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Parameterization of Aggregated Distributed Energy Resources (DER_A) Model for Transmission Planning Studies

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SUMMARY

With an increased number of distributed energy resources (DERs) connected to the distribution system, visibility of the response of the aggregated DER to a transmission system event can be critical to power system stability. In the near future, DERs are expected to provide advanced functions such as voltage ride through and dynamic voltage support to maintain stable power system operation. However, at present, there are hundreds of 'non - smart' inverters already in service along the various feeders. In this context, an aggregated model of dynamic DERs that includes these advanced functions while also representing the mix of smart and non - smart DERs has been developed previously. In order to provide model parameters appropriate for an actual distribution system, however, dynamic simulations based on a detailed feeder model are required. Therefore, the purpose of this study is to evaluate the dynamic voltage response of a detailed feeder model incorporating non - smart legacy DERs while also achieving realistic computation time. This work builds upon previous work and serves to extend the technical basis upon which parameterization of an aggregate distribution model can be carried out for use in bulk power system transient simulation studies.

KEYWORDS

Distributed energy resources, locational variation, transmission system stability,

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INTRODUCTION

With the increased proliferation of distribution connected behind the meter inverter based resources, transmission planning and analysis have to be expanded to consider the effects of these resources. However, until recently, no effective simulation model existed in order to suitably represent the aggregated performance characteristic of hundreds of distributed connected resources (DERs), especially the tripping of a varying number of these resources for an event on the transmission system. Due to being spread out along a feeder, a single transmission system event can result in either only few DERs tripping, or all DERs tripping. The level of the voltage sag/swell on the substation bus, the duration of the event, the type of DER and its location on the feeder with respect to the substation all play a role in determining the number of DERs that trip. In March 2018, under the aegis of the Western Electricity Coordinating Council (WECC) Model Validation Working Group (MVWG), a positive sequence model that would represent this aggregated performance of DERs was approved for use in bulk power system planning studies. This model has been named as DER_A [1] and is now available in the latest versions of four major positive sequence time domain simulation software (GE – PSLF™, Siemens PTI PSS®E, PowerWorld Simulator, Powertech Labs DSA Tools).

As with any aggregated model, parameterization of the variables is an important step. Preliminary work on parameterizing this model was carried out in [2]. However, due to the heavy computation burden of the method, large sets of simulations could not be run to obtain a complete picture of the parameters. In this paper, a new process is detailed which significantly improves the computation burden while maintaining the accuracy of the results.

METHODOLOGY

The parameterization of the variables of the DER_A model was carried out using the IEEE 8500 Node Test Feeder [3] simulated in the OpenDSS software.[4]. This test feeder allowed to adequately simulate abnormal voltage conditions to observe the aggregated response of individual legacy DERs allocated at various distances from the substation. The DERs were exposed to voltage sags and swells below/above their under-voltage/over-voltage trip thresholds. It was found that trip of the DERs occurs in a narrow voltage range of a small percentage of the nominal substation voltage and is dependent of the location of the DERs. The ratio of the total DER injected power remaining (DERs that were able to ride through) after each voltage abnormality and the total power before the disturbance are extracted to observe the tripping characteristics of the aggregated DERs with respect to voltage sag/swell and distance from the substation. These simulations results provide the voltage break points for low/high voltage cut-out of inverters (vl0, vl1, vh0, vh1), parameters needed to allow emulation of partial tripping for the DER_A model.

The IEEE 8500 Node Test Feeder has around 11.0 MW of load with a substation voltage of 1.05pu. The one-line diagram as well as the voltage profile with balanced loads and without any additional inverter are shown in Figure 1 and Figure 2.

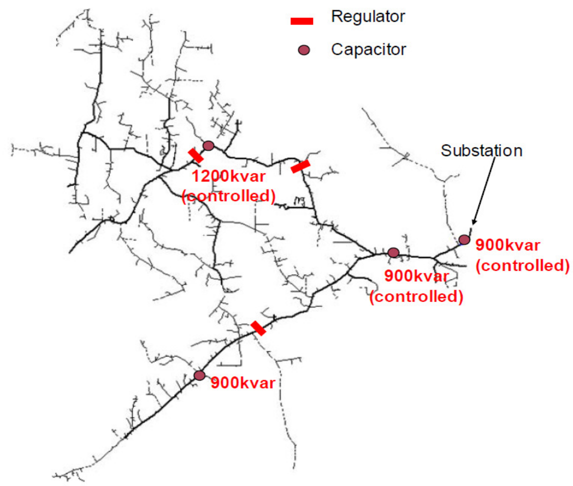

Figure 1: 8500 Node Model One-Line Diagram [3]

