- he coordinates the flexible demand of the EVs in such a way that the net deviation between EV load and renewable generation is minimized.
- In Section 5.2 a direct load control approach will be described which enables a general assessment of the flexibility of the given EV fleets. As this direct load control approach is not likely to be accepted by a major- ity of EV-owners, a decentralized, price based charging coordination mechanism is evaluated in a comparable setting with respect to the renewable energy adop- tion rates in Section 5.3.
- The aggregator has the objective to minimize the utilization of conventional genera- tion in order to reduce his variable costs for energy provision
- IBM I_LOG CPLEX 12.4
- different locations of charging infrastructure: home, work, leisure
- the potential to inte- grate renewable energy highly depends on the assumptions about the minimum SOC level requirements that EV users demand
- Also lower charging powers lead to additional infeasible days in the daily optimization scenario
- In reality some of this load synchronicity will be diminished by stochastic elements in the

demand and generation patterns, but this still shows that a decentralized charging coordination mechanism must set the right signals and incentives for EVs to shift their demand such that regional grid constraints and trip requirements are met.

Figures

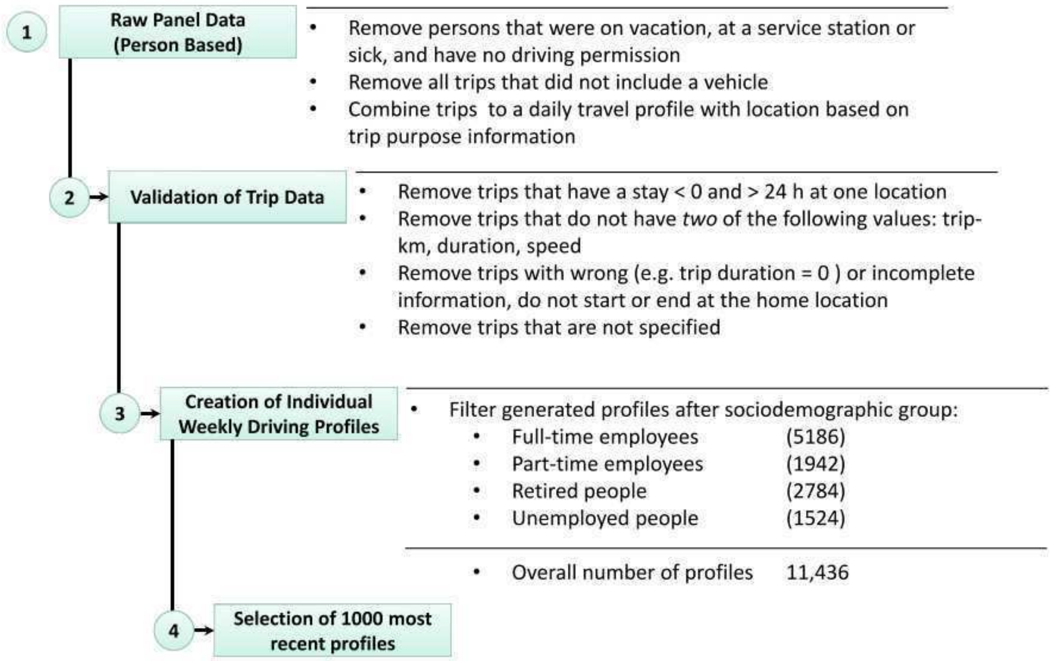

Figure 3.3: Driving profile deduction process based on data from the German Mobility Panel, adapted from (Dietz et al., 2010).

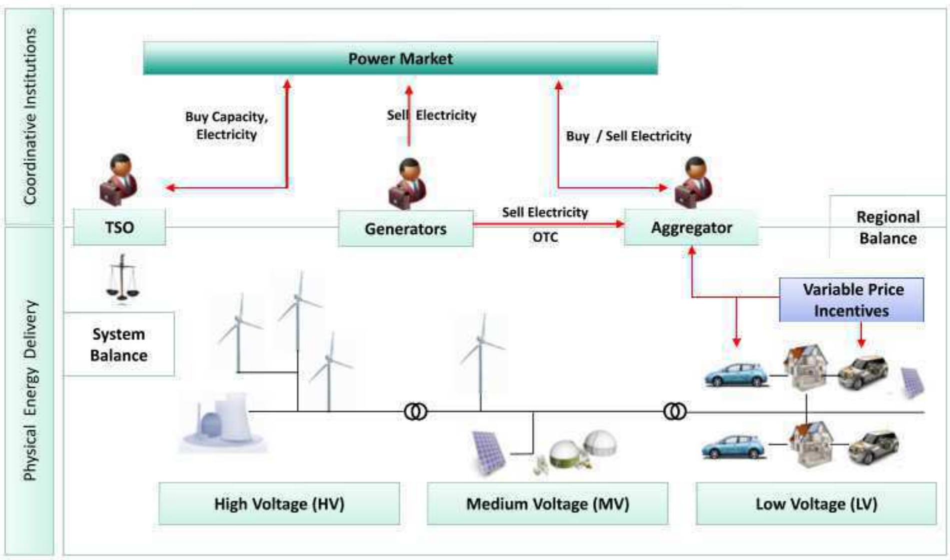

Figure 4.1: Analysis scenario overview for the individual demand side assessment.

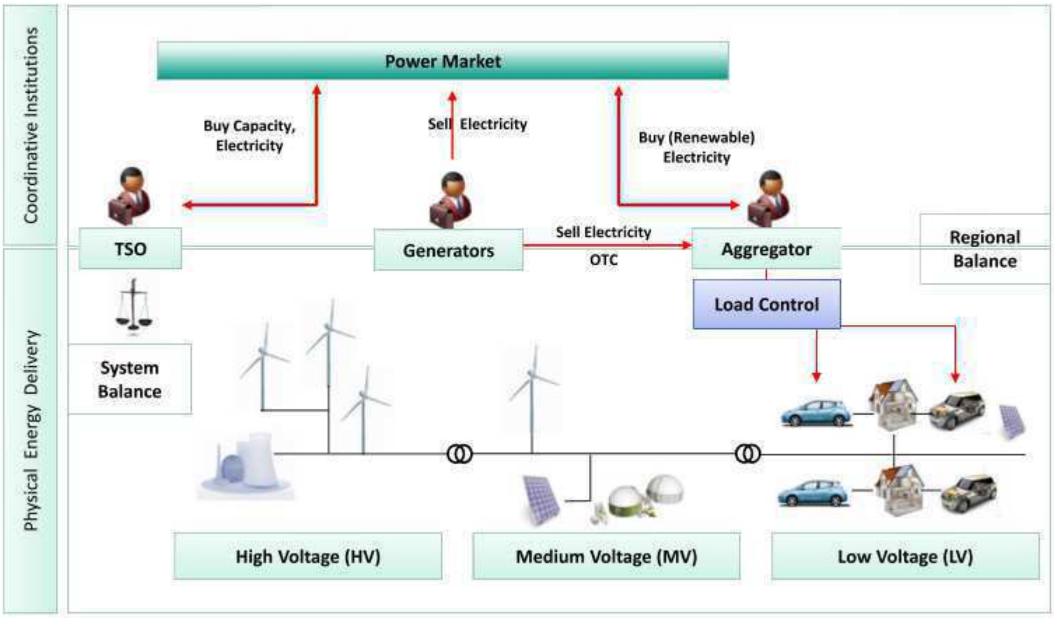

Figure 5.1: Analysis scenario overview for the optimal benchmark case.

4.2.3 Charging Strategies

In the following section, five distinct charging strategies are assessed with respect to their individual economic implications. The strategies are:

- *AFAP* charging which serves as a benchmark for uncoordinated charging since it only seeks to recharge whenever possible in order to maximize the available driving range. *AFAP* does not consider the system status, renewable energy availability or electricity prices for its charging decisions.

- *Smart Charging (SC)* initially minimizes the individual payment of the vehicle given the variable hourly prices based on the EEX-spot prices of 2007 (cf. Equation 4.4). This strategy is further denoted as *EEX* and serves as the best case benchmark of the individual costs incurred.

- *SC* with the objective to maximize the relative wind power share for each time step t used for charging. This strategy shifts charging to time slots of the highest relative availability of renewable energy, in particular wind power, and is further denoted as *WL, (wind-load)*. The formal objective of this strategy is thus to maximize charging during time slots in which the following ratio has the highest values:

$$\frac{P_{Wind_t}}{P_{Load_t}} \quad \forall t \in [1, T] \tag{4.12}$$

- *SC* with the objective to minimize the system load factor in each hour t in which charging occurs is denoted as *LF*. This strategy shifts EV demand distinctively to times with the lowest overall system load factor, thus corresponding to the well known night or off-peak charging strategy often mentioned in related literature. The strategy seeks to minimize its average system load factor, and thus shifts charging to time slots in which the following ratio has the lowest values within the optimization horizon:

$$\frac{P_{Load_t}}{max\ P_{Load_{2007}}} \quad \forall t \in [1, T] \tag{4.13}$$

- *SC* minimizing the system impact while balancing for renewable energy generation in the optimization period. Following the concept of the residual load, the *Residual* charging strategy has the objective to charge the EV whenever the residual load in the optimization period is the lowest. The residual load is defined as the total system load subtracted by the amount of variable and uncontrollable generation. The residual load is therefore the "*net*" load of the system that has to be covered by (conventional) controllable sources. This charging strategy thus provides a signal for EVs to charge only at a low overall load situation, or at times in which renewable, and in particular wind, generation provides a high share of total load. This strategy minimizes the following term for the charging time slots selected:

$$\frac{P_{Load_t} - P_{Wind_t}}{max\ P_{Load_{2007}}} \quad \forall t \in [1, T] \tag{4.14}$$

AFAP and *EEX* charging are implemented following Equation 4.2 and the objective function formulated in Equation 4.4. In order to coordinate EV charging according to the objectives of *WL*, *LF* and *Residual*, the objective function has to be adapted accordingly. The next paragraph introduces the rank concept which provides a possibility to set the required signals for EV charging coordination.

In an overall comparison of the five strategies it is obvious that *AFAP* is a simple to implement, but with respect to economic and renewable energy utilization objectives, unattractive strategy with a low performance. *EEX* charging in turn maps quite well on different objective criteria like wind-share and system load. This appears reasonable since in times of high demand prices are high and in times of high wind in-feed the prices are low, especially if demand is also low during the particular time. The price-reducing effect of wind power on the EEX-price was empirically shown and is commonly referred to as the merit order effect (cf. (Sensfuss et al., 2008; Nicolosi, 2010)). *Residual* and *LF* charging in turn emphasize the aspect of system peak avoidance but do not perform as well in economic terms as *EEX* does. *Residual* appears to be a good compromise in the direction of a higher wind-power share which is utilized for charging while maintaining a reasonable cost level and at the same time avoiding overall system peak and thus contingency situations.

22 March 2017 (Dos and Marking Scheme)

Notebook:	MA Journal		
Created:	22/03/2017 14:23	**Updated:**	05/08/2017 19:09
Author:	Fabian Neumann		

D&D of dissertation projects

1. Own your project. (what, why, how - your responsibility)
2. Record keeping including raw data (electronic records fine, but print for signature, receive feedback from supervisor: recommendations for further steps, quality control for external examiners, reproducibility)
3. Literature survey (peer-reviewed, patents / intellectual property, critical / identify contradiction, Pal Grave / Stella Cottrell - Critical Thinking Skills, Web of Science, ILIAD, syntesizing, Book: Designing qualitative research, common metrics)
4. Define clear metrics
5. Spend time to design your experiment
6. Make implementation of models as generic as possible
7. Spend enough time on describing and analysing your results
8. Read the marking scheme
9. Make results readily auditable

Missions Statement

- 21 April 2017, not marked, signed
- picture of thinking after literature review, selection of methods, depth of research done so far, clarity of thinking

June

- Weekly meeting with supervisor
- Feedback via seminars with fellow students & supervisor
- meeting/interview with examiner meant as a support, will report to supervisor -- minimum one week after seminar -- end of June

Dissertation Content

- electronic copy of your results
- marking scheme
- learning outcomes
- be constructive
- simple language
- footnotes

Marking Scheme summarised

Overall	**Weight**	**Weight**	**Notes**
Project Planning and Management	10	10	regular contact, little guidance, hard working, self-motivating, productive meetings, daybook
Appraisal of academic approach	10	10	original inputs to the shape, direction or outcome of the project, initiative, creativity
Thesis production	15		
Language and Presentation		7.5	publishable quality, coherence, referencing
Structure, Clarity and Focus		7.5	comprehensive, efficient, professional, ordered thought
Context of Research	15	15	systematic and comprehensive literature survey, critical, state-of-the art applications
Quality of Research	20	20	original elements, critical estimates, error discussion
Analysis and Conclusions	25		
Understanding of Theory		12.5	command of subject, original thought
Critical Analysis		12.5	critical evaluation, integration of available data and ideas, depth, academic maturity
Poster	5		
Layout, Visual Impact		2.5	appearance, choice, coherence, creativity
Contents, Explanation and Oral		2.5	fluent and coherent explanations, ability to answer questions with confidence, insight

20 April 2017 (Literature Review)

Notebook:	MA Journal		
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Author:	Fabian Neumann		
Tags:	lit		

Sustainable Energy - Without the hot air

- range problem has been solved by the advent of modern batteries
- exchange batteries for a fresh set at a battery exchange station

Renewable Energy

- conservation and efficiency measures are usually more cost-effective than many low-carbon supply options
- marginal abatement cost curve
- Are renewable energy supplies available when we want them?
- Review of options to match electricity supply to short-term demand fluctuations
  - pumped storage
  - gas turbine peaking plants
  - CAES
  - Rechargeable batteries
    - anywhere
    - low ratings
    - quick discharge
    - rapid response
- Solutions
  - decarbonisation of electricity generation
  - development of alternative transport fuels
  - reduction of heat demand / fuels
  - demand management in electricity grids
    - concept of a smart grid involves a parallel flow of both electricity and price information that would allow increased flexibility in electricity demand and supply
  - strengthening and extension of electricity grids, both to provide short-term diversity of supply and to tap into a wider range of supplies over the year
  - complementary rather than competitive electricity generation
  - hydrogen

Energy Systems and Sustainability

- battery technology has been the critical limiting factor
- rapid charging of batteries
- easily replaceable battery packs
- difference between fully electric vehicles and hybrid electric vehicles?
- two-way flow of information is needed: cost, demand, control information
  - clear general energy use information
  - remote meter reading

    - peak demand tariffs
    - import-export metering for microgeneration
    - remote scheduling of loads

System Security and Ancillary Services

- markets for electrical energy can function only if they are supported by the infrastructure of a power system
- security means that the power system should be kept in a state in which it can continue operating indefinitely if external conditions do not change.
- System operated must treat balancing energy as service (ancillary services) which must be purchased on a commercial basis.
- each causes component of imbalance with different time signature --> treat separately
- In general, if the time that elapses between the closure of the open market and the real time is short, the system operator is able to buy a substantial portion of its balancing needs in the spot energy market. On the other hand, if the market operates on a day-ahead basis, a complex mechanism is likely to be needed for the procurement of balancing services
- markets provide a more flexible and more economically efficient mechanisms for the procurement of ancillary services than compulsion
- Encouraging consumers to offer ancillary services has several advantages. First, a larger number of providers should increase competition in the markets for ancillary services. Second, from a global economic perspective the provision of ancillary services by the demand side improves the utilisation of resources
- Security is a system concept that must be centrally managed. The system operator is thus responsible for purchasing security on behalf of the users of the system. If we assume that a market mechanism has been adopted for the procurement of ancillary services then this system operator will have to pay the providers of these services. It will then have to recover this cost from the users. Since the amount of money involved is not negligible these users are likely to scrutinize this purchasing process. They need to be convinced that the optimal amount of services is purchased, that the right price is paid and that each user pays its fair share of the cost of ancillary services

Project Description (original)

- mitigate deterioration of voltage profiles and network overloading
- coordinated / centralised charging as option to defer network reinforcement
- tackle uncertainty of customer behaviour and electricity price

RFA12

- advantages and disadvantages of local and central charging strategies in terms of capacity utilisation and energy delivered
- consensus: existing distribution networks should be able to accommodate substantial penetration levels of EVs if the majority of charging is restricted to off-peak times
- real-time pricing or active demand side management will aid the control and predictability of the load patterns on residential networks
- assumption: load control capability is present in each household with EV
- no bidirectional flow from EV battery
- Modeling

    - distribution network
    - residential customer load modeling
    - electric vehicle load modeling
    - time periods for investigation
- local control charging
    - advantages
        - minimal communications infrastructure required
        - sufficient for lower EV penetration levels
    - disadvantages
        - no communication links to rest of network
        - larger safety margin required to maintain operating limits
- central control charging
    - advantages
        - real time insight into operating conditions at all points on network
        - better utilisation of network capacity
        - option to include bsoc weighting
    - disadvantages
        - requires significant communications infrastructure across the network
        - requires 3rd party to control charging rates

OF17

- realistically prioritise both the customers and the utilitys objectives
- incorporate the uncertainty in the forecasted demand
- account for customers flexibility in their charging demand
- specify a fair pricing scenario to all customers while protecting their privacy
- centralised
    - relatively more weight to maximised utilisation and grid performance than to individual customer's satisfaction
    - collecting and assessing large amounts of data from distributed PEVs
    - intensive computation and communication
- decentralised
    - firstly fulfill customer's desires, not necessarily overall system's optimal operation
    - lower communication cost and computational complexity
    - fast response time to changes in objectives and operational abnormalities
    - less privacy concerns as customers' data personal data such as arrival and departure times are usually not communicated
- non-cooperative strategies: every agent reacts to the change in a signal sent by the utility and determines its own best charging profile
- cooperative or distributed strategies: agents cooperate with their neighboring agents, based on the consensus algorithm to achieve an optimal solution for the entire group

LSL14

- stochastic modeling and simulation for analysing impacts of EV charging demands on DN
- steps: data collections, statistical clustering, feeder modeling, charging scenarios, feeder analysis, mitigation
- impact depends on (highly uncertain [7])
    - load pattern of existing feeder nodes
    - charging locations
    - charging start time
    - battery SOC during charging
    - charging mode

- capacity of battery
- Stochastic models
  - feeder load profile (with scenario reduction algorithm used to deduce a set of load profile classes and occurrence probability from historical demand data
  - EV start charging time
  - battery SOC at start charging time

HJB14

- the impact of charging of PHEVs on distribution grid is typically analyzed int erms of voltage deviations and power losses by studying driving patterns, vehicle penetration and charging characteristic
- economic dispatch in the presence of PHEVs [10]
- aggregator in the power system operation and electricity market [9]

Table 1
Phev integration to smart grid.

Sl. no	Study aspects	Operation modes/control objectives/major issues	References
1.	Charging and Scheduling of PHEVs	(a) Unidirectional charging methods in optimization based frameworks and real time intelligent algorithms	[23–28]
		(b) V2G mode, both charging and discharging control using various deterministic, and heuristic optimization techniques	[29–43]
		(c) Charging control in the grid	[44–49]
		(d) Online mechanisms for coordinated charging and game theoretic models	[50–53]
		(e) Optimal battery charging operation	[54–56]
2.	Application in reducing intermittence of renewable energy production	(a) Suitable control strategies of PHEVs for integration of wind and other intermittent renewable energy resources	[57–60, 72–75]
		(b) V2G mode of operation of PHEVs for renewable energy integration	[61–69]
		(c) Unconventional approaches	[76–79, 70–71]
3.	PHEV participation in Electricity Markets	(a) Multi-agent based, game theoretic models for PHEV participation in electricity market	[80–87]
		(b) Optimization-based methods	[88–94]
		(c) The customer perspective regarding the PHEV market and its participation	[95–96]
		(d) V2G mode of operation	[97–101]
		(e) Scheduling of PHEVs within a parking station and optimal charging/discharging rate determination	[102–106]
4.	Infrastructure facilities and Energy management schemes	(a) Estimation of availability of PHEVs for charging	[107–109]
		(c) Parking areas functionality as power sinks or power source, charging station requirements	[110–117]

Table 2
Charging and scheduling of PHEVs.

Sl. no	Operating modes	Studied problem	Solution approach	References
1.	Unidirectional operation	(a) Coordinated charging of PHEVs	RT-SLM, Optimization based frameworks, optimal charging algorithms	[24–26,28]
		(b) Functions of electric vehicle charging provider	Optimization based technique	[27]
2.	Vehicle-to-grid operation	(a) Scheduling of charge/discharge times of PHEVs and effects of grid faults on V2G	Binary Particle Swarm Optimization (BPSO)	[29]
		(b) Control of both charging/discharging of PHEVs in V2G mode for meeting peak demand voltage reduction, reduction of charging costs, minimization of charging time, maximization of profits etc.	Linear and quadratic approximation model, fuzzy based controllers, BPSO, discrete and continuous PSO, dynamic programming, optimal algorithms, Q-learning algorithm, Markov chain	[30–35, 37–40, 42,43]
		(c) Utilization of PHEV parking lot to provide both active and reactive power	A real time current controlled PHEV parking lot	[36]
		(d) Impact of PHEVs on power quality of the smart grid for different battery charging rates	MATLAB, Decoupled harmonic power flow	[41]
3.	Charging control in the grid	(a) PHEV charging schedule	Joint OPF-charging optimization	[44]
		(b) Illustration of trade-offs that distribution network operators might encounter when implementing various load control approaches of electric vehicles	TCOPF	[45]
		(c) Utilization of excess distribution capacity	Queuing theory, statistical analysis	[46]
		(d) EV recharger allocation	Voronoi diagram, priority order circular diagram	[47]
		(e) Integration of electric vehicles through unbundled smart metering and virtual power plant (VPP) technology in the smart grid	Smart meter unbundled architecture	[48]
		(f) Implementation of V2G concept	Multilayer framework, PSO	[49]
4.	Online mechanism and game theoretic models	(a) Coordination of PHEVs charging schedule	Online mechanisms, decentralized smart charging strategy, MATsim, Nash certainty equivalence	[50–53]
5.	Optimal battery charging operation	(a) Minimization of PHEVs battery degradation	NSGA-II, BPSO	[54,56]
		(b) Maximization of energy trading profits and minimization of PHEVs battery aging costs	Genetic algorithm	[55]

Table 3
Application in reducing intermittence of renewable energy production.

Sl. no	Operating modes	Studied problem	Solution approach	References
1.	Unidirectional operation	(a) Control of charging rate of PHEVs to aid in integration of wind and other intermittent renewable energy resources	Optimization based frameworks, sliding mode control strategies	[57–60]
		(b) Case studies on German and Spanish electricity markets	Optimization based methods	[72–75]
2.	Vehicle-to-grid model	(a) Control of both charging and discharging rate of PHEVs for renewable energy integration applications	Mixed PSO, BPSO, integer PSO, PCLF, queuing theory, hybrid learning automata system	[61–65]
		(b) Case studies on Danish electricity market on effectiveness of V2G	Different methods, mostly using market data	[66–69]
3.	Unconventional approaches	(a) Integrated power hub for a residential consumer	Lab VIEW , FPGA	[76]
		(b) Application of Battery, PHEV and fuel cell vehicle types in V2G paradigm	Based on the existing literatures of storage technologies	[77]
		(c) Charging of old PHEV batteries	MLIPC	[78]
		(d) Applicability of PHEVs to provide additional balancing power	Heuristic control scheme, model predictive control scheme.	[79]
		(e) Case study on Brazilian electricity sector	MESSAGE Tool	[70–71]

Phev participation in electricity markets.

