Nissan LEAF Range Calculation

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Introduction

This article delineates the equations needed to calculate the range of the 2012 Nissan LEAF. The ranges for two example drives of the Nissan LEAF from the author's home in Blacksburg VA are given and the results agree well with the actual drives.

State-Of-Charge Meter

I strongly recommend using the Giddings State-Of-Charge (SOC) meter (http://www.wwwsite.com/puzzles/socmeter/) when driving, especially for long trips when the battery will get low in charge:

It attaches to the OBD2 plug under the dash.

Red button changes modes. Black button changes values for a mode.

1. Mode 1: Value 1: SOC as % of 281 raw ("Gids"). Value 2: Raw CAN-bus data.
2. Mode 2: Value 1: Output amperes (-99 to +200). Value 2: Volts (~350 to 400). Value 3: Output kW (~C99.9 for charging, P99.9 for output)

Toggle switches: Top one is for the device to be **always on when up** and **only on when the car is running when down**. Bottom one is to switch between data buses; currently **only switch down bus is being used**.

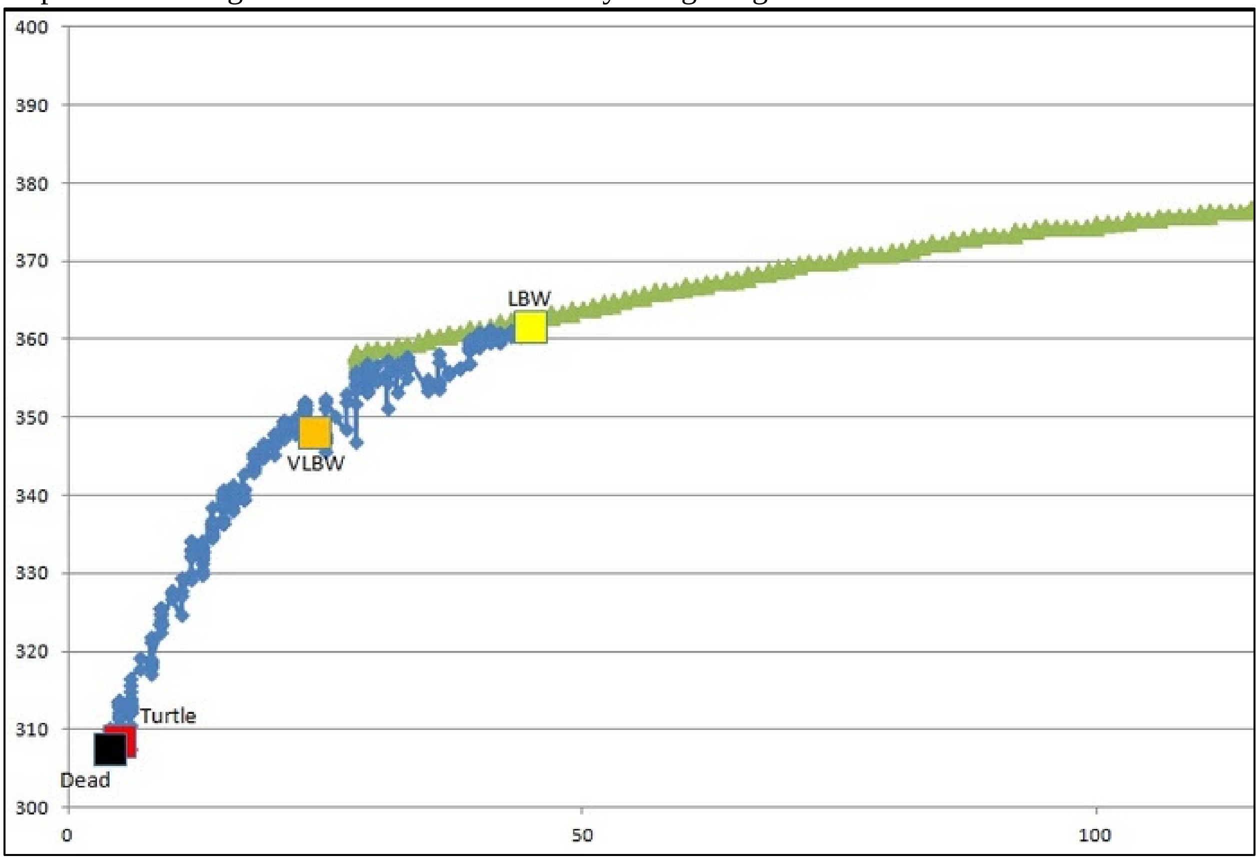
I mount it on the ledge just behind the top of the center console.

