Optimal Configuration of Distribution Networks under Technical Constraints based on Predictive Methods

Master's Thesis Dissertation by
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M2 - Smart Grids and Buildings

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June 25, 2014

Agenda

for today's presentation

Introduction

- Background
- Introduction to the Problem
- Literature Review

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Preliminary Work

- Work Objectives
- Test Networks
- Day-ahead Load and DRES Models

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- Formulation & Economic Models
- Components
- Working of the Algorithm

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Results & Conclusions

- Results Obtained
- Conclusions
- Future Work

Background

Electrical Distribution Network Optimization

- **Merlin and Back** method, close to 40 years ago!

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- Problems with DRES integration!
- Distribution network optimization has to take a new, giant leap.

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- Problems with DRES integration!
- Distribution network optimization has to take a new, giant leap.
- This work proposes a method to take this leap!

Introduction

to the problem

Why is large-scale DRES integration is a problem?

- Variability / Intermittency
- Bi-directional Power Flows
- Grid Weakening
- Network Imbalance
- Fault Current Issues
- And finally: Money!

There is a **real need** to find solutions that assuage the problem with the integration of DRES.

Literature Review

Current Work in the Domain

Forecasting:

- A lot of work has been done in forecasting for DRES and Loads
- Persistency / NWP based methods
- Both traditional and stochastic load forecasting: fairly **mature**
- But are they applicable to Distribution Networks?

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Distribution Network Optimization:

- "Snapshot" based optimization
- Few instances of multi-temporal optimization
- Even they don't take a lot of issues into account
- Hence, there is a real need for a novel tool

Part II

Preliminary Work

Work Objectives

The following requirements were defined for the work to be done. The work should:

- Create a **day-ahead schedule** based on DRES and Load forecasts

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- Be **multi-objective**
- Be **modular**

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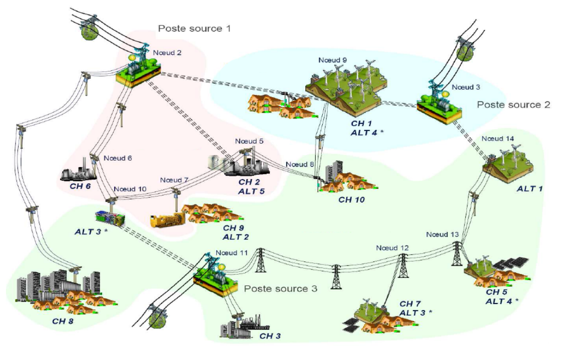
- Be **multi-objective**
- Be **modular**
- Be a **black box** for end-users

Test Networks

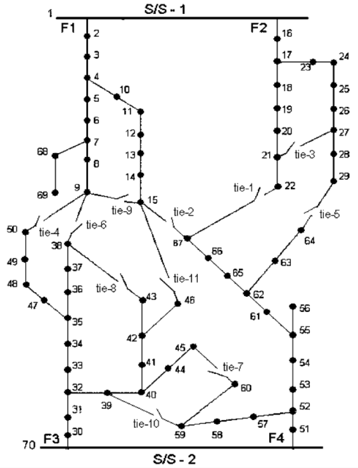
Network 1 - PREDIS Urban Network



- Reduced-scale Urban Network
- 14 buses, 17 lines
- Connected Load: 26.5 MVA
- Installed DRES Capacity: 27 MW
- Undervoltage and overcurrent problems

Test Networks

Network 2 - IEEE 11kV Rural Network

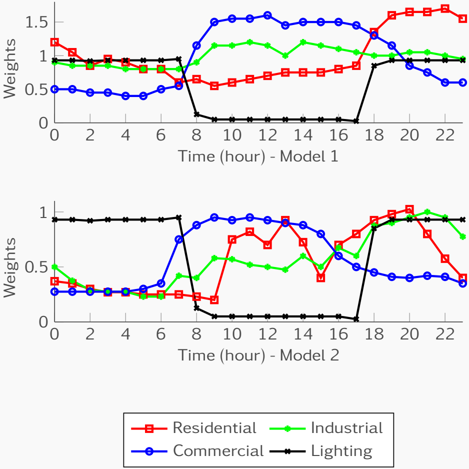


- Larger Network than PREDIS
- 70 buses, 79 lines
- Connected Load: 5.41 MVA
- DRES Info not available

Day-ahead Load and DRES Models

Raw Models

- **Two raw models** extracted from literature.
- Specific weights for different types of loads.
- Residential, Industrial, Commercial, and Public Lighting.
- DRES Models: Values based on characteristic curves.
- Variation of Solar Power etc., taken into account.



Day-ahead Load and DRES Models

Models Applied to Networks

Load Model A

- This model consists of a simple association of each load type to one node.
- The load in each node varies accordingly for a given 24 hour period.

