Solar Eclipse 2015

- Impact Analysis -

Report prepared by

Regional Group Continental Europe and
Synchronous Area Great Britain

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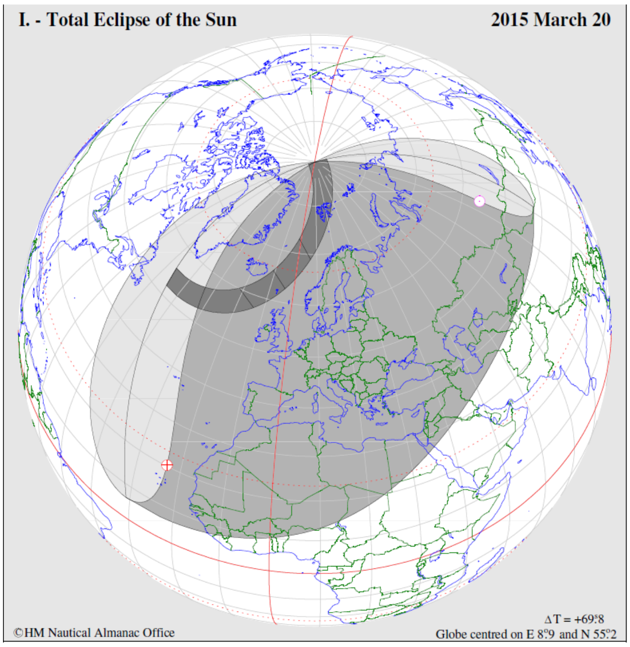
Contents

Analysis for the Continental Europe Synchronous Area

1. Introduction

On 20 March 2015 a solar eclipse will pass over the Atlantic Ocean between 07:40 and 11:50 UTC (08:40-12:50 CET) and the eclipse will be visible across Europe. The reduction in solar radiation will directly affect the output of the photovoltaics (PV) and for the first time this is expected to have a relevant impact on the secure operation of the European power system. In the synchronous area of Continental Europe and the synchronous area of Great Britain preliminary studies to evaluate the impact of the solar eclipse and possible countermeasures to be taken by the TSOs have been performed.

In 2015 the installed capacity on PV in the synchronous region of Continental Europe is expected to reach 90 GW and the eclipse may potentially cause a reduction of the PV infeed by more than 30 GW during clear sky conditions. This situation will pose a serious challenge to the regulating capability of the interconnected power system in terms of available regulation capacity, regulation speed and geographical location of reserves.



Source: http://astro.ukho.gov.uk/eclipse/0112015/

Although a solar eclipse is perfectly predictable the transformation from solar radiation to electric power is associated with uncertainties which call for a careful coordination throughout the entire interconnected power system of Continental Europe including adjacent power systems.

This report addresses in chapters two till five the following issues for Continental Europe related to the solar eclipse

- Estimation of the installed PV capacity on March 20 2015 per country
- Estimation of the PV infeed on March 20 by combining capacity and coincidence factors for each country with radiation data with and without the solar eclipse
- Inventory of potential mitigation measures

In chapters six till ten an analysis of the situation in Great Britain performed by National Grid addresses the following issues:

- Model for Eclipse effect
- Model for the Residual Demand

2. Methodology

The assessment is based on the following input per country

a) Installed PV capacity ($P_{installed}$)

b) Coincidence factor during the hour of year with maximum radiation (75% assumed)

c) Maximum radiation factor for the year during clear sky conditions (average) (I_{max})

d) Radiation factors for each hour of March 20 during clear sky conditions (average) (I(t))

e) Begin of eclipse, end of eclipse and maximum solar obscuration (average).

The PV infeed during clear sky conditions is then calculated by combining a) to d).

$$P_{clear\ sky}(t) = P_{installed}*0.75*\ I(t)/I_{max}$$

Similarly, the PV infeed considering the solar eclipse is calculated by correcting the normal infeed by e).

$$P_{eclipse}(t) = P_{clear\ sky}(t) * [1 - \text{obscuration factor}(t)]$$

The formula for the obscuration factor is shown in annex 1.

The following assumptions should be mentioned

- Proportional relation between radiation and PV infeed.
- Average data for each country

No change of system load is considered; the study focuses only on PV variation due to solar eclipse.

3. Input Data

In order to calculate the installed PV capacity on March 2015 per country a linear extrapolation of the capacity for 2012 and 2013 [1] is assumed as a default rule. This estimation was improved by TSOs reviewing and correcting where necessary. Table 1 shows the development in installed PV capacity (MW) per country.

	End of 2012	End of 2013	March 20, 2015
Albania	n/a	n/a	n/a
Austria	363	613	917
Belgium	2,768	2,983	3,245
Bosnia	0	0	0
Bulgaria	1,010	1,020	1,032
Croatia	0	20	44
Czech Republic	2,087	2,175	*2,100
Denmark	332	548	*600
France	4,060	4,673	5,419
Germany	32,411	35,715	39,734
Greece	1,536	2,579	3,848
Hungary	12	22	*55
Italy	16,479	17,928	19,691
Luxembourg	30	30	30
Macedonia	n/a	n/a	n/a
Montenegro	n/a	n/a	n/a
Netherlands	360	*780	*1,180
Poland	7	7	7
Portugal	242	278	322
Romania	51	1,151	2,489
Serbia	n/a	n/a	*6
Slovakia	523	524	525
Slovenia	201	212	225
Spain	*6,320	*6,722	*6,739
Switzerland	437	737	1,102
Turkey	12	18	25
Ukraine West	n/a	n/a	n/a
Total	**69,241**	**78,735**	**89,335**

*Table 1 Expected installed capacity on photovoltaic in Continental Europe on March 2015 in MW. The estimate is based on a linear extrapolation of data for 2012 and 2013 from [1].*marks estimates corrected by request of TSOs. The data of Spain includes 2.3 GW of concentrated solar thermal power.*

The eclipse start and end time and the maximum obscuration per country are derived from [2]. From this data source 181 locations are available in the region of Continental Europe. For each country the available location nearest to the geographical centre has been chosen. See Table 2.

	Start eclipse UTC	End eclipse UTC	Max obscuration	Location
Austria	08:31	10:52	62%	Klagenfurt
Belgium	08:27	10:45	80%	Brussels
Bosnia	08:35	10:54	51%	Sarajevo
Bulgaria	08:44	10:59	40%	Plovdiv
Croatia	08:33	10:53	58%	Zagreb
Czech Republic	08:36	10:57	69%	Prague
Denmark	08:40	10:58	83%	Arhus
France	08:20	10:38	77%	Orleans
Germany	08:33	10:52	76%	Kassel
Greece	08:38	10:51	37%	Larisa
Hungary	08:39	10:59	58%	Budapest
Italy	08:24	10:44	59%	Florence
Luxembourg	08:27	10:46	76%	Luxembourg
Netherlands	08:30	10:48	80%	Nijmegen
Poland	08:45	11:05	67%	Lodz
Portugal	08:02	10:12	70%	Coimbra
Romania	08:48	11:05	47%	Brasov
Serbia	08:39	10:58	51%	Belgrade
Slovakia	08:41	11:01	61%	Banska Bystrica
Slovenia	08:31	10:52	60%	Ljubljana
Spain	08:05	10:18	67%	Madrid
Switzerland	08:24	10:44	70%	Berne
Turkey	09:01	11:03	25%	Ankara

Table 2 Duration and maximum solar obscuration assumed for each country on March 20, 2015. Data are calculated for the specific location for each country from [2].

Annex 2 contains detailed information on each of the chosen locations.
The radiation factors are provided by RTE [3] and are shown in Table 3.
The radiation factors are available with hourly resolution whereas the obscuration data are calculated with one minute resolution.

