VOLTAGE-SLOPE METHOD RESERVE TIME ACCURACY

The Rhyme (Pattern) & Reason (Logic)

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Introduction

Aspects of an algorithm for computing reserve time during discharge were discussed in the 2018 Battcon paper "Time (Only) Referenced Rundown Test" [2]. It presented an example of capacity predictions made using the voltage-slope technique explained by Thomas D. O'Sullivan in US Patent 6,211,654 [1].

The voltage-slope technique predicts remaining reserve time based on two voltage measurements taken during the discharge. This follow-up paper examines the accuracy of such predictions. It also explains how the basic and *refined* methods work, plus demonstrates how the calibration improves predictions.

Using datasets from two different 8-hour discharges[1], predictions and actual results are compared. In a third dataset, predictions made from a Telco rundown test are compared to the expected capacity (based on battery age, load and curve tables). The paper illustrates how the accuracy is dependent on key variables and suggests the algorithm is *tuned* for an 8-hour discharge.

Background

Many years ago, a simple test method was discovered at Bell Labs to gauge remaining reserve time during a battery discharge or rundown test.

As noted in the patent, discharge tests were performed on VLA batteries at 3, 5- and 8-hour rates on Pb/CA Rectangular and Pure Lead Cylindrical batteries, having varying ages (8, 14 and 21 years). VRLA batteries were also tested at 6.38- and 7.98-hour rates. No testing was performed for high discharge rate UPS applications.

By testing a representative cross-section of batteries (types, ages, and rates), O'Sullivan defined a *generic* method to gauge remaining reserve time to a pre-determined end-voltage based on the voltage-slope during the discharge.

The result – with basic math and two voltage readings taken after the coup de fouet[2] (Figure 1), an operator could gauge the remaining time to the desired end-voltage with fairly reasonable accuracy.

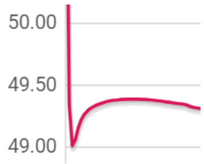

Figure 1
Coup de Fouet

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[1] One dataset supplied by a manufacturer and another from a test performed by a VAR (Value-Added Reseller).

[2] The period from the bottom of the initial voltage drop to the top plateau of the ensuing recovery voltage.

Applications

Since a standard *off-line* (pulling a string out of a bank) 8-hour discharge is costly, the voltage-slope method was developed for operators interested in trending capacity using a rundown test. This type of test is described later, but in general the technique applies mostly to constant power loads.

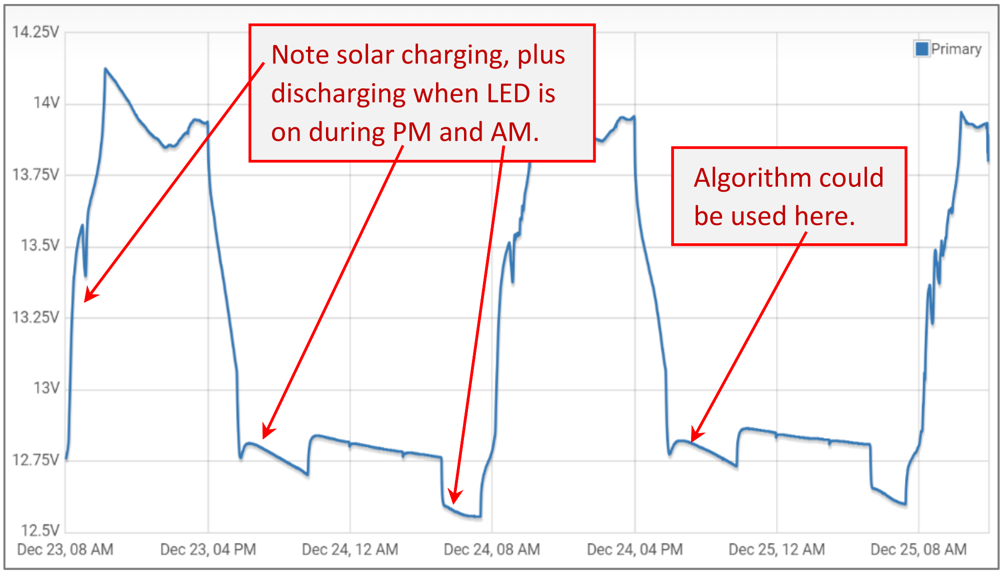
Conceivably, the technique could hasten VLA bank testing by conducting an off-line capacity test for each string using *only* a 2-hour discharge. However, this would not be a valid IEEE-450[3] capacity test. Nor is it intended to replace an IEEE-1188[4] discharge test or impedance testing. Impedance testing is required to detect cell dry-out, a condition specific to valve-regulated lead-acid (VRLA) batteries, when it runs out of usable electrolyte in contact with the plates

If the algorithm is built into a permanent voltage monitor, it can opportunistically detect premature failure such as shorts when a sudden voltage dip occurs. Similarly, if the discharge is extended enough such that the voltage collapses on the dried-out cell, the algorithm can detect it.[2]

In another application, a permanent voltage monitor could track a VLA battery bank nearing the end of its useful life, recording all discharges and helping understand when the batteries have reached 80% of rated capacity.

A more apt use case is pictured in Figure 2 – a simple IoT[3] volt meter to track capacity in solar LED lighting applications[4]. It's not as critical as telecom, but there are serious logistics problems with distributed sites when fines incur for outages, as in transportation and outdoor advertising lighting applications.

Figure 2
Retrofit Volt Meter
Solar LED Bus-Stop



Note solar charging, plus discharging when LED is on during PM and AM.

Algorithm could be used here.

Figure 3
Battery Voltage History for Solar Charging and LED Illumination

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[3] Internet-of-Things (IoT); the idea that common things such as a battery can have a *digital presence* in the cloud.

[4] The author wishes to thank MJ Hollister & Associates, LLC for the picture and data.

Gauge Explained

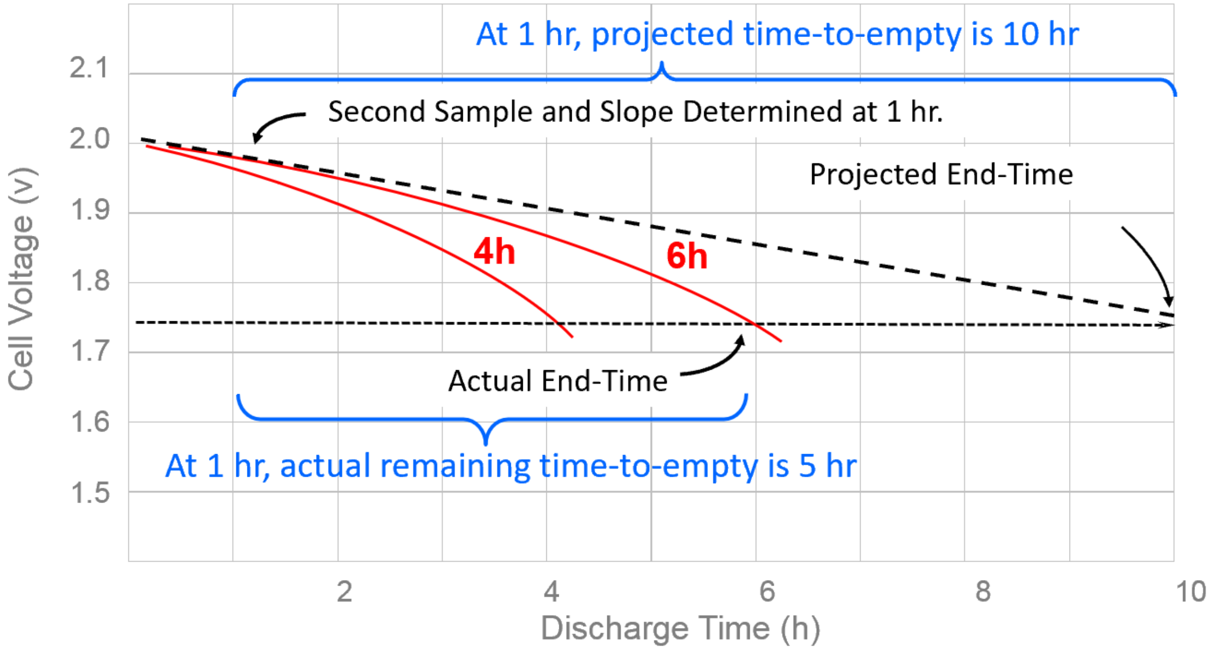
Unlike other methods, the novelty of the voltage-slope fuel gauge is that battery current is not required. In contrast, typical fuel gauges treat a battery like an energy bucket requiring current measurement to totalize coulombs. But measuring current can be costly and is not always possible in power systems.

Moreover, gauges based on software models are inherently complex with variables like efficiency and aging factors. Invariably then, when presented a *current-less, coulomb-less* fuel gauge the initial reaction is disbelief.

Yet, intuitively we know a relationship exists between the battery load current and reserve time. It is seen in battery curve tables with the various sloped curves at different discharge rates. A defined relationship between voltage-slope and reserve time is what O'Sullivan empirically determined and codified.

The basic relationship can be understood by looking at Figure 4[5] while considering the following:

1. The slope of the voltage (dashed line) steepens with increasing discharge rates (e.g. 4h vs. 6h).
2. During discharge, the slope *projects* a line that intersects the desired end-voltage (e.g. 1.75 vpc).
3. At one hour, the *projected* line crosses the end-voltage at a multiple of the actual end time.
4. For the six-hour rate, the projected line intersects the 1.75 vpc around 10 hours
5. The predicted remaining time is (10 hr / 2.00) = 5 hours and total capacity is 1 + 5 = 6 hours.



Depiction of Voltage-Slope Relationship
Figure 4

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[5] The chart appeared in my 2018 Battcon paper but was not annotated showing actual and projected duration.

Gauge Methods

The patent actually defines three variants of the algorithm. The basic technique described on the previous page using 2.00 as the division factor is defined as **Method 1.** A *refinement* of the technique known as **Method 2** lists division factors for predetermined end-voltages shown in Figure 5.

An iterative, self-calibrating aspect is defined as **Method 3**, which improves reserve time predictions as the end-voltage approaches.

End Vpc	Divisor
2.15	1.005
2.10	1.01
2.05	1.02
2.00	1.05
1.95	1.10
1.93	1.15
1.90	1.25
1.85	1.50
1.80	1.70
1.75	2.00
1.70	2.60
1.65	3.20

Table 10 from
US 6,211,634
Figure 5

Adoption in Operator Rundown Tests

Prior to the patent publishing, some operators interested in trending capacity began using Method 1 with their annual rundown tests. This is because a standard off-line 8-hour discharge test is impractical and performing rundown tests is fairly straightforward in a telecom DC power system.

For example, during an annual inspection, a power technician would conduct a rundown test, lowering the charger voltage so the battery powers the load. Modern power systems often have a test *mode* to simplify the process of lowering the float voltage for such a test. After the coup de fouet a first voltage reading is taken. Another hour or two later a second reading is taken for the prediction.

Adoption in Power System Controllers

At least two power system vendors incorporated the algorithm into their offerings. There are two basic use cases in a system controller, which are both touched on here. The first use is a time-to-empty gauge; essentially using it as a real-time fuel gauge continually updating reserve time predictions down to the end-voltage.

The second use case is for trending battery capacity and providing a threshold to alarm on *potential* battery end-of-life (e.g. 80%). In this case, the algorithm can operate opportunistically, meaning capacity predictions can be produced automatically from any sufficiently long outage. An opportunistic prediction could obviate the need for an annual rundown test.

Questions about Accuracy

It is understandable to question the accuracy of such a simple algorithm.

