My Electric Avenue (I^2EV)

SDRC 9.7.1: Impact of Esprit on Cable Thermal Ratings

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The 'My Electric Avenue' project is the public identity for the Low Carbon Networks Fund Tier 2 project "I^2EV." The formal title "I^2EV" is used for contractual and Ofgem reporting purposes.

Project leads

Project partners

My Electric Avenue has received support from Ofgem through the Low Carbon Networks (LCN) Fund.

Version Tracking

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Final Approval

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12.06.2015	Issue 3	Dr David Roberts (Technical approval)	
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Executive summary

My Electric Avenue has conducted analysis to support the SDRC 9.7 report 'An assessment of the most appropriate integration of the Technology for different applications and suitable cycling times'.

The Technology refers to 'Esprit', the settings for which must consider the needs of the customer, electric vehicle (EV), charging equipment and also the Low Voltage (LV) network. As such, analysis has been conducted to understand the potential impact that different charge cycle times may have on thermal stress experienced by LV cables due to EV charging.

This report details the results of a basic study conducted on the data from one Technical trial cluster; Chiswick.

In scenarios where there are only a small number of EVs charging the proportional contribution of that to the overall phase current is slight. Even with long periods of un-curtailed charging they are unlikely to significantly affect the cable temperature.

However cable thermal limits may be breached in scenarios when charging curtailment may be delayed due to a longer cycle time, depending on the number of EVs charging.

Unbalanced loading caused by the majority of EVs being connected to the same phase is a further concern for cable thermal ratings. Though not studied in detail in this project, it is clear that relatively short control times and the use of control strategies for each phase (rather than three phase) are sensible strategies.

A clear relationship exists between the number of EVs to be accommodated and the required responsiveness of the control system (using the existing Esprit algorithm) if the risk of cable thermal damage is to be managed.

The results from this basic study suggest that a 30-minute control cycle time or less will lead to reduced cable thermal stress than higher control cycle times and should be considered the maximum for reducing risk of cable damage.

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1 Introduction

1.1 My Electric Avenue

My Electric Avenue is an innovative project that will provide a solution to the potential impact that the recharging of electric vehicles (EVs) may have on the local electricity network. The project is funded by Ofgem's Low Carbon Networks (LCN) Fund.

The project is trialling a new solution, Esprit, which directly controls and manages EV charging on Low Voltage (LV) feeders. Esprit is designed to provide an alternative approach to traditional network reinforcement, which is anticipated due to increased EV uptake in coming years.

The project is required to provide an assessment of the most appropriate integration of the Technology (Esprit) for different applications and suitable cycling times, or reasons why this is not possible if the trials are not successful.

To provide a full assessment of Esprit cycling times, it is prudent to not just consider the impacts on the customer, charging point and EV, but also the potential impacts on the network. As such, this report provides additional learning to that required by the SDRC, into the impacts of different cycle times on cable thermal ratings to provide a more informed view.

1.2 Cable Thermal ratings

For EV clusters controlled by the Esprit system, the control cycle time is an important variable which impacts the supporting LV network. A minimum value of the control cycle time was considered by assessing its effects on the flicker severity at the Chiswick EV cluster[1]. To assess any potential upper limit to the control cycle time value, the thermal stress on LV cables, due to EV charging, has been considered. The Chiswick EV cluster was selected for study since it was used to assess a potential minimum value of the control cycle time.

1.3 Thermal Modelling of the Chiswick LV Network

In order to model the thermal stress on the LV network supporting the Chiswick EV cluster, phase current measurements from the Chiswick feeder were used. This data covered the winter 2014-2015 period. Issues with the monitoring equipment meant that phase current measurements were not available for five weeks during the 2014/2015 winter period. To complete the analysis here, the missing data was calculated using Half Hour (HH) current data from approximately two and a half week periods preceding and following the data gap. The reconstructed HH data was scaled to account for the average rate of change of phase current between the two periods where data was available.

