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NIA Site Modelling & Simulation Report

Modelling, Simulation Methods and Simulation Results for the EAVC NIA Project

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Confidential

Electricity North West LTD

Enhanced Voltage Control

ENWL011

About this report

Version Information

Rev	Date	Purpose of Issue / Changes	Authored	Checked	Approved
1.0	16/09/2017	First Issue	J.Gault	H. Shishtawi	H. Shishtawi

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Abbreviations

AVC	Automatic Voltage Control
DG	Distributed Generation
EAVC	Enhanced Automatic Voltage Control
ENW	Electricity North West
LDC	Load Drop Compensation
SLD	Single Line Diagram
TPN	Trafford Park North

1 Introduction

The modernisation of power systems has called for new smart Automatic Voltage Control (AVC) systems. These systems can accommodate the utilisation of embedded and distributed generation (DG) to an extent using a mixture of past settings/knowledge and advanced functionality. To fully utilize available power, studies into closed portions of the network with high amounts of generation will allow for new and up to date settings design for Enhanced Automatic Voltage Control (EAVC).

In order to study a network, accurate and detailed models must be designed which replicate the real network. Simulations can be carried out to examine different load and generations scenarios to monitor the effects on the network. The scenario simulations can then be examined to address the effect of DG and recommend EAVC settings.

The network for study is an Electricity North West (ENW) substation, Trafford Park North (TPN), and the closed portion of the network that it feeds. This substation has been chosen for modelling due to the 15MW of local generation which is pushing the power flow into reverse power and swinging the power factor. TPN is part of a typical modern power system.

1.1 Modelling Focus

The modelling will focus on the following elements:

- Recognisable and readable design
- Accurate properties of transformers and line data
- Switchable network running arrangements
- Cater for additional interconnections to neighbouring closed networks

1.2 Simulation Focus

The simulation will focus mainly on the following elements:

- Model calibration
- Specific scenarios for simulations, both real and extreme
- Voltage drop across primary transformers in different scenarios
- Voltage drop across feeders in different scenarios
- Voltage drop at remote points of the network in different scenarios

The simulation scenarios will focus on changing change the three main elements:

- Load level
- Generation level
- Generation power factor

2 Modelling Design

To improve previous models (HDA) the model will incorporate the real impedance values of lines in order to improve reliability of results. The model is drawn in IPSA2 power system analysis software.

2.1 Design Process

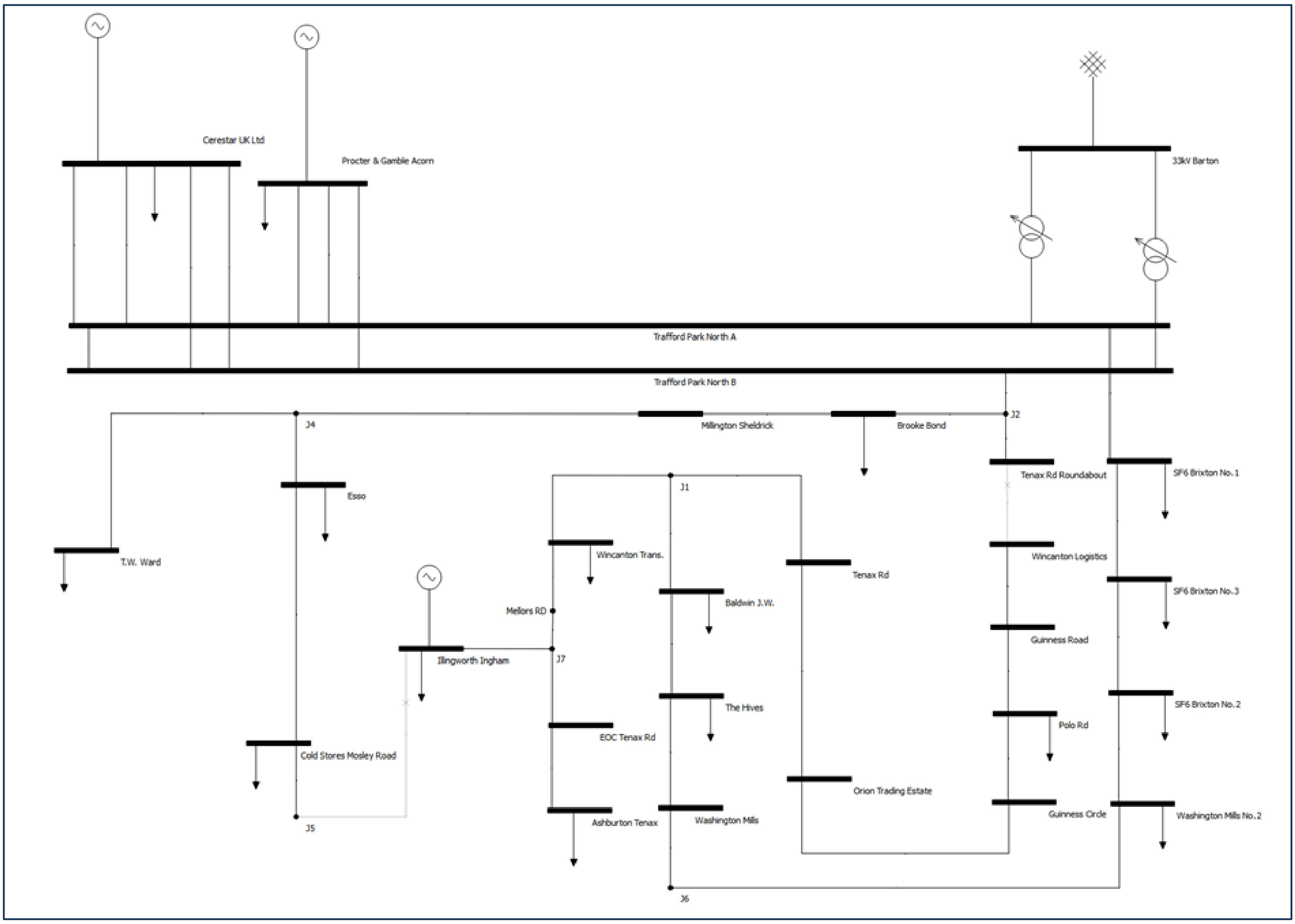
The design process follows this order:

1. Site information
2. Drawing the network
3. Extract and set line impedances
4. Load flow

2.1.1 Site Information

The site information includes transformer ratio, rating and impedance. This information is readily available from ENW electronically or locally at the substation from transformer rating plates.

Figure 1 Trafford Park North IPSA



2.1.2 Drawing the Network

To draw the network we follow the previous criteria, it must be recognisable and readable. A single line diagram (SLD) can be used to see the local arrangement of transformers, busbars and feeders at the substation. From there the loads can be mapped out, adding a busbar per load to clearly map out the entire closed network. As in Figure 1, the model is laid out with both the SLD and readability in mind. The model is recognisable using real names and accurate feeder arrangements.

Loads are set from the distribution transformer rating. These are placed on busbars and represented by the downward arrows.

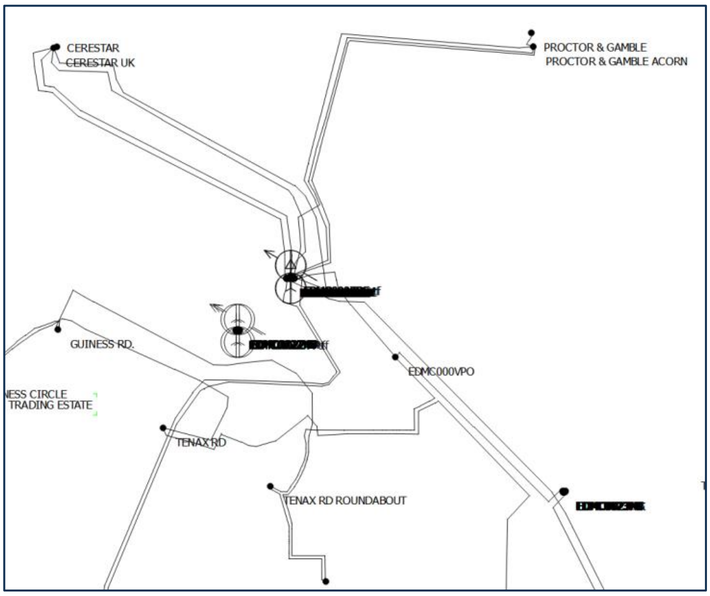
Generators are set from the ENW database and represented by the generator symbol above the bus bar.

2.1.3 Extract and Set Line Impedances

In previous models it was not feasible to extract the line impedances and so had to be estimated. Although the model gave a good sense of the power flow through the network, the results would not be comparable to real data.

The line impedances are extracted from Figure 2's model. The model is converted from DINIS to IPSA. From this model, lines are cross referenced to Figure 1's model and the lines can be selected to view their properties. These can then be filled into the simulation model.

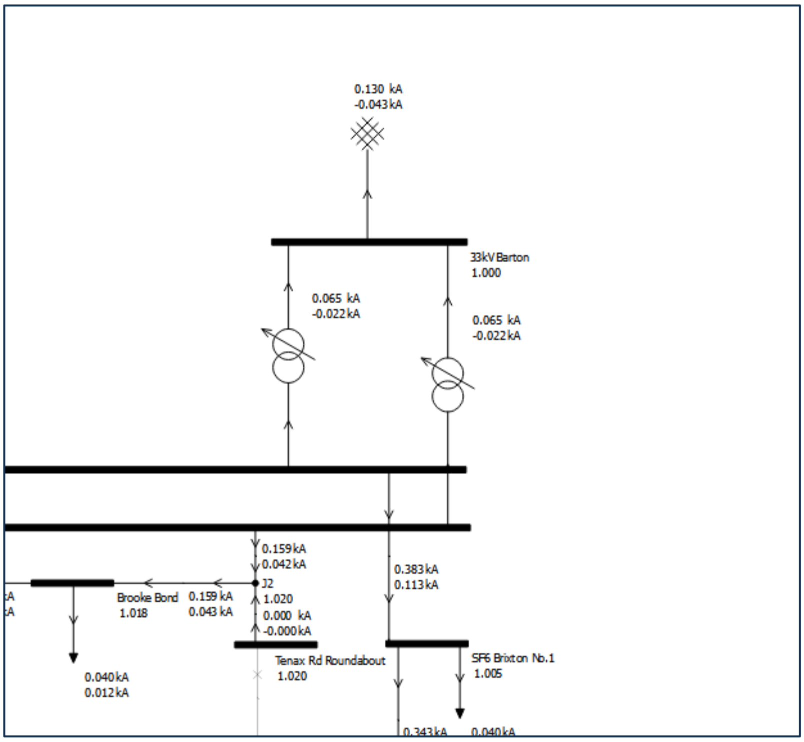
Figure 2 Trafford Park North DINIS extraction



2.1.4 Load Flow

In order to test the functionality a load flow can be carried out to test the model as in Figure 3 below. The figure shows 60% load scaling and generators at maximum output at unity power factor.

Figure 3 Load flow TPN



3 Methodology

As described earlier, a number of scenarios will be examined in order to achieve the desired objectives. The flowchart of the simulation process is shown in **Error! Reference source not found.**

3.1 Initial Simulation Description

For the first simulation the load will start at 20% of the nominal and will be increased in 10% steps until 130%. Additionally, the generation will start at 0% and move straight to 25% of the nominal. A 40% generation level will then be simulated and will be incremented in steps of 20% reaching 100% of the nominal capacity. The case where there is no generation will also be considered. Finally, the generation power factor will be varied as follows:

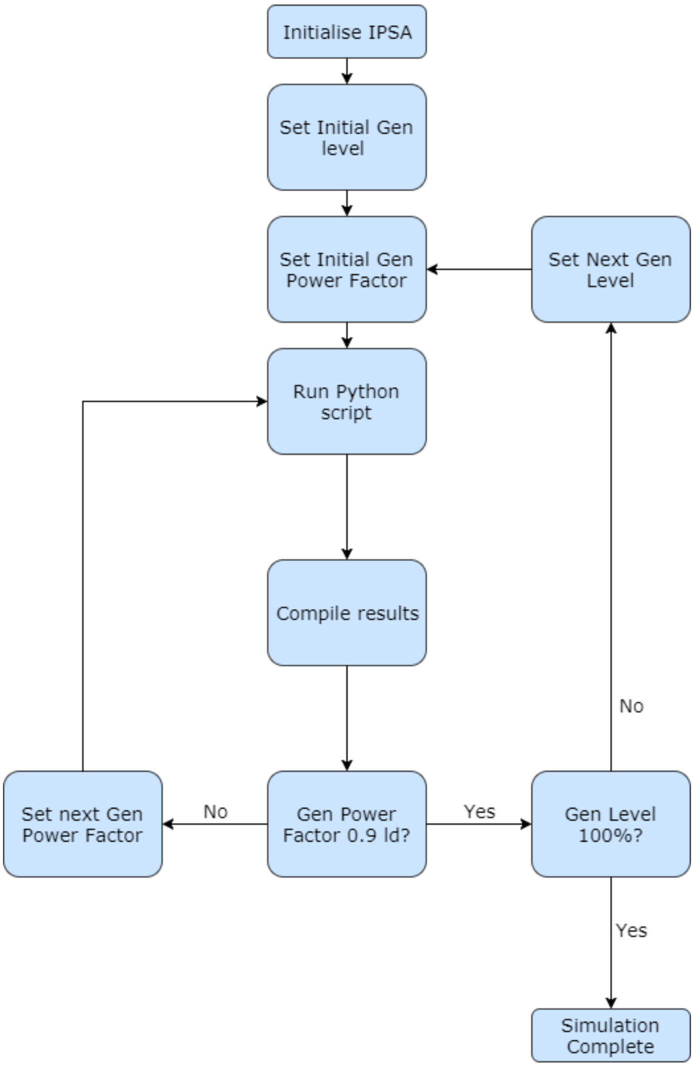
- 0.70 Lagging.
- 0.80 Lagging.
- 0.90 Lagging.
- 0.95 Lagging.
- Unity.
- 0.95 Leading.
- 0.90 Leading.

3.2 Advanced Simulation Description

The second simulation the load will start at 25% of the nominal and will be increased in 5% steps until 120%. The generation will be additionally simulated at 5% and 15% as well as all the levels from the first simulation. The power factors will remain the same as the first simulation.

Every possible combination of the above stated conditions will be simulated to provide the needed comprehensive set of results. The outcomes of these simulations will then be examined thoroughly, and the relevant effects on the network voltages and AVC systems will be studied in more depth.

Figure 4 Simulation flowchart



4 Assumptions

The following assumptions have been made in order to fully understand the effects being studied:

- The load power factor is fixed at 0.96 lag throughout the simulation.
- No voltage control is utilised throughout the simulation.
- All primary substation transformers are set to operate at their nominal tap positions to provide nominal system transformation ratios throughout the simulation.
- All primary substation transformers are operating under locked taps conditions throughout the simulation.

5 Initial Simulation

5.1 Simulation results

The simulation results are shown as figures in **Appendix A: Initial Simulation Results**.

As can be seen from the results, the relationship between the voltage drop across the transformers and the load level id directly proportional; the more load supplied the more voltage drop across the transformers.

On the other hand, the relationship between the generation and the voltage drop across the transformer is rather more complex. The relationship is not only a function of the generation level, but also a function of the generation power factor.

Disregarding the power factor, and hence considering a unity power factor only, the relationship between the voltage drop across the transformers and the generation level is inversely proportional. This can be clearly seen in Figure 5 through to Figure 16, where the voltage drop across the transformers decreases (voltage rise) as the generation level increases.

Moreover, the effect of the generation level on the voltage drop across the transformer is minimal when the generator is operating at unity power factor compared to when operating at different power factors. This is due to the, almost, totally reactive impedance of power transformers.

5.2 Generation Power Factor Effect

The relationship between the generation power factor and the voltage drop across the transformers can be easily observed in Figure 17 through to Figure 28; however it is also dependent upon the generation level. Generally, voltage drop is at its minimum (or voltage rise is at its maximum) when the generation power factor is more lagging (the generator produces reactive power). On the other hand, the more leading generation power factor at high generation level means more voltage drop across the transformers.

It can also be seen that for different generation levels (as a function of the load level) there is always an optimum generation power factor capable of adjusting the voltage drop trend (move it up and down) to minimise the voltage drop/rise deviation from zero.

6 Advanced Simulation

6.1 Simulation Results

The advanced simulation is mainly aimed at considering situations where the generation level is low; namely generation outputs at 0%, 5% and 15% of the generation capacity. The original level only tested scenarios with 40% and above generation levels. The results of the advanced simulation are shown in **Appendix B: Advanced Simulation Results**.

As the majority of the generation is connected directly to the substation busbars, it can be seen from the results that the major effect of the generation is very noticeable on the voltage drop across the transformers rather than at the remote node of Trafford Park North system.

For instance, a 5% generation level can change the voltage drop across the transformers by approximately ±0.2% (compared to the case when no generation is running) while having almost no effect on remote nodes of the system. Moreover, at 100% generation level the voltage change across the transformers can change approximately by ±3% (for power generation power factors between 0.9 lag and 0.9 lead), in the same manner this amount of generation can only change the voltage drop at the remote point approximately by ±0.2% for the same considered power factors.

7 Conclusion

7.1 Distributed Generation Effect on the Network

It can be easily observed that the generation at Trafford Park North substation has got:

1. A major effect on the voltage drop across both transformers. The voltage drop across the transformers is a function of three variables:
    a. The load level (assuming fixed load power factor).
    b. The generation level.
    c. The generation power factor.
2. A minor effect on voltage drops at nodes remote to the substation busbars. This is because the power feeding those remote points still flows through the same direction, facing the same impedance and dropping voltages across them.

7.2 Generation Control

As the previous section states that the voltage drop across the transformers (and the across network feeders) is a function of a number of variables some of which are directly related to the generation output, then voltage drop optimisation is possible if those variables are modified dynamically.

It is believed that there is an optimum generation level and generation power factor for every load level. Further studies shall be considered to mathematically model the described voltage drops as functions of the generation level and power factor. If such model is developed, this model can then be used to control distributed generator outputs to reduce the losses across the network.

7.3 EAVC Settings

The results showed that the maximum voltage drop across the network is in the region on 6% at full; corresponding to voltages in the region of 94% at remote ends. Additionally, the voltage drop at full load at nodes closest to the substation busbars is in the region of 1%. In the same manner, the maximum voltage rise at the substation busbars is in the region of 5% at full generation.

The voltage control settings at Trafford Park North substation are:

- Basic voltage target = 99.5%.
- Bandwidth = 1.5%.
- LDC = 0%.
- Generator bias = 0%.

To cover all the scenarios, and to optimise the voltage level at all nodes, the following settings are proposed:

- No change to the basic voltage target.
- No change to the bandwidth.
- LDC = 3.5%.
- Generator bias = 3%.
- The feeders with generators connected to them should be measured by the EAVC SuperTAPP SG relay with their functions set to 'Generator'.
- No reverse LDC is required at this point.

The above settings are to be reviewed on regular basis to optimise for the voltages.

7.4 Future Work

Reactive current can circulate between substations interconnected through dedicated interconnectors and/or through network feeders. This can happen if the busbar voltage of one substation is higher/lower than the other one.

To study the effect of reactive currents circulating between substations through network interconnections, and to advise appropriate EAVC settings to govern this scenario using 'Network Circulating Current Factor' feature of the SuperTAPP SG relay, it is proposed to parallel Trafford Park North with another substation for a period of time.

When the specified period of time has elapsed, new EAVC settings should be devised, and the performance of the EAVC relay using such settings should be studied. Recommendations should then be made based on the outcome.