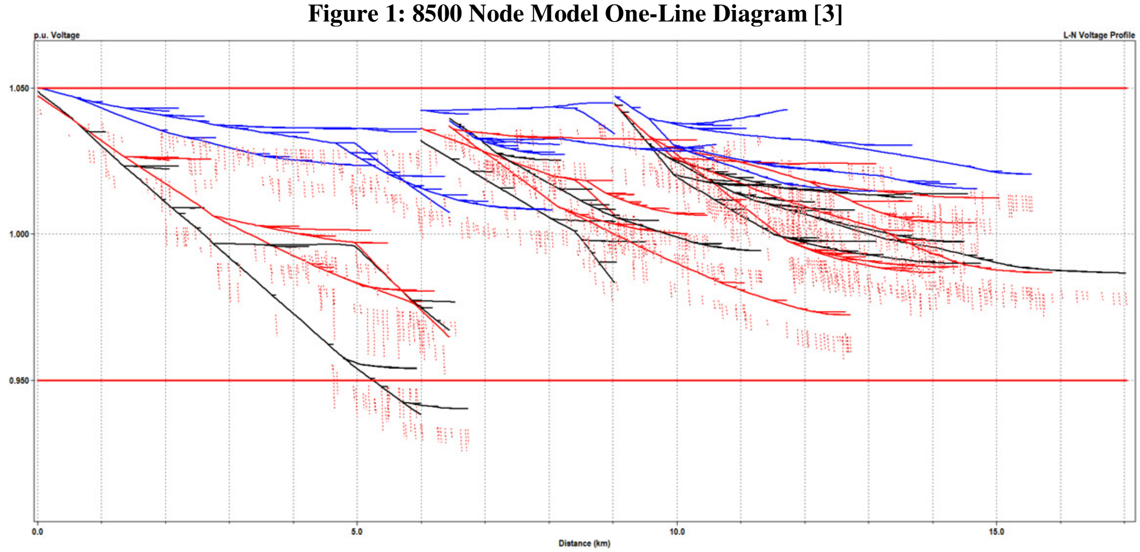

Figure 2: 8500 Node Model LN Voltage Profile

The feeder was scanned to extract buses with a line to line voltage rating of 12.47 kV and three phase connection capability. A total of 642 buses possessed these characteristics. This allowed to sort and separate the buses based on their distance with respect to the substation. Four distance ranges were allotted: 0-5km, 5-10km, 10-15km, and 0-15km (covering the entire feeder length). The number of available nodes per distance range is tabulated in Table 1. A total of 100 individual random locations were chosen from each distance range to install DERs with various combinations of both Type A and B inverters.

Table 1: Number of Available DERs w.r.t Location Range

Location Range	Number of Possible 3-Phase Connection
0-5km	150
5-10km	243
10-15km	249

The inverters are designed using OpenDSS generator model=7 which is current limited with a constant active and reactive power. This model approximately represents the dynamic behaviour of a legacy inverter. Its behaviour was verified by placing a generator at an arbitrary three phase bus in the feeder; a voltage sag was induced to observe the voltage, current, active and reactive power as shown in Figure 3. V1, V2 and V3 correspond to the voltages at each phase of the generator, similarly I1, I2, and I3 represent the current at each phase of the generator. P/Q 0, 1, 2 correspond to zero sequence, positive sequence and negative sequence active and reactive power output of the generator.