Moreover, when the patent published in 2001 it may have inadvertently instilled doubt about the efficacy of the algorithm because the Figure 5 division factors differed from what was in use.

In particular, the patent recommends a <u>1.50</u> division factor for a battery having an end-voltage of 44.40V (1.85 vpc). Meanwhile, a Telco had used <u>2.00</u> during annual rundown tests obtaining reasonable predictions (when compared to estimates based on battery age, relevant curve tables and load).

It's not known if O'Sullivan explained this discrepancy, or if it dissuaded other operators or companies from employing the technique. However, the analysis herein provides an improved understanding of the algorithm, and that it is in fact OK to employ different division factors.

Description of Tests and Source Data

Three discharge datasets[6] were evaluated. Appendix A is an 8-hour discharge down to 1.75 Vpc on a Unigy II 12V AVR95-15 with an 83-amp load. This dataset supplied by the battery manufacturers is the least granular and is used to evaluate the Method 3 self-calibration aspect of the algorithm.

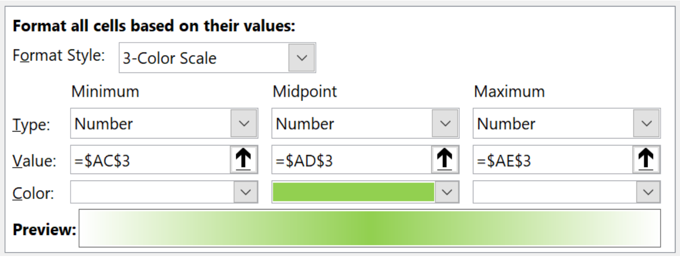
Appendix B is a 2-hour Telco rundown test (having a 1.85 Vpc end voltage) performed on a battery consisting of a dozen KS-20472 L-1S round cells and two GU-45 batteries. The measured load was 290 amps. This dataset is used for predicting battery capacity early in a discharge.

The Appendix C dataset[7] is an 8-hour discharge down to 1.85 Vpc for VRS12-215F with a test load of 23.5 amps. This dataset was used to see if the division factors were tuned for an 8-hour discharge.

Process for Analyzing Accuracy

A spreadsheet is used to carry out the analysis and assess accuracy of the algorithm. It is organized to evaluate the effect of different slopes with different division factors. It uses a conditional formatting technique for visual analysis to help reveal situations where a prediction is acceptable.

The conditional formatting rule is basic and appears as follows:



Format all cells based on their values:

Format Style: 3-Color Scale

	Minimum	Midpoint	Maximum
Type:	Number	Number	Number
Value:	=$AC$3	=$AD$3	=$AE$3
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Preview:

Figure 6

Conditional Formatting Rule Applied

The conditional formatting helps visualize an important dependency between the prediction accuracy and the voltage slope (the decrease in voltage over the period between the two sample readings).

In the analysis to follow, the maximum conditional formatting value is set to 103% of the actual value, while the minimum for the TTE gauge and CRT are 80% and 90% respectively. The reason for the different percentages follows.

A time-to-empty gauge should be conservative and avoid overestimating the runtime. It is better to be pleasantly surprised when a runtime is longer than expected. It is far worse when a system shutdown happens unexpectedly. This is the primary reason for a relatively tight 103% maximum setting. The minimum settings are somewhat arbitrary but intended to reveal the valid range for when the second sample should be taken.

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[6] The first dataset was supplied by the battery manufacturer and is sampled at a 5-minute rate. The sampling technique (i.e. averaging) and data precision are unknown about the recording device. The next two datasets consist of 1-minute averages, each average composed of one-second readings sampled by a 16-bit A/D converter.

[7] The author acknowledges Battery USA and John Klein of Cogenient for conducting the 8-hour discharge test.

Definitions of Terms

The analysis and spreadsheets in the appendices make use of the following terms:

Slope (Width) – this variable is the time between the voltage samples. The patent does not give specific guidance on how far apart the two samples must be, so one objective of this analysis was to evaluate how the different slope widths effect the algorithm results.

Big changes are fairly normal early into a discharge cycle until the discharge slope "settles down" after the coup de fouet period. In general, longer slope widths can be beneficial in predicting capacity and tend to "average-out" any data imprecision.

One must also be cognizant of the time when both samples are taken, as this affects the slope and hence the prediction.

Time-to-Empty (TTE) – the remaining time to the desired end-voltage computed at the time the second sample is taken. This is analogous to "miles to go" on a car trip computer. When added to the elapsed time on discharge, it results in the following metric.

Calculated Reserve Time (CRT) – this is total predicted battery capacity with units in time (not Amp-Hrs.). It amounts to the TTE + TOD, where TOD is the Time on Discharge when the second reading occurs. The CRT would ordinarily be expected to degrade slowly over the battery life.

As with any useful metric, there are benefits to trending the CRT value. Any significant change may warrant an investigation, especially if the load has not changed appreciably. For example, a big change could indicate a change in battery health or even loose battery strap connections.

Target End Voltage – the intermediate voltage checkpoint (for Method 3) to see how well the battery is performing. The first Vpc checkpoint used in the example in Appendix C is 2.0V (or 48V).

Time-to-Target (TTT) – the predicted time it will take to get to the intermediate target voltage.

Correction Factor – refers to the correction factor defined in Method 3. For improved accuracy, the divisor / end-voltage pairs can be used to compute a correction factor, which can then be used to adjust subsequent predictions. This technique can be used iteratively and is shown in Figure A.2.

TTE Predictions During Full Discharge

In this example, prediction accuracy is examined over the course of an 8-hour discharge down to 42 volts. Per Figure 5, the corresponding 1.75 Vpc end-voltage calls for a division factor of 2.00 and is used for the analysis appearing in Appendix A. A 10-minute slope was used for the TTE computation.

Referring to figure A.1, note how the conditional formatting indicates reserve time predictions become sufficiently accurate around 70% DoD, or about 6 hours into the discharge.

In the final hour, note how many minutes "Off" the prediction is from actual (last column). With one hour remaining, the predictions are off roughly 1 – 2 minutes in general.

There is one anomalous reading at minute 440 when the slope (23 mV drop) *flattened*, affecting the prediction time increasing it to ~10 minutes for two prediction cycles (since a 10m slope is used). But also note when the slope recovers, so does the prediction accuracy. In this sense, the algorithm inherently is self-correcting.

Figure A.2 contains the analysis when the calibration Method 3 is applied. According to the patent “the third method provides a more accurate iterative prediction method derived from the first and second methods. In particular, using the division factors derived for the second method and set forth in Table 10 (Figure 3 in this paper), predictions can be made to any end discharge voltage. In accordance with the third method, predictions for higher end-voltages can then be compared to actual results and the comparison can be used as a correction factor for predictions to lower end-voltages.[1]

Note how the calibrated predictions become acceptable about 2 hours earlier into the discharge. Acceptable predictions occurred earlier, around 50% DoD instead of 70% DoD.

Below is an accuracy perspective using a line-chart. The Y-axis represents the actual minutes to empty, while the X-axis plots the 45 TTE predictions made over the course of the discharge. With an ideal performing gauge, the prediction line would be collinear with the actual (straight line). In this case, note the “Before and After” improvement once the correction factor is introduced.

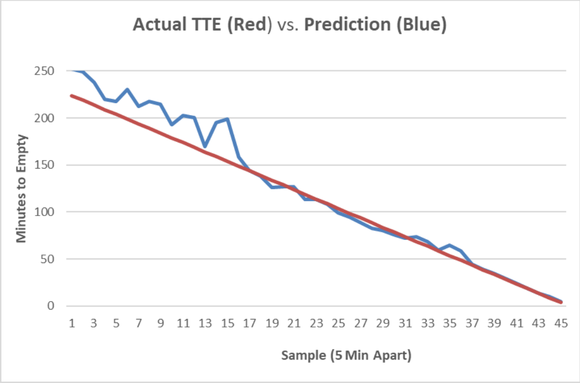

Figure 7
TTE Predictions vs. Actual - Uncorrected

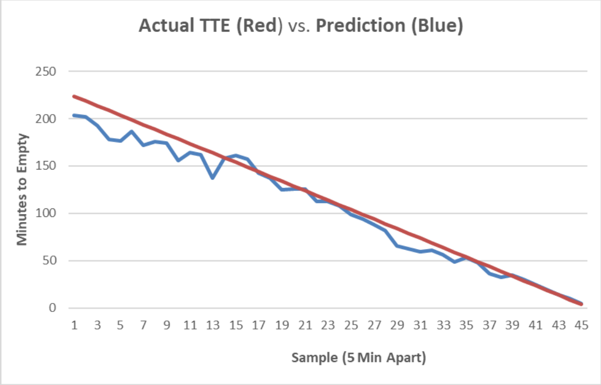

Figure 8
TTE Predictions vs. Actual - Corrected

In a sense, the correction factor attenuates the over-estimation. This helps assure that future reserve time predictions are conservative, which is desirable during a system rundown.

CRT Predictions During Partial Discharge

The previous example explained how the voltage-slope algorithm is more accurate towards the end of a discharge when predicting TTE. The next example evaluates the accuracy of the algorithm when used early in a discharge to predict the CRT. The analysis appears in Appendix B.

In this example, a 2-hour discharge test is used to gauge the capacity of a battery having a 44.40V cutoff. To validate the CRT prediction, it is compared to the expected[8] reserve time, which itself is based on

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[8] The author wishes to thank Curtis Ashton and Century Link for their cooperation in this analysis.

battery curve tables and the measured load current. In this case, based on the manufacturer's tables at midlife (90% capacity) these batteries should last 9 hours and 12 minutes.

Per Figure 3, a 44.40V end-voltage requires a division factor of 1.50 (1.85 Vpc) But as it turns out, the operator was accustomed to using a division factor of 2.00 (Method 1). However, through this analysis it was determined that 2.00 is also valid division factor for this duration test and end-voltage.

Figure B.1 contains the dataset for the first hour (60 samples) of the discharge test. Note the different sections for analysis using slopes ranging from 30 to 60 minutes. The highlighted box denotes the coup de fouet period. No valid prediction regions exist within the first 60 minutes.

Referring to Figure B.2, it appears predictions made with two samples 60m apart and a division factor of 2.00 form a valid test when it concludes at the 120m mark. The analysis also suggests shorter tests can be valid as well. For example, samples taken 30m apart could terminate at the 100-minute mark.

Figure B.3 is the same dataset but uses Method 2 recommended 1.50 division factor. Note how the valid test areas shift. With samples 60m apart the valid test area shifts down (off the chart) and is no longer valid at the 2-hour mark. However, a valid test may be possible when samples are 5m apart. This begs the following question, “What happens when using a *higher* division factor?”

Referring to Figure B.4, note how with a higher 2.50 division factor valid tests appear possible at the 90m mark using samples 30m apart!

Tuning the Algorithm Division Factors

With the ability to shift valid test regions forward and backward timewise, an argument can be made that what O’Sullivan published is but *one* table correlating division factor to end-voltage, and that other valid tables exist.

Furthermore, it could also be said the relationship between end-voltage and division factors is actually a curved line, as depicted in Figure 9. Considering Method 3, this line could also act as a guide *steering* an iterative estimation process toward the end-voltage, allowing for more frequent checkpoints than the handful of division factors in Figure 5.

