

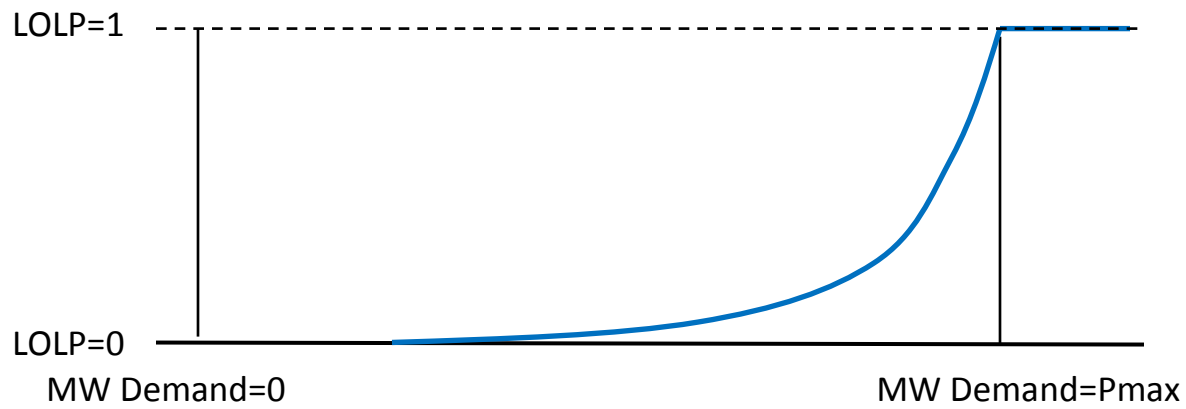
RTS Program Information

The RTS program calculates reliability indices for a single area (i.e. no transmission) LOLE (d/y), LOLH (h/y), and EUE (MWh/y).

The calculations are done in two phases. The first phase is to read in all the generator data from a file G...txt or G...csv file and calculate an 'exact' COPT (capacity outage probability table). How to create this 'exact' table is technically described by Dr Roy Billington in his book:

<http://www.springer.com/us/book/9788132209867>

Visualization of the COPT (capacity outage probability table) is helpful:



If the MW demand is greater than Pmax installed generation capacity, then the probability there is a loss of load is 1. For lower demands than Pmax the LOLP drops down quickly. The LOLP curve in RTS is actually a stair-step curve in 1 MW increments. In the computer program the Pmax location is stored at the index $i=0$ location and for lower load levels i is greater than 0. So the above curve is drawn flipped over left to right from what the array actually is in the program.

When each generator is 'convolved' into the curve to create it, there is an exact alignment of scaled, shifted, and summed curves, resulting in the so called 'exact' calculation of the LOLP values. The outage states shifting is to the left in the above curve from the Demand = Pmax position.

The LOLPs are verified two ways. One way uses a binary tree to calculate LOLPs. The other way is a verification of the RTS.for program to reproduce Dr Billington's IEEE RTS (reliability test system) 1986 paper showing many digits 'exact' answers for LOLE, LOLH, and EUE. Ref: <http://ieeexplore.ieee.org/document/4335006/>

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The second phase of the RTS.for program is to read hourly demand and variable resource (VR) profiles from file H...txt or H...csv files. The format of the HDATAGB.txt file is shown below:

```
30 Years RTS 1979 Hourly Loads GB Wind 1985-2014,,
YYYYMMDDHH,D,RTS Load ,GBwind,
1985010101,1,0.5371122, 0.578,
1985010102,1,0.5050458, 0.580,
1985010103,1,0.4809960, 0.582,
1985010104,1,0.4729794, 0.583,
```

The first line is a title for the hourly file in which you describe the nature of the hourly data in the file. There is also a single line of title in the generator file for you to describe the overall study purpose. The maximum length of the title in both the H and G files is 220 characters.

The title can contain commas and special characters and hypertext. In the OP.csv and OPH.csv output reports the hypertext in the title will appear as a clickable link in excel when clicked on.