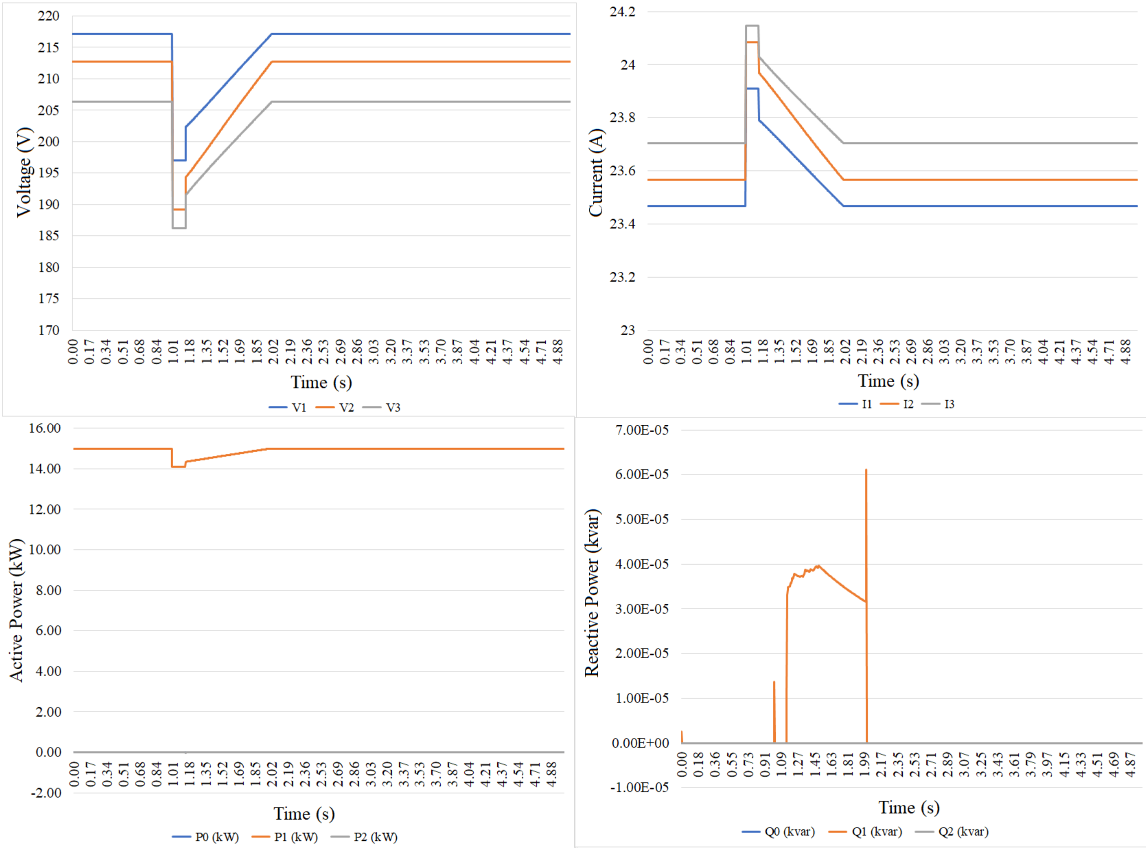

Figure 3: a) Voltage/Time b) Current/Time c) Active Power/Time d) Reactive Power/Time

The generator model is Δ connected at each of the randomly selected 100 individual locations through a three phase Δ-Y 12.47/0.36kV transformer. The per unit transient reactance (Xdp) and sub-transient reactance (Xdpp) were set as 5.27pu and 5.0pu respectively. The inertia constant of the machine (H) was set to 100.0s and the damping constant (D) to 0.2. A voltage relay and a monitor were connected on the secondary side of each transformer. The monitor allows the power to be extracted for each voltage sag/swell simulation to be able to identify the ratio of DER active power after each voltage event.

A hosting capacity study was performed using EPRI-DRIVE tool [5] to acquire a sense of the total amount of MWs of DER the feeder could accommodate. This analysis was performed with PV as the DER type with a full uniform distribution along the feeder at peak load level (11MW). Three values were extracted based on the PV concentration in the feeder:

- For the full feeder: 3.3 MW
- For the front of the feeder: 3.4 MW
- For the end of the feeder: 1.7 MW

Based on these results, the maximum amount of power injection was chosen to be 3.5MW due to inability to obtain hosting capacity for specific location ranges within the feeder. Therefore, the power of the legacy inverters was chosen to be either 15kW or 35kW; for all combinations of Type A or B inverters the power will range between 1.5-3.5MW. The rated power along with trip characteristics for both inverter types are tabulated in Table 2.

Table 2: Legacy Inverters based on IEEE1547-2003 [6]

Inverter Type	P (kW)	S (kVA)	Under-voltage Trip	Over-voltage Trip
Group A (residential)	15	15	0.88pu for 0.1s	1.2pu for 0.1s
Group B (commercial)	35	35	0.5pu for 0.1s	

Dynamic simulations were performed to derive the relationship between the voltage sags/swells and the ratio of DERs that recovered after each event. This is done by setting OpenDSS in dynamics mode and at every time step, the voltage sags/swells are induced at the substation via an external voltage source. The simulation runs from 0-5s with a step size of 4ms. The played-in voltage sags/swells parameter values at the substation are user selected and set as tabulated in Table 3 and plotted in Figure 4 for Group A.