Load Model B

Each node has a particular % of loads of each type.

Load Type	PREDIS Network	Rural Network
Residential	5 – 80%	8 – 50%
Industrial	5 – 50%	20 – 75%
Commercial	0 – 50%	5 – 70%
Lighting	5 – 15%	5 – 15%

Day-ahead Load and DRES Models

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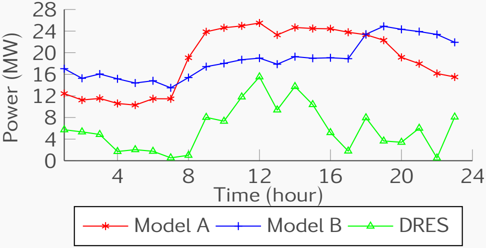
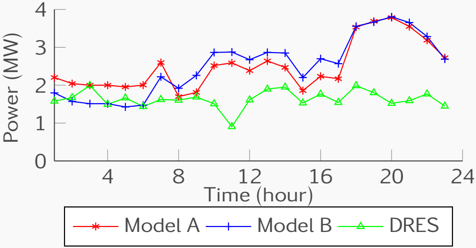
PREDIS Network (Based on Model 1)



Rural Network (Based on Model 2)



Part III

The Algorithm

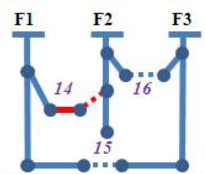
The Algorithm

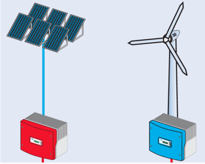
Formulation

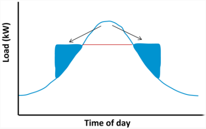
The Algorithm

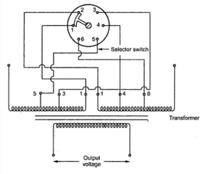
Formulation

Available Flexibilities









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The Algorithm

Economic Models

- Switching:

$$Cost/switching = \frac{C_{sw}}{n_{sw}} + C_{OM} + C_{log}$$

$$C_{OM} = c \cdot f(t_{sw})$$

- OLTC:

$$Cost/operation = \frac{C_{OLTC}}{n_{op}} + C_{OM} + C_{log}$$

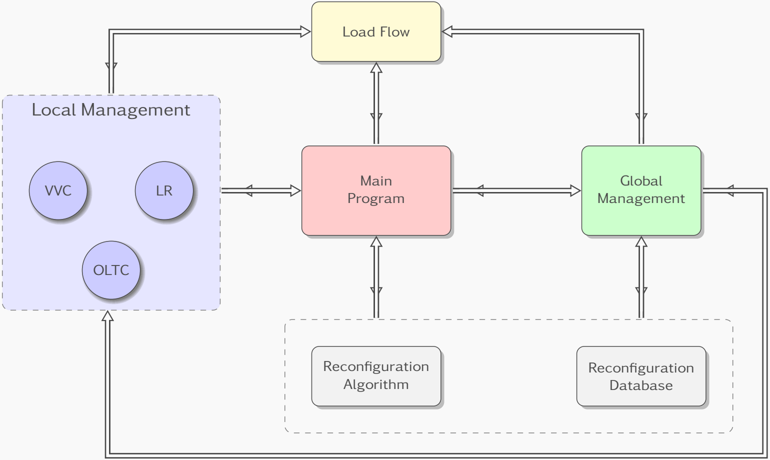
$$C_{OM} = c \cdot f(t_{op})$$

- Models for Load Reduction, VVC, and Violations are more difficult to develop.

Switching Operation	300 €
Load Reduction	6 €/MWh
OLTC Operation	20 €/Tap Change
VVC	132.9 €/MWh
Violations	500 €/violation

The Algorithm

Components

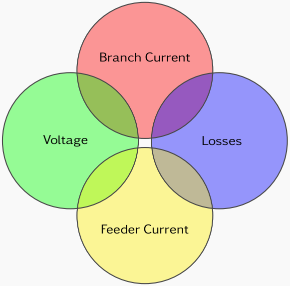


Legend: VVC: Voltage VAr Control, LR: Load Reduction, OLTC: On-Load Tap Changing

The Algorithm

Components - Reconfiguration

Multi-Objective Reconfiguration



- Branch exchange based method with pre-selection
- Membership Functions for Each Objective:

$$x_i = \frac{PLOSS(i)}{PLOSS0} \qquad i = 1, 2, N_k$$

$$\mu L_i = \frac{(x_{max} - x_i)}{(x_{max} - x_{min})} \qquad \text{for } x_{min} < x_i < x_{max}$$

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- Fuzzy min-max principle for finding branch to exchange
- Reconfiguration database based on “maximum” conditions

The Algorithm

Components - Local Management

To manage "local" violations in distribution networks for the hour when it is launched.

