Testing the Available Transfer Capability of a New Generator Interconnection

By Gene Preston April 15, 2011

Outline of what I will discuss today:

1) The interested new generation party contacts me
   - I provide examples of work and clients
   - I discuss what load flow data files I have on hand
   - A non disclosure agreement is usually needed
   - The specifics of the study are then discussed

2) The specifics of the study include:
   - The specific point of interconnection
   - Where the power is to be sent
   - Other new generators nearby that may affect the ATC – available transfer capability
   - What years and load levels to test: summer, spring
   - If there are constraints, how hard are they to fix?
   - What are the other generator harmers and helpers?
   - Are the constraints contingency driven N-1, N-1-1, N-1 double line outage, or N-0, no lines outaged
   - The study will show how distant the constraints are
   - The study will show if a SPS (special protection scheme) can be used or not to overcome a problem
   - How much energy will be lost due to curtailments?

- There are other topics I will not discuss today such as voltage ride through, short circuit, transient stability, dynamic stability, locational marginal pricing (LMP) and others because I do not perform those calculations, although they are important.
- The primary purpose of my studies are two fold, one is to perform front end preliminary screening for a client before they spend larger amounts of money on a project, and the other purpose is to provide a second independent check to bankers financing a project to see if there are fatal flaws that others have not identified.

3) The mathematics of performing ATC calculations
- Standard Load Flow, you know how to do that
- Zipflow, a fast AC line outage technique
- How to quickly test if a line will be an ATC constraint or not using an overload circle diagram

4) The steps for setting up and solving an ATC study
- Two base cases, with and without the transfer
- Define the study area lines with flow >0.005 PDF
- Perform the zipflow calculations
- Identify overloaded lines
- Calculate the ATCs and sort them ascending
- Print out the results
- Examples

Load Flow data files are available from different regions through the FERC CEII process.
FERC = Federal Energy Regulatory Commission
CEII = Critical Energy Infrastructure Information

Typical cases for a wind generator study might be:

2012 spring peak load case
2012 summer peak load case
2017 light load case
2017 summer peak load case

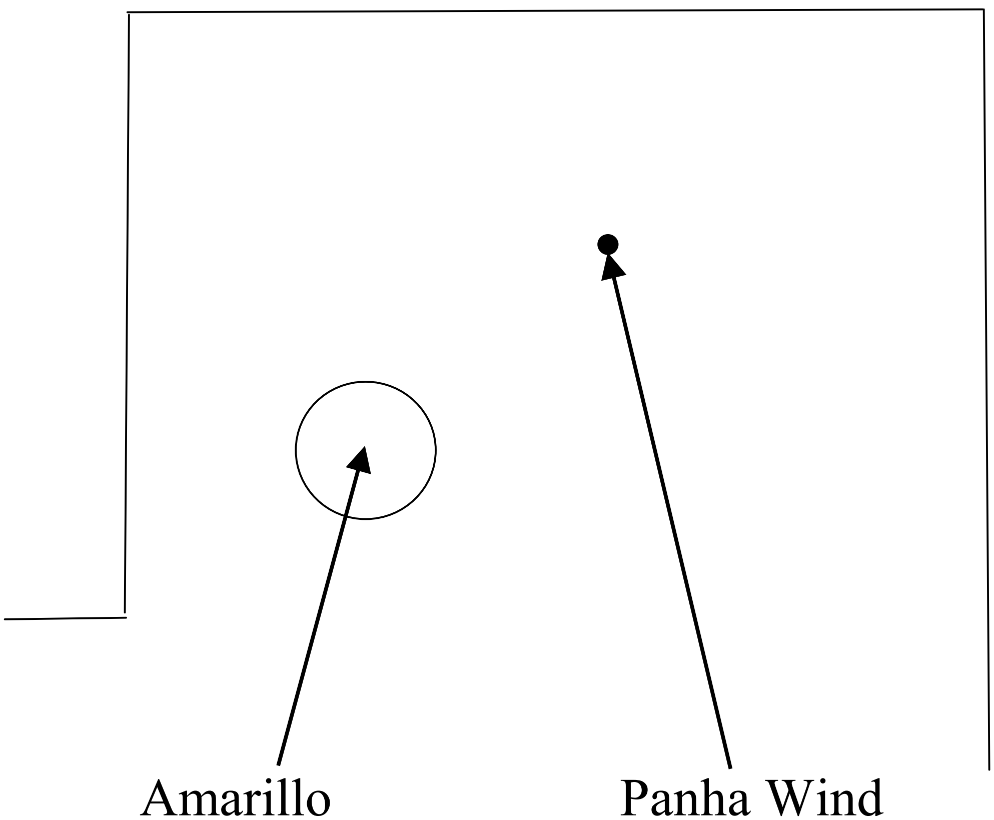
Early cases such as 2012 show the system at the initial interconnection time.