8 Appendix A: Initial Simulation Results

Figure 5 0% Generation level – T11

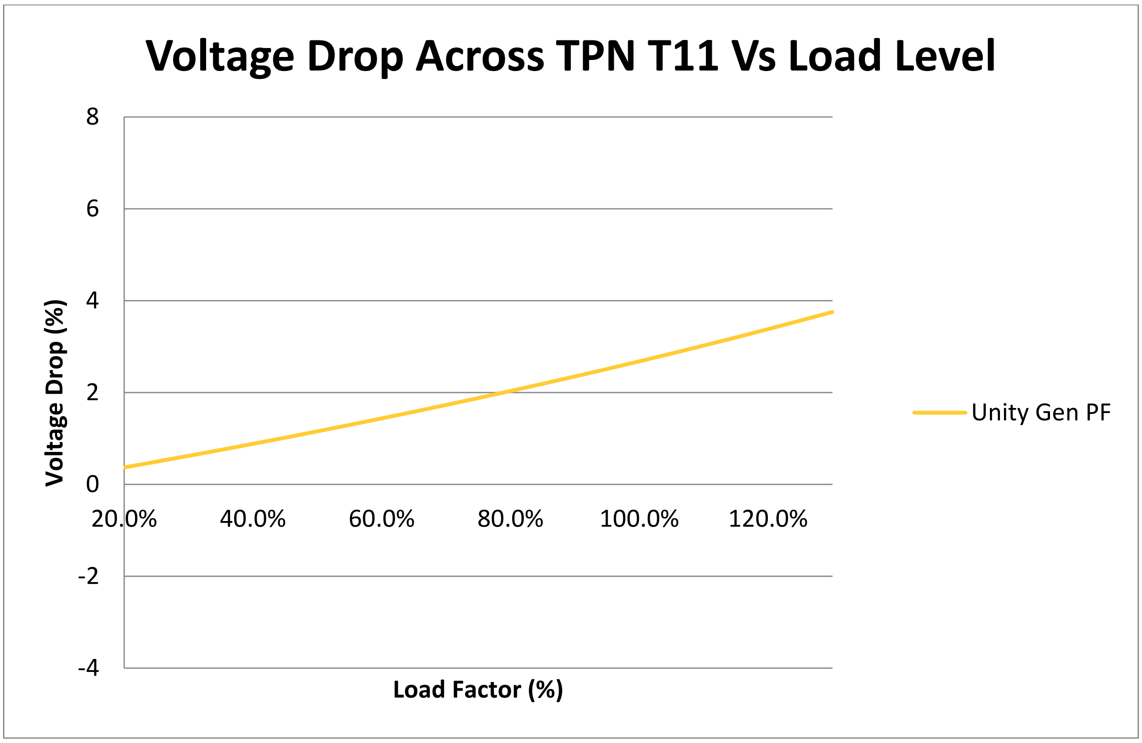


Figure 6 0% Generation level – T12

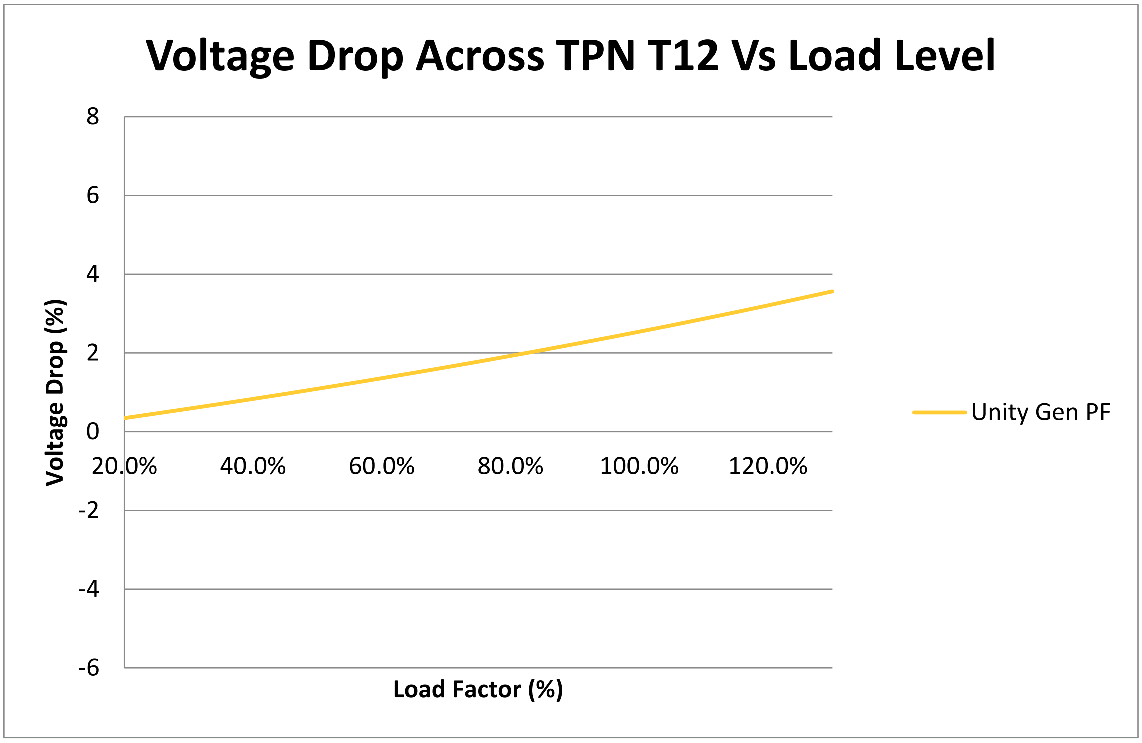


Figure 7 25% Generation level – T11

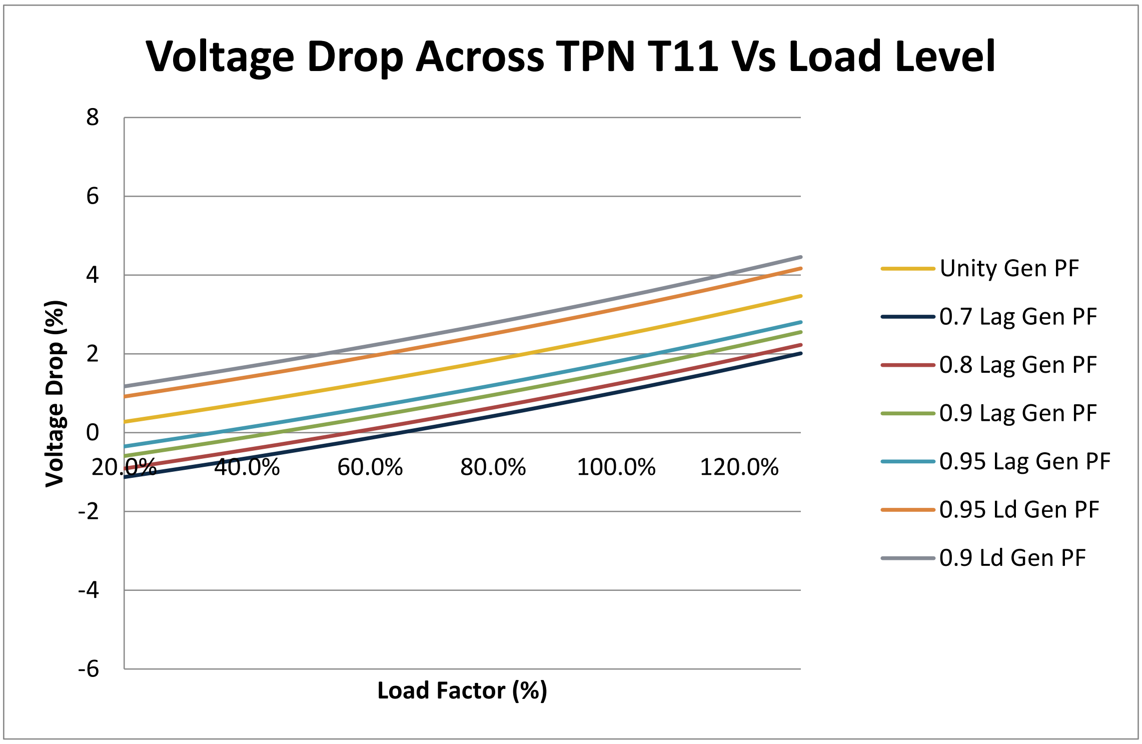


Figure 8 25% Generation level – T12

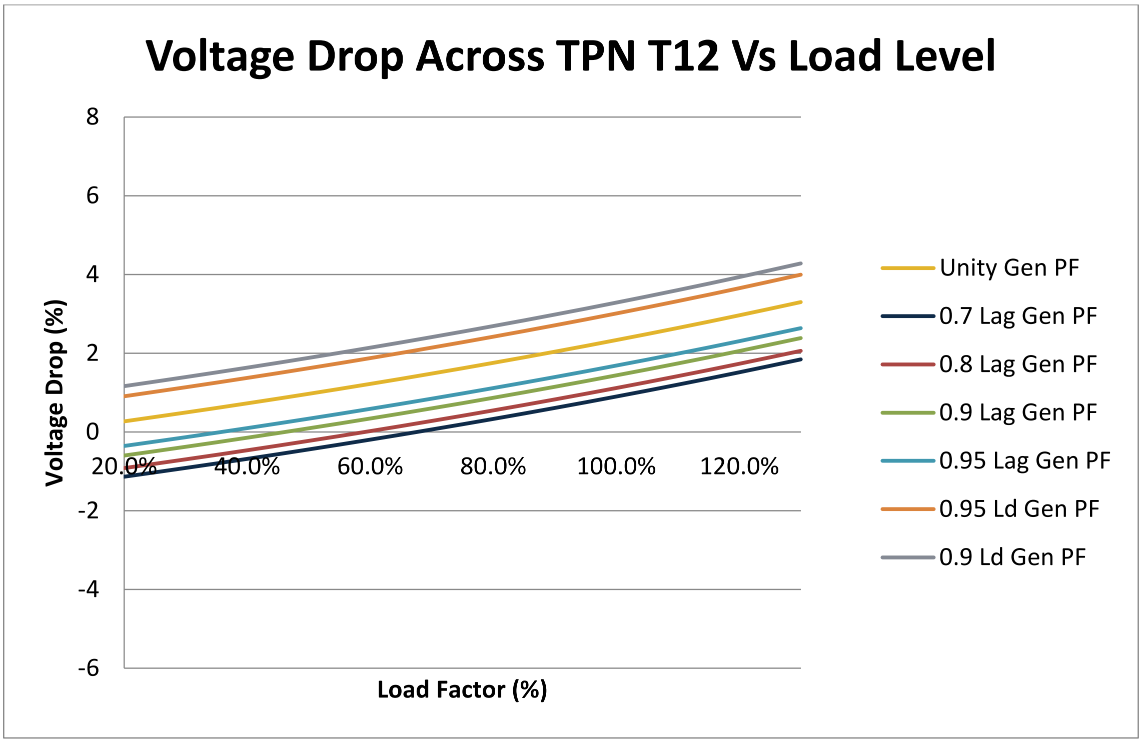


Figure 9 40% Generation level – T11

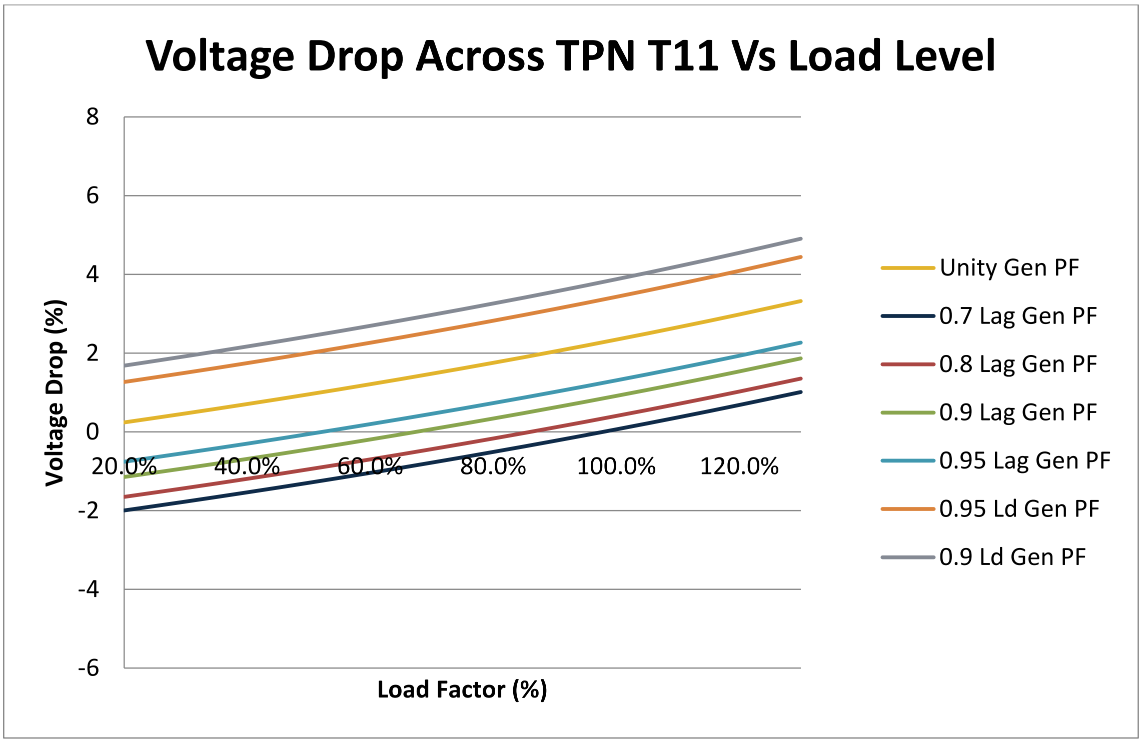


Figure 10 40% Generation level – T12

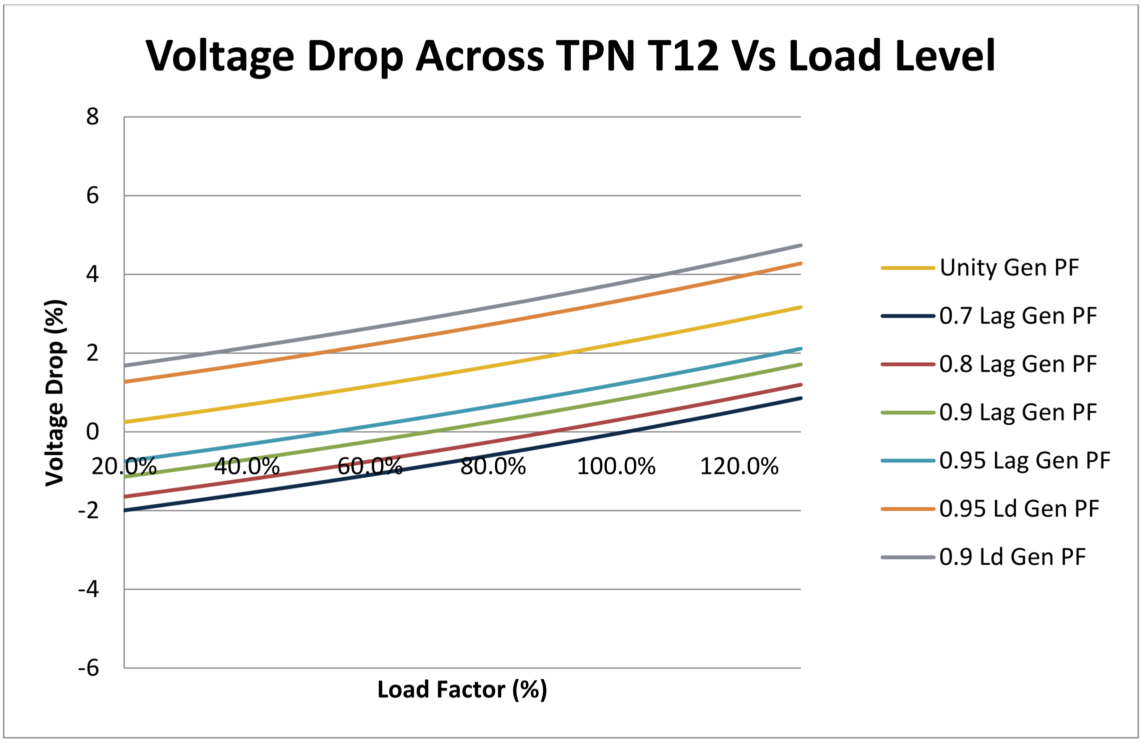


Figure 11 60% Generation level – T11

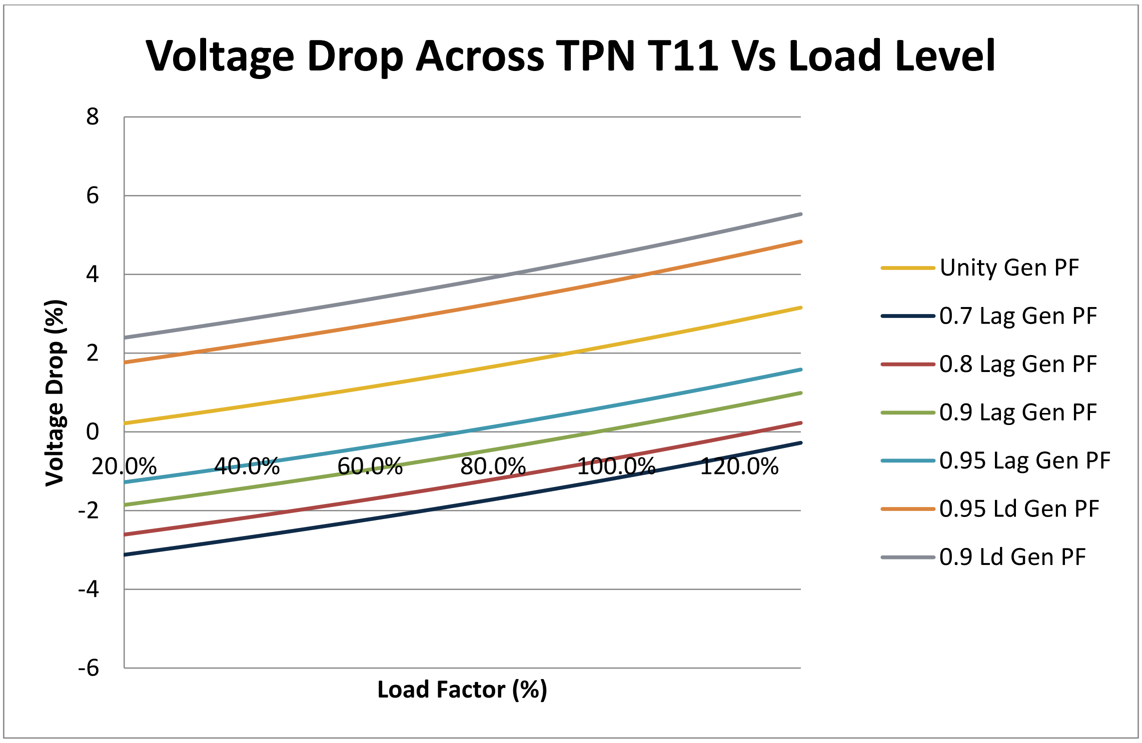


Figure 12 60% Generation level – T12