Voltage Violations

- When $V < 0.95pu$ or $V > 1.05pu$
- Solution: Use nearby nodes to improve voltage profile
- Objective function: $f = abs(V - (0.95 + c))$

Current Violations

- When $I > I_{max}$
- Solution: Use downstream nodes to try reduce line current
- Objective function: $f = abs(I_{max} - (I + c))$

- When both current and voltage violations exist, consider both sets of nodes, $f = abs(V - (0.95 + c)) + abs(I_{max} - (I + c))$
- Once done, check if $C_{spent} \geq C_{org}$, if yes, do not optimize.
- Return solution to calling function.

The Algorithm

Components - Global Management

Global Management (hour h)

With Reconfiguration

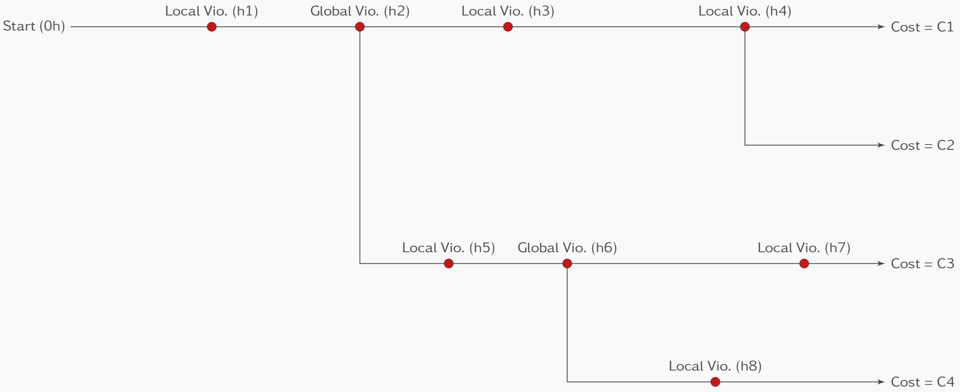
- At hour *h*, perform reconfiguration, and globally optimize using LM functions
- From hour *h+1* to end of the day, check for violations
- Classify violations found and launch the respective management function
- At the end of the day, calculate overall costs and feed it back to calling function

Without Reconfiguration

- At hour *h*, use only LM functions to optimize globally
- From hour *h+1* to end of the day, check for violations
- Classify violations found and launch the respective management function
- At the end of the day, calculate overall costs and feed it back to calling function

The Algorithm

Working

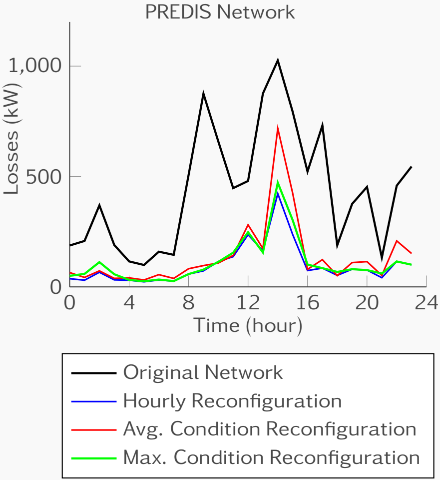


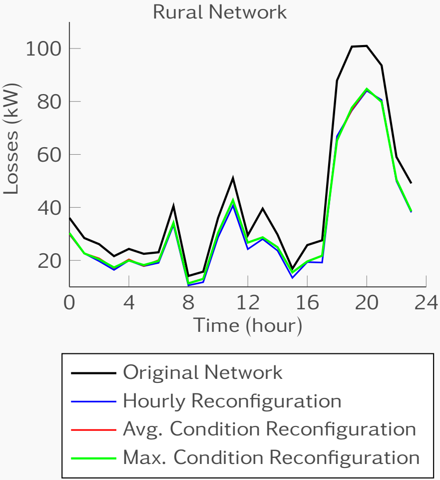
Part IV

Results & Conclusions

Initial Results

Why "Maximum" Condition was Chosen





Results

Methodology

- Both networks were tested with the two load models.
- Two initial configurations were used: the original, and the 24 hour optimal configurations.