I find this device to be a great help when taking long trips on which the battery is near depletion at the end; it is a more reliable indicator than the "miles to go" LEAF indicator of what speed should be driven to get to the destination. Combining its reading with the navigation's "distance to go" and the LEAF's "miles to go" help get there without running out of charge. Every LEAF driver should have it!

Another similar device, LEAFSCAN, is being developed (http://www.mynissanleaf.com/viewtopic.php?f=37&t=8251).

How Low for the Battery Should One Drive?

The graph of battery voltage versus Gids at http://www.mynissanleaf.com/viewtopic.php?f=31&t=6116&hilit=turtle+dead&start=79 is helpful in deciding how low to allow the battery charge to get:



LBW = Low Battery Warning (~48 Gids = ~17.1%); VLBW = Very Low Battery Warning (~25 Gids = ~8.9%). Getting below the knee in battery voltage is hard on the battery; so stay above 10% on the SOC meter. I like to stay above 20% (56 Gids) to allow for unexpected route changes and to avoid the LBW.

Parameters Needed

General parameters

Acceleration of gravity:	g	9.81 m/s^2
Air density:	ρ	1.2 kg/m^3
	kg/lbs	0.45359
	m/mile	1609
	miles/km	0.6214
	miles-ph/mps	2.237
	joules/kWh	2.778x10^(-7)

LEAF parameters

Frontal area:	A	2.27 m^2
Car mass:	M_c	1521 kg
Example driver mass:	M_d	90 kg
Drag coefficient:	C_d	0.29
Regeneration fraction:	G	0.25 for drive mode 0.35 for ECO mode
Rolling fraction:	R	0.012
Useable battery:	B	21 kWh
Charger energy/hour:		~3.3 kWh

The R and C_d values are taken from
http://www.mynissanleaf.com/viewtopic.php?f=31&t=5224 .
See http://www.itrn.ie/uploads/sesB1-ID131.pdf for regeneration factor of 0.3 and maximum AC load of 6 kW.

The LEAF gives a warning at 5 to 8 miles to empty according to its calculation based on the recent driving style. At~ 3.5 miles/kWh, 8 miles corresponds to ~3 kWh, or ~15% of the 20 kWh available battery energy. So, to stay above the 8-miles warning, the amount left in the battery should be >15%. The author plans to have at least 20% left at the finish of trips, to have considerable leeway for unexpected route changes.

Regeneration Factor

According to http://www.wwwsite.com/puzzles/socmeter/ , the Giddings SOC meter shows either 0-281 or 0%-100% of 21 kWh as a measure of the charge left in the battery. The ratio is 100/281 = 0.35587 .

I drove up a steady slope a distance of 2043 meters (6704 ft).

The elevation change was 456 ft = 139 meters. The speed was constant at 55 mph = 24.6 m/s and there was no wind. The slope % = 100*139/2043% = 6.8%. Temperature was 70 deg F.

I recorded the average power within a few tenths of a % by the Giddings SOC meter.

Drive Mode:
Up trip: ~40 kW; Down trip: ~10 kW: thus the regeneration factor is 10/40 = 0.25

ECO Mode:
Up trip: ~40 kW; Down trip: ~14 kW: thus the regeneration factor is 14/40 = 0.35

Equations Needed

Kinetic energy gain or loss

$$K = (M_c + M_d)v^2/2 \text{ where } v = \text{speed in m/s.}$$

Gravitational energy gain or loss

$$G_e = (M_c + M_d)gh$$

where h = elevation change in meters.

Drag energy loss

$$D = C_d A \rho v^2 d/2$$

where d = distance traveled in meters.

Rolling resistance energy loss

$$R_r = r(M_c + M_d)gd \ .$$

Calculation Procedure

1. Use http://www.maps.google to define a trip.
    a. Click on Get Directions.
    b. Type in the locations for the trip.
    c. Click on the link button () near the top and copy (Ctrl-c) the URL highlighted in the small box.
2. Use http://www.gpvisualizer.com/profile_input to plot an elevations graph for the trip.
    a. Keep Units at Metric.
    b. Paste the URL (Ctrl-v) into the "Or provide the URL of data on the Web:"
    c. Click on "Draw the profile".
    d. Right click on the elevations graph and copy it (Ctrl-c).
3. Visually divide the elevations graph into inclines and declines segments.
    a. Measure the distances of the inclines and declines.
    b. Measure the elevation changes of the inclines (+) and declines (-).
    c. Decide speeds (m/s) for the inclines and declines.
    d. The free Engauge digitizer (http://digitizer.sourceforge.net) can be used to determine the distances and elevations.
4. Create a spreadsheet.
    a. Put the general and LEAF parameters at the top.
    b. Create columns equal to the number of inclines and declines segments.
    c. Create rows for the distances, elevations and speeds for the inclines and declines.
    d. Create lines for the following calculations:
        i. Kinetic-energy changes between trip segments (See below.)
        ii. Gravitational-energy changes between trip segments (See below.)
        iii. Air-drag energy losses for each trip segment
        iv. Rolling-resistance energy losses for each trip segment
        v. Trip times in minutes for each trip segment
        vi. Energy use due to low-beam and high-beam lights on
        vii. Energy use due to climate control and wipers on
    e. Add the four partial energies to get the total energy expended by the car for each trip segment.
    f. Add the energies expended for each segment to get the total energy expended for the entire trip.
    g. Divide the total energy by 0.9 to account for the efficiency of electric motors being ~90%.
    h. Calculate energy consumed by the LEAF's electrical system using 0.25 kW; energy consumed by using climate control using 0.25 kW and energy used by lights, if on, using 0.125 kW for low beam and 0.25 kW for high beam. Add the sum of these to the total energy
    i. Add the times for each segment to get the total time for the entire trip.
    j. If there is a return trip over the reverse route, reverse the columns for distances, elevations and speeds to calculate the return trip. Change the signs of the elevation changes.