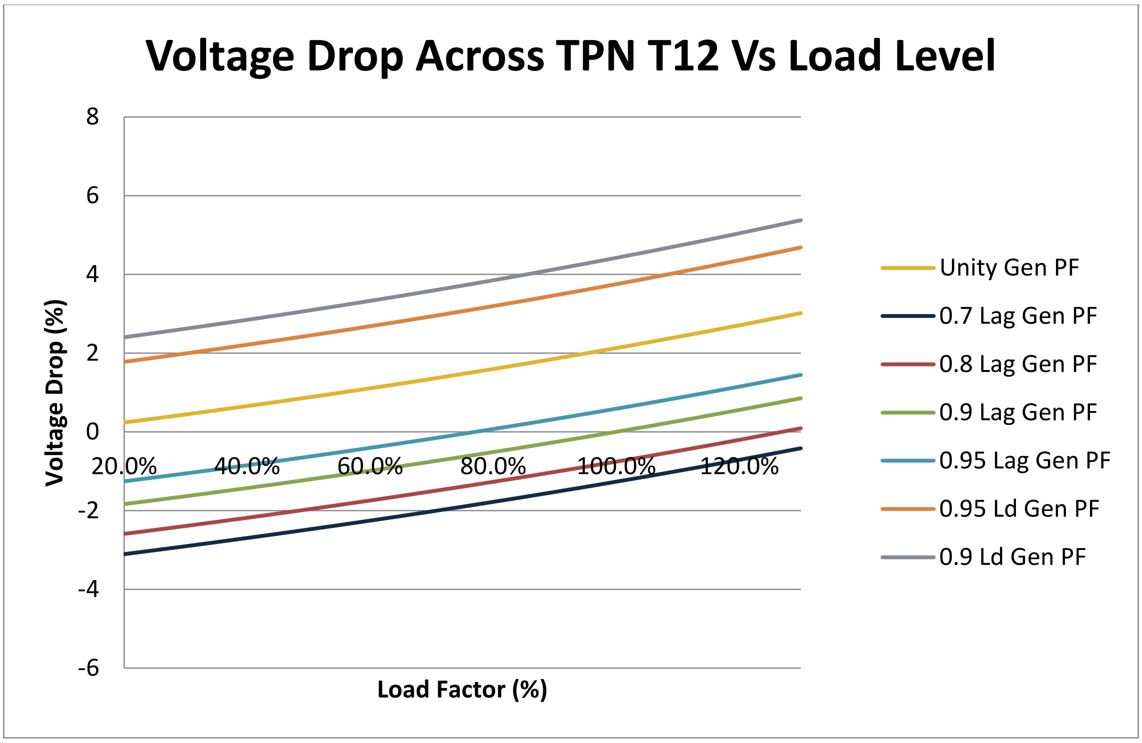


Figure 13 80% Generation level – T11

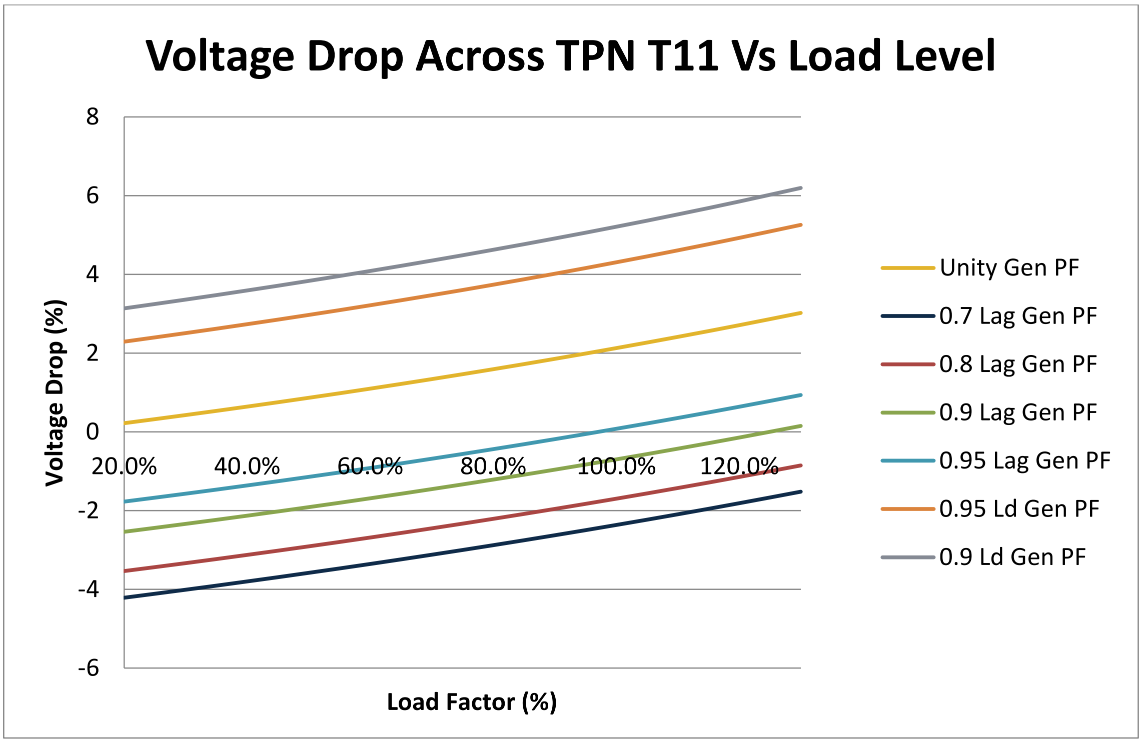


Figure 14 80% Generation level – T12

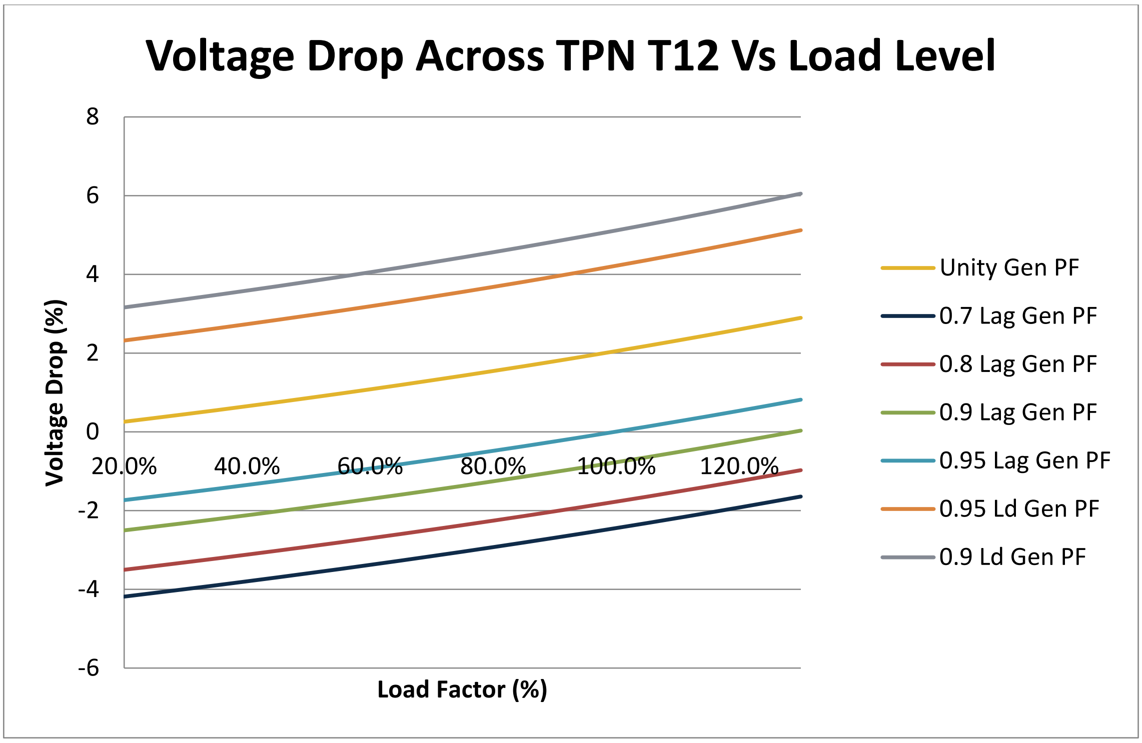


Figure 15 100% Generation level – T11

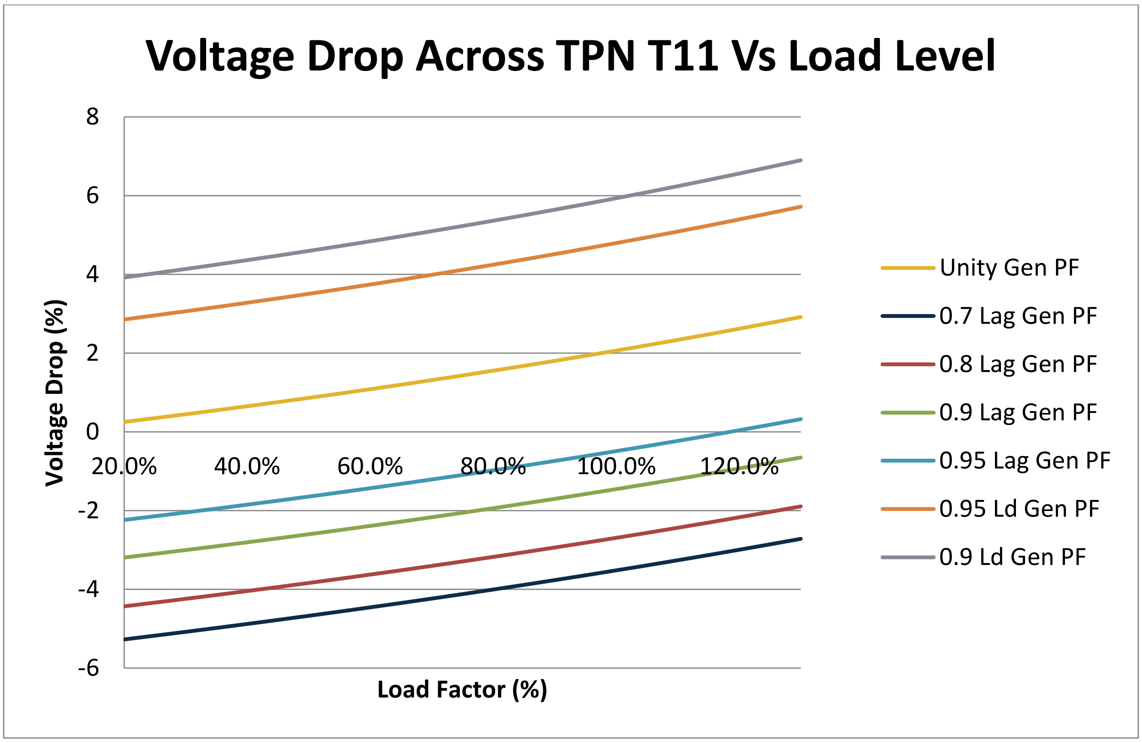


Figure 16 100% Generation level – T12

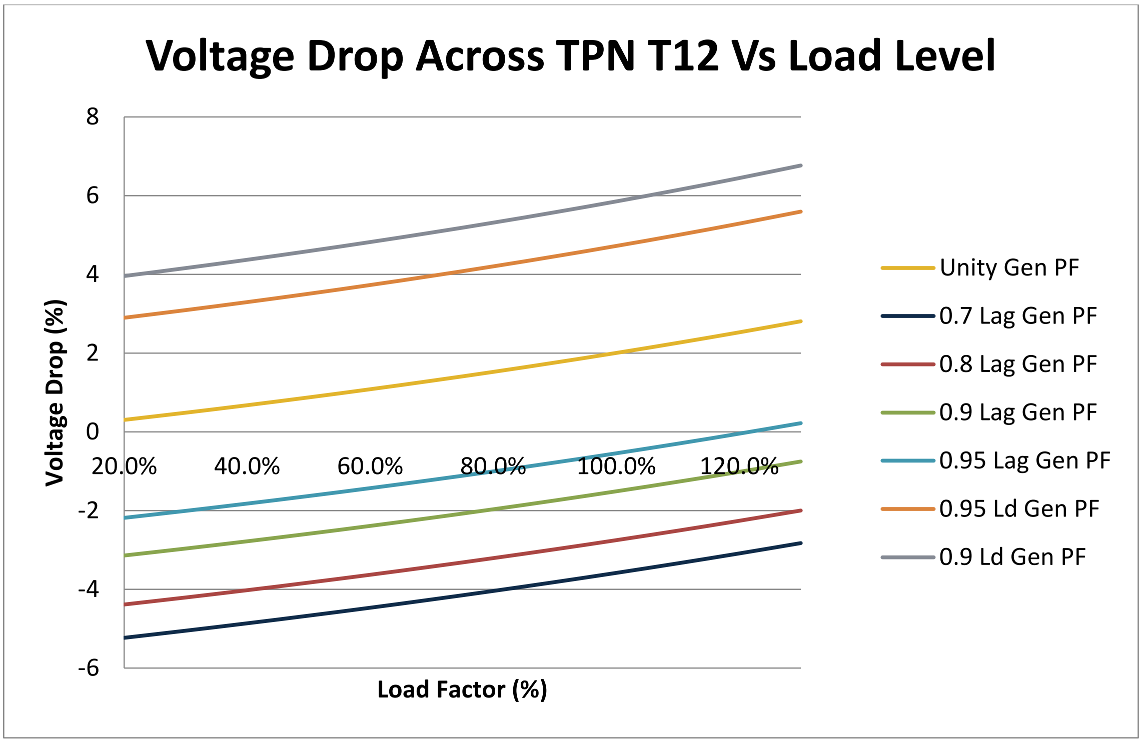


Figure 17 20% Load level – T11

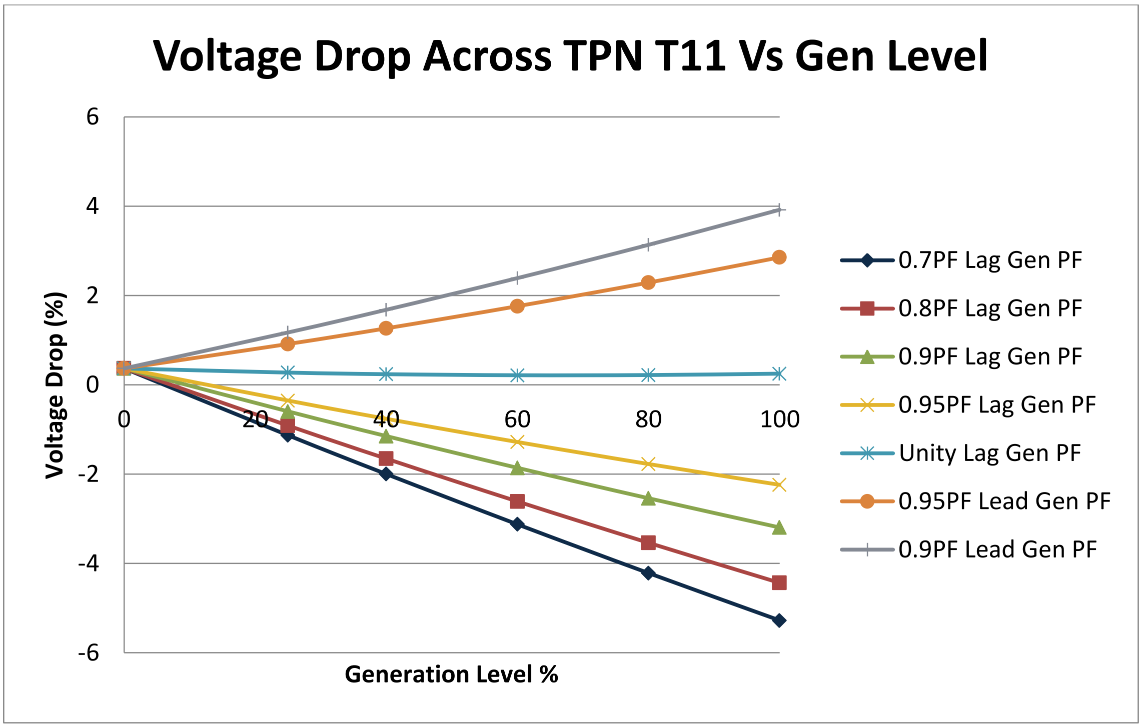


Figure 18 20% Load level – T12

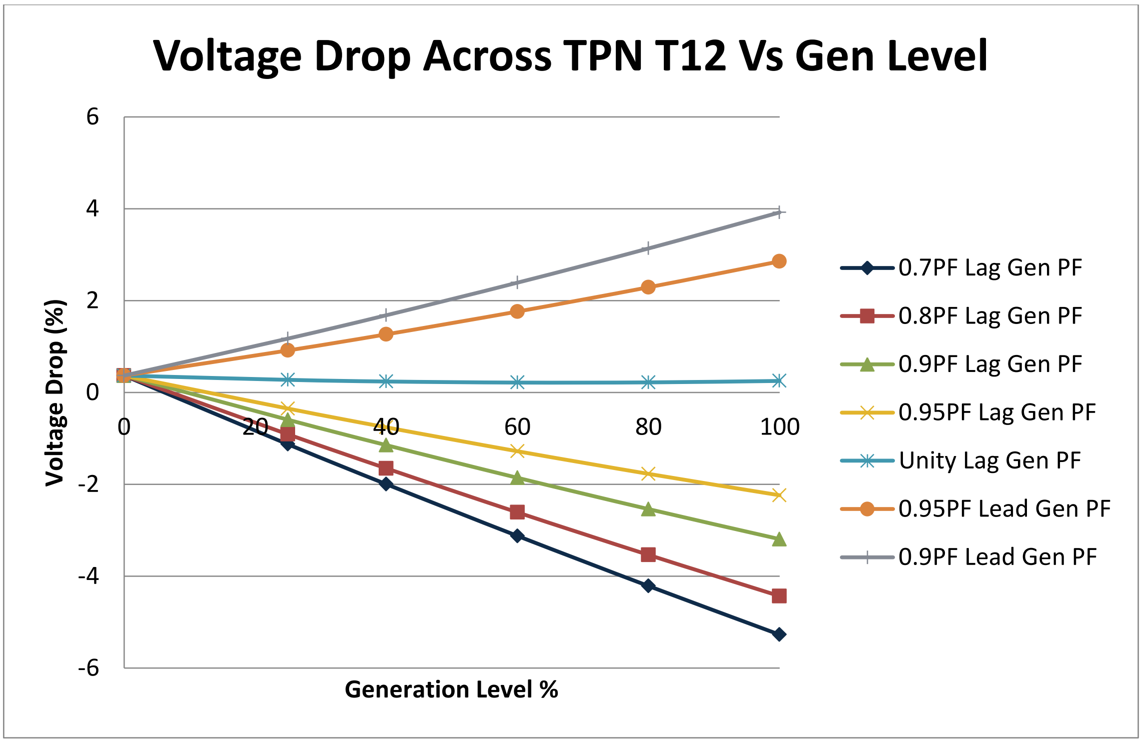


Figure 19 20% Load level – Tenax

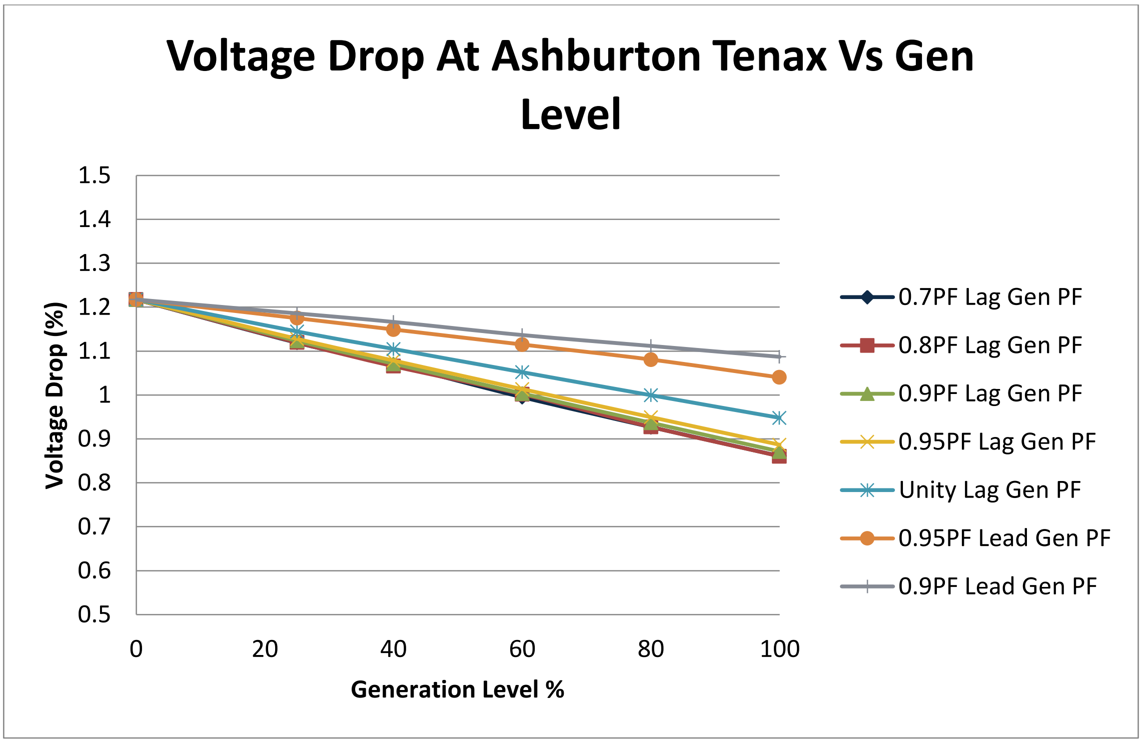


Figure 20 40% Load level – T11