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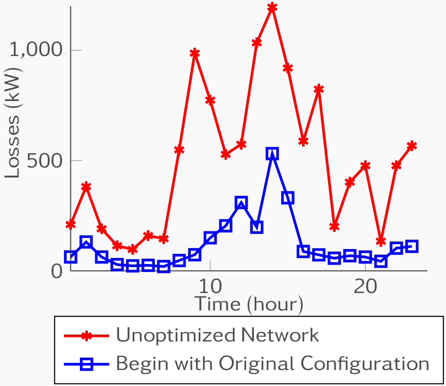
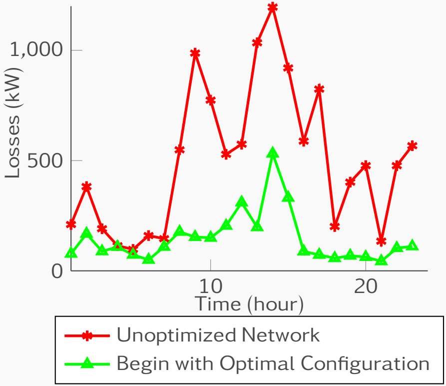
Output Variables	
Money Spent without Optimization	Money Spent with Optimization
Load Reduction effected	DRES VVC Outputs
Number of Switching Operations	Number of OLTC Operations
Loss Curves over the 24h period	Complete Bus Voltage Profiles
Violations in the Network	Final Line and Bus statuses for every hour

Results

PREDIS Network - Load Model A





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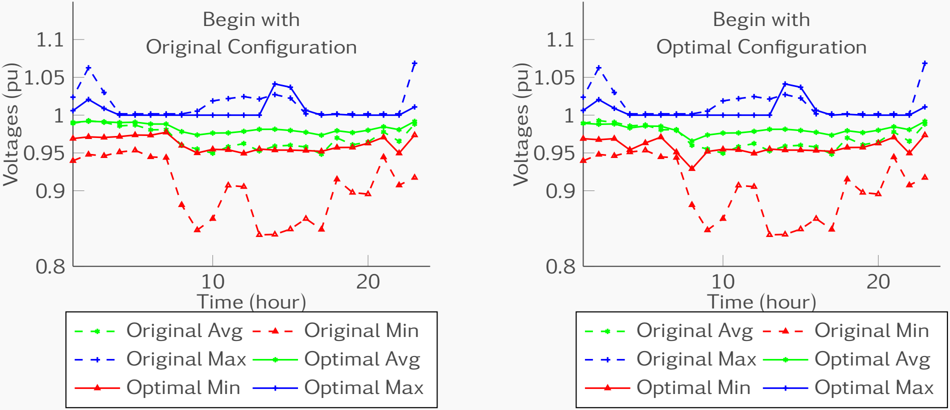
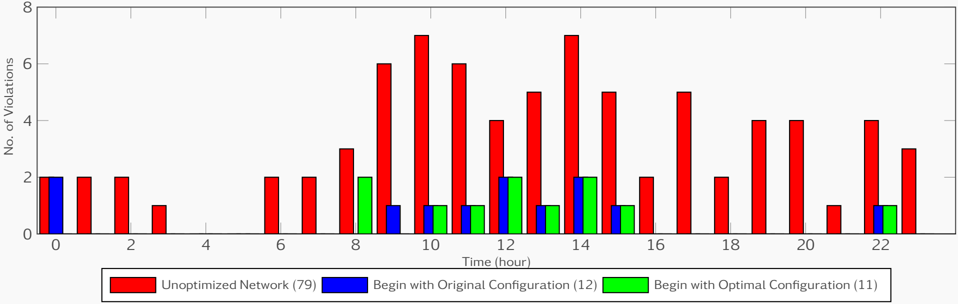


	Unoptimized Network	Begin With Original Configuraiton	Begin With Optimal Configuration
Minimum Voltage (pu)	0.8417	0.9359	0.9290
Average Voltage (pu)	0.9700	0.9826	0.9809
Maximum Voltage (pu)	1.0686	1.0413	1.0413

Results

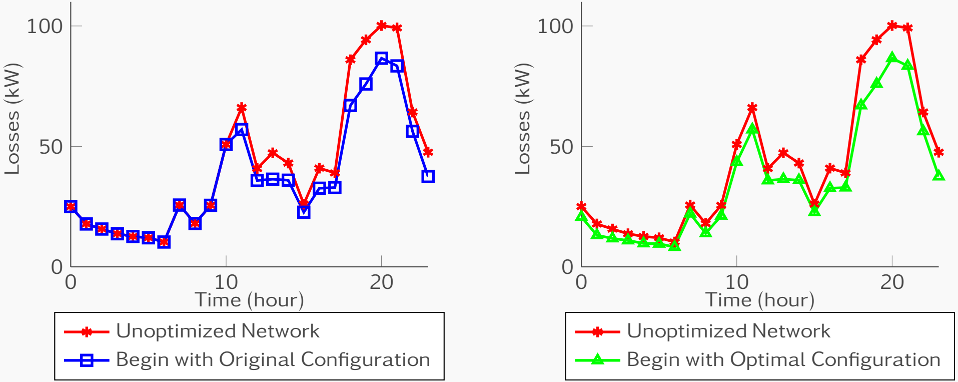
PREDIS Network - Load Model A



Network Parameter	Original Configuration	Optimal Configuration
Money Spent without Optimization	€ 41057	
Money Spent with Optimization	€ 14096	€ 13994
Original Losses	11503 kWh	
Optimal Losses	2991 kWh	3406 kWh
Load Reduced	354 kWh	
VVC Energy	512 kVArh	
Switching Operations	8 (1 Reconfiguration)	6 (1 Reconfiguration)
OLTC Operations	3	

