Orchestration of Renewable Integrated Generation in Neighbourhoods

Grant Agreement Number: 314742

D4.5 Full Specification of Combined DPA, Control and Optimisation Algorithms

---

WP4 - Modelling of the energy networks and development of the prediction, optimization and control algorithm

Delivery Date : June 2014

REVISED: March 2015

Dissemination Level : PU

Nature of deliverable : R

ORIGIN	WP4 – Modelling of the energy networks and development of the prediction, optimization and control algorithm
Deliverable	D4.5 Full Specification of Combined DPA, Control and Optimisation Algorithms

Deliverable Lead		
Organisation	**Contact**	**email**
Heriot-Watt University	David Corne	d.w.corne@hw.ac.uk

Contributors		
Organisation	**Community name (if applicable)**	**Contact**
University of Strathclyde (InstEE)		Bruce Stephen
University of Strathclyde (ESRU)		Paul Tuohy
Heriot-Watt University (MACS)		Manju Dissanayake

1 Table of Contents

2 Introduction

2.1 Scope of this Deliverable

This deliverable in part mark an algorithm development milestone in the ORIGIN project, highlighting the fact that all of the major algorithms and approaches that will be deployed in the ORIGIN smart energy management system have now been designed. In marking this milestone, this deliverable also serves two additional functions:

- This deliverable brings together the full ORIGIN algorithm specification in suitably summarised form (fuller details of individual parts remain in previous deliverables)
- This deliverable adds emphasis to explaining how the hour-to-hour operation of the ORIGIN system is shaped by the constant stream of sensor information coming from the many sensors and other smart devices installed in individual households and other buildings in the ORIGIN communities

2.2 Context of the DPA, Control and Optimization Algorithms in ORIGIN

The ORIGIN system that is now deployed comprises a set of algorithms and approaches that:

- Audit community energy characteristics;
- Survey community goals and behaviour;
- Establish a community communications network for data collection, monitoring and actuation;
- **Predict localised weather variables (Weather Prediction Algorithm - WPA);**

- **Predict localised renewable generation (Renewables Prediction Algorithm - RPA);**
- **Predict electrical demand in individual households and buildings (Demand Prediction Algorithm - DPA);**
- **Predict opportunities for load shifting in individual households (Opportunities Prediction Algorithm - OPA);**
- **Provide an optimised set of load-shift actions that will ideally serve community goals for increased renewables utilisation (balanced with cost) (Gap Analysis and Orchestration/Control Algorithm - OCA);**
- Deliver those actions daily (typically) partly via automated device actuation and partly via informational display.

The algorithms in **boldface** are those that comprise the 'Combined DPA, Control and Optimisation algorithms', and also represent that part of the ORIGIN project that can be most easily replicated without alteration for arbitrary communities across Europe or elsewhere, and are relatively independent of the communications infrastructure, device designs, or nature and scale of the communities involved.

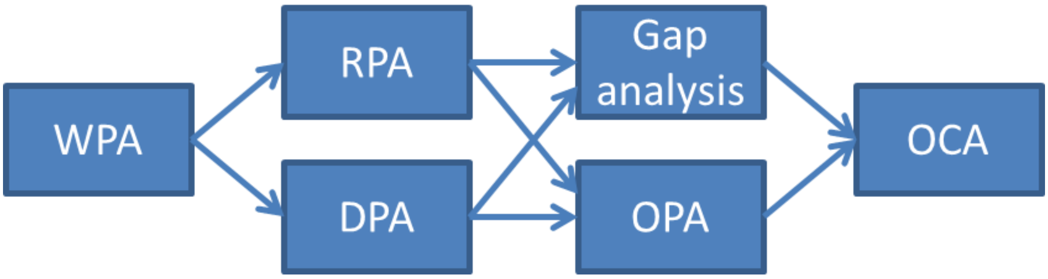

Figure 2.1. High Level Architecture of key transferable components of ORIGIN, representing also the set of components now specified at the current milestone.

Figure 2.1. shows all of the components that constitute the combined DPA, optimisation and control algorithms. It recaps a figure also delivered with variant highlighting in previous deliverables as its components were developed over time. The figure also shows the main flows of information between the components. As also indicated in previous deliverables, these flows represent the outputs of one component being used as the input to one or more other components, and this is achieved by communication through text and csv files.

In this deliverable, we provide a specification of the 'Combined DPA, Control and Optimisation algorithms'. Specifications of these algorithms have been delivered respectively in:

ORIGIN Deliverable 4.2: Deliverable D4.2 Demand and renewable prediction algorithms developed and tested, April 2014. This deliverable described the WPA, DPA and RPA.