An Excel based calculation tool called CRATER[2] was used for dynamic thermal modelling of the 3-core LV cable. CRATER is a suite of programs designed to provide distribution ratings for a multitude of cable types at the distribution level, taking into account thermal capacitance of the cable and

[1] For more information on the Esprit algorithm, please see Section 5.1.3 in SDRC 9.7.1: An Assessment of 'Esprit' integration

[2] CRATER is a cable rating tool developed by EA Technology Ltd

surrounding soil. To provide the distribution rating for a given cable, the CRATER program must calculate the cable temperature over a sufficient simulation time to allow long term temperature trends to reach a steady state value. The dynamic rating module calculates the varying temperatures in cables where the load is continually varying.

The dynamic cable temperature feature in CRATER was used calculate the peak LV cable temperature increases due to EV charging at peak load times. At Chiswick, the phase currents are monitored at the substation, where the feeder current is highest. It is however considered indicative of the area where maximum thermal stress would be experienced and therefore appropriate for use in this study. The LV cable input parameters used in the CRATER program are shown in Table 1.

Table 1 CRATER input parameters for the Chiswick LV cable. XLPE stands for cross-linked polyethylene.

Cable Characteristics		Operating Conditions	
Cable Type	CU Waveform, BS 7870-3.20: 2001, Single Rubber Layer	Conductor Temperature °C	45
Conductor Type	Aluminium Shaped Solid	Soil Temperature °C	10
Conductor Size, mm^2	300	Soil Thermal Resistivity, $m°CW^{-1}$	1.2
Insulation Type	XLPE	Soil Depth, (surface to cable centre), mm	600
Sheath Type	PVC or LSF	Cable/Duct Configuration	Direct in ground
Neutral/Earth Wires	Copper		

In addition to cable information, CRATER requires half hourly (HH) averaged phase current values to calculate the cable temperature for each HH interval. The maximum number of phase current data points is 4032, covering a time range of 2016 hours (12 weeks). To ensure any temperature changes with a long characteristic time are captured, the simulation used the maximum time range available.

Figure 1 shows the base current profile used as the input data for the CRATER simulation. The recorded phase current data is shown in blue and the reconstructed data is shown in red. The missing data was calculated using HH current data from approximately two and a half week periods preceding and following the data gap. The reconstructed HH data was scaled to account for the average rate of change of phase current between the two periods where data was available. The maximum averaged HH current observed during the 12 week period was 416A, which is below the 550A assumed winter cyclic rating for this cable.