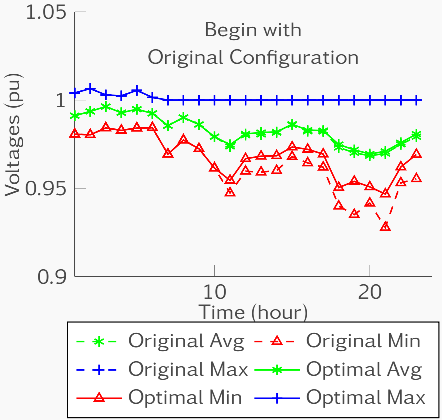
Results

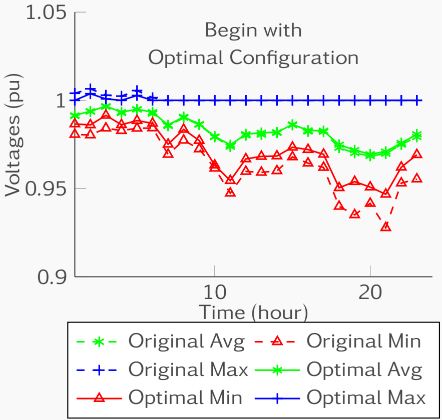
Rural Network - Load Model B



Results

Rural Network - Load Model B

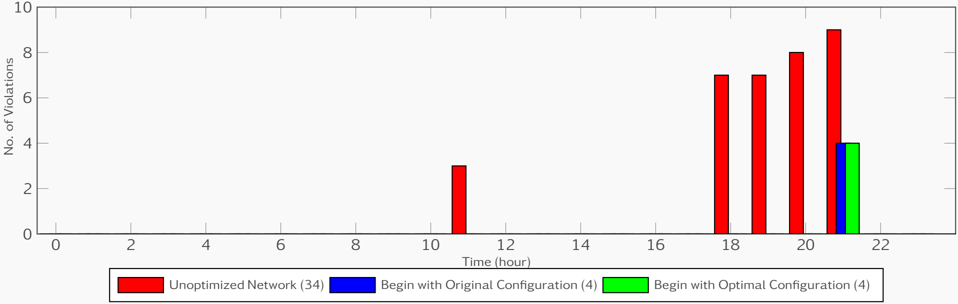




	Unoptimized Network	Begin With Original Configuraiton	Begin With Optimal Configuration
Minimum Voltage (pu)	0.9278	0.9467	0.9467
Average Voltage (pu)	0.9829	0.9834	0.9836
Maximum Voltage (pu)	1.0065	1.0065	1.0037

Results

Rural Network - Load Model B



Network Parameter	Original Configuration	Optimal Configuration
Money Spent without Optimization	€ 17136	
Money Spent with Optimization	€ 7818	€ 10824
Original Losses	1022 kWh	
Optimal Losses	887 kWh	845 kWh
Load Reduced	~ 0 kWh	
VVC Energy	0 kVArh	
Switching Operations	14 (2 Reconfigurations)	2 (1 Reconfiguration)
OLTC Operations	0	

Conclusions

The developed algorithm

- Can optimize networks with a variety of characteristics.
- Is multi-objective and multi-temporal.
- Takes into account the day-ahead forecasts of DRES and loads, and uses inherent flexibilities.
- Outputs a day-ahead schedule.
- Provides Up to 70% reduction in **expenditure**, 91% reduction in **violations**, and 75% reduction in **losses**.
- Executes quickly.

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Professional and Personal Perspectives

- Professional Perspectives: about my work in the laboratory
- Personal Perspectives: studying abroad

Future Work

Work envisaged

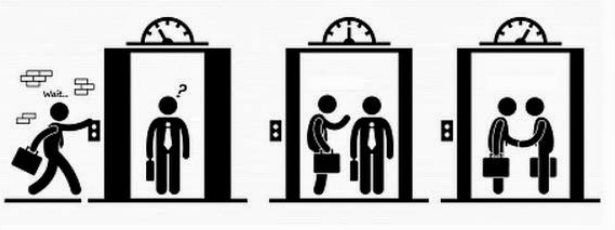
- Sensibility studies
- The development of a novel reconfiguration function
- The development of a better multi-objective constrained optimization function
- The development of a complete economic model
- The development of a day-ahead market based purchase scenario
- The development of a probabilistic load-flow function

All as a part of my PhD here at G2ELab, commencing in September.