Table 3: Voltage Sag/Swell Arrays

Voltage Event	Group A	Group B
Sag	0.94, 0.93, 0.92, 0.91, 0.9, 0.89	0.5, 0.49, 0.48, 0.47, 0.46, 0.45
Swell	1.11, 1.12, 1.13, 1.14, 1.15, 1.16	

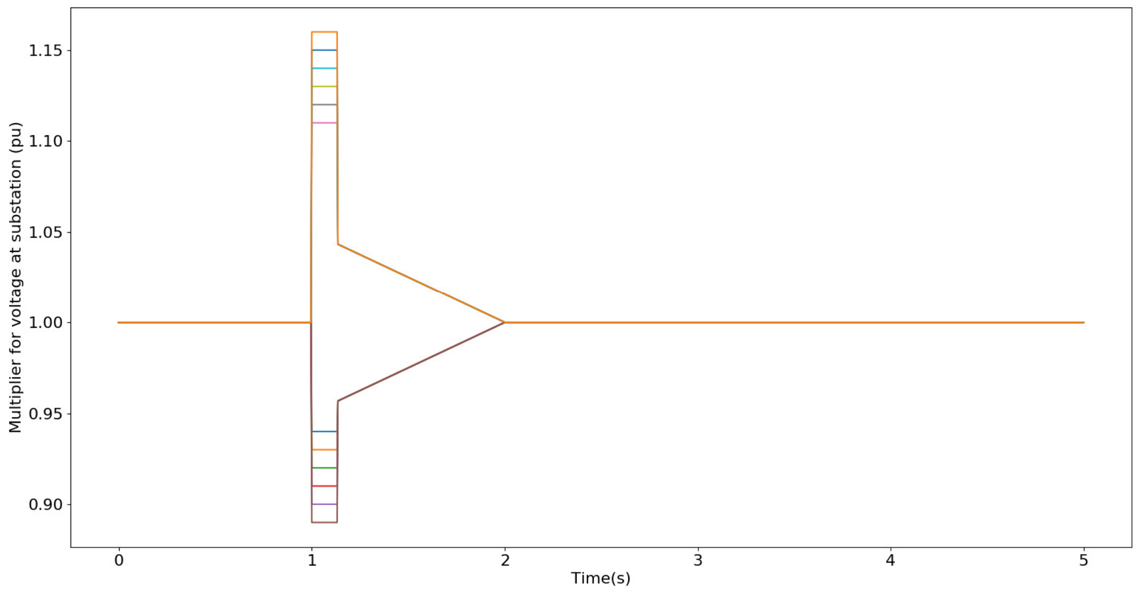

Figure 4: Played in voltage sags/swells for Group A

At the end of the event, i.e. at 5s, the aggregate power from the remaining DERs that were able to ride through the event was stored and the ratio of this remaining DER's active power is calculated by dividing the total remaining power by the total initial power. For a single simulation of 100 Group A inverters the total active power before any voltage sag/swell is induced is 1.5MW. The total output of the DERs before and after the voltage events are shown in Figure 5, Figure 6 and Figure 7.

Time-Current Characteristic Curve (TCC_Curve) is used to define the voltage relays that monitor each DER. These relays require time curves and they vary with accordance to over-voltage/under-voltage of Group A and B inverters following Table 2 under-voltage/over-voltage trip characteristics.