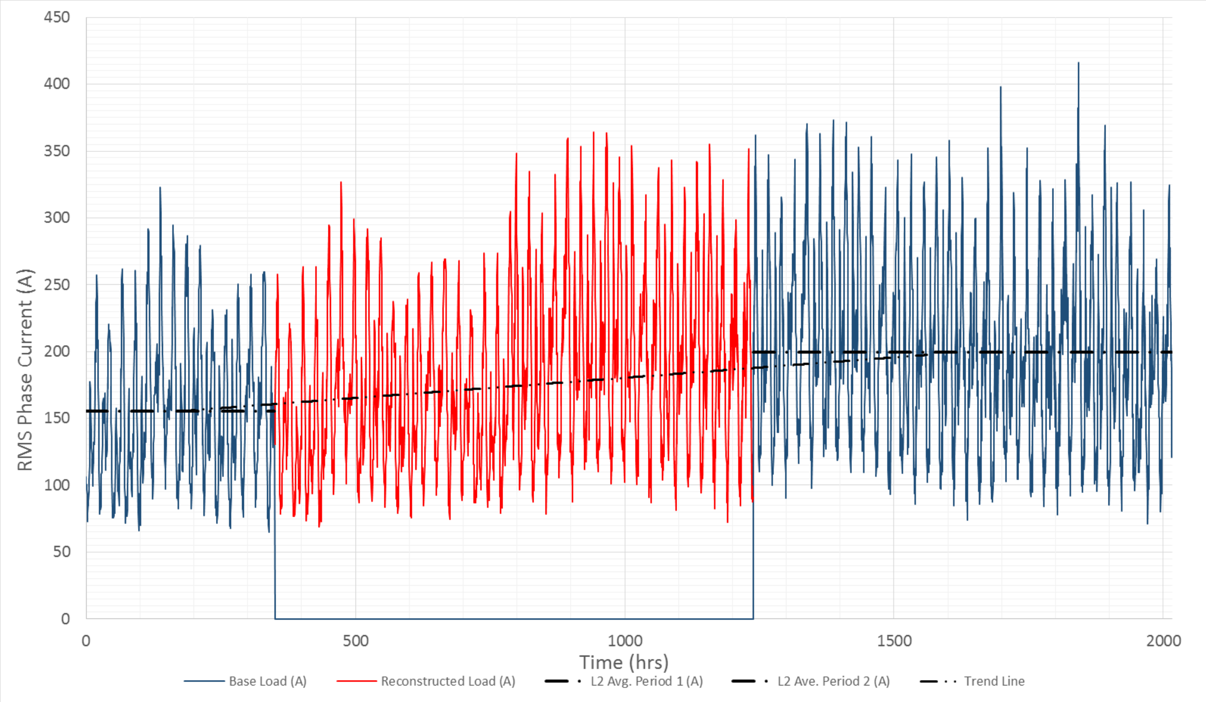

Figure 1. Phase L2 RMS current data using a rolling average of 30 minutes. Reconstructed data is shown in red.

To establish the effect of increasing control cycle times on the LV feeder temperatures, an EV load was added to the base load. A load of 16A per EV started at 18:00 hours each day to coincide with the peak background loading period. As this analysis is being used to determine the upper cycle time limit, control cycle times (and therefore duration of application of the EV load after 18:00) of between 0.5 hours and 3 hours have been considered. The scenario being that the current threshold is exceeded just after a control cycle has started, a whole control cycle will therefore be completed before curtailment is started, leaving the network in an overloaded state for this length of time.

In this basic study, once curtailed, the vehicle load was assumed not to come back on until 18:00 the following day. In the present Esprit algorithm, load would be re-established after the load had dropped below the lower current threshold – assumed to be the prelude to a low load period later in the evening. In the basic study, the cable cooling is more exaggerated than it would actually be. The cable temperatures (an indicator of risk of damage) should thus considered to be the maximum in a 24 hour period for comparative purposes. Note that in the use of numbers of EVs deployed in the study, a zero diversity has been assumed i.e. all the EVs are on during this peak period.

A small number of EVs provide only a small contribution to the overall phase current. Even with long curtailment delays they are unlikely to significantly affect the cable temperature. Therefore, the EV load was also varied to investigate how the effect of curtailment delay, on LV cable temperatures, changes with the number of EVs on the feeder. The EV load was varied between 80 A and 400 A, in steps of 16A, for six different values of curtailment delay time. This provided peak cable temperature results from 126 simulations.

2 Results

Table 2 shows the maximum half hourly (HH) cable temperature results from the all the simulations. XPLE waveform cable has a maximum design temperature of 90°C. It can be seen in Figure 2 and Figure 3 that increasing the curtailment delay increases maximum HH cable temperature reached. Regardless of the number of EVs in the cluster, curtailment delays between 0.5 and 1.5 hours show a greater difference on half hourly temperature than delays above 1.5 hours. Figure 3 also shows that the number of EVs also increases the maximum HH cable temperature and shows a shallow exponential relationship for every curtailment delay value. Maximum HH temperatures were reached at 1338 and 1843 hours into the simulation for curtailment delays ≤ 1 and ≥ 1.5 hours respectively.

Table 2 Maximum half hourly cable temperature results for varying EV curtailment delay while charging during peak times

No. of EVs	Curtailment Delay (hrs)					
	0.5	1	1.5	2	2.5	3.0
5	41°C	44°C	48°C	48°C	48°C	48°C
6	42°C	46°C	50°C	50°C	51°C	51°C
7	43°C	47°C	53°C	53°C	53°C	53°C
8	45°C	49°C	55°C	55°C	55°C	56°C
9	46°C	51°C	57°C	58°C	58°C	58°C
10	48°C	54°C	60°C	60°C	61°C	61°C
11	49°C	56°C	63°C	63°C	64°C	64°C
12	51°C	58°C	66°C	66°C	66°C	67°C
13	53°C	61°C	68°C	69°C	69°C	70°C
14	54°C	63°C	72°C	72°C	73°C	73°C
15	56°C	66°C	75°C	75°C	76°C	77°C
16	58°C	68°C	78°C	79°C	79°C	80°C
17	60°C	71°C	81°C	82°C	83°C	84°C
18	62°C	74°C	85°C	86°C	87°C	87°C
19	64°C	77°C	89°C	90°C	91°C	91°C
20	66°C	80°C	93°C	94°C	94°C	95°C
21	68°C	83°C	97°C	98°C	99°C	100°C
22	71°C	87°C	101°C	102°C	103°C	103°C
23	73°C	90°C	105°C	106°C	106°C	106°C
24	76°C	94°C	109°C	110°C	109°C	110°C
25	78°C	98°C	113°C	114°C	114°C	114°C