Sl. no	Operating modes	Studied problem	Solution approach	References
1.	Agent-based and game theoretic models	(a) PHEVs as primary reserve	Decentralized MAS, aggregative architecture, game theoretic Cournot-model, agent-based model	[80–81]
		(b) PHEVs as regulation service providers	MAS, coalition formation strategies, game theoretic models	[82,83,87]
		(c) Bidding strategies for PHEV agents	Heuristic reinforcement learning approach combined with genetic algorithm, model predictive bidding	[84,85]
		(d) Impacts of PHEVs on imperfectly competitive Germany electricity market	Game theoretic Cournot-model	[86]
2.	Optimization-based models	(a) PHEV aggregator role in electricity market	Conceptual basis	[88]
		(b) Control strategy for aggregator performing frequency regulation	Optimal control strategy, dynamic programming technique	[89]
		(c) Strategy for load aggregator for battery charging	Optimal bidding strategy, stochastic programming strategy	[90]
		(d) Aggregator in day ahead and secondary reserve market	Optimization based techniques	[91–92]
		(e) Utilization of PHEVs as active power balancing	Stochastic linear programming	[93]
		(f) Coordination of charging/discharging of PHEVs	Stochastic linear programming, Monte Carlo simulation	[94]
3.	Consumer perspective	(a) Customer perspective of the PHEV role on the electricity market	Conceptual basis	[95]
		(b) Charging scheduling for a fleet of PHEVs	Aggregator based model	[96]
4.	Vehicle-to-grid	(a) Estimation of electric power capacity of a V2G parking lot	Battery modeling	[97]
		(b) Reference architecture for control markets to control a large number of vehicles	Different requirement domains like delimitations, control market constraints	[98]
		(c) Coordination of V2G unidirectional services	Mixed integer stochastic linear program	[99]
		(d) Effect of driving efficiencies on optimal V2G bidding	Optimal preferred operating point algorithms	[100]
		(e) Utilization of V2G power for real time frequency regulation	Practical demonstration	[101]
5.	Unit commitment	(a) Scheduling of PHEVs for charging/discharging	PSO, integer PSO, probabilistic estimation, BPSO, hybrid of PSO and ACO	[102–106]

23 April 2017 (Literature Review)

Notebook:	MA Journal		
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Author:	Fabian Neumann		
Tags:	lit		

KP11

- The scheduling problem is naturally cast as a Markov decision process.
- The current work looks at the smart scheduling problem exclusively at the consumer's side, with the goal of maximizing individual economic advantage. This is sharply different from the scheduling problem in direct load control, which is performed by utilities.
- neglecting the prediction noise may lead to a significant economic loss to the consumers.

SW11 (c)

- We model the electricity price as a Markov chain with unknown transition probabilities and formulate the problem as a Markov decision process (MDP).
- The Q-learning algorithm is then used to adapt the control operation to the hourly available price in order tomaximize the profit for the EV owner during the whole parking time.
- With V2G abilities, the EVs have a dual role in the electricity market. On one hand, they are power consumers when the batteries are being charged. On the other hand, they are power suppliers when they sell excessive energy from the batteries.
- As each EV is in different conditions (e.g., arrival and departure time, SOC, and capacity)
- Both algorithms assume that the future electricity pricing information is given in advance based on a day-ahead pricing model.
- Upon the EV arriving, the driver needs to inform the expected departure time and expected departure SOC to the aggregator.

YZP14 (c)

- risk-aware day-ahead scheduling and real-time dispatch for electric vehicle (EV) charging, aiming to jointly optimize the EV charging cost and the risk of the load mismatch between the forecast and the actual EV loads
- minimizes the EV charging cost and the risk of the load mis- match between the forecast and actual EV loads, due to the random driving activities of EVs.

WWG13

- contingency constraints
- a chance constraint is applied to ensure the loss of load probability LOLP is lower than a pre-defined risk level
- lack of attention, latency in communication, change in consumption behaviour

SS12 (c)

- The formulation takes into account unplanned EV departures during the contract periods and compensates accordingly.
- This can be accomplished by discharging energy through bidirec- tional power flow, or through charge rate modulation with uni- directional power flow
- Unidirectional V2G also cannot pro- vide the system with the energy stored in the EV batteries
- Though the customers will be compensated for the cost of degradation, they will have to purchase replacement batteries more frequently, which is an inconvenience they may not want to deal with

EL12

- biggest concerns about EVs according to survey
    - high cost
    - battery range
    - reliability
    - charging infrastructure
    - battery degradation

19 May 2017 (Residential Demand Simulation)

Notebook:	MA Journal
Created:	19/05/2017 14:17
Updated:	08/08/2017 14:23
Author:	Fabian Neumann
URL:	https://www.uswitch.com/gas-electricity/guides/economy-7/#step2

Individual Demands

Meter	# residents	house type	gas/oil for central heating	gas/oil for water heating	electric heaters	electric shower	economy tariff and timers	local generatior
05	1	detached	yes	yes	no	no	yes	no
06	2	semi-detached	yes	yes	no	no	no	no
07	4	terraced	yes	yes	no	no	no	no
12	1	detached	no	yes	no	yes	yes	no
18	4	detached	yes	yes	no	yes	yes	no

Daylight saving in 2009: 29 March, 25 October
Economy7 tariff: https://www.uswitch.com/gas-electricity/guides/economy-7/

- Economy 7 start, it is usually either 11.00pm to 6.00am, 12.00am to 7.00am or 1.00am to 8.00am. However this can vary according to where you live.

1-5 June 2017 (User Behaviour LR, OpenDSS, Architecture, MC Simulation, Ancillary)

Notebook:	MA Journal		
Created:	01/06/2017 11:04	**Updated:**	14/08/2017 14:50
Author:	Fabian Neumann		
URL:	https://ewh.ieee.org/soc/pes/dsacom/testfeeders/		

Ideas

- Optimisation at different granularity than simulation (15min vs. 1min)
- multilevel optimisation (price, technical)

EV User Behaviour

Literature Review

- Salah2016a
    - for statistical robustness each scenario repeated 100 times with randomly drawn values -> Monte Carlo Simulation
    - parking behaviour described by Weibull distribution F(x) = 1-exp{-x/\lambda}^k
- Wang2015
    - extract features from raw data and estimate schedule parameters given start time and user index -> inference
    - used 10000 charging sessions for 200 users -> 50 sessions per user
- Soares2011
    - Monte Carlo techniques to be used for distribution grid planning, providing a characterization of possible grid operation conditions, regarding voltage profiles, branch loading, grid peak power and energy losses
    - often only able to reveal effects of a possible scenario for a given period -> explore different scenarios in a coordinated way
    - stochastic model using a Markov chain and a Monte Carlo method proposed to estimate the EV impacts along one year in MV network
    - discrete-state, discrete-time Markov chain to define states of all EV at each time step of 30 minutes (alterations possible)
        - periodically stationary
        - period of this cycle is one week

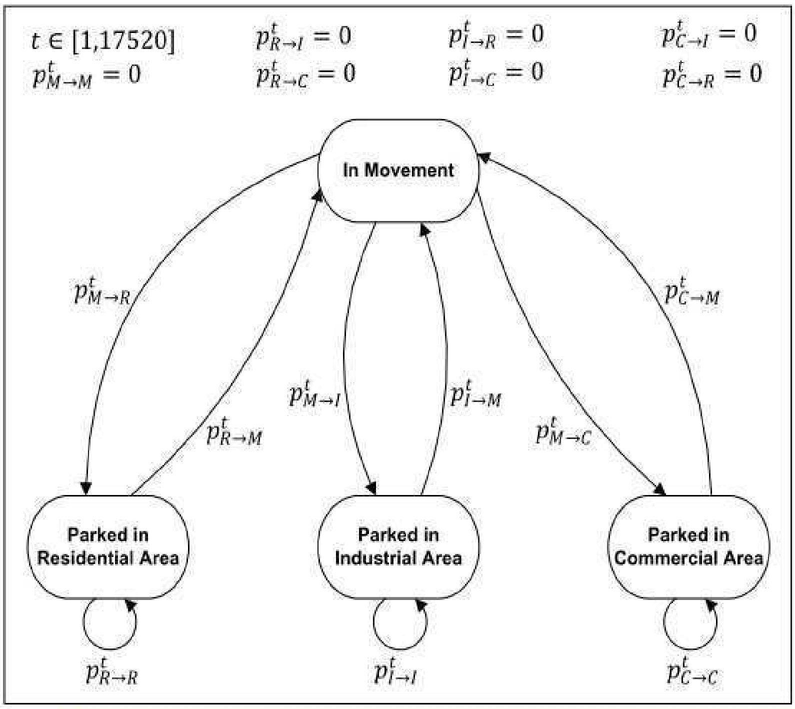


Figure 1: Discrete-state and discrete-time Markov chain.

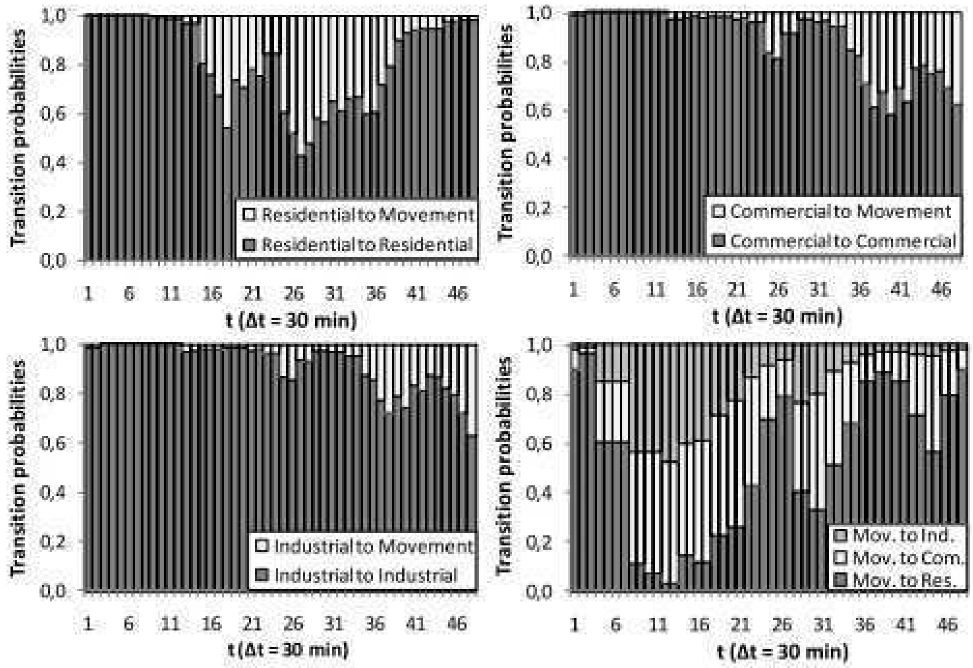


Figure 2: EV state transition probabilities: week day.

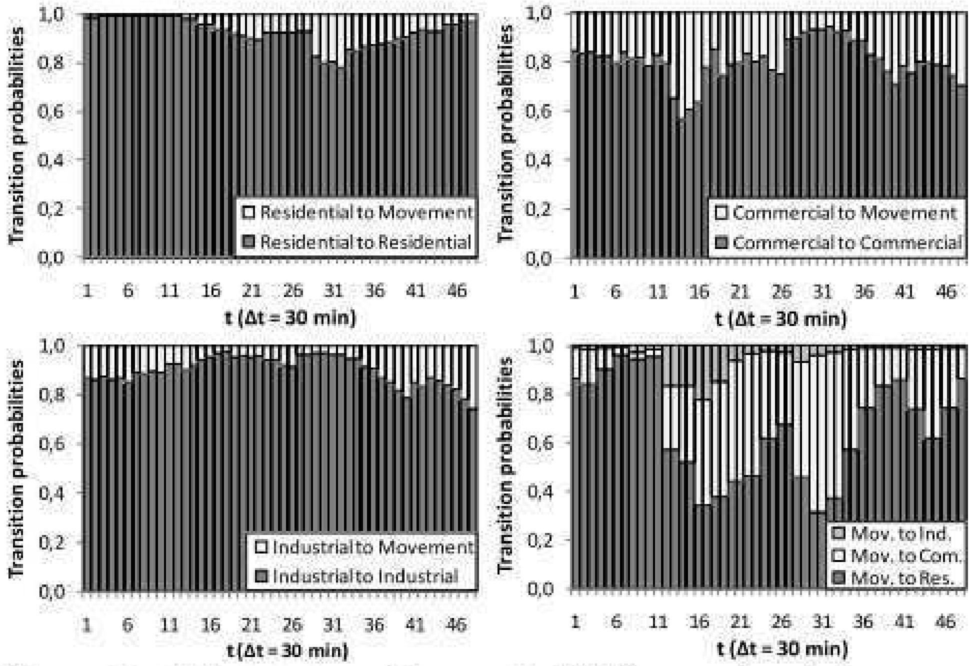


Figure 3: EV state transition probabilities: weekend day.

	Average	Standard deviation	Maximum value allowed	Minimum value allowed
Battery capacity (kWh)	24.73	17.19	85.00	5.00
Slow charging rated power (kW)	3.54	1.48	10.00	2.00
Energy consumption (kWh/km)	0.18	0.12	0.85	0.09
Initial battery SoC (%)	75.00	25.00	95.00	25.00

- **Table 1:** Gaussian distributions for EV characterization.
-

- Acha2012
    - agent-based model that simulates the travelling patterns of vehicles on a road network
    - output data is used as a forecast for OPF model -> help DNO to resolve ideal EV charging times
    - providing utilities the capacity to predict when and where these vehicles may require energy for their travelling needs while
    - agent-based model for spatial, temporal and energy demand
    - vehicle usage data often aggregated such as average trip distances
        - problematic for individual modeling when analysing the effects of EVs on the distribution network
        - use activity based approach to trip generation which results in temporal spatial information on EV movements
    - defines 3 groups: people with a job, without a job, pensioners
    - Nissan Leaf 24 kWh, 0.25 kWh/mile, 240V/16A charger
- Dallinger2010a
    - simulate restrictions arising from unpredictable mobility requests by vehicle users and investigate the impact of driving behaviour on value of V2G
    - reveals a significant difference in the power a vehicle can offer for ancillary services and provides insights into the necessary size of vehicle pools and possible adaptations required in the regulation market to render V2G feasible
        - A Monte Carlo simulation using stochastic mobility behavior results in a 40% reduction of the power available for regulation compared to the static approach.
    - a pool size of 10 000 vehicles seems reasonable to balance the variation in each individual's driving behavior.
    - The dynamic simulation of driving behavior uses probability distributions for when the first trip of the day starts and when the last trip of the day finished -> vehicles enter the system after their last trip of the day and they leavie it with the first trip on the next day
    - battery of each vehicle and its state of charge are combined in a virtual pool battery
    - repeats 500 times for Monte Carlo Simulation
- Hu2016
    - EV agents provide information regarding the trip requirements and battery status to EV VPP agents
    - EV owner can define some minimum limits regarding the energy stored in the EV batteries
- Rassaei2014

    - queuing theory
    - interesting statistical analysis provided
- Wu2010c
    - The initial SOC is suggested to be 85% in order to avoid the floating charging stage for EV batteries and the possibility of overcharging. Therefore, the initial SOC of EV batteries can be assumed to be 85%.
- Schauble2017
    - mobility studies eReady, iZeus, CROME
    - model to simulate EV loads based on statistical characteristics of the conducted studies
    - currently no demand for EV load forecasting by electricity suppliers
    - only few projects created new or alternative mobility patterns instead of basing their research on conventional mobility patterns
    - "when looking at applications of simulated EV loads for further analysis in a large part of literature underlying input data for EV load profiles is not transparent and mainly derived from general conventional mobility patterns" -> criticism to current methodology
    - use several user types
- Pasaoglu2013
    - must use individual driving profiles of a representative sample of individuals, coupled with assumptions on the penetration of different types of EVs
    - common assumptions
        - an individual uses an EDV for all trips made in the day;
        - that EDV is used only by one individual (i.e. the energy consumption is explained only by the driving pattern of a single individual);
        - one individual uses the same EDV on all days of the week.
- Daina2017
    - classifications of short period models
        - Summary travel statistics models
            - empirical distributions obtained from travel surveys
            - lack consistent travel schedule structure
            - miss the spatial and temporal details required for impact analysis at the distribution network level
            - effects of charging demand management inevitably neglected
        - Models based on entire activity travel schedules: (Direct use of observed activity travel schedules, DUOATS; and proper activity based models, ABM)
            - behaviour derived from differences in lifestyles and activity participation among the population
            - multiple drivers would lead to an underestimate of the daily energy needs of the vehicle and to an overestimate o fthe time the vehicle is available for charging (equivalent to assuming that each driver uses a different vehicle)
            - underlying assumption: introduction of EVs does not significantly change travel patterns, even in large deployment scenarios
                - for BEVs assumption is justified by the high feasibility of journeys
                - insensitive to policies potentially affecting EV travel and charging behaviour
        - Markov chain models (MCM) of vehicle state.
            - fully disaggregate year long EV patterns
            - lack of theoretical link between activity demand and travel demand

- Fundamental Questions
    - How can EV mobility and charging data be processed to create descriptive EV load profiles and what are the characteristics of these EV load profiles
    - How can EV load profiles be simulated using empirical charging data?
    - What are the characteristics of these simulated EV load profiles?

Network Topology / OpenDSS

- OpenDSS Facts/Intro
    - object oriented data ideas
    - script-driven, flexible, limited GUI
    - development of DG models for IEEE test feeders is original purpose
    - LV/MV distribution networks
    - dynamic power flow (daily, yearly)
    - co-simulation, unbalanced, time-series profiles, probabilistic
- OpenDSS tips
    - energy meters must be registered
    - in some cases neutral phase should be explicitly modelled
    - loadshapes as normalised values
    - plotting the circuit topology requires CSV with coordinates
    - write loadshape files in binary; loads 6x faster than text files
    - there are storage shapes in OpenDSS
- OpenDSS interfacing
    - files should be in same folder
    - many commands can either be done with typical text or through the COM interface
    - controlmode, mode, solve, exports are controlled by VBA/MATLAB/Python
    - helpful for management of data from a large number of simulations

- In-process COM server: OpenDSSEngine.DLL
    - call start(0) method to initialise the DSS

```
% Python
self.engine = win32com.client.Dispatch('OpenDSSEngine.DSS')

% MATLAB
DSSobj = actxserver('OpenDSSEngine.DSS')
```

- Motivation for accurate modelling
    - balanced networks inadequate for LV network analysis
    - simplified profiles neglect actual control of network elements
    - traditional modeling is originally deterministic -> uncertainties due to the variability, size of common and future loads as well as renewable generation are neglected
    - common to analyse simplified networks or american real-life networks which are much smaller than EU LV networks
    - max gen / min load worst case scenarios <--> time series analysis
- European network characteristics

- simply strucutred MV
- extensive LV
- many houses per MV/LV transformer
- At the primary substation, the voltage is usually stepped down to 11 kV, where it is distributed to a number of radial circuits called Feeders (also known as 11 kV secondary circuits).

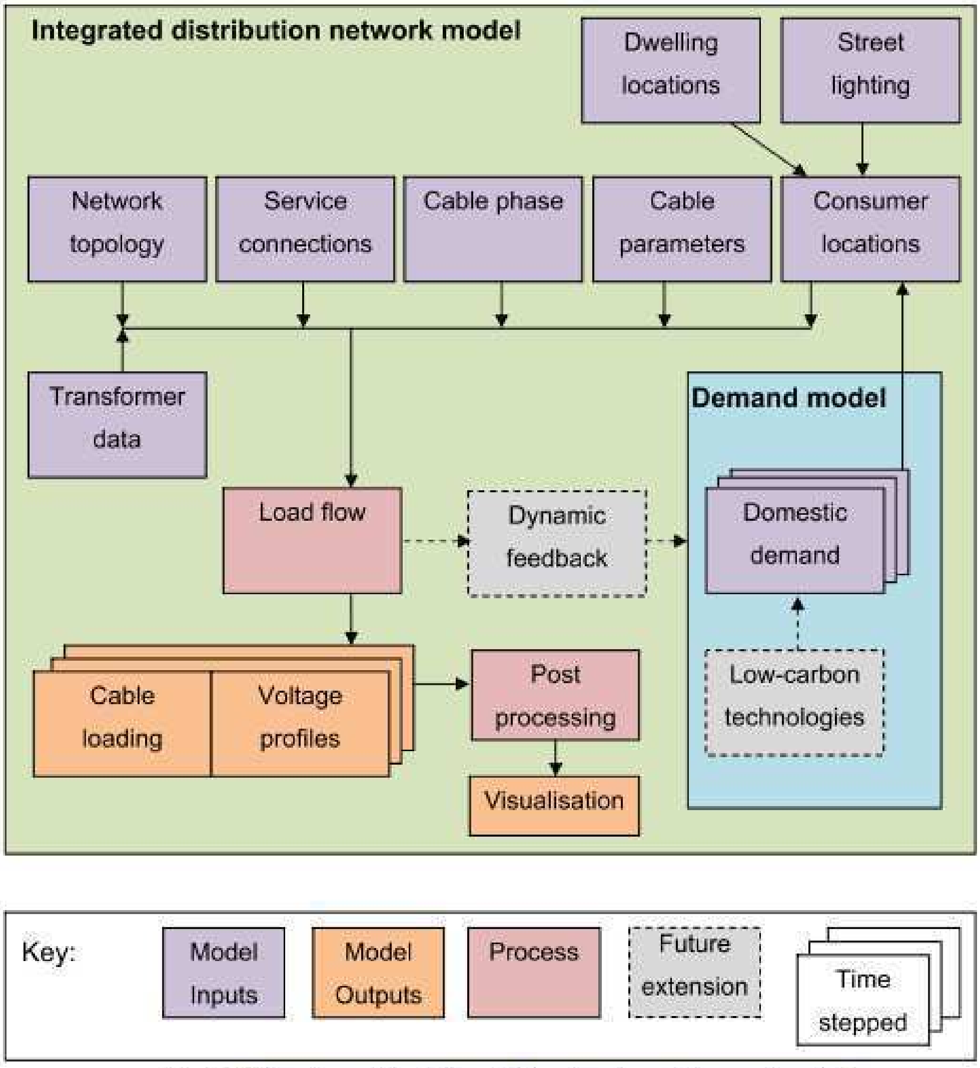


Fig. 59. Structure of the integrated network and demand model

-
  [Richardson2011]
- Navarro-Espinosa2016 (Europena LV network)

A. Definition of Parameters

The physical feeder characteristics investigated are given here.