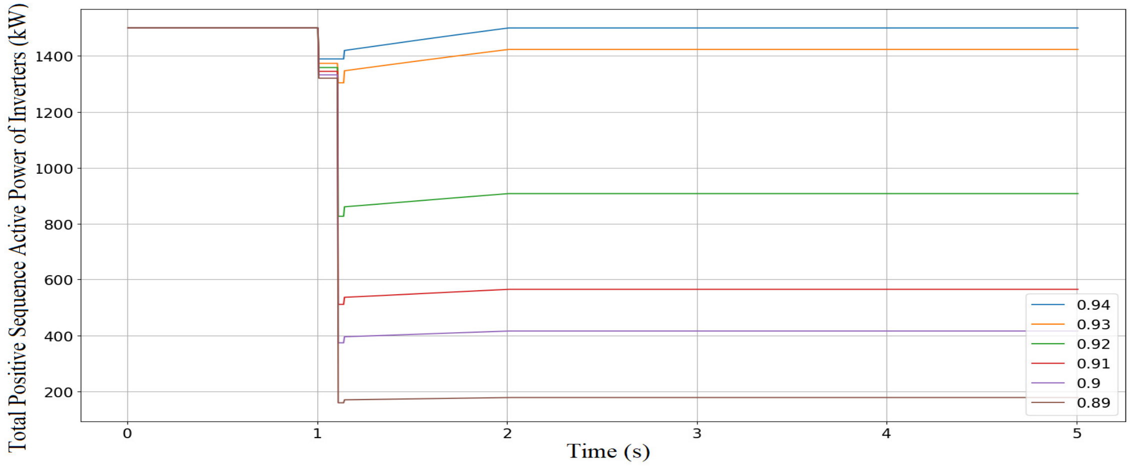

Figure 5: Voltage Sags for 100 Group A Inverters

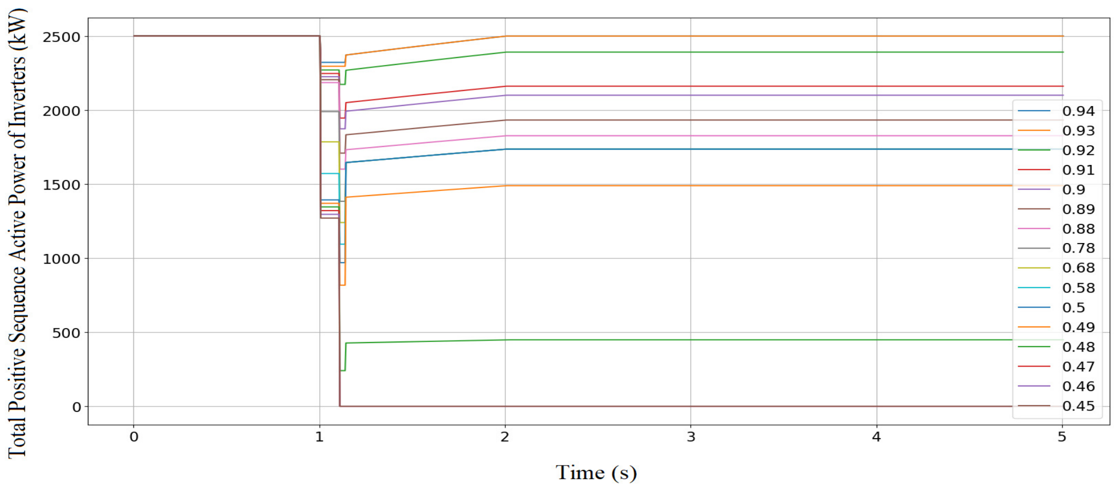

Figure 6: Voltage Sags for 50 Group A and 50 Group B Inverters

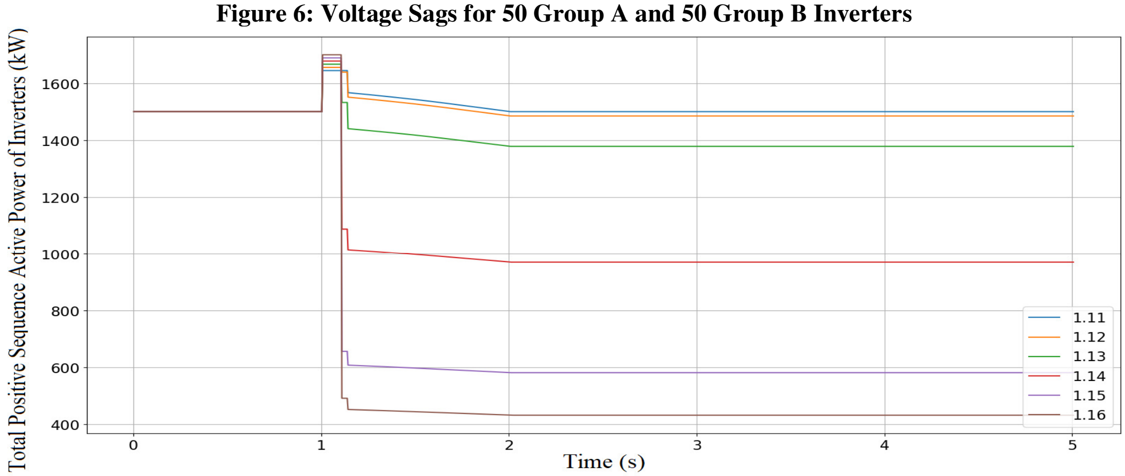

Figure 7: Voltage Swells for 100 Group A Inverters

SIMULATION RESULTS

Simulations were executed for all combinations of Group A and Group B inverters from 0-100 in increments of 10 (i.e. A=100 and B=0, A=90 and B=10, … , A=0 and B=100) for all four location ranges. Although the total amount of simulations was extensive and time intensive, computation time was significantly reduced by using Python parallel processing. This allowed for all four location ranges to run all voltage sags/swells and combinations simultaneously.