Thank You! ☺

Questions? ☹

Elevator Pitch

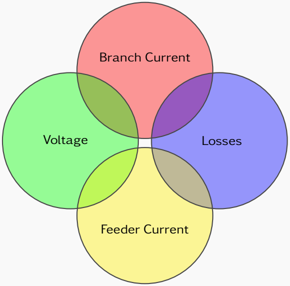


Back-up Slides

The Algorithm

Components - Reconfiguration (Extras)

Multi-Objective Reconfiguration



- Branch exchange based method with pre-selection
- Membership Functions for Each Objective:

$$x_i = \frac{PLOSS(i)}{PLOSS0} \quad i = 1, 2, N_k$$

$$\mu L_i = \begin{cases} \frac{(x_{max} - x_i)}{(x_{max} - x_{min})} & \text{for } x_{min} < x_i < x_{max} \\ 0 & \text{for } x_i \leq x_{min} \\ 1 & \text{for } x_i \geq x_{max} \end{cases}$$

$$y_i = |min(V_{nodes}) - V_s|$$

$$\mu V_i = \begin{cases} \frac{(y_{max} - y_i)}{(y_{max} - y_{min})} & \text{for } y_{min} < y_i < y_{max} \\ 1 & \text{for } y_i \leq y_{min} \\ 0 & \text{for } y_i \geq y_{max} \end{cases}$$

$$z_i = max\left(\frac{I}{I_{max}}\right) \quad \text{for all branches}$$

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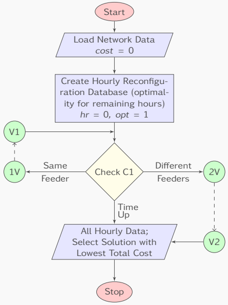
$$u_i = max\left(\frac{IF_{max} - IF_{feeder}}{IF_{max}}\right) \quad \text{for all feeders}$$

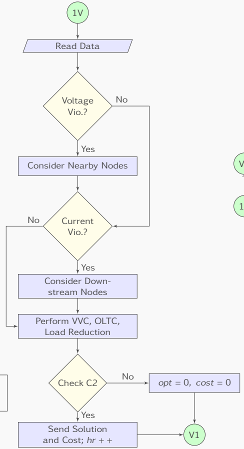
$$\mu B_i = \begin{cases} \frac{(u_{max} - u_i)}{(u_{max} - u_{min})} & \text{for } u_{min} < u_i < u_{max} \\ 1 & \text{for } u_i \leq u_{min} \\ 0 & \text{for } u_i \geq u_{max} \end{cases}$$

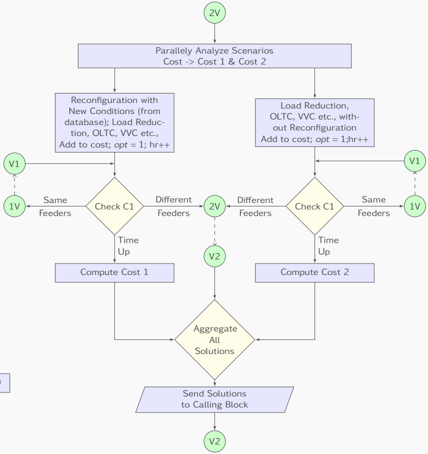
- Fuzzy min-max principle for finding branch to exchange
- Creation of the reconfiguration database based on “maximum” conditions

The Algorithm

Working







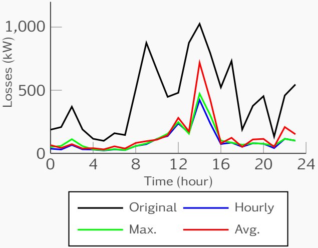
Condition C1:
if hr == 24
  go to "Time Up"
else if opt == 0
OR violations in different feeders
  go to "Different Feeders"
else if violations in the same feeder
  go to "Same Feeder"
else
  hr++; Check C1
end

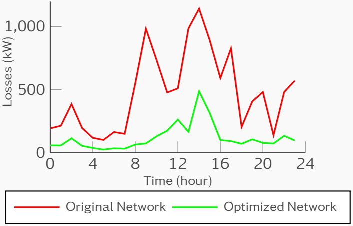
Condition C2:
Check if $n\_vio\_new \geq n\_vio\_old$
OR $cost \geq cost\_vio + cost\_losses$