	Max hour	8:00 UTC 9:00 CET	9:00 UTC 10:00 CET	10:00 UTC 11:00 CET	11:00 UTC 12:00 CET
Austria	91%	51%	68%	77%	81%
Belgium	90%	36%	55%	69%	76%
Bosnia	92%	57%	72%	81%	83%
Bulgaria*	90%	65%	76%	81%	80%
Croatia	92%	57%	72%	81%	83%
Czech Republic	91%	51%	66%	75%	78%
Denmark	88%	36%	53%	64%	69%
France	92%	34%	56%	71%	79%
Germany	90%	43%	60%	71%	76%
Greece	91%	69%	81%	86%	86%
Hungary	91%	56%	71%	79%	81%
Italy	92%	53%	70%	81%	84%
Luxembourg*	90%	36%	55%	69%	76%
Netherlands	90%	35%	54%	67%	74%
Poland	90%	49%	64%	73%	75%
Portugal	92%	23%	49%	69%	81%
Romania	90%	65%	76%	81%	80%
Serbia	90%	62%	75%	82%	82%
Slovakia	91%	55%	70%	78%	80%
Slovenia	92%	54%	70%	79%	82%
Spain	92%	29%	53%	71%	82%
Switzerland	91%	45%	63%	76%	81%
Turkey*	90%	65%	76%	81%	80%

Table 3 Clear sky radiation factors for hour of year with maximum radiation and for the relevant hours of March 20 without solar eclipse. [3] marks countries where data is not available. Instead, the nearest country is chosen.*

4. Results

Figure 1 shows the total impact of the solar eclipse on the continental European power system. Compared to clear sky conditions the PV output may drop by 34 GW at 9:41 (UTC) or 10:41 (CET).

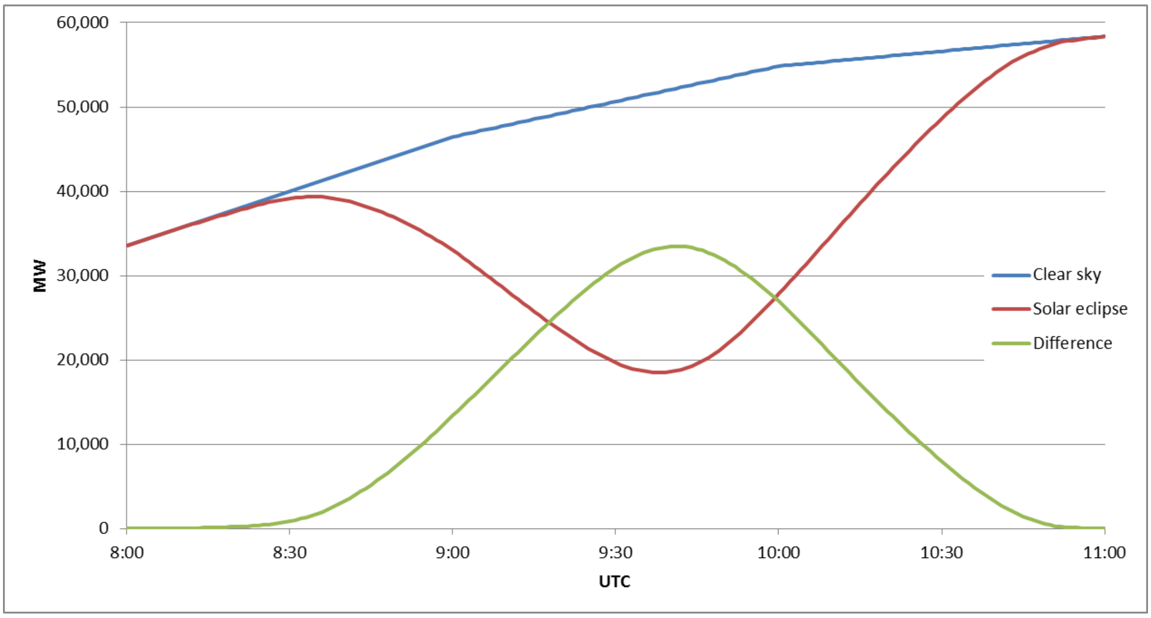


Figure 1 Comparison of expected infeed from solar on March 20 during clear sky conditions with and without solar eclipse.

Figure 2 shows that the minute-to-minute power gradient may exceed -400 MW/minute and +700 MW/minute. Fortunately, the highest gradient occurs when the PV infeed returns (requiring a reduction in the load following reserves). Note that a gradient exceeding -400 MW/minute persists for half an hour.

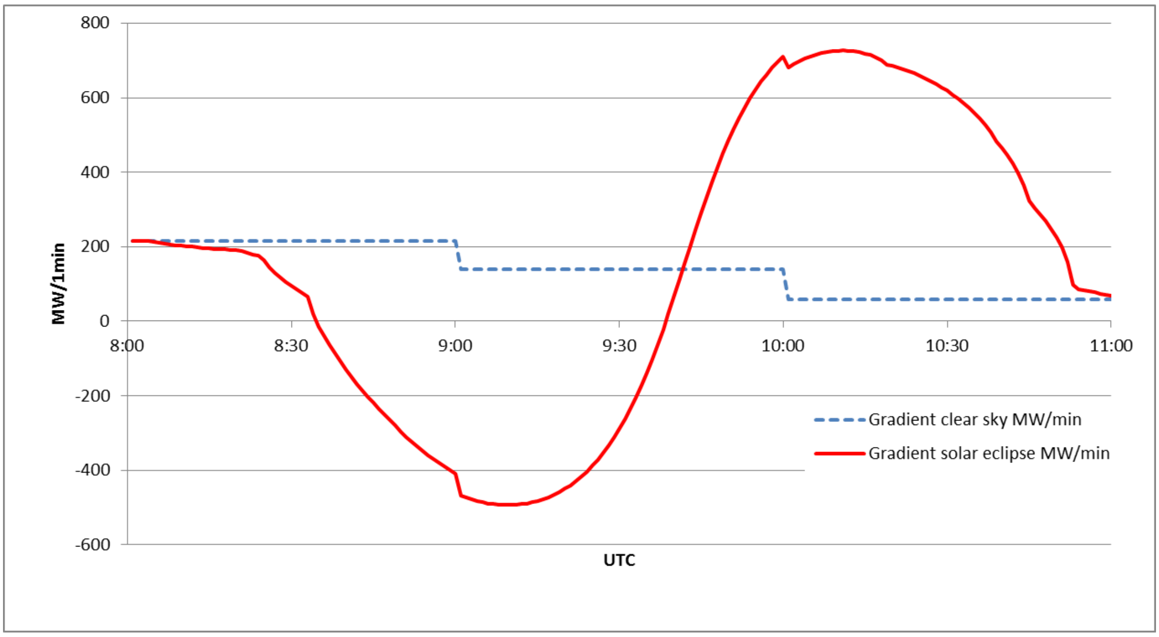


Figure 2 Expected power gradient in MW per minute from solar power on March 20 during clear sky conditions with and without solar eclipse.

The same result can be seen in Figure 3 the power gradient over 5 minutes.