Additionally, for each combination, 20 simulations were carried out. Here, one simulation is defined as the process of random selection of 100 locations for the DERs followed by applications of all voltage sags/swells. However, since the 100 locations were selected randomly from a larger subset of suitable locations, 20 simulations Monte Carlo simulations were carried out to account for the uncertainty in actual location of an individual DER. The results of the ratio of DER active power with respect to sag level at the substation are shown in Figure 8 and Figure 9. Based on these results, one can conclude that the location of high concentration of DERs plays a role with how many trip with each voltage event. This is predominately due to the nature of the feeder. The majority of available three phase buses are located between the range 5-10km, lining up closely with the results obtained from the full range simulation (0-15km). Availability of three phase buses in the 0-5km range is smaller than the others by a factor of 3. Furthermore, hosting capacity at the end of the feeder is 1.7MW which is half of the total maximum power injection possibly causing instability during the 0-5km range simulation. The red line in the plot depicts a possible characteristic for the DER_A model's voltage trip settings.

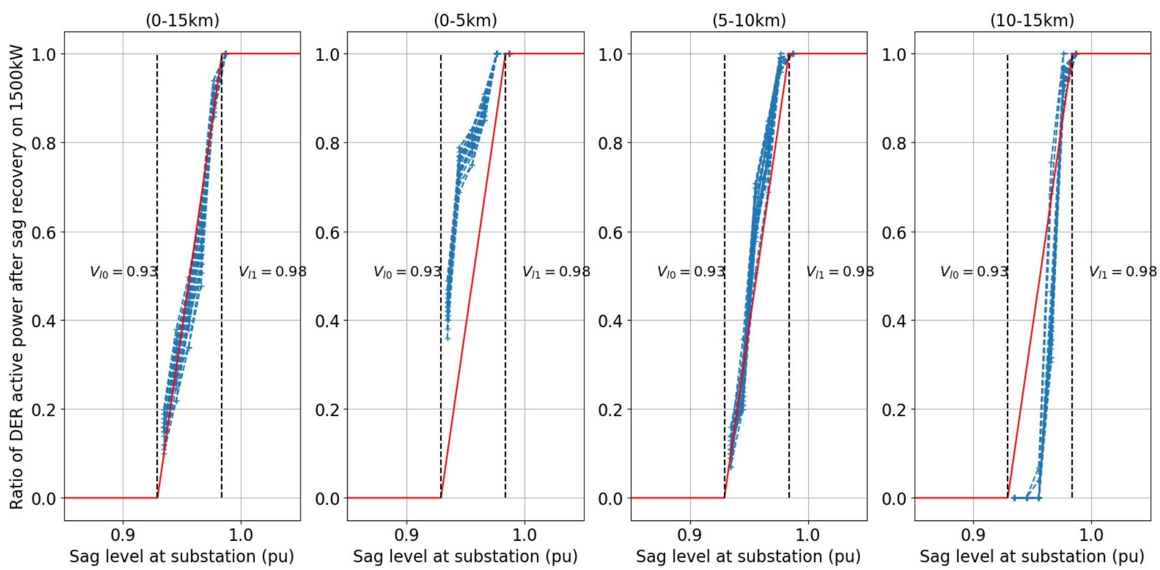

Figure 8: Ratio of DER Active Power for All Distance Ranges (A=100, B=0)

Figure 9 displays the results for 100 DERs, 50 Group A and 50 Group B inverters. The lower band of each plot provides the ratio of active power after each sag for Group B inverters with under-voltage trip of 0.5pu (blue). The same applies for Group A inverters, but with a higher under-voltage trip value of 0.88pu (blue). Since the over-voltage trip characteristics are the same for both inverter types, the ratio of active power after the voltage sags has a linear trend (green).