Initial Results

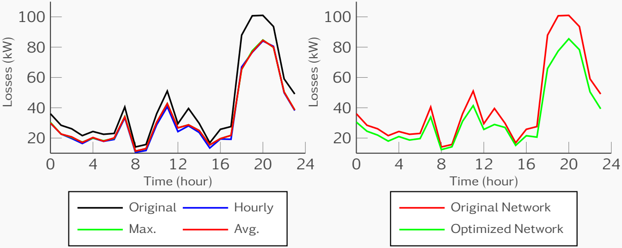
Why "Maximum" Condition was Chosen

PREDIS Network - Reconfiguration Results





Rural Network - Reconfiguration Results

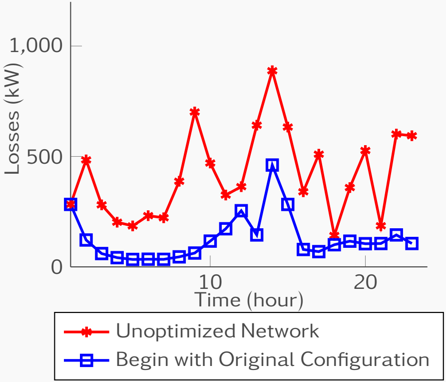


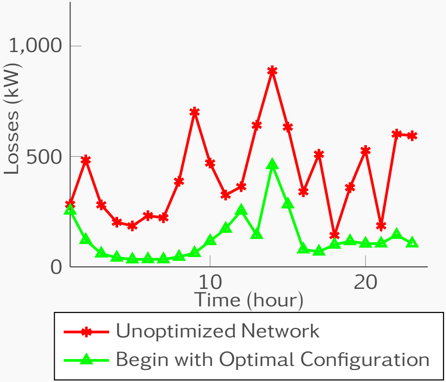
Comparison for "Maximum" Conditions

Parameter	Original Network	Merlin & Back	Fuzzy Algorithm
PREDIS Network			
Power Losses (kWh)	11503.77	2678.49	2796.41
Minimum Voltage (pu)	0.9359	0.9415	0.9433
Voltage Violations	70	9	5
Rural Network			
Power Losses (kWh)	999.81	814.11	822.82
Minimum Voltage (pu)	0.9262	0.9410	0.9462
Voltage Violations	34	11	7

Results

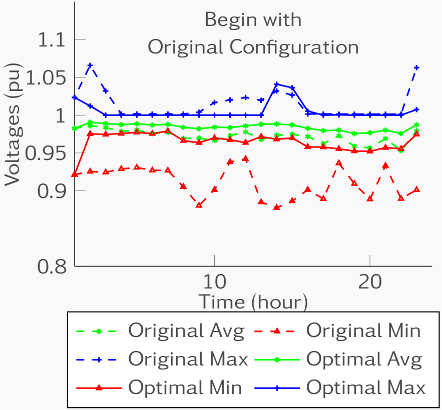
PREDIS Network - Load Model B

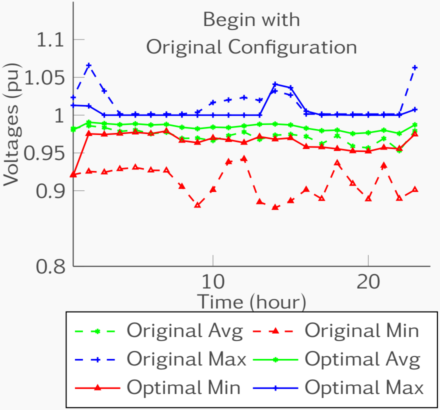




Results

PREDIS Network - Load Model B

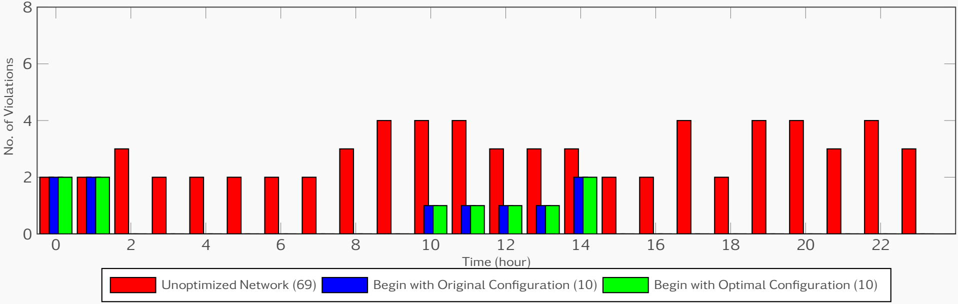




	Unoptimized Network	Begin With Original Configuraiton	Begin With Optimal Configuration
Minimum Voltage (pu)	0.8775	0.9156	0.9122
Average Voltage (pu)	0.9722	0.9836	0.9836
Maximum Voltage (pu)	1.0658	1.0409	1.0409