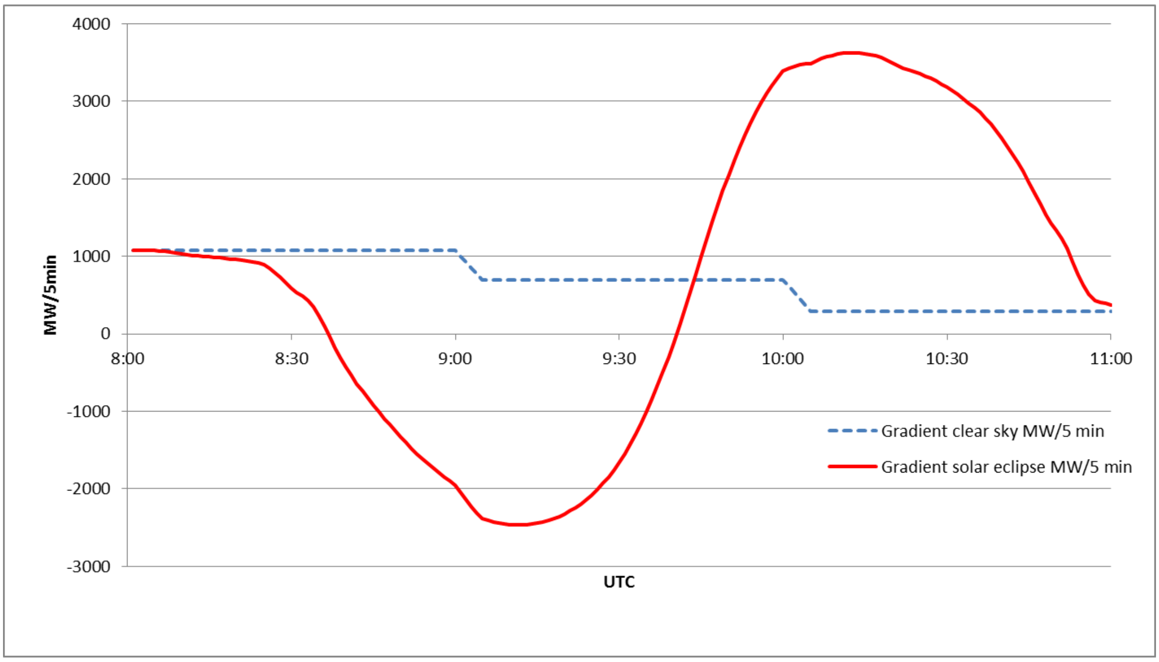


Figure 3 Expected power gradient in MW per 5 minutes from solar power on March 20 during clear sky conditions with and without solar eclipse.

Table 4 shows that 50% of the infeed reduction is expected in Germany and that Italy amounts for 21%. This indicates that the risk of line overloading shall especially focus on this region. In addition this table shows the expected maximum power gradient for each country and Figure 4 the corresponding power gradient for the five countries mostly affected by the eclipse.

	Installed capacity MW	Reduction 09:41 (UTC)	Reduction share	Min gradient MW/min	Max gradient MW/min
Albania	n/a				
Austria	917	346	1%	-6	7
Belgium	3,245	1,360	4%	-21	31
Bosnia	0	0	0%	0	0
Bulgaria	1,032	258	1%	-5	6
Croatia	44	16	0%	0	0
Czech Republic	2,100	838	3%	-14	18
Denmark	600	240	1%	-4	6
France	5,419	2,011	6%	-32	53
Germany	39,734	16,916	51%	-273	361
Greece	3,848	976	3%	-18	21
Hungary	55	19	0%	0	0
Italy	19,691	7,168	21%	-111	159
Luxembourg	30	12	0%	0	0
Macedonia					
Montenegro					
Netherlands	1,180	494	1%	-8	11
Poland	7	2	0%	0	0
Portugal	322	53	0%	-1	3
Romania	2,489	682	2%	-14	16
Serbia	6	2	0%	0	0
Slovakia	525	188	1%	-3	4
Slovenia	225	85	0%	-1	2
Spain	6,739	1,392	4%	-23	61
Switzerland	1,102	440	1%	-7	10
Turkey	25	3	0%	0	0
Ukraine West	n/a				
Total	**89,335**	**33,501**	**100%**		

Table 4 Installed capacity in MW, minute with the largest reduction in PV and the largest power gradient per minute due to PV infeed per country based on the assumption of one geographical location per country.

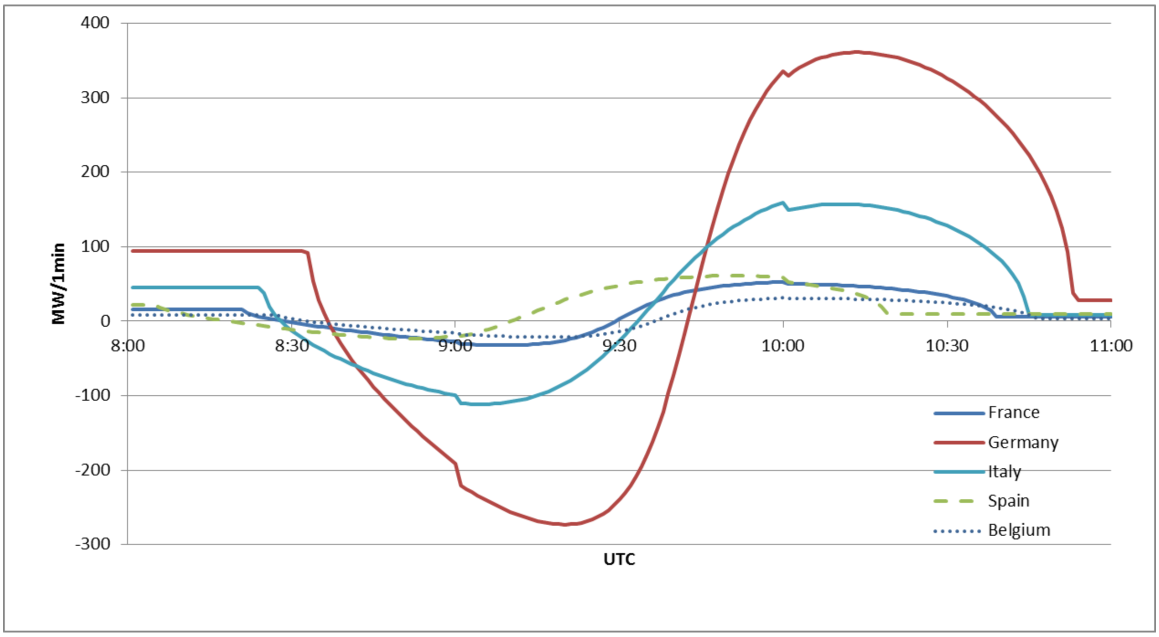


Figure 4 Expected power gradient for the Top 5 countries based on the assumption of one geographical location per country.

5. Next Steps

Not all the TSOs will be affected by the eclipse on the same scale, but all will see the same impact on the frequency; some countries are not affected by PV variations, but can support the other TSOs by providing them reserves. The main challenge for the TSOs will be to coordinate the use of the reserves in order to balance the power in real time without creating overloads on the grid. Therefore coordination procedures should be exercised well in advance.

The proposed recommendations to the TSOs from Continental Europe synchronous region can be split in two levels.

Individual TSOs

- The infeed from PV is highly depending on cloud coverage. The results presented in this report assume clear sky conditions which may not appear. Day-ahead forecast of PV is particularly important for March 20 and careful preparation and coordination of solar forecasts are necessary between TSO-DSO-Balance responsible parties as well as between TSOs.
- Each TSO shall inform the Balance Responsible Parties (BRP) in charge of PV, and check that they prepare the adequate measures to follow the PV variations on March, 20th, in order to remain balanced on each program slot.
- Even if each BRP follows exactly the PV variation with intra-day programs, the TSOs will have to balance the system within each program path slot, in order to follow the gradient of PV variations. Each TSO shall estimate the amount of control reserves with adequate gradient (mainly Frequency Restoration Reserve (whether automatic and manual)) will be needed for this specific situation.
- Each TSO shall increase control reserves as much as necessary for its own needs. In case of high probability not to cover its own control block/area, each TSO shall estimate and declare to other TSOs the amount of control reserve he will need in real time.
- TSOs which can provide more control reserve than they need shall propose these reserves to help frequency management in real-time.
- Training of control room personnel for this specific event

- Due to change in thermostatic controlled loads and lighting, the demand could also be affected by the solar eclipse. The effect is very difficult to estimate on a global scale. It is advised that each TSO prepare its best estimate.
- Each TSO expecting significant changes in PV infeed shall estimate the available power regulation speed and if possible check or test the capabilities.

TSOs expecting difficulties in balancing their control areas with their own reserves shall ensure the use of reserves from other TSOs. Each TSO, in case of no possibility / high probability not to cover its own control block/area, shall estimate the amount of reserves needed from other TSOs.

Continental Europe synchronous area coordination

- Impact on tie line flows cannot be properly assessed until a hypothesis for allocation of the balancing power has been developed. However, before and during the eclipse the NTC on the critical borders could be decreased in order to reserve as much capacity as needed for reserve exchanges.
- RSCIs[1] can be involved in D-2, D-1 and ID to check forecast files, detect potential constraints due to reserve exchanges, evaluate limits, propose remedial actions
- If necessary TSOs will set up an extraordinary operational coordination until the day of the eclipse, including day-ahead and real-time teleconference to coordinate PV forecasts, real-time frequency management, reserve exchanges and flow management.