Later cases such as 2017 have more wind and the planned transmission improvements in the cases.

The spring cases have gas peakers off line, coal and nuclear base loaded, and wind generators at high output.

The summer cases have wind generators at a low output and the conventional generators at high output.

Here is how to identify generators nearby your generator.
The ATCs when hypothetical Panha wind is used as a ref.



2012 SPRING CASE, PANHA WIND ATC
GENERATION SUMMARY REPORT:

BUS#	BUS NAME	W	AR#	AREANAME	ZN#	ZONENAME	MW	PMAX	RESERV	%	mi
	PANHA	W					23.04	80.	57.	29	0
							48.00	244.	196.	20	37
numbers and names have been removed							347.00	347.	0.	100	38
							347.00	347.	0.	100	38
		W					0.10	80.	80.	0	58
		W					2.88	10.	7.	29	59
							110.00	110.	0.	100	78
							110.00	110.	0.	100	78
		W					5.76	20.	14.	29	80
		W					46.08	160.	114.	29	86
							8.70	20.	11.	43	90
							20.00	20.	0.	100	91
		W					4.88	25.	20.	20	93
		W					3.45	35.	31.	10	98
		W					5.76	20.	14.	29	104
		W					2.88	10.	7.	29	115
		W					5.76	20.	14.	29	138

ATC Study Results For Panha Wind:

```
2012 SPRING CASE, PANHA WIND ATC
Available Transfer Capability Summary:
New generation added to the base case =    121 MW  ---------------.
Number of lines outaged and monitored =   1134                    V
                                                    ratg  %-of-ratg   dist    ATC
        -------from-------    --------to-------- ID mi  MVA  0-MW X-MW   fact     MW      RUN#
outage:       PANHA_WN 115         SUBSTNX_  115 1
 loads:       AUTOXFMR 115         AUTOXFMR   69 1   0   86     1  144  0.950    84 max     3 *
   N-0:    11 mi  from             PANHA_WN 115          75    27   86  0.353

normal:
 loads:       AUTOXFMR 115         AUTOXFMR   69 1   0   75    27   86  0.353   150 max     6 *
   N-0:    11 mi  from             PANHA_WN 115          75    27   86  0.353

outage:       AUTOXFMR 115         PANHA_WN 115 1
 loads:       PANHA_WN 115         SUBSTNX_  115 1   9  154     1   80  0.987   150 max     7 *
   N-0:     0 mi  from             PANHA_WN 115         120    17   50  0.633

outage:       AUTOXFMR 115         PANHA_WN 115 1
 loads:       SUBSTNX_ 115         SUBSTNY   115 1  27  154     4   77  0.958   156 max     9 *
   N-0:     9 mi  from             PANHA_WN 115         120    22   45  0.626

outage:       PANHA_WN 115         SUBSTNX_  115 1
 loads:       AUTOXFMR 115         PANHA_WN 115 1  11  160     0   77  0.996   156 max    10 *
   N-0:     0 mi  from             PANHA_WN 115         159    13   40  0.357

outage:       PANHA_WN 115         SUBSTNX_  115 1
 loads:       SUBSTNXX  69         AUTOXFMR   69 1   5   88     8   77  0.480   159 max    12 *
   N-0:    11 mi  from             PANHA_WN 115          88    19   45  0.185

outage:       PANHA_WN 115         SUBSTNX_  115 1
 loads:       SUBSTNXX  69         SUBSTN     69 1   6   88     3   68  0.467   175 max    20 *
   N-0:    16 mi  from             PANHA_WN 115          88    10   35  0.183
```

The blue and red constraints are the most important ones. The blue constraint shows that N-1 outage of the Panha to SubstnX line causes the Autoxfmr 138/69 kV auto to overload if the Panha wind exceeds 84 MW output. We would normally say that the Panha wind N-1 ATC is 84 MW. If we were to devise a special operating scheme that allowed Panha wind to exceed 84 MW when the outaged line were in service, we still see that this auto overloads when Panha wind exceeds 150 MW for the N-0 no line outages. Note that turning on other wind generators can harm and help the Panha wind ATC.