ORIGIN Deliverable 4.3: Deliverable D4.3 Optimisation and Control Algorithm Developed, June 2014. This deliverable described the Gap Analysis, the OPA and the OCA.

In this deliverable, we aim to clarify how the complete ORIGIN Smart orchestration system works, by indicating how these algorithms are combined and implemented in ORIGIN's hour-to-hour operation. This will be done by using suitable pseudo-code and high-level description of the flow of control, with reference to fuller details elsewhere when necessary.

3 The Full ORIGIN Control Algorithm

In this section we will provide a full specification of the algorithm that defines the ORIGIN smart control system. We proceed in three steps. First, in section 3.1, we provide a high-level overview of the five main stages of the algorithm. In section 3.2, we look in more detail at those five stages by elaborating how household and community data is used in each stage separately. Section 3.3 then offers a full high-level pseudo-code description of the algorithm.

3.1 High-level overview of the full ORIGIN Control Algorithm

In the simplest terms, the following five stages define the ORIGIN system; each of these stages is itself a suite of algorithms and/or processes. The first ('Setup') happens before ORIGIN starts operating, and then the next four stages represent the ORIGIN system in operation; they happen sequentially (in the sequence given below), once per hour.

Setup: Having identified a community where ORIGIN is to be installed, a variety of setup activities take place, ranging from community audits to algorithm parametrisation.

Forecasting: weather, renewables supply, and electrical demand are forecast (for at least 24 hrs ahead), at community level and for individual households/buildings with sensors installed.

Analysis: Forecasts of demand (at both community and household level) and of community renewables supply, are scrutinised; household-level opportunities for load-shifting are calculated and characterised.

Optimisation/Control: optimisation algorithms are run to produce a specific schedule of load-shifting opportunities that maximises the balance between renewables supply and individual household demand, while taking community goals into account. The optimised schedule is activated, by providing information to households and by actuating a range of devices under ORIGIN's control.

Adaptation: Updating and rebuilding of predictive models occurs 'behind the scenes'; in particular, forecasting models are updated (weather, renewables, and demand) according to the latest relevant sensor data.

Each of these stages is itself composed of a collection of one or more algorithms or other procedures (only 'Setup' is not entirely automated), which have, for the most part, been described in earlier deliverables. A more detailed explication is provided in section 3.3, but first we take a closer look at each of these stages in terms of how the stages use data from sensors that were installed in the community (as part of the 'Setup' stage).

3.2 Sensor-Data-streams and the full ORIGIN Control Algorithm

Here we highlight the role of sensor data in each of the five stages, partly to help clarify how the hour-to-hour operation of the ORIGIN system is influenced by the up-to-date behaviour and conditions in the community and in individual households.

Many sensors and sensing/actuation devices are likely to be involved in an ORIGIN installation (and indeed are involved in current installations); however we simplify the explication below by referring to four main categories of sensors.

The terminology used below reflects that used in Deliverable 3.1 "D3.1 Hardware setup and software installed at each site and set to run in monitoring mode". In Deliverable 3.1, specifics are provided of the sensors and other devices installed in each of the three ORIGIN communities. In addition, we use "WSS" to refer to weather station sensors (a weather station is set up at each ORIGIN site, as detailed in Deliverable 3.3 "Weather Station Set up").

- CT: these are 'current clamp' devices which are primarily used to provide a stream of *demand data* – that is, indication of the electrical energy being consumed in the building it is installed. CT sensors, judiciously installed, also provide community-level renewables generation data.
- WSS: these are 'weather sensors', and refer to devices installed at onsite weather stations.
- TRH: this denotation refers to 'temperature and/or relative humidity sensors'; distinct from temperature sensing at a weather station, this refers to sensors installed within the water heating and/or solar-thermal heating systems at each of several participating ORIGIN households;
- CLOOGY: finally, this refers to 'Cloogy' devices, which, in ORIGIN, provide our 'actuators' for specific devices under ORIGIN's control; a Cloogy device t can be automatically switched on and off by ORIGIN systems.

We now recap the five stages of ORIGIN operation from section 3.1, and outline the role of sensors in their operation:

Setup: Among several other activities, this is the stage at which sensor devices are installed in buildings at the chosen ORIGIN site. Each of CT, WSS, TRH and CLOOGY categories will typically be installed. Not all sensors need to be installed initially – the later ORIGIN stages can update seamlessly as new sensors come online. Initially, however, the minimal ORIGIN system would require community-level CT sensors both to report community level demand and community-level renewable generation. Meanwhile, CT, TRH, and CLOOGY equipment will be installed in buildings with systems that are to be placed under ORIGIN control.