[1] A regional unified scheme set up by TSOs in order to coordinate Operational Security Analysis in a determined geographic Area.

Analysis for the Great Britain Synchronous Area

1. Summary

Loss of Photo Voltaic (PV) infeed during the eclipse, and its return after maximum obscuration will occur at a maximum rate of just below 50 MW/min.
The change in residual demand caused by human behaviour (halting normal activities to observe the eclipse) will dominate the PV effect.
The PV effect acts in the opposite direction on the residual demand to the human-demand effect, and so will in fact ameliorate the situation.
The rates of change of residual demand are therefore slightly less than experience during the previous eclipse in 1999.
National Grid Transmission System coped well with the eclipse in 1999 as a result of careful planning. We are confident that the system will cope well with the 2015 eclipse.

2. Model for Eclipse Effect

Data available

- Start of eclipse t_S
- End of eclipse t_e
- Maximum obscuration M

Result

At time t
% obscuration

$$= \frac{2}{\pi}\left[\cos^{-1}\sqrt{d^2 + {a(t)^2}/{4}} - \sqrt{d^2 + {a(t)^2}/{4}}\sqrt{1-\left(d^2 + {a(t)^2}/{4}\right)} \right]$$

where

$$a(t) = A\left[2\left(\frac{t-t_s}{t_e-t_s}\right)-1\right]$$
$$A = 2\sqrt{1-d^2}$$

and d is evaluated by solving

$$M = \frac{2}{\pi}\left[\cos^{-1} d - d\sqrt{1-d^2} \right]$$

3. Model for the Residual Demand

We assume a bright day in March.
PV generation is assumed proportional to solar incident radiation. Solar radiation is obtained from UK Metrological Office data at hourly intervals from 0800 to 1100 (GMT) on dates within 10 days of March 20 for all years in which we have data (since 2007). Maximum values are selected for each hour to represent a clear day. We then interpolate with a smooth cubic spline to produce a smooth incident radiation curve, and this is then transformed into a PV output.
The analysis has been done twice

- First, with a single point approximation. Birmingham was chosen as being near centre of GB system. Conditions for eclipse and solar radiation were found, and the model applied.
- Secondly, GB was broken down into 28 regions, and the relevant conditions found for each region. The results were then combined to provide a GB model.

As expected, the regional model reduces rates of change, and overall loss of PV, because of a smearing effect as timing of eclipse is spread across the geographical region. However, the differences are relatively small, so a single point approximation would be justified. Figure 1 shows PV generation during the eclipse from the two models.

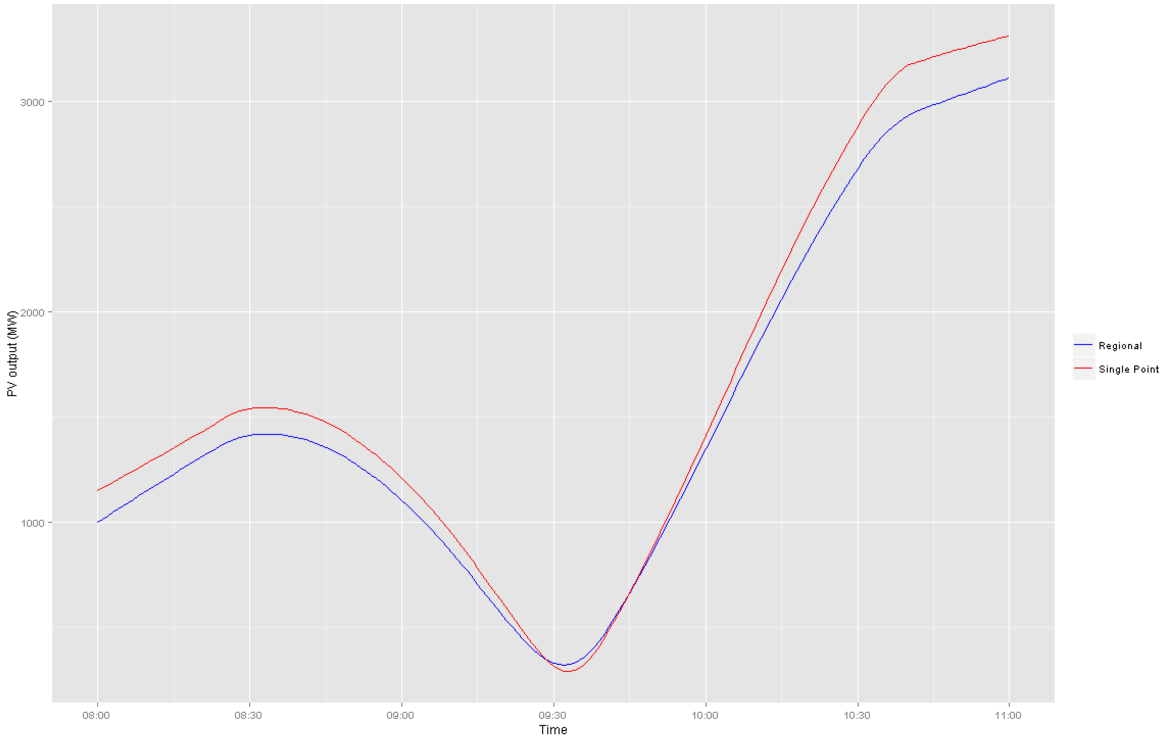
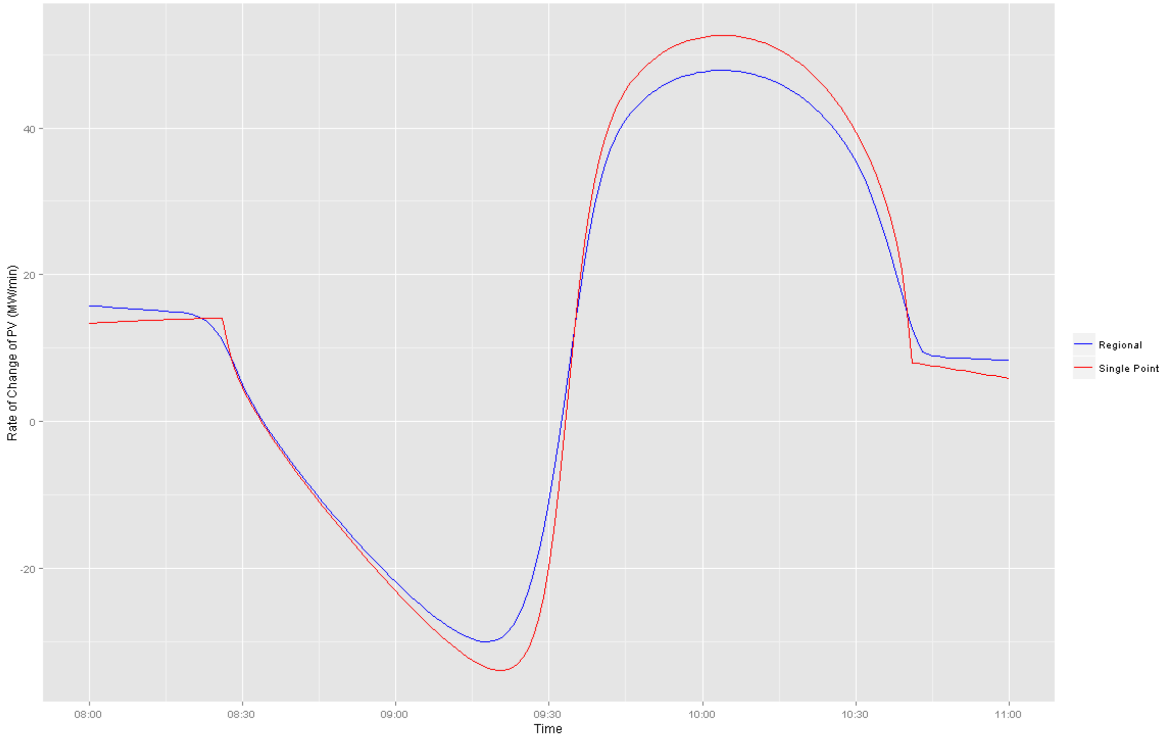


Figure 2 shows rates of change of PV generation for the two models.