Below are the harmers and helpers to Panha wind.

```
ATC RUN #s with LP limiting ckts:
ovld: AUTOXFMR 115  - AUTOXFMR  69    1
+PDFs are harmers  -PDFs are helpers           PMAX      BGEN
GEN         PANHA_WN 115 W   PDF=  0.3542     80.00    100.04
GEN                      W   PDF= -0.0118     99.00      7.99
GEN                      W   PDF=  0.0118     20.00      5.75
GEN                      W   PDF=  0.0112    160.00     45.94
GEN                          PDF=  0.0111    347.00    345.94
GEN                          PDF=  0.0110    244.00     47.85
GEN                          PDF=  0.0109    347.00    345.94
GEN                      W   PDF=  0.0097     80.00     22.97
GEN                          PDF= -0.0094     20.00     19.97
GEN                          PDF= -0.0094     20.00      8.68
GEN                          PDF=  0.0094    189.00    188.42
GEN                          PDF=  0.0094    535.00    454.26
GEN                      W   PDF=  0.0093    120.00     34.45
GEN                          PDF=  0.0093    102.00    101.69
GEN                          PDF=  0.0093    103.00    102.68
```

And we see that there are no other generators that have significant PDF's on the AUTOXFMR autotransformer loading. The PDF is the incremental line MW flow divided by the power being injected at Panha. The above calculations are for N-0, all lines in service.

(Example) CONFIDENTIALITY AGREEMENT

This Agreement is entered into January ___, 2010 between:

Eugene G. Preston PhD, PE of 6121 Soter Parkway, Austin, TX 78735-6100 hereinafter referred to as "EUGENE PRESTON" and **XYZ Wind Energy Services** of Rt 2 Funny Farm Road, Nowhere, Maine 01050 hereinafter referred to as "XYZ" and hereinafter jointly referred to as the "Parties". "Disclosing Party" means the party furnishing information and "Receiving Party" means the party receiving information.

RECITALS

A. The Parties wish to engage in discussions about transmission adequacy for proposed wind project, hereinafter referred to as the "Discussions"

B. EUGENE PRESTON is willing to disclose to XYZ in confidence certain information in connection with the Discussions, including Confidential Information as defined herein

C. XYZ is willing to disclose to EUGENE PRESTON in confidence information about XYZ's plans in connection with the Discussion including confidential information as defined herein

D. The Parties wish to define the terms and conditions under which said Confidential Information may be disclosed and maintained in confidence by the Parties.

AGREEMENT

1. Confidential Information

1.1 For the purpose of this Agreement, "Confidential Information" shall mean any and all information in any form relating to the business operations of the Parties

1.2 Confidential Information also includes materials produced by the Disclosing Party in which Confidential Information, as defined above, have been included in any form or part. Specifically, the Receiving Party expressly acknowledges and agrees that the Disclosing Party's use of the Disclosing Party's proprietary computer software, databases, designs, methodology, procedures, trade secrets, copyrights, patents, trademarks, logos, or other proprietary information in connection with the Services shall not be deemed as a transfer of rights with respect thereto. Nothing in this Agreement is intended to grant or confer any rights by license or otherwise to the Receiving Party under any patent or copyright of the Disclosing Party except as expressly set forth herein.

1.3 Confidential Information shall not apply to:

(a) information which the Receiving Party can prove was in its possession at the time of disclosure and was not acquired directly or indirectly from the Disclosing Party under restricitions or confidentiality; or

(b) information, which after disclosure by the Discloser, is published or becomes generally available to the public otherwise than through any act or omission on the part of the Recipient; or

(c) information which the Receiving Party obtains form a third party with good legal title thereto; or

(d) information the Receiving Party is required to produce to any law, subpoena, or court order or in the defense of a claim

2 Confidentiality

2.1 The Parties agree that Confidential Information shall be used by the receiving party only for the purpose of the Discussions. Confidential Information may therefore only be disclosed to those employees and/or advisors, who need to have access to the specific information in question for the purpose of the Discussions. The Parties agrees to ensure and to be fully responsible and liable for that those employees and/or advisors are fully aware of the party's obligations hereunder and comply with such obligations as if such persons were parties hereto.