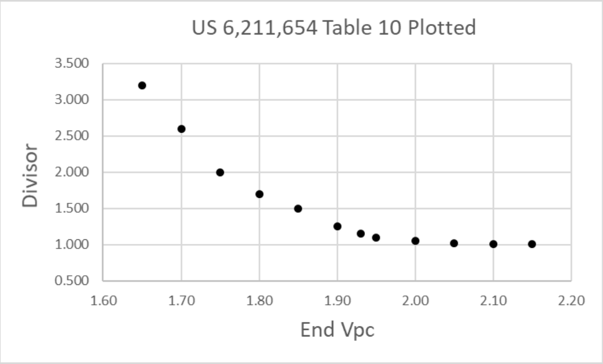


Figure 9
Division Factors vs. End-Voltage

But it does appear O’Sullivan *tuned* the algorithm for an 8-hour discharge as suggested in Appendix C. For an 8-hour rate, Figure C.1 shows that a 2.00 division factor is not optimized for a 1.85 Vpc end voltage; a discharge must hit 88% DoD to achieve 98% accuracy! But with the prescribed 1.50 division factor, the valid test region moves much earlier to 45% DoD to achieve 98% accuracy.

In the quest to acquire valid predictions earlier into a discharge – similar to Appendix B that concluded at 20% DoD – to accomplish that with an 8-hour rate (versus 9.2 Hr), a division factor of 1.65 is required as shown in Figure C.3. This suggests that rate too is an important variable when applying this technique.

Summary and Conclusion

In battery applications, the *charge* voltage is critical for ensuring battery health and is therefore controlled and monitored by the charging system controller. In telecom, *discharge* voltage is also monitored to help track battery capacity over its life. By applying the voltage-slope technique during a rundown test, a capacity estimate is easily obtained and avoids the cost of doing a full discharge test.

Using three examples, this paper examined the accuracy of the algorithm and interplay with four variables: division factor, slope-width, discharge rate and depth. The first example looked at how well predictions tracked over the course of a full discharge cycle. It was shown how predictions become more accurate closer to the end-voltage, plus it was shown how the Method 3 self-calibration aspect can improve the TTE (and hence CRT) predictions.

The second example evaluated predictions made early into a discharge against an expected reserve time (based on load current, age and curve tables). It was shown that for a given end-voltage using a slightly higher division factor shifts the area of valid predictions earlier into a discharge. This may be advantageous for predicting capacity earlier into a discharge.

From the examples shown here, for a given division factor the voltage slope (after the coup de fouet) will project outward to the exact multiple of the eventual end time, thereby making a 100% accurate prediction theoretically possible. The challenge is picking the right set of variables.

One objective of this paper was to understand the discrepancy between the Figure 5 division factors and what was in use by operators at the time the patent published. As was shown, the discrepancy in division factors does not affect the utility of the general voltage-slope technique. From the analysis, it is clear other division factors can be used depending on the desired objective.

For capacity trending, finding the desired *sweet-spot* and taking measurements consistently over the battery life is critical. As a reference, a good starting point would be to pull out 20% of the energy as shown in the second example.

Though seemingly crude, the O'Sullivan algorithm is based on simple physics and is an intriguing natural phenomenon. As with a natural resource like crude oil, a refined understanding can harness its potential.

With the expected proliferation of lead-acid batteries in energy storage cycling applications such as solar LED lighting, the voltage-slope algorithm would be valuable for trending battery reserve capacity using a non-invasive and scientific approach.

Further Research

The author would like to acquire other 8-hour discharge datasets comparable to the VRLA dataset in Appendix C. One intention is to understand how the prediction accuracy might vary among battery types (VLA , AGM, Gel etc.).

A second intention is to further validate the idea that the division factors were *tuned* for an 8-hour discharge curve.

References

1. Thomas D. O’Sullivan, “Method for Predicting Battery Capacity”. U.S. Patent 6,211,654 issued April 3, 2001.

2. David F. Essi III, “Time (Only) Referenced Rundown Test”, proceedings of Battcon 2018.

3. IEEE Std 450-2010, Recommended Practice for Maintenance, Testing and Replacement of Vented Lead-Acid Batteries for Stationary Applications

4. IEEE Std 1188-2005, Recommended Practice for Maintenance, Testing and Replacement of Valve-Regulated (VRLA) Lead-Acid Batteries for Stationary Applications

Appendix A – Full Discharge Test to Vpc = 1.75

OUTPUT section includes three calculations using different slope widths – 10, 20- and 30-minutes. Columns include TTE and CRT predictions in minutes and slope (m). The % Act compares CRT to actual time.

CALIBRATION and CORRECTED TTE sections explained on chart A1.2 where the correction factor CorF is computed.

INPUT section includes Depth of Discharge, time of reading, millivolt reading, mV delta from prior reading and Vpc equivalent.

The % Act divides the CRT prediction by the actual. If the prediction over-estimates the actual, the accuracy is > 100%. If the prediction under-estimates the actual, the accuracy < 100%.

Takeaway: predictions become accurate around 75% DoD, or 6 hours into discharge.