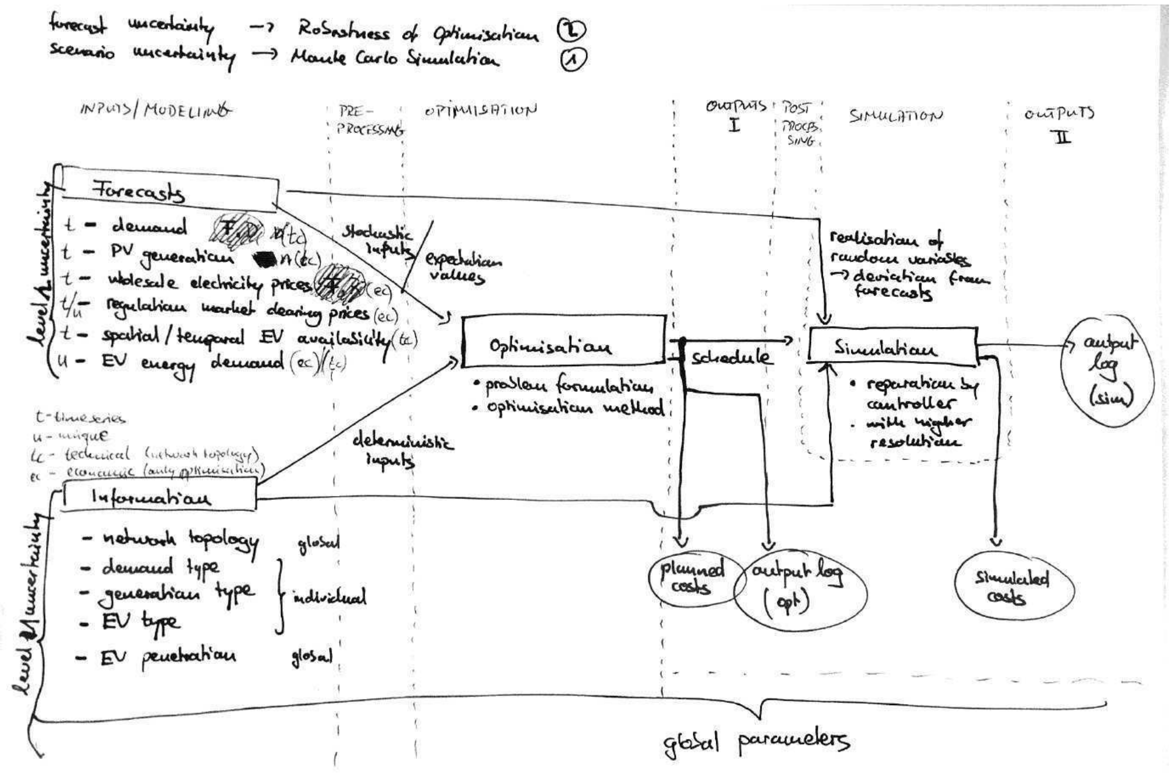
- **Feeder length**: total length of each feeder taking into account main and services cables.
- **Customer number**: total number of customers supplied per feeder.
- **Initial loading level**: loading level (hourly maximum current divided by the ampacity) at the head of each feeder without any LCT.
- **Main path**: distance between the MV/LV transformer busbar and the furthest customer.
- **Main path resistance**: sum of all series resistances (– sequence) in the main path. Note that the average R/X ratio of the main paths in the 128 studied feeders is 3.9.
- **Supplied area**: total area supplied by the feeder. This area is estimated by calculating the convex hull that encloses all the feeder vertices.
- **Total resistance aggregation**: sum of all cable resistances (| sequence) in the feeder (including service cables).
- **Supplied perimeter**: length of the convex hull.
- **Total path resistance:** sum of all path resistances between the busbar and each customer

$$\mathrm{TPR} = \sum_{i=1}^{N} \text{path resistance}_i \qquad (2)$$

where TPR is the total path resistance, N is the number of loads in each feeder, and the path resistance is the resistance between the busbar and the load i.

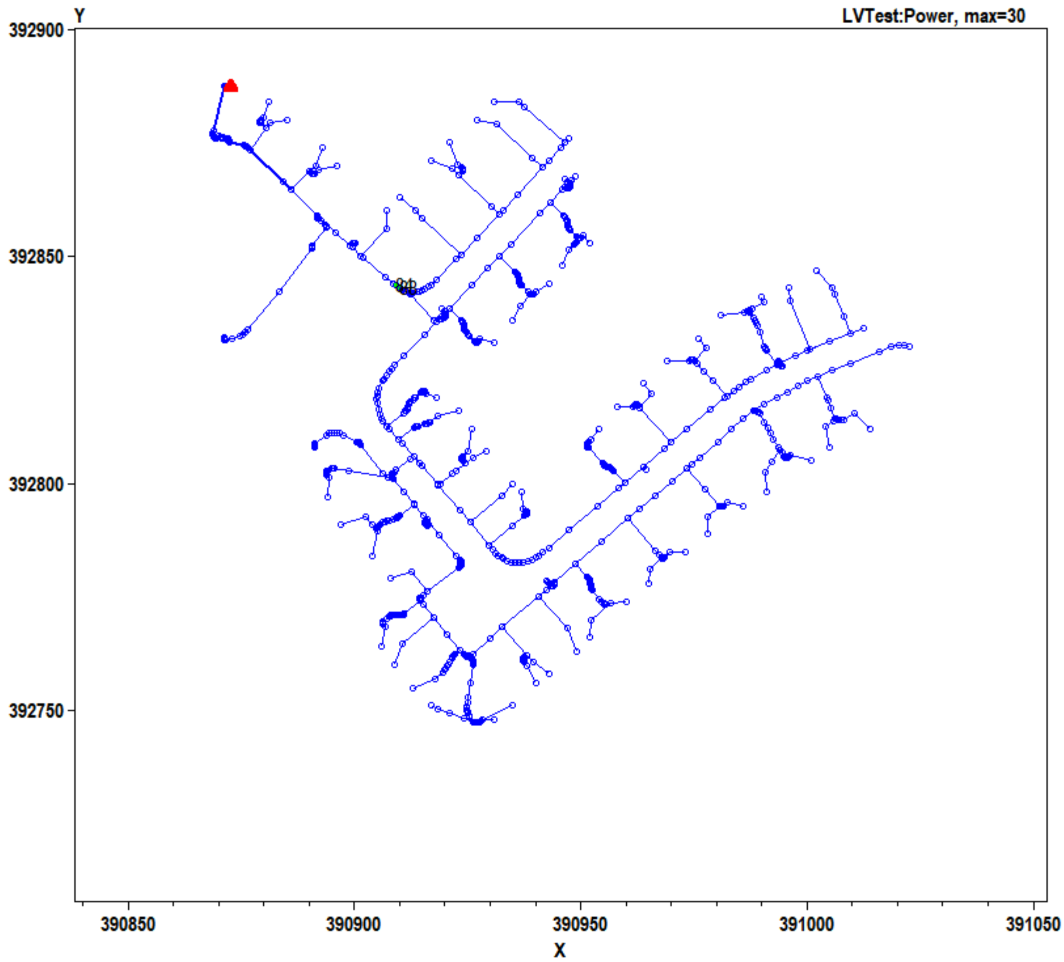
Programming Architecture

First Draft



EV penetration done by manual sensitivity analysis, not based on empirical findings
Network topology as provided by https://ewh.ieee.org/soc/pes/dsacom/testfeeders/ under European Low Voltage Test Feeder.

- The current test cases are focused on North American style systems; however it is common outside of North America to see low-voltage distribution systems, both radial and meshed. It is important to make sure that tools support both dominant styles of distribution system configuration. This test case seeks to fill a benchmark gap by presenting a number of common low-voltage configurations
- Some characteristics
  - 906 buses
  - 55 loads all single phase at 230 volts
  - 905 lines , all 3 phases, different linecodes
  - 1 transformer 11kV to 416V
  - 1 slack generator, no local generation (unless modelled by negative demand)
- Some ideas to implement
  - https://github.com/gregoriovelasquezgomez/European_LV_TF_GridLAB-D
-



-

Open Questions

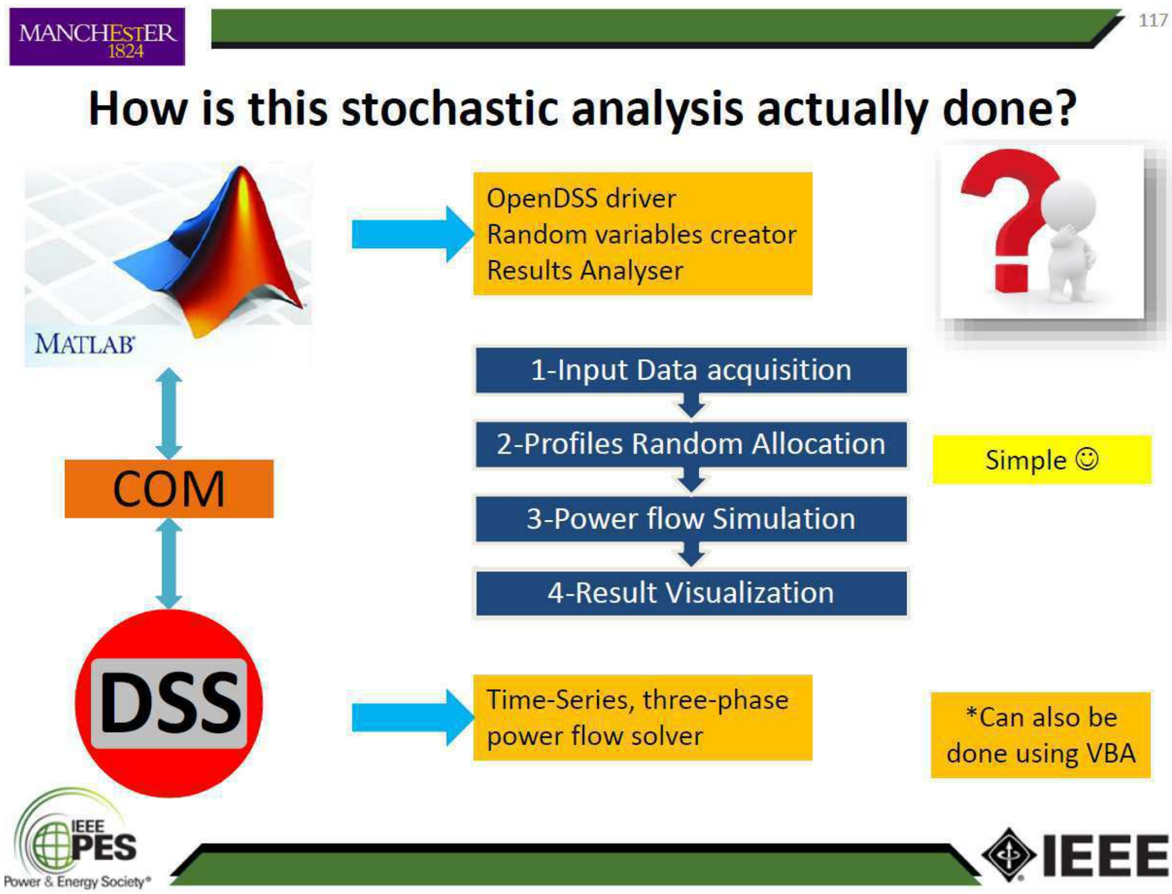
- Incorporation of OpenDSS Power Flow Analysis into optimisation procedure / problem formulation
    - I presume: easy for dynamic programming, difficult for LP/NLP

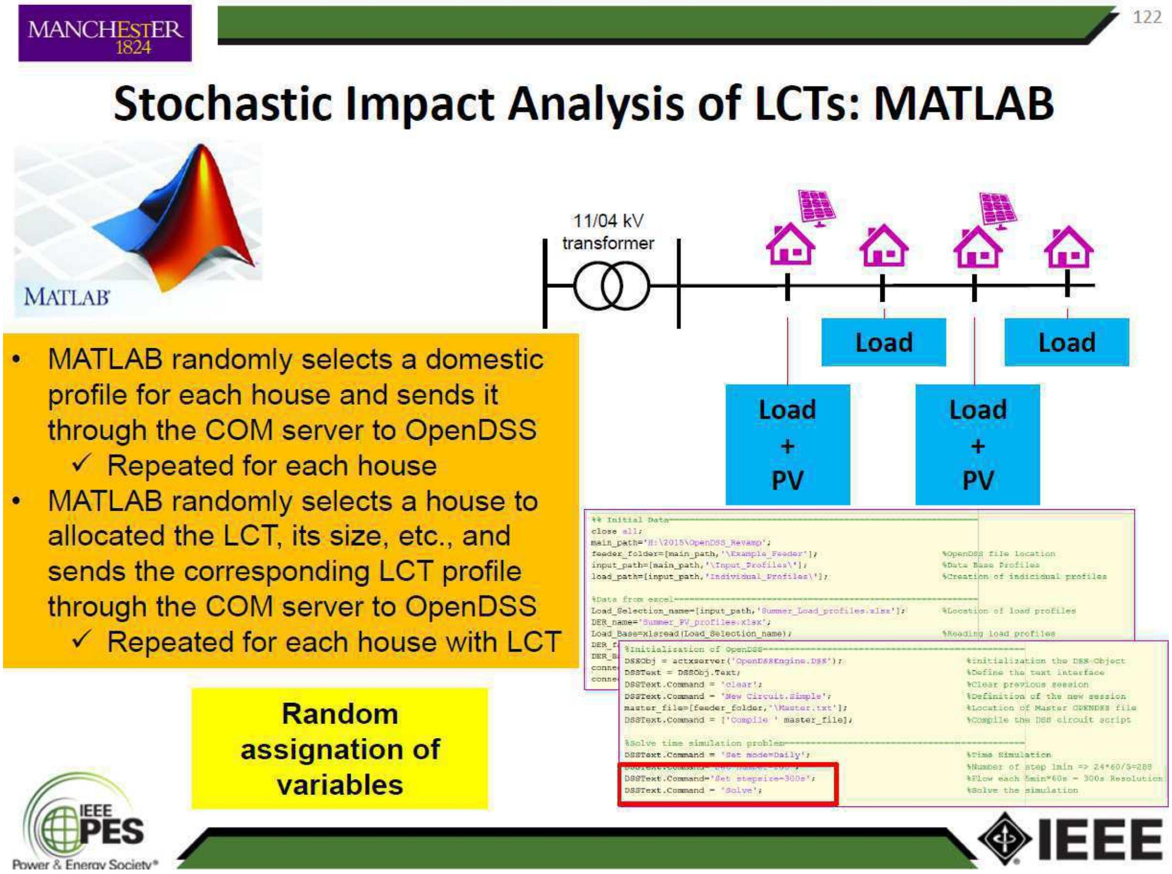
Monte Carlo Simulation / Stochastic Impact Analysis

- cope with the uncertainty (LCT size and location, sun profile, EV utilization, load profile)
    - generate time series in arbitrary interval (1min, 5min, 15min)
- performs risk analysis by building models of possible results by substituting a range of values (PDF) for any factor that has inherent uncertainty
    - repeated calculations
    - produces distributions of possible outcome values
    - values are sampled at random for the input probability distributions, where each set of samples is an iteration
    - what could happen, but also how likely is it to happen
    - probabilistic results, sensitivity analysis, scenario analysis
- Monte Carlo methods are used to assign parameters by generating random draws from probability distributions of empirically observed data, such as the number of occupants

in a dwelling. Another common approach is the use of the Markov-chain technique to generate representative stochastic sequences of discrete random variables

- benefit of stochastic modelling is that it facilitates a model to be self-contained, as the use of large datasets can be avoided by instead using the statistics that summarise and characterise them.
- Navarro-Espinosa2016
    - *Within the proposed Monte Carlo-based approach, 100 simulations were performed in each penetration level. This number was chosen considering the trade-off between computational time and accuracy of the results. To exemplify this effect, different simulation numbers (i.e., 25, 50, 75, 100, 400, 600, and 1000) were analyzed for one specific feeder (feeder 3 in Fig. 4). The simulation time for each of the cases is presented in Table VII. It is possible to observe that computational time increases linearly with the number of simulations carried out.*





Ancillary Service Markets

- TSO after gate closure for imbalance settlement
    - security of supply
    - minimise backup generation
- e.g. STOR, FFR, FCDM, FR
- UK: Balancing Services Use of System (BSUoS)
    - internal costs
    - external costs
- STOR as monthly auction

Definitions

- PLC: Programmable Logic Controller used for event handling
- COM server: supports driving the simulator from user written programs

New Sources

- International Energy Agency, "Technology Roadmap – Electric and plug-in hybrid electric vehicles" (updated June 2011). [Online]. Available: http://www.iea.org/roadmaps/plug_in_electric_vehicles.asp

Unsorted

- Acha2012
    - factors
        - flexible electricity tariffs
        - carbon content of power
        - battery capacity
        - rate of charge characteristics
        - vehicle travel patterns
        - user activities
        - network features (topologies)
- Dallinger2010a
    - novel players in the regulation market can create more competition and improve the efficiency of regu- lation. Evidence is accumulating that batteries combined with power electronics can react as very fast regulation units
    - Economic aspects of V2G services have been an- alyzed in a number of previous studies [1]–[5]. Most studies identify benefits forV2G vehicle owners in the range of a few to several hundred dollars per month
    - Positive control and feeding back electricity are not found to be promising options due to the costs in terms of battery degrada- tion and for the bidirectional power electronics.
    - ENTSO-E is responsible for frequency control in Central Europe

TABLE I

AVERAGE MARKET PRICES IN 2008 FOR DIFFERENT ANCILLARY SERVICES OF THE FOUR GERMAN TSO AREAS

Regulation Reserve			Capacity	Normalized capacity price	Dispatch	Energy price	Dispatch probability
			[MW]	[€/MW·h]	[MWh/Month]	[€Cent/kWh]	
Primary control			667	20.51	-	-	n.s.
Secondary control	HZ	Positive	3,081	22.05	120,163	11.16	14.9%
		Negative	2,451	4.04	106,521	0.1	16.6%
	NZ	Positive	3,050	7.41	116,290	6.91	8.1%
		Negative	2,413	8.23	270,227	0.01	23.8%
Tertiary control	HZ	Positive	3,263	10.4	9,332	21.43	1.1%
		Negative	1,949	0.31	11,681	0.04	2.3%
	NZ	Positive	3,205	2.73	3,181	16.73	0.2%
		Negative	1,919	3.92	18,770	0.00	2.1%

Prime time (Hauptzeit); secondary time (Nebenzeit); data basis: German Transmission System Operators 2009.

-
    - A fixed period of operating availability has to be guaranteed for the regulation capacity offered
    - **Very good paragraph on summary of providing negative and positive regulation capacity:**
        - "Providing Positive Regulation Capacity: Providing positive regulation capacity does not seem to make economic sense. In the market for positive secondary regulation capacity, the high dispatch probability results in very high variable costs.Approxi- mately one third of these costs comprise those for battery degradation and two thirds those for energy costs. In the market for positive spinning reserves, dispatches are so seldom that the income from providing regulation capacity and the fixed

costs are decisive. The capacity price is too low and the rare dispatch occurrences result in it not being economical tomake the relatively high investment in the bidirectional power electronics. The only profitable way to feed energy back into the grid is to participate in the primary control market. The profits are still relatively small at today's prices for regulation energy, but this option could becomemore relevant considering the strong price increase in the past (compare [15]) and the presumed upwards trend in demand due to the expansion of renewable energies. At the moment participation seems to be ruled out by the regu- latory requirements. Because the prequalification requirements are very high and since they do not allow for pooling resources, each generation unit has to be able to provide at least 10 MW capacity.

        - Positive and negative control were analyzed separately to reduce the complexity and reveal the different secondary and tertiary markets. In general, either negative or positive regulation is neededwithin one regulating zone. Therefore, it is possible to bid for positive and negative control at the same time. Especially in the secondary market, it seems promising to realize further benefits by providing positive control after loading the battery with negative control services.Moreover, pooling vehicles provides new options for advanced bidding strategies. A vehicle pool can provide positive control simply due to the reduction of the load. Hence the pool can participate on the positive control marketwithout a bidirectional grid connection. Overall, this could result in an economic benefit since there are no costs for battery degradation or the bidirectional grid connection.
        - Providing Negative Regulation Capacity: The results illustrate that the biggest profits can bemade in themarket for negative secondary regulation capacity. The relatively high dispatch probability means that the energy costs of conventional charging can be avoided. In this way, drivers are able to draw some of their power practically free of charge. The technical effort and the investments in the infrastructure are relatively small.Battery degradation does not occur since the batteries are not addition- , ,ally discharged. The tertiary control market is less attractive. The necessary investments are identical, but less income can be earned due to the lower dispatch probability.
        - Summary: Providing negative secondary regulation capacity is the best way to participate in the regulation markets under present conditions inGermany.Alongside the economic advan- tages, the prequalification requirements already plan for pooling generation units to provide secondary regulation capacity (compare [15]) in contrast to those for providing primary regulation. Since this type of regulation energy ismainly called for at night, it matches the typical behavior pattern of vehicle drivers, who tend to recharge their vehicle after the final trip of the day."
    - question of market volume for ancillary services will become more relevant
- Dianes2017
    - "On one hand electric grids capacity can be strained by an unmanaged EV load, especially at the distribution level where the capacity bottlenecks are most easily reached. On the other, if charging demand flexibility can be harnessed by implementing smart charging strategies, not only can costly grid capacity upgrades be minimised, but the operation of grid systems can be enhanced making use of a potentially very large responsive storage constituted by the batteries of grid- connected EVs"

- Quiros-Tortos2016
    - Results for LV networks show that problems may occur for EV penetrations higher than 20%
    - considering 1-min resolution data and unbalanced (three-phase) LV network models with single-phase customer connection points
    - control cycles of up to 10min, the control algorithm successfully mitigates problems on the examined LV networks
    - most of these studies are focused on mitigating the aggregated EV impacts on medium voltage (MV) circuits (i.e., kV) [6]–[11]. However, highly dense residential LV networks, such as those in Europe (multiple feeders, hundreds of customers), are likely to be the first bottleneck and thus the corresponding impacts must be investigated.
    - Proposed technical Control Algorithm (based on ESPRIT Technology)

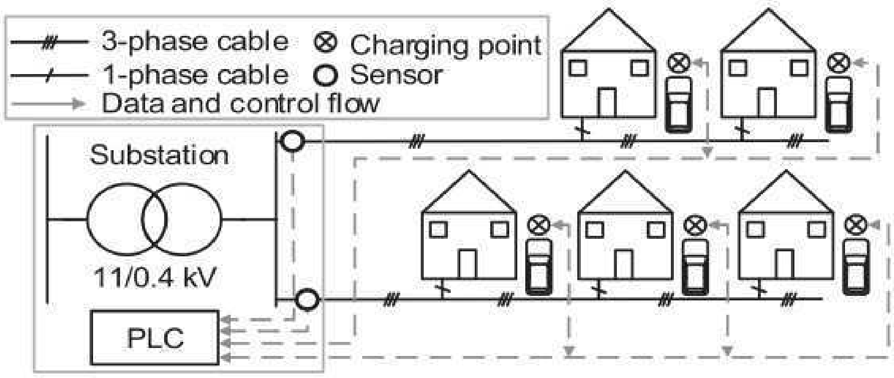


Fig. 6. Practical implementation architecture.

