University of Strathclyde Engineering

Control of Distribution Network with Active Management of Demand

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Research objectives

- To accommodate
  - the availability of stochastic power sources in DN
  - the expected variations in demand

- To effectively control voltages
  - set appropriate control targets over a certain time period/use a minimal number of control actions
  - basing on a minimum set of local measurements
  - using devices such as online tap-changing transformers (OLTCT) and mechanically switched capacitors(MSC)

- To explore the heuristic planning methodology
  - for other possible power planning applications
    - e.g. decentralised control of loads & generation

Background

Active Distribution Substation

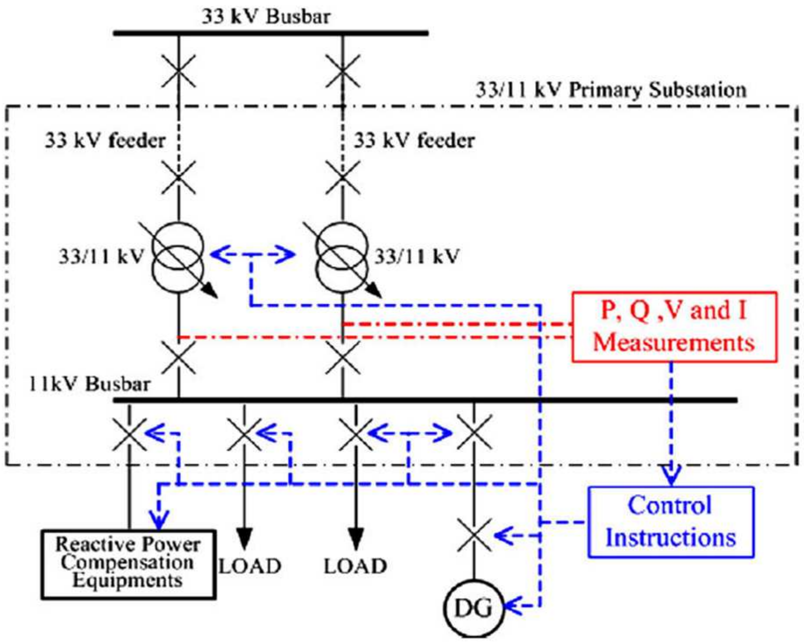


Figure 1. Example of a substation with active management facilities

Source: R.A.F. Currie, G.W. Ault, C.E.T. Foote, G.M. Burt, J.R. McDonald

On-load tap changing transformer

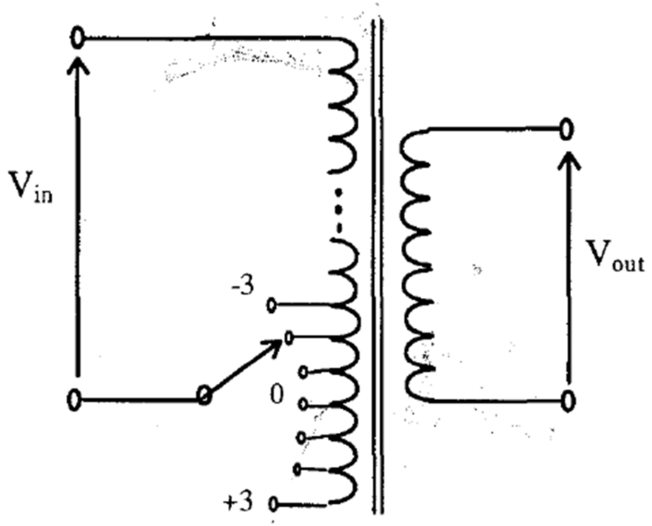


Figure 2. Explanation of tap positions of an OLTCT

Source: Jiang Fan, Z.Bo

Idea development

- Challenges
  - – the coordination of control actions
- Questions
  - – How to schedule control actions with a minimal of costs?
  - – How to model control effects? Voltage change/control cost
- Answers
  - – Artificial intelligence planning – existing work [1]
    - Planer objective function

$$PM = \alpha * T + \beta * M + \gamma * LV + \delta * HV$$

- – PM: plan metric
- – T: transformer turns
- – M: MSC switches
- – LV/HV: low voltage/high voltage

[1]:K. Bell, A.I. Coles, M. Fox, D. Long, A.J. Smith, 2009, "The Role of AI Planning as a Decision Support Tool in Power Substation Management", *AI Communications*, IOS Press, vol.22, 37-57.