k. If there are rapid speed changes (e.g., going around many curves) add ~1 kWh to the total energy

Kinetic-Energy-Changes Calculation

When the speed changes between two trip segments, there are four different considerations:

- At the beginning of the trip, calculate the kinetic energy for the speed of the first trip segment.
- When the speed increases between two trip segments, calculate the difference between the two kinetic energies.
- When the speed decreases between two trip segments, calculate the difference between the two kinetic energies and multiply it by the regeneration coefficient, G.
- When the car stops, use the final speed to calculate the loss in kinetic energy and multiply it by the regeneration coefficient, G.

Gravitational-Energy-Changes Calculation

When the elevation changes between two trip segments, there are two different considerations:

- When the elevation increases between two trip segments, just calculate the difference between the two gravitational energies.
- When the elevation decreases between two trip segments, calculate the difference between the two gravitational energies and multiply it by the regeneration coefficient, G.

Energy Use Due to Lights

The LEAF energy display shows ~1.25 kW power for low-beam lights and ~2.5 kW power for high-beam lights. So, one needs to estimate the % of time the lights are on and the high-beams are on.

Energy Use Due to Climate Control and Wipers

This is harder to estimate. I use 2 kW as an average power when climate control and/or wipers are used.

Example Calculations

Trip on the Flat

Travel on the flat:	**mph**	**mps**
speed:	65	29.1
Elevation change (m):	0	
Distance (miles):	75	
Distance (km):	120.7	
Speed (m/s):	29.1	
Air drag energy (kWh):	11.37	

Roll Res. energy:	6.47	
Gravitational Energy:	0.00	
Kinetic Energy:	0.04	
Total Energy (kWh):	19.51	kWh
Time (minutes):	69.23	tank=21 kWh
Time (hours):	1.15	km=0.6214 miles
	% battery used:	95.5%

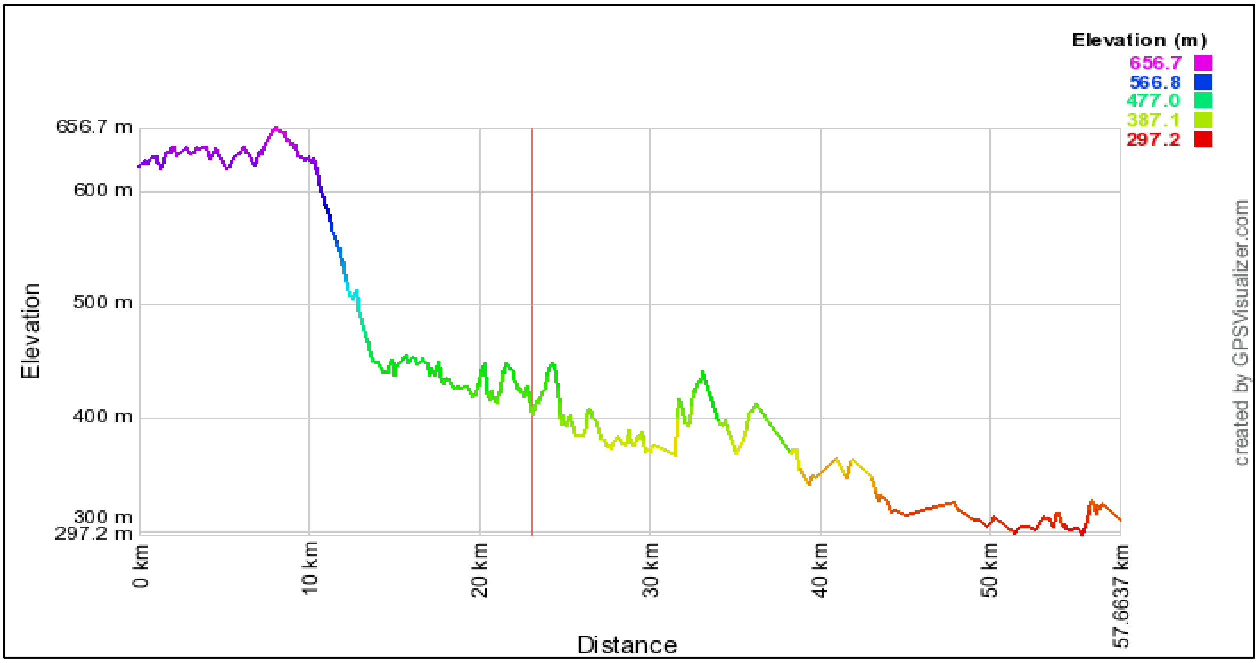
This agrees very well with the chart at http://www.mynissanleaf.com/viewtopic.php?p=101293#p101293 .