The next line is a header which is read and used to create column headers in the OP.csv report file. D is the day of the week which for the RTS day 1 is a Monday. You can define any day of the week to be day 1, such as Sunday. The day of the week has no effect on the RTS calculations.

Because the RTS is 364 days per year the last day of December is absent as are the leap year days. Using the file RTSDATES the Great Britain hourly wind data from the Renewables Ninja web site <https://www.renewables.ninja/> was laid alongside the data in this file. Feb 29 and Dec 31 are identified as days with day 0 and these days were manually removed in file HDATAGB.txt. Since RTS can handle any number of years and can handle leap years and also daylight savings time is acceptable, a real study should not truncate the actual historical hourly data.

The third line and remaining lines of data contain the numerical data. Note that the last line of the hourly data file must have the word **end** in columns 1-3. Inserting 'end' on any line within the hourly file tells RTS to stop reading the data. You may add comments to the right of the numerical data. Spaces and commas can be used as number separators. The use of commas allows you to view the

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data in excel if the filename is given an extension of .csv. RTS does not use the file type extension for G and H files. The .xxx extension could be omitted entirely.

The numerical data consists of the date and time stamp YYYYMMDDHH, the day of the week D, per unit load, and per unit data for up to 20 variable resources such as wind, water, solar, and storage. The HH in the time stamp is 1 – 24 hours. Since hour 24 is tested for in the program, if you have data in the form of 0-23 hours, be sure to use 1-24 hours in the H data file. The time stamp on each line must be in the YYYYMMDDHH format. A program named DST.for is included for you to prepare the YYYYMMDDHH and D data which may or may not contain leap years. If the time stamp does contain leap years then DST.for will make the time changes. Daylight Savings Time or DST causes a duplication of an hour and an omission of an hour. This is ok in the RTS program to have a duplication of an hour or a gap.

RTS uses the YYYY number to tell when one year has ended and a new year begins. The 24th hour is also used to signify the end of a day in which RTS collects the information for that day if the LOLP exceeds the significant LOLP test for that day. The significant LOLP is entered into the G data file and is discussed later. RTS can read any number of historical years of hourly data. These historical years are then projected forward to the study year as possible future year occurrences.

The peak demand each historical year is given a value of 1.0000. Because the RTS only prescribes one year of hourly loads the same hourly load profile is repeated each year in the RTS hourly file HDATAGB.txt 30 year file.

Up to 20 remaining per unit values can be entered on each line. Each variable resource has its own column. These need to be actual historical values of wind water, and solar that would have occurred each hour in the past at a specific location or geographic area. The HDATAGB.txt file contains just one wind column, the 30 year wind profile history of Great Britain, which is available on the Renewable Ninja web site. File HDATAGB2014.txt has just 2014 hourly wind data but from six sites obtained from Renewables Ninja. The column headers give the latitude and longitude locations for those six sources. Select the first option for each question such as wind generator type. The wind per unit values are referenced to the wind net plant maximum capacity. This means that it's ok and

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even expected that the per unit wind may never reach 1 per unit. In the case of GB wind data we assume the per unit values are consistent with wind capacity. The generator data is read from a G... file. G30YRWIND120.txt is shown below:

```
1996 Three Area IEEE RTS With 120 MW Wind Peak Demand...
HDATAGB.TXT, hourly sequential demand and VR data for...
9055.227,5,8.E-3 demand column multiplier, %LFU, SLOLP
1, number of VR (variable resources 20 max)
42., <---up from 38% estimated to hold RM constant at...
120., installed Pmax MW for each Variable Resource
BU#,GENERATORNAM,ID,PMAX,RM%, FOR, DFR,DMW,DFR=derated...
101,ABEL___OIL___,06, 20,100,.100,.000, 0 ,
101,ABEL___OIL___,07, 20,100,.100,.000, 0 ,
101,ABEL___COAL___,L1, 76,100,.020,.000, 0 ,
```

The first line of the generator data is a title up to 220 characters and can contain commas and hypertext links. If you use hypertext, place enough commas in front of the hypertext so it will appear in its own cell in excel. Use this title to describe the specifics of the study. Since many different G generator files can use the same hourly H profile file, use the H file title primarily to describe the hourly data and the G file title to describe the overall study. Both titles appear in all reports.

