Northern Arizona University
NAU Capstone
New Mexico State University
2.A Distribution System Impact Analysis—Approach to Power Flow Model

1 Sizing of PV systems

Implementing the team's sub-system designs into the original distribution system OpenDSS model required translating the data output from other software tools into appropriate object parameters within the campus circuit model. This section will provide example code from the OpenDSS scripting window along with accompanying explanations and descriptions illustrating the most significant elements of the team's sub-systems.

While the team's initial system design implemented the photovoltaic systems as generator objects in OpenDSS, this final design utilizes PVsystem objects. Each sub-system is comprised of at least a PV panel array and its associated inverter module whose models are informed by data obtained through AuroraSolar and System Advisory Model (Figure 1). Each PVsystem object has unique parameters, while two sub-systems utilize the same model of inverter. As such, the INV_dirtlot and INV_parklot objects have the same parameters.

```
! PV Systems and Inverters
! information obtained from Syste Advisory Model (SAM) for our chosen inverter model

! Dirt Lot
New PVsystem.PV_dirtlot phases=3 bus1=dirtlot_pv kV=0.82 kVA=2999.761 irrad=1 Pmpp=310.149 temperature=25 PF=1
~ effcurve=Eff P-TCurve=PvsT Yearly=dirtlot_irr TYearly=tempcurve

New Transformer.INV_dirtlot phases=3 xhl=2.406
~ wdg=1 bus=dirtlot_pv kV=0.82 kVA=912.455 conn=LL
~ wdg=2 bus=L00 kV=0.48 kVA=888.000 conn=LL

! Hadley Hall
New PVsystem.PV_hadley phases=3 bus1=hadley_pv kV=0.48 kVA=164.646 irrad=1 Pmpp=114.816 temperature=25 PF=1
~ effcurve=Eff P-TCurve=PvsT Yearly=hadley_irr TYearly=tempcurve

New Transformer.INV_hadley phases=3 xhl=2.406
~ wdg=1 bus=hadley_pv kV=0.48 kVA=3.75745 conn=LL
~ wdg=2 bus=L02 kV=0.208 kVA=3.6 conn=LL

! Parking Lot
New PVsystem.PV_parklot phases=3 bus1=parklot_pv kV=0.82 kVA=1946.495 irrad=1 Pmpp=310.149 temperature=25 PF=1
~ effcurve=Eff P-TCurve=PvsT Yearly=parklot_irr TYearly=tempcurve

New Transformer.INV_parklot phases=3 xhl=2.406
~ wdg=1 bus=parklot_pv kV=0.82 kVA=912.455 conn=LL
~ wdg=2 bus=L01 kV=0.48 kVA=888.000 conn=LL
```

Figure 1. OpenDSS instantiation of sub-system transmission lines

The team arrived at the consensus that the largest PV system was the only sub-system in which battery storage is practical. While the battery modules implemented into this system have a prepackaged controller integrated into the modules themselves, these two elements had to be instantiated as discrete objects in OpenDSS (Figure 2). Although the manufacturer of these batteries claims a 100% depth of discharge, the battery is modeled to discharge no more than 95% of the system capacity to account for any potential discrepancies in the battery nameplate.

```
! Battery Storage Subsystem
New Storage.dirtlot_batt phases=1 bus1=dirtlot_pv
~ kV=0.48 pf=0.9 kWhrated=580 kWrated=341 kWhstored=290
~ %EffCharge=95 %EffDischarge=95 %IdlingkW=1 State=IDLING %Discharge=95
~ Vminpu=0.83 Vmaxpu=1.24 TimeChargeTrig=-1

New StorageController.dirtlot_battctl element=Line.L00 ElementList=dirtlot_batt terminal=1
~ ModeDischarge=peakshave ModeCharge=Time TimeChargeTrigger=9.5 TimeDischargeTrigger=14.5
~ kWTarget=300 PFTarget=0.98 %ratekw=30
```

Figure 2. OpenDSS instantiation of battery sub-system

The battery controllers are equipped to perform various operations in order to regulate the charge and discharge of the battery sub-system. Such operations include limiting the rate of discharge, regulating charge and discharge times, and some minor power factor correction. The team's design was optimized around the implementation of peak shaving, and these operations are further illustrated in the following section.

The New Mexico State University circuit model utilizes two types of transmission line: a thicker gauge for the high-voltage grid connection and long-distance transmission and a thinner gauge for actual load delivery. The team reused these existing line codes in order to model the connections between the sub-systems and their respective points of contact with the rest of the distribution system. These lines typically ran from a photovoltaic sub-system inverter to another line element. As such, the two larger systems are connected to the system with the thicker line gauge while the smallest sub-system is connected with the thinner gauge.

2 Impact of PV system interconnection

The addition of the team's photovoltaic systems into the current NMSU OpenDSS circuit model affected the original distribution system power delivery to loads further downstream as well as the total circuit losses. Before adding the systems, the per unit voltage profile of the circuit was highest at the geothermal sub-station and gradually decreased as you traveled down the line. The addition of the team's covered parking and Hadley Hall PV systems appear to have provided enough supplemental power to these downstream loads to raise the ratio of power actually reaching these nodes. These effects can be seen below in Figure 3.