The maximum rate of change caused by the variation in PV generation is approximately 50 MW/min. This is well within the capabilities of the system.
Note that, as PV generation decreases, residual demand will increase, and vice versa. So rate of change of demand as a consequence of PV will be positive before maximum eclipse, and negative afterwards.

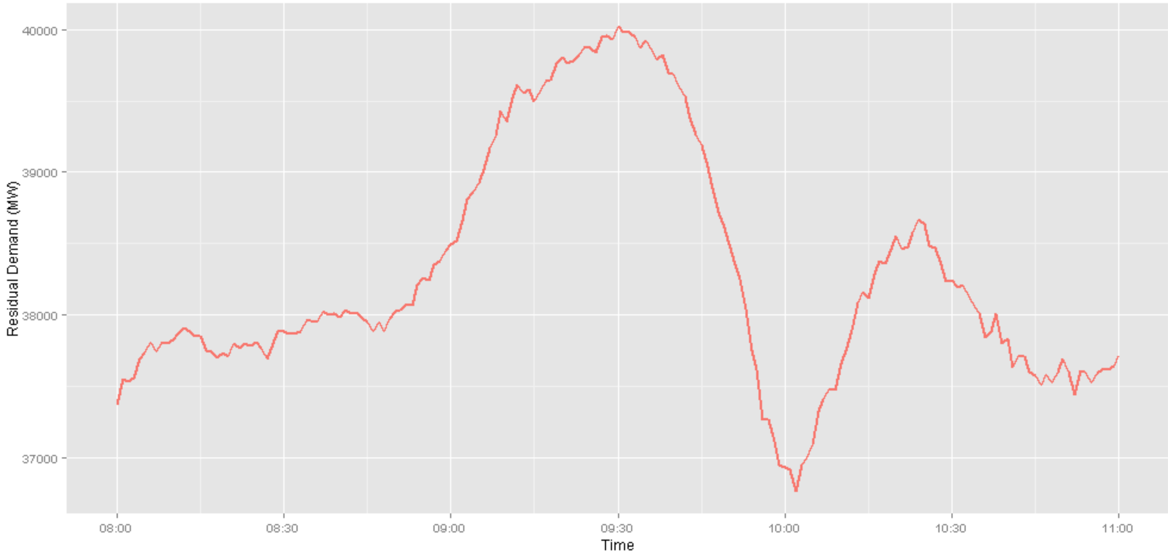
4. Demand Effects

Based on evidence from the 1999 eclipse, we expect a depression in demand around the time of maximum obscuration from human causes – people stopping work and going to look at the phenomenon…We refer to this as the human-demand effect. This should depress demand before maximum eclipse – negative rate of change, and increase demand after – positive rate of change.
These rates of change work in the opposite direction to the PV changes.
From 1999 evidence we expect the demand effect to dominate the PV effect.

5. Model for Residual Demand

A sample minute-by-minute demand curve is chosen to represent 20 March 2015. Data from 21 March 2014 is chosen. This demand curve is adjusted to account for the (modelled) PV generation for 21 March 2014 to give the underlying demand met by transmission system and PV generation.
The modelled PV generation with eclipse effects for a clear 20 March 2015 are then applied to give the residual demand without the human-demand effect.
The human-demand effect is obtained by comparing demand as observed on the day of the 1999 eclipse with a similar day from the same year (obviously without the eclipse).
The human-demand effect is applied to obtain a minute-by-minute illustrative demand curve for 20 March 2015.
Note: This is not a forecast, but an illustrative curve to give control engineers an idea of the type of curve they will have to deal with.

The results are shown in Figure 3.



The greatest rates of change are caused by the human-demand effect rather than the PV effect, with a maximum minutely rate of change of -300 MW/min, but typical values of -200 MW/min before maximum eclipse, and +200 MW/min after.
The PV effect is most noticeable between 08:45 and 09:30 (all times are GMT), and 10:15 to 10:45. But the rates of change here lie within +/- 150 MW/min. This rate of change is in a wider range than the PV model on its own predicted because it is combined with the natural variability of the pure demand signal. In 1999, with careful planning, the system coped with rates of change of demand comparable to this, and in fact slightly higher, so National Grid is confident that this is a situation we have the experience and tools to handle.

6. References

[1] “Global market outlook 2014,” EPIA, http://www.epia.org/fileadmin/user_upload/Publications/EPIA_Global_Market_Outlook_for_Photovoltaics_2014-2018_-_Medium_Res.pdf, 2014.

[2] UK Hydrographic Office, [Online]. Available: http://astro.ukho.gov.uk/eclipse/0112015/.

[3] RTE Thierry Dellac, *Simulation production éclipse 20-03-2015.xlsx.*

Annex 1: Solar Obscuration Factor

Data available

- Start of eclipse t_S
- End of eclipse t_e
- Maximum obscuration M_0

Result
At time t
% obscuration

$$= \frac{2}{\pi}\left[\cos^{-1}\sqrt{d^2 + {a(t)^2}/{4}} - \sqrt{d^2 + {a(t)^2}/{4}}\sqrt{1-\left(d^2 + {a(t)^2}/{4}\right)}\right]$$

where

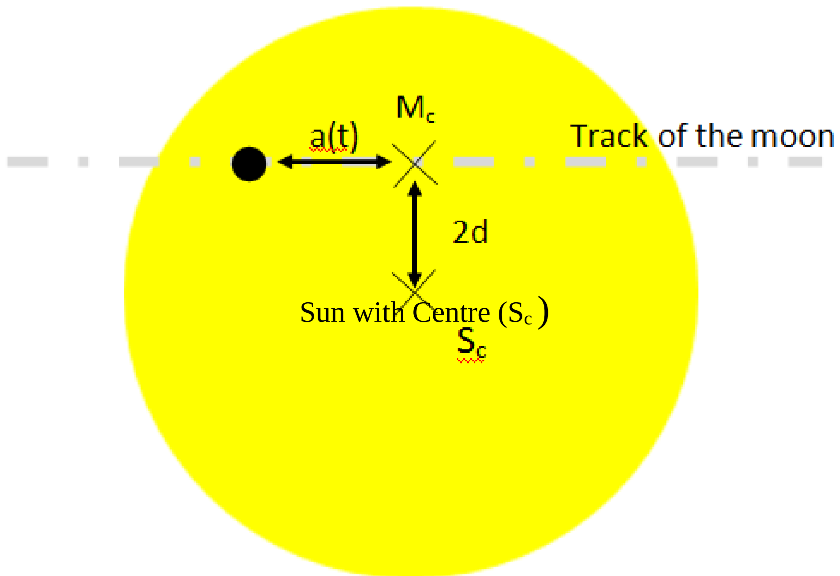
$$a(t) = A\left[2\left(\frac{t-t_s}{t_e-t_s}\right)-1\right]$$
$$A = 2\sqrt{1-d^2}$$

and d is evaluated by solving

$$M_o = \frac{2}{\pi}\left[\cos^{-1}d - d\sqrt{1-d^2}\right]$$

Assumptions
Assume :

- Sun and Moon are the same size.
- Centre of moon travels across Sun's disc in a straight line at constant speed.