The second line contains the name of the hourly file to be used for this study. In the above example the file name is HDATAGB.txt which is a 30 year file. Put a comma after the file name. The rest of line two can contain your comments.

The 3rd line has three numbers. The first number is the demand multiplier. The 9055.227 shown above is the peak demand which is multiplied times the hourly per unit values in the hourly data file. This means the 9055 appears as the peak demand for each historical year. So if you had actual historical years of per unit data in the hourly file, the historical demand is still the same future peak demand for each historical year. Only the shape of the historical year is used, not the actual historical year's peak demand.

The 2nd number on the 3rd line is the load forecast uncertainty in percent (%LFU) which is entered as 5% in this example. The seven step normal curve approximation. Roy Billington explains this widely used 7 step LFU in his 1986 paper (see the previous references).

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The 3rd number on the 3rd line shown as 8.E-3 is a significant LOLP (SLOLP) test. The RTS program keeps a running sum of the number of hours the LOLP is greater than or equal to this value. It also tells RTS to display in file OPH.csv all the hours of that day so you can see what is happening each hour of the day. Since OPH.csv can be read by excel you can graph these hourly curves easily. Note that SLOLP must have only one significant digit for both the value and the exponent.

SLOLP has another use. The significant days are also days with maximum net demand. This is the hourly demand minus the hourly sum of variable sources. This is the demand that conventional generators serve. This is the net demand that is used in the COPT curve to look up the LOLP. We can calculate the net demand in a spreadsheet. We can also sort those net demand numbers in descending order. The RTS program prints out the number of sorted net demand numbers to use that are 'significant' demand numbers. We can average in our spreadsheet the variable resources MWs during those hours and calculate an average capacity credit contribution for each resource. This is exactly what RTS does at the end of the OP.TXT file when the simulation contains variable resources. By knowing the number of significant hours you can duplicate the RTS printed out values using your own spreadsheet external to the RTS program. ERCOT uses the peak 20 hours each year, however this set of calculations is more consistent with the ELCC (effective load carrying capability) than using a fixed 20 hours each year. If you run the RTS program with ever increasing variable resources you will find that the effective capacity of them drops significantly. The 120 MW wind used in this RTS example is very small so the wind gets a high capacity value. This drops as more wind is added. The RTS program easily captures this declining effect.

The 4th line has a single number on it, the number of variable resource columns to read in the hourly file. It also tells how many numbers to read on lines 5 through 7, the next three lines.

The 5th line contains the percent capacity credit to give each variable resource that is used only in the reserve margin (RM) percentage calculation. In this example 42 percent is shown. If the correct capacity values are given to the variable sources then the RM% should stay nearly constant as RTS is solved each time using the target LOLE solution feature. If the RM increases as VR increases, then the VR are being given capacity credits that are too high.

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The 6th line are the MW capacities of the variable resources in the hourly file. This example shows a single 120 MW. The number of numbers on this row should be equal to the number of variable resources specified on line 4.

The 7th line is a header that is read. If you view the G data file in excel as a .csv file these headers will line up with data in each column.

The rest of the lines are the conventional dispatchable generators. Do not put generators in this file that are weather driven, i.e. wind, water, and solar. Put those sources as per unit historical profiles in the H data file. For the COPT to be correct for the peak demands of the year, the generators in the generator file are fully dispatchable (except for the probability of not being available, i.e. the FOR forced outage rate).

On each line there is a number, which in this instance is the bus number of the load flow case, followed by a 12 character generator name and note there are no blank spaces, then followed by a 2 character generator type ID. The ID type is convenient for sorting generators into categories for convenient assignment of FOR (forced outage rate) data for that generator type. The RTS program has no generic default data so you have to specify the FOR data for each generator. This is easily done when all the same types are clustered together. Then you could sort the bus numbers to put them back in their original order.