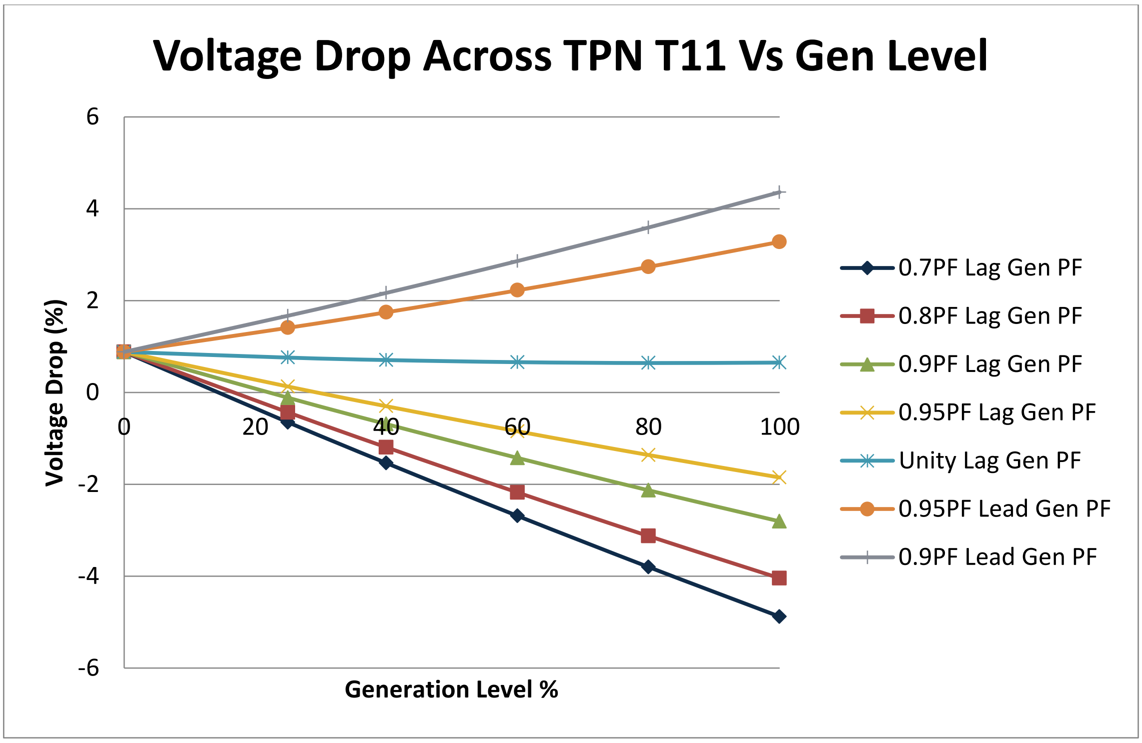


Figure 21 **40% Load level – T12**

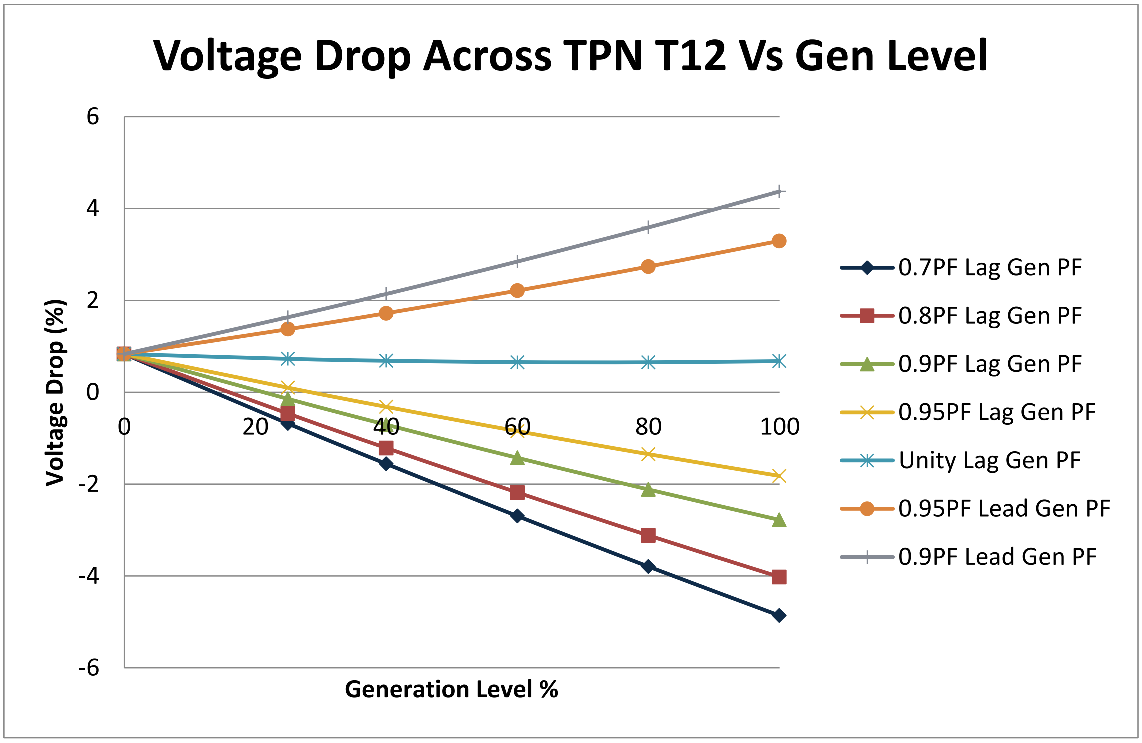


Figure 22 **40% Load level – Tenax**

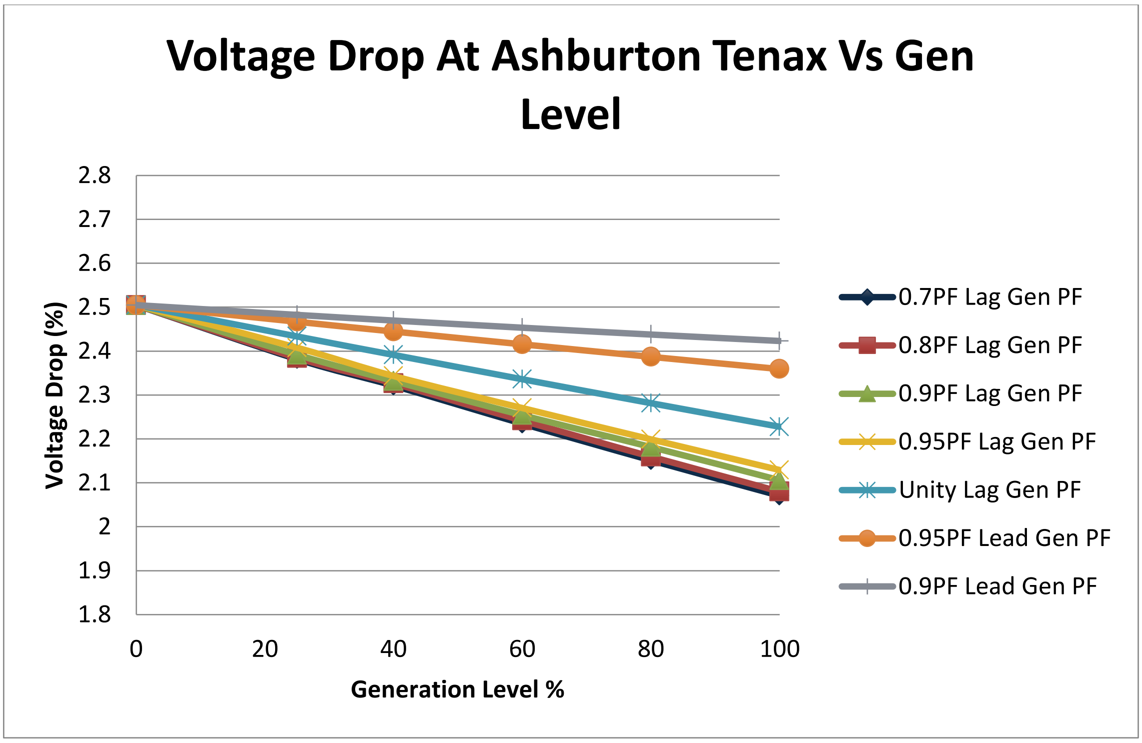


Figure 23 **60% Load level – T11**

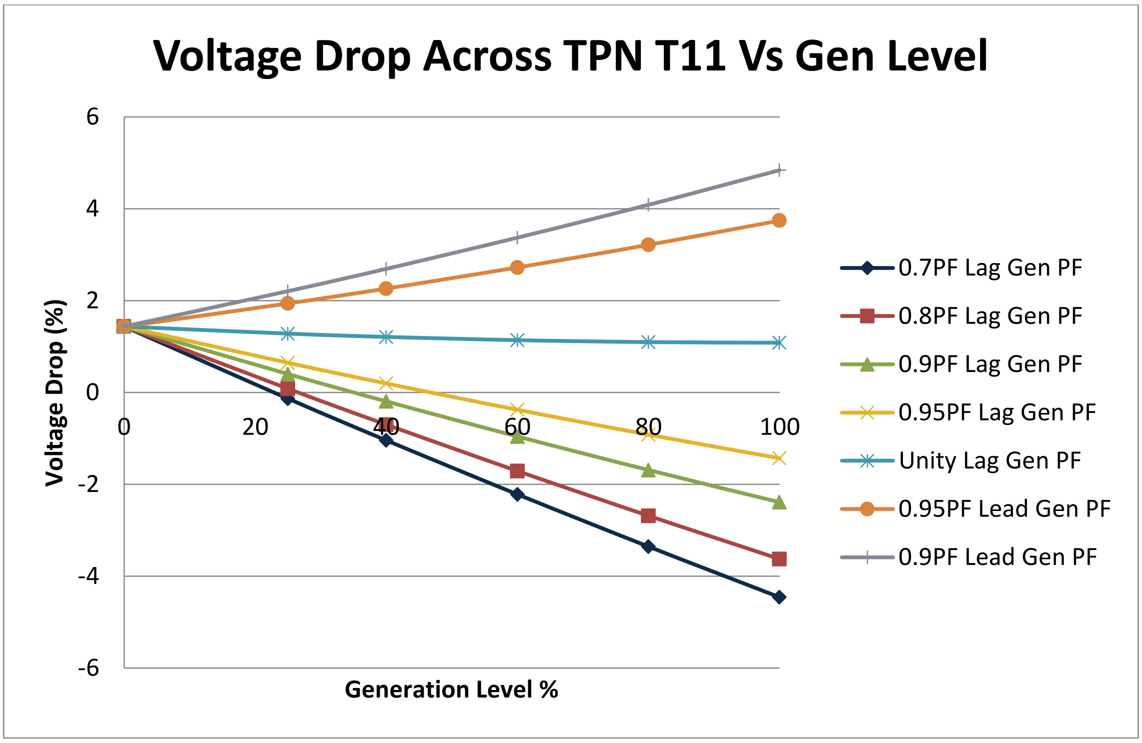


Figure 24 **60% Load level – T12**

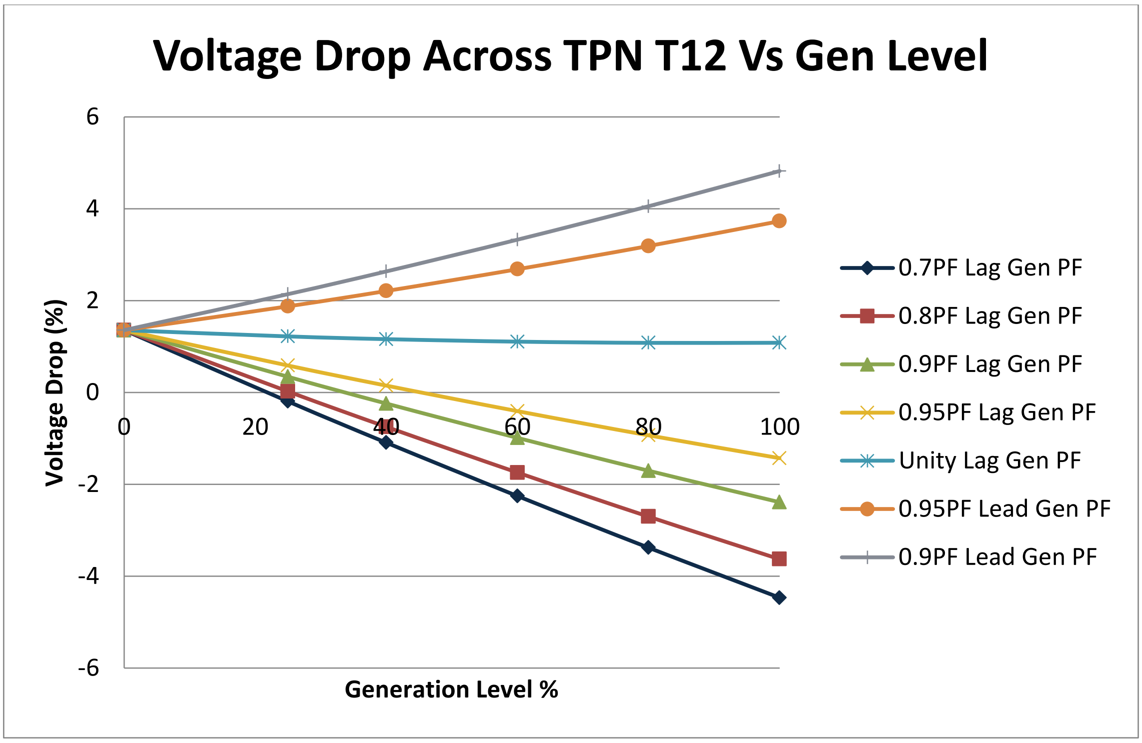


Figure 25 60% Load level – Tenax

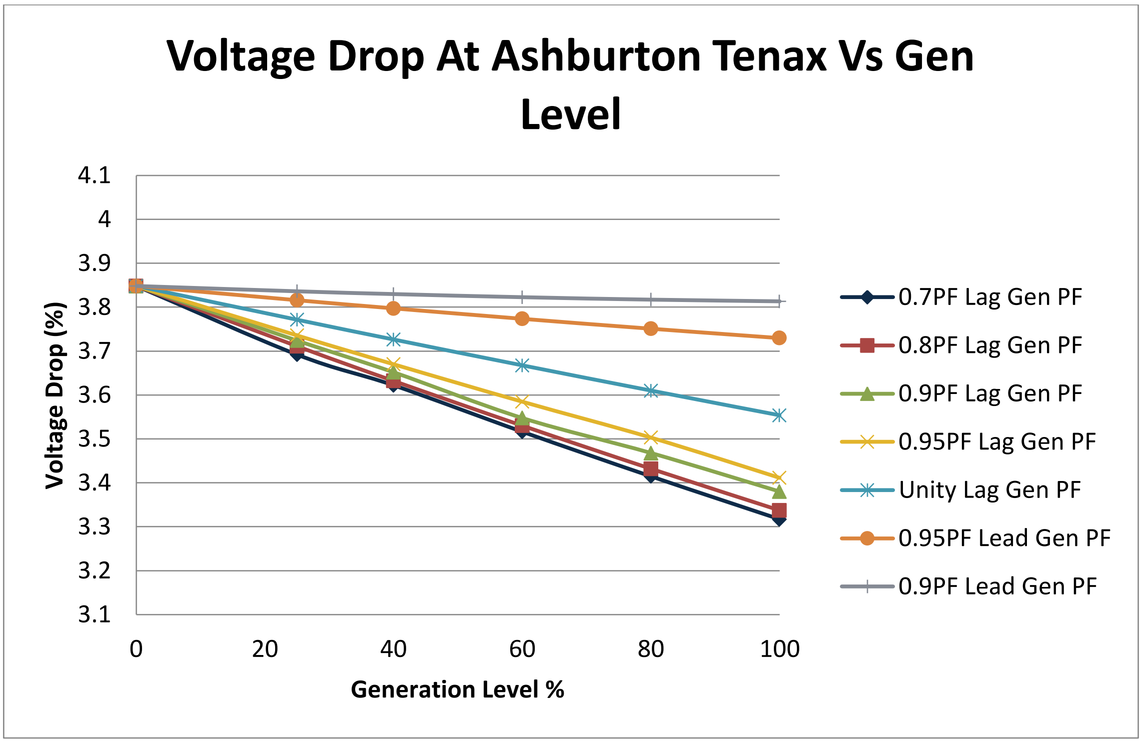


Figure 26 100% Load level – T11

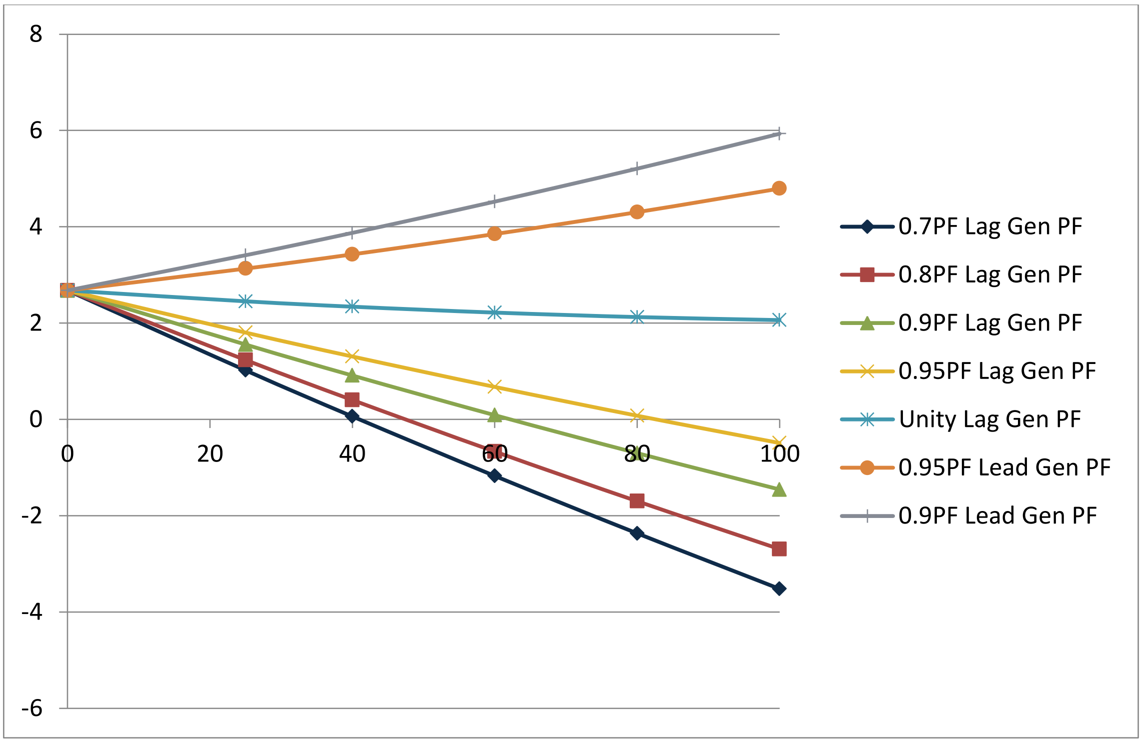


Figure 27 **100% Load level – T12**

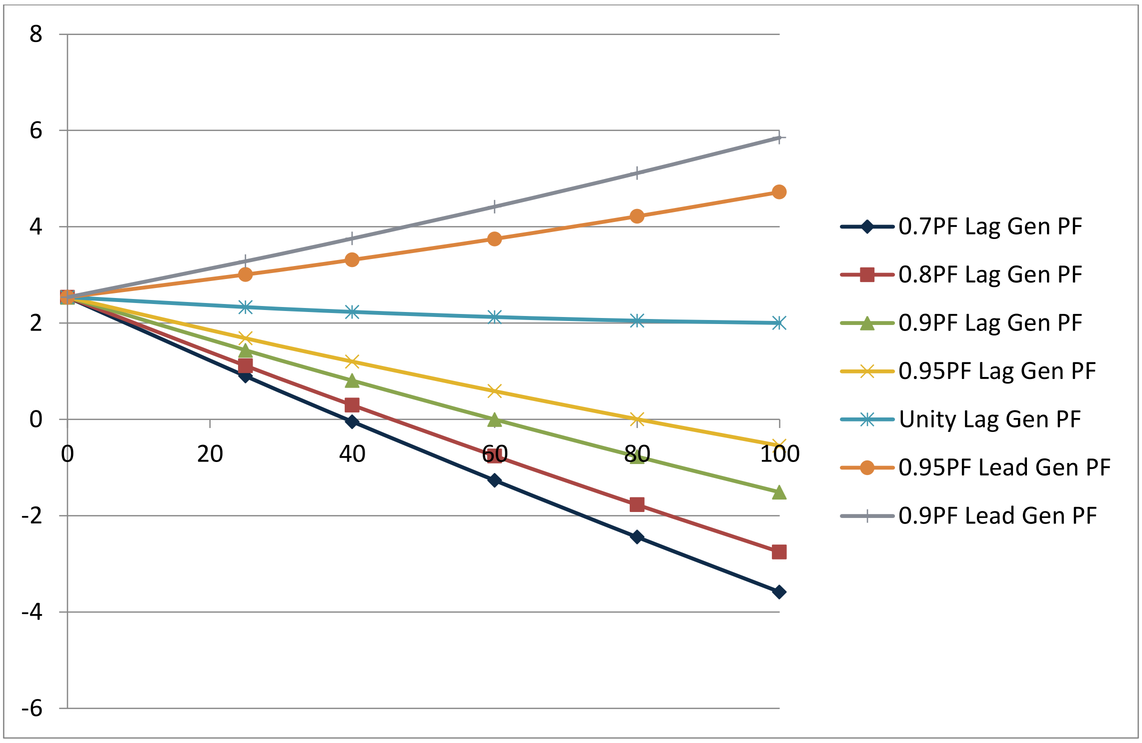
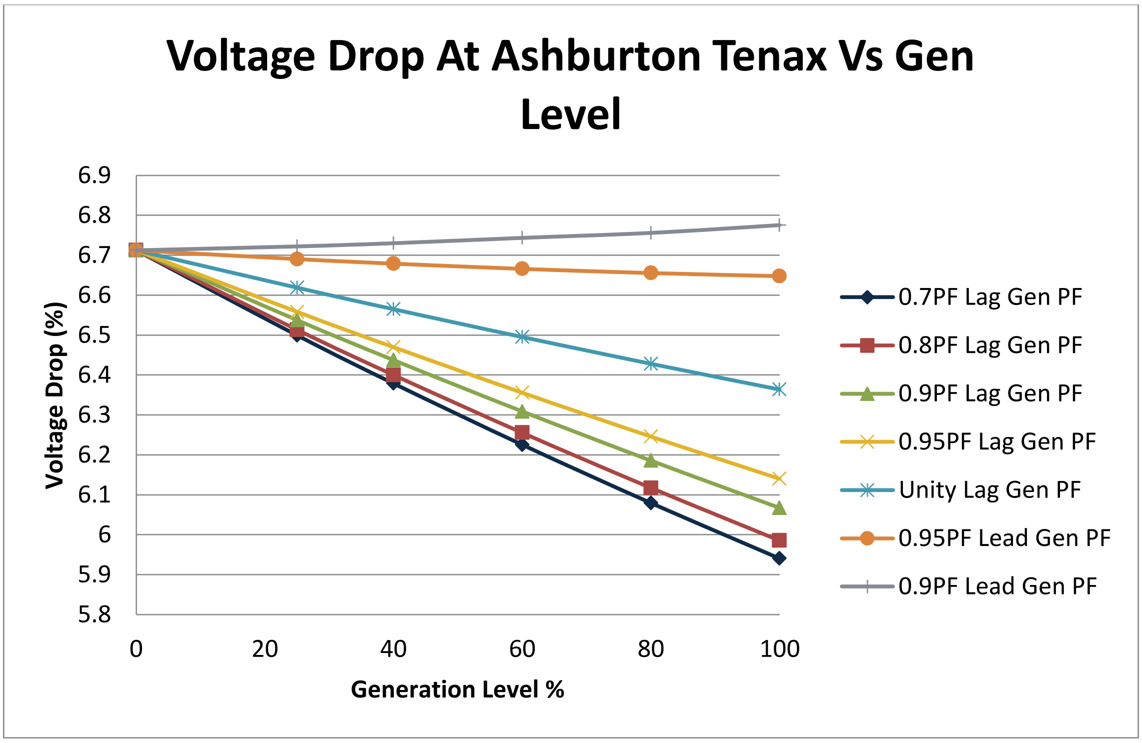