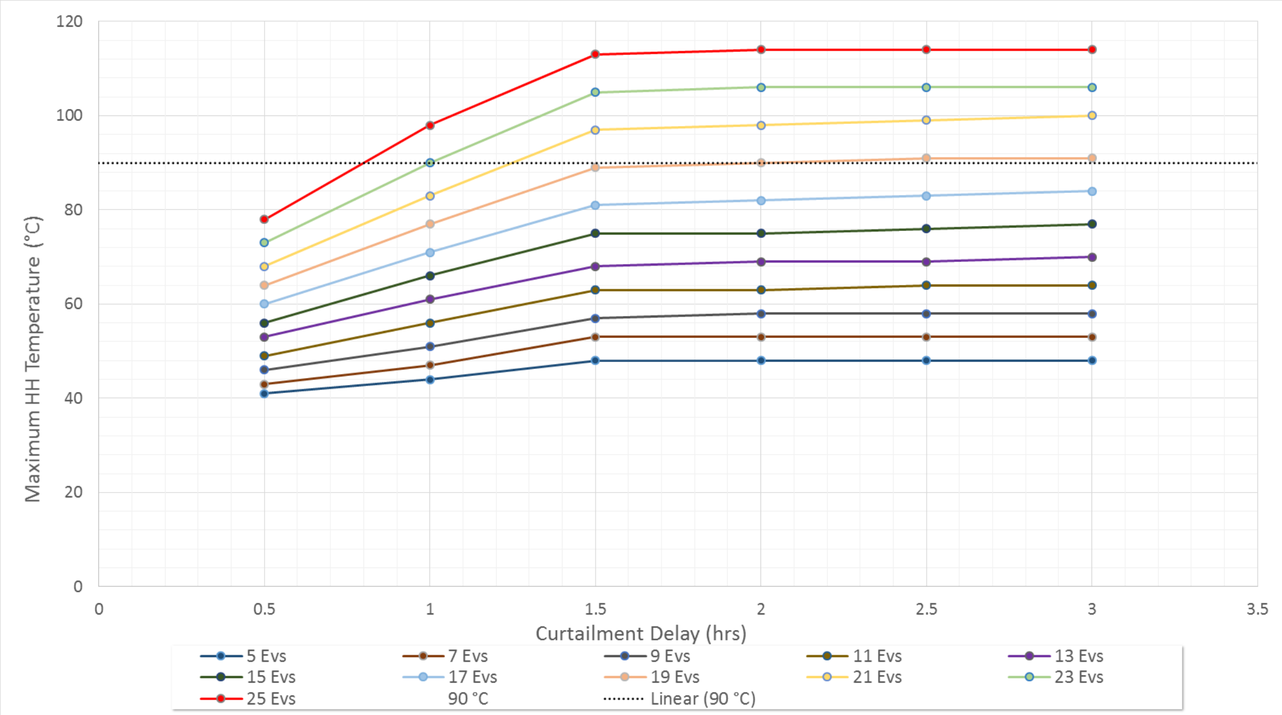

Figure 2. Maximum half hourly cable temperature results for varying EV curtailment delay while charging during peak times. Each curve represents a fixed number of EVs.