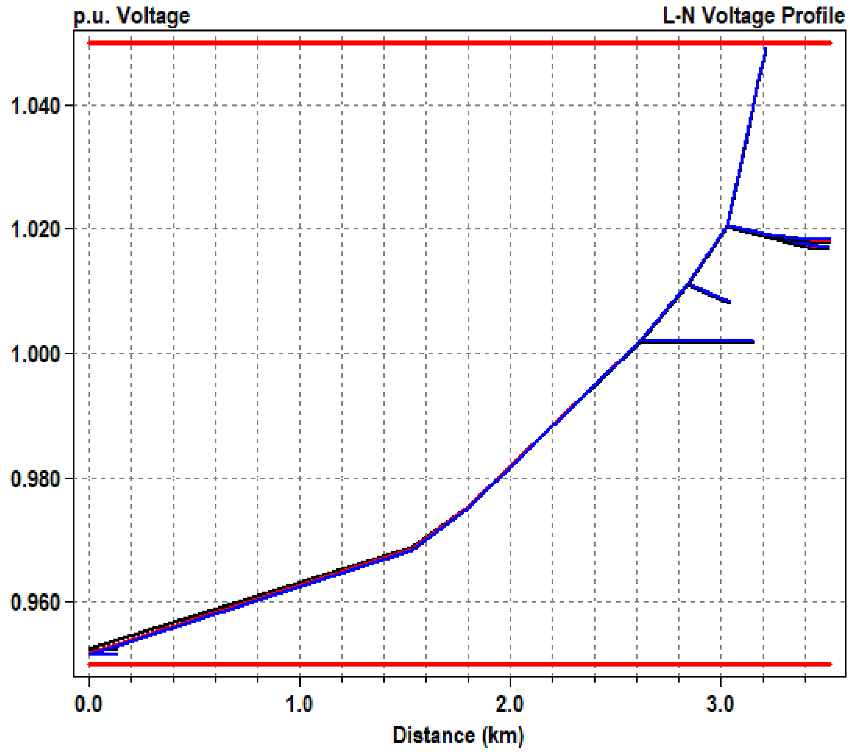

Figure 3. OpenDSS output of voltage per unit over distance from the meter

Due to the fact that more power is being supplied closer to the node, less power from the dirt lot PV system and grid is being used to service these loads, and thus fewer transmission losses are observed.

3 Sensitivity analysis

Although the addition of the downstream photovoltaic systems helped to mitigate some of the voltage drops experienced at the loaded nodes, the related sub-systems appear to cause some impedance matching issues within the larger distribution system. While these issues do not pose any risks to the integrity of the system, they significantly lower the efficiency of certain circuit elements. The only apparent effects can be seen on the transmission line side of the PV inverter sub-systems below (Figure 4).

```
ELEMENT = "Transformer.INV_DIRTLOT"
DIRTLOT_PV        ( 28)    1         2.2873 (  0.9523) /_    8.6
DIRTLOT_PV        ( 29)    2         2.2856 (  0.9516) /_ -111.0
DIRTLOT_PV        ( 30)    3         2.2857 (  0.9517) /_  129.0
DIRTLOT_PV        (  0)    0              0 (       0) /_    0.0
------------
L00               ( 67)    1         1.3384 (  0.5573) /_    8.7
L00               ( 68)    2         1.3357 (  0.5561) /_ -111.1
L00               ( 69)    3         1.3406 (  0.5582) /_  128.9
L00               (  0)    0              0 (       0) /_    0.0

ELEMENT = "Transformer.INV_HADLEY"
HADLEY_PV         ( 34)    1         2.5187 (   1.049) /_   31.8
HADLEY_PV         ( 35)    2         2.5195 (   1.049) /_  -87.9
HADLEY_PV         ( 36)    3         2.5198 (   1.049) /_  152.2
HADLEY_PV         (  0)    0              0 (       0) /_    0.0
------------
L02               ( 70)    1          1.092 (  0.4546) /_   31.9
L02               ( 71)    2         1.0898 (  0.4537) /_  -87.9
L02               ( 72)    3         1.0934 (  0.4553) /_  152.1
L02               (  0)    0              0 (       0) /_    0.0

ELEMENT = "Transformer.INV_PARKLOT"
PARKLOT_PV        ( 31)    1          2.406 (   1.002) /_   27.4
PARKLOT_PV        ( 32)    2         2.4065 (   1.002) /_  -92.3
PARKLOT_PV        ( 33)    3         2.4063 (   1.002) /_  147.8
PARKLOT_PV        (  0)    0              0 (       0) /_    0.0
------------
L01               ( 73)    1         1.4089 (  0.5866) /_   27.5
L01               ( 74)    2          1.406 (  0.5854) /_  -92.3
L01               ( 75)    3         1.4108 (  0.5874) /_  147.7
L01               (  0)    0              0 (       0) /_    0.0
```

Figure 4. OpenDSS Line-Node voltage report output for select circuit elements

While the power coming from the panel arrays have a power factor around one, the power factor on the output is significantly lower than when the team accounts for expected losses from the inverters' nameplate conversion efficiencies. A balanced 3-phase transmission will have three power signals that are leading and lagging relative to their neighbors by 120°. Any impedance mismatch in the individual lines or within the internal circuitry of the load and conversion element will displace relation of these signals and result in an unbalanced delivery. However, the inverters appear to be out of phase by only a few degrees, so these power factors must be caused by the PV panel arrays providing too low a voltage to the inverters when there is very little sun exposure.