2.2 Save as set out in section 2.1 above, no Confidential Information may be disclosed to any third party without the disclosing party's prior written consent.

2.3 At the disclosing party's request the receiving party shall immediately either (i) return any and all written Confidential Information to the disclosing party or (ii) destroy it. Having done this the receiving party shall confirm in writing to the disclosing party that the obligations according to this section 2.3 have been fulfilled.

3. Breach of Confidentiality

Each party acknowledges that, in the event of a default by the other under this Agreement, damages will not be a sufficient remedy. Accordingly in addition to other remedies the disclosing party shall have the right to injunctive relief and specific performance of the other party's obligations. Any such remedy shall not be deemed to be exclusive or all inclusive and shall be in addition to any and all other remedies which may be available to the parties at law.

4. Non-Circumvent

EUGENE PRESTON will not attempt to deliberately circumvent XYZ for any work or services that XYZ subcontracts to EUGENE PRESTON or deliberately attempt to circumvent XYZ to provide work or services directly to XYZ's clients. All inquiries shall be only directed through XYZ.

5. Term

This Agreement shall be effective from the date first above written and is valid for a term of two years. The confidentiality undertaking of the Parties relating to the Confidential Information shall be valid during the term of this Agreement and for a period of two (2) years thereafter.

6. Amendments

Amendments to this Agreement shall be in writing, and duly signed by the Parties.

7. Governing Law and Disputes

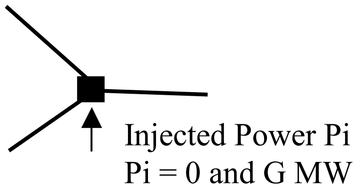
7.1 Each of the parties hereby irrevocably and unconditionally consents to the jurisdiction of any federal or state court of Maine sitting in Pine County and irrevocably agrees that all actions or proceedings arising out of or relating to this Agreement or the transactions contemplated hereby shall be litigated exclusively in such Courts. Each of the parties agrees not to commence any legal proceeding related hereto except in such Court. Each of the parties irrevocably waives any objection which it may now or hereafter have to the laying of the venue of any such proceeding in any such Court and hereby further irrevocably and unconditionally waives and agrees not to plead or claim in any such Court that any such action, suit or proceeding bought in any such court has been brought in an inconvenient forum. Each of the parties irrevocably waives any right it may have to a trial by jury in any such action, suit or proceeding. Each of the parties agrees that the prevailing party in any action or proceeding arising out of or relating to this Agreement or the transactions contemplated hereby shall be entitled to recover its reasonable fees and expenses in connection therewith, including legal fees.

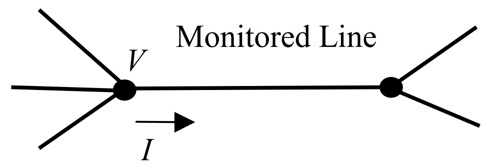
____

This Agreement has been executed in two copies of which the parties have taken one each.