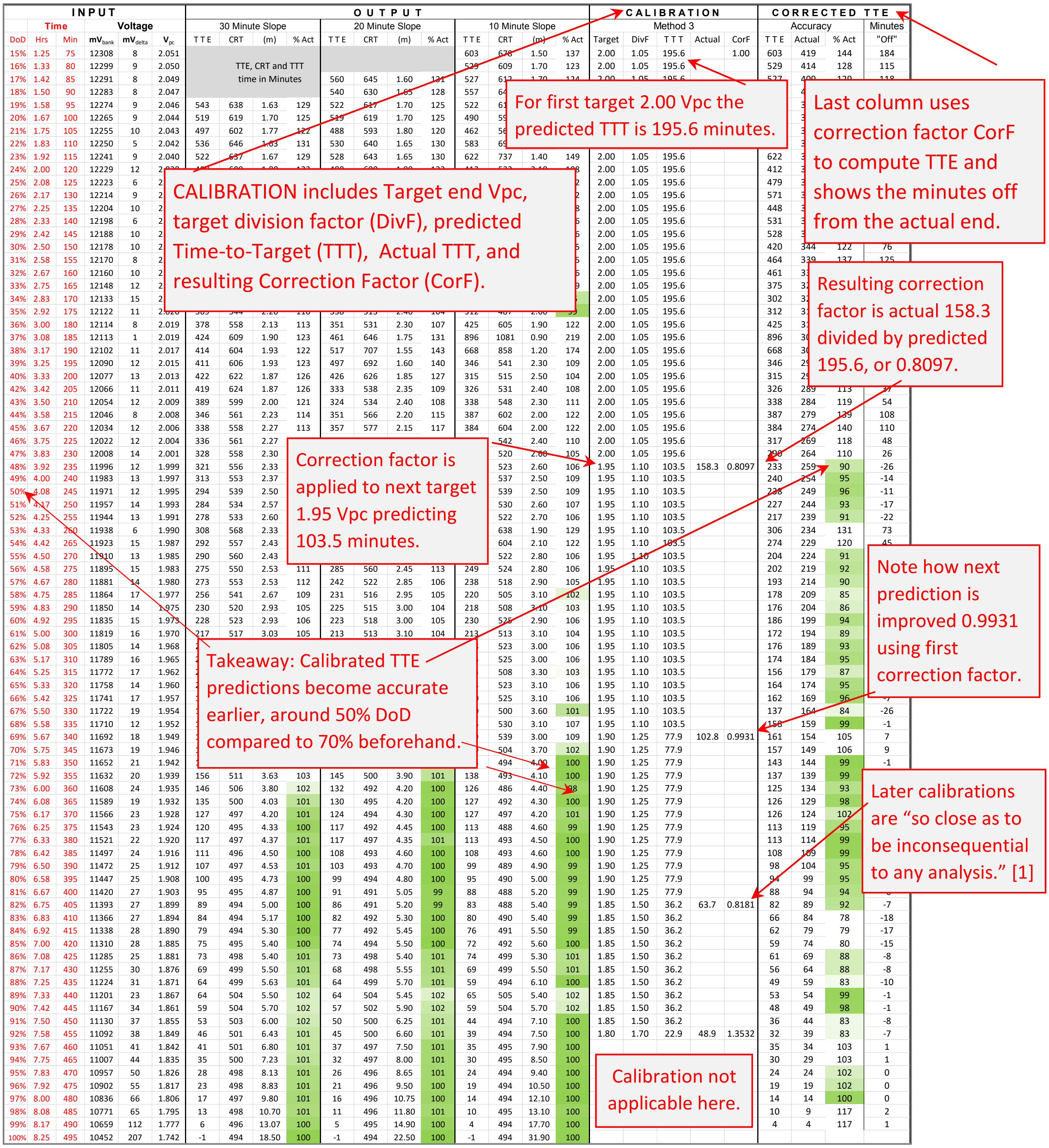
INPUT						OUTPUT												CALIBRATION					CORRECTED TTE			
	Time		Voltage			30 Minute Slope				20 Minute Slope				10 Minute Slope				Method 3					Accuracy			Min.
DoD	Hrs	Min	mV_{bank}	mV_{delta}	V_{pc}	TTE	CRT	(m)	% Act	TTE	CRT	(m)	% Act	TTE	CRT	(m)	% Act	Target	DivF	TTT	Actual	CorF	TTE	Actual	% Act	"Off"
15%	1.25	75	12308	8	2.051		TTE, CRT and TTT time in Minutes							603	678	1.50	137	2.00	1.05	195.6			603	419	144	184
16%	1.33	80	12299	9	2.050									529	609	1.70	123	2.00	1.05	195.6			529	414	128	115
17%	1.42	85	12291	8	2.049					560	645	1.60	131	527	612	1.70	124	2.00	1.05	195.6			527	409	129	118
18%	1.50	90	12283	8	2.047					540	630	1.65	128	557	647	1.60	131	2.00	1.05	195						
19%	1.58	95	12274	9	2.046	543													5	195						
20%	1.67	100	12265	9	2.044	519													5	195						
21%	1.75	105	12255	10	2.043	497													5	195						
22%	1.83	110	12250	5	2.042	536													5	195						
23%	1.92	115	12241	9	2.040	522													5	195						
24%	2.00	120	12229	12	2.038	480													5	195						
25%	2.08	125	12223	6	2.037	507													5	195						
26%	2.17	130	12214	9	2.036	504													5	195						
27%	2.25	135	12204	10	2.034	501													5	195						
28%	2.33	140	12198	6	2.033	490													5	195.6			531	354	150	177
29%	2.42	145	12188	10	2.031	478													5	195.6			528	349	151	179
30%	2.50	150	12178	10	2.030	494													5	195.6			420	344	122	76
31%	2.58	155	12170	8	2.028	473													5	195.6			464	339	137	125
32%	2.67	160	12160	10	2.027	461	621	1.80	126	437	597	1.90	121	461	621	1.80	126	2.00	1.05	195.6			461	334	138	127
33%	2.75	165	12148	12	2.025	441	606	1.87	123	412	577	2.00	117	375	540	2.20	109	2.00	1.05	195.6			375	329	114	46
											533	2.25	108	302	472	2.70	96	2.00	1.05	195.6			302	324	93	-21
											513	2.40	104	312	487	2.60	99	2.00	1.05	195.6			312	319	98	-7
											531	2.30	107	425	605	1.90	122	2.00	1.05	195.6			425	314	135	111
											646	1.75	131	896	1081	0.90	219	2.00	1.05	195.6			896	309	290	587
											707	1.55													220	364
											692	1.60													116	47
											626	1.85													107	22
											538	2.35													113	37
43%	3.50	210	12054	12	2.009	389	599	2.00	121	324	534	2.40													119	54
44%	3.58	215	12046	8	2.008	346	561	2.23	114	351	566	2.20													139	108
45%	3.67	220	12034	12	2.006	338	558	2.27	113	357	577	2.15													140	110
46%	3.75	225	12022	12	2.004	336	561	2.27	114	346	571	2.20													118	48
47%	3.83	230	12008	14	2.001	328	558	2.30	113	328	558	2.30													110	26
48%	3.92	235	11996	12	1.999	321	556	2.33	113	299	534	2.50													111	29
49%	4.00	240	11983	13	1.997	313	553	2.37	112	291	531	2.55													117	43
50%	4.08	245	11971	12	1.995	294	539	2.50	109	288	533	2.55													118	45
51%	4.17	250	11957	14	1.993	284	534	2.57	108	286	536	2.55													115	36
52%	4.25	255	11944	13	1.991	278	533	2.60	108	278	533	2.60	108	267	522	2.70	106	1.95	1.10	103.5			267	239	112	29
53%	4.33	260	11938	6	1.990	308	568	2.33	115	320	580	2.25	117	378	638	1.90	129	1.95	1.10	103.5			378	234	162	145
54%	4.42	265	11923	15	1.987	292	557	2.43	113	296	561	2.40	114	339	604	2.10	122	1.95	1.10	103.5			339	229	148	110
55%	4.50	270							113	300	570	2.35	115	252	522	2.80	106	1.95	1.10	103.5			252	224	112	28
56%	4.58	275							111	285	560	2.45	113	249	524	2.80	106	1.95	1.10	103.5			249	219	114	30
57%	4.67	280							112	242	522	2.85	106	238	518	2.90	105	1.95	1.10	103.5			238	214	111	24
58%	4.75	285							109	231	516	2.95	105	220	505	3.10	102	1.95	1.10	103.5			220	209	105	11
59%	4.83	290							105	225	515	3.00	104	218	508	3.10	103	1.95	1.10	103.5			218	204	107	14
60%	4.92	295							106	223	518	3.00	105	230	525	2.90	106	1.95	1.10	103.5			230	199	116	31
61%	5.00	300							105	213	513	3.10	104	213	513	3.10	104	1.95	1.10	103.5			213	194	110	19
62%	5.08	305							106	221	526	2.95	107	218	523	3.00	106	1.95	1.10	103.5			218	189	115	29
63%	5.17	310							105	211	521	3.05	106	215	525	3.00	106	1.95	1.10	103.5			215	184	117	31
64%	5.25	315	11772	17	1.962	207	522	3.07	106	202	517	3.15	105	193	508	3.30	103	1.95	1.10	103.5			193	179	108	14
65%	5.33	320	11758	14	1.960	205	525	3.07	106	206	526	3.05	107	203	523	3.10	106	1.95	1.10	103.5			203	174	117	29
66%	5.42	325	11741	17	1.957	198	523	3.13	106	194	519	3.20	105	200	525	3.10	106	1.95	1.10	103.5			200	169	119	31
67%	5.50	330	11722	19	1.954	189	519	3.23	105	182	512	3.35	104	170	500	3.60	101	1.95	1.10	103.5			170	164	104	6
68%	5.58	335	11710	12	1.952	191	526	3.17	107	195	530	3.10	107	195	530	3.10	107	1.95	1.10	103.5			195	159	123	36
69%	5.67	340	11692	18	1.949	184	524	3.23	106	181	521	3.30	105	199	539	3.00	109	1.90	1.25	77.9			199	154	129	45
70%	5.75	345	11673	19	1.946	178	523	3.30	106	173	518	3.40	105	159	504	3.70	102	1.90	1.25	77.9			159	149	106	10
71%	5.83	350	11652	21	1.942	163	513	3.53	104	165	515	3.50	104	144	494	4.00	100	1.90	1.25	77.9			144	144	100	0
72%	5.92	355	11632	20	1.939	156	511	3.63	103	145	500	3.90	101	138	493	4.10	100	1.90	1.25	77.9			138	139	99	-1
73%	6.00	360	11608	24	1.935	146	506	3.80	102	132	492	4.20	100	126	486	4.40	98	1.90	1.25	77.9			126	134	94	-8
74%	6.08	365	11589	19	1.932	135	500	4.03	101	130	495	4.20	100	127	492	4.30	100	1.90	1.25	77.9			127	129	98	-2
75%	6.17	370	11566	23	1.928	127	497	4.20	101	124	494	4.30	100	127	497	4.20	101	1.90	1.25	77.9			127	124	102	3
76%	6.25	375	11543	23	1.924	120	495	4.33	100	117	492	4.45	100	113	488	4.60	99	1.90	1.25	77.9			113	119	95	-5
77%	6.33	380	11521	22	1.920	117	497	4.37	101	117	497	4.35	101	113	493	4.50	100	1.90	1.25	77.9			113	114	100	0
78%	6.42	385	11497	24	1.916	111	496	4.50	100	108	493	4.60	100	108	493	4.60	100	1.90	1.25	77.9			108	109	100	0
79%	6.50	390	11472	25	1.912	107	497	4.53	101	103	493	4.70	100	99	489	4.90	99	1.90	1.25	77.9			99	104	96	-5
80%	6.58	395	11447	25	1.908	100	495	4.73	100	99	494	4.80	100	95	490	5.00	99	1.90	1.25	77.9			95	99	96	-4
81%	6.67	400	11420	27	1.903	95	495	4.87	100	91	491	5.05	99	88	488	5.20	99	1.90	1.25	77.9			88	94	94	-5
82%	6.75	405	11393	27	1.899	89	494	5.00	100	86	491	5.20	99	83	488	5.40	99	1.85	1.50	36.2			83	89	93	-6
83%	6.83	410	11366	27	1.894	84	494	5.17	100	82	492	5.30	100	80	490	5.40	99	1.85	1.50	36.2			80	84	96	-4
84%	6.92	415	11338	28	1.890	79	494	5.30	100	77	492	5.45	100	76	491	5.50	99	1.85	1.50	36.2			76	79	97	-3
85%	7.00	420	11310	28	1.885	75	495	5.40	100	74	494	5.50	100	72	492	5.60	100	1.85	1.50	36.2			72	74	98	-2
86%	7.08	425	11285	25	1.881	73	498	5.40	101	73	498	5.40	101	74	499	5.30	101	1.85	1.50	36.2			74	69	108	5
87%	7.17	430	11255	30	1.876	69	499	5.50	101	68	498	5.55	101	69	499	5.50	101	1.85	1.50	36.2			69	64	108	5
88%	7.25	435	11224	31	1.871	64	499	5.63	101	64	499	5.70	101	59	494	6.10	100	1.85	1.50	36.2			59	59	101	1
89%	7.33	440	11201	23	1.867	64	504	5.50	102	64	504	5.45	102	65	505	5.40	102	1.85	1.50	36.2			65	54	121	11
90%	7.42	445	11167	34	1.861	59	504	5.70	102	57	502	5.90	102	59	504	5.70	102	1.85	1.50	36.2			59	49	120	10
91%	7.50	450	11130	37	1.855	53	503	6.00	102	50	500	6.25	101	44	494	7.10	100	1.85	1.50	36.2			44	44	101	1
92%	7.58	455	11092	38	1.849	46	501	6.43	101	45	500	6.60	101	39	494	7.50	100	1.80	1.70	22.9			39	39	102	1
93%	7.67	460	11051	41	1.842	41	501	6.80	101	37	497	7.50	101	35	495	7.90	100						35	34	103	1
94%	7.75	465	11007	44	1.835	35	500	7.23	101	32	497	8.00	101	30	495	8.50	100						30	29	103	1
95%	7.83	470	10957	50	1.826	28	498	8.13	101	26	496	8.65	101	24	494	9.40	100						24	24	102	0
96%	7.92	475	10902	55	1.817	23	498	8.83	101	21	496	9.50	100	19	494	10.50	100						19	19	102	0
97%	8.00	480	10836	66	1.806	17	497	9.80	101	16	496	10.75	100	14	494	12.10	100						14	14	100	0
98%	8.08	485	10771	65	1.795	13	498	10.70	101	11	496	11.80	101	10	495	13.10	100						10	9	117	2
99%	8.17	490	10659	112	1.777	6	496	13.07	100	5	495	14.90	100	4	494	17.70	100						4	4	117	1
100%	8.25	495	10452	207	1.742	-1	494	18.50	100	-1	494	22.50	100	-1	494	31.90	100									

Figure A.1

Standard Method 2 Predictions

Division Factor **2.00**, Actual Reserve: 8.2 Hr.