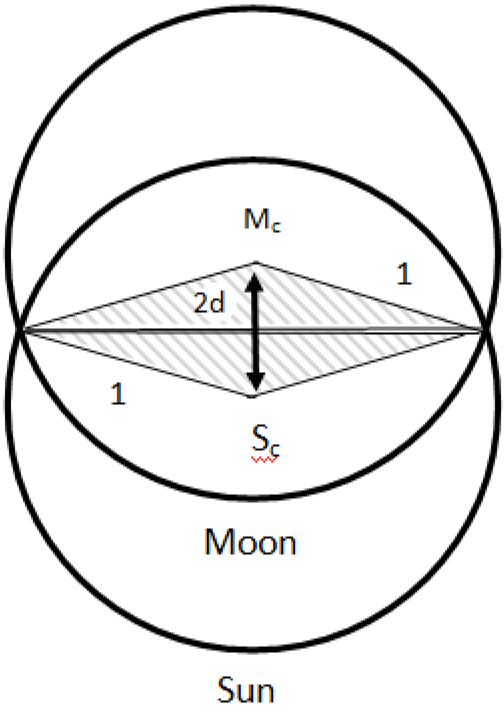
d.1

Proof
Let

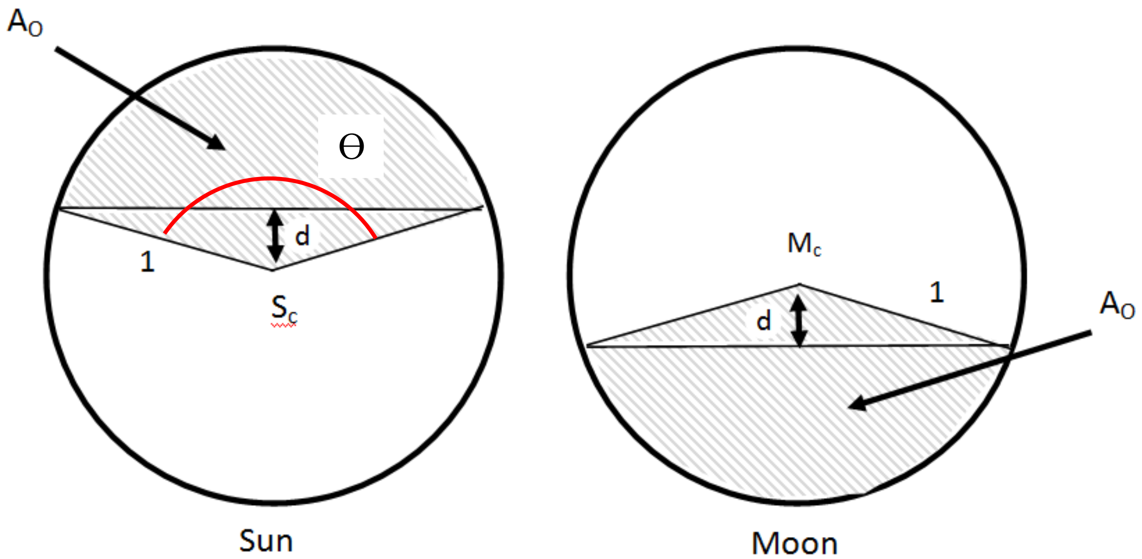
- radius of Sun and Moon = 1

- distance of nearest approach of Moon's centre = 2d
- as moon moves across Sun, let distance of Moon's centre at time, t from closest approach to Sun be a(t)
- distance of Moon's centre from point of closest approach to Sun's centre be $A = a(t_s) = a(t_e)$

First consider instant of maximum obscuration



Calculate area of overlap of the two circles.



The two shaded areas are equal by symmetry

$$Angle\ \theta = 2\cos^{-1} d$$

$$A_0 = \frac{2\pi\cos^{-1} d}{2\pi} = \cos^{-1} d$$

Area of overlap

$$= 2A_0 - area\,of\,rhombus = 2A_0 - 2d\sqrt{1-d^2}$$

Overlap therefore

$$2\left[\cos^{-1} d - d\sqrt{1-d^2}\right]$$

% Overlap

$$\frac{2}{\pi}\left[\cos^{-1} d - d\sqrt{1-d^2}\right] = M_0$$

Given M_0 we can calculate **d**

[Note: this is not analytically invertible, but can easily be solved numerically]

Now consider obscuration when Moon's centre is distance a(t) = a from point of closest approach
Variable area of overlap can be calculated in exactly the same way, but instead of separation of 2d, use the separation between M_C and S_C

[M_C to S_C] = $\sqrt{a^2 + 4d^2}$ so replace **d** with $\sqrt{\frac{a^2}{4} + d^2}$

% Overlap at time t is

$$= \frac{2}{\pi}\left[\cos^{-1}\sqrt{d^2 + {a(t)^2}/{4}} - \sqrt{d^2 + {a(t)^2}/{4}}\sqrt{1 - \left(d^2 + {a(t)^2}/{4}\right)}\right]$$

Now calculate distance from Moon's centre to point of closest approach at the instant of first (or last) contact

$$A = 2\sqrt{1-d^2}$$

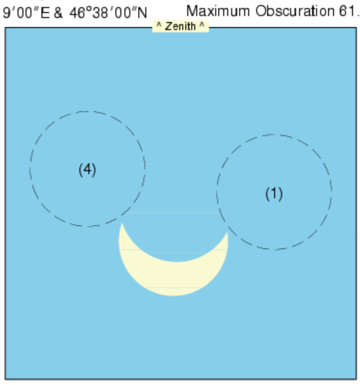
Finally find the distance of Moon's centre from point of closest approach at time t. Moon moves from –A at time, t_s to +A at time t_e so a(t) = $A\left[2\left(\frac{t-t_s}{t_e - t_s}\right) - 1\right]$.

Putting this together we obtain stated result.
The formula is derived by Andrew Richards, National Grid, UK.

Annex 2: Solar eclipse data for each country

The eclipse start and end time and the maximum obscuration per country are derived from data calculated by the UK Hydrographic Office made available on http://astro.ukho.gov.uk/eclipse/0112015/

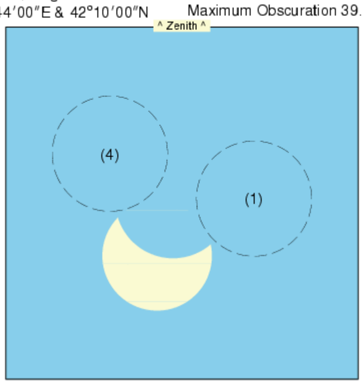
Klagenfurt, Austria — 2015 March 20
14°19′00″E & 46°38′00″N — Maximum Obscuration 61.87%



Local Circumstances of the Partial Eclipse

Phenomenon	Time (UT) h m s	
Eclipse begins - First Contact	08:31:57.7	(1)
Maximum magnitude of 0.688242	09:40:41.7	
Eclipse ends - Fourth Contact	10:52:29.3	(4)

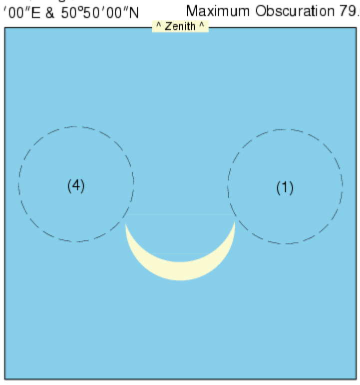
Plovdiv, Bulgaria — 2015 March 20
24°44′00″E & 42°10′00″N — Maximum Obscuration 39.81%



Local Circumstances of the Partial Eclipse

Phenomenon	Time (UT) h m s	
Eclipse begins - First Contact	08:44:06.3	(1)
Maximum magnitude of 0.501128	09:50:44.3	
Eclipse ends - Fourth Contact	10:58:55.3	(4)

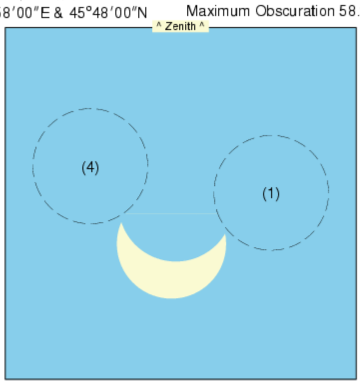
Brussels, Belgium — 2015 March 20
4°21′00″E & 50°50′00″N — Maximum Obscuration 79.69%



Local Circumstances of the Partial Eclipse

Phenomenon	Time (UT) h m s	
Eclipse begins - First Contact	08:27:16.5	(1)
Maximum magnitude of 0.830667	09:34:28.7	
Eclipse ends - Fourth Contact	10:45:24.0	(4)