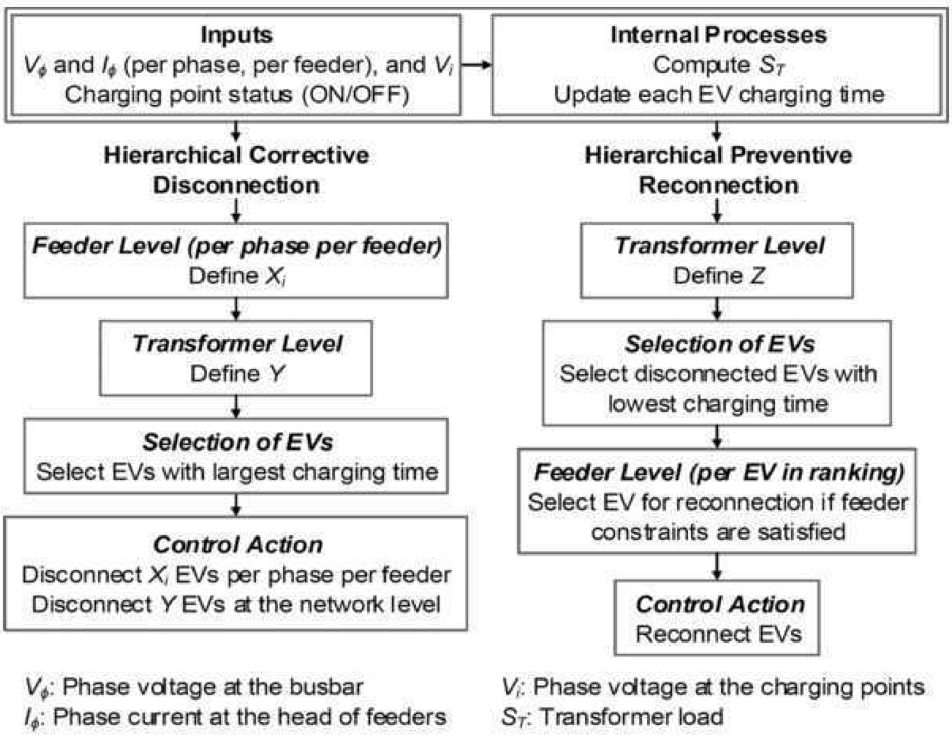


Fig. 7. Flowchart of the proposed control algorithm.

    -

- Navarro-Espinosa2016

- Recent statistics [19] are used for a realistic mix of PV sizes: 1%, 8%, 13%, 14%, 12%, and 37% of the PV profiles use installed capacities of 1.0, 1.5, 2.0, 2.5, 3.0, 3.5 and 4.0 kWp, respectively
- the probability distributions of connection times and the corresponding energy required are combined to produce the daily behavior of individual EVs considering one charge at homeper day.Given that U.K. residential loads are single phase, EV users are initially expected to mostly adopt slow charging modes at home.

23 May (Dissertation Outline)

Notebook:	MA Journal		
Created:	03/06/2017 13:47	Updated:	08/08/2017 14:23
Author:	Fabian Neumann		

Mind Map of Dissertation Outline

- https://1drv.ms/u/s!AhL_5CCCtxYlh7I8yXetSU5b2q0kKg
- file:///C:/Users/Fabian%20Neumann/OneDrive/Studium/UOE/Dissertation/Administration/Dissertation%20Outline.xmind

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Tasks / Ideas

- General
    - sort dissertation related files
    - summarise and select focus for uncertainties
- Motivation
    - ...
- Demand Modelling
    - Generate sufficient number of load profiles using CREST
    - Generate sufficient number of PV profiles using CREST
    - Decide on uncertainty modelling options (noise or another profile)
    - implementation for optimisation
- EV Behaviour Modelling
    - statistical analysis and distribution fits
    - statistical analysis for weekends (postponed)
    - implementation for optimisation
- Network Topology
    - Question: Where can I place loads/customers in the distribution network?
- Electricity Markets
    -
- Optimisation Routine
    - optimisation/simulation architecture [VBA, MATLAB, Python, CPLEX, OpenDSS]
    - translate Resampler from Java to Python
- Optimisation Methods
    - Stochastic Dynamic Programming

5-6 June (Driving Patterns)

Notebook:	MA Journal		
Created:	05/06/2017 15:55	**Updated:**	08/08/2017 14:24
Author:	Fabian Neumann		
URL:	https://uk.mathworks.com/help/stats/examples/simulating-dependent-random-vari...		

Related Documents

- Excel
  - Dissertation\Data Processing\Excel\travelpatterns - mileage
  - Dissertation\Data Processing\Excel\travelpatterns - tripstartend
- Matlab
  - MATLAB\Disseration\TravelPatterns\travelpatterns_fitting.m
- Outputs
  - see below

Resources and Thoughts

- most studies use aggregate distributions of e.g. daily mileage but give no notion of the distributions of uncertainty
- basing their research on conventional mobility patterns
- a scatterplot of standard deviations and average arrival/departure times or mileage reveal
  - data is not reasonably possible to cluster
  - fits for marginal distributions are easy to obtain
  - correlations make it necessary to use multivariate random variables (by transformation)
- Motivation for using common continuous distribution functions is to allow reproducibility of simulation without heavy datasets!
- None of the distribution fits will be accepted by a Chi2 or Kolmogorov-Smirnoff goodness of fit test to the significance niveau \alpha = 0.1
- objective to additionally capture varying levels of uncertainty, while still allowing reasonable Monte Carlo Simulation
- limited number of data points forces assumption for normal distribution (drawback)
- In Monte Carlo Simulation driving behaviour will be assigned with a given normal distribution reflecting its uncertainty.

- Simulating Dependent Random Variables
  - https://uk.mathworks.com/help/stats/examples/simulating-dependent-random-variables-using-copulas.html
  - simulating dependent random variables using copulas
  - Copulas are functions that describe dependencies among variables and provide a way to create distributions to model correlated multivariate data
  - One of the design decisions for a Monte-Carlo simulation is a choice of probability distributions for the random inputs. Selecting a distribution for each individual variable is often straightforward, but deciding what dependencies should exist between the inputs may not be, but it is generally difficult to generate random

inputs with dependence with non-standard multivariate distributions

---

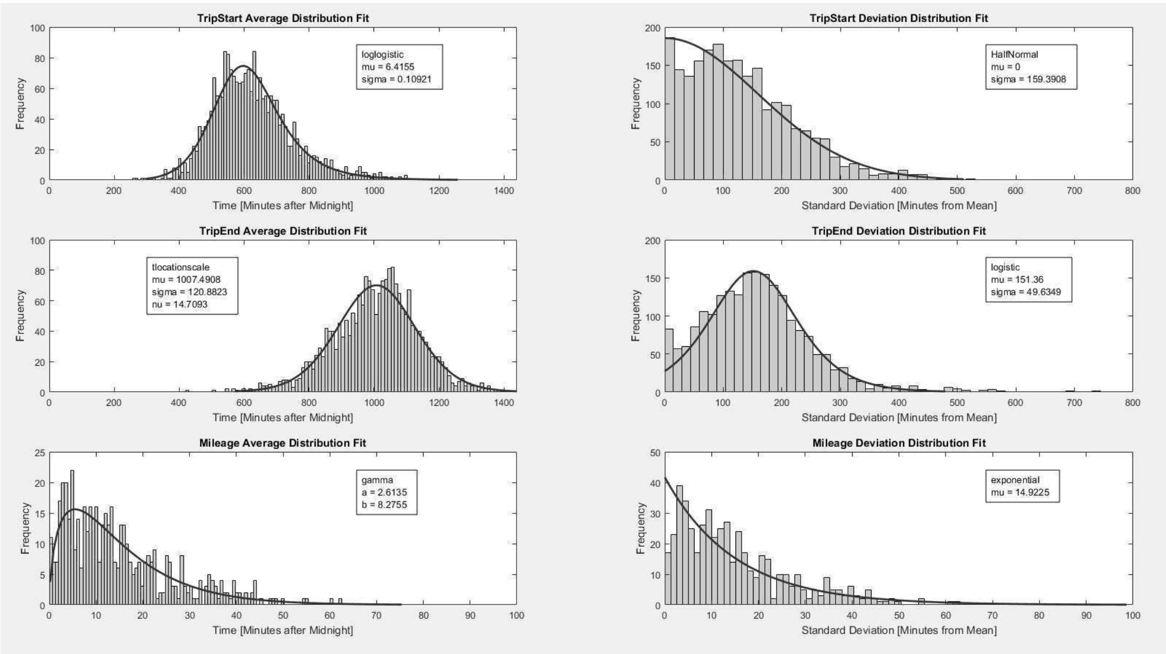
Method Summary

- **Sufficiently large extract of trip data from the National Transport Survey loaded (4000 most current householdIDs in the data set amounting to 30000 trips by car logged)**
- **Filter for trips by car, regardless of purpose, choose only weekdays**
- **for analysing the distributions of first trips of the day only consider first journey sequence**
    - for each household determine the average and standard deviation of tripstart time (minutes after midnight) from the number of days logged
    - avoid too low number of samples (e.g. < 3) -> reduced number of samples ~2300
    - assume normal distribution for each individual pair of average and standard deviation of tripstart time
    - find best fit marginal distributions of empirical average/standard deviation
    - analyse correlation between average and standard deviation -> yield 0.35 -> relatively weak but must be considered
    - simulate draws dependent and not independent
        - generate multivariate normal distribution with empirical correlation coefficients
        - transform to respective best fit marginal distribution via uniform distribution
        - check simulated correlation coefficients (where is the information loss?)
- **for analysing the distributions of last trips of the day only consider last journey sequence**
    - for each household determine the average and standard deviation of tripendtime (minutes after midnight) from the number of days logged
    - avoid too low number of samples (e.g. < 3) -> reduced number of samples ~2300
    - assume normal distribution for each individual pair of average and standard deviation of tripend time
    - find best fit marginal distributions of empirical average/standard deviation
    - analyse correlation between average and standard deviation -> yield -0.16 -> very weak, does not have to be considered, but possible
    - simulate draws independently for now, simple adaptation possible
- **for analysing the distributions of mileage**
    - for each day/household combination, sum all individual trips to receive a daily mileage
    - filter distances that lie outwidth typical EV range (>120 miles)
    - for each household determine the average and standard deviation of mileage from the number of days logged
    - avoid too low number of samples (e.g. < 3) -> reduced number of samples ~500
    - find best fit marginal distributions of empirical average/standard deviation
    - analyse correlation between average and standard deviation -> yield 0.70 -> strong and must be considered
    - simulate draws dependent and not independent
        - generate multivariate normal distribution with empirical correlation coefficients
        - transform to respective best fit marginal distribution via uniform

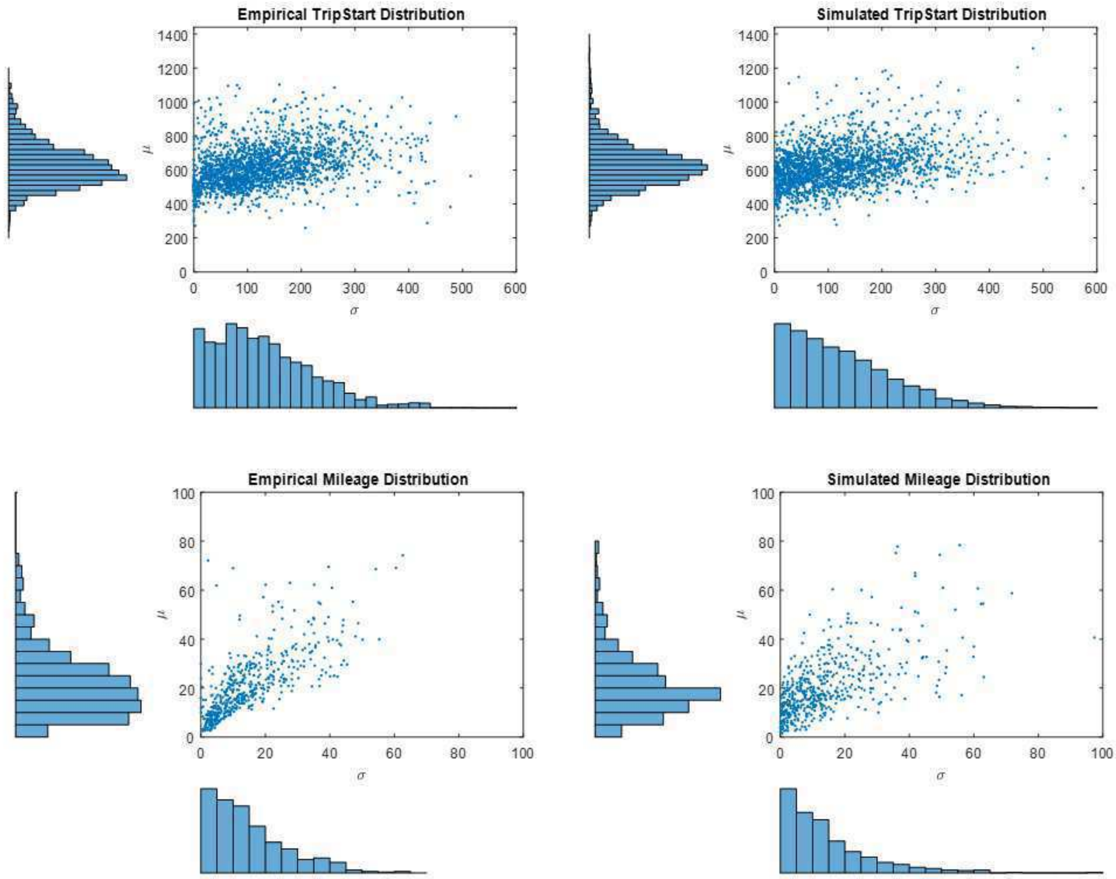
distribution
    - check simulated correlation coefficients (where is the information loss?)
- **check whether time of earliest trip start and last trip end of a day correlate**
  - for both yields very weak positive correlation
  - may be disregarded such that tripend and tripstart may be simulated independently
- **everything else is considered to be uncorrelated (such as the time difference between tripstart and tripend to daily mileage)**

Outputs

- **many more in**
  - travelpatterns - mileage
  - travelpatterns - tripstartend



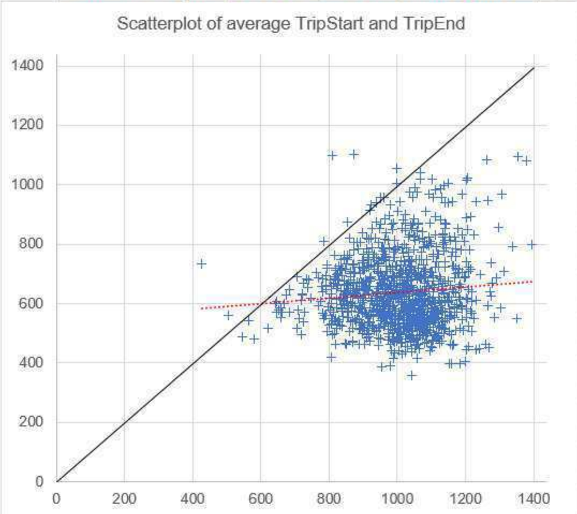
NB: TripEnd Deviation Distribution Fit will be truncated to [0,inf)
NB: Mileage Deviation Distribution Fit alternative is generalized extreme value distribution

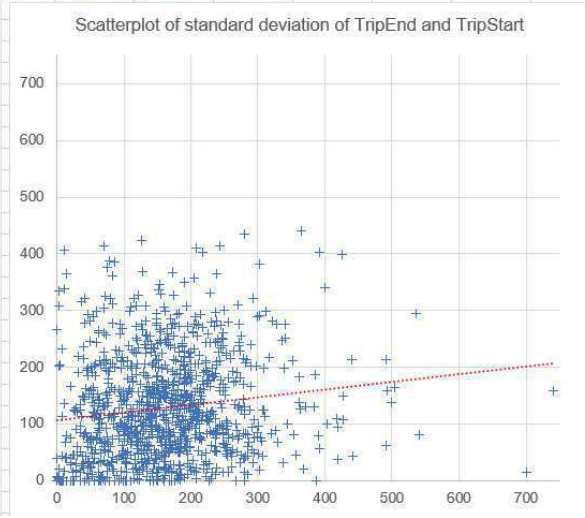



```
% empirical correlation coefficients of tripstart average and standard
deviation
cc_ts_empirical =

    1.0000    0.3547
    0.3547    1.0000

% simulated correlation coefficients of tripstart average and standard
deviation
cc_ts_simulated =

    1.0000    0.3491
    0.3491    1.0000

% empirical correlation coefficients of mileage average and standard
deviation
cc_mi_empirical =

    1.0000    0.6814
    0.6814    1.0000

% simulatedcorrelation coefficients of mileage average and standard
deviation
cc_mi_simulated =

    1.0000    0.6636
    0.6636    1.0000
```

Correlation of σ	Correlation of μ
0.1350	0.0952

Correlation is very weak, hence it is sufficient two model via two independent univariat probability distribution funcitons





14 June (Meeting)

Notebook:	MA Journal		
Created:	14/06/2017 10:49	**Updated:**	15/06/2017 10:44
Author:	Fabian Neumann		

Meeting Agenda

1. Present driving patterns model (approved)
2. Discuss dissertation outline (open)
3. Discuss difficulty of OpenDSS power flow incorporation (discussed, linearisation of power flow [not necessary] or incorporate in fitness evaluation in metaheuristics)
4. Discuss choice of optimisation schemes (base scenario, greedy, GA/PSO)
5. Discuss value of developing yet another optimisation scheme (heuristics are fine)
6. Ask for contents of project presentation (problem formulation)

Notes

- rolling optimisation (run for fixed period / no overlap first)
    - using knowledge of previous realisation period to adapt initialisation of new optimisation routine
- Monte Carlo Simulation only for scenario generation (assignment of loads and electric vehicles in network topology)
- Overview of robust/stochastic/MC optimisation
- Regulation service market in the UK is not very interactive
    - choose however you want it to be
    - use foreign regulation service market for exemplary purposes (e.g. Nordpool, PJM)
- start with unidirectional power flow, extend bidirectional power flow
- semantics of regulation down and regular demand
    - avoid introducing new decision variables (keep it simple)
    - then actual price = market price - regulation down price (not realistic, price vs. engaged)
- most likely highly feasible search space
- look into pyswarm and DEAP package (already downloaded and installed)

Multivariate Random Variables Theory

Waldmann

- not interested in the distribution of single random variables but in the dependency of multiple random variables
- joint probability distribution

$$p(x,y) := P(X=x, Y=y) \qquad x \in I,\ y \in J$$

- marginal distribution

$$p_X(x) = \sum_{y \in J} p(x,y) \qquad x \in I$$

$$p_Y(y) = \sum_{x \in I} p(x,y) \qquad y \in J$$

- Generally the knowledge of the marginal distributions does not suffice to determine the joint probability distribution
  ↳ only if X and Y independent $P(X \in C, Y \in D) = P(X \in C)\, P(Y \in D)$
    ↳ JPD $= \prod$ MD
    ↳ one of the fundamental assumptions of stochastic modeling
- covariance quantifies the dependency of two random variables
  ↳ 0 if independent $\mathrm{Cov}(X,Y) = E[(X - E(X)) \cdot (Y - E(Y))]$
- normalised covariance is correlation

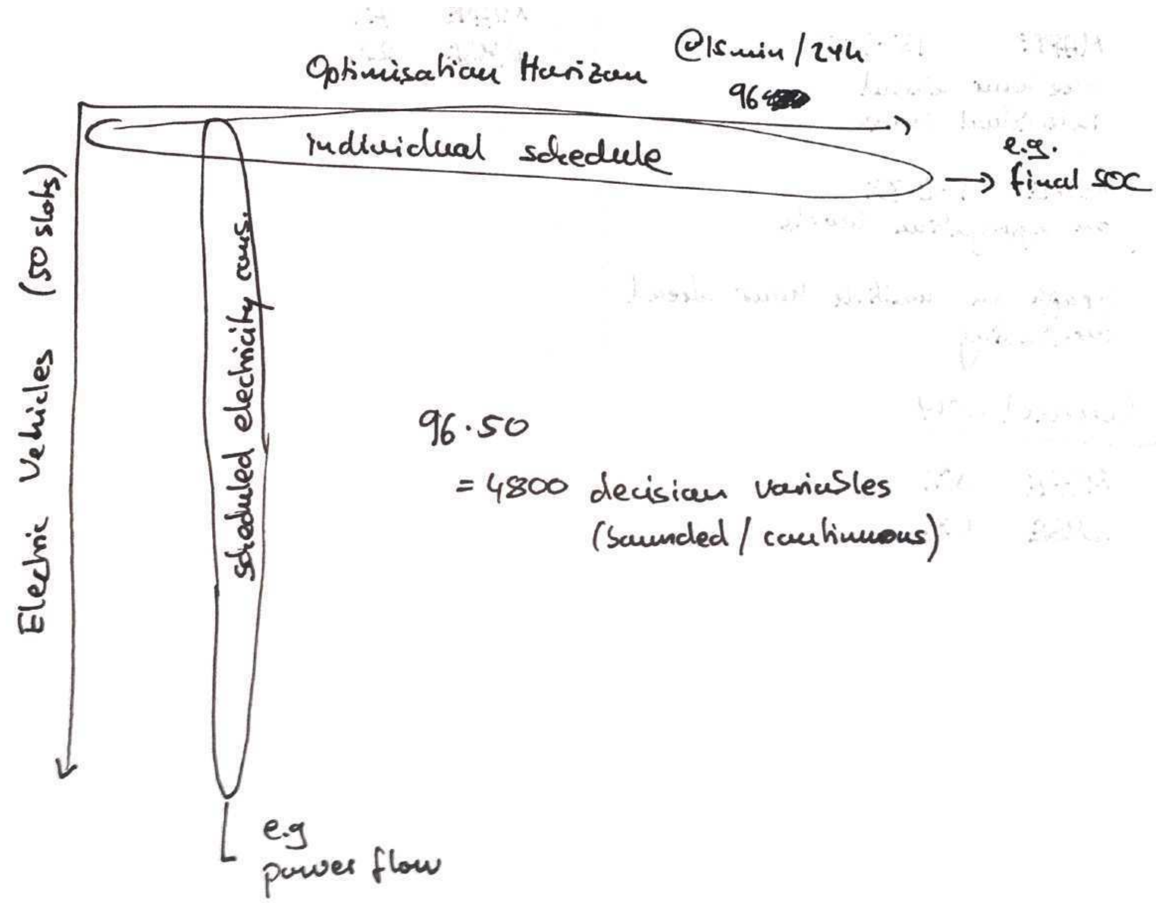
$$\rho_{XY} = \frac{\mathrm{cov}(X,Y)}{\sqrt{\mathrm{Var}(X)\,\mathrm{Var}(Y)}}$$

multivariate normal distribution

where \mu is a vector of expectation values
and \Sigma is covariance matrix / correlation matrix (offdiagonal elements may reflect correlations