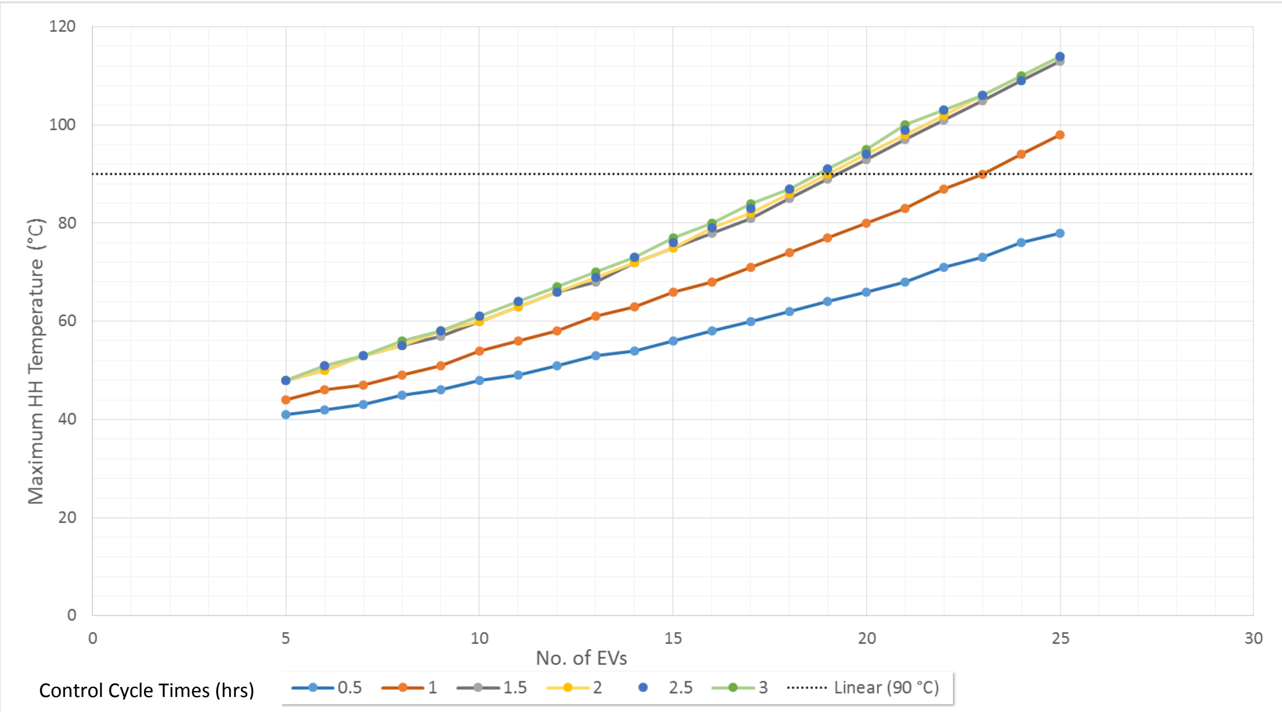

Figure 3. Maximum half hourly cable temperature results for varying numbers of EVs while charging during peak times. Each curve represents a fixed curtailment delay.

Assuming that each property has a maximum capacity for one EV, the maximum number of EVs per phase in the Chiswick EV cluster is 64. The information contained in Table 2 can be summarised by considering the maximum penetration levels of EVs possible without breaching the maximum cable design temperature. This is dependent on curtailment delay.

Table 3 shows the estimated maximum EV penetration levels for the Chiswick EV cluster based on the results in Table 2. It shows that the more responsive the control system, the higher the levels of EV penetration attainable. Any curtailment in excess of two hours will not significantly affect the maximum EV penetration level from its value at two hours. No results are available for curtailment delay times below 0.5 hours due to the temporal resolution of the CRATER program.

Table 3 Maximum allowable EV penetration with curtailment delay. Figures are based on a maximum of one EV per property in the Chiswick EV cluster. *Estimated value based on extrapolated results

Curtailment Delay	Estimated Maximum EV Penetration
> 2hours	~30%
> 1.5 hours	~31%
> 1 hours	~35%
> 0.5 hours	~45%*

The analysis shows a clear relationship between the number of EVs and the required responsiveness of the control system (using the existing Esprit algorithm) if the risk of cable thermal damage is to be managed. The smaller the cycle time, the less the risk of thermal damage. It should be noted that:

- The number of vehicles in the above graphs relate to the extra loading per phase on the cable. The actual additional load per phase is 16A multiplied by the number of EVs on that phase.
- No diversity factor has been added to account for the different time of use for EV charging which has become apparent in recent studies (e.g. Northern Powergrid's Customer-Led Network Revolution).
- Cycle times less than 30 minutes were not studied due to the temporal resolution of the CRATER dynamic rating tool.
- The basic study did not account for the reduced cable cooling during the lower load periods as interrupted vehicles would continue to charge.
- A separate study using the CRATER dynamic rating tool showed that spreading load out to reduce peak loading by deferring to times of lower loading resulted in lower cable temperatures.
- The simple analysis indicates that an advantage may be gained in future by incorporating thermal models into the control algorithm. More work is required in this area.