The next data on the generator line is the generator maximum net power output its capacity or Pmax power max. The Pmax must be an integer because the COPT is formed using integer values of generator capacity. The use of generator capacity integers allows the COPT to be an 'exact' calculation.

The next column is the generator's capacity contribution in the reserve margin calculation. It's possible to give each of the dispatchable generators a lower capacity value than 100% and then a lower reserve margin could be used.

The last three numbers are the FOR forced outage rate, the DFOR or derated forced outage rate, i.e. a probability of being in the derated power state, and then the last number is the derated MW and this has to be an integer. This is the amount of decrease of capacity from Pmax. It's not the capacity available in the derated state. It's the amount of derating.

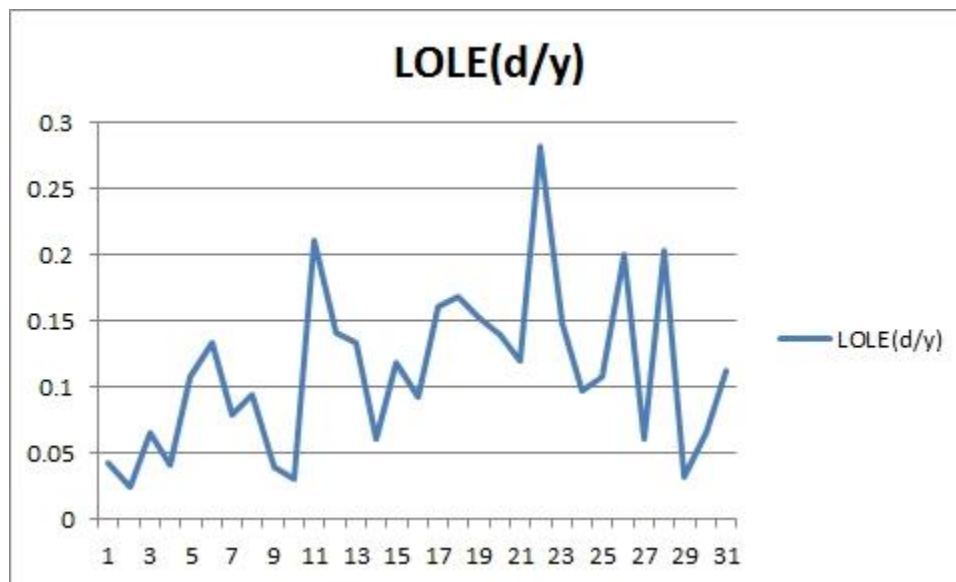
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Additional Notes:

The LOLH is the sum of LOLP's for a year because each hour the LOLP represents a small bit of unserved energy for a period of time. The LOLE is the sum of the daily max LOLP's for a year. If there is a peak in LOLP's in the morning and then again in the afternoon, the day can have a double hump. The RTS program keeps track of these periods separately. If a large amount of solar is installed the duck curve can form. RTS should be able to capture this effect.

The hourly EUE is calculated by integrating the COPT from the net demand MW to 0 MW. Summing up the hourly EUEs gives the annual EUE. The annual EUE agrees with Roy Billington's 1986 paper for the IEEE RTS. File <http://egpreston.com/RTS1986.zip> shows several tests confirming the RTS program produces all of the indices for the single area RTS Roy tested in his 1986 paper. It's important to continue this benchmarking to insure programs are getting accurate results into the future.