Figure 28 **100% Load level – Tenax**



9 Appendix B: Advanced Simulation Results

Figure 29 0% Generation level T11

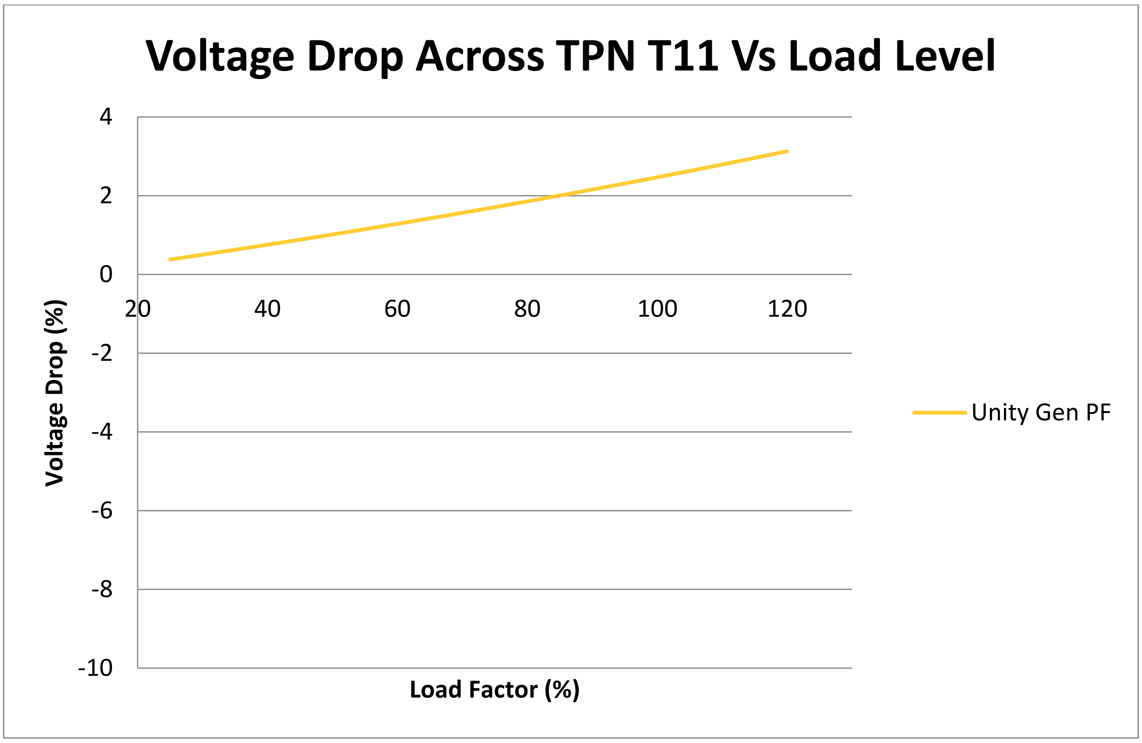


Figure 30 0% Generation level T12

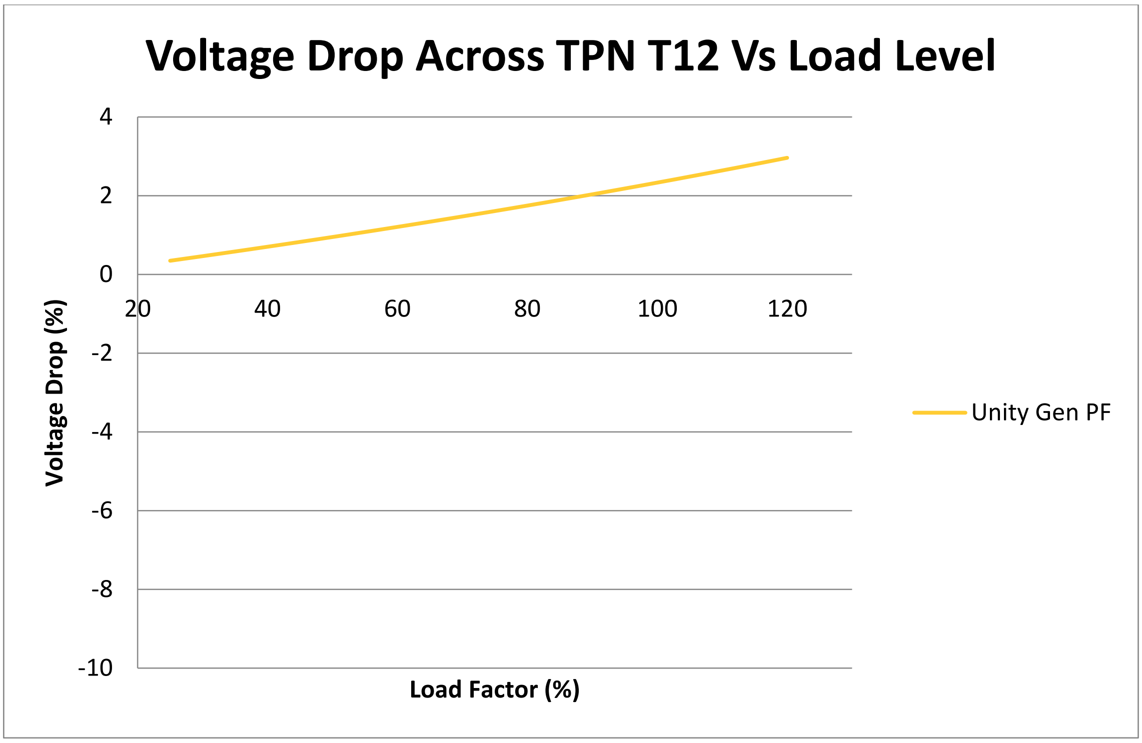


Figure 31 0% Generation level Tenax

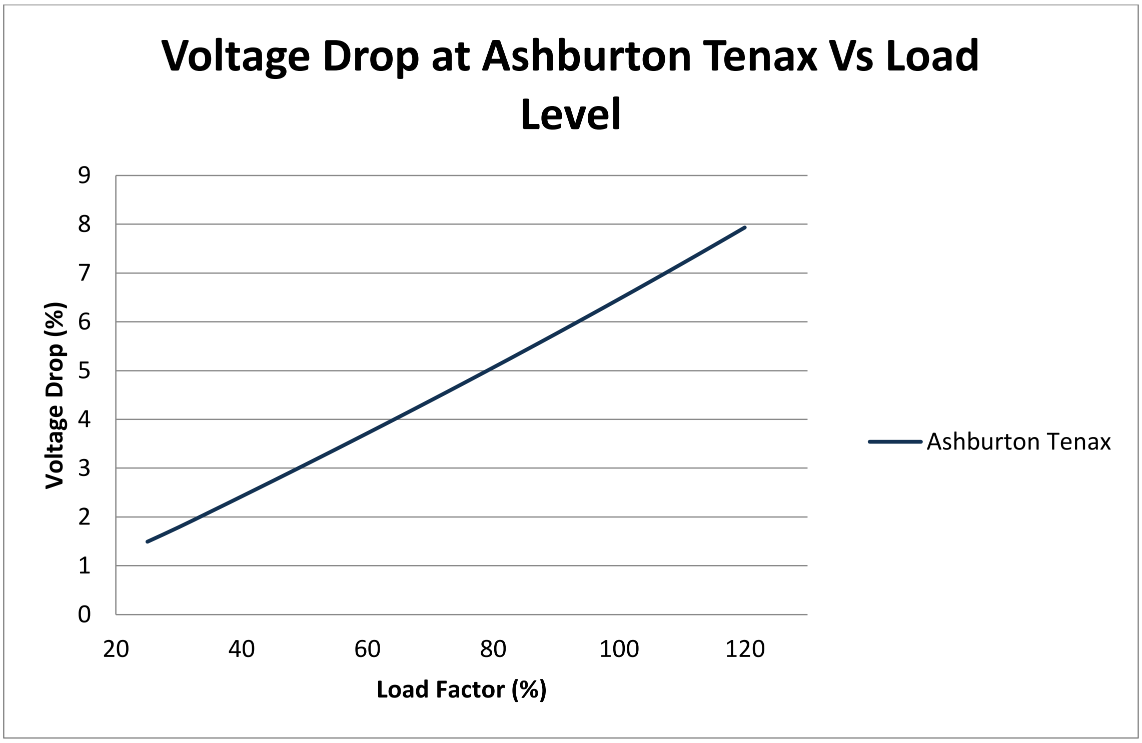


Figure 32 5% Generation level T11

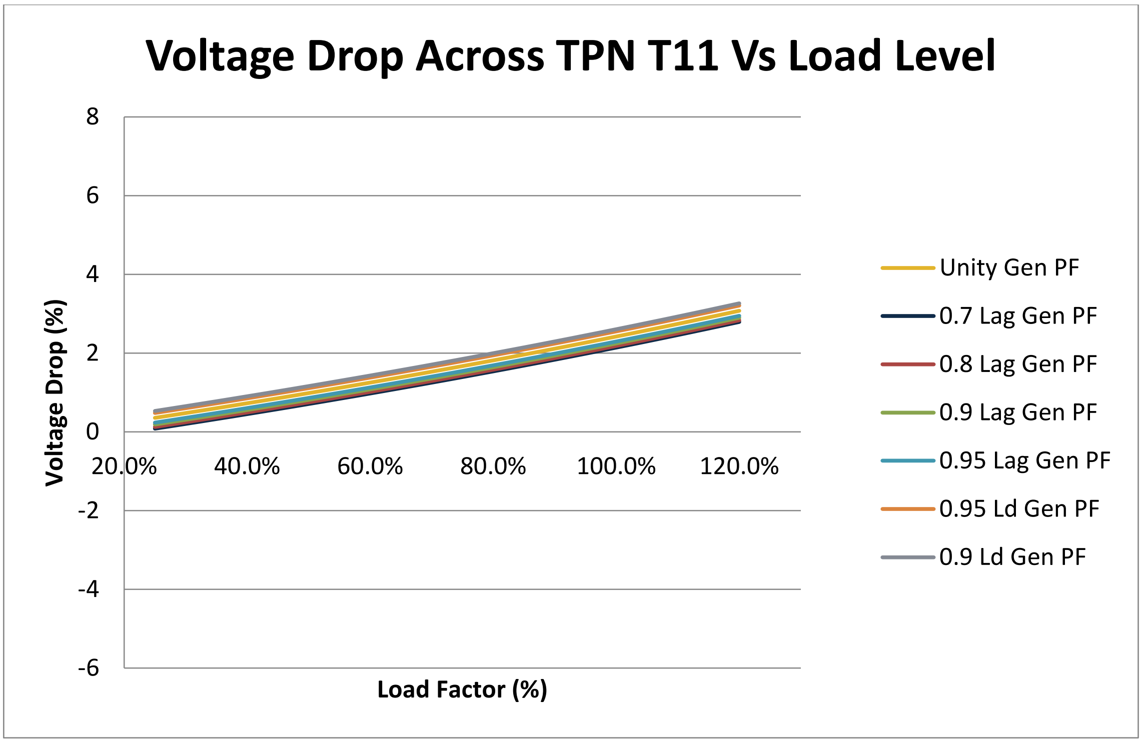


Figure 33 **5% Generation level T12**

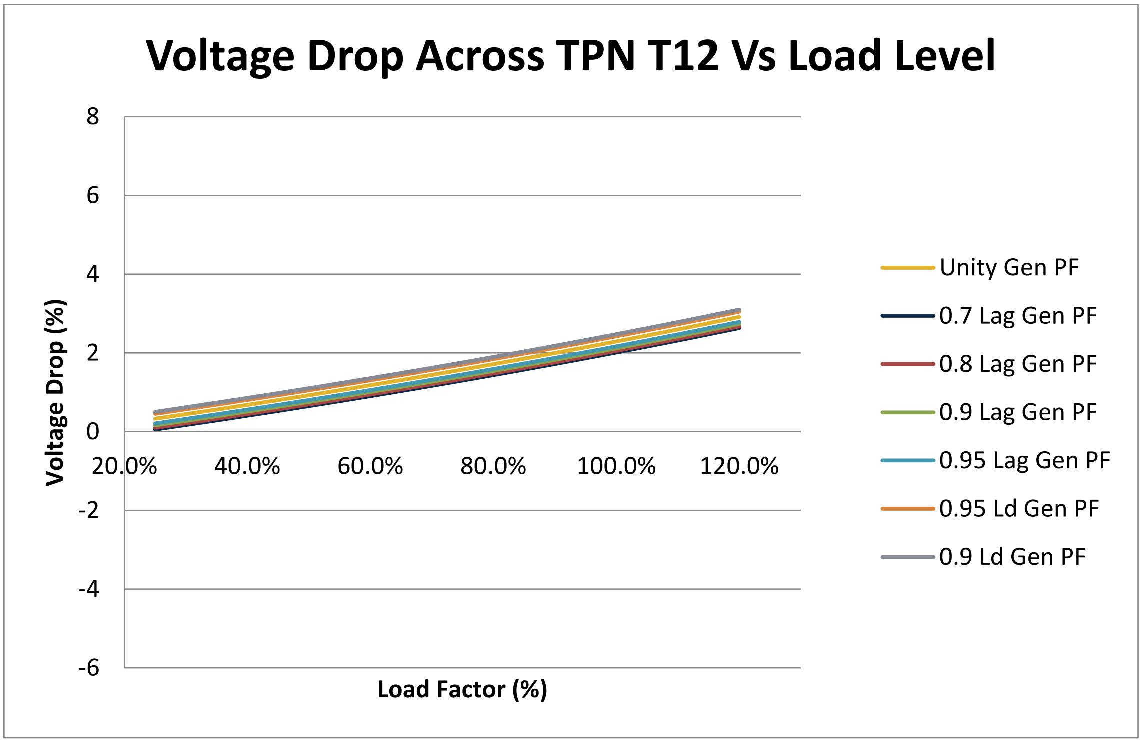


Figure 34 **5% Generation level Tenax**

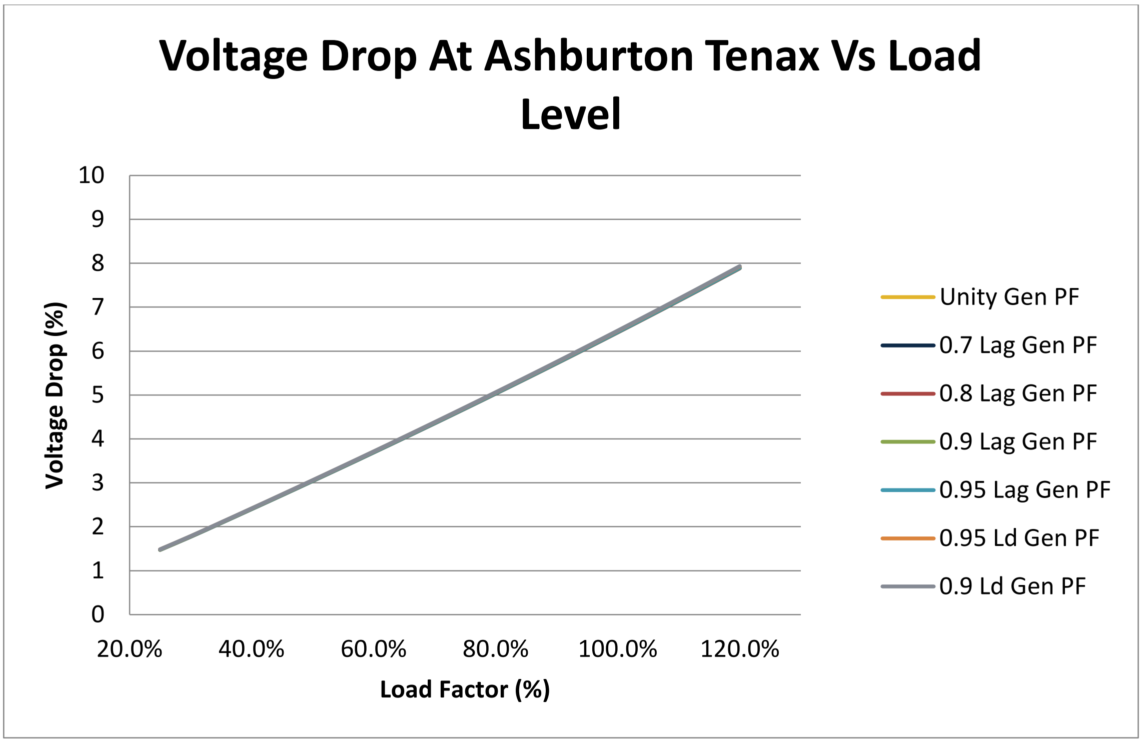


Figure 35 15% Generation level T11

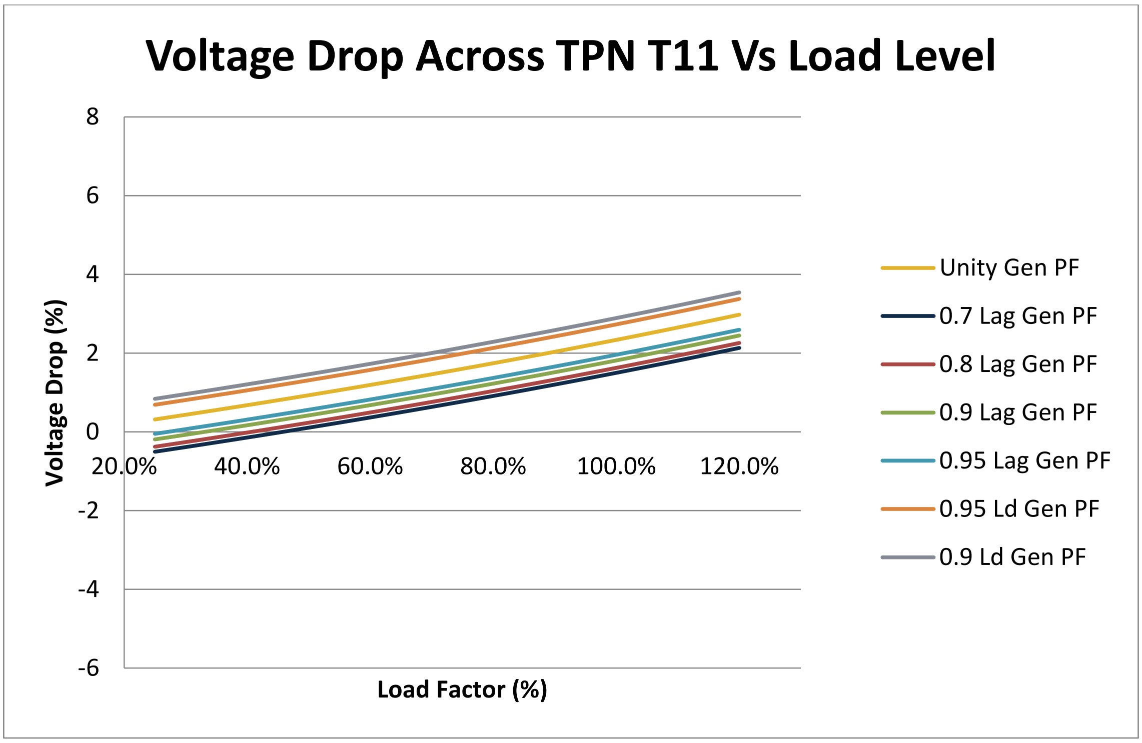


Figure 36 15% Generation level T12

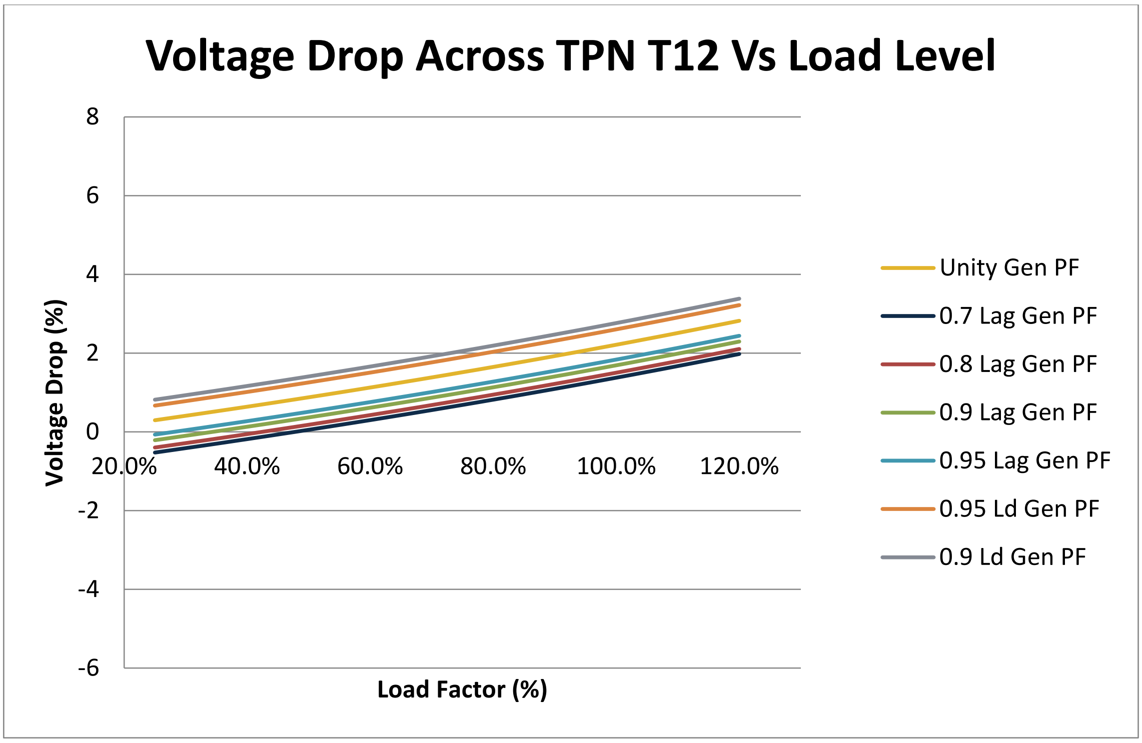