---

Decision Variables



Demand and Price Uncertainty (also cf. OConnel2014)

demand 27 - 29	price 30 - 31
Sevlian 2014 MAPE 15-30% one hour ahead Individual loads MAPE 1-2-3% on aggregation levels Graph on multiple hour ahead forecasting **OConnel 2014** MAPE 5% RMSE 6%	**OConnell 2014** MAPE 7% RMSE 2%

14 June (Stochastic Optimisation Approaches)

Notebook:	MA Journal		
Created:	14/06/2017 19:38	**Updated:**	08/08/2017 14:24
Author:	Fabian Neumann		

- many parameters in optimization models are uncertain
- sometimes deterministic models where a single value for each may be the best choice
- fitting a probability distribution is yet another modeling approximation (uncertain)
- situation: taking a decision before observing the random vector
- optimal decision is the one that maximises the expectation value of the objective function

---

Robust Optimisation

- do not significantly increase the complexity of the considered optimisation problem
- for risk-averse decision making: worst case analysis as maximin models
- when the parameters are known only within certain bounds
- goal to find a solution which is feasible for all such data and optimal in some sense
- quantify the uncertainty in the true value of the parameter of interest by probability distribution functions --> stochastic programming

---

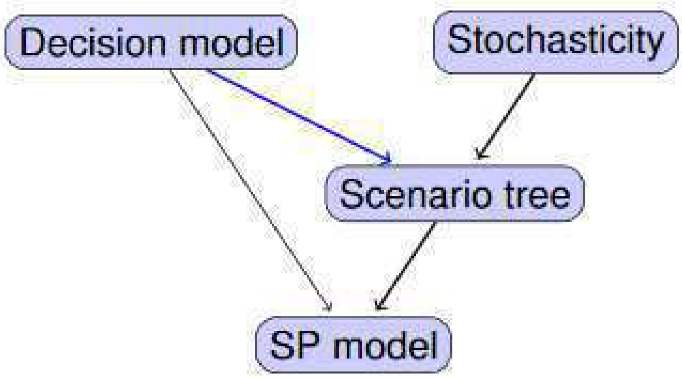
Stochastic Programming

- dependency on availability of historical data and complex modeling
- based on the assmuption of known or estimated probability distributions for parameters
- goal: feasible for almost all possible data instances and maximisation of expectation of function of decisions and random variables
- modeling optimisation problems which involve uncertainty
- with a finite number of scenarios two-stage stochastic linear programs can be modelled as large linear programming problems - deterministic equivalent linear program
- Monte Carlo sampling is common approach to reduce the scenario set to a manageable size: given a sample, the expectation function is approximated by the sample average. This is known as sample average approximation method

---

Scenario Optimisation

- technique for obtaining solutions to robust optimisation and chance-constrained problems
- extracting at random some instances of the uncertainty and then finding the optimal solution where only the constraints associated to the instances are considered



- Stochastic programming can only handle discrete samples of limited size so needs to approximate distribution by scenario tree

---

Chance constrained optimisation (infeasible!)

- EXPECTATION CONSTRAINTS: $min\{f(x)|g(x, \mathbb{E}\xi) \geq 0\}$

  Pro: easy to solve, solutions at low costs Con: solutions not robust

- WORST-CASE CONSTRAINTS: $min\{f(x)|g(x, \xi) \geq 0 \quad \forall \xi\}$

  Pro: absolutely robust solutions Con: solutions extremely expensive or do not even exist

- CHANCE CONSTRAINTS:

$$min\{f(x)|\underbrace{\mathbb{P}(g(x, \xi) \geq 0)}_{\varphi(x)} \geq p\} \quad p \in [0, 1]$$

  Pro: robust solutions, not too expensive Con: often difficult to solve

a) use e.g. maximum likelihood estimator
b) robust optimisation
c) chance-constrained optimisation: the probability that constraint is fulfilled must be larger than a pre-defined probability

---

Dynamic Programming (infeasible?)

- breaking problems down in collection of simple subproblems, store solutions, lookup
- recursive method to solve multiple stage decision problems
- 2^50 options at each time slot if 50 vehicles in network

Greedy Heuristic Optimisation

- treats solution as sequence of steps and picks the locally optimal choice at each step
- does not guarantee optimal solution, but fast to calculate
- never reconsiders its choices

Particle Swarm Optimisation

- population based stochastic optimisation technique
- as a metaheuristic it makes few or no assumptions about the problem being optimised.

but do not guarantee optimal solution
- system is initialised with a population of random solutions and searches for optima by updating generations
- particles flow through the search space by following better particles
- each particle keeps track of its coordinates in the search space including its best solution: also information about local best and global best
- differ from evolutionary algorithms in the sense that they do not learn by selection but by learning from neighbouring individuals
- individuals consist of genotype, change vector and their path in the search space
- new genotype = old genotype + updated change vector
- change vector: return to good solutions along the path and orientation toward the success of neighbours
- little need for parameters makes PSO attractive

Bild 4.37.
Modifikation des Veränderungsvektors v im Partikelschwarm.

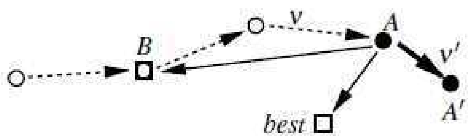


Tabelle 4.15.
Empfohlene Parameterwerte bei der Optimierung mit Partikelschwärmen.

Parameter	Wertebereich
Trägheit β:	0,8–1,0
kognitiver Faktor α_1:	1,5–2,0
sozialer Faktor α_2:	1,5–2,0
maximale Veränderung MAX:	$og_i - ug_i$
Populationsgröße μ:	20–60

Metaheuristics Overview (German, Weicker2015)

Tabelle 4.16: Vergleich der Standardalgorithmen (Teil 1)

Algorithmus	Genotyp	Mutation	Rekombination	Selektion	Population	Besonderheiten
Genetischer Algorithmus	klassisch: $\mathbb{B}^\ell$ mit fester Länge ℓ, auch: $\mathbb{R}^\ell$ und $\mathscr{S}_\ell$, Dekodierung	Bitflipping, gleichverteilte reellwertige Mutation, spezielle Permutationsoperatoren	k-Punkt- und uniformer Crossover, arithmetischer Crossover, mehrere Rekombinationsoperatoren für Permutationen	fitnessproportionale Elternselektion, auch: skaliert, rangbasiert oder als Turnierselektion	mittelgroße bis große Populationen	theoretische Grundlage: Schema-Theorem
Evolutionsstrategie	$\mathbb{R}^\ell$, meist gilt Genotyp = Phänotyp, zusätzliche Strategieparameter	(selbst-)adaptive Gauss-Mutation, erst Mutation der Strategieparameter	anfangs keine, später: arithmetischer und uniformer Crossover, auch: globale Varianten, anderer Operator auf Strategieparameter	Eltern: gleichverteilt, Kinder: Komma- bzw. Plus-Selektion	kleinere Populationen, manchmal: $\mu = 1$; bei Komma: $\lambda > \mu$	unterschiedliche Mechanismen der Selbstadaptation für die Schrittweitenanpassung, auch: adaptive $1/5$-Erfolgsregel
Evolutionäres Programmieren	anfangs: endlicher Automat, später: $\mathbb{R}^\ell$ mit Strategieparametern	Modifikation der Zustände und Übergänge in Automaten, Gauss-Mutation, gleichzeitige Mutation der Strategieparameter	keine	anfangs: Plus-Selektion, später: q-stufige 2-fache Turnierselektion aus Eltern und Kindern	mittelgroße Populationen, Es gilt $\mu = \lambda$	Selbstadaptation der Schrittweite; bei Automaten: unterschiedliche Behandlung unerreichbarer Zustände möglich
Genetisches Programmieren	Bäume, aber auch lineare Darstellungen variabler Länge (für Graphen, Assemblerprogramme etc.)	internes Umhängen oder Modifikation von Teilbäumen, spezielle Operatoren	Austausch von Teilbäumen, spezielle Operatoren	verschiedene, meist wie beim genetischen Algorithmus	sehr große Populationen	oft nur ein Operator auf ein Individuum, spezielle Initialisierung, Methoden zur Intron-Vermeidung, Evolution von ADFs
lokale Suche	beliebig	beliebig	keine	Verbesserungen immer, Verschlechterungen mit gewisser Wahrscheinlichkeit	ein Individuum	zentrales Problem: zu frühe Konvergenz

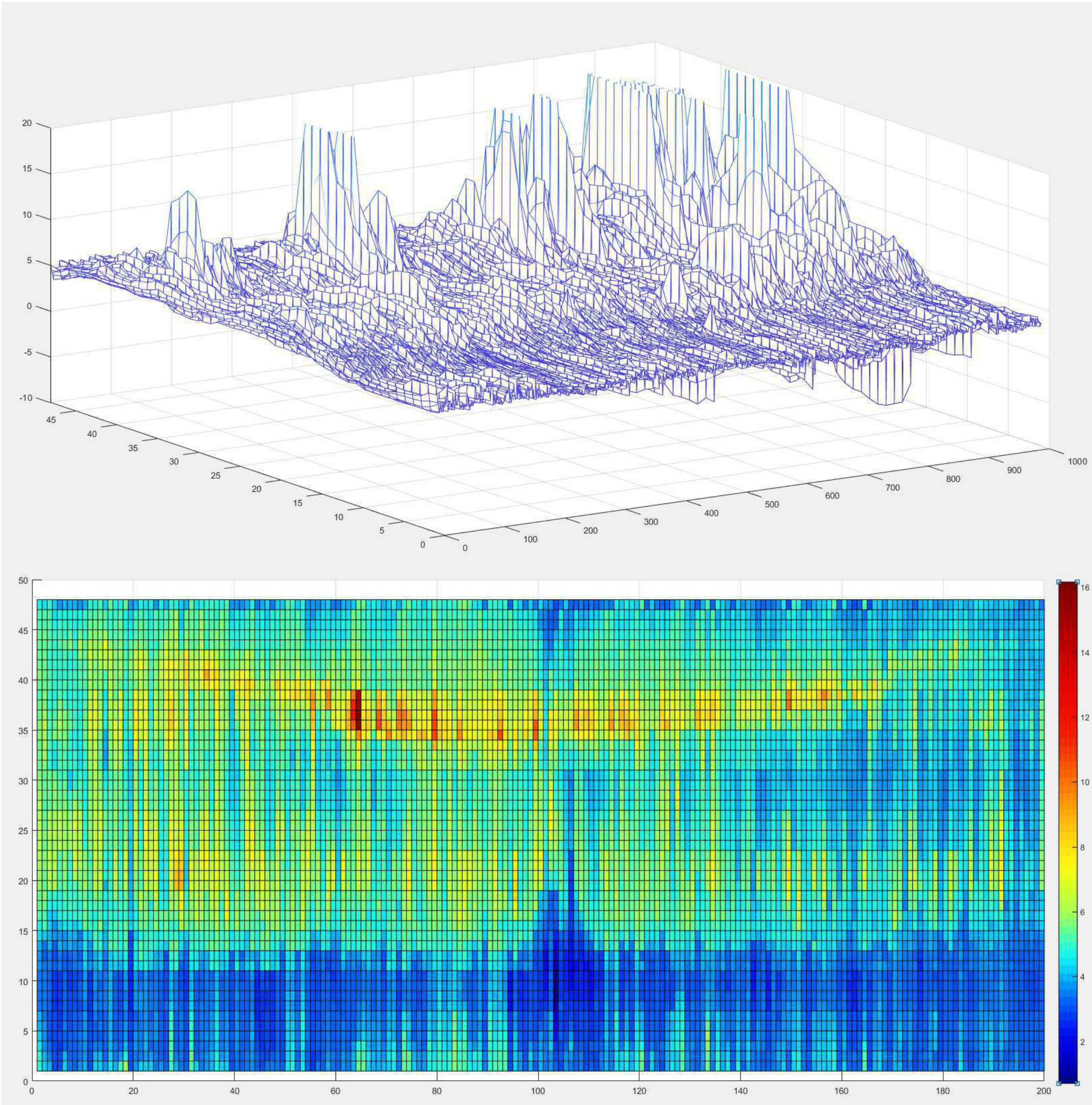
Tabelle 4.17.: Vergleich der Standardalgorithmen (Teil 2)

Algorithmus	Genotyp	Mutation	Rekombination	Selektion	Population	Besonderheiten
Klassifizierendes System	Regel oder Menge an Regeln, klassisch: $\{0, 1, *\}^\ell$	Bitflipping	k-Punkt-Crossover	fitnessproportional, klassisch: überlappende Populationen	bei Michigan: ausreichend für Komplexität der Aufgabe	Michigan: Population ist Regelsatz, Pittsburgh: Individuum ist Regelsatz
Tabu-Suche	phänotypnah	unumkehrbar durch Tabu-Listen	keine	bestes Individuum	ein Elter, mehrere Kinder	bestes gefundenes Individuum wird zusätzlich gespeichert
Memetischer Algorithmus	beliebig	beliebig	beliebig	beliebig	beliebig	jedes neue Individuum wird lokal optimiert
Populationsbasiertes inkrementelles Lernen	Populationsstatistik $[0, 1]^\ell$	Änderung in der Populationsstatistik	implizit beim Erzeugen von Individuen	bestes Kindindividuum geht in Statistik ein	wird durch Populationsstatistik ersetzt	benötigte Individuen werden aus der Statistik zufällig erzeugt
Differentialevolution	$\mathbb{R}^\ell$	Mischoperator	Mischoperator	Kind ersetzt Elter bei Verbesserung	klein bis mittelgroß	Operator nutzt Populationsinformation
Scatter Search	$\mathbb{R}^\ell$ und andere	keine	Teilmengengenerator und Kombination	Selektion der Besten	mittelgroß	viele Varianten, deterministisches Verfahren
Kultureller Algorithmus	$\mathbb{R}^\ell$ (und andere) mit Strategieparametern	nutzt Information des Überzeugungsraums	keine	Umweltselektion	mittelgroß	Überzeugungsraum speichert normatives und situationsbezogenes Wissen
Ameisenkolonie	verschiedene	jede Ameise konstruiert einen Lösungskandidaten	keine	Güte bestimmt Einfluss auf die globale Pheromonmenge	Anzahl der Ameisen pro Iterationsschritt	kein EA-Schema, globale Pheromonmengen repräsentieren Lösungskandidaten ähnlich zur Statistik in PBIL
Partikelschwarm	$\mathbb{R}^\ell$ mit Strategieparametern	basiert auf Trägheit und Orientierung an den Nachbarn	keine	Orientierung am Besten (Population/eigene Historie)	klein bis mittelgroß	kein EA-Schema, eher: synchrones Durchkämmen des Suchraums

15 June (Time Series Inputs)

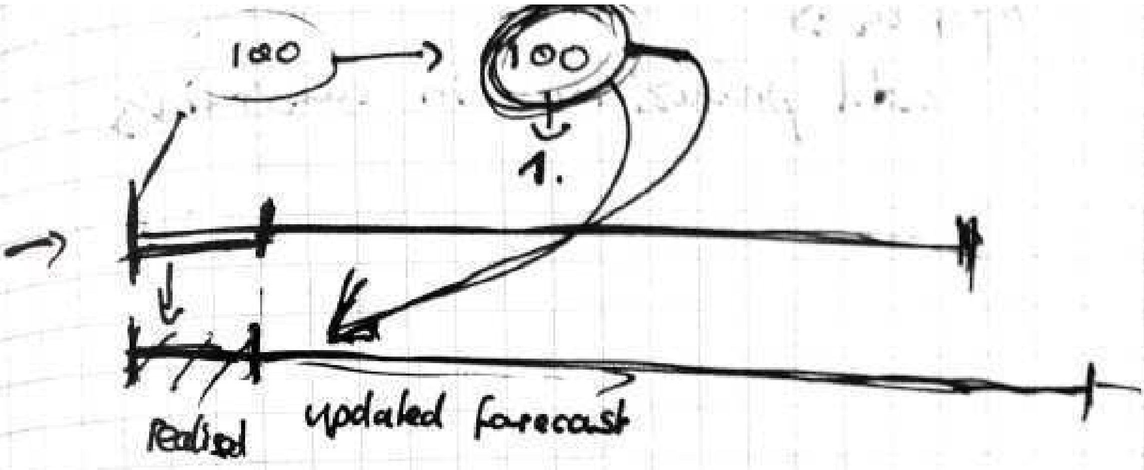
Notebook:	MA Journal		
Created:	15/06/2017 16:21	**Updated:**	04/07/2017 14:14
Author:	Fabian Neumann		

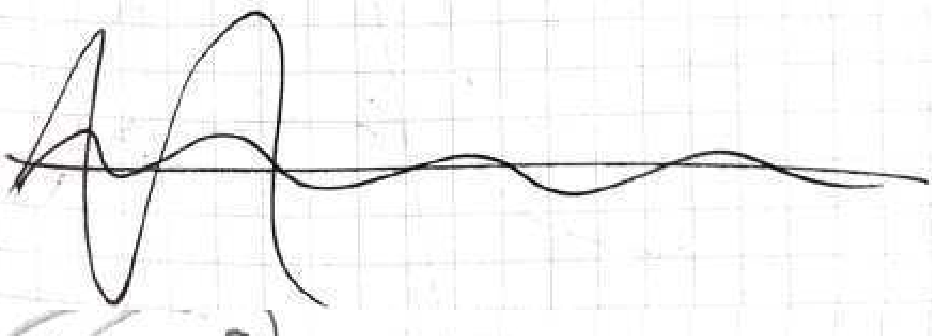
Programming: parameter implementation
cf. commits in github



19 June (Meeting Notes)

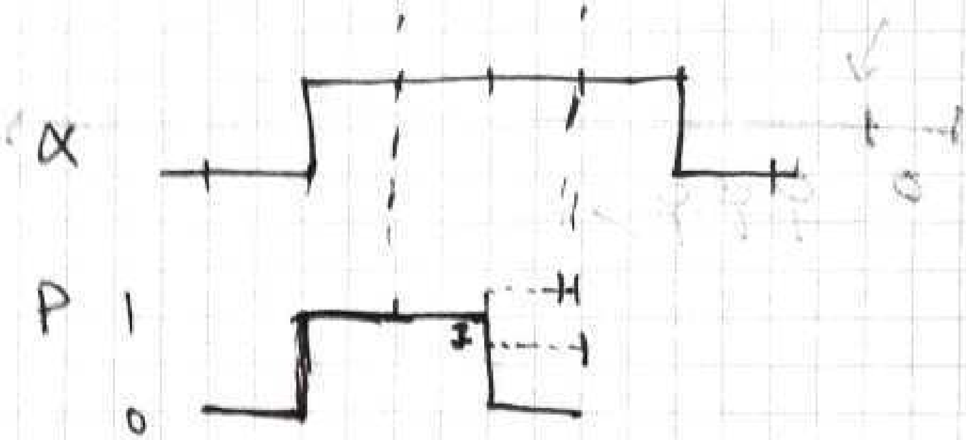
Notebook:	MA Journal		
Created:	19/06/2017 17:23	**Updated:**	19/06/2017 17:24
Author:	Fabian Neumann		





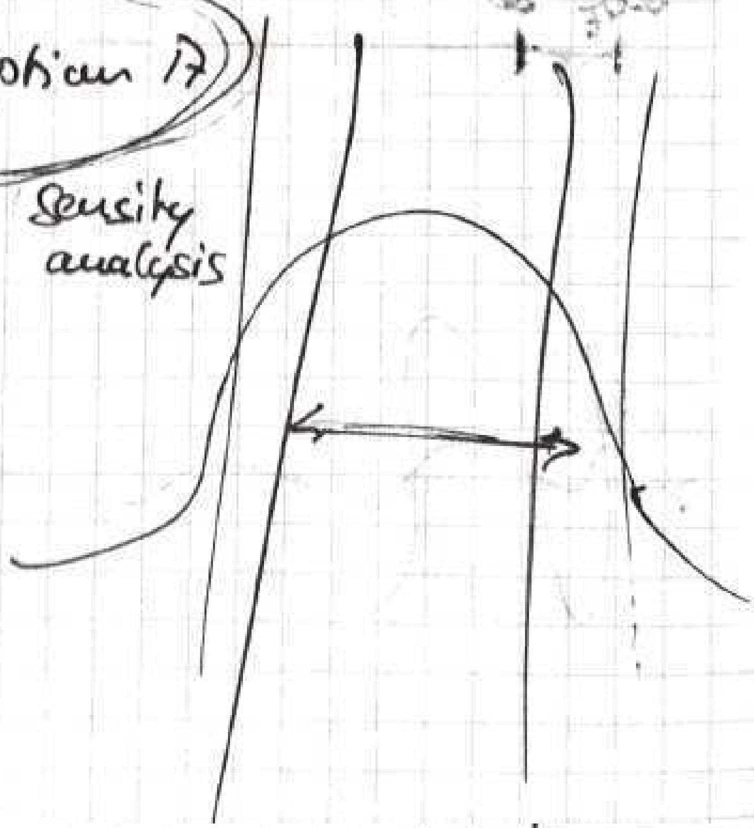
Option B

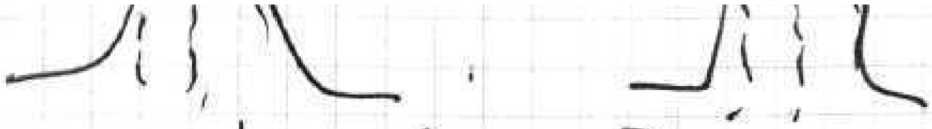
add probabilities in constraints



Option A?