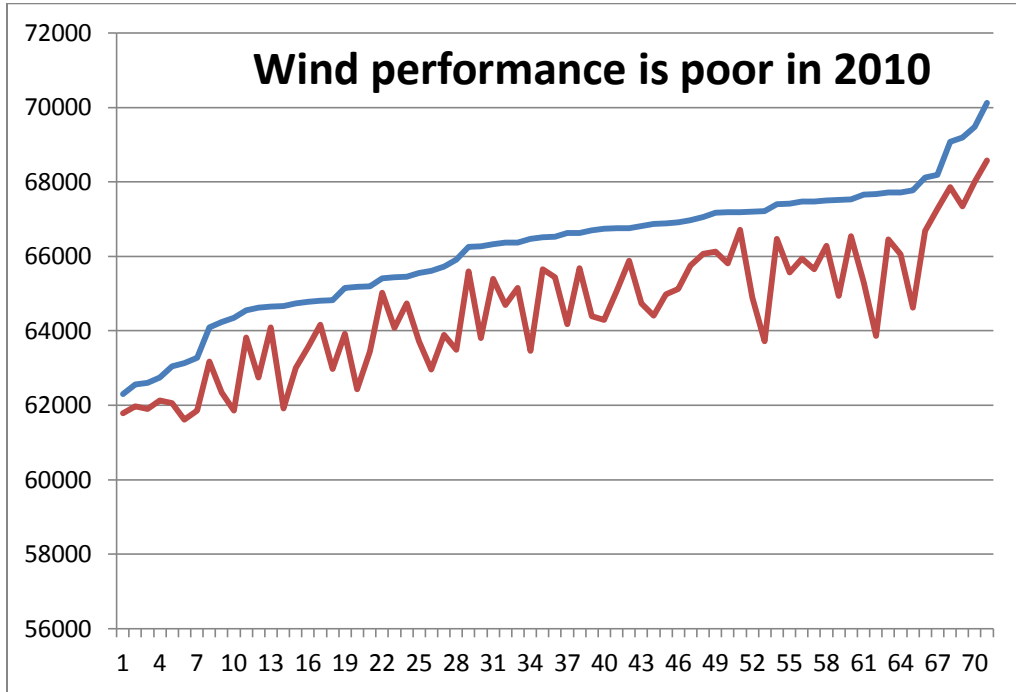
In developing the cases for the UK 30 year runs it was noticed that there seems to be a long range weather pattern in the data as shown below:



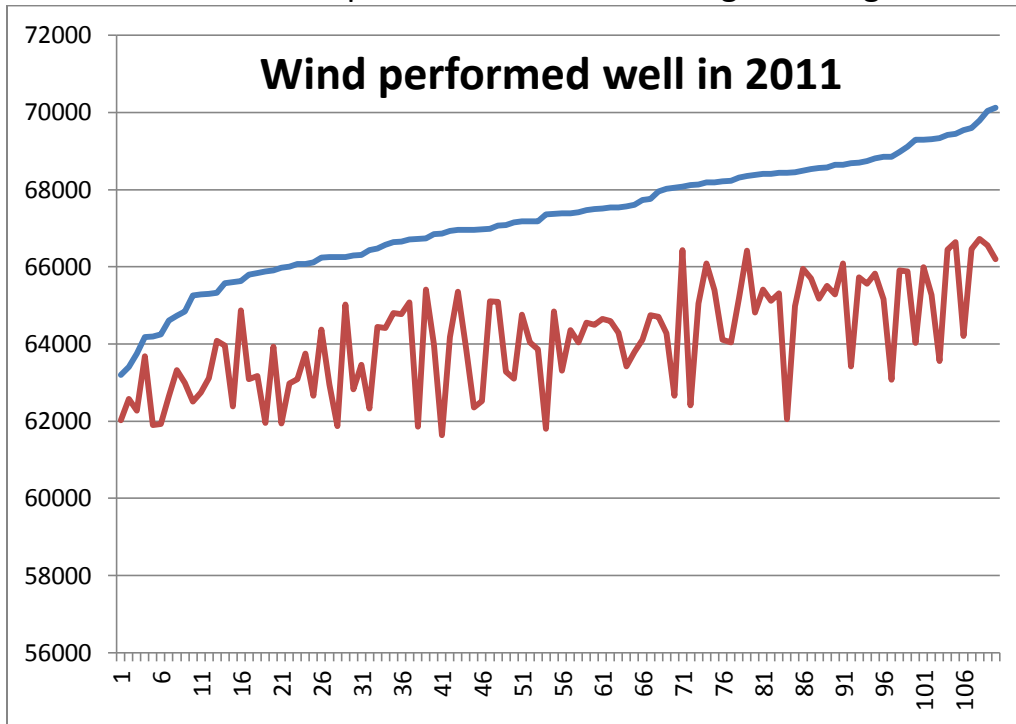
The peak LOLE occurred for 2010. As Great Britain wind is increased the swing in the LOLE also increases. The idea that we could move stored energy from one year to the next is not feasible. This is something we will need to watch closely as

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we become more dependent on weather driven energy sources. Interestingly ERCOT (Texas) also shows poor wind performance in 2010 compared to 2011. The graph below is the peak demands (blue line) and the wind contribution each hour (red line). Both the UK and Texas had their worst wind years in 2010.