Figure 37 15% Generation level Tenax

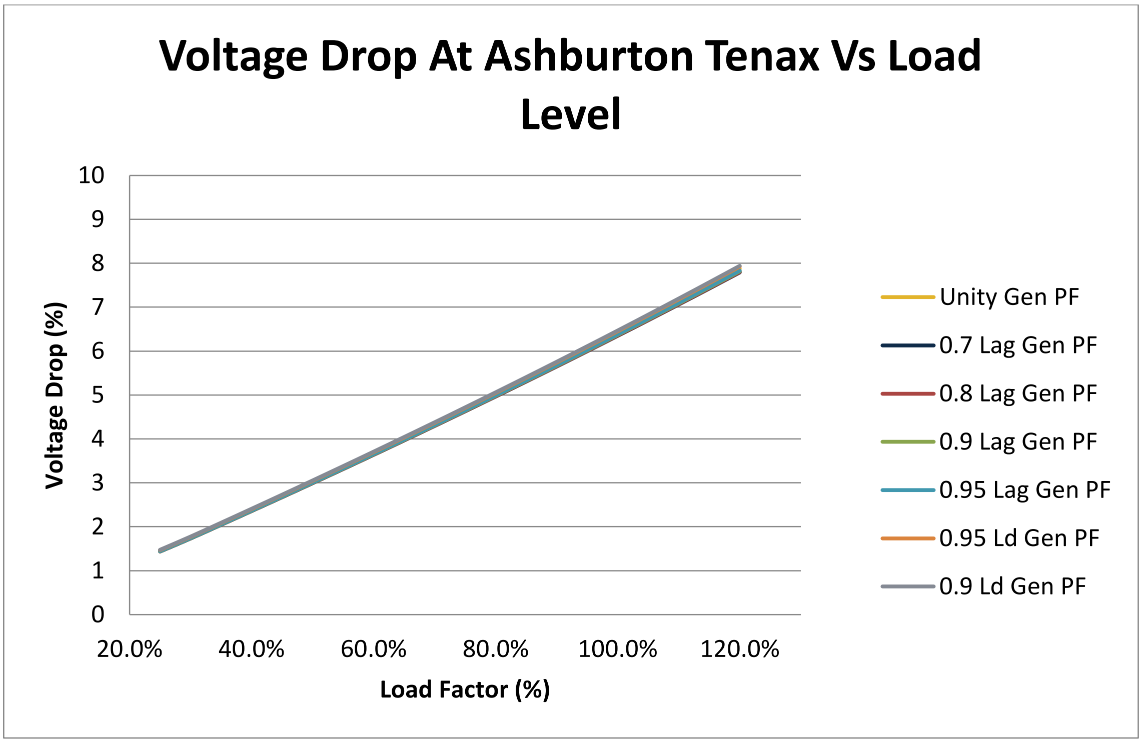


Figure 38 25% Gen Factor T11

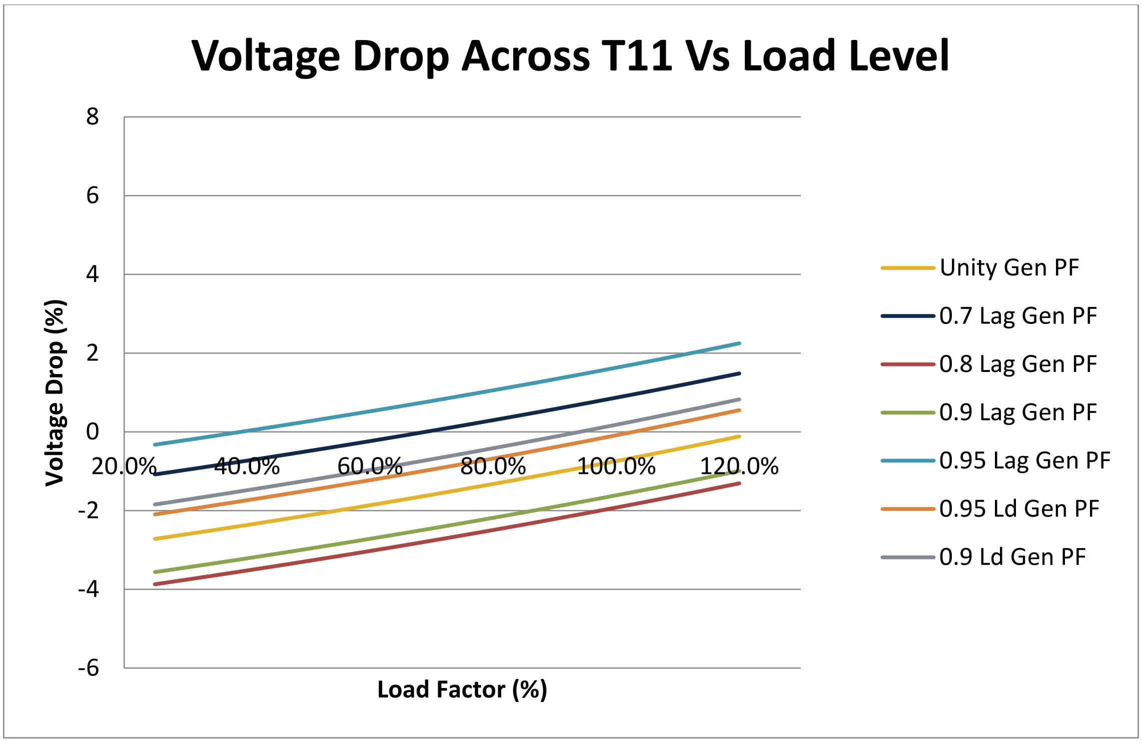


Figure 39 25% Gen Factor T12

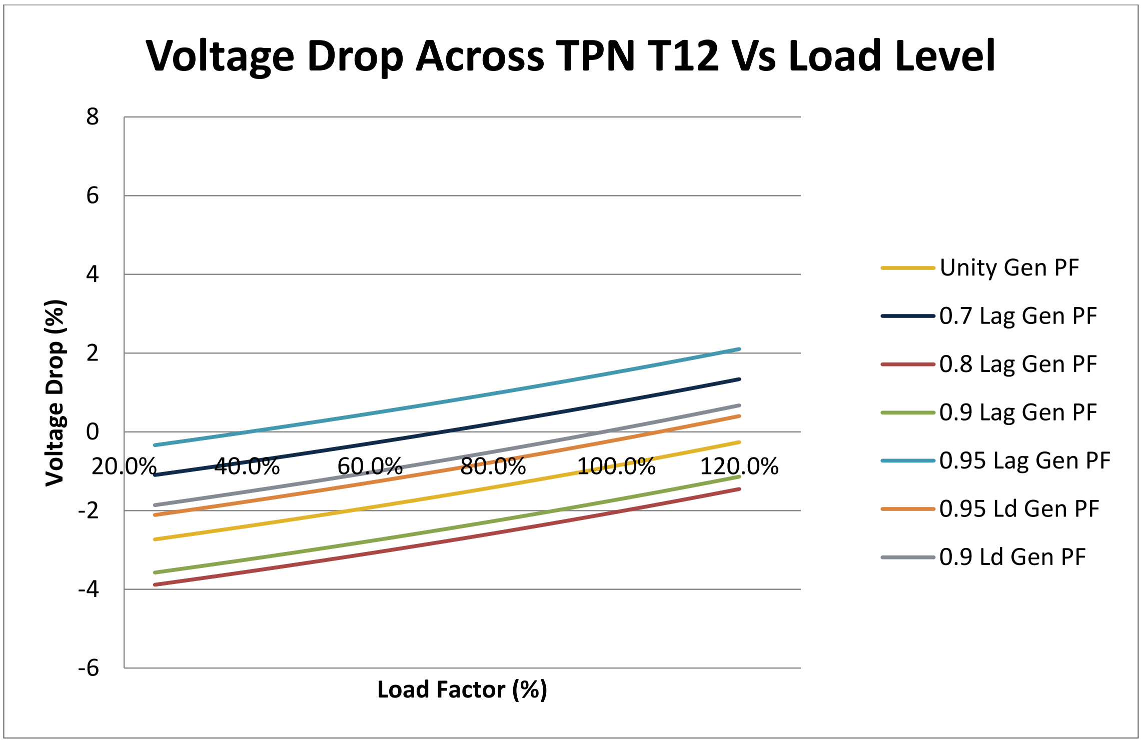


Figure 40 25% Gen Factor Tenax

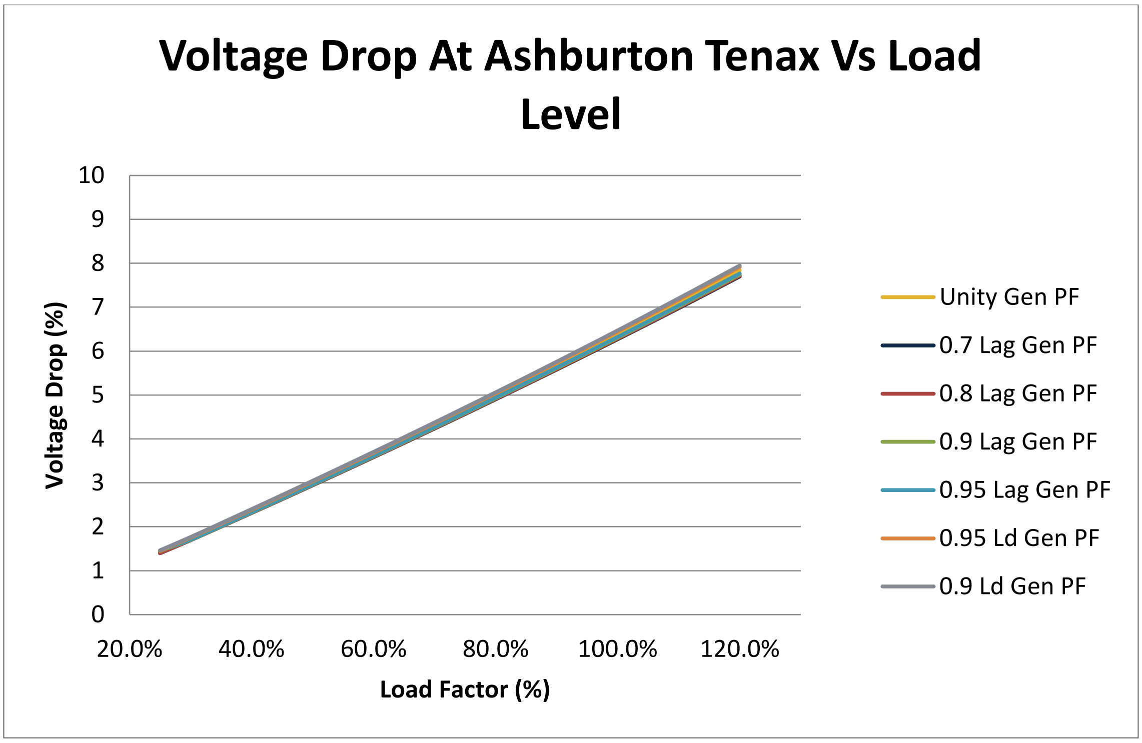


Figure 41 40% Generation level T11

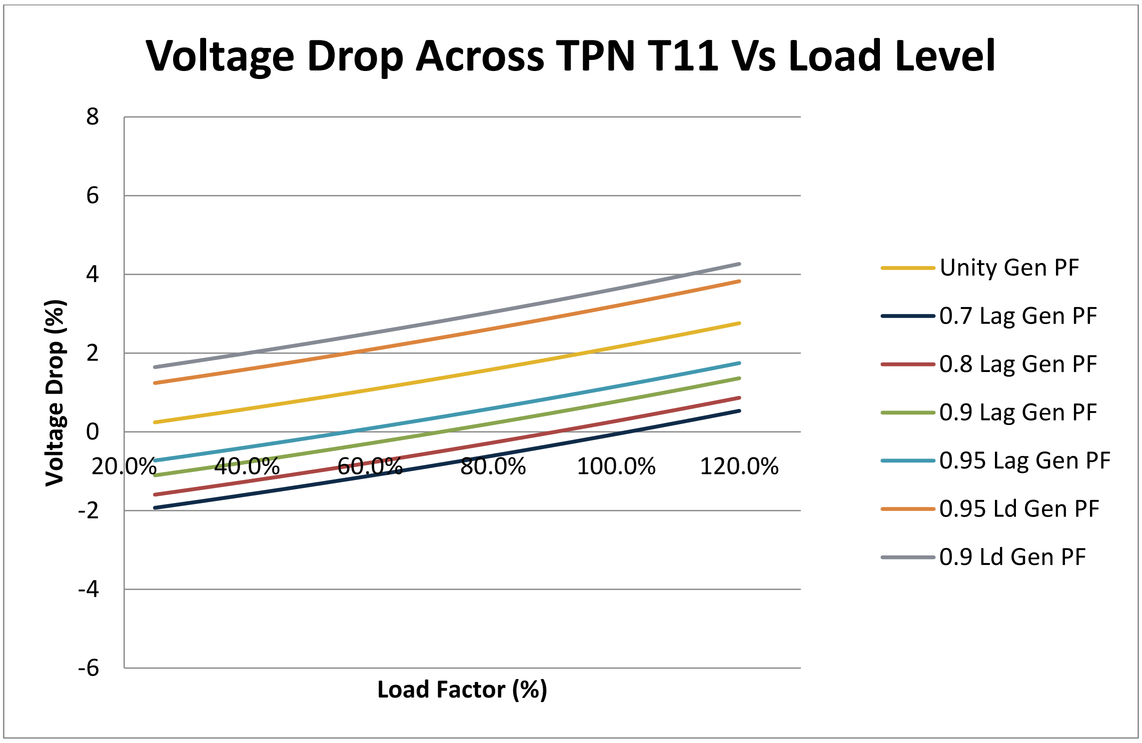


Figure 42 40% Generation level T12

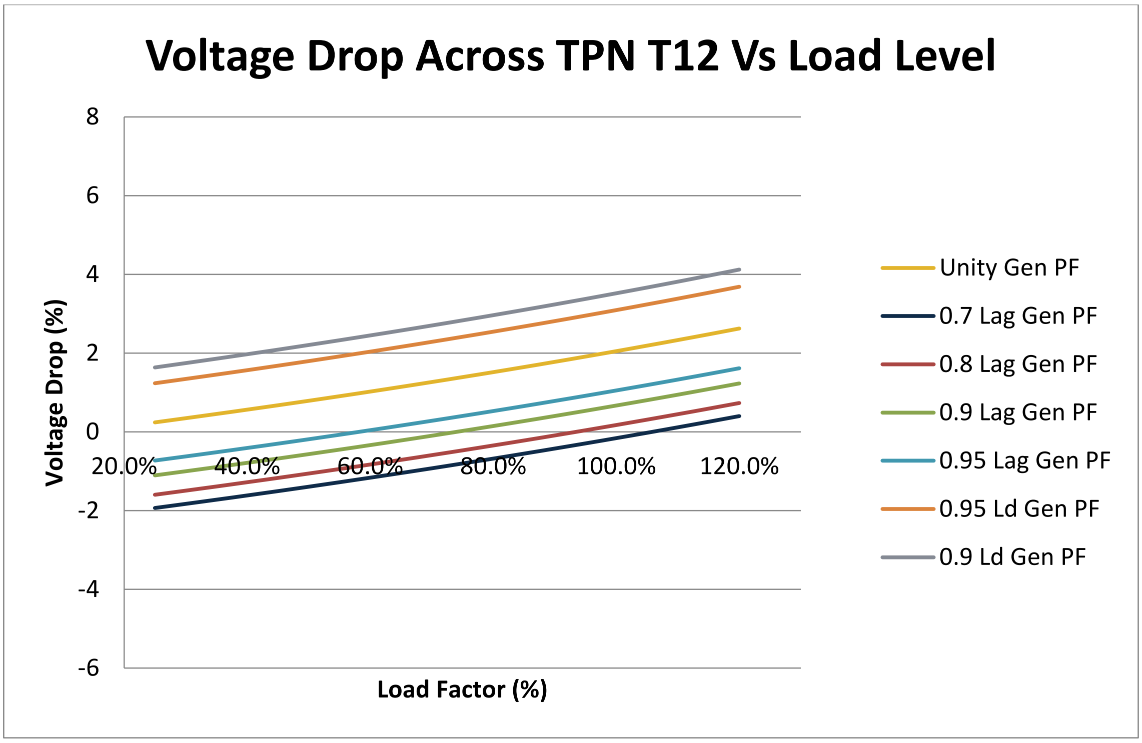


Figure 43 **40% Generation level Tenax**

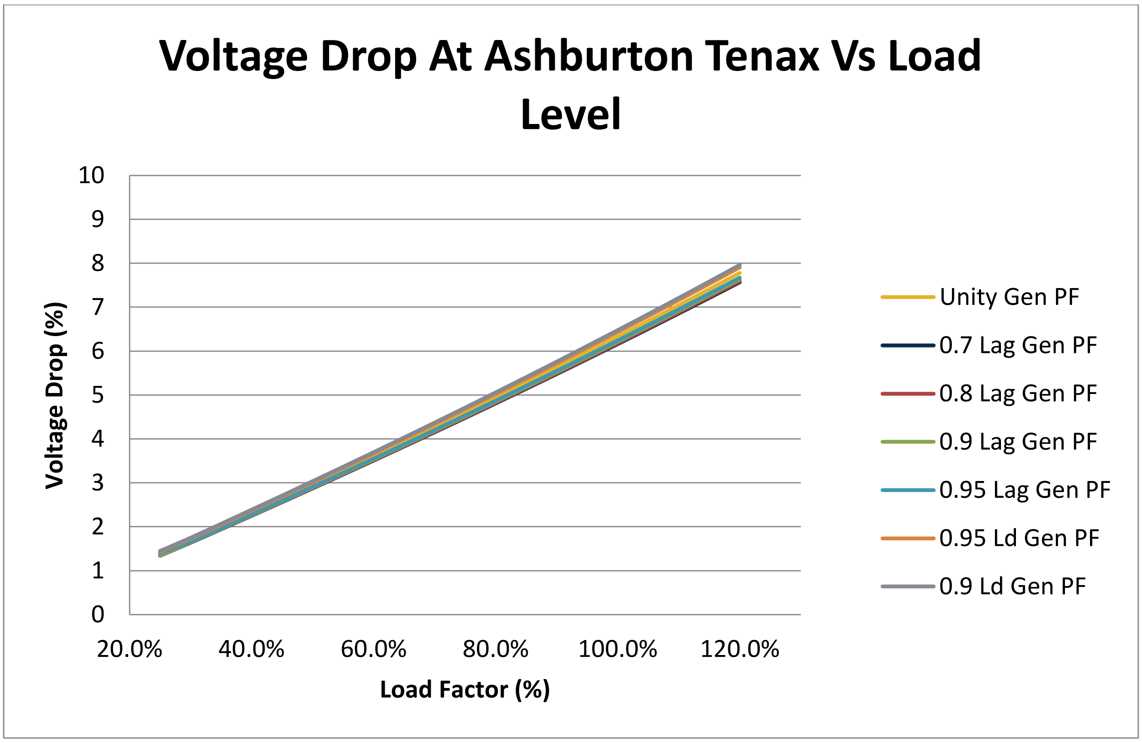


Figure 44 **60% Generation level T11**

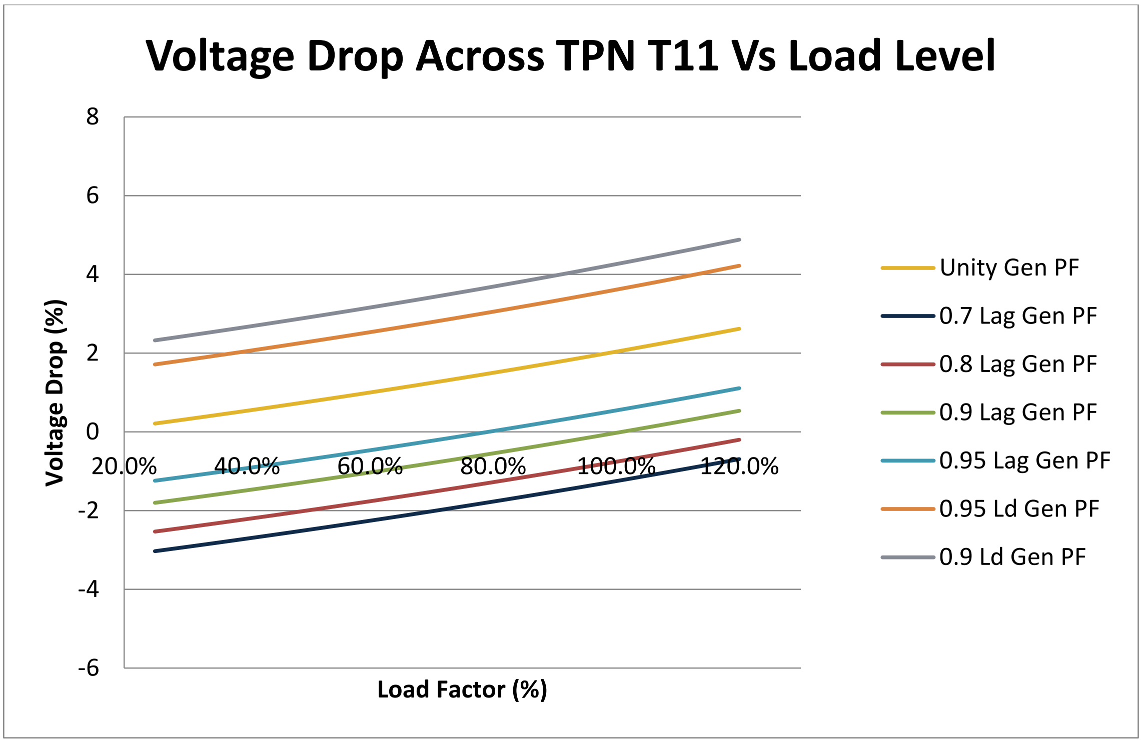


Figure 45 60% Generation level T12

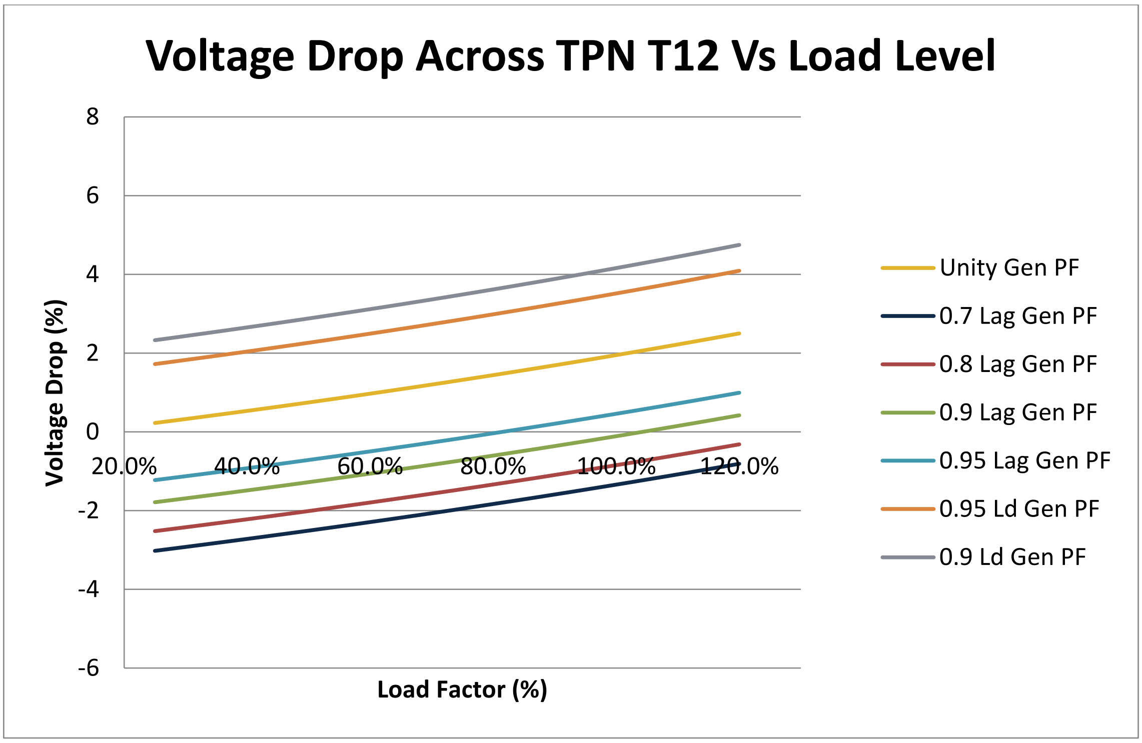