Existing Planner

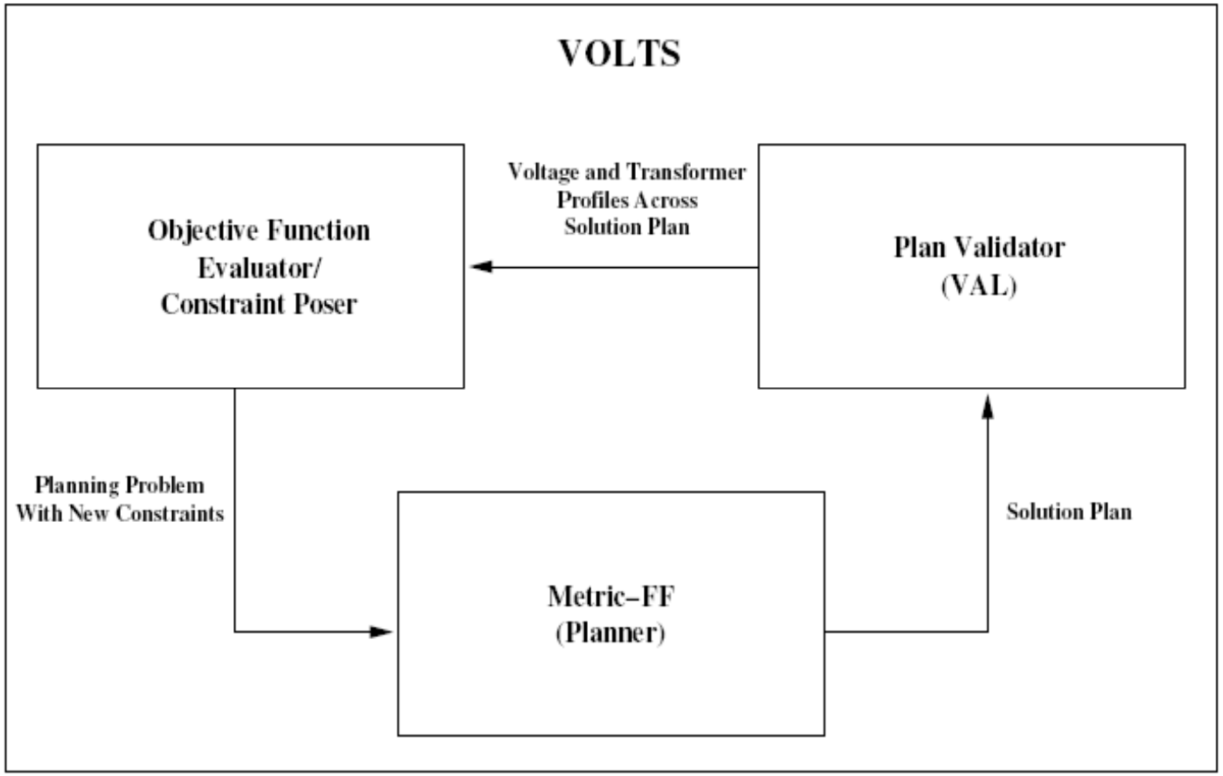


Figure 1. Overview of the VOLTS system

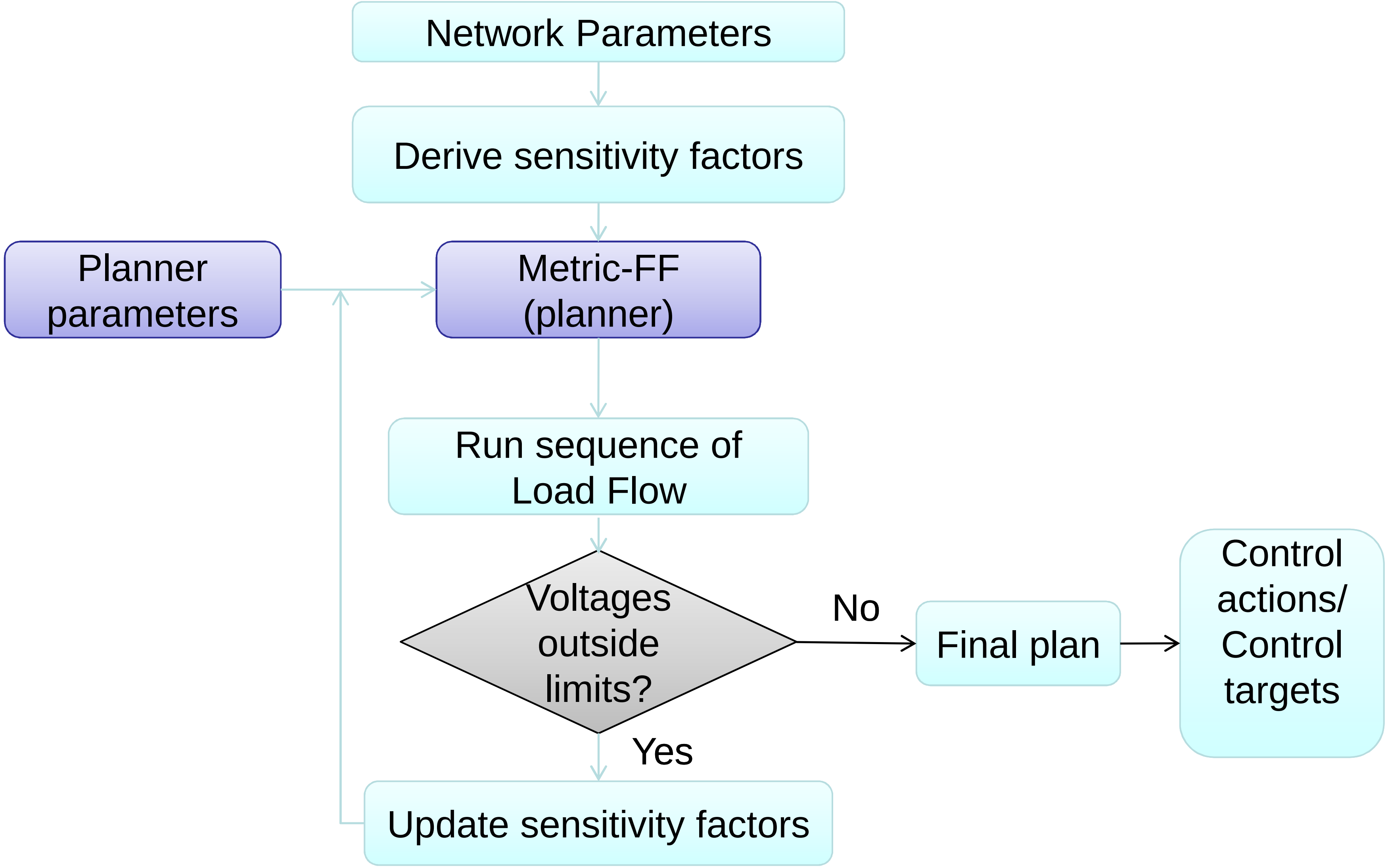
Source: Keith Bell, Andrew Coles, Maria Fox, Derek Long and Amanda Smith

Using PDDL (planning domain definition language)