<u>Forecasting</u>: ORIGIN's **demand forecasting procedures rely extensively on sensors installed in households and buildings.** CT sensors are installed in several individual households and buildings, and also at the community level (typically, at the installation that links the community to the grid). To forecast demand, ORIGIN uses the most up-to-date stream of values from each such sensor, to maintain and update the statistical demand profile for each building. In addition, weather forecasting relies on site weather station data (WSS), which is harvested along with other observations and forecasts available on the internet; WSS data are then used as inputs to weather forecasting models. Finally, the forecasting of renewable generation depends on the data-stream from CT sensors that are installed at community level renewables installation.

<u>Analysis</u>: The role of the analysis stage is to identify suitable load-shifting needs and opportunities from the forecast renewables surplus/deficit profile over the next 24 hours. When it comes to shiftable opportunities (associated with water heating (or similar) systems where ORIGIN has been given control), this process relies intensively on the data stream from TRH sensors associated with the individual devices under control. The use of these sensors is mainly in the 'Adaption' stage (below). Here, shiftable load opportunities for individual households are identified on the basis of models re-built every hour based on TRH sensors.

<u>Optimisation/Control</u>: The optimisation process relies on sensor data that has been pre-processed in the stages above. The 'Control' stage then acts on the results of optimisation, and influences the community and individual households, to adapt their behaviour. This is done via CLOOGY devices (which switch individual devices, such as water heaters, on or off), and by placing suggestions and recommendations at targeted user interfaces (individual household apps and/or web areas).

<u>Adaptation</u>: In this stage, all of the predictive models are re-learned and updated by using the latest data from all of the installed sensors. The CT sensor stream is used to update the statistical model of demand for each household, and for the community as a whole, and the updated models are then used in the next Forecasting stage. Similarly, WSS sensors are used to update the weather prediction models, and CT sensors reporting community generation are used to update the renewable prediction models, both of which are then used in the next Forecasting stage. Finally, the TRH sensor stream is used to update the models of individual devices used, in the next Analysis stage, to characterise load-shift opportunities involving those devices.

In less simplified terms, the next section breaks down the above four steps to indicate more clearly the relationships between these activities and algorithms described in previous deliverables

3.3 Specification of the full ORIGIN Control Algorithm

We now present a high-level yet detailed specification of the ORGIN control algorithm. The exposition below correctly reflects the sequence of events, and can be considered as accurate pseudo-code for the ORIGIN Control algorithm; meanwhile additional useful annotation is included, particularly to point to fuller description elsewhere.

Install ORIGIN-CONTROL-ALGORITHM

A. Establish parameters SITE (where the system is to be installed) and HRS (the furthest ahead forecast window)
B. Perform community audits and questionnaires;
C. establish community goals and individual household/building goals
D. Install sensors, actuators and weather stations;
E. Perform weather prediction initialisation, by running the Data-Source-Choice procedure (Deliverable 4.2, section 3.2.1)
F. Perform failsafe forecast setup to enable forecasting even when sensors/internet are down (using approach in Deliverable 4.2 section 3.2.4)
G. Collect initial datasets from installed sensors to bootstrap the WPA, RPA, and DPA;

While ORIGIN is installed at the SITE, repeat the following steps every hour:

1. Run WPA: This provides forecasts of the weather variables that are relevant for predicting renewables supply at the SITE (the required variables having been determined during step B of installation, and implemented at step E). These forecasts are provided for 1, 2, …, up to HRS hours ahead. Details of the WPA are in Deliverable 4.2 section 3.
2. Run RPA: The RPA takes output from step 1, and provides forecasts of the renewable energy supply at SITE. These forecasts are provided for 1, 2, … up to HRS hours ahead. Details of the RPA are provided in Deliverable 4.2 section 4.
3. Run DPA for community-level demand: Forecasts of energy demand are made, for the community as a whole, using community-level CT sensor stream, from 1 to HRS hours ahead; The DPA is detailed in Deliverable 4.2 section 5.
4. Run DPA for individual households: Forecasts of energy demand are made, for every individual household/building that has CT sensors installed, from 1 to HRS hours ahead; The DPA is detailed in Deliverable 4.2 section 5 – note that the individual-household demand forecasting and community-level forecasting are done by precisely the same approach – essentially, in step 3, the community as a whole is treated as a very large individual building.