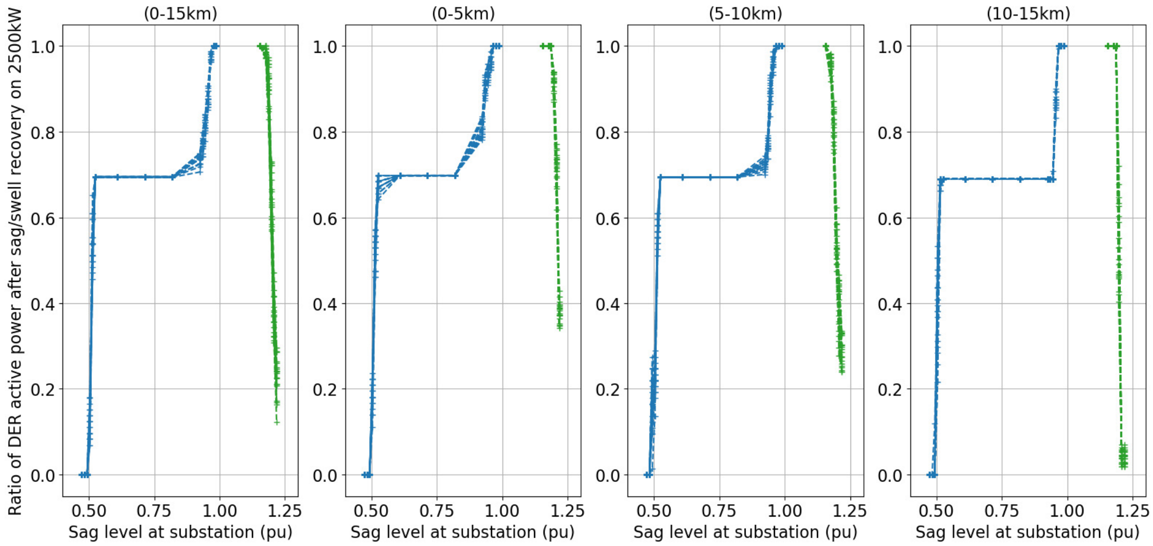

Figure 9: Ratio of DER Active Power for All Distance Ranges (A=50,B=50)

These results provided the necessary preliminary trip characteristics to parameterize the DER_A model. These values were then implemented and compared to the DER_A model performance. To do so, the benchmark test system shown in Figure 10 was used.

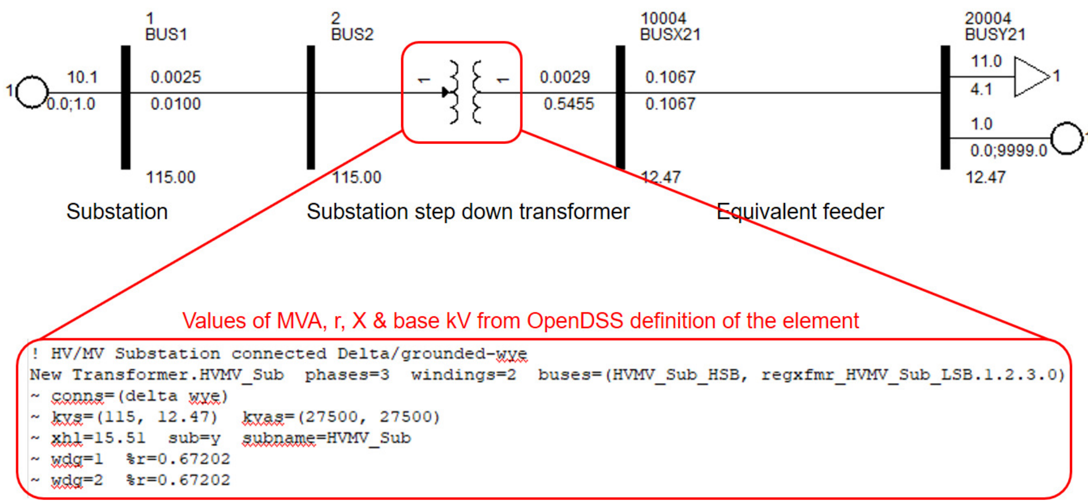

Figure 10: DER_A Benchmark Test System

DER_A voltage break points for low/high voltage cut-out of inverters (vl0, vl1, vh0, vh1) correspond to the DER_A model's terminal voltage, where the values provided by OpenDSS correspond to the substation voltage. The DER_A model block diagram is displayed in the Figure 11 containing the preliminary parameters such as voltage breakpoints and timers.