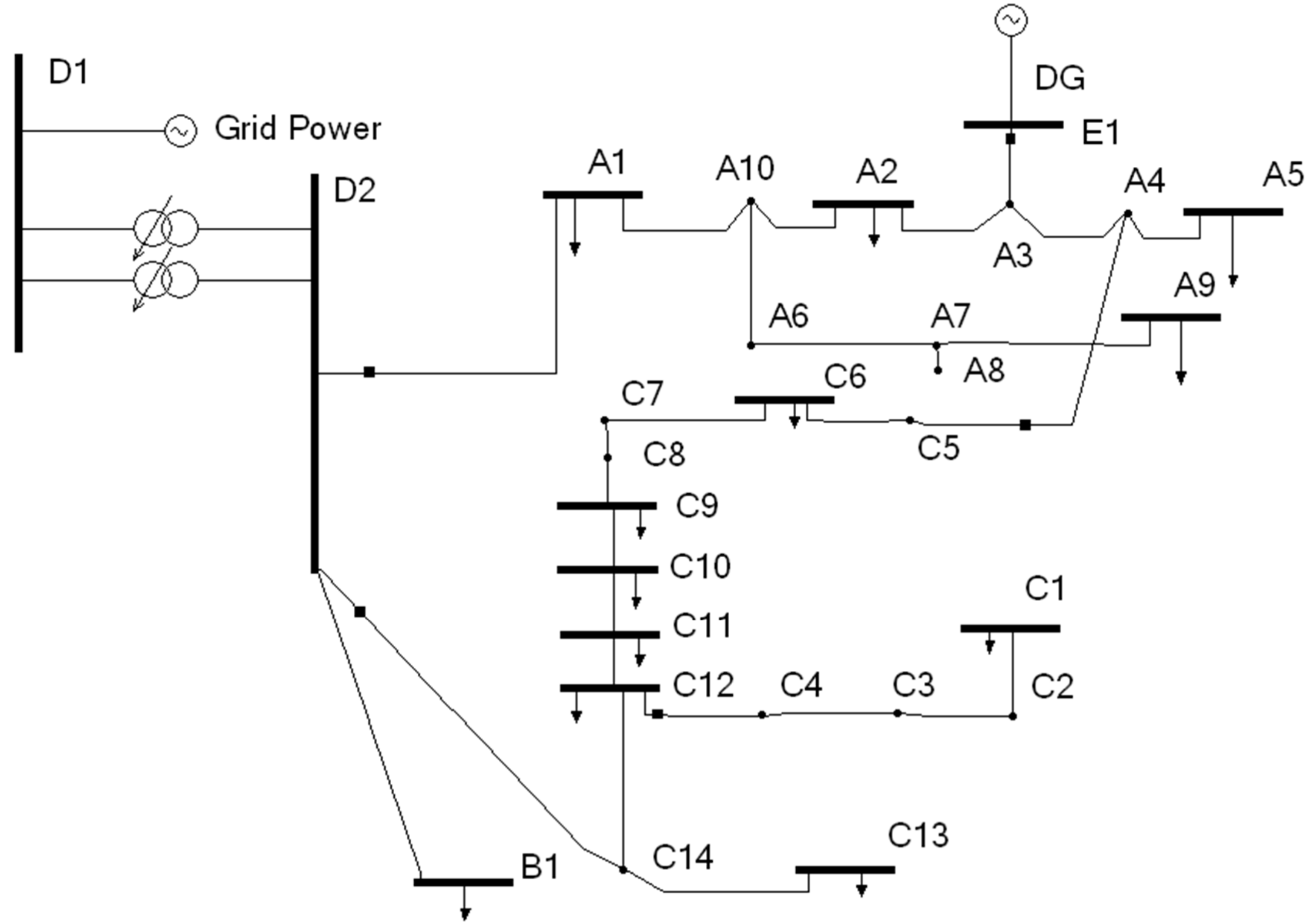
Two files included in PDDL:

1. A domain file for predicates and actions
2. A problem file for objects, initial states and goal specifications

Software integration



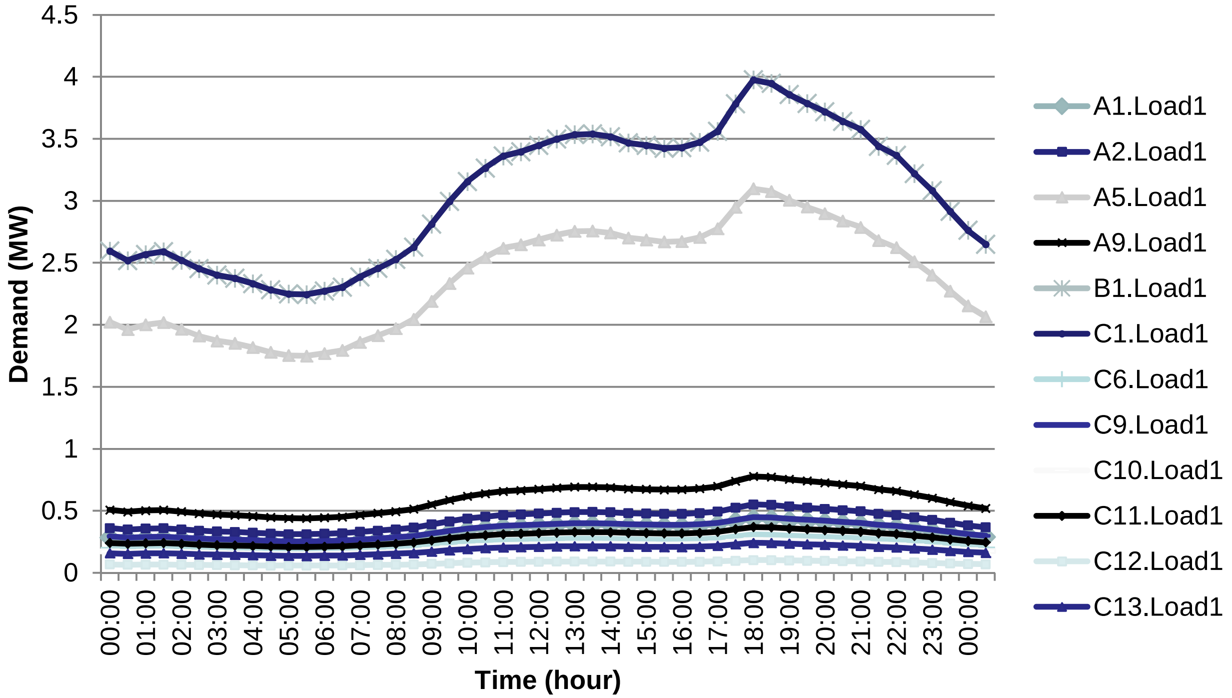
Distribution Network Model



Source: AuRA-NMS project

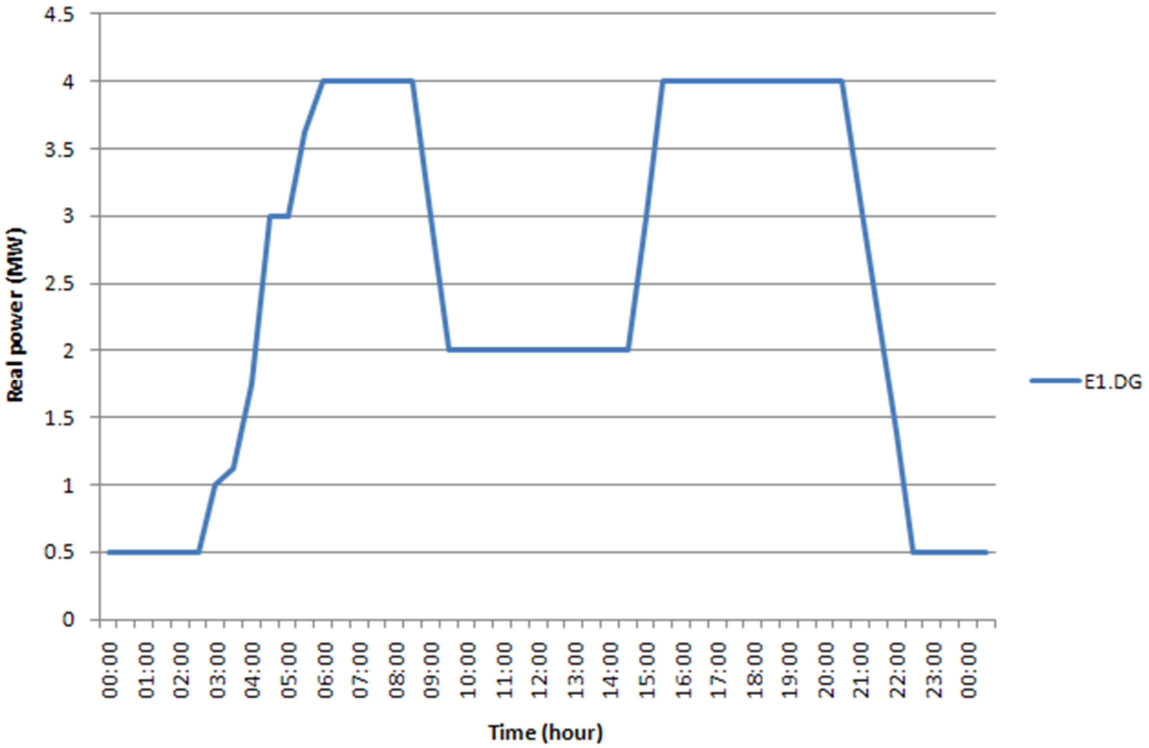
Demand data

- Assuming constant power factor for each load
- Peak demand
- Following the trend of National Grid's half an hour data (MW)
  - E.g. 30-Oct-2010



Generation data

- Combined Heat and Power (CHP)
  - Maximum power
    - space and water heating are most likely to be needed
  - Reactive power capability
    - between 0 and 1.95 MVAr