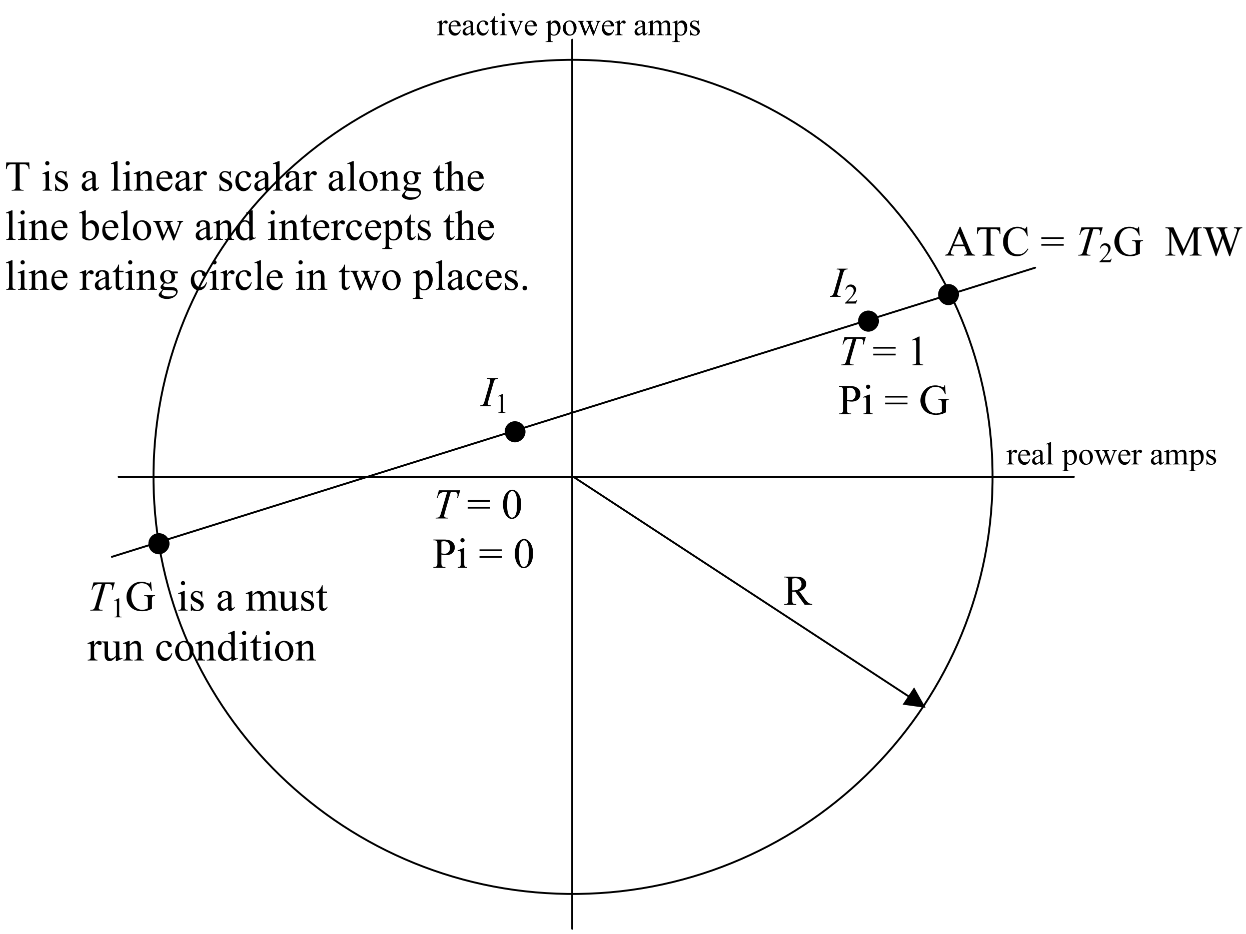
Place: Nowhere, ME	Place: Austin, TX
Date:	Date:
XYZ Wind Energy Services	
____________________	____________________

How to find the ATCs for any Transmission Line:





Run two load flow cases, one with no power injected (case 1), and another with the power injected (case 2). Chose one end of a line to monitor. For both cases calculate a line current $I = [(P+jQ)/V]^*$. There is a real component of I in phase with V which will be the I representing real power flow. Then the imaginary component of I at 90 degrees to V represents the reactive power flow. Now consider that the monitored line has a maximum current magnitude R as shown in the diagram below. We plot the two base case I results on the diagram.



Here are my notes I used to write the ATC program I currently use.