Sensity analysis



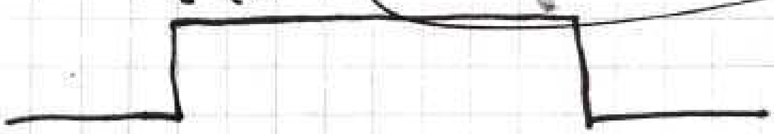


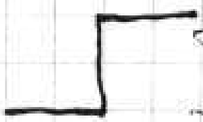
1 2 3

1 0 1

0 0 0 1 1 0 0

t ttl





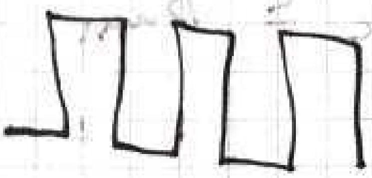
0 1 0 | 11

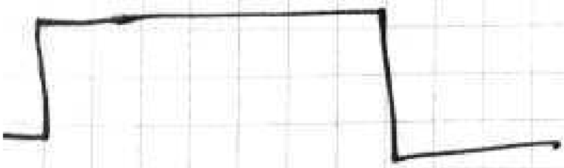
0 0 1 | 11

0 0 1 | 1 1 | 0 0

0 0 0 | 1 1 | 0 0

0 1 1 | 0 0 | 0 0





0 0 111 00

0 0 0 11 00

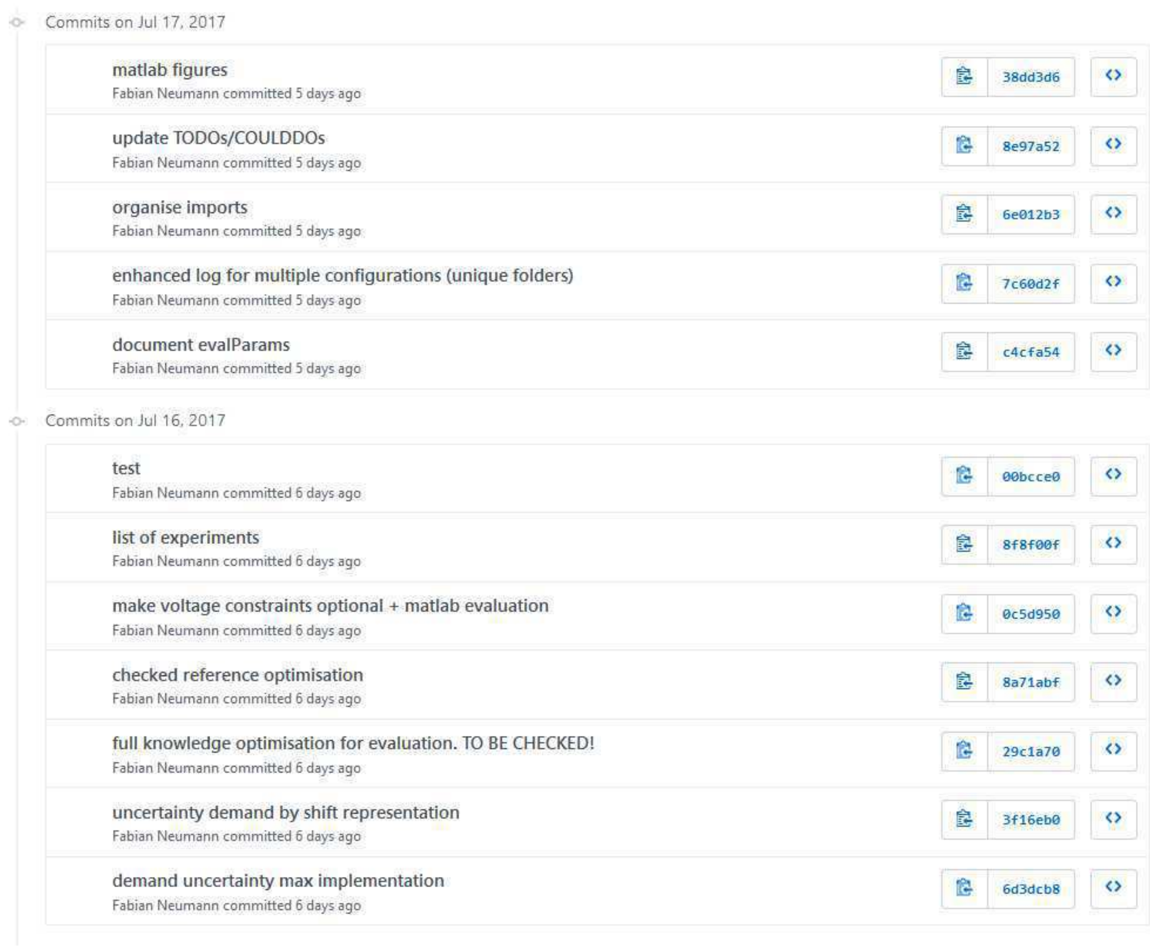
20-23 June (Github)

Notebook:	MA Journal
Created:	20/06/2017 09:46	**Updated:**	22/07/2017 10:58
Author:	Fabian Neumann

Python Best Practice Code

- https://gist.github.com/sloria/7001839
- http://python-guide-pt-br.readthedocs.io/en/latest/writing/structure/
- https://github.com/kennethreitz/samplemod
- https://www.python.org/dev/peps/pep-0008/

Refer to github commits for progress on implementation
https://github.com/orley-enterprises/ev_chargingcoordination2017/commits/master



Commits on Jul 14, 2017

availability uncertainty mitigation by penalty in LP Fabian Neumann committed 8 days ago	8be39c4
pep8 style adjustment Fabian Neumann committed 8 days ago	801b9fa
docstrings Fabian Neumann committed 8 days ago	144041b
additional monitors Fabian Neumann committed 8 days ago	e6f20ed
tidy Fabian Neumann committed 8 days ago	2418706
organise imports Fabian Neumann committed 8 days ago	956364d
Merge branch 'master' of https://github.com/orley-enterprises/ev_char... … Fabian Neumann committed 8 days ago	3bb6fcc
individual households in log in separate folder Fabian Neumann committed 8 days ago	90e8de3
individual households in log in separate folder Fabian Neumann committed 8 days ago	9dc8511
clean commit (reorganisation, comments, reformat) Fabian Neumann committed 8 days ago	ac0d39b

Commits on Jul 13, 2017

price_uncertainty difference per slot - sense? Fabian Neumann committed 9 days ago	bd6773a
modify log Fabian Neumann committed 9 days ago	7874be5
MC simulation log Fabian Neumann committed 9 days ago	627a7b7

Commits on Jul 12, 2017

comments Fabian Neumann committed 10 days ago	1c6bdbb
thermal loading sensitivity incorporation Fabian Neumann committed 10 days ago	ffee496
gurobi implementation LP with additional constraints and target Fabian Neumann committed 10 days ago	a55f05e

Commits on Jul 11, 2017

2nd networkGREEDY with voltage sensitivities Fabian Neumann committed 11 days ago	d53386b
networkGREEDY with voltage sensitivities Fabian Neumann committed 11 days ago	b285f32
voltage sensitivity matrix Fabian Neumann committed 11 days ago	6a6793c

Commits on Jul 9, 2017

check Fabian Neumann committed 13 days ago	7f90022
check Fabian Neumann committed 13 days ago	ef9408d
uncertainty mitigation prob, penalty, output availability prob Fabian Neumann committed 13 days ago	f7845a3

Commits on Jul 7, 2017

shift
Fabian Neumann committed 15 days ago — 1e8b414

overload constraint NG, GA/PSO speed control, schedule on arrival impl.
Fabian Neumann committed 15 days ago — 2653c98

documents
Fabian Neumann committed 15 days ago — 3605b4b

minor
Fabian Neumann committed 15 days ago — e47f2d7

Commits on Jul 6, 2017

line thermal limits, vizualisation, red noise
Fabian Neumann committed 2 hours ago — 09246da

Commits on Jul 5, 2017

closing commit for today
Fabian Neumann committed 22 hours ago — 6cd57da

delete
Fabian Neumann committed 22 hours ago — 33efee8

comparison adjustments
Fabian Neumann committed 22 hours ago — 86f8c38

manual urgency order (joint partial feeders in order)
Fabian Neumann committed a day ago — 270f62d

urgency by electrical distance (networkGREEDY)
Fabian Neumann committed a day ago — 6b172af

accurate constraint observation in networkGREEDY
Fabian Neumann committed a day ago — 27b77d1

solved voltage inconsistencies
Fabian Neumann committed a day ago — 6fc4c5e

Commits on Jul 4, 2017

mileage multiplier added
Fabian Neumann committed 2 days ago — 0a1fc2c

schedule reality adjustment
Fabian Neumann committed 2 days ago — c9f5c18

testing
Fabian Neumann committed 2 days ago — a166094

avoid negative parameters mu & sigma for normal distributions
Fabian Neumann committed 2 days ago — 0a47a98

sort logs
Fabian Neumann committed 2 days ago — 8d5dcda

Commits on Jul 3, 2017

load multiplier for more challenging network state
Fabian Neumann committed 3 days ago — 3491eb1

progress display
Fabian Neumann committed 3 days ago — 92a2c78

multiple penetration levels possible
Fabian Neumann committed 3 days ago — 904db29

minor
Fabian Neumann committed 3 days ago — 4b4266c

log extension, monte carlo simulations and PSO implementation
Fabian Neumann committed 3 days ago — 0c86f9f

Commits on Jun 26, 2017

comments / reorganise
Fabian Neumann committed 10 days ago — 5dd94ba

first genetic algorithm
Fabian Neumann committed 10 days ago — de6f44f

Commits on Jun 25, 2017

network based greedy optimisation implemented, voltage inconsistency
Fabian Neumann committed 11 days ago — 3e273a1

Commits on Jun 24, 2017

timer added
Fabian Neumann committed 12 days ago — 159a56c

generate some new result files
Fabian Neumann committed 12 days ago — 08867bb

minor
Fabian Neumann committed 12 days ago — c2904dd

added file export of result matrices
Fabian Neumann committed 12 days ago — 3f40254

some comments added
Fabian Neumann committed 12 days ago — 93a9017

slotwise aggregate evaluation added
Fabian Neumann committed 12 days ago — 5448102

Set voltage base to 230V instead of 240V + add voltage and schedule logs
Fabian Neumann committed 12 days ago — a7a4090

Commits on Jun 23, 2017

Implement log outputs and introduce some calculations on results. Fabian Neumann committed 6 minutes ago	1910878

Commits on Jun 22, 2017

result handling started Fabian Neumann committed 18 hours ago	ac4fb3c
output formats Fabian Neumann committed 22 hours ago	4720c24
As Fast As Possible Charging Routine Fabian Neumann committed 22 hours ago	40cb342

Commits on Jun 21, 2017

delete obsolete load profiles Fabian Neumann committed 2 days ago	b4601f0
household specifications Fabian Neumann committed 2 days ago	1fdbe7a
reordering Fabian Neumann committed 2 days ago	562527f
readme Fabian Neumann committed 2 days ago	2921c65
forecast generation Fabian Neumann committed 2 days ago	8a0af7f

Commits on Jun 20, 2017

gitignore Fabian Neumann committed 3 days ago	61ce16f
daily clean update Fabian Neumann committed 3 days ago	b94f14b
fitter for scipy format + vehicle specification class Fabian Neumann committed 3 days ago	bb74b67
scenario1 Fabian Neumann committed 3 days ago	a836640

scenario
Fabian Neumann committed 3 days ago — 1cfdaa1

merge parameters and runner
Fabian Neumann committed 3 days ago — cc43f51

restructuring
Fabian Neumann committed 3 days ago — 24665cc

Commits on Jun 15, 2017

seasonal sampled pv time series
Fabian Neumann committed 8 days ago — d197cc4

price and demand time series
Fabian Neumann committed 8 days ago — e2e9182

parameters first commit
Fabian Neumann committed 8 days ago — 9089135

Commits on Jun 1, 2017

network integration
Fabian Neumann committed 22 days ago — 1131800

add network
Fabian Neumann committed 22 days ago — 51dbc6b

project files
Fabian Neumann committed 22 days ago — 06bb4f0

First commit
Fabian Neumann committed 22 days ago — 733c258

Commits on May 31, 2017

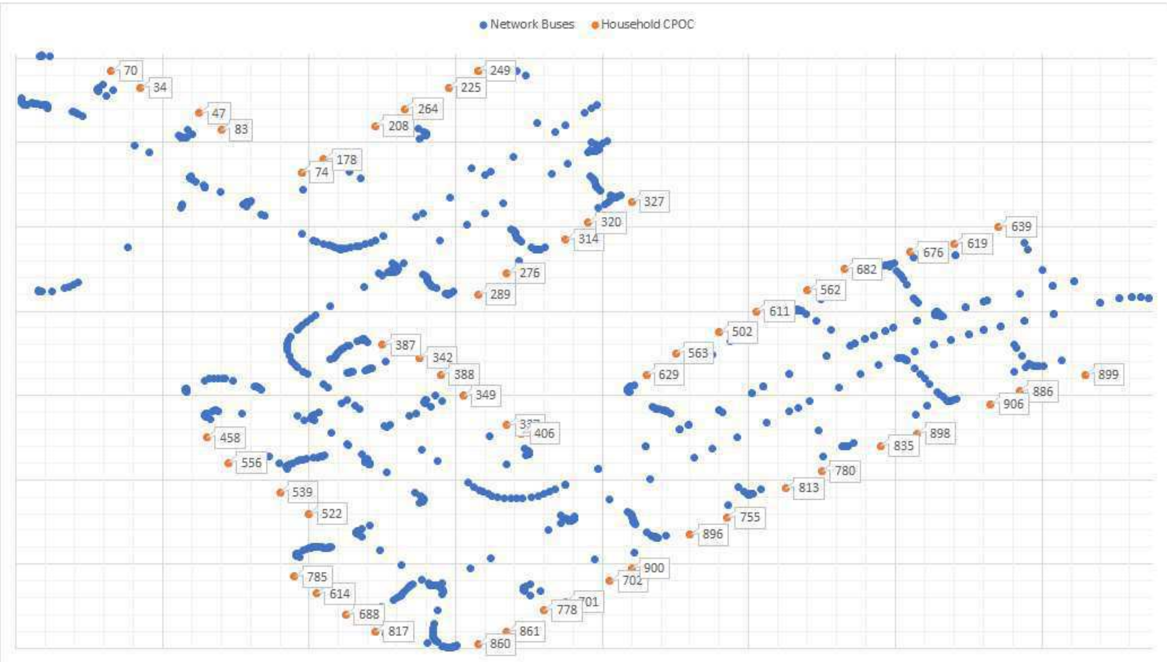
Initial commit
orley-enterprises committed 23 days ago — 9107451

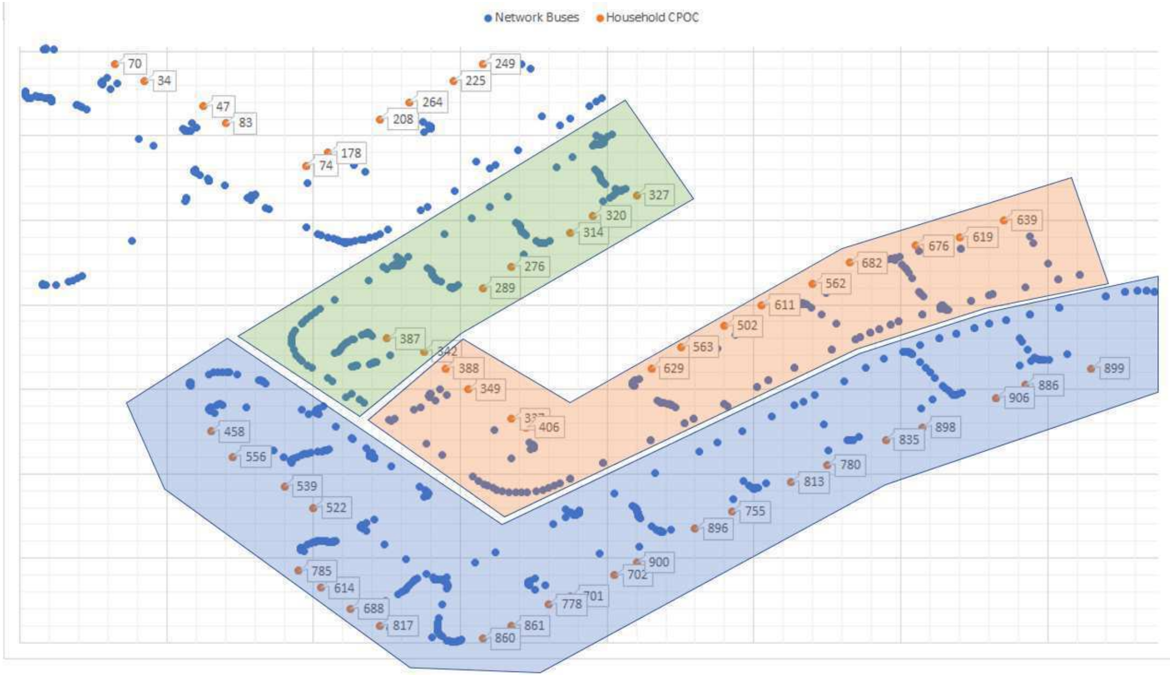
23 June (Examiner Meeting)

Notebook:	MA Journal		
Created:	23/06/2017 16:11	**Updated:**	08/08/2017 14:24
Author:	Fabian Neumann		

Examiner Interview

- prioritise workload into musts / coulds / neglects
- categorize
- Look into standards for EV charging EU/US
- draw the picture where model is allocated in the literature
- describe factors which influence the problem and the solution
- analyse how network layout influences costs
- writing
  - guideline more than results
  - concise and logical reasoning
- poster
  - limited space
  - plan ahead





Network Buses
Household CPOC
70
34
47
83
249
225
264
208
178
74
327
320
314
276
289
682
676
619
639
562
611
502
563
629
387
342
388
349
406
458
556
539
522
785
614
688
817
860
861
778
701
702
900
896
755
813
780
835
898
906
886
899

26 June (DEAP Package)

Notebook:	MA Journal
Created:	26/06/2017 08:42	**Updated:**	08/08/2017 14:24
Author:	Fabian Neumann
URL:	https://deap.readthedocs.io/en/master/tutorials/basic/part4.html

Online Resource
https://deap.readthedocs.io/en/master/

Local Mirror
file:///C:/Users/Fabian%20Neumann/Tests/DEAP%20Documentation/deap.readthedocs.io/en/master/index.html

Parallelisation

- multiprocessing
- SCOOP

3 July (Programming)

Notebook:	MA Journal		
Created:	03/07/2017 14:20	**Updated:**	08/08/2017 14:24
Author:	Fabian Neumann		

cf. github commits for code changes
cf. project for immediate in-code TODO list

need to make sure that residential loads with inherent voltage violations are excluded from ev optimisation - constraint cannot be fulfilled

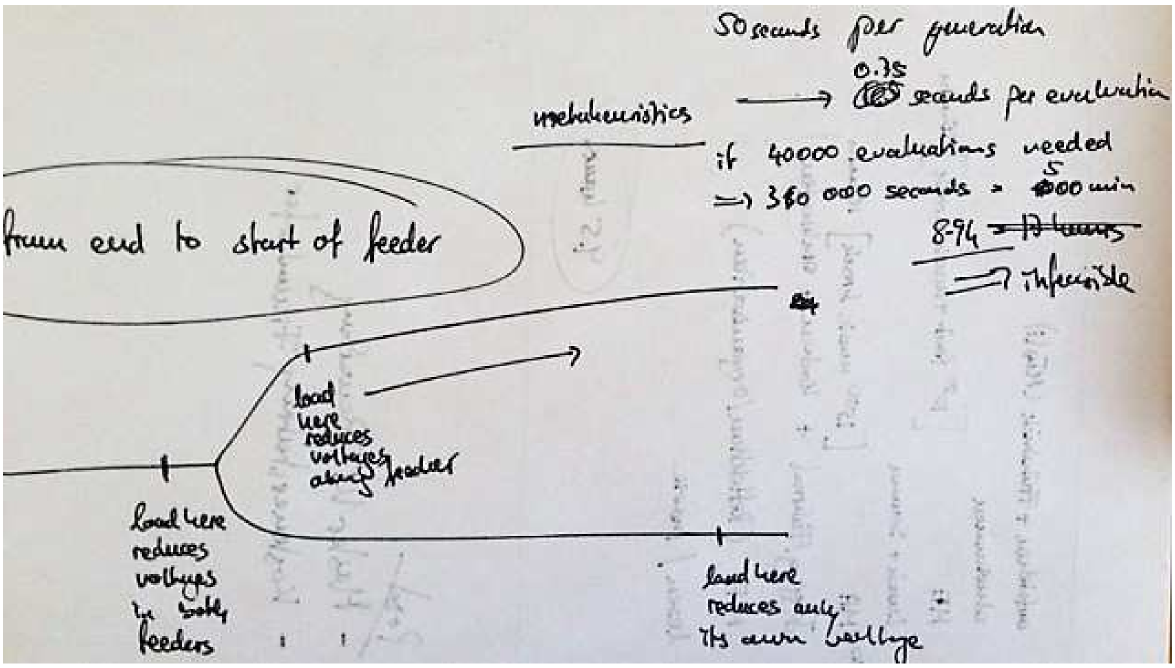
---

Problems

- evaluation of power flow takes 0.75 seconds per evaluation
- if 40000 evaluations are needed -> 8-9 hours
- dimension needed for metaheuristics to work properly

Improvement of networkGREEDY

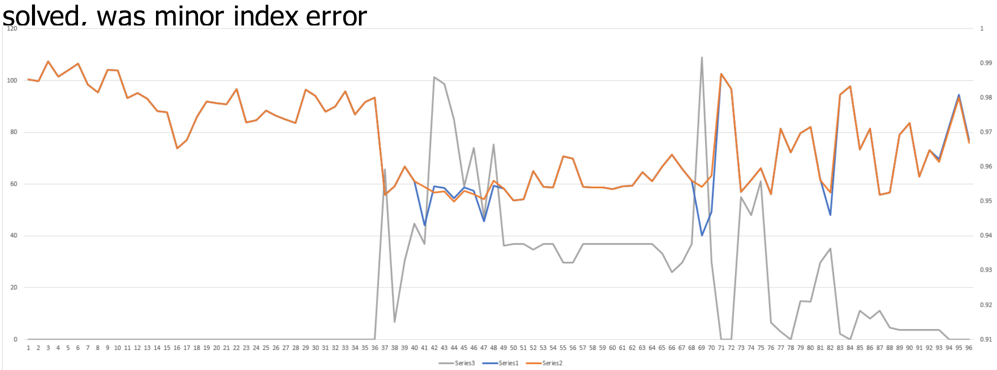
- schedule EVs from end to start of feeder to accommodate maximum amount of EVs in supposedly cheap slots
- puts EVs at the beginning of the feeder at a disadvantage - schedules to more expensive blocks - redistribution necessary



Programming notes

- Initial Perfect Forecast Results

- priceGREEDY = 100% (0.5 sec per cycle)
- networkGREEDY = 138% (50.0 sec per cycle)
- AFAP = 234% (0.0 sec per cycle)
- priceGREEDY and AFAP lead to voltage violations
- no results for metaheuristics --> too slow evaluation