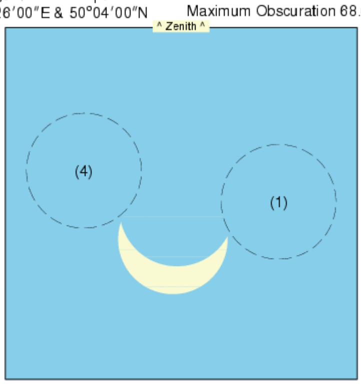
Zagreb, Croatia — 2015 March 20
15°58′00″E & 45°48′00″N — Maximum Obscuration 58.29%



Local Circumstances of the Partial Eclipse

Phenomenon	Time (UT) h m s	
Eclipse begins - First Contact	08:33:09.1	(1)
Maximum magnitude of 0.658916	09:41:52.0	
Eclipse ends - Fourth Contact	10:53:28.1	(4)

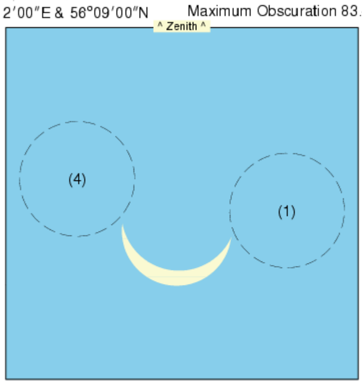
Prague, Czech Republic — 2015 March 20
14°26′00″E & 50°04′00″N — Maximum Obscuration 68.68%



Local Circumstances of the Partial Eclipse

Phenomenon	Time (UT) h m s	
Eclipse begins - First Contact	08:36:32.3	(1)
Maximum magnitude of 0.743229	09:45:26.8	
Eclipse ends - Fourth Contact	10:57:00.4	(4)

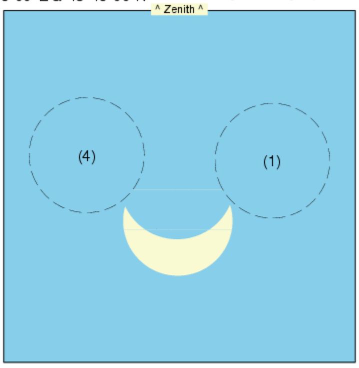
Arhus, Denmark — 2015 March 20
10°12′00″E & 56°09′00″N — Maximum Obscuration 83.45%



Local Circumstances of the Partial Eclipse

Phenomenon	Time (UT) h m s	
Eclipse begins - First Contact	08:40:37.2	(1)
Maximum magnitude of 0.860347	09:48:13.3	
Eclipse ends - Fourth Contact	10:58:15.2	(4)

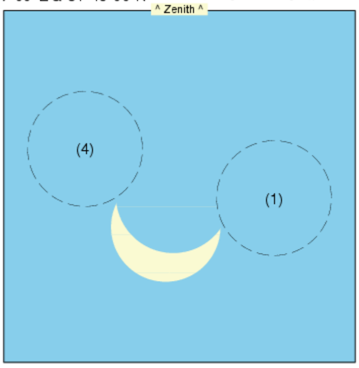
Florence, Italy — 2015 March 20
11°16′00″E & 43°46′00″N — Maximum Obscuration 59.21%



Local Circumstances of the Partial Eclipse

Phenomenon	Time (UT) h m s	
Eclipse begins - First Contact	08:24:23.2	(1)
Maximum magnitude of 0.666450	09:32:19.0	
Eclipse ends - Fourth Contact	10:44:04.8	(4)

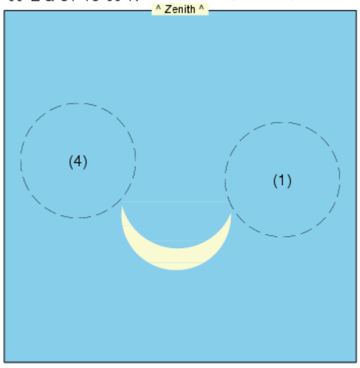
Lodz, Poland — 2015 March 20
19°27′00″E & 51°46′00″N — Maximum Obscuration 66.88%



Local Circumstances of the Partial Eclipse

Phenomenon	Time (UT) h m s	
Eclipse begins - First Contact	08:44:50.6	(1)
Maximum magnitude of 0.728827	09:53:59.8	
Eclipse ends - Fourth Contact	11:04:53.7	(4)

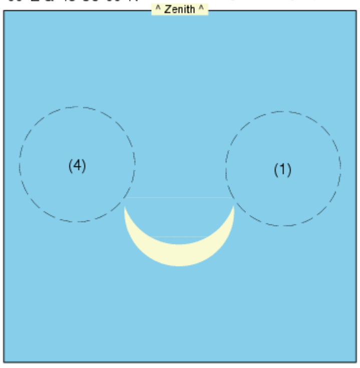
Kassel, Germany — 2015 March 20
9°30′00″E & 51°19′00″N — Maximum Obscuration 75.88%



Local Circumstances of the Partial Eclipse

Phenomenon	Time (UT) h m s	
Eclipse begins - First Contact	08:32:51.4	(1)
Maximum magnitude of 0.800572	09:41:02.1	
Eclipse ends - Fourth Contact	10:52:20.6	(4)

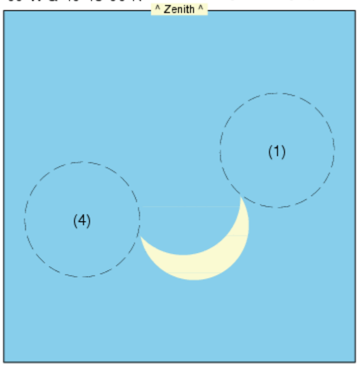
Luxembourg, Luxembourg — 2015 March 20
6°08′00″E & 49°36′00″N — Maximum Obscuration 75.91%



Local Circumstances of the Partial Eclipse

Phenomenon	Time (UT) h m s	
Eclipse begins - First Contact	08:26:59.5	(1)
Maximum magnitude of 0.800817	09:34:37.0	
Eclipse ends - Fourth Contact	10:45:58.0	(4)

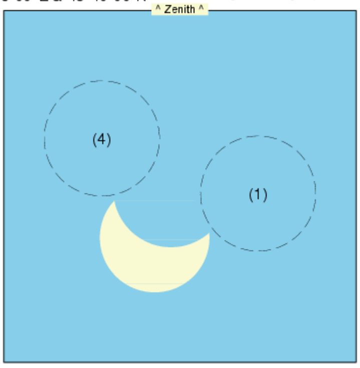
Coimbra, Portugal — 2015 March 20
8°25′00″W & 40°13′00″N — Maximum Obscuration 69.67%



Local Circumstances of the Partial Eclipse

Phenomenon	Time (UT) h m s	
Eclipse begins - First Contact	08:01:35.4	(1)
Maximum magnitude of 0.751508	09:03:56.7	
Eclipse ends - Fourth Contact	10:11:52.4	(4)

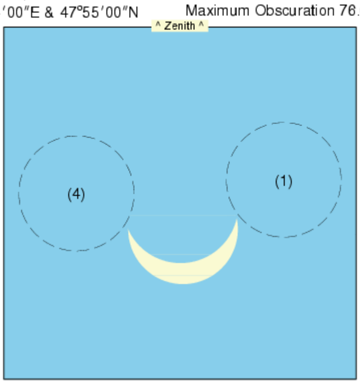
Brasov, Romania — 2015 March 20
25°36′00″E & 45°40′00″N — Maximum Obscuration 46.83%



Local Circumstances of the Partial Eclipse

Phenomenon	Time (UT) h m s	
Eclipse begins - First Contact	08:48:10.2	(1)
Maximum magnitude of 0.562628	09:56:11.7	
Eclipse ends - Fourth Contact	11:05:23.0	(4)