Calculating ATC from two load flow Solutions

by Dr. Eugene Preston
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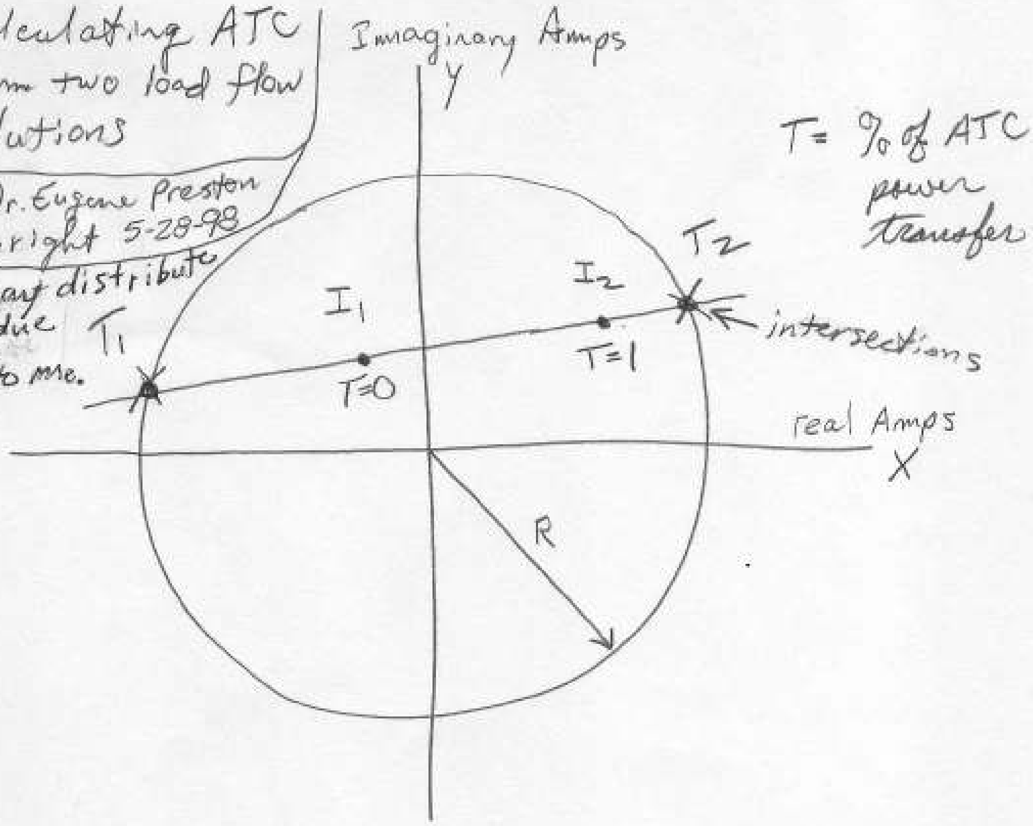

I_1 is the complex line current such that the x and y components of current in I_1 give the line real and reactive power when multiplied times the bus voltage magnitude. Therefore

$$I_1 = \frac{\text{line real power} + j \text{ line reactive power}}{\text{Bus voltage mag and angle}}$$

I_1 is the line current for T = 0 where T ranges from 0 to 1, T = 0 is no ATC transfer.

I_2 is the line current for T = 1, which is the 100% ATC power transfer amount.

1

R is the current magnitude in amps that is the line rating.

The objective is to calculate the intercept points T_1 and T_2, given $I_1(T=0)$, $I_2(T=1)$, and R.

The I_1 and I_2 are each calculated from the full AC load flow cases that created the bus voltages and line currents.

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an equation for the line is:

$$\frac{y - y_1}{x - x_1} = \frac{y_2 - y_1}{x_2 - x_1} \quad \text{where} \quad I_1 = x_1 + j y_1, \quad I_2 = x_2 + j y_2$$

$$y - y_1 = \frac{y_2 - y_1}{x_2 - x_1}(x - x_1)$$

$$y = \underbrace{\left(\frac{y_2 - y_1}{x_2 - x_1}\right)}_{m} x + \underbrace{y_1 - \frac{y_2 - y_1}{x_2 - x_1} x_1}_{b}$$

$$y = mx + b \qquad m = \frac{y_2 - y_1}{x_2 - x_1}$$

$$\Downarrow$$

$$b = y_1 - m x_1$$

we now have the line defined

The intersection of the line with the circle occurs for

$$x^2 + y^2 = R^2$$

$$x^2 + (mx + b)^2 = R^2$$

$$x^2 + m^2x^2 + 2mxb + b^2 = R^2$$

$$x^2(1+m^2) + 2mxb + b^2 - R^2 = 0$$

$$x^2 + \underbrace{\frac{2mb}{1+m^2}}_{B} x + \underbrace{\frac{b^2 - R^2}{1+m^2}}_{C} = 0$$

