Appendix B - Non Linear Estimation and Faulty Equipment Classification

Loading and Training Data

In [1]:
```
import pandas as pd
import matplotlib.pyplot as plt
from scipy.optimize import curve_fit
import numpy as np
```

In [2]:
```
df = pd.read_csv('Data/Plant_1_Clean.csv')
```

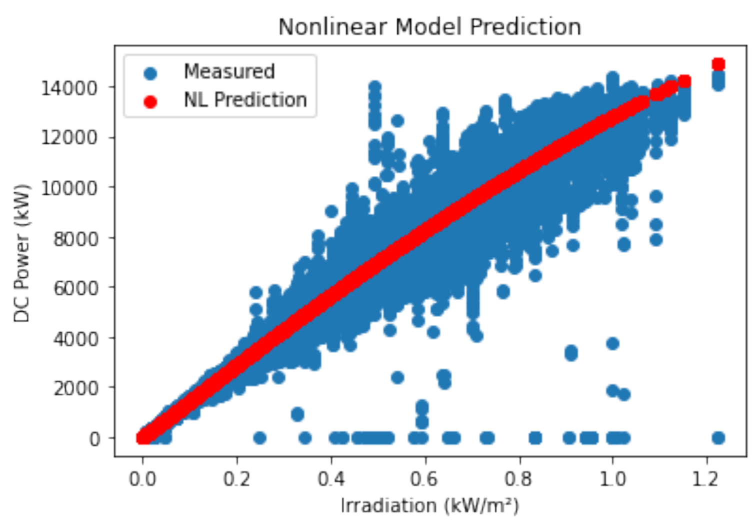
In [3]:
```
# choose training data
train_dates = ["2020-05-16", "2020-05-17","2020-05-18" ,"2020-05-19", "2020-05-20", "2020-05-21"]
df_train = df[df["DATES"].isin(train_dates)]
```

Defining Non-Linear Function

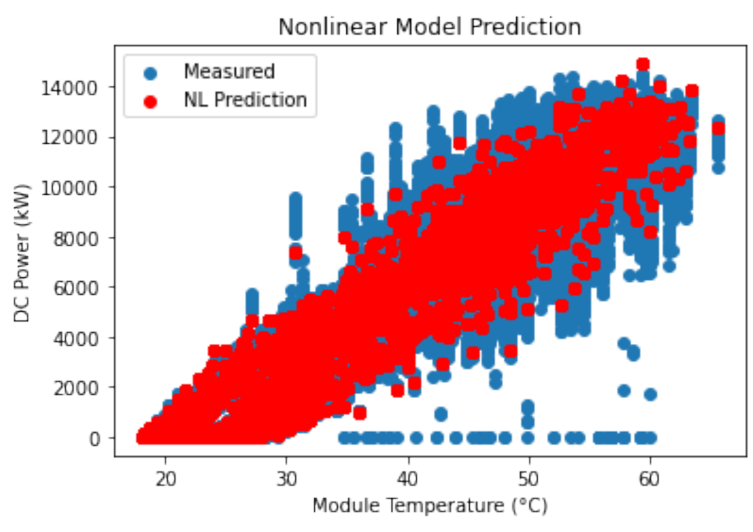
In [4]:
```
def func(X, a, b, c, d):
    '''Nonlinear function to predict DC power output from Irradiation and Temperature.'''
    x,y = X#E(t), T(t)
    x=x*1000
    y=y*1000
    return a*x*(1-b*(y+x/800*(c-20)-25)-d*np.log(x+1e-10))

# fit function
p0 = [1.,0.,-1.e4,-1.e-1] # starting values
popt, pcov = curve_fit(func, (df_train.IRRADIATION, df_train.MODULE_TEMPERATURE), df_train.DC_POWER, p0, maxfev=5000)
sigma_abcd = np.sqrt(np.diagonal(pcov))

# predict & save
df_train["Prediction_NL"] = func((df_train.IRRADIATION, df_train.MODULE_TEMPERATURE), *popt)
df_train["Residual_NL"] = df_train["Prediction_NL"] - df_train["DC_POWER"]

df["Prediction_NL"] = func((df.IRRADIATION, df.MODULE_TEMPERATURE), *popt)
df["Residual_NL"] = df["Prediction_NL"] - df["DC_POWER"]
```

```
<ipython-input-4-f4408d9065be>:14: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame.
Try using .loc[row_indexer,col_indexer] = value instead

See the caveats in the documentation: https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy
  df_train["Prediction_NL"] = func((df_train.IRRADIATION, df_train.MODULE_TEMPERATURE), *popt)
<ipython-input-4-f4408d9065be>:15: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame.
Try using .loc[row_indexer,col_indexer] = value instead

See the caveats in the documentation: https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy
  df_train["Residual_NL"] = df_train["Prediction_NL"] - df_train["DC_POWER"]
```