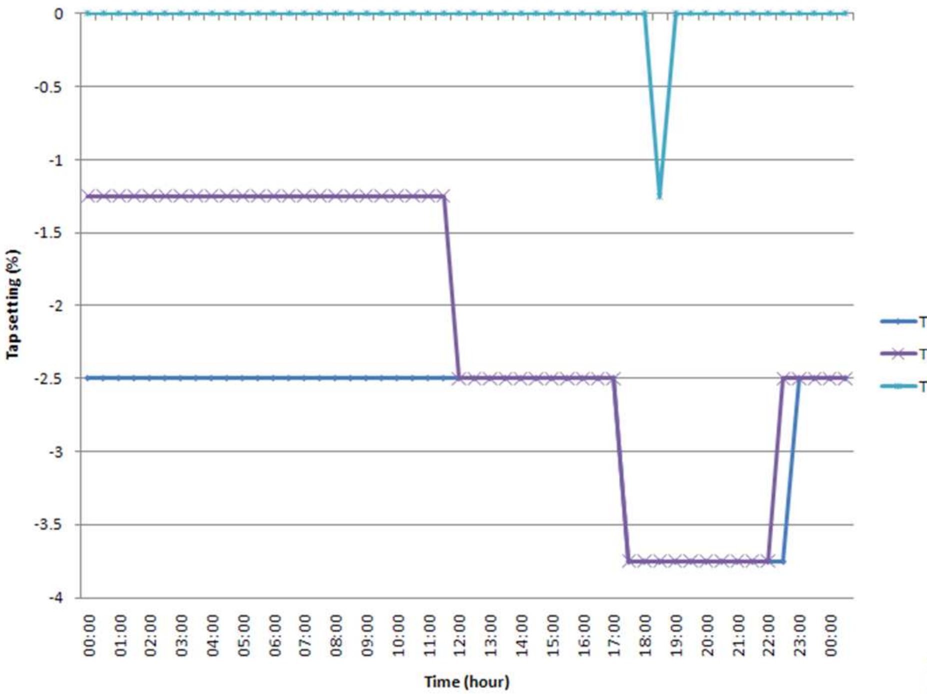


Simulation Process

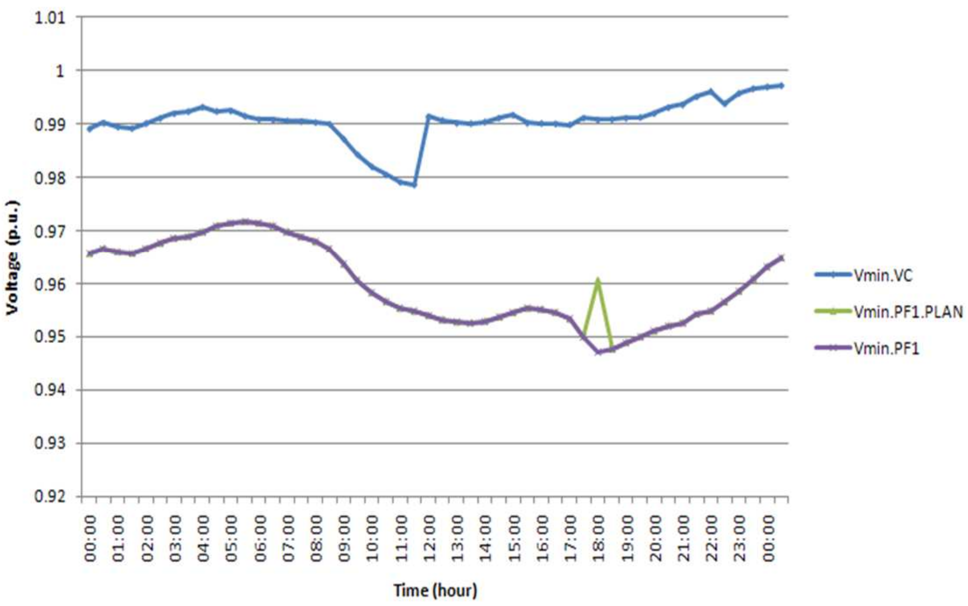
- Set the voltage target of the OLTCT to be 1.0 per unit
- Run load flows to get tap settings & voltages (base case 1)
- Set the tap position of the transformers to be nominal (0)
- Obtain the resultant voltage profile (base case 2)
- Feed the planner with sensitivity factors & initial conditions derived from load flow results
- Generate new transformer tap settings
- In a sequence of load flows, set the tap positions according to the planner’s control output
- Compare against the base case.

Simulation results

- Tap settings



- Minimum voltage



Summary

- Conclusion
  - Successful integration between the planner and a load-flow simulator
  - Achieved required voltage profile with less tap changes under PF1 mode
  - Hence less wear-and-tear on the equipment

- How does the work contribute to my research?
  - Control methods along with optimisation techniques to achieve the research objectives
  - Ability to plan ahead and effectively schedule control actions using sensitivity factors

Current progress

- Generate sensitivity factors first
- Planning
  - – Start off from a reference point (a certain time slot)
  - – Predict voltage performance using factors
  - – Compare those against AC load flow results in IPSA
    - If close, generate a plan (target/controls)
    - Otherwise, recalculate factors
- Apply the voltage targets/control actions
- Run load flows to test the results
- Include generation scheduling/load management/outage to better control voltages by using relevant sensitivity factors

$$S = [S_p | S_q | S_{msc} | S_{tap} | S_{outage}]$$

$$\Delta V_k = S_{tap}\Delta Tap + S_{MSC}\Delta MSC + S_p \Delta P + S_Q \Delta Q + S_{outage}\Delta outage$$

Future work

- Larger distribution network
  - More distributed generators/loads/transformers
- Other case scenarios
  - E.g. Minimum demand
- Work with the planner more effectively
  - Robustness to be tested
  - Re-planning might be required
- The planner’s robustness to forecast errors to be tested along with further work on alternative strategies in which differences between (non-linear) load flow solutions and a (linear) plan are significant.