Appendix A – Full Discharge Test to Vpc = 1.75



INPUT						OUTPUT												CALIBRATION					CORRECTED TTE			
	Time		Voltage			30 Minute Slope				20 Minute Slope				10 Minute Slope				Method 3					Accuracy			Minutes
DoD	Hrs	Min	mV_{bank}	mV_{delta}	V_{pc}	TTE	CRT	(m)	% Act	TTE	CRT	(m)	% Act	TTE	CRT	(m)	% Act	Target	DivF	TTT	Actual	CorF	TTE	Actual	% Act	"Off"
15%	1.25	75	12308	8	2.051	TTE, CRT and TTT time in Minutes								603	678	1.50	137	2.00	1.05	195.6		1.00	603	419	144	184
16%	1.33	80	12299	9	2.050									529	609	1.70	123	2.00	1.05	195.6			529	414	128	115
17%	1.42	85	12291	8	2.049					560	645	1.60	131	527	612	1.70	124	2.00	1.05	195.6			527	409	129	118
18%	1.50	90	12283	8	2.047					540	630	1.65	128	557	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
19%	1.58	95	12274	9	2.046	543	638	1.63	129	522	617	1.70	125	522	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20%	1.67	100	12265	9	2.044	519	619	1.70	125	519	619	1.70	125	490	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
21%	1.75	105	12255	10	2.043	497	602	1.77	122	488	593	1.80	120	462	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
22%	1.83	110	12250	5	2.042	536	646	1.63	131	530	640	1.65	130	583	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
23%	1.92	115	12241	9	2.040	522	637	1.67	129	528	643	1.65	130	622	737	1.40	149	2.00	1.05	195.6			622	[illegible]	[illegible]	[illegible]
24%	2.00	120	12229	12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.00	1.05	195.6			412	[illegible]	[illegible]	[illegible]
25%	2.08	125	12223	6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.00	1.05	195.6			479	[illegible]	[illegible]	[illegible]
26%	2.17	130	12214	9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.00	1.05	195.6			571	[illegible]	[illegible]	[illegible]
27%	2.25	135	12204	10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.00	1.05	195.6			448	[illegible]	[illegible]	[illegible]
28%	2.33	140	12198	6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.00	1.05	195.6			531	[illegible]	[illegible]	[illegible]
29%	2.42	145	12188	10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.00	1.05	195.6			528	[illegible]	[illegible]	[illegible]
30%	2.50	150	12178	10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.00	1.05	195.6			420	344	122	76
31%	2.58	155	12170	8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.00	1.05	195.6			464	339	137	125
32%	2.67	160	12160	10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.00	1.05	195.6			461	[illegible]	[illegible]	[illegible]
33%	2.75	165	12148	12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.00	1.05	195.6			375	[illegible]	[illegible]	[illegible]
34%	2.83	170	12133	15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.00	1.05	195.6			302	[illegible]	[illegible]	[illegible]
35%	2.92	175	12122	11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.00	1.05	195.6			312	[illegible]	[illegible]	[illegible]
36%	3.00	180	12114	8	2.019	378	558	2.13	113	351	531	2.30	107	425	605	1.90	122	2.00	1.05	195.6			425	[illegible]	[illegible]	[illegible]
37%	3.08	185	12113	1	2.019	424	609	1.90	123	461	646	1.75	131	896	1081	0.90	219	2.00	1.05	195.6			896	[illegible]	[illegible]	[illegible]
38%	3.17	190	12102	11	2.017	414	604	1.93	122	517	707	1.55	143	668	858	1.20	174	2.00	1.05	195.6			668	[illegible]	[illegible]	[illegible]
39%	3.25	195	12090	12	2.015	411	606	1.93	123	497	692	1.60	140	346	541	2.30	109	2.00	1.05	195.6			346	[illegible]	[illegible]	[illegible]
40%	3.33	200	12077	13	2.013	422	622	1.87	126	426	626	1.85	127	315	515	2.50	104	2.00	1.05	195.6			315	[illegible]	[illegible]	[illegible]
42%	3.42	205	12066	11	2.011	419	624	1.87	126	333	538	2.35	109	326	531	2.40	108	2.00	1.05	195.6			326	289	113	[illegible]
43%	3.50	210	12054	12	2.009	389	599	2.00	121	324	534	2.40	108	338	548	2.30	111	2.00	1.05	195.6			338	284	119	54
44%	3.58	215	12046	8	2.008	346	561	2.23	114	351	566	2.20	115	387	602	2.00	122	2.00	1.05	195.6			387	279	139	108
45%	3.67	220	12034	12	2.006	338	558	2.27	113	357	577	2.15	117	384	604	2.00	122	2.00	1.05	195.6			384	274	140	110
46%	3.75	225	12022	12	2.004	336	561	2.27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	542	2.40	110	2.00	1.05	195.6			317	269	118	48
47%	3.83	230	12008	14	2.001	328	558	2.30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	520	2.60	105	2.00	1.05	195.6			290	264	110	26
48%	3.92	235	11996	12	1.999	321	556	2.33	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	523	2.60	106	1.95	1.10	103.5	158.3	0.8097	233	259	90	-26
49%	4.00	240	11983	13	1.997	313	553	2.37	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	537	2.50	109	1.95	1.10	103.5			240	254	95	-14
50%	4.08	245	11971	12	1.995	294	539	2.50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	539	2.50	109	1.95	1.10	103.5			238	249	96	-11
51%	4.17	250	11957	14	1.993	284	534	2.57	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	530	2.60	107	1.95	1.10	103.5			227	244	93	-17
52%	4.25	255	11944	13	1.991	278	533	2.60	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	522	2.70	106	1.95	1.10	103.5			217	239	91	-22
53%	4.33	260	11938	6	1.990	308	568	2.33	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	638	1.90	129	1.95	1.10	103.5			306	234	131	73
54%	4.42	265	11923	15	1.987	292	557	2.43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	604	2.10	122	1.95	1.10	103.5			274	229	120	45
55%	4.50	270	11910	13	1.985	290	560	2.43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	522	2.80	106	1.95	1.10	103.5			204	224	91	[illegible]
56%	4.58	275	11895	15	1.983	275	550	2.53	111	285	560	2.45	113	249	524	2.80	106	1.95	1.10	103.5			202	219	92	[illegible]
57%	4.67	280	11881	14	1.980	273	553	2.53	112	242	522	2.85	106	238	518	2.90	105	1.95	1.10	103.5			193	214	90	[illegible]
58%	4.75	285	11864	17	1.977	256	541	2.67	109	231	516	2.95	105	220	505	3.10	102	1.95	1.10	103.5			178	209	85	[illegible]
59%	4.83	290	11850	14	1.975	230	520	2.93	105	225	515	3.00	104	218	508	3.10	103	1.95	1.10	103.5			176	204	86	[illegible]
60%	4.92	295	11835	15	1.973	228	523	2.93	106	223	518	3.00	105	230	525	2.90	106	1.95	1.10	103.5			186	199	94	[illegible]
61%	5.00	300	11819	16	1.970	217	517	3.03	105	213	513	3.10	104	213	513	3.10	104	1.95	1.10	103.5			172	194	89	[illegible]
62%	5.08	305	11805	14	1.968	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	523	3.00	106	1.95	1.10	103.5			176	189	93	[illegible]
63%	5.17	310	11789	16	1.965	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	525	3.00	106	1.95	1.10	103.5			174	184	95	[illegible]
64%	5.25	315	11772	17	1.962	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	508	3.30	103	1.95	1.10	103.5			156	179	87	[illegible]
65%	5.33	320	11758	14	1.960	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	523	3.10	106	1.95	1.10	103.5			164	174	95	[illegible]
66%	5.42	325	11741	17	1.957	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	525	3.10	106	1.95	1.10	103.5			162	169	96	[illegible]
67%	5.50	330	11722	19	1.954	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	500	3.60	101	1.95	1.10	103.5			137	164	84	-26
68%	5.58	335	11710	12	1.952	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	530	3.10	107	1.95	1.10	103.5			158	159	99	-1
69%	5.67	340	11692	18	1.949	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	539	3.00	109	1.90	1.25	77.9	102.8	0.9931	161	154	105	7
70%	5.75	345	11673	19	1.946	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	504	3.70	102	1.90	1.25	77.9			157	149	106	9
71%	5.83	350	11652	21	1.942	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	494	4.00	100	1.90	1.25	77.9			143	144	99	-1
72%	5.92	355	11632	20	1.939	156	511	3.63	103	145	500	3.90	101	138	493	4.10	100	1.90	1.25	77.9			137	139	99	[illegible]
73%	6.00	360	11608	24	1.935	146	506	3.80	102	132	492	4.20	100	126	486	4.40	98	1.90	1.25	77.9			125	134	93	[illegible]
74%	6.08	365	11589	19	1.932	135	500	4.03	101	130	495	4.20	100	127	492	4.30	100	1.90	1.25	77.9			126	129	98	[illegible]
75%	6.17	370	11566	23	1.928	127	497	4.20	101	124	494	4.30	100	127	497	4.20	101	1.90	1.25	77.9			126	124	102	[illegible]
76%	6.25	375	11543	23	1.924	120	495	4.33	100	117	492	4.45	100	113	488	4.60	99	1.90	1.25	77.9			113	119	95	[illegible]
77%	6.33	380	11521	22	1.920	117	497	4.37	101	117	497	4.35	101	113	493	4.50	100	1.90	1.25	77.9			113	114	99	[illegible]
78%	6.42	385	11497	24	1.916	111	496	4.50	100	108	493	4.60	100	108	493	4.60	100	1.90	1.25	77.9			108	109	99	[illegible]
79%	6.50	390	11472	25	1.912	107	497	4.53	101	103	493	4.70	100	99	489	4.90	99	1.90	1.25	77.9			98	104	95	[illegible]
80%	6.58	395	11447	25	1.908	100	495	4.73	100	99	494	4.80	100	95	490	5.00	99	1.90	1.25	77.9			94	99	95	[illegible]
81%	6.67	400	11420	27	1.903	95	495	4.87	100	91	491	5.05	99	88	488	5.20	99	1.90	1.25	77.9			88	94	94	[illegible]
82%	6.75	405	11393	27	1.899	89	494	5.00	100	86	491	5.20	99	83	488	5.40	99	1.85	1.50	36.2	63.7	0.8181	82	89	92	-7
83%	6.83	410	11366	27	1.894	84	494	5.17	100	82	492	5.30	100	80	490	5.40	99	1.85	1.50	36.2			66	84	78	-18
84%	6.92	415	11338	28	1.890	79	494	5.30	100	77	492	5.45	100	76	491	5.50	99	1.85	1.50	36.2			62	79	79	-17
85%	7.00	420	11310	28	1.885	75	495	5.40	100	74	494	5.50	100	72	492	5.60	100	1.85	1.50	36.2			59	74	80	-15
86%	7.08	425	11285	25	1.881	73	498	5.40	101	73	498	5.40	101	74	499	5.30	101	1.85	1.50	36.2			61	69	88	-8
87%	7.17	430	11255	30	1.876	69	499	5.50	101	68	498	5.55	101	69	499	5.50	101	1.85	1.50	36.2			56	64	88	-8
88%	7.25	435	11224	31	1.871	64	499	5.63	101	64	499	5.70	101	59	494	6.10	100	1.85	1.50	36.2			49	59	83	-10
89%	7.33	440	11201	23	1.867	64	504	5.50	102	64	504	5.45	102	65	505	5.40	102	1.85	1.50	36.2			53	54	99	-1
90%	7.42	445	11167	34	1.861	59	504	5.70	102	57	502	5.90	102	59	504	5.70	102	1.85	1.50	36.2			48	49	98	-1
91%	7.50	450	11130	37	1.855	53	503	6.00	102	50	500	6.25	101	44	494	7.10	100	1.85	1.50	36.2			36	44	83	-8
92%	7.58	455	11092	38	1.849	46	501	6.43	101	45	500	6.60	101	39	494	7.50	100	1.80	1.70	22.9	48.9	1.3532	32	39	83	-7
93%	7.67	460	11051	41	1.842	41	501	6.80	101	37	497	7.50	101	35	495	7.90	100						35	34	103	1
94%	7.75	465	11007	44	1.835	35	500	7.23	101	32	497	8.00	101	30	495	8.50	100						30	29	103	1
95%	7.83	470	10957	50	1.826	28	498	8.13	101	26	496	8.65	101	24	494	9.40	100						24	24	102	0
96%	7.92	475	10902	55	1.817	23	498	8.83	101	21	496	9.50	100	19	494	10.50	100						19	19	102	0
97%	8.00	480	10836	66	1.806	17	497	9.80	101	16	496	10.75	100	14	494	12.10	100						14	14	100	0
98%	8.08	485	10771	65	1.795	13	498	10.70	101	11	496	11.80	101	10	495	13.10	100						10	9	117	2
99%	8.17	490	10659	112	1.777	6	496	13.07	100	5	495	14.90	100	4	494	17.70	100						4	4	117	1
100%	8.25	495	10452	207	1.742	-1	494	18.50	100	-1	494	22.50	100	-1	494	31.90	100									

For first target 2.00 Vpc the predicted TTT is 195.6 minutes.

Last column uses correction factor CorF to compute TTE and shows the minutes off from the actual end.

CALIBRATION includes Target end Vpc, target division factor (DivF), predicted Time-to-Target (TTT), Actual TTT, and resulting Correction Factor (CorF).

Resulting correction factor is actual 158.3 divided by predicted 195.6, or 0.8097.

Correction factor is applied to next target 1.95 Vpc predicting 103.5 minutes.

Note how next prediction is improved 0.9931 using first correction factor.

Takeaway: Calibrated TTE predictions become accurate earlier, around 50% DoD compared to 70% beforehand.

Later calibrations are "so close as to be inconsequential to any analysis." [1]

Calibration not applicable here.

Figure A.2

Corrected Test

Division Factor **2.00**, Actual Reserve: 8.2 Hr.