On this heavily loaded network, a significant number of vehicles can be sustained within the thermal limit of the cable at the substation end. A control cycle time of 30-minutes or less improves the situation further. A 30-minute control cycle time or less will lead to less cable thermal stress than higher control cycle times and should be considered the maximum for reducing risk of cable damage.

Current unbalance introduced by a markedly different number of EV connections on a single phase of a previously balanced network will exacerbate cable temperature rise and thermal stress. On a previously unbalanced network, it may make things better or worse. Shorter cycle times, rather than long ones, and individual phase settings and control appear to be sensible strategies for the application of Esprit.

During the analysis, some additional work was done to determine the maximum rate of rise of current on what is a relatively heavily loaded feeder (Chiswick). Whilst not of direct relevance for cable thermal rating, it does to some degree substantiate the requirement for a relatively short control cycle to help manage excursions above static cable ratings. It has therefore been included here (Figure 4) as it may be of later relevance in this project and, anyway, to others working to limit the risk of asset damage in low carbon LV networks.

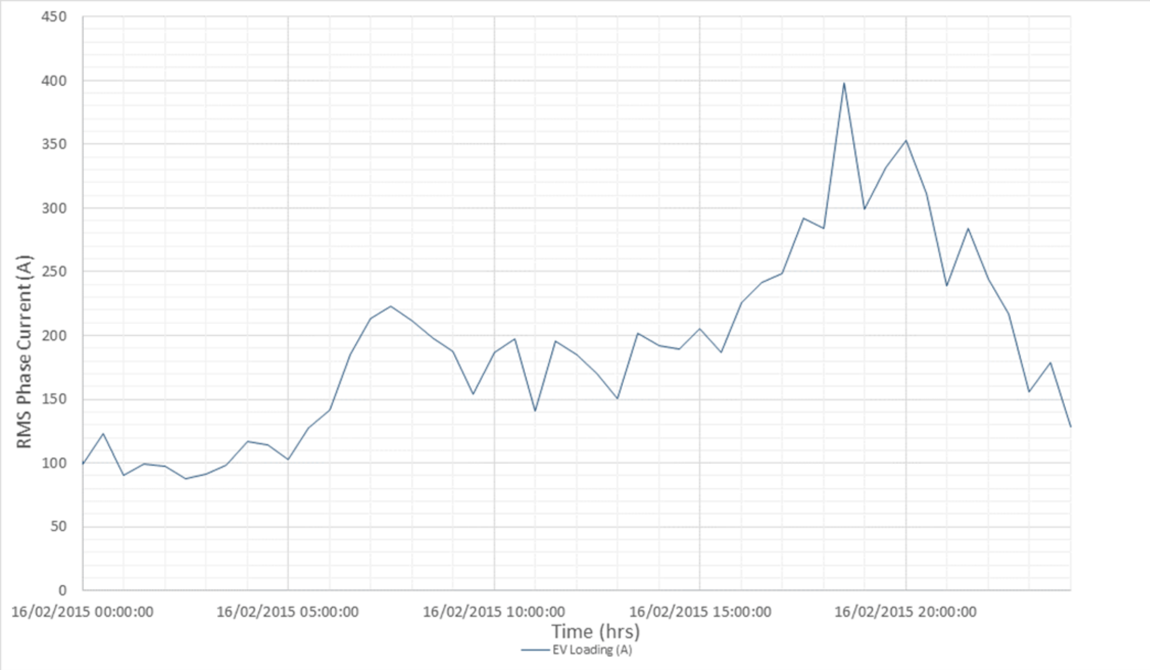

Figure 4: Weekday loading from 16th February on Phase A of the cluster feeder at Chiswick

Figure 4 shows an example of weekday phase A loading (using HH data) at Chiswick, before the addition of the simulated EV load is added. The graph includes any loading from the five EVs that were connected on this phase of this feeder at this time. Typically for domestic networks, the peak is recorded at 18:30. The maximum rate of rise of load is over any half hour period is approximately 4A/minute occurring between 18:00 and 18:30.