5. Perform Gap analysis: The profile, over the next HRs hours, of expected surplus/deficit in renewables is calculated, for the community as a whole; Gap Analysis is a relatively simple process detailed in Deliverable 4.3 section 3.
6. Identify Profile Opportunities: At community level and for each individual household/building in which CT are installed, run the algorithm to identify profile-based load-shift opportunities; this algorithm is detailed in Deliverable 4.3 Section 4.1.
7. Run the OPA to identify device-based "shiftability vectors": the OPA is the 'opportunity prediction algorithm', which stands for a suite of individual 'opportunity quantification algorithms' related to different types of individual devices that are to be controlled by the ORIGIN system. In this step we proceed as follows: For every device that has associated TRH and CLOOGY sensors installed, run the appropriate Opportunity Quantification Algorithm, resulting in a set of shiftability vectors for that device. These vectors are then inputs to step 8. Opportunity Quantification Algorithms for a selection of key devices are given in Deliverable 4.3 Sections 4.3, 4.4 and 4.5.
8. Run the OCA: the orchestration and control algorithm (OCA) identifies an optimised subset of opportunities from the complete collection of opportunities (as estalished in steps 6 and 7), in the context of the upcoming surplus/deficit profile established in step 5; this subset, if implemented by individual households and buildings in the community, will combine to maximise the utilisation of community renewables over the next HRS hrs (or, maximise an alternative set of goals if such is desired by the community). The output of the OCA is a schedule of actions. The OCA itself is described in Deliverable 4.3 section 5.2.
9. Activate the OCA's schedule of actions. The actions are of two types: (i) informational **suggestions** (these are communicated to individual household and community user interfaces), (ii) **actuations** (these are directly actioned by sending signals to smart plugs (or similar devices) that control water heaters, freezers, or other devices. In this step, the informational suggestions for individual households are communicated directly to targeted web areas that are accessible only to those households, while informational suggestions for the community as a whole are sent to designated community screens. Actuation actions are directly implemented, device by device, via the ACTS actuator (typically this is a smart plug that is directly turned ON or OFF by ORIGIN at a scheduled time, which itself was detailed in the schedule of actions emerging from step 8.
10. Rebuild/Adapt WPA models: the weather variable prediction models will be rebuilt, in order to ensure that the predictive model tracks the latest relevant weather dynamics. This is done via the procedure in Deliverable 4.2 section 3.2.5.
11. Rebuild/Adapt RPA models: the renewable energy prediction models will be updated by building them anew with reference to the most recent data stream from community-level CT sensors that tap the actual generation. At this step, therefore an RPA model will be retrained, either for wind (Deliverable 4.2. section 4.1) or solar (Deliverable 4.2. section 4.2) or both, depending on what is relevant for SITE.
12. Rebuild/Adapt DPA models: to ensure that steps 3 and 4 in the next hour are as accurate as possible, in this step we harvest the latest data from CT sensors that tap consumption, to ensure

we have an up-to-date statistical profile of demand for each individual household and for the community as a whole.

13. Rebuild/Adapt OPA models: In step 7, shiftability vectors are identified for each device, using Opportunity Quantification Algorithms (Deliverable 4.3 Sections 4.3, 4.4 and 4.5.); in current ORIGIN operation, running these algorithms in step 7 includes the process of updating the model according to the latest data from relevant TRH sensors. In general, however, some devices may require a separate model-updating stage here.
14. Rebuild/Adapt OCA Probabilities: the OCA runs in step 8, and its outcomes are actioned in step 9. When the OCA runs in step 8, it makes use of 'Action Likelihoods' (ALs) (see Deliverable 4.3 Section 5.1). These ALs indicate the perceived probability that a given informational suggestion to a specific household will be acted upon. In this step, we run a simple routine that considers, for each household, the informational suggestions that have been delivered over the previous HRS hrs, and considers the relevant stream of CT data for that household, and makes a broad assessment of how often the household has implemented the suggestions made by ORIGIN. ALs for each household are updated appropriately, to ensure more effective optimisation in the next run of step 8.

4 Concluding Notes

In this deliverable we have shown how the complete ORIGIN Smart Control algorithm works, as a combination of the WPA, RPA, DPA, OPA, OCA and other algorithms detailed in previous deliverables, and also following various initial setup procedures. Section 3.1 gave a high-level overview of how it all fits together, while section 3.2. provided an overview from an alternative angle, showing how each of the main stages makes use of the many sensors and actuators installed in an ORIGIN community. Finally, section 3.3 provided a step by step walk through the complete ORIGIN algorithm, which is currently in operation at three sites in Europe (via cloud-based servers).

Continuing work on the ORIGIN project is now evaluating of these algorithms in the context of their deployment (on schedule) in the three ORIGIN communities (Findhorn, Northern Scotland; Damanhur, Northern Italy; Tamera, Southern Portugal). This activity will involve ongoing work on the algorithms themselves, but focussing primarily on the refinement of the several community-specific components according to lessons we expect to learn during deployment. Other activity continues to investigate and design variants of the generic approaches and their components that may be required for communities quite unlike the ORIGIN validation communities – these efforts will contribute to a commercialisation theme in the ORIGIN project that will contribute to Deliverables 7.5 (Commercialisation Plan) and 7.6 (Joint-Venture Company).