let $B = \frac{2mb}{1+m^2}$ and $C = \frac{b^2 - R^2}{1+m^2}$

then the solutions are

$$X = \frac{-B \pm \sqrt{B^2 - 4C}}{2}$$

given the two X solutions, we can find the T or transfer amount. Note that

$$X = X_1(1-T) + X_2 T$$

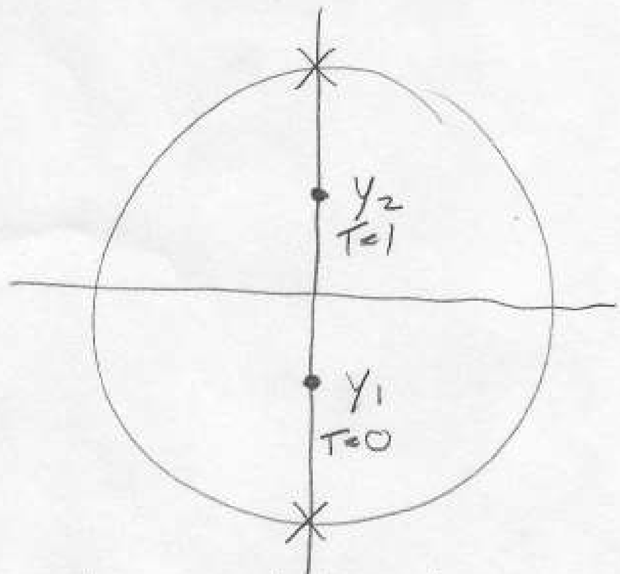
when $T=0$ $X = X_1$
when $T=1$ $X = X_2$

$$T = \frac{X - X_1}{X_2 - X_1}$$

plug in each X solution to get T.

(3)

Special case of $X_1 = X_2$



there is no variation in X, so we solve the problem in y.

$X_1^2 + y^2 = R^2$

$y^2 = R^2 - X_1^2$

$y = \pm\sqrt{R^2 - X_1^2}$ are the two crossover points

$y = y_1(1-T) + y_2(T)$ when $T=0$ $y = y_1$, when $T=1$ $y = y_2$

$y = y_1 - y_1 T + y_2 T$

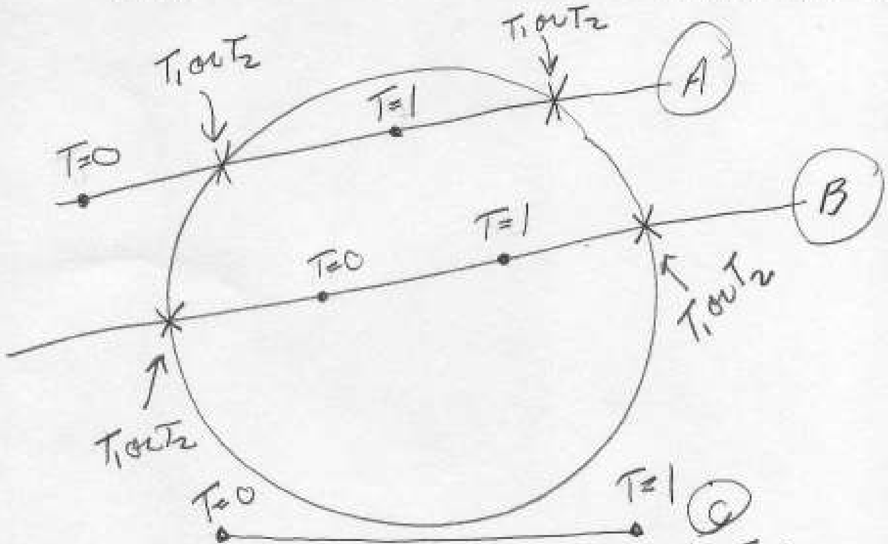
$y = y_1 + (y_2 - y_1)T$

$$T = \frac{y - y_1}{y_2 - y_1}$$

plug into this the two y roots from $y = \pm\sqrt{R^2 - X_1^2}$ to get T_1 and T_2

(4)

How to test for max and min (must run)



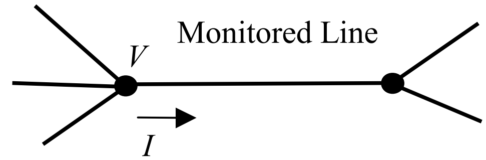
In case A the line is overloaded at $T=0$ and not overloaded at $T=1$. The two solutions are T_1 and T_2. The smaller T_1 or $_2$ value will be the min or must run and the larger will be a max value.

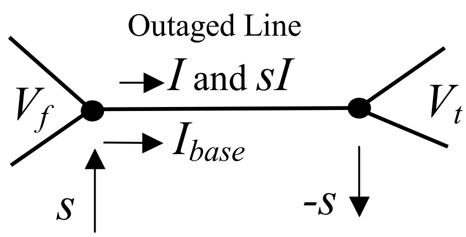
In case B, the line is never overloaded except for $T>1$ or $T<0$. Both solutions are max values of transfer. There is no minimum.