- Uncertainty Effect
  - due to examined price profiles, charging occurs almost exclusively from 2300 to 0700 (main charging period)
  - this period offers enough flexibility to accommodate all 55 EVs in the network - little pressure to move into regions of uncertain availability
  - What is the benefit of scheduling EVs later (if price permits) to periods of lower availability probability
  - Low effect of uncertainty
- Uncertainty Errors (EV)
  - SOC scheduled too high - driven less than predicted
  - SOC scheduled too low - driven more than predicted
  - SOC scheduled too low - could not load as residential demand unexpectedly causing voltage deviation
  - SOC scheduled too low - arrived later than expected (missed scheduled spot)
  - SOC scheduled too low - departed earlier than expected (missed scheduled spot)
  - Voltage violation - demand higher than expected
- Controller (overrule schedule)
  - block if SOC = capacity
  - AFAP if no more allocation, but SOC < targetSOC
  - if voltage deviation - reschedule [highestSOC] to slot [after] without voltage problem
  - reschedule upon arrival
    - easy way around arrival and SOC uncertainty; requires intraday markets (balancing mechanism in UK) or good prediction of aggregate
- Voltage inconsistencies
  - investigate!
  - solved, was minor index error
  - 

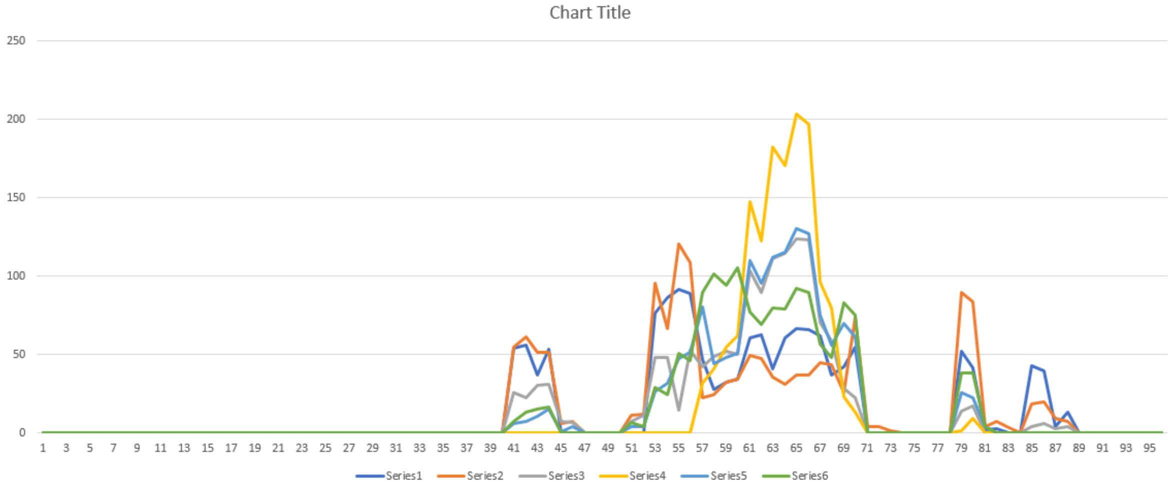
5 July (networkGREEDY)

Notebook:	MA Journal		
Created:	05/07/2017 14:15	**Updated:**	08/08/2017 14:27
Author:	Fabian Neumann		

Exemplary schedules and performance comparison of optimisation heuristics

Schedules (kW)	opt	%	sim
Series 1: SOC urgency	46.33	142%	45.40
Series 2: -DISTANCE urgency	48.56	136%	43.46
Series 3: DISTANCE urgency (decrement = 2.0)	40.52	119%	39.02
Series 4: priceGREEDY	34.10	100 %	24.08
Series 5: DISTANCE urgency (decrement = 0.3)	39.63	116%	38.58
Series 6: MANUAL urgency (decrement = 2.0)	42.18	124%	40.29

Chart: Aggregate EV loads for optimisation heuristics



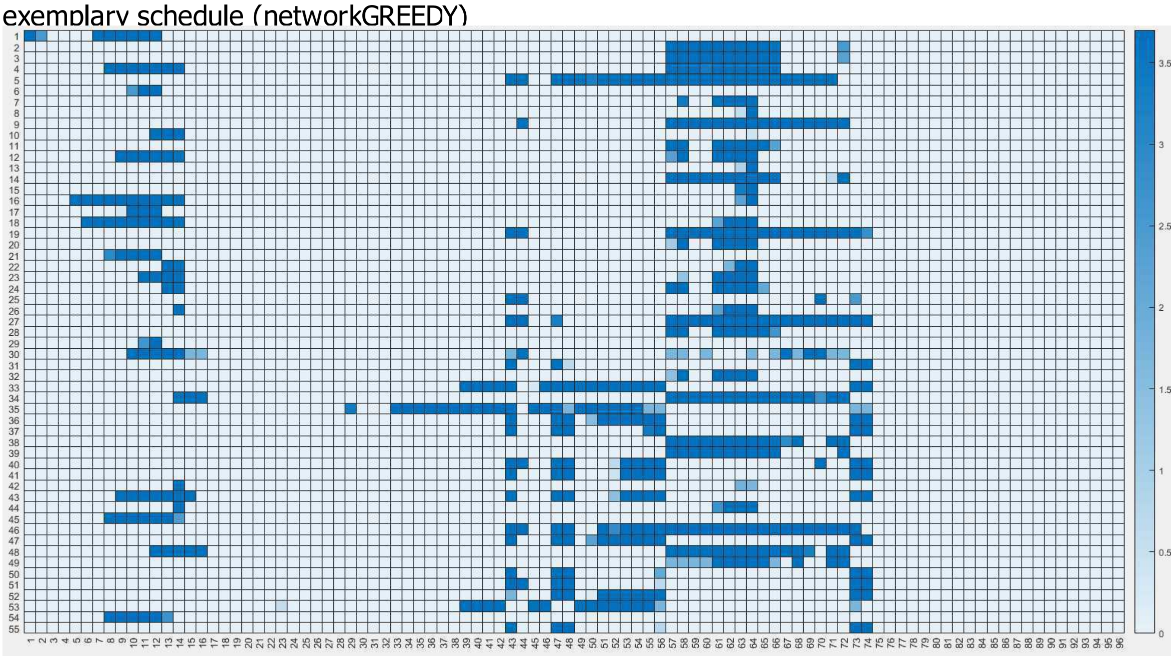
Mini-MC analysis (indicative)

priceGREEDY	networkGREEDY	factor of net charging costs
4.38E+01	4.52E+01	1.03E+00
5.61E+01	6.06E+01	1.08E+00
4.74E+01	4.88E+01	1.03E+00
5.21E+01	5.28E+01	1.01E+00
4.72E+01	5.03E+01	1.07E+00
3.66E+01	3.83E+01	1.05E+00
4.04E+01	4.26E+01	1.05E+00
2.68E+01	3.37E+01	1.26E+00
4.97E+01	5.08E+01	1.02E+00
5.77E+01	5.86E+01	1.02E+00
		1.06E+00

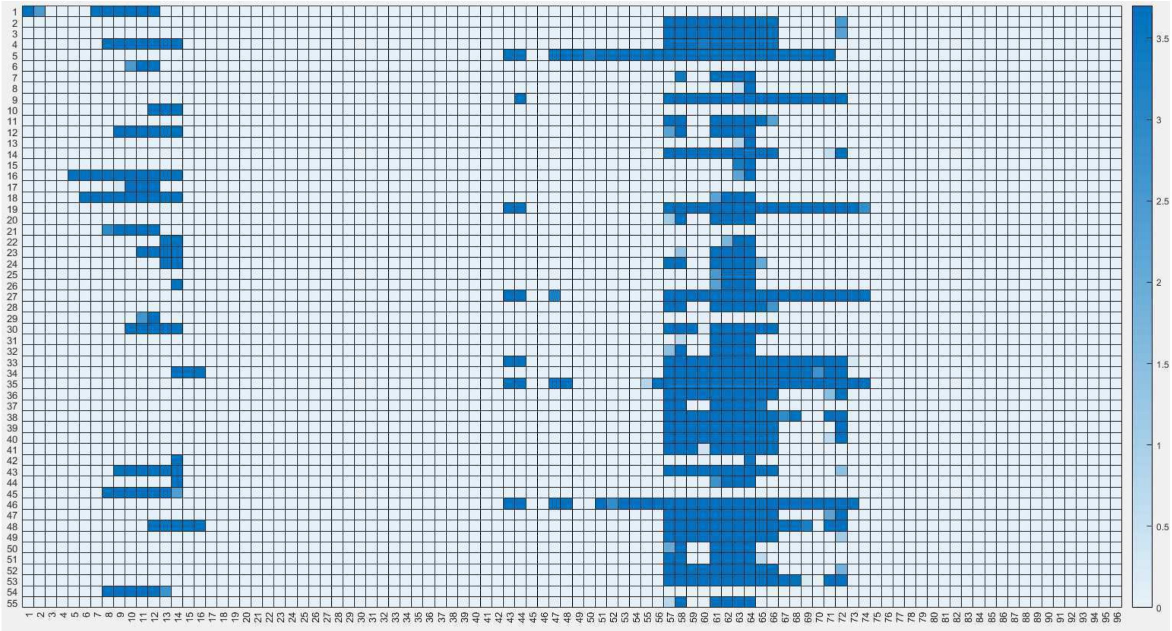
More runs yield +6% on average for net charging costs compared to priceGREEDY

---

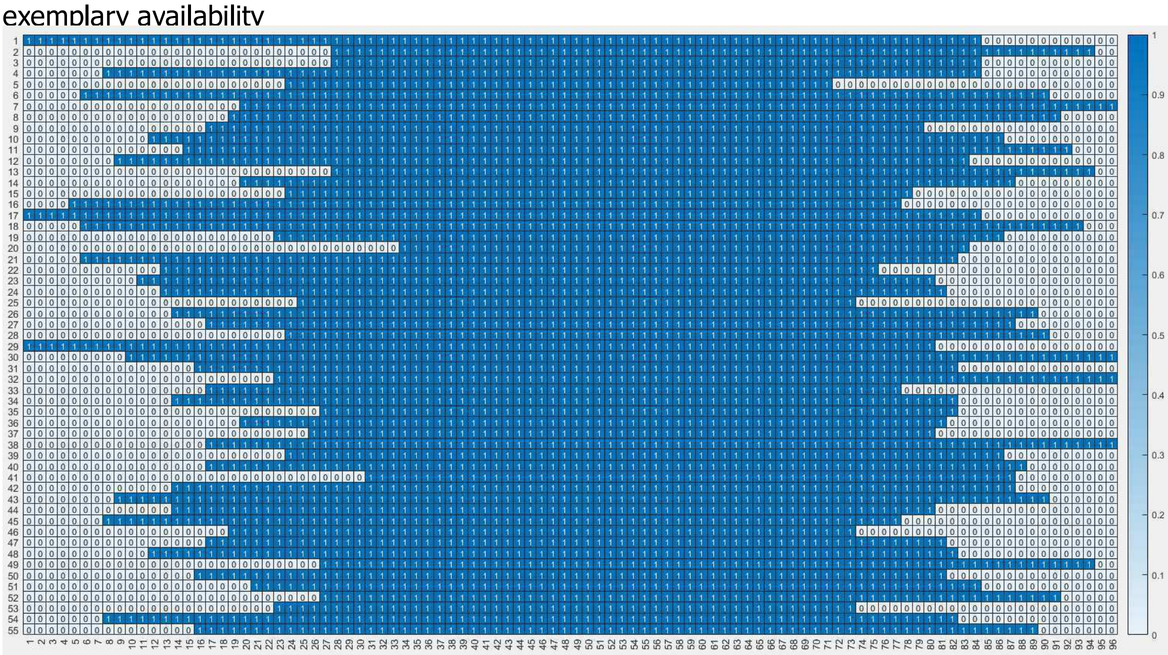
exemplary schedule (networkGREEDY)

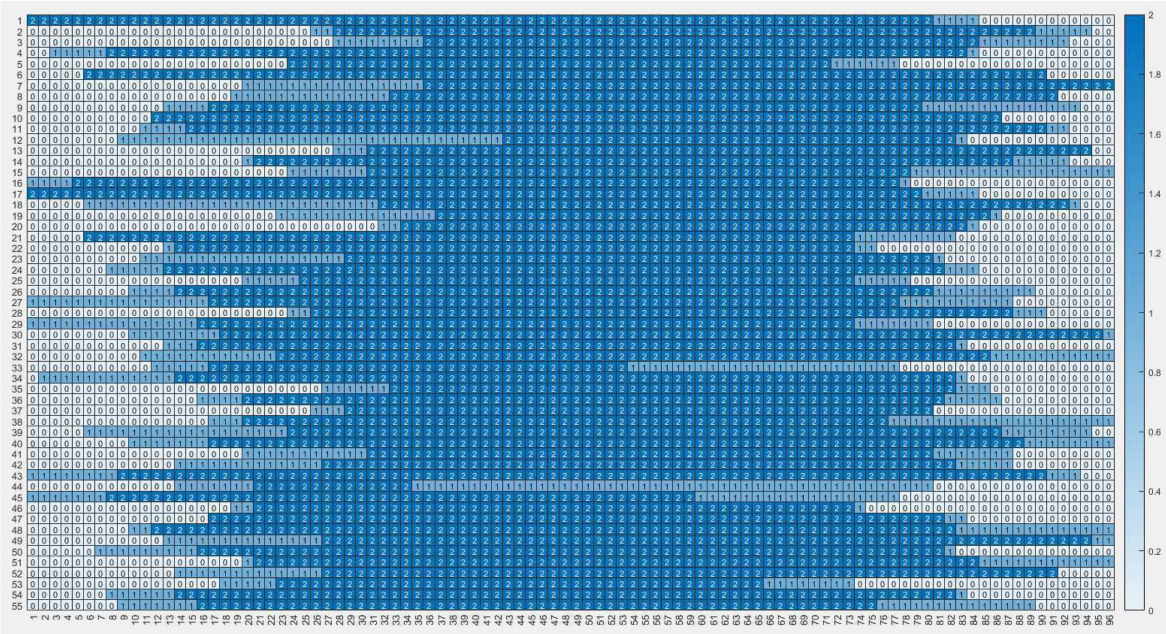


exemplary schedule (priceGREEDY)

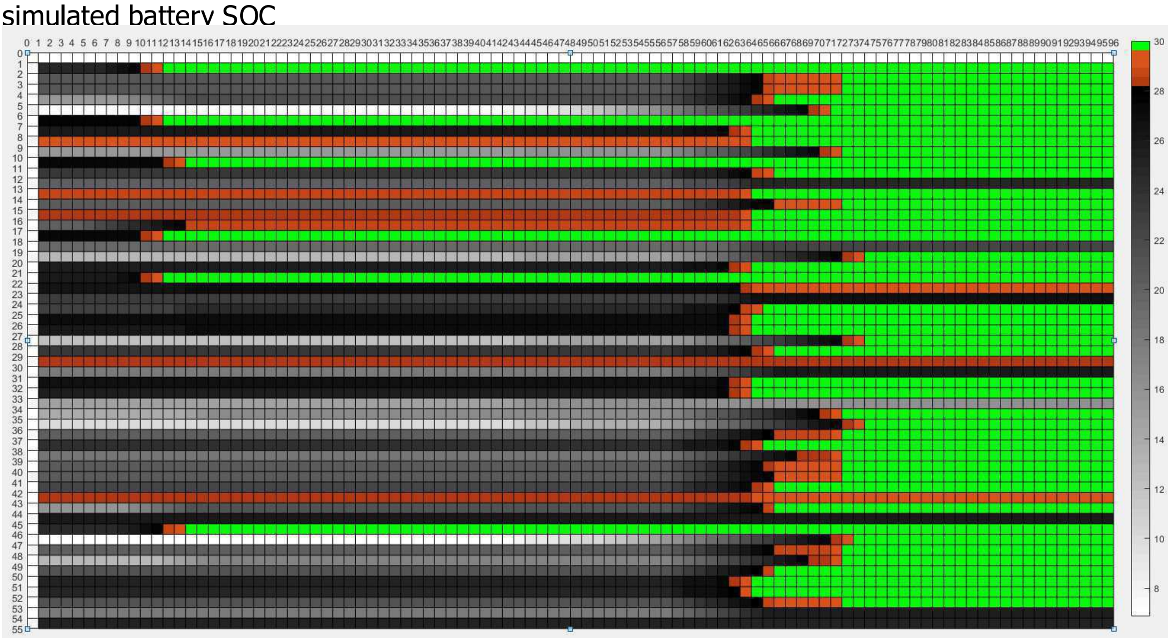


exemplary availability





simulated battery SOC



6-8 July (Meeting)

Notebook:	MA Journal		
Created:	06/07/2017 14:21	**Updated:**	08/08/2017 14:25
Author:	Fabian Neumann		

Agenda:

- performance of heuristics against purely price based optimisation (excellent, different urgency orders, +6% on average)
- discuss working principle of heuristics (extensions)
- show that consideration of thermal limits might be necessary
- go through parameter adjustments (mileage multiplier,
- GA/PSO evaluation
- uncertainty heuristic thoughts
- sense of price time series (not really exogenous, if many aggregators exist, historical prices might not be representative, would reduce price volatility, simplification)

Power Flow Computation Time for Metaheuristics

- around 0.5 seconds, too slow, tenfold increase necessary
- would require 0.05 seconds to run in under 10 minutes per day/scenario
- Solution: reduce number of power flow calculations (given GA already running in parallel)
  - reduce number of evaluations
    - heuristic population initialisation (unlikely)
  - reduce time step granularity
    - divide and conquer: 1 hour optimisation, then 4 individual
    - does not work: 24 is the minimum number of power flow simulations
  - reduce horizon
    - would reduce charging flexibility, might miss good price, reduces financial benefit of optimisation
    - 20-8 / 21-7 --> 12-14 hours --> this most likely halves computation time --> not enough

```
PF: 0.4290647071920215
PF: 0.4792878245504888
PF: 0.48746958387744144
PF: 0.4802691935404919
PF: 0.4275180443992488
PF: 0.4955526536438555
PF: 0.5108001907471822
PF: 0.44824245735426693
PF: 0.4291061568074479
PF: 0.5151918761911833
PF: 0.450293226422275
PF: 0.44415868333915043
PF: 0.49742972908531335
PF: 0.4417723697653084
```

```
PF: 0.4419160617654523
PF: 0.4478362511230891
PF: 0.3676813795695253
PF: 0.3645781850279235
PF: 0.36249780909175655
PF: 0.4154400212222029
PF: 0.40376030911149385
```

10 July (Linearisation of Power Flow)

Notebook:	MA Journal		
Created:	09/07/2017 10:28	**Updated:**	08/08/2017 14:26
Author:	Fabian Neumann		

A. Soroudi and A. Keane, "Robust optimization based EV charging,"
In principle, very close to what I would do. However, I assume to know some kind of error distribution around the price profile. As long as these are identical, my "worst case" ranking expectation won't change. It gets more exciting when I know prices are generally more variable in one period over another and change the error parameter for every time step. I could look into this.

- exactly what I am doing, just expressed more complicated
- does robust optimisation work for electricity prices?
  ↳ each time slot must have variable distributions
- level of conservatism

[10]

- stronger voltage constraints to account for predictive nature of network sensitivities.
- nonlinear due to P-1

relationship via voltage

- Jacobian through current mismatches from nodal admittance matrix Y

Linear power flow

- voltage/loading sensitivity Rich12 [11]
- identify sensitivities
- effect of single phase load onto other phases
- are phases asymmetrically loaded
- compare network losses

change of
3phases 906 lines · 55 power positions

2 1 ? 3

s_init [phase] [line_id] [timeslot]

s_sensitivity [hd] [phase] [line_id]

schedules [hd] [timeslot]

linecurrents [phase] [

approximation overestimates
loading increase!

saved actual loading

↳ 10A difference max
if scheduling to limit
↳ no deviation if not sched.

A. O'Connell, A. Keane and D. Flynn, "Rolling multi-period optimization to control electric vehicle charging in distribution networks," and
P. Richardson, D. Flynn and A. Keane, "Local Versus Centralized Charging Strategies for Electric Vehicles in Low Voltage Distribution Systems,"
Yes, I was aware of these two papers. Yet although they calculate a network sensitivity matrix, their problem remains nonlinear as they work via current alterations but maintain power in the

objective function.

A. O'Connell, D. Flynn, P. Richardson and A. Keane, "Controlled charging of electric vehicles in residential distribution networks,"
Most promising to me. Linearised via voltage/loadings sensitivities. See below:

(+ instantaneous voltage)

207 • sensitivity of voltage predetermined and not updated (55 flow calculations)

* V_{init} from 1 PF per time step

- quicker
- series of load flow calculations
- each household -> average daily household demand / could be max. daily household demand for more conservative estimate
- impact of multiple EV charging simultaneously

$$V_{min} \leq V_{init} + \mu P \leq V_{max}$$

$$V_{init}^{j} + \sum_{i=1}^{I} \mu_{ij} P_i \leq V_{max} \quad \forall j \in J \quad \forall t \in T$$

My proposal derived from the above:

- For each network/household type scenario
    - Assign average (or higher – depending on level of conservatism) residential load to households and get initial voltages at connection points
    - For each household (55 power flow calculations)
        - Change load by e.g. 1 kW (any increment)
        - Note voltage changes at each household
    - Obtain voltage sensitivity matrix (size: #EV x #EV)
    - For each time step in optimisation horizon calculate actual initial voltages at each household (24 power flow calculations)
- Run optimisation
- Run actual power flow with proposed schedule, evaluate, etc. pp.

So, the corresponding voltage constraint for each time step would somewhat look like this:

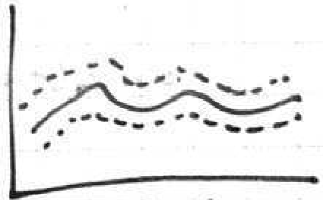
$$V_{min} \leq V_{init}^{j} + \sum_{i=1}^{I} \mu_{ij} \cdot P_i \leq V_{max} \qquad \forall j \in [1 \dots J]$$

… if μ is the is the voltage matrix of voltage at the j-th household to active power at the i-th household (V/kW).

Note on size: I would not calculate sensitivities to each household only instead of each bus and limit load sensitivity to transformer rating and mains cable (tended to be most sensitive so far)

Note on GA/PSO: If this succeeds to linearise the problem, I doubt that the metaheuristic will have any chance against a linear solver.