2011 had high temperatures and high winds following 2010. Did light winds in 2010 cause ocean temperatures to rise resulting in strong winds the next year?



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The Renewables Ninja web site gives the hourly winds from 1985 – 2014 for all the EU countries. The RTS program is capable of modeling all of them together or individually using the RTS generators and load profile. This has not been run yet.

The ELCC is the effective load carrying capability or capacity. It is another way to evaluate the capacity credit of a new energy source. The definition of the ELCC is how much load can be increased as new generation is added while holding the LOLE or one of the other indices constant.

The ELCC is extremely easy to run using the RTS program. First you start with a base case without the new generator. You need to know the load level that will produce a given LOLE. Suppose you want to hold the LOLE to 0.1 days per year. But your file does not have an LOLE of 0.1 days per year. This is no problem. Simply tell RTS you have a target LOLE of 0.1 when it asks the question. It will iterate adjusting the load level until a nearly exact LOLE = 0.1 d/y is achieved. The program will tell you that demand level. This is how the load level of 9055.227 MW was determined that produced an exact LOLE of 1 d/y. The program used a Newton convergence scheme to find the exact load needed.

So let's say you run the base case and the load level is 9000 MW. Now turn on the wind generation in a new case and ask for RTS to converge to LOLE = 0.1 again. Let's say you put in 120 MW and the load level is now 9048. The increase in load is 48 MW. Both cases have the same LOLE of 0.1 so the reliability is the same. The ELCC is $(9048-9000)/120 = 0.4$ or 40% capacity credit of the wind.

If you enter the 40% capacity credit on line 5 of the generator data file you should observe that the reserve margin remains constant before and after the wind is added. So this is one way to calculate an effective capacity credit, using the ELCC.

There is a faster way however. When you ran the wind turned on case you would notice in the bottom of OP.TXT file is a calculated capacity credit. Put this number in line 5 of the generator data. Rerun the case for the target LOLE. Now check the reserve margin. If the reserve margin has dropped a bit, increase the capacity value and rerun the case.

In testing this method on the 30 year case I began with the suggested 39%. However I had to bump up the value to 42% to hold the reserve margin constant.

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This brings up another interesting point about the wind capacity credit. In the 30 year case the wind capacity credit for 120 MW of wind is 42%. However in the one year 2014 case with six wind farms, the capacity credit is 60%. As you can see the capacity credit of these variable resources varies all over the place as a function of the weather itself, which can be very erratic from year to year.

There is another thing to consider in assigning a variable resource capacity credit. As you add more and more MW of a resource at a particular location, the capacity credit at that location diminishes. Once there is a lot of power from that source, the net demand after subtracting this variable resource load has already pushed the net demand load level well below the MW level that produces a high LOLP from the COPT. Further reductions of load do not reduce the LOLPs since they are already approaching zero for those hours.

Running RTS and increasing the wind and solar, you will find that there is a point reached where their incremental capacity values go to zero. The only way to have them make contributions at hours other than when they are generating is to have large amounts of storage. But that is another topic for another time....

I will say however that you can model storage in the RTS program by creating a variable resource column that takes power in and sends power out. Create this model using the G data and H data files externally to the RTS simulation. You should be able to achieve rather dramatic reductions in the indices allowing you to retire some of the conventional generators.

Also I will be working on a two area version of the RTS program. See this WECC presentation for how it will work: <http://www.egpreston.com/WECCAUG2016.pdf>

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<http://egpreston.com>

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