In case C, the line is always overloaded and there is no solution at all. This is observed to occur when $B^2-4C<0$ or in the special case of $m=\infty$ when $R^2-X_1^2<0$.

(5)

Zipflow – Estimating Line Currents For Line Outages





I is found for s = 1 A

We want to inject a current s such that when the component of s going through the outaged line satisfies $s = sI + I_{base}$ then we have a circulation current and the outaged line is disconnected.

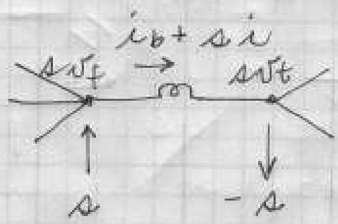
First create an inverted sparse Y branch matrix with no shunts in it, only series elements (except for one point in the network which is grounded to make the matrix solution non singular). Then inject 1 amp into the from end of the outaged line and –1 amp on the to end of the outaged line. This gives us a set of incremental node voltages throughout the network. Using these node voltages, calculate the line current I in the outaged line. This is the fraction of current going through the outaged line due to the 1 and –1 amp injections. Now we need to scale up the 1 amp to a level s so that the equation $s = sI + I_{base}$ is satisfied.

$$s = I_{base} / (1 - I)$$

Then multiply the complex scalar s times all the node voltages due the 1 and –1 amp injection and then add these voltages to the original base case bus voltages to get the new line flows for the network as though the line had been outaged.

Using the new line currents for the outaged line, repeat the ATC calculations. Here are my notes for the Zipflow model.

Line Outage Model: (one line out)



i is calculated from $s = 1$ injections

line is disconnected when

$$s = i_b + s i$$

$$s(1 - i) = i_b$$

$$s = \frac{i_b}{1 - i}$$

if $i = 1$, then the line cannot be opened.

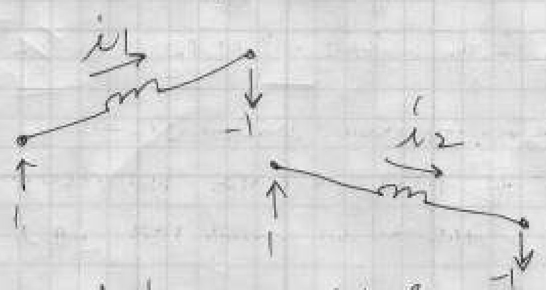
the injection of 1 amp yielded v_f and v_t

so

$$s = \frac{i_b}{1 - (v_f - v_t) y}$$

then let $v_i = s v_i$ for all i
and these v_i describe incremental
bus voltages that disconnect the
line.

Line Outage Model: (two lines)



i_1 and i_2 result from separate 1 amp injections.

s_1 and s_2 are scale factors for first and second 1 amp injection currents.

$$\begin{cases} s_1 = i_{b1} + s_1 i_1 + s_2 i_{12} \\ s_2 = i_{b2} + s_2 i_2 + s_1 i_{21} \end{cases}$$

$$s_1(1 - i_1) - s_2 i_{12} = i_{b1}$$
$$s_2(1 - i_2) - s_1 i_{21} = i_{b2}$$

$$\begin{bmatrix} (1-i_1) & -i_{12} \\ -i_{21} & (1-i_2) \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} = \begin{bmatrix} i_{b1} \\ i_{b2} \end{bmatrix}$$

i_{12} is the current in line$_1$ resulting from the injection in line$_2$. i_{21} is the current in line$_2$ resulting from the injection in line$_1$.

Line 1839

Line Outage Model: (3 lines)

$$\begin{bmatrix} i_{b1} \\ i_{b2} \\ i_{b3} \end{bmatrix} = \begin{bmatrix} 1-i_1 & -i_{12} & -i_{13} \\ -i_{21} & 1-i_2 & -i_{23} \\ -i_{31} & -i_{32} & 1-i_3 \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \\ s_3 \end{bmatrix}$$

and the same format is repeated for four or more lines.

if the matrix is ill conditioned, then the lines cannot be opened.

This means that all states with more lines open also cannot be opened.

a quick way to calculate the total probability of all these states is needed. → we just calculate the probability of the states of the ~~generators~~ three lines, ignoring all generator states and other line states.

This file is posted on line at http://egpreston.com/ATCstudies.pdf