Appendix B – *Partial* Discharge, End Vpc = 1.85

INPUT					OUTPUT															
	Time	Voltage			60 Minute Slope				50 Minute Slope				40 Minute Slope				30 Minute Slope			
DoD	Min.	mV_{bank}	mV_{delta}	V_{pc}	TTE	CRT	(m)	% Act	TTE	CRT	(m)	% Act	TTE	CRT	(m)	% Act	TTE	CRT	(m)	% Act
0%	0	48293		2.012																
0%	1	46756	1537	1.948																
0%	2	47009	-253	1.959																
1%	3	47165	-156	1.965																
1%	4	47227	-62	1.968																
1%	5	47267	-40	1.969																
1%	6	47298	-31	1.971																
1%	7	47324	-26	1.972																
1%	8	47344	-20	1.973																
2%	9	47362	-18	1.973																
2%	10	47378	-16	1.974																
2%	11	47362	16	1.973																
2%	12	47378	-16	1.974																
2%	13	47392	-14	1.975																
3%	14	47406	-14	1.975																
3%	15	47418	-12	1.976																
3%	16	47427	-9	1.976																
3%	17	47437	-10	1.977																
3%	18	47447	-10	1.977																
3%	19	47455	-8	1.977																
4%	20	47463	-8	1.978																
4%	21	47471	-8	1.978																
4%	22	47477	-6	1.978																
4%	23	47483	-6	1.978																
4%	24	47489	-6	1.979																
5%	25	47493	-4	1.979																
5%	26	47497	-4	1.979																
5%	27	47503	-6	1.979																
5%	28	47505	-2	1.979																
5%	29	47509	-4	1.980																
5%	30	47513	-4	1.980																
6%	31	47515	-2	1.980																
6%	32	47517	-2	1.980																
6%	33	47519	-2	1.980																
6%	34	47521	-2	1.980																
6%	35	47523	-2	1.980																
7%	36	47523	0	1.980																
7%	37	47525	-2	1.980																
7%	38	47527	-2	1.980																
7%	39	47527	0	1.980																
7%	40	47529	-2	1.980																
7%	41	47529	0	1.980																
8%	42	47531	-2	1.980																
8%	43	47531	0	1.980																
8%	44	47531	0	1.980																
8%	45	47531	0	1.980																
8%	46	47531	0	1.980																
9%	47	47531	0	1.980																
9%	48	47531	0	1.980																
9%	49	47531	0	1.980																
9%	50	47529	2	1.980																
9%	51	47529	0	1.980																
9%	52	47527	2	1.980																
10%	53	47527	0	1.980																
10%	54	47525	2	1.980																
10%	55	47525	0	1.980																
10%	56	47523	2	1.980																
10%	57	47521	2	1.980																
11%	58	47521	0	1.980																
11%	59	47519	2	1.980																
11%	60	47517	2	1.980																
11%	61	47515	2	1.980																
11%	62	47513	2	1.980																
11%	63	47513	0	1.980																
12%	64	47511	2	1.980																
12%	65	47509	2	1.980																

Predictions not valid until after coup de fouet.

Plateau of coup de fouet.

First reading could be sampled here, or 10 minutes after coup de fouet.

Figure B.1

Partial Discharge 1st Hour

Division Factor **2.00**, Expected Reserve: 9.2 Hr.

Appendix B – *Partial* Discharge, End Vpc = 1.85

INPUT					OUTPUT															
	Time	**Voltage**			60 Minute Slope				50 Minute Slope				40 Minute Slope				30 Minute Slope			
DoD	Min.	**mV_{bank}**	**mV_{delta}**	**V_{pc}**	TTE	CRT	(m)	% Act	TTE	CRT	(m)	% Act	TTE	CRT	(m)	% Act	TTE	CRT	(m)	% Act
11%	59	47519	2	1.980																
11%	60	47517	2	1.980																
11%	61	47515	2	1.980																
11%	62	47513	2	1.980																
11%	63	47513	0	1.980																
12%	64	47511	2	1.980																
12%	65	47509	2	1.980																
12%	66	47507	2	1.979																
12%	67	47505	2	1.979																
12%	68	47503	2	1.979																
13%	69	47501	2	1.979																
13%	70	47499	2	1.979																
13%	71	47495	4	1.979																
13%	72	47493	2	1.979																
13%	73	47491	2	1.979																
13%	74	47489	2	1.979																
14%	75	47485	4	1.979													928	1003	1.53	182
14%	76	47483	2	1.978													888	964	1.60	175
14%	77	47481	2	1.978													852	929	1.67	168
14%	78	47477	4	1.978													788	866	1.80	157
14%	79	47475	2	1.978													759	838	1.87	152
14%	80	47473	2	1.978													759	839	1.87	152
15%	81	47469	4	1.978													707	788	2.00	143
15%	82	47467	2	1.978													707	789	2.00	143
15%	83	47465	2	1.978													683	766	2.07	139
15%	84	47461	4	1.978													661	745	2.13	135
15%	85	47459	2	1.977									783	868	1.80	157	641	726	2.20	131
16%	86	47455	4	1.977									741	827	1.90	150	621	707	2.27	128
16%	87	47451	4	1.977									703	790	2.00	143	602	689	2.33	125
16%	88	47449	2	1.977									685	773	2.05	140	585	673	2.40	122
16%	89	47445	4	1.977									652	741	2.15	134	569	658	2.47	119
16%	90	47443	2	1.977									652	742	2.15	134	568	658	2.47	119
16%	91	47439	4	1.977									622	713	2.25	129	552	643	2.53	117
17%	92	47435	4	1.976									608	700	2.30	127	538	630	2.60	114
17%	93	47433	2	1.976									594	687	2.35	125	524	617	2.67	112
17%	94	47429	4	1.976									581	675	2.40	122	510	604	2.73	109
17%	95	47426	3						663	758	2.10	137	563	658	2.48	119	503	598	2.77	108
17%	96	47422	4						638	734	2.18	133	551	647	2.53	117	491	587	2.83	106
18%	97	47420	2						626	723	2.22	131	550	647	2.53	117	491	588	2.83	106
18%	98	47416	4						603	701	2.30	127	529	627	2.63	114	479	577	2.90	104
18%	99	47412	4						582	681	2.38	123	518	617	2.68	112	467	566	2.97	103
18%	100	47408	4						572	672	2.42	122	508	608	2.73	110	456	556	3.03	101
18%	101	47404	4						553	654	2.50	118	498	599	2.78	109	456	557	3.03	101
18%	102	47400	4						543	645	2.54	117	488	590	2.83	107	445	547	3.10	99
19%	103	47398	2	1.975					534	637	2.58	115	480	583	2.88	106	445	548	3.10	99
19%	104	47394	4	1.975					526	630	2.62	114	471	575	2.93	104	435	539	3.17	98
19%	105	47390	4	1.975	585	690	2.35	125	509	614	2.70	111	462	567	2.98	103	434	539	3.17	98
19%	106	47386	4	1.974	568	674	2.42	122	501	607	2.74	110	454	560	3.03	101	425	531	3.23	96
19%	107	47382	4	1.974	552	659	2.48	119	493	600	2.78	109	446	553	3.08	100	415	522	3.30	95
20%	108	47378	4	1.974	537	645	2.55	117	479	587	2.86	106	438	546	3.13	99	415	523	3.30	95
20%	109	47374	4	1.974	522	631	2.62	114	471	580	2.90	105	431	540	3.18	98	406	515	3.37	93
20%	110	47370	4	1.974	515	625	2.65	113	464	574	2.94	104	423	533	3.23	97	398	508	3.43	92
20%	111	47366	4	1.974	502	613	2.72	111	457	568	2.98	103	423	534	3.23	97	397	508	3.43	92
20%	112	47362	4	1.973	495	607	2.75	110	451	563	3.02	102	416	528	3.28	96	389	501	3.50	91
20%	113	47360	2	1.973	489	602	2.78	109	444	557	3.06	101	415	528	3.28	96	389	502	3.50	91
21%	114	47354	6	1.973	476	590	2.85	107	432	546	3.14	99	402	516	3.38	93	380	494	3.57	90
21%	115	47350	4	1.973	465	580	2.92	105	426	541	3.18	98	401	516	3.38	94	373	488	3.63	88
21%	116	47348	2	1.973	464	580	2.92	105	426	542	3.18	98	401	517	3.38	94	380	496	3.57	90
21%	117	47344	4	1.973	458	575	2.95	104	420	537	3.22	97	395	512	3.43	93	379	496	3.57	90
21%	118	47340	4	1.973	448	566	3.02	102	414	532	3.26	96	394	512	3.43	93	372	490	3.63	89
22%	119	47336	4	1.972	442	561	3.05	102	408	527	3.30	96	388	507	3.48	92	371	490	3.63	89
22%	120	47330	6	1.972	432	552	3.12	100	398	518	3.38	94	376	496	3.58	90	357	477	3.77	86

With samples 60 minutes apart, CRT is valid at 120 min mark.

Figure B.2

Partial Discharge 2nd Hour

Division Factor **2.00**, Expected Reserve: 9.2 Hr.

Appendix B – *Partial* Discharge, End Vpc = 1.85

INPUT					OUTPUT															
		Voltage			30 Minute Slope				20 Minute Slope				10 Minute Slope				5 Minute Slope			
DoD	Min.	mV_{bank}	mV_{delta}	V_{pc}	TTE	CRT	(m)	% Act	TTE	CRT	(m)	% Act	TTE	CRT	(m)	% Act	TTE	CRT	(m)	% Act
11%	60	47517	2	1.980													1199	1259	1.60	228
11%	61	47515	2	1.980									1369	1430	1.40	259	1198	1259	1.60	228
11%	62	47513	2	1.980									1368	1430	1.40	259	1197	1259	1.60	228
11%	63	47513	0	1.980									1368	1431	1.40	259	1197	1260	1.60	228
12%	64	47511	2	1.980									1367	1431	1.40	259	1196	1260	1.60	228
12%	65	47509	2	1.980									1195	1260	1.60	228	1195	1260	1.60	228
12%	66	47507	2	1.979									1195	1261	1.60	228	1195	1261	1.60	228
12%	67	47505	2	1.979									1194	1261	1.60	228	1194	1261	1.60	228
12%	68	47503	2	1.979									1060	1128	1.80	204	954	1022	2.00	185
13%	69	47501	2	1.979									1060	1129	1.80	204	954	1023	2.00	185
13%	70	47499	2	1.979									1059	1129	1.80	205	953	1023	2.00	185
13%	71	47495	4	1.979					1120	1191	1.70	216	952	1023	2.00	185	793	864	2.40	157
13%	72	47493	2	1.979					1119	1191	1.70	216	951	1023	2.00	185	793	865	2.40	157
13%	73	47491	2	1.979					1056	1129	1.80	205	864	937	2.20	170	792	865	2.40	157
13%	74	47489	2	1.979					1055	1129	1.80	205	863	937	2.20	170	791	865	2.40	157
14%	75	47485	4	1.979					948	1023	2.00	185	790	865	2.40	157	677	752	2.80	136
14%	76	47483	2	1.978					948	1024	2.00	185	790	866	2.40	157	790	866	2.40	157
14%	77	47481	2	1.978					947	1024	2.00	186	789	866	2.40	157	789	866	2.40	157
14%	78	47477	4	1.978					860	938	2.20	170	727	805	2.60	146	675	753	2.80	136
14%	79	47475	2	1.978					859	938	2.20	170	727	806	2.60	146	675	754	2.80	137
14%	80	47473	2	1.978					858	938	2.20	170	726	806	2.60	146	787	867	2.40	157
15%	81	47469	4	1.978	943	1024	2.00	186	820	901	2.30	163	725	806	2.60	146	674	755	2.80	137
15%	82	47467	2	1.978	942	1024	2.00	186	819	901	2.30	163	725	807	2.60	146	673	755	2.80	137
15%	83	47465	2	1.978	911	994	2.07	180	785	868	2.40	157	724	807	2.60	146	785	868	2.40	157
15%	84	47461	4	1.978	882	966	2.13	175	752	836	2.50	151	672	756	2.80	137	672	756	2.80	137
15%	85	47459	2	1.977	854	939	2.20	170	752	837	2.50	152	723	808	2.60	146	671	756	2.80	137
16%	86	47455	4	1.977	828	914	2.27	166	722	808	2.60	146	670	756	2.80	137	670	756	2.80	137
16%	87	47451	4	1.977	803	890	2.33	161	694	781	2.70	141	625	712	3.00	129	586	673	3.20	122
16%	88	47449	2	1.977	780	868	2.40	157	694	782	2.70	142	669	757	2.80	137	585	673	3.20	122
16%	89	47445	4	1.977	758	847	2.47	153	668	757	2.80	137	623	712	3.00	129	584	673	3.20	122
16%	90	47443	2	1.977	758	848	2.47	154	667	757	2.80	137	623	713	3.00	129	584	674	3.20	122
16%	91	47439	4	1.977	737	828	2.53	150	666	757	2.80	137	622	713	3.00	129	583	674	3.20	122
17%	92	47435	4	1.976	717	809	2.60	146	643	735	2.90	133	582	674	3.20	122	582	674	3.20	122
17%	93	47433	2	1.976	698	791	2.67	143	642	735	2.90	133	582	675	3.20	122	582	675	3.20	122
17%	94	47429	4	1.976	680	774	2.73	140	620	714	3.00	129	581	675	3.20	122	581	675	3.20	122
17%	95	47426	3	1.976	671	766	2.77	139	630	725	2.95	131	563	658	3.30	119	546	641	3.40	116
17%	96	47422	4	1.976	655	751	2.83	136	608	704	3.05	128	562						3.40	116
18%	97	47420	2	1.976	654	751	2.83	136	608	705	3.05	128	598						3.00	129
18%	98	47416	4	1.976	638	736	2.90	133	607	705	3.05	128	561						3.40	116
18%	99	47412	4	1.976	623	722	2.97	131	587	686	3.15	124	560						3.40	116
18%	100	47408	4	1.975	608	708	3.03	128	568	668	3.25	121	527						3.60	111
18%	101	47404	4	1.975	607	708	3.03	128	567	668	3.25	121	526						3.60	111
18%	102	47400	4	1.975	594	696	3.10	126	549	651	3.35	118	526						4.00	102
19%	103	47398	2	1.975	593	696	3.10	126	549	652	3.35	118	525						3.60	111
19%	104	47394	4	1.975	580	684	3.17	124	548	652	3.35	118	525	629	3.50	114	510	614	3.60	111
19%	105	47390	4	1.975	579	684	3.17	124	531	636	3.45	115	509	614	3.60	111	509	614	3.60	111
19%	106	47386	4	1.974	566	672	3.23	122	531	637	3.45	115	509	615	3.60	111	509	615	3.60	111
19%	107	47382	4	1.974	554	661	3.30	120	530	637	3.45	115	481	588	3.80	107	508	615	3.60	111
20%	108	47378	4	1.974	553	661	3.30	120	514	622	3.55	113	480	588	3.80	107	456	564	4.00	102
20%	109	47374	4	1.974	541	650	3.37	118	513	622	3.55	113	480	589	3.80	107	456	565	4.00	102
20%	110	47370	4	1.974	530	640	3.43	116	499	609	3.65	110	479	589	3.80	107	455	565	4.00	102
20%	111	47366	4	1.974	529	640	3.43	116	498	609	3.65	110	478	589	3.80	107	454	565	4.00	102
20%	112	47362	4	1.973	518	630	3.50	114	497	609	3.65	110	478	590	3.80	107	454	566	4.00	102
20%	113	47360	2	1.973	518	631	3.50	114	497	610	3.65	110	477	590	3.80	107	504	617	3.60	112
21%	114	47354					3.57	113	482	596	3.75	108	452	566	4.00	103	452	566	4.00	103
21%	115	47350					3.63	111	475	590	3.80	107	452	567	4.00	103	452	567	4.00	103
21%	116	47348					3.57	113	488	604	3.70	109	475	591	3.80	107	501	617	3.60	112
21%	117	47344					3.57	113	474	591	3.80	107	474	591	3.80	107	501	618	3.60	112
21%	118	47340					3.63	111	474	592	3.80	107	474	592	3.80	107	450	568	4.00	103
22%	119	47336					3.63	111	473	592	3.80	107	473	592	3.80	107	499	618	3.60	112
22%	120	47330					3.77	108	460	580	3.90	105	448	568	4.00	103	448	568	4.00	103