Figure 46 60% Generation level Tenax

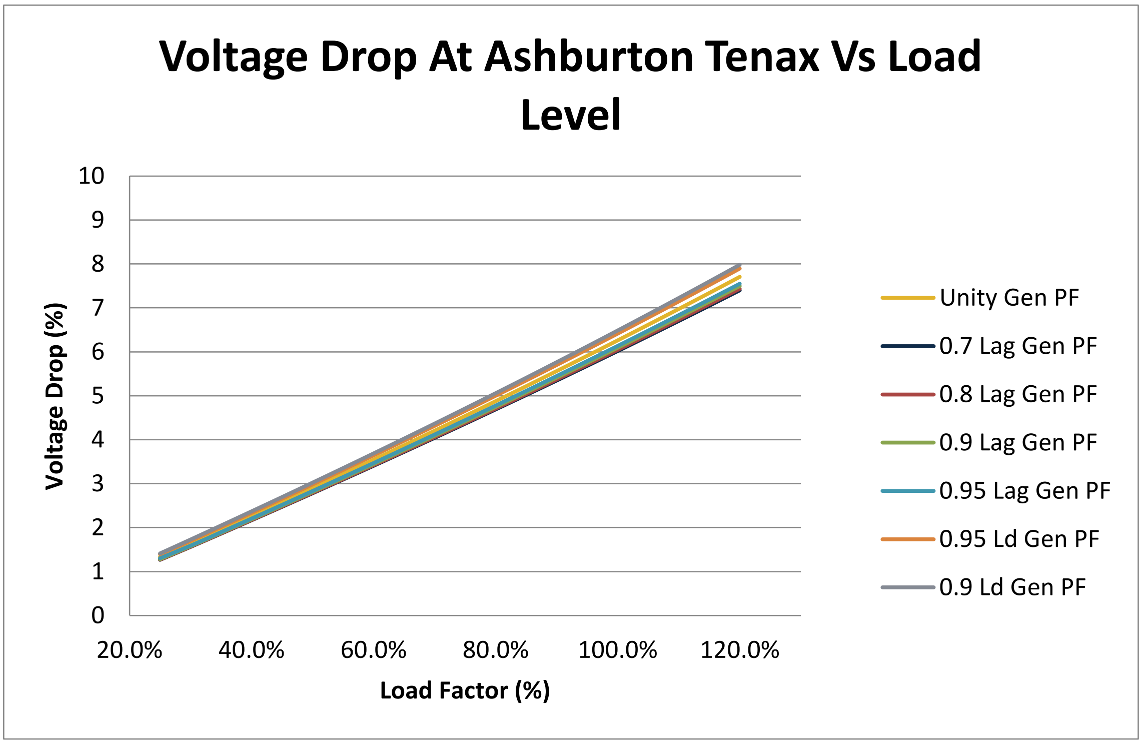


Figure 47 80% Generation level T11

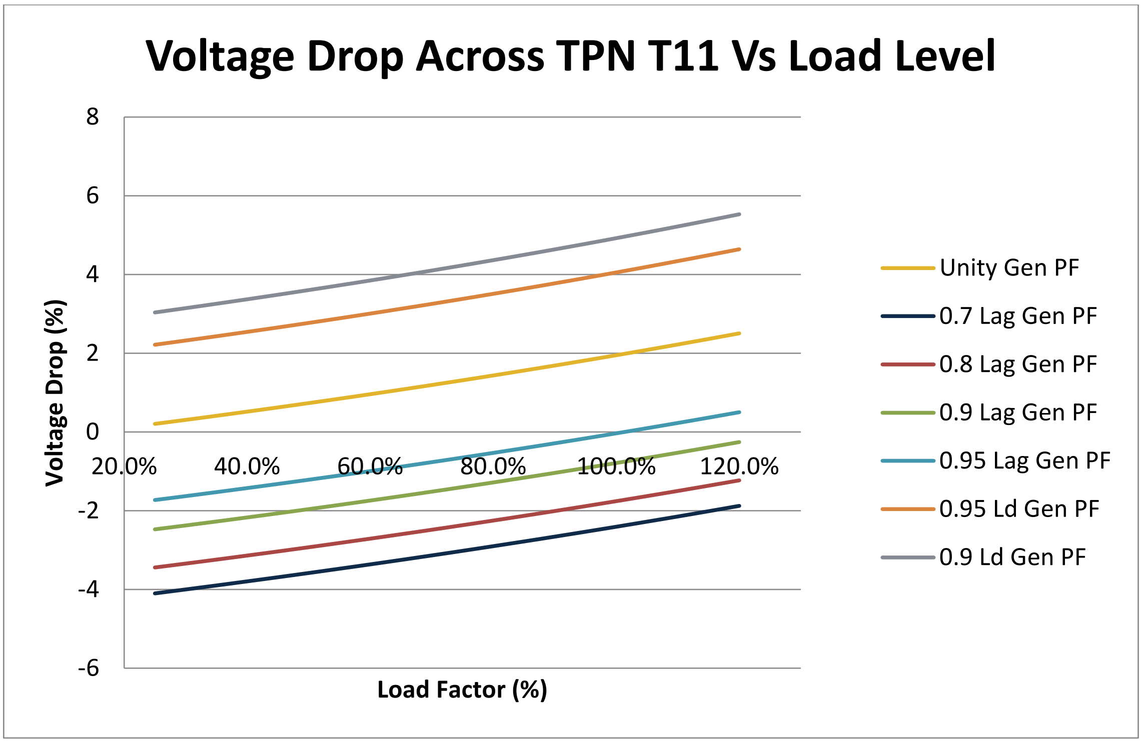


Figure 48 80% Generation level T12

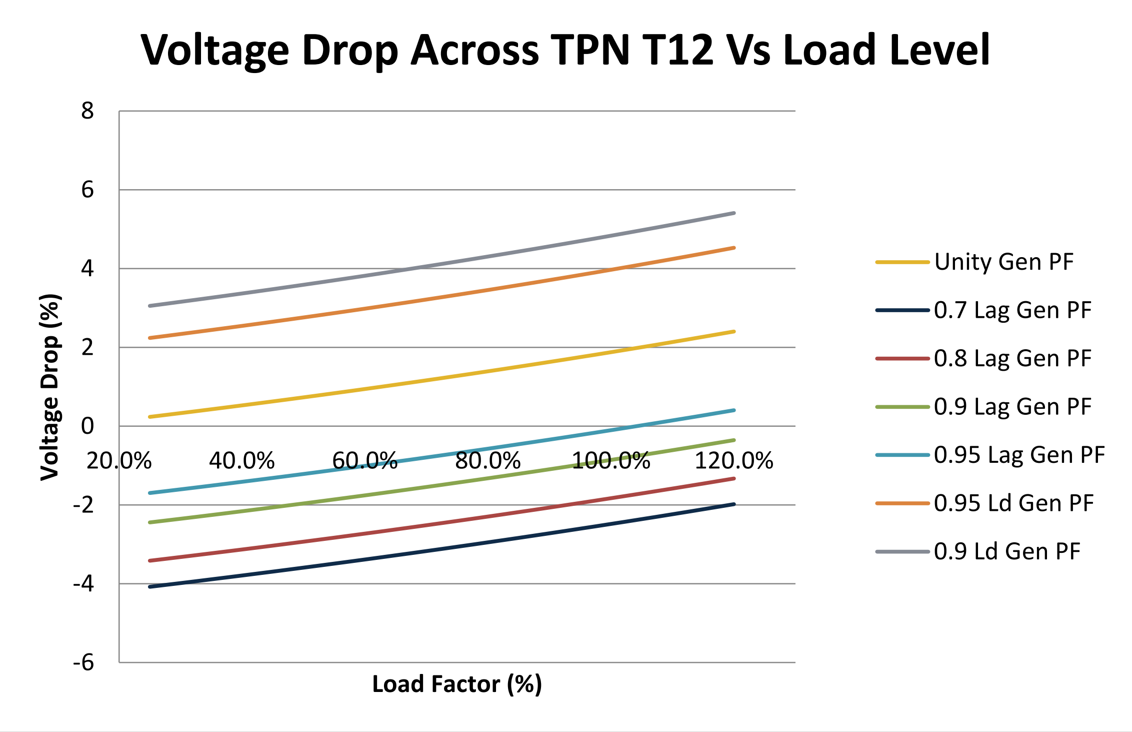


Figure 49 80% Generation level Tenax

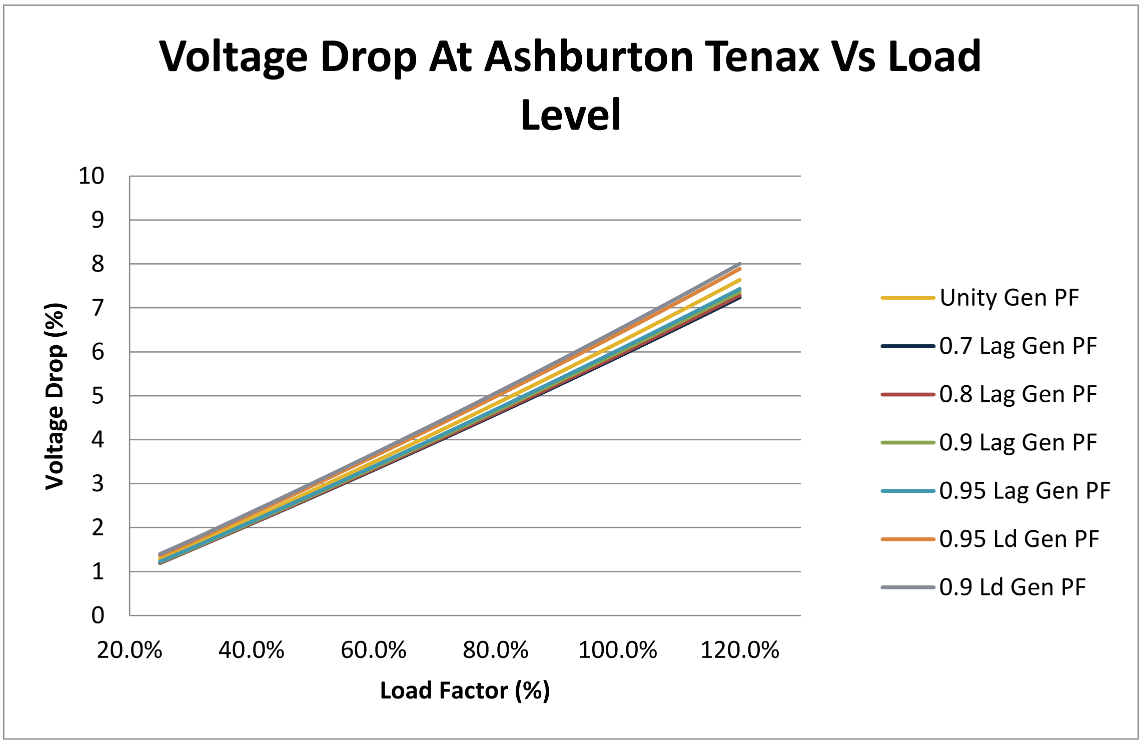


Figure 50 100% Generation level T11

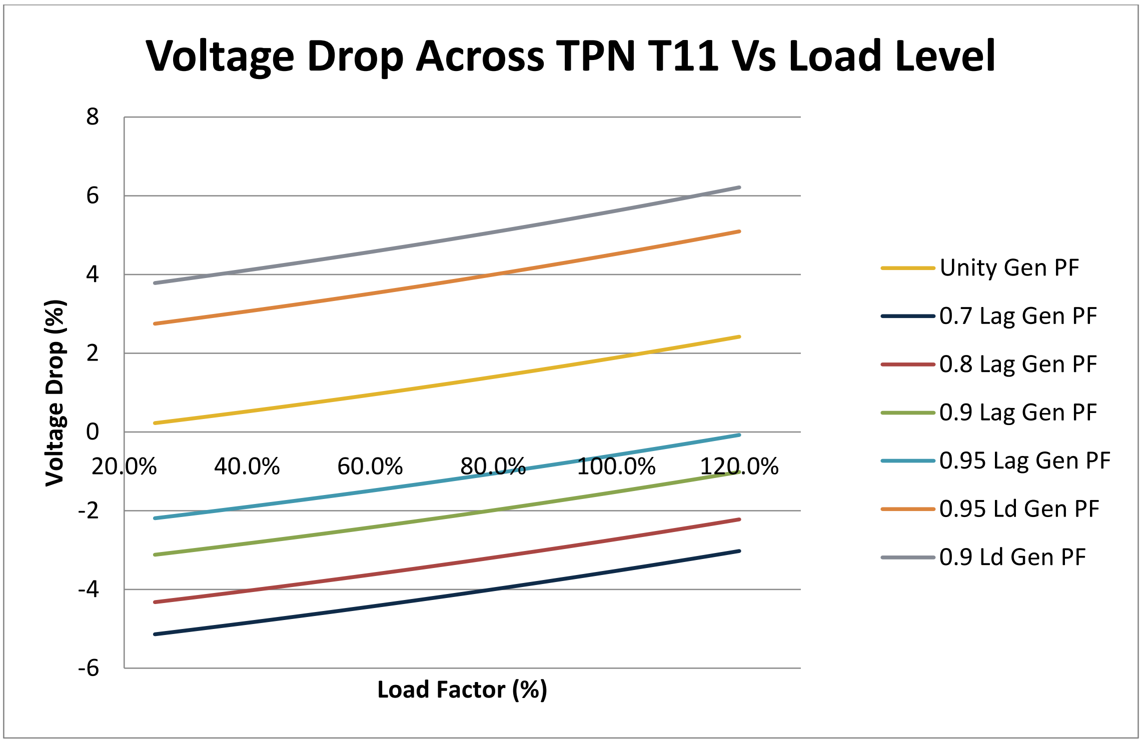


Figure 51 100% Generation level T12

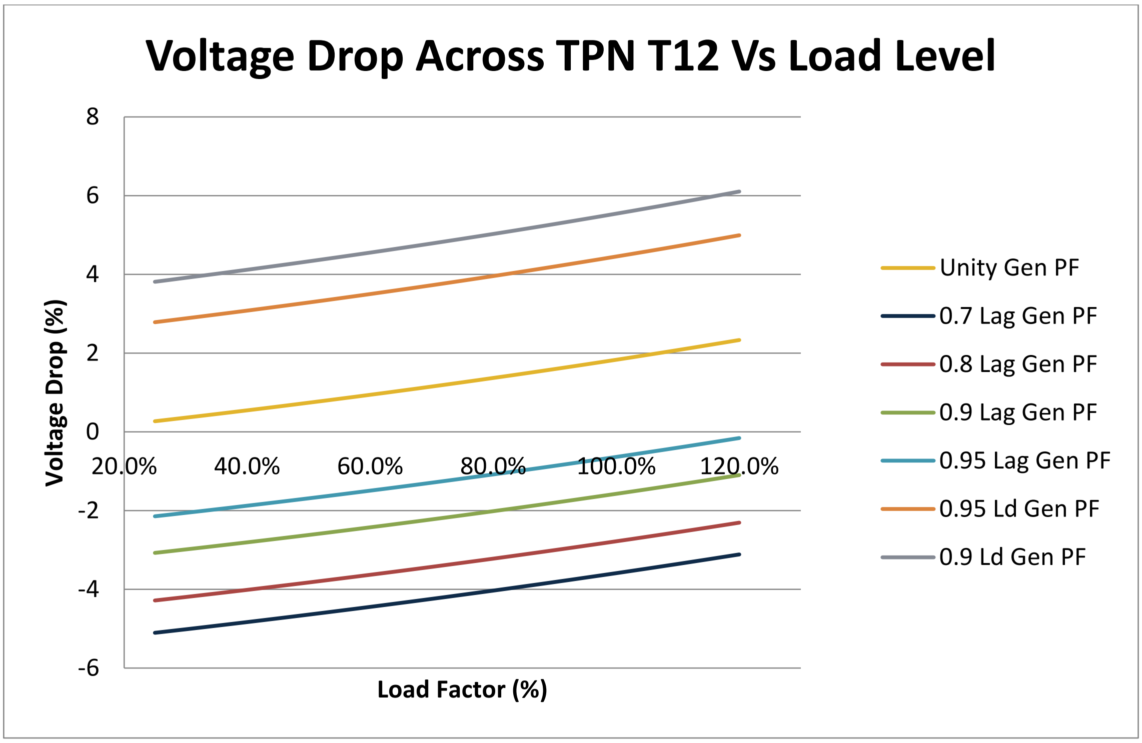


Figure 52 100% Generation level Tenax

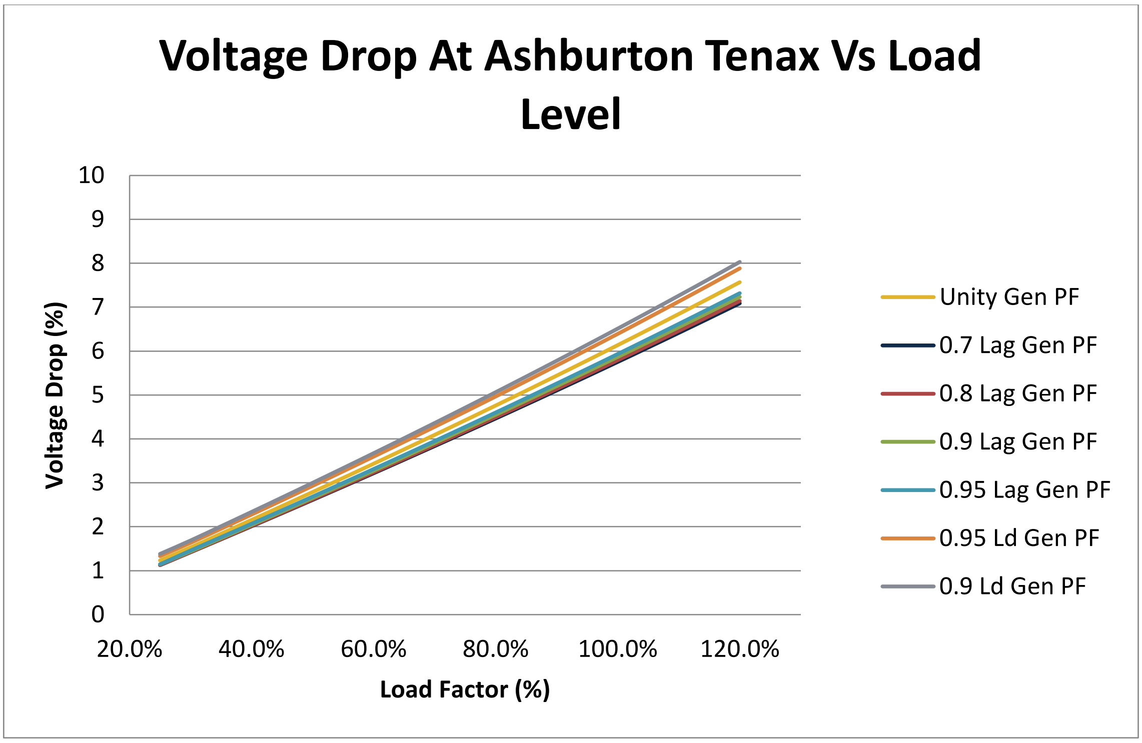
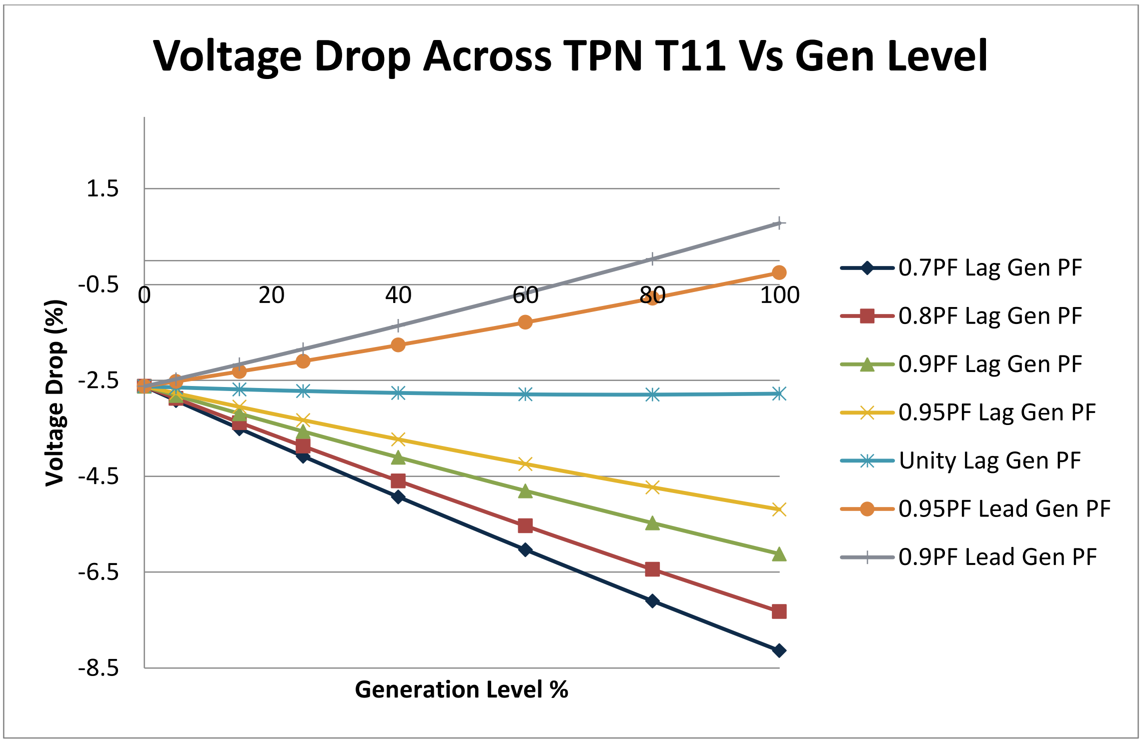


Figure 53 25% Load factor – T11



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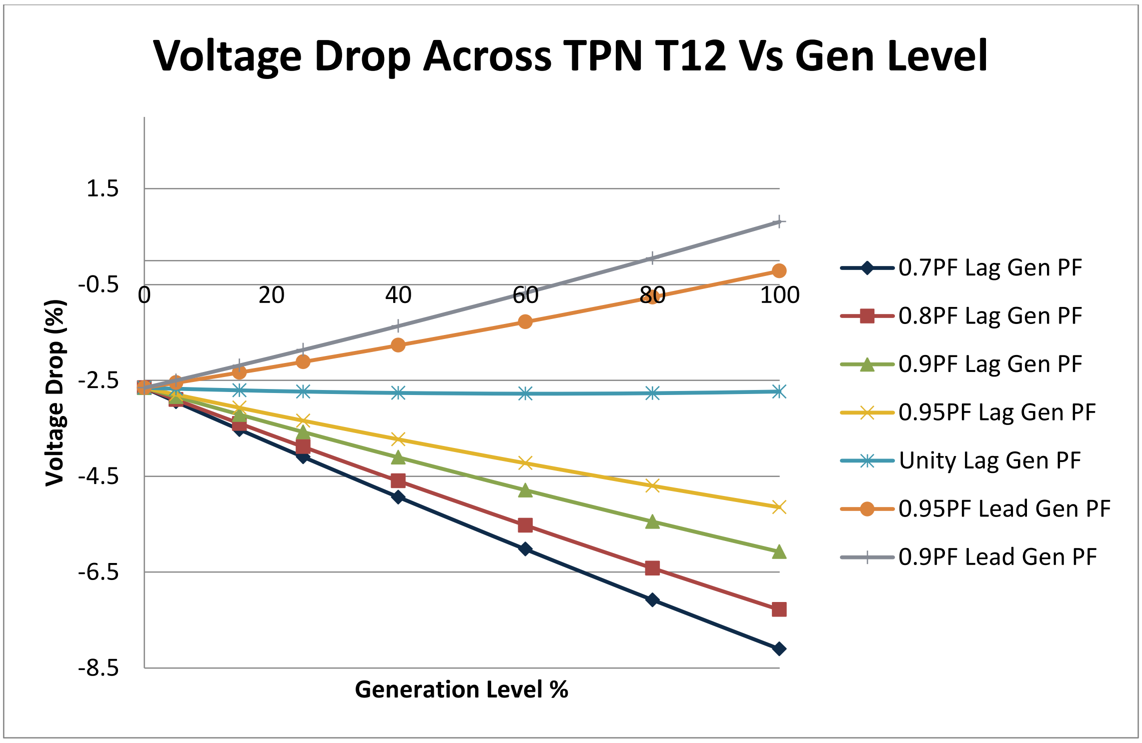