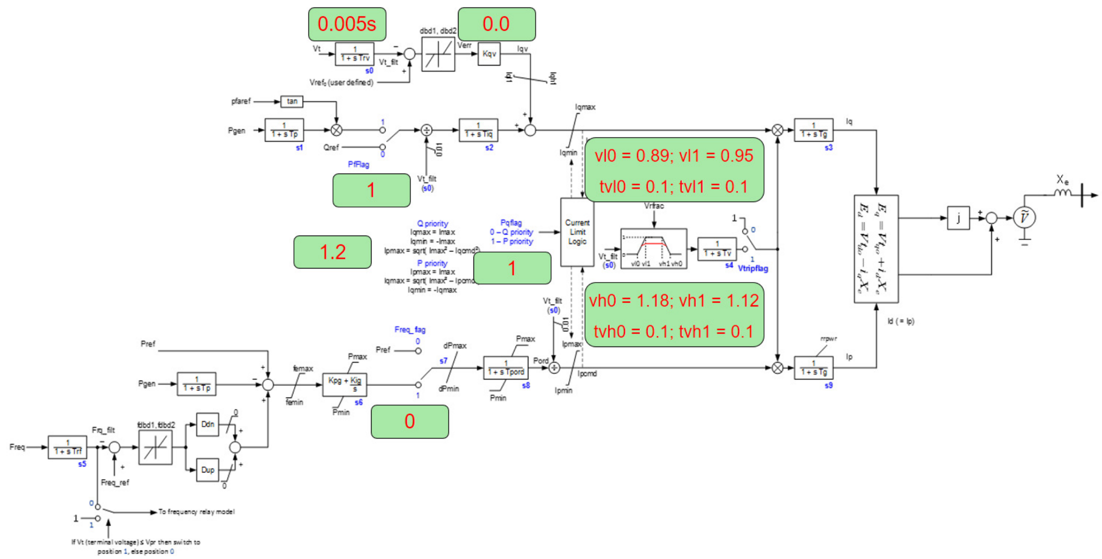

Figure 11: DER_A Block Diagram

With these parameters, the same voltage sags/swells were played-in in a positive sequence simulation software (GE – PSLF™ [7]) to observe the response of the DER_A model. The results were plotted with respect to the results obtained from OpenDSS simulations. The DER_A model with the parameters displayed above was placed at both Bus Y and X of the benchmark test system. Figure 12 shows the comparison between the two. It can be seen that the results from the DER_A model largely align with the outputs from the OpenDSS simulation. The solid black horizontal lines in the figure are the ratio of post disturbance active power to pre-disturbance active power as measured from the DER_A model. The sag/swell level corresponding to each line are the x-axis values of the point on the black horizontal line that is closest to the red linear characteristic.

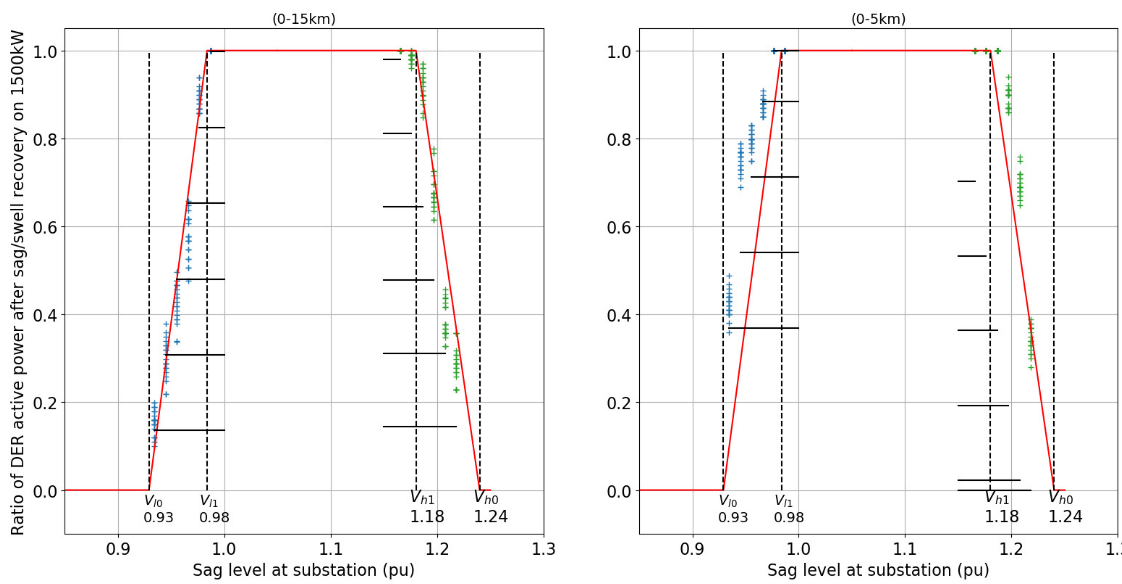

Figure 12: Comparison of DER_A and OpenDSS Results

CONCLUSION

In this paper, an improved parameterization process for the DER_A model has been discussed. The process makes use of the popular OpenDSS platform. Due to the increased computational efficiency, it is possible to observe the impact of random placement of individual DERs along a feeder while also observing the impact of the distance of the individual DER with respect to the substation. Both these criteria play a crucial role in determining the number of DERs that remain connected to the system following a voltage event. Using the simulation results from OpenDSS, parameterization of the DER_A model was made possible and preliminary positive sequence simulation results align with the performance characteristics from the OpenDSS simulations.

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