Using a 1.5 division factor, a CRT might be valid but in general wider slope-widths are preferred.

Valid tests using 60 min sample widths are pushed out beyond 2 hours (not shown here).

Figure B.3

Partial Discharge 2nd Hour

Division Factor **1.50**, Expected Reserve: 9.2 Hr.

Appendix B – *Partial* Discharge, End Vpc = 1.85

INPUT					OUTPUT															
	Time	Voltage			60 Minute Slope				50 Minute Slope				40 Minute Slope				30 Minute Slope			
DoD	Min.	mV_{bank}	mV_{delta}	V_{pc}	TTE	CRT	(m)	% Act	TTE	CRT	(m)	% Act	TTE	CRT	(m)	% Act	TTE	CRT	(m)	% Act
11%	59	47519	2	1.980																
11%	60	47517	2	1.980																
11%	61	47515	2	1.980																
11%	62	47513	2	1.980																
11%	63	47513	0	1.980																
12%	64	47511	2	1.980																
12%	65	47509	2	1.980																
12%	66	47507	2	1.979																
12%	67	47505	2	1.979																
12%	68	47503	2	1.979																
13%	69	47501	2	1.979																
13%	70	47499	2	1.979																
13%	71	47495	4	1.979																
13%	72	47493	2	1.979																
13%	73	47491	2	1.979																
13%	74	47489	2	1.979																
14%	75	47485	4	1.979													742	817	1.53	148
14%	76	47483	2	1.978													711	787	1.60	143
14%	77	47481	2	1.978													682	759	1.67	137
14%	78	47477	4	1.978													630	708	1.80	128
14%	79	47475	2	1.978													608	687	1.87	124
14%	80	47473	2	1.978													607	687	1.87	124
15%	81	47469	4	1.978													566	647	2.00	117
15%	82	47467	2	1.978													565	647	2.00	117
15%	83	47465	2	1.978													547	630	2.07	114
15%	84	47461	4	1.978													529	613	2.13	111
15%	85	47459	2	1.977									626	711	1.80	129	513	598	2.20	108
16%	86	47455	4	1.977									593	679	1.90	123	497	583	2.27	106
16%	87	47451	4	1.977									562	649	2.00	118	482	569	2.33	103
16%	88	47449	2	1.977									548	636	2.05	115	468	556	2.40	101
16%	89	47445	4	1.977									522	611	2.15	111	455	544	2.47	99
16%	90	47443	2	1.977									521	611	2.15	111	455	545	2.47	99
16%	91	47439	4	1.977									498	589	2.25	107	442	533	2.53	97
17%	92	47435	4	1.976									486	578	2.30	105	430	522	2.60	95
17%	93	47433	2	1.976									475	568	2.35	103	419	512	2.67	93
17%	94	47429	4	1.976									465	559	2.40	101	408	502	2.73	91
17%	95	47426	3	1.976					531	626	2.10	113	450	545	2.48	99	403	498	2.77	90
17%	96	47422	4	1.976					510	606	2.18	110	441	537	2.53	97	393	489	2.83	89
18%	97	47420	2	1.976					501	598	2.22	108	440	537	2.53	97	392	489	2.83	89
18%	98	47416	4	1.976					483	581	2.30	105	423	521	2.63	94	383	481	2.90	87
18%	99	47412	4	1.976					466	565	2.38	102	415	514	2.68	93	374	473	2.97	86
18%	100	47408	4	1.975					458	558	2.42	101	406	506	2.73	92	365	465	3.03	84
18%	101	47404	4	1.975					442	543	2.50	98	398	499	2.78	90	364	465	3.03	84
18%	102	47400	4	1.975					435	537	2.54	97	391	493	2.83	89	356	458	3.10	83
19%	103	47398	2	1.975					428	531	2.58	96	384	487	2.88	88	356	459	3.10	83
19%	104	47394	4	1.975					420	524	2.62	95	377	481	2.93	87	348	452	3.17	82
19%	105	47390	4	1.975	468	573	2.35	104	407	512	2.70	93	370	475	2.98	86	347	452	3.17	82
19%	106	47386	4	1.974	455	561	2.42	102	401	507	2.74	92	363	469	3.03	85	340	446	3.23	81
19%	107	47382	4	1.974	442	549	2.48	99	395	502	2.78	91	357	464	3.08	84	332	439	3.30	80
20%	108	47378	4	1.974	429	537	2.55	97	383	491	2.86	89	350	458	3.13	83	332	440	3.30	80
20%	109	47374	4	1.974	418	527	2.62	95	377	486	2.90	88	344	453	3.18	82	325	434	3.37	79
20%	110	47370	4	1.974	412	522	2.65	95	371	481	2.94	87	339	449	3.23	81	318	428	3.43	78
20%	111	47366	4	1.974	401	512	2.72	93	366	477	2.98	86	338	449	3.23	81	318	429	3.43	78
20%	112	47362	4	1.973	396	508	2.75	92	361	473	3.02	86	332	444	3.28	81	311	423	3.50	77
20%	113	47360	2	1.973	391	504	2.78	91	356	469	3.06	85	332	445	3.28	81	311	424	3.50	77
21%	114	47354	6	1.973	381	495	2.85	90	346	460	3.14	83	322	436	3.38	79	304	418	3.57	76
21%	115	47350	4	1.973	372	487	2.92	88	341	456	3.18	83	321	436	3.38	79	298	413	3.63	75
21%	116	47348	2	1.973	371	487	2.92	88	341	457	3.18	83	321	437	3.38	79	304	420	3.57	76
21%	117	47344	4	1.973	367	484	2.95	88	336	453	3.22	82	316	433	3.43	78	303	420	3.57	76
21%	118	47340	4	1.973	358	476	3.02	86	331	449	3.26	81	315	433	3.43	79	297	415	3.63	75
22%	119	47336	4	1.972	354	473	3.05	86	327	446	3.30	81	310	429	3.48	78	297	416	3.63	75
22%	120	47330	6	1.972	345	465	3.12	84	318	438	3.38	79	301	421	3.58	76	286	406	3.77	73

Compared to Figure **B.2**, note how a higher division factor moves the valid test range earlier; about 15 minutes

Figure B.4

Partial Discharge 2nd Hour

Division Factor **2.5**, Expected Reserve: 9.2 Hr.

Appendix C – O'Sullivan Algorithm Tuning

Full Discharge, End Vpc = 1.85, Actual Reserve 7.97 Hr.