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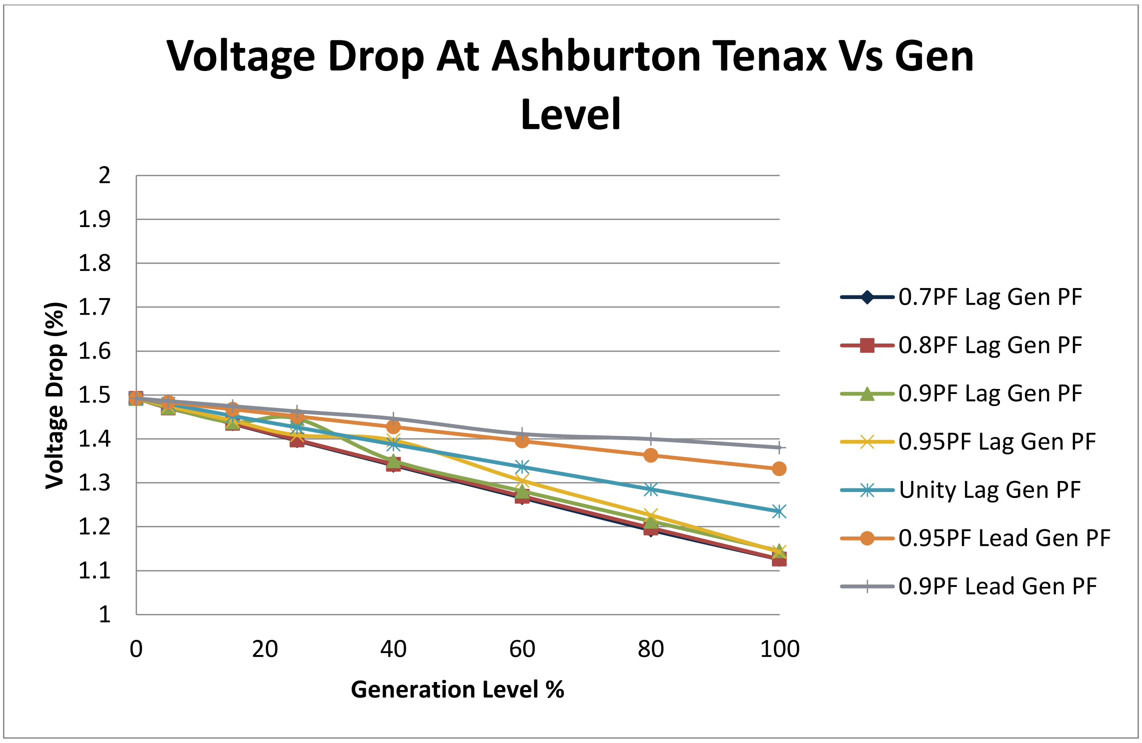
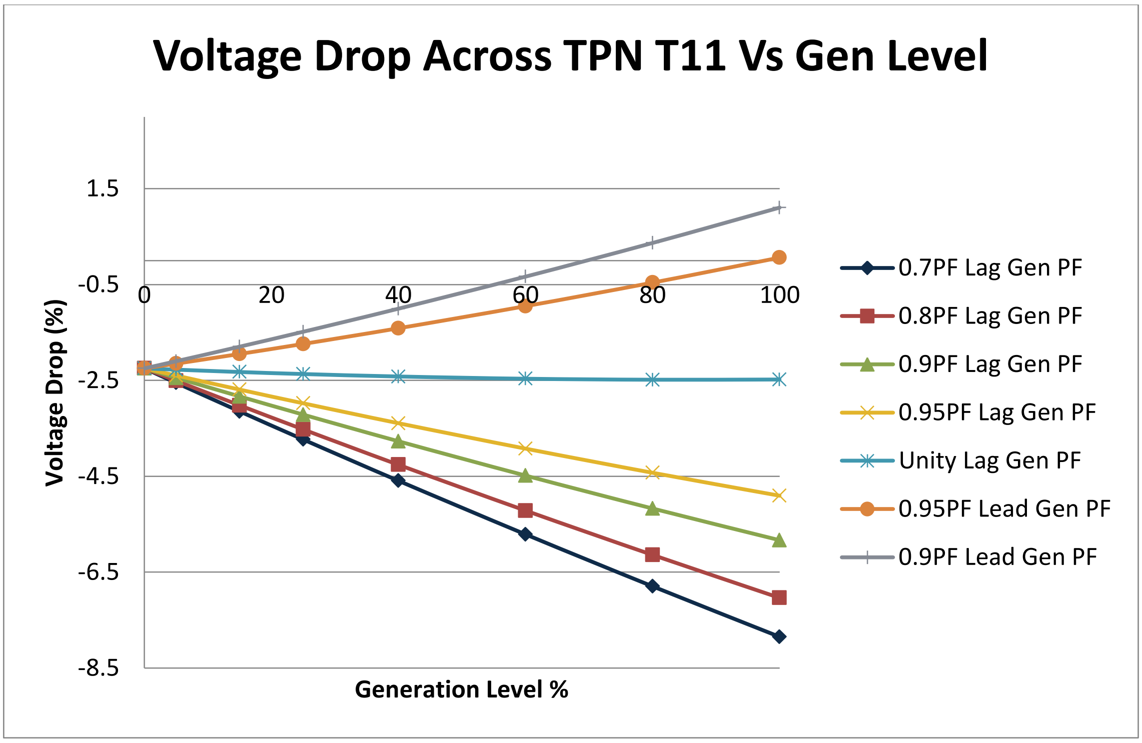


Figure 56 40% Load factor – T11



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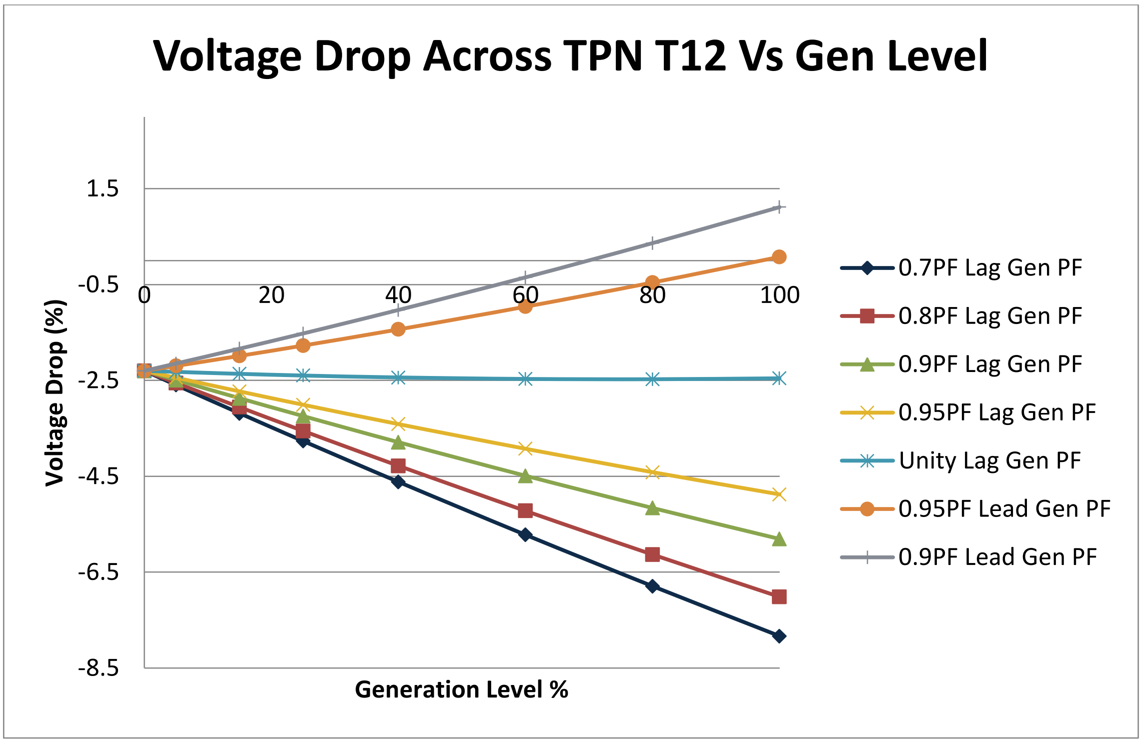

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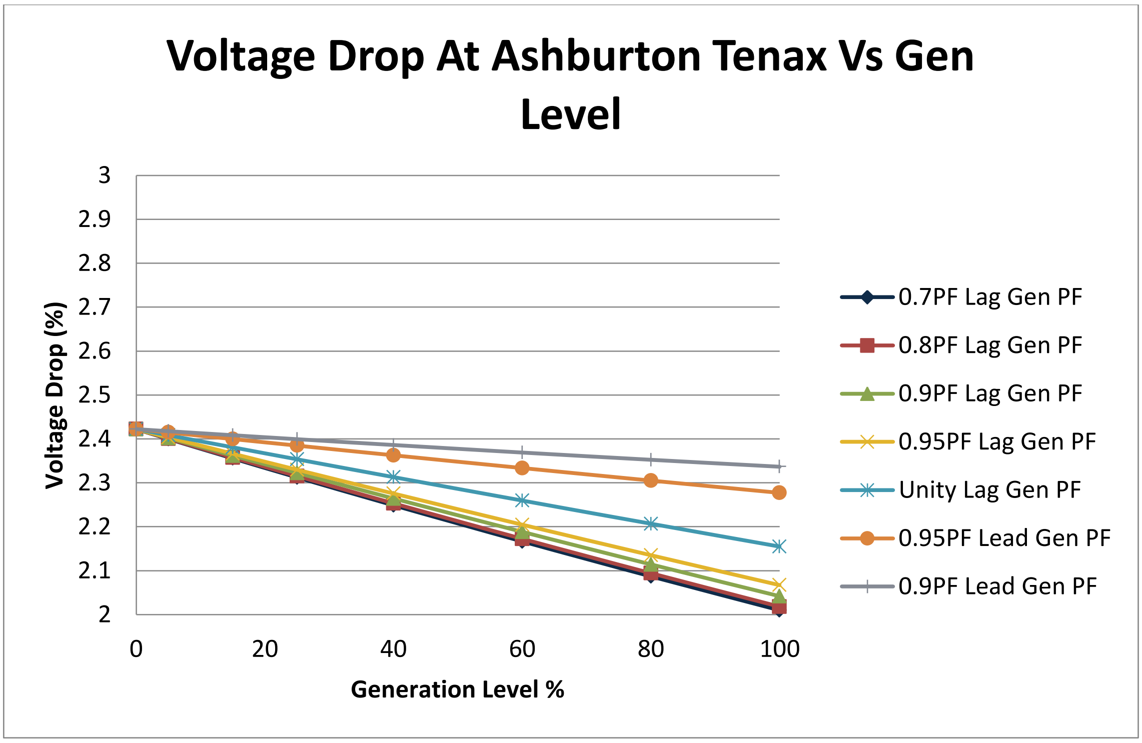

Figure 59 60% Load factor – T11

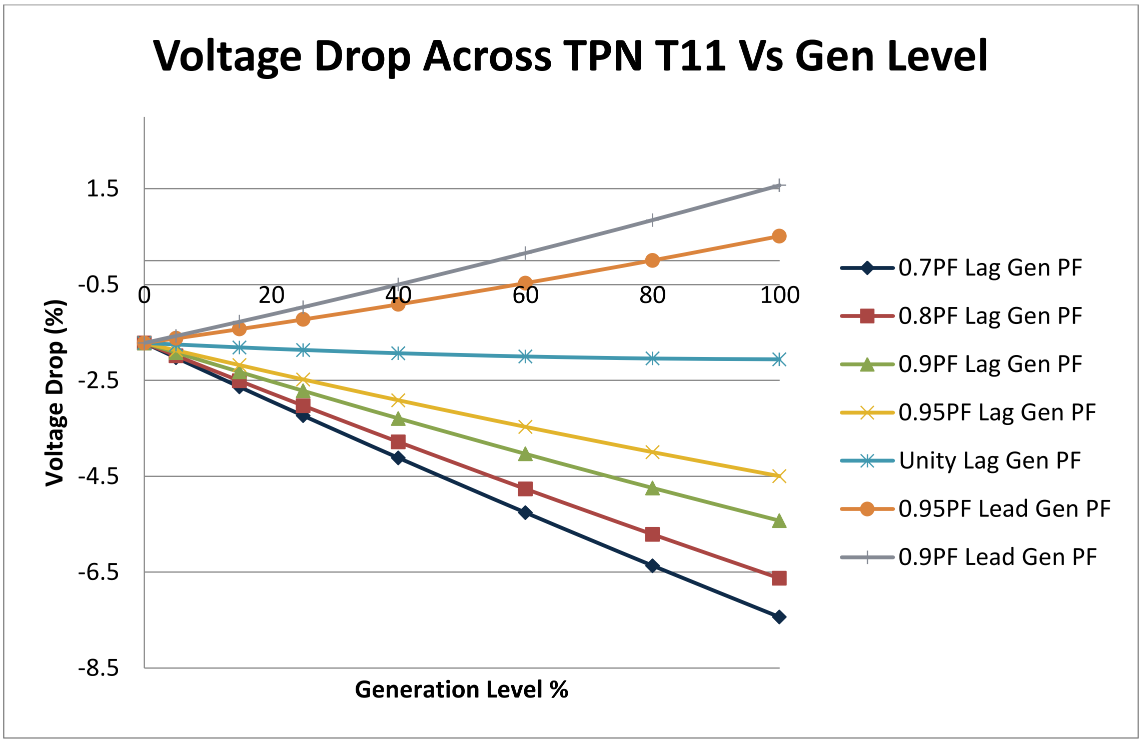

Figure 60 60% Load factor – T12

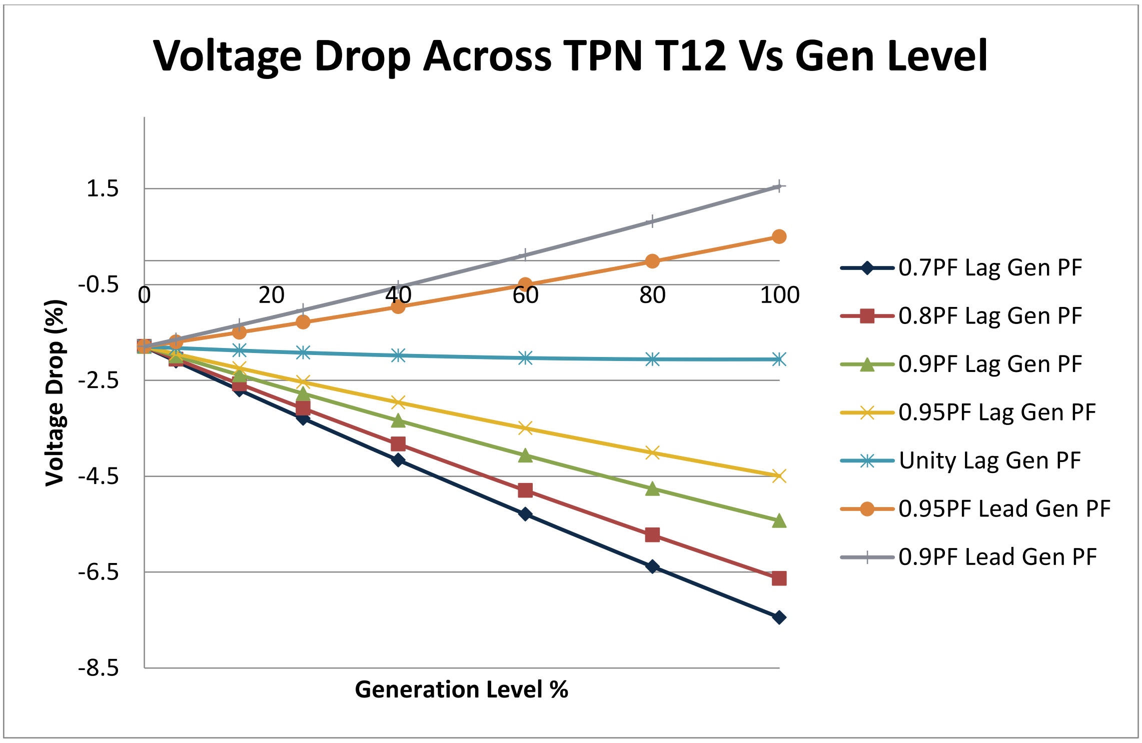

Figure 61 60% Load factor – Tenax

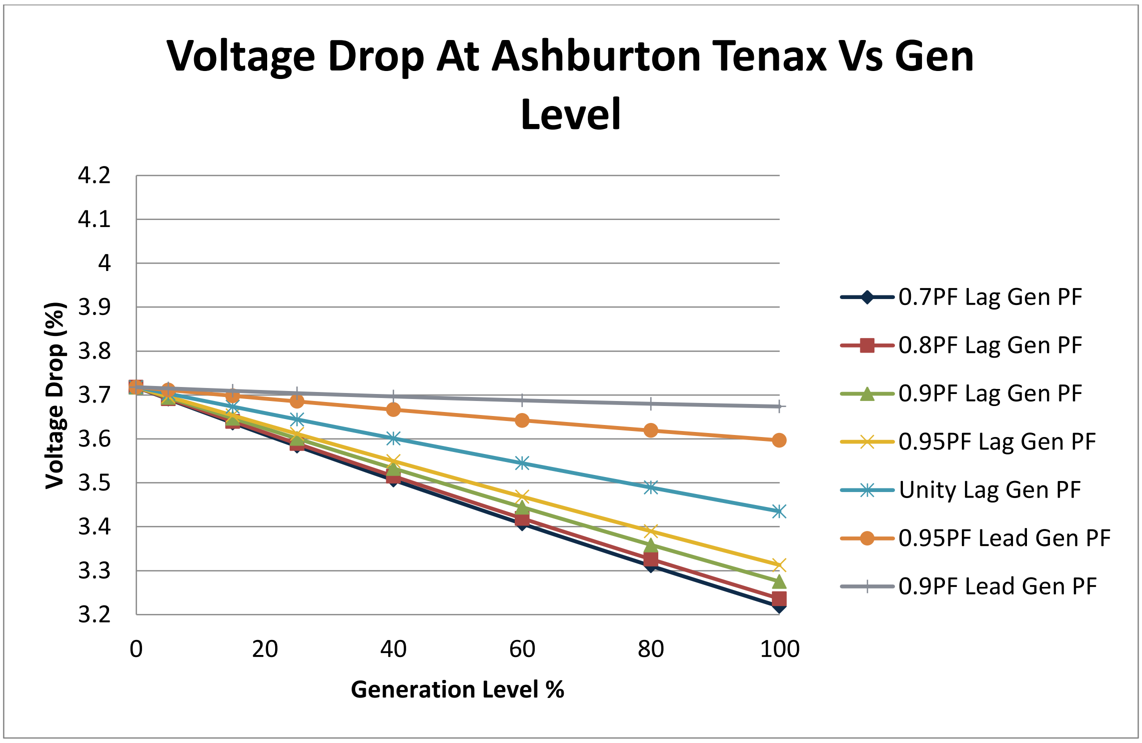

Figure 62 100% Load factor – T11

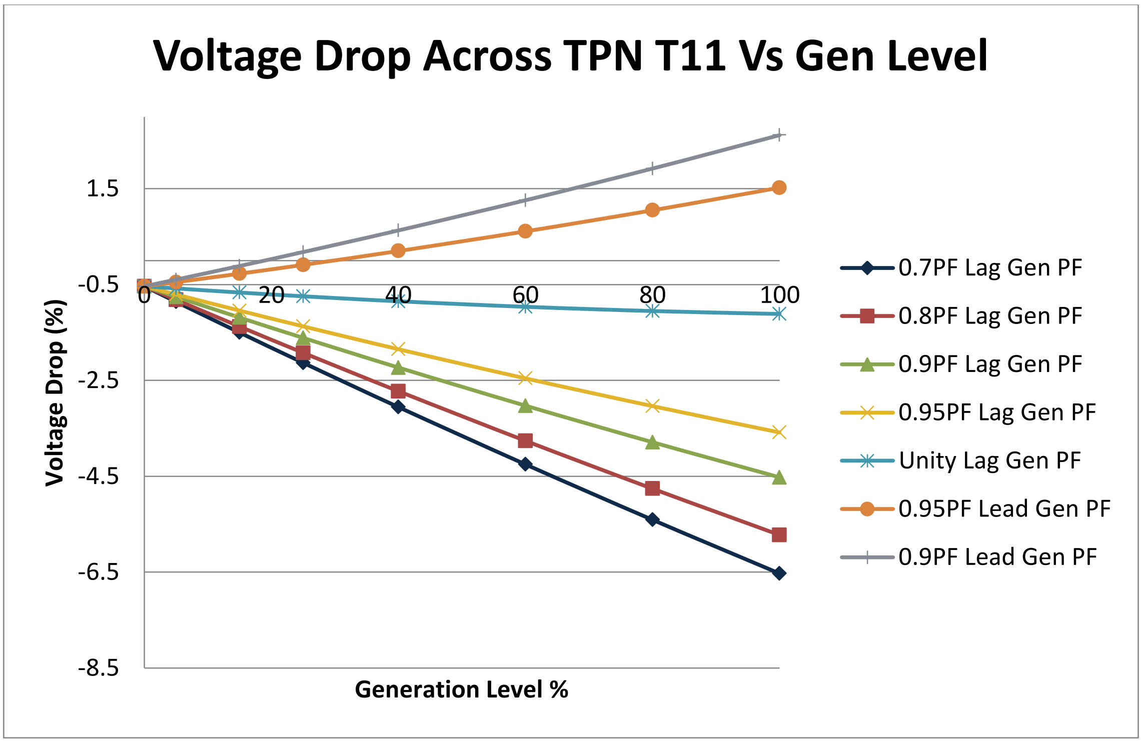

Figure 63 100% Load factor – T12

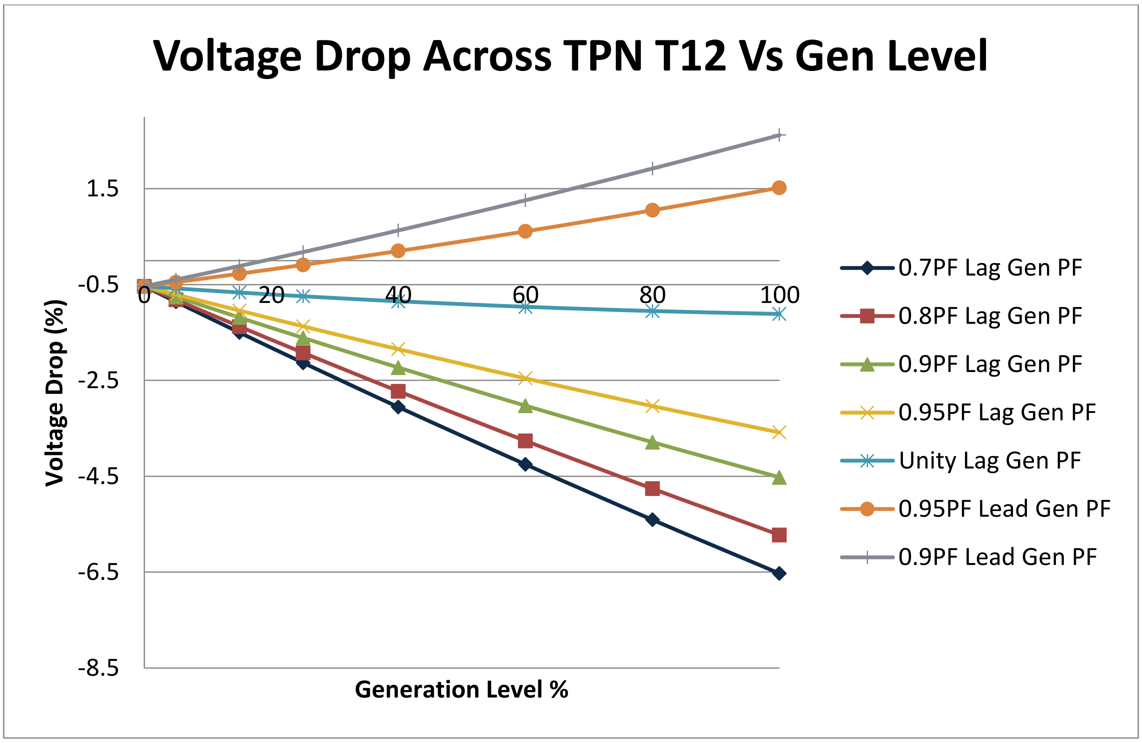

Figure 64 100% Load factor – Tenax