From http://www.mynissanleaf.com/viewtopic.php?f=8&t=8266 :

"The reported SOC usable range seems to be from about 95% (fully charged) to 2% when the battery main contactor opens up and disconnects the pack. The first low battery warning occurs at around 18%, and the second one at around 9%. If I remember correctly, Turtle mode comes on at about 5%, and begins limiting power. At about 2%, you are totally dead."

Trip with Mountain at One End

This is a trip from the author's house to the Grandin Theatre in Roanoke VA and the return.



I divided this trip into seven segments.

Roper to Grandin Theatre:		mph	mps							
speed1:	65	29.1	I-81							
speed2:	45	20.1	State Rts.					Total		
Elevation change (m):	21	-217	-30	-45	80	-80	-55	-271	meters	
Distance (miles):	5.0	3.7	5.6	5.3	0.6	3.4	12.1	35.7	miles	
Distance (km):	8	6	9	8.5	1	5.5	19.5	57.5	km	
Speed (m/s):	20.1	20.1	20.1	29.1	29.1	29.1	20.1			
Air drag energy:	0.43	0.32	0.48	0.95	0.11	0.62	1.05	2.91		
Roll Res. energy:	0.42	0.32	0.47	0.45	0.05	0.29	1.03	2.00		
Grav. Energy:	0.09	- 0.76	-0.11	- 0.16	0.35	- 0.28	-0.19	-0.86		
Kinetic Energy:	0.09	0.00	0.00	0.10	0.00	0.00	-0.08	0.19	miles/kWh	
Total Energy (kWh):	1.03	- 0.12	0.85	1.34	0.52	0.62	1.80	6.04	5.92	
time(min):	6.63	4.97	7.46	4.88	0.57	3.15	16.16	43.82	minutes	
time(hrs):	0.11	0.08	0.12	0.08	0.01	0.05	0.27	0.73	hours	
							% Battery Left:	0.71	km=0.6214 miles	

Return trip:	mph	mps								
speed1:	65	29.1	I-81							
speed2:	45	20.1	State Rts.					Total		
Elevation change (m):	55	80	-80	45	30	217	-21	347	meters	Total
Distance (miles):	12.1	3.4	0.6	5.3	5.6	3.7	5.0	35.7	miles	71.5
Distance (km):	19.5	5.5	1	8.5	9	6	8	57.5	km	115
Speed (m/s):	20.1	29.1	29.1	29.1	20.1	20.1	20.1			
Air drag energy:	1.05	0.62	0.11	0.95	0.48	0.32	0.43	3.53		
Roll Res. energy:	1.03	0.29	0.05	0.45	0.47	0.32	0.42	2.61		
Grav. Energy:	0.24	0.35	-0.28	0.20	0.13	0.95	-0.07	1.59		
Kinetic Energy:	0.09	0.02	0.00	0.00	0.01	0.00	0.00	0.12	miles/kWh	
Total Energy (kWh):	2.40	0.00	-0.12	1.60	1.10	1.59	0.78	7.35	4.86	
time(min):	16.16	3.15	0.57	4.88	7.46	4.97	6.63	43.82	minutes	
time(hrs):	0.27	0.05	0.01	0.08	0.12	0.08	0.11	0.73	hours	
							Total Energy:	13.39		
							% Battery Left:	0.36	Battery=21 kWh	

Thus, this trip will end with ~36% left in the available 21 kWh, which is well above the warning level of ~15%.

References

- http://www.roperld.com/science/hillydrivingelectric.pdf
- http://www.roperld.com/science/NissanLEAF.htm
- http://www.roperld.com/science/LEAFRoper.pdf
- http://www.roperld.com/science/LEAFRoperDrive.pdf