Results

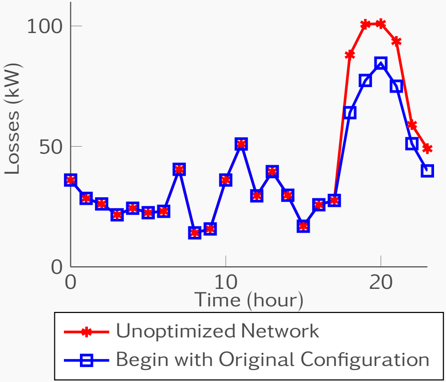
PREDIS Network - Load Model B

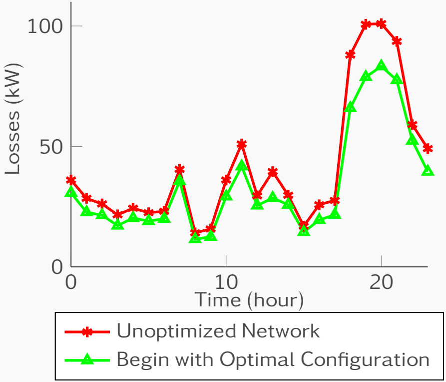


Network Parameter	Original Configuration	Optimal Configuration
Money Spent without Optimization	€ 35807	
Money Spent with Optimization	€ 12560.6	€ 14793.89
Original Losses	9834 kWh	
Optimal Losses	3247 kWh	3219 kWh
Load Reduced	$\sim$ 0 kWh	
VVC Energy	0 kVArh	
Switching Operations	10 (1 Reconfiguration)	6 (2 Reconfigurations)
OLTC Operations	0	

Results

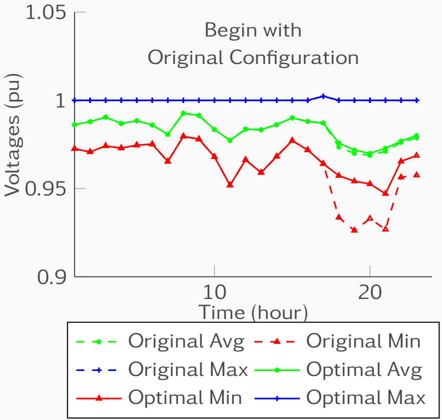
Rural Network - Load Model A

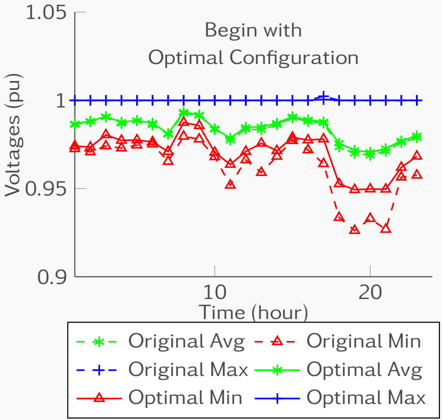




Results

Rural Network - Load Model A

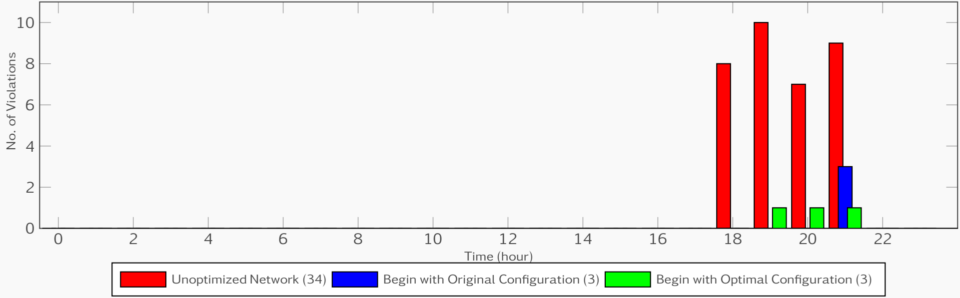




	Unoptimized Network	Begin With Original Configuraiton	Begin With Optimal Configuration
Minimum Voltage (pu)	0.9262	0.9471	0.9494
Average Voltage (pu)	0.9829	0.9833	0.9838
Maximum Voltage (pu)	1.0023	1.0023	1.0004

Results

Rural Network - Load Model A



Network Parameter	Original Configuration	Optimal Configuration
Money Spent without Optimization	€ 17133	
Money Spent with Optimization	€ 5246	€ 6243
Original Losses	1000 kWh	
Optimal Losses	900 kWh	814 kWh
Load Reduced	∼ 0 kWh	
VVC Energy	45 kVArh	40 kVArh
Switching Operations	12 (1 Reconfiguration)	0 (0 Reconfigurations)
OLTC Operations	1	