INPUT						OUTPUT															
	Time		Voltage			60 Minute Slope				30 Minute Slope				15 Minute Slope				5 Minute Slope			
DoD	Hrs.	Min.	mV_{bank}	mV_{delta}	V_{pc}	TTE	CRT	(m)	% Act	TTE	CRT	(m)	% Act	TTE	CRT	(m)	% Act	TTE	CRT	m	% Act
87%	6.90	414	45821	16	1.909	51	465	14.00	97	47	461	15.10	96	45	459	15.73	96	42	456	16.80	95
87%	6.92	415	45805	16	1.909	50	465	14.07	97	46	461	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	456	17.20	95
87%	6.93	416	45787	18	1.908	49	465	14.17	97	45	461	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	456	17.20	95
87%	6.95	417	45772	15	1.907	48	465	14.22	97	45	462	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	458	16.60	96
87%	6.97	418	45756	16	1.907	47	465	14.28	97	44	462	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	460	16.20	96
88%	6.98	419	45740	16	1.906	47	466	14.33	97	43	462	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	460	16.20	96
88%	7.00	420	45722	18	1.905	46	466	14.43	97	43	463	15.53	97	41	461	16.27	96	40	460	16.60	96
88%	7.02	421	45706	16	1.904	45	466	14.47	98	42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	461	16.20	97
88%	7.03	422	45688	18	1.904	44	466	14.57	98	41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	460	16.80	96
88%	7.05	423	45670	18	1.903	43	466	14.63	98	40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	460	17.20	96
89%	7.07	424	45654	16	1.902	43	467	14.70	98	39	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	460	17.20	96
89%	7.08	425	45637	17	1.902	42	467	14.78	98	39	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	461	17.00	97
89%	7.10	426	45621	16	1.901	41	467	14.85	98	38	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	462	17.00	97
89%	7.12	427	45603	18	1.900	40	467	14.92	98	37	464	16.13	97	36	463	16.80	97	35	462	17.00	97
90%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15.02	98	37	465	16.20	97	35	463	16.80	97	35	463	17.00	97
90%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15.08	98	36	465	16.33	97	34	463	16.93	97	34	463	17.40	97
90%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15.20	98	35	465	16.43	97	34	464	17.07	97	33	463	17.60	97
90%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15.30	98	34	465	16.50	97	33	464	17.07	97	31	462	18.00	97
90%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15.37	98	33	465	16.63	97	32	464	17.27	97	31	463	18.00	97
91%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15.45	98	33	466	16.67	97	32	465	17.33	97	31	464	17.80	97
91%	7.23	434	45478	18	1.895	35	469	15.52	98	32	466	16.80	98	31	465	17.47	97	30	464	17.80	97
91%	7.25	435	45460	18	1.894	34	469	15.62	98	31	466	16.87	98	30	465	17.47	97	30	465	17.80	97
91%	7.27	436	45442	18	1.893	33	469	15.68	98	31	467	17.00	98	30	466	17.60	97	29	465	17.80	97
91%	7.28	437	45424	18	1.893	33	470	15.75	98	30	467	17.07	98	29	466	17.60	98	29	466	17.80	97
92%	7.30	438	45404	20	1.892	32	470	15.85	98	29	467	17.20	98	28	466	17.73	98	27	465	18.40	97
92%	7.32	439	45382	22	1.891	31	470	15.98	98	28	467	17.43	98	27	466	18.13	98	26	465	19.20	97
92%	7.33	440	45364	18	1.890	30	470	16.08	98	27	467	17.57	98	26	466	18.20	98	25	465	19.20	97
92%	7.35	441	45345	19	1.889	29	470	16.18	98	27	468	17.60	98	26	467	18.40	98	24	465	19.40	97
92%	7.37	442	45323	22	1.888	28	470	16.32	98	26	468	17.73	98	25	467	18.67	98	23	465	20.20	97
93%	7.38	443	45301	22	1.888	27	470	16.41	98	25	468	17.87	98	24	467	18.88	98	22	465	20.50	97
93%	7.40	444	45281	20	1.887	27	471	16.51	98	25	469	17.94	98	23	467	19.00	98	21	465	20.50	97
93%	7.42	445	45261	20	1.886	26	471	16.61	99	24	469	18.06	98	23	468	19.13	98	21	466	20.17	98
93%	7.43	446	45237	24	1.885	25	471	16.77	99	23	469	18.32	98	21	467	19.50	98	20	466	21.17	97

Note for this table slope widths are: 60m, 30m, 15m and 5m.

Please note on this chart the conditional formatting band was narrowed to 97 – 103 % of actual.

At 88% DoD with **2.00** Division Factor prediction accuracy is 98%.

Figure C.1

Division Factor **2.00**

INPUT						OUTPUT															
	Time		Voltage			60 Minute Slope				30 Minute Slope				15 Minute Slope				5 Minute Slope			
DoD	Hrs.	Min.	mV_{bank}	mV_{delta}	V_{pc}	TTE	CRT	(m)	% Act	TTE	CRT	(m)	% Act	TTE	CRT	(m)	% Act	TTE	CRT	m	% Act
43%	3.42	205	48273	10	2.011	260	465	9.93	97	258	463	10.00	97	260	465	9.93	97	258	463	10.00	97
43%	3.43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9.97	97	258	464	10.00	97	259	465	9.93	97	258	464	10.00	97
43%	3.45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9.97	97	257	464	10.00	97	259	466	9.93	97	257	464	10.00	97
44%	3.47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9.98	97	257	465	9.97	97	260	468	9.87	98	261	469	9.80	98
44%	3.48	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9.98	97	256	465	9.97	97	257	466	9.93	98	261	470	9.80	98
44%	3.50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9.98	97	253	463	10.07	97	253	463	10.07	97	260	470	9.80	98
44%	3.52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9.98	97	253	464	10.07	97	253	464	10.07	97	259	470	9.80	98
44%	3.53	212	48204	10	2.009	254	466	9.98	97	252	464	10.07	97	255	467	9.93	98	259	471	9.80	98
45%	3.55	213	48194	10	2.008	254	467	9.97	98	251	464	10.07	97	251	464	10.07	97	253	466	10.00	97
45%	3.57	214	48184	10	2.008	252	466	10.00	98	252	466	10.00	98	251	465	10.07	97	252	466	10.00	98
45%	3.58	215	48174	10	2.007	252	467	10.00	98	252	467	10.00	98	253	468	9.93	98	252	467	10.00	98
45%	3.60	216	48164	10	2.007	251	467	10.00	98	251	467	10.00	98	253	469	9.93	98	251	467	10.00	98
45%	3.62	217	48154	10	2.006	250	467	10.00	98	250	467	10.00	98	252	469	9.93	98	250	467	10.00	98
46%	3.63	218	48144	10	2.006	249	467	10.03	98	251	469	9.93	98	251	469	9.93	98	250	468	10.00	98
46%	3.65	219	48134	10	2.006	248	467	10.03	98	251	470	9.93	98	251	470	9.93	98	249	468	10.00	98
46%	3.67	220	48124	10	2.005	247	467	10.03	98	250	470	9.93	98	250	470	9.93	98	248	468	10.00	98
46%	3.68	221	48115	9	2.005	247	468	10.02	98	250	471	9.90	99	251	472	9.87	99	253	474	9.80	99
46%	3.70	222	48105	10	2.004	247	469	9.98	98	249	471	9.90	99	250	472	9.87	99	252	474	9.80	99
47%	3.72	223	48095	10	2.004	247	470	9.98	98	249	472	9.90	99	248	471	9.93	99	251	474	9.80	99
47%	3.73	224	48085	10	2.004	246	470	9.98	98	247	471	9.93	99	247	471	9.93	99	251	475	9.80	99
47%	3.75	225	48075	10	2.003	245	470	10.02	98	245	470	10.00	98	247	472	9.93	99	250	475	9.80	99
47%	3.77	226	48065	10	2.003	244	470	10.00	98	244	470	10.00	98	246	472	9.93	99	244	470	10.00	98
47%	3.78	227	48055	10	2.002	244	471	10.00	98	245	472	9.93	99	245	472	9.93	99	244	471	10.00	98
48%	3.80	228	48045	10	2.002	243	471	10.00	99	243	471	10.00	99	245	473	9.93	99	243	471	10.00	99

At 45% DoD with **1.50** Division Factor prediction accuracy is 98%.

Figure C.2

Division Factor **1.50**

Appendix C – O'Sullivan Algorithm Tuning

Full Discharge, End Vpc = 1.85, Actual Reserve 7.97 Hr.

INPUT						OUTPUT															
	Time		Voltage			60 Minute Slope				30 Minute Slope				15 Minute Slope				5 Minute Slope			
DoD	Hrs.	Min.	mV_{bank}	mV_{delta}	V_{pc}	TTE	CRT	(m)	% Act	TTE	CRT	(m)	% Act	TTE	CRT	(m)	% Act	TTE	CRT	m	% Act
14%	1.10	66	49606	8	2.067					442	508	7.13	106	426	492	7.40	103	385	451	8.20	94
14%	1.12	67	49598	8	2.067					438	505	7.20	106	426	493	7.40	103	384	451	8.20	94
14%	1.13	68	49590	8	2.066					433	501	7.27	105	425	493	7.40	103	403	471	7.80	99
14%	1.15	69	49580	10	2.066					424	493	7.40	103	417	486	7.53	102	374	443	8.40	93
15%	1.17	70	49572	8	2.066					424	494	7.40	103	409	479	7.67	100	373	443	8.40	93
15%	1.18	71	49564	8	2.065					419	490	7.47	103	408	479	7.67	100	373	444	8.40	93
15%	1.20	72	49556	[illegible]	[illegible]					415	487	7.53	102	408	480	7.67	100	372	444	8.40	93
15%	1.22	73	49546	[illegible]	[illegible]					407	480	7.67	100	400	473	7.80	99	354	427	8.80	89
15%	1.23	74	49538	[illegible]	[illegible]					406	480	7.67	100	399	473	7.80	99	371	445	8.40	93
16%	1.25	75	49528	[illegible]	[illegible]					400	475	7.77	99	367	442	8.47	92	353	428	8.80	90
16%	1.27	76	49520	[illegible]	[illegible]					400	476	7.77	99	366	442	8.47	93	353	429	8.80	90
16%	1.28	77	49512	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	399	476	7.77	100	366	443	8.47	93	352	429	8.80	90
16%	1.30	78	49502	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	391	469	7.90	98	365	443	8.47	93	351	429	8.80	90
17%	1.32	79	49494	8	2.062	456	535	6.77	112	391	470	7.90	98	362	441	8.53	92	351	430	8.80	90
17%	1.33	80	49487	7	2.062	450	530	6.85	111	389	469	7.93	98	364	444	8.47	93	376	456	8.20	95
17%	1.35	81	49477	10	2.062	443	524	6.95	110	385	466	8.00	97	358	439	8.60	92	358	439	8.60	92
17%	1.37	82	49469	8	2.061	438	520	7.02	109	384	466	8.00	97	357	439	8.60	92	357	439	8.60	92
17%	1.38	83	49459	10	2.061	431	514	7.12	107	380	463	8.07	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	440	8.60	92
18%	1.40	84	49451	8	2.060	426	510	7.18	107	379	463	8.07	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	440	8.60	92
18%	1.42	85	49441	10	2.060	419	504	7.28	106	373	458	8.20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	417	9.20	87
18%	1.43	86	49433	8	2.060	415	501	7.35	105	372	458	8.20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	433	8.80	91
18%	1.45	87	49423	10	2.059	409	496	7.45	104	368	455	8.27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	418	9.20	87
18%	1.47	88	49415	8	2.059	406	494	7.48	103	368	456	8.27	95	348	436	8.73	91	345	433	8.80	91
19%	1.48	89	49407	8	2.059	402	491	7.55	103	367	456	8.27	95	347	436	8.73	91	345	434	8.80	91
19%	1.50	90	49397	10	2.058	398	488	7.62	102	352	442	8.60	92	347	437	8.73	91	344	434	8.80	91
19%	1.52	91	49387	10	2.058	393	484	7.68	101	349	440	8.67	92	341	432	8.87	90	329	420	9.20	88
19%	1.53	92	49377	10	2.057	389	481	7.75	101	345	437	8.73	92	335	427	9.00	89	328	420	9.20	88
19%	1.55	93	49367	10	2.057	383	476	7.85	100	345	438	8.73	92	334	427	9.00	89	314	407	9.60	85
20%	1.57	94	49355	12	2.056	378	472	7.95	99	337	431	8.90	90	324	418	9.27	87	289	383	10.40	80
20%	1.58	95	49348	7	2.056	375	470	8.00	98	338	433	8.87	91	324	419	9.27	88	306	401	9.80	84
20%	1.60	96	49338	10	2.056	373	469	8.03	98	335	431	8.93	90	323	419	9.27	88	305	401	9.80	84
20%	1.62	97	49330	8	2.055	370	467	8.07	98	334	431	8.93	90	322	419	9.27	88	318	415	9.40	87
21%	1.63	98	49320	10	2.055	367	465	8.13	97	331	429	9.00	90	322	420	9.27	88	317	415	9.40	87
21%	1.65	99	49310	10	2.055	363	462	8.20	97	331	430	9.00	90	317	416	9.40	87	331	430	9.00	90

Note how an 8-hour rate requires a **1.65** Division Factor for an accurate prediction at 20% DoD.

Also note at 15% DoD an accurate prediction can occur with other slopes.

Figure C.3

Division Factor **1.65**