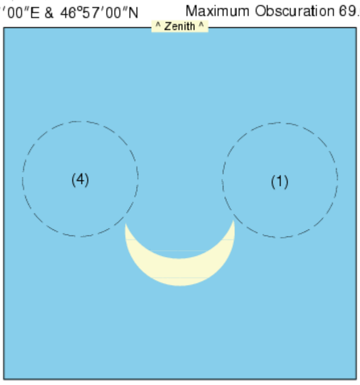
Orleans, France — 2015 March 20
1°54′00″E & 47°55′00″N — Maximum Obscuration 76.64%



Local Circumstances of the Partial Eclipse

Phenomenon	Time (UT) h m s	
Eclipse begins - First Contact	08:20:35.5	(1)
Maximum magnitude of 0.806629	09:27:13.8	
Eclipse ends - Fourth Contact	10:38:12.1	(4)

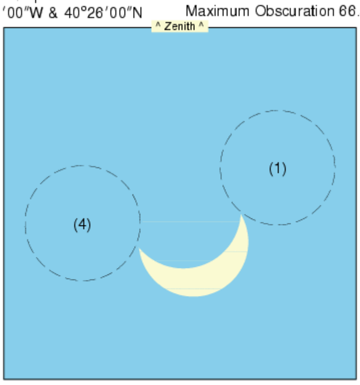
Berne, Switzerland — 2015 March 20
7°27′00″E & 46°57′00″N — Maximum Obscuration 69.66%



Local Circumstances of the Partial Eclipse

Phenomenon	Time (UT) h m s	
Eclipse begins - First Contact	08:24:21.6	(1)
Maximum magnitude of 0.751120	09:32:10.2	
Eclipse ends - Fourth Contact	10:43:55.3	(4)

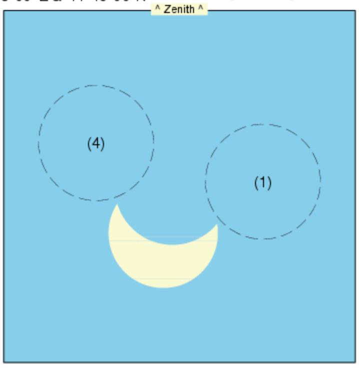
Madrid, Spain — 2015 March 20
3°40′00″W & 40°26′00″N — Maximum Obscuration 66.59%



Local Circumstances of the Partial Eclipse

Phenomenon	Time (UT) h m s	
Eclipse begins - First Contact	08:04:55.9	(1)
Maximum magnitude of 0.726693	09:08:46.9	
Eclipse ends - Fourth Contact	10:18:07.2	(4)

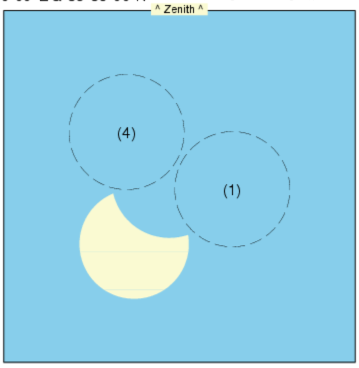
Belgrade, Serbia and Montenegro 2015 March 20
20°29′00″E & 44°48′00″N Maximum Obscuration 50.90%



Local Circumstances of the Partial Eclipse

Phenomenon	Time (UT) h m s	
Eclipse begins - First Contact	08:38:48.7	(1)
Maximum magnitude of 0.597338	09:47:14.1	
Eclipse ends - Fourth Contact	10:57:50.8	(4)

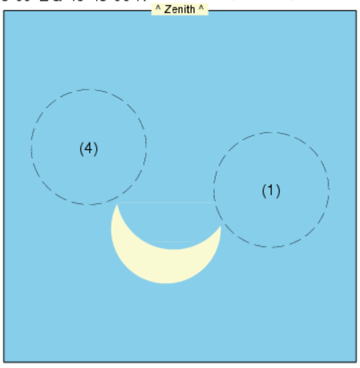
Ankara, Turkey 2015 March 20
32°50′00″E & 39°56′00″N Maximum Obscuration 24.87%



Local Circumstances of the Partial Eclipse

Phenomenon	Time (UT) h m s	
Eclipse begins - First Contact	09:01:12.7	(1)
Maximum magnitude of 0.360398	10:02:20.3	
Eclipse ends - Fourth Contact	11:03:33.7	(4)

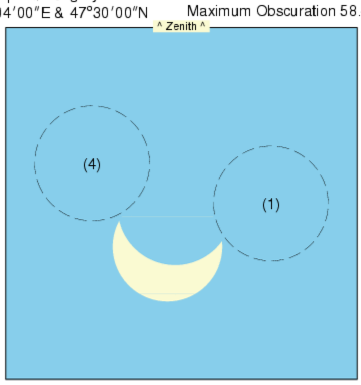
Banska Bystrica, Slovakia 2015 March 20
19°09′00″E & 48°45′00″N Maximum Obscuration 60.99%



Local Circumstances of the Partial Eclipse

Phenomenon	Time (UT) h m s	
Eclipse begins - First Contact	08:41:00.1	(1)
Maximum magnitude of 0.681075	09:50:08.8	
Eclipse ends - Fourth Contact	11:01:21.6	(4)

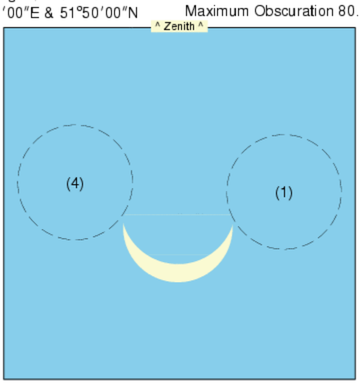
Budapest, Hungary 2015 March 20
19°04′00″E & 47°30′00″N Maximum Obscuration 58.43%



Local Circumstances of the Partial Eclipse

Phenomenon	Time (UT) h m s	
Eclipse begins - First Contact	08:39:29.3	(1)
Maximum magnitude of 0.660088	09:48:30.8	
Eclipse ends - Fourth Contact	10:59:44.5	(4)

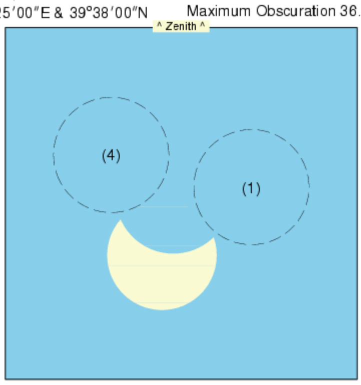
Nijmegen, Netherlands 2015 March 20
5°52′00″E & 51°50′00″N Maximum Obscuration 80.08%



Local Circumstances of the Partial Eclipse

Phenomenon	Time (UT) h m s	
Eclipse begins - First Contact	08:30:10.5	(1)
Maximum magnitude of 0.833758	09:37:38.1	
Eclipse ends - Fourth Contact	10:48:31.9	(4)

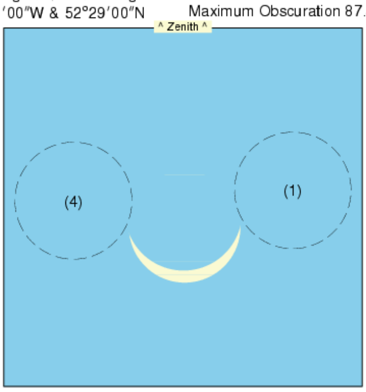
Larisa, Greece 2015 March 20
22°25′00″E & 39°38′00″N Maximum Obscuration 36.84%



Local Circumstances of the Partial Eclipse

Phenomenon	Time (UT) h m s	
Eclipse begins - First Contact	08:37:55.1	(1)
Maximum magnitude of 0.474382	09:43:32.1	
Eclipse ends - Fourth Contact	10:51:19.5	(4)

Birmingham, United Kingdom 2015 March 20
1°53′00″W & 52°29′00″N Maximum Obscuration 87.35%



Local Circumstances of the Partial Eclipse

Phenomenon	Time (UT) h m s	
Eclipse begins - First Contact	08:25:08.9	(1)
Maximum magnitude of 0.891104	09:30:44.3	
Eclipse ends - Fourth Contact	10:40:14.9	(4)