- not only voltage sensitivity but also load sensitivity
  ↳ only transformer + mains cable disregarding losses
- if I can formulate a linear problem, metaheuristics will not outperform linear solver!
- measure capacity utilisation
- run multiple times for the same network to get



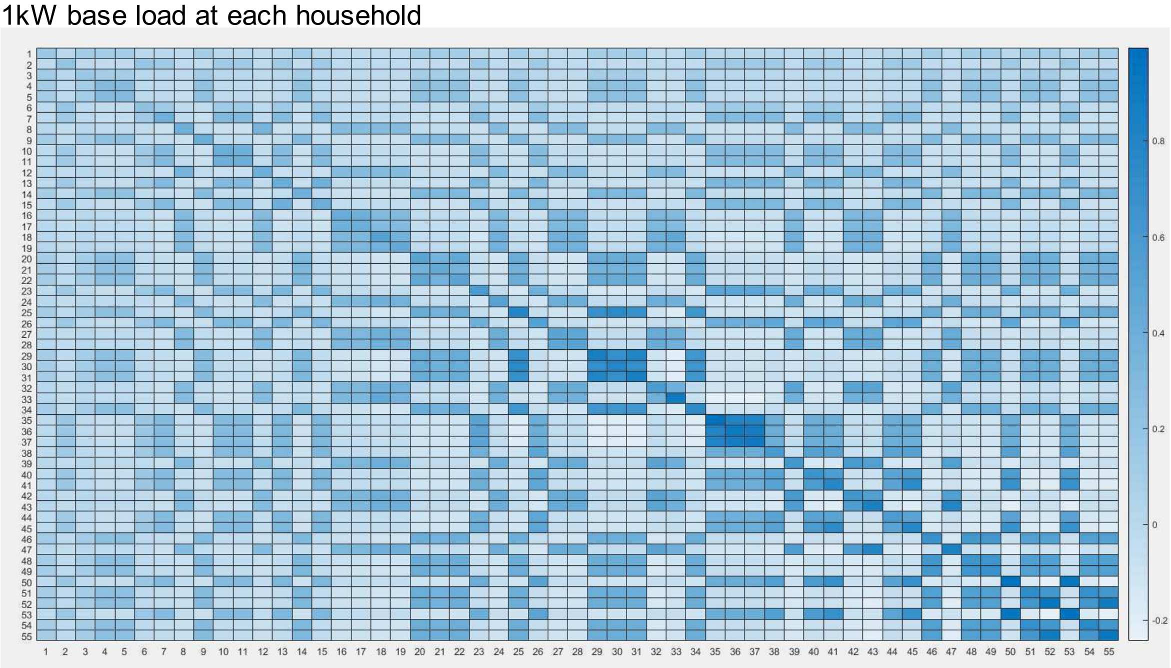
  → but may be computationally expensive and infeasible

11 July (voltage sensitivity matrix)

Notebook:	MA Journal		
Created:	11/07/2017 12:19	**Updated:**	08/08/2017 14:27
Author:	Fabian Neumann		

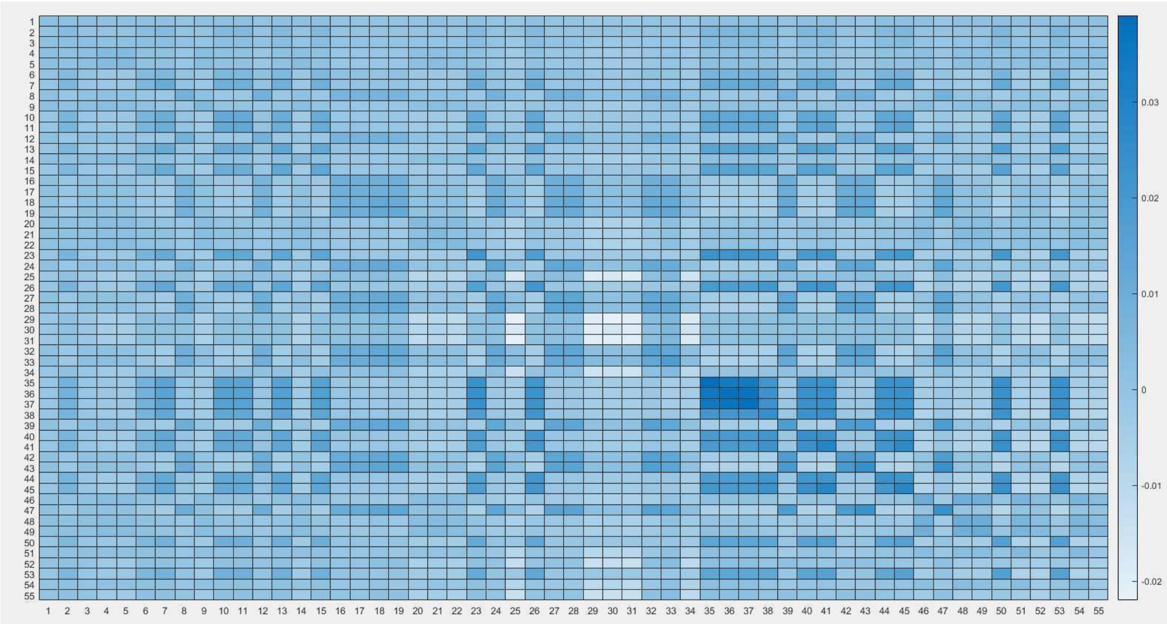
order: power change at i to voltage sensitivity at j for that power change
first test: 99.99% accuracy!, schedules very similar to

(higher IDs tend to be further away from the substation). Shows voltage drop per 1 kW from a 1kW base load at each household



There are a few cases where the voltage increases when an additional load is placed. Could this be due to single phase connections at different phases?

Changes from 1 to 2 kW baseload



11-20 July (Final Notes complementary to Github commits)

Notebook:	MA Journal		
Created:	22/07/2017 10:23	**Updated:**	08/08/2017 14:27
Author:	Fabian Neumann		

Recent Extensions

- [ ] automatic new folder with INI file copy
- [ ] check random seeds produce same outputs
- [ ] Dissertation Structure

- ~~Start cost~~ option B
- overlap
- price uncertainty
- ~~turn off shift in price uncertainty and demand~~
- ~~log MC results – which~~
- ~~delete target SOC~~
- ~~search for appropriate rate of change of charging~~
- ~~reasonable regulation price – Dallinger~~
- ~~(voltage max constraints)~~

A
- demand uncertainty
  ↳ go via position of peaks? (moving maximum)
- demand uncertainty parameters

B
- price uncertainty range plus rednoise + parameters
- ~~alter problem formulation because it is nonlinear with regulation service~~
  ↳ salvable as long as Q pos. semidef.
- ~~always run ATAP / priceGreedy~~
- voltage profile for final schedule ~~24~~ 96 slots
  [4d, slots]

outputs

~~lines loadings~~

• ~~add time series~~

~~↳ a) 906 · 96 matrix~~

~~↳ b) line 1 → slotwise agg~~
~~= household agg~~
~~= households~~

MC outputs

econ. reliability: costs < sim, opt

cust. reliability: • fulfilment ratio < min, total } < sim, opt

tech. reliability: • constraint adherence < sim, opt
↳ % overload violations
↳ % voltage violations

~~schedule comparison~~

same schedule -> different realisations of uncertain random variables

• demand uncertainty higher the ~~higher~~ lower the load

• price uncertainty higher the higher deviation from mean

Forecast Concerns

- value of accurate forecasts?
- how good are day-ahead price forecasts?

- how stable are day-ahead price forecasts in terms of ranking?

Demand uncertainty mitigation

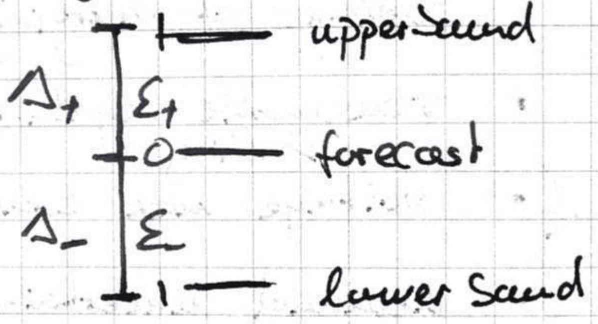
- Option A (discarded)
  - rank demand profiles by correlation
  - take N closest samples of historical profiles
  - take maximum for each time step as prediction
  - take closest rank as simulation
- Option B (employed)
  - take moving maximum of length n as prediction
    - 1. based on 1 minute profile
    - 2. based on respective resolution
  - take actual profile as simulation

Price Uncertainty Mitigation

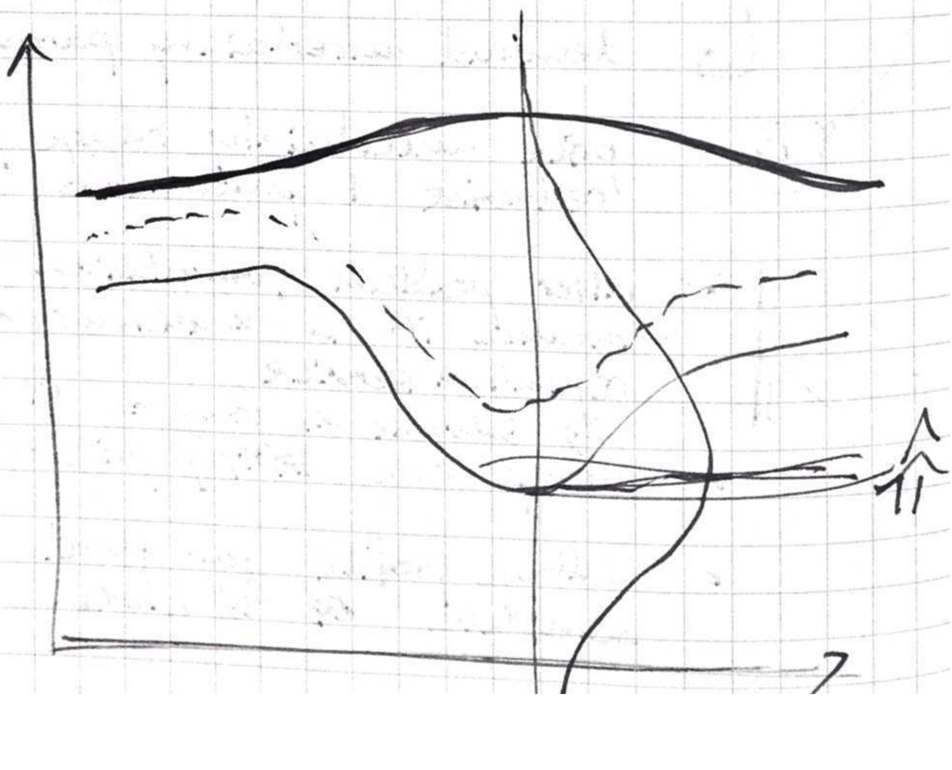
Soroudi 2014 Robust Optimisation

- consider price uncertainty
- econ optimisation under technical constr.
- optimal actions depend on input parameters
- no price information other than bounds

→ price higher than forecasted



- bi-level optimisation



•

assume constant (e.g.)

$$\max_{\varepsilon_t} \left(\sum_{t=1}^{T} P_t \right) \cdot \Delta_t^{+} \cdot \varepsilon_t$$

not only protect against higher than expected prices but also lower than expected prices!

price uncertainty not severe enough to turmoil ranking!

Robustness to changes of same schedule

- run full knowledge optimisation afterwards and compare with simulated/optimised schedules
- V_init should be optimised for simulated optimisation

Topic brainstorming

TOPICS ~~history of electric vehicles → recent developments / milestones~~
~~political targets and gov. subsidies/incentives (EU/UK/Scotland) (World)~~
~~monetary incentives~~
~~user acceptance~~

~~EV market scenarios - uptake / Faktoren zur Wirtschaftlichkeit~~

~~Impact of electromobility on~~ < ~~energy system - Infrastrukturbedarf~~ / ~~energy market~~

~~influence of high RES share~~
~~business models (Nagl)~~
~~perspectives of optimal charging coordination~~ / ~~differentiate MV/TS/LV challenges~~

~~Einordnung Themenfeld~~ !

→ infrastructure
~~Anforderungen/Unterschiede / Vor und Nachteile fahrzeugseitiger Ladetechnologie (RWE)~~
↳ ~~asymmetrische Belastung 1-phasig~~

~~Market roles in the context of charging coordination~~
↳ responsibilities
~~drivers for emobility~~
~~Ländervergleich (prokopf EV)~~
~~Challenges - difference of EU and US distribution network~~

~~potential of optimal charging coordination~~
concept of future coordination and marketmodel
~~Netzampel~~ what kind of regulation is beneficial? (Rajakaruna 2015)

~~collect ideas for literature review~~
~~DR and DSM~~

Gleichzeitigkeit - graph (% EV)
flowchart / algorithm pseudocode
get single line diagram of network

load profiles following different ~~EV~~ control strategies

---

network heatmap - voltage + overloads
Voltage profile plot 3D (Rajakaruna 4.18)

give simple examples (as figures)

~~categories of PEV charging coordination~~

~~objectives of EVCC~~

~~relief of loads by PV generation~~
~~from network~~

~~layers of control frameworks~~

EVCC in system wide context
↳ what if ~~anybody~~ there are many aggregators
↳ ~~transmission vs distribution system~~

why linear power flow approximation does not work in DG
need for data exchange → flow of information digram (Rajakaruna S.8)
different levels of uncertainty under different market conditions (day-ahead, intraday)
characteristics low voltage grid / network topology

dynamic pricing (Rajakaruna)

Buchholz2014 [1, 2.4, 3.4, 4.1, 4.3, 5.3.1, 6, 7.2

- smart grid definition
- effect of RES on scheduling / network loading / dispatch
- describe category of LV distribution network
- 3 pillars of smart distribution !
- dynamic tariffs

EXCHANGE SCHEDULE BY PRIORITY LIST !
+ CHARGING_RATE LIST ?

-

Measures / Evaluation Criteria

- utilisation rate of networks

Uncertainty Mitigation

does price time series make sense??

must consider thermal limits!

dist causes overloads BI-100 up to 150%

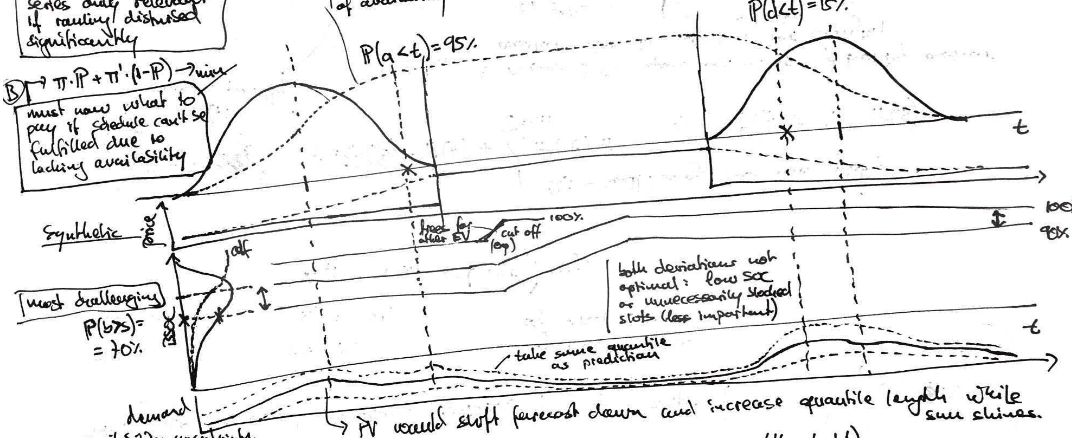
soc causes overloads BI-100 up to 120%

→ rank correlation

uncertainty of price time series only relevant if ranking disturbed significantly

(B) → $\pi \cdot \mathbb{P} + \pi' \cdot (1-\mathbb{P})$ → min

must now what to pay if schedule can't be fulfilled due to lacking availability



- availability uncertainty
  - (A) schedule only if probability of availability is above ~~X%~~ (threshold)
- BSOC uncertainty
  - (A) schedule for BSOC that is exceeded X% of time (threshold) — expensive (?)
  - (B) reschedule upon arrival → participate in balancing mechanism / intraday market.
  - (C) similar to availability (handling)

(demand uncertainty)
and PV uncertainty
and price uncertainty
with autocorrelated random variables : + shift ξ $\mathcal{N}(0, 0.15)$

guess red noise:

$r = 0.8$

w_j = white noise

x_j = red noise

$x_1 = w_1$

$x_{j+1} = r x_j + \sqrt{1-r^2}\, w_{j+1}$

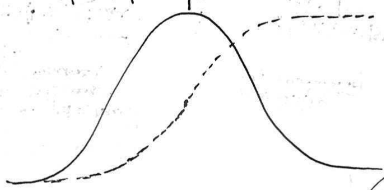
$c = \sum_{\tau=t}^{T} \mathbb{P}(\tau) \cdot \pi'$? if I don't: expected penalty

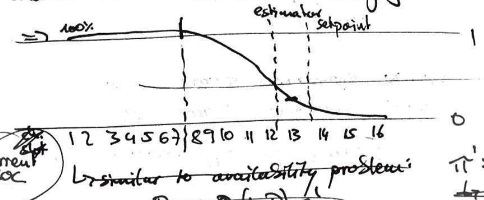
$c' = [\text{illegible}] \cdot \pi(t) P + \sum_{\tau=t+1}^{T} \mathbb{P}(\tau)\, \pi' P$

Q: should I charge one more slot?

$\Rightarrow \mathbb{P}(t)\pi' > \pi(t)$

→ transfer BSOC upon arrival to probability whether another slot is needed for charging





→ individual price signal ↗ WTP

~~↳ similar to availability problem:~~

~~$\mathbb{P}\pi + (1-\mathbb{P})\pi'$~~

π' : penalty

~~↳ static~~

~~↳ BSH?~~

17 July (Summary)

Notebook:	MA Journal		
Created:	22/07/2017 11:08	**Updated:**	08/08/2017 14:27
Author:	Fabian Neumann		

Done (as in commit history: https://github.com/orley-enterprises/ev_chargingcoordination2017/commits/master)

- Checked accuracy of linearised power flow (exceptional, slight overestimation for line loadings)
- Re-implemented uncertainty model
    - Demand uncertainty → assumed quantity is known but timing uncertain within a certain window
    - Price uncertainty → based on empirical profiles: uncertainty higher the higher the expectation value is from median
- Implemented uncertainty mitigation options for all sources of uncertainty
    - Price uncertainty → worst case ranking (dis-incentivised time slots with a large uncertainty range)
    - Demand uncertainty → rolling maximum as input parameter (e.g. D_t = max(t-30min, t+30min))
    - Availability uncertainty → either by penalty or giving a threshold (e.g. only charge vehicle when availability probability above 80%) // alternatively, intraday scheduling
    - Battery SOC uncertainty → schedule with battery SOC that is not exceeded in e.g. 20 % of all cases // alternatively, intraday scheduling
- Optimisation additionally runs with perfect information for comparison (what would the schedule have been, had all parameters been known in advance)

Unsure

- Mileage scaling: So far, to make charging more challenging, I have scaled the daily mileage distributions by a factor of 2.

Upcoming

- Check validity of all parameters (see current options below, maybe you can have a look whether something looks odd to you)
- Run and evaluate experiments
- Decide on table of contents
- Write-up

Discarded

- For the evaluating the impact of uncertainty I don't think I need a reparation controller, except for a simple reality adjustment (i.e. not charging when not available, not exceeding battery capacity)

03 Aug (Weblinks Organisation)

Notebook:	MA Journal		
Created:	03/08/2017 10:20	**Updated:**	08/08/2017 14:30
Author:	Fabian Neumann		

Articles
http://www.nextgreencar.com/electric-cars/
https://www.gov.uk/government/statistics/public-attitudes-towards-electric-vehicles-2016

Data Sources

- Elexon Standard Load Profile: https://www.elexon.co.uk/reference/technical-operations/profiling/
- Energy Bill Breakdown: http://www.energy-uk.org.uk/customers/about-your-energy-bill/the-breakdown-of-an-energy-bill.html

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Information

- Balancing Mechanism UK:
  - https://www.bmreports.com/bmrs/?q=help/about-us
  - http://www2.nationalgrid.com/uk/services/balancing-services/

Markets
https://www.ofgem.gov.uk/electricity/wholesale-market/gb-electricity-wholesale-market

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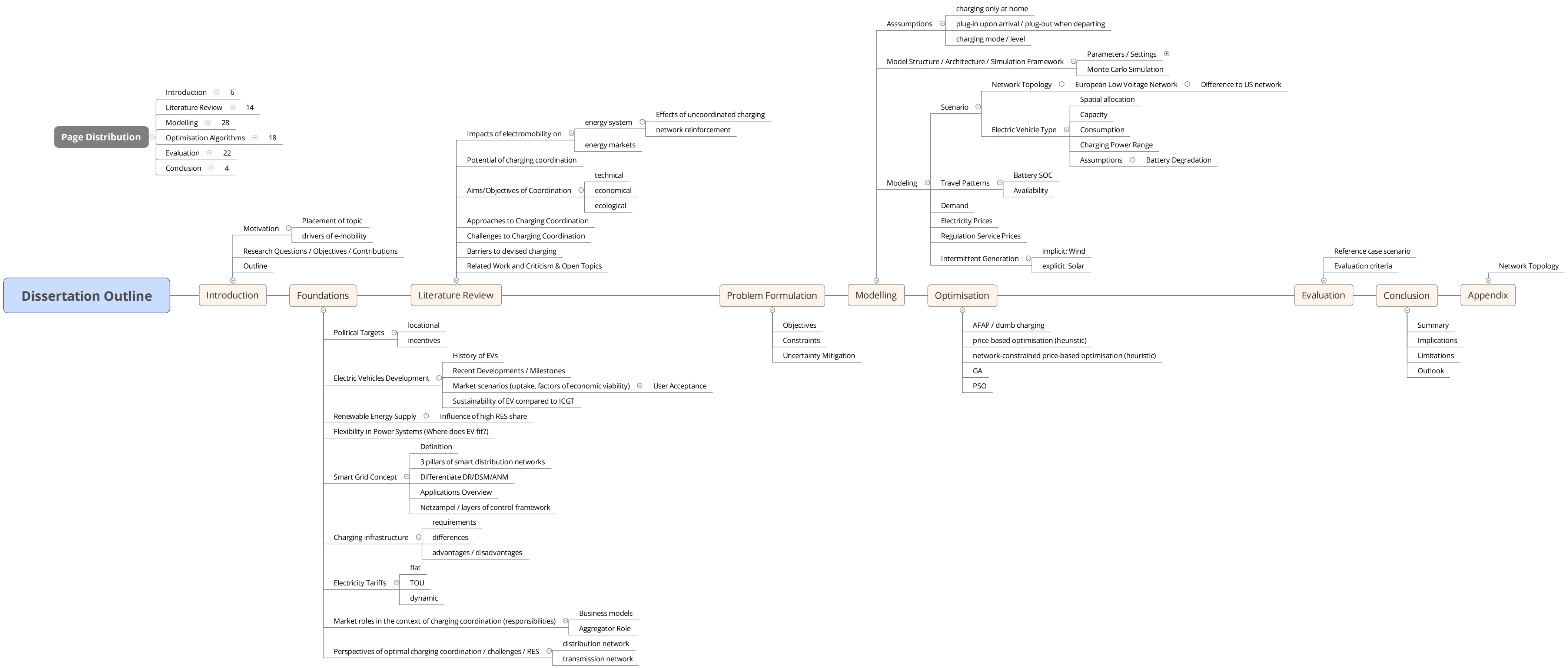
Travel
https://www.gov.uk/government/statistics/national-travel-survey-2015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