In [5]:
```
plt.scatter(df.IRRADIATION, df.DC_POWER, label="Measured")
plt.scatter(df.IRRADIATION, df.Prediction_NL, color="r", label="NL Prediction")
plt.legend()
plt.xlabel("Irradiation (kW/m²)")
plt.ylabel("DC Power (kW)")
plt.title("Nonlinear Model Prediction")
plt.show()
```



In [6]:
```
plt.scatter(df.MODULE_TEMPERATURE, df.DC_POWER, label="Measured")
plt.scatter(df.MODULE_TEMPERATURE, df.Prediction_NL, color="r", label="NL Prediction")
plt.legend()
plt.xlabel("Module Temperature (°C)")
plt.ylabel("DC Power (kW)")
plt.title("Nonlinear Model Prediction")
plt.show()
```



Parameter Estimates and Signal to Noise

In [7]:
```
popt
```

Out[7]:
```
array([ 1.11066843e+01, -8.30279162e-10, -2.90893800e+08, -6.56017151e-02])
```

In [8]:
```
(popt / sigma_abcd).astype(float)
```

Out[8]:
```
array([ 2.04447912e+01, -2.93911876e-03, -2.95693986e-03, -5.24375084e+00])
```

Calculating Residuals and Coming Up w/ Threshold for Classifying Faults

In [9]:
```
resids = df.Prediction_NL - df.DC_POWER
```

In [10]:
```
iqr = resids.quantile(0.75) - resids.quantile(0.25)

upperfence = resids.quantile(0.75) + 3*iqr
upperfence

faultdf = df[resids > 5000 ]
nonfaultdf = df[(resids <= 5000) ]
```

In [11]:
```
faultdf.to_csv('Data/faulty.csv')
```

In [12]:
```
faultdf.shape
```

Out[12]:
```
(82, 14)
```

In [13]:
```
faultdf.SOURCE_KEY.value_counts()
```

Out[13]:
```
1BY6WEcLGh8j5v7    23
bvBOhCH3iADSZry    23
z9Y9gH1T5YWrNuG     8
wCURE6d3bPkepu2     7
McdE0feGgRqW7Ca     7
sjndEbLyjtCKgGv     5
zBIq5rxdHJRwDNY     3
uHbuxQJl8lW7ozc     1
ih0vzX44oOqAx2f     1
VHMLBKoKgIrUVDU     1
rGa61gmuvPhdLxV     1
pkci93gMrogZuBj     1
7JYdWkrLSPkdwr4     1
Name: SOURCE_KEY, dtype: int64
```

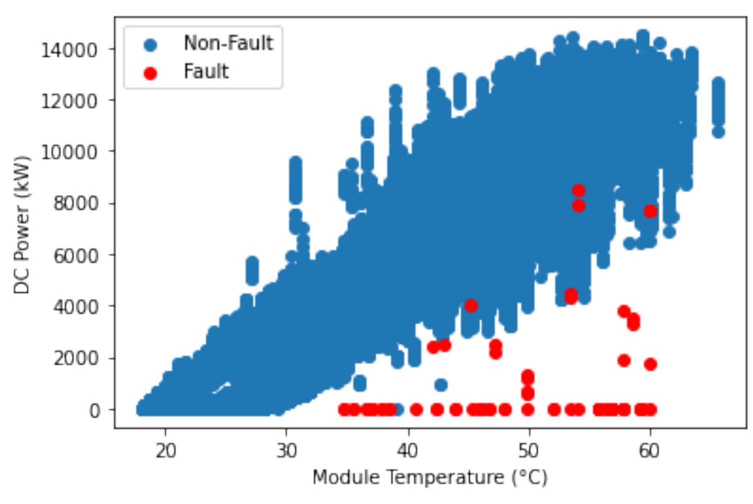
In [14]:
```
faultdf.describe()
```

Out[14]:

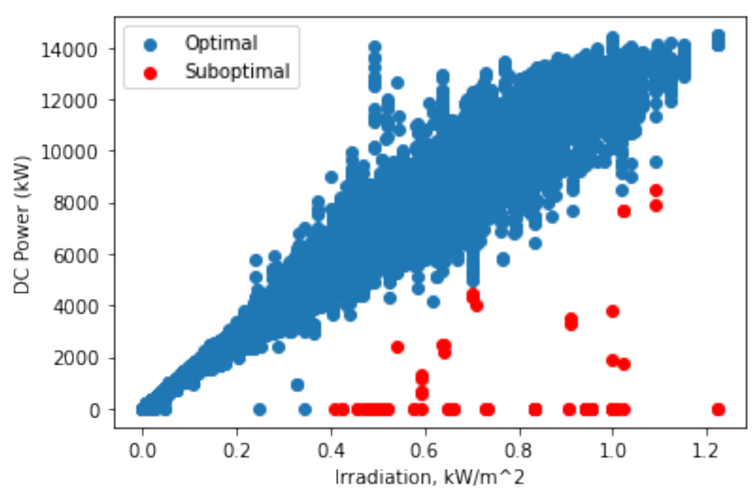
	Unnamed: 0	PLANT_ID	DC_POWER	AC_POWER	DAILY_YIELD	TOTAL_YIELD	AMBIENT_TEMPERATURE	MODULE_TEMPERATURE	IRRADIATION	Prediction_NL	Residual_NL
count	82.000000	82.0	82.000000	82.000000	82.000000	8.200000e+01	82.000000	82.000000	82.000000	82.000000	82.000000
mean	49298.768293	4135001.0	884.252831	86.397125	3226.540723	6.749501e+06	28.427553	50.547176	0.772513	10190.528142	9306.275311
std	12967.318944	0.0	1967.500697	192.150720	1011.282435	3.606795e+05	1.832779	7.796285	0.215521	2478.742175	2758.308371
min	11976.000000	4135001.0	0.000000	0.000000	1280.857143	6.258289e+06	24.932560	34.780682	0.406296	5737.528259	5035.275684
25%	46725.500000	4135001.0	0.000000	0.000000	2389.968750	6.466065e+06	27.048904	45.547812	0.591769	8150.855964	6866.400713
50%	46795.500000	4135001.0	0.000000	0.000000	3551.000000	6.520020e+06	28.884908	53.509308	0.783414	10440.270900	8983.796284
75%	61435.250000	4135001.0	429.281250	42.121875	4021.000000	7.181310e+06	29.951886	56.895085	0.954715	12320.832060	12202.754099
max	65737.000000	4135001.0	8479.428571	828.700000	6464.000000	7.645856e+06	33.761304	59.987771	1.221652	14891.731663	14891.731663

Plotting Faulty Classifications

In [15]:
```
plt.scatter(nonfaultdf.MODULE_TEMPERATURE, nonfaultdf.DC_POWER,  label="Non-Fault")
plt.scatter(faultdf.MODULE_TEMPERATURE, faultdf.DC_POWER, label="Fault",color="r")
plt.legend()
plt.xlabel("Module Temperature (°C)")
plt.ylabel("DC Power (kW)")
plt.savefig('Plots/suboptimal.png', dpi = 600)
plt.show()
```



In [16]:
```
plt.scatter(nonfaultdf.IRRADIATION, nonfaultdf.DC_POWER,  label="Optimal")
plt.scatter(faultdf.IRRADIATION, faultdf.DC_POWER, label="Suboptimal",color="r")
plt.legend()
plt.xlabel("Irradiation, kW/m^2")
plt.ylabel("DC Power (kW)")
plt.savefig('Plots/suboptimal.png', dpi = 600)
plt.show()
```



In [17]:
```
df.describe()
```

Out[17]:

	Unnamed: 0	PLANT_ID	DC_POWER	AC_POWER	DAILY_YIELD	TOTAL_YIELD	AMBIENT_TEMPERATURE	MODULE_TEMPERATURE	IRRADIATION	Prediction_NL	Residual_N
count	68774.000000	68774.0	68774.000000	68774.000000	68774.000000	6.877400e+04	68774.000000	68774.000000	68774.000000	68774.000000	68774.0000
mean	34387.500000	4135001.0	3147.177450	307.778375	3295.834644	6.978728e+06	25.558521	31.244997	0.232305	3163.865830	16.6883
std	19853.488044	0.0	4036.441826	394.394865	3145.220597	4.162707e+05	3.361300	12.308283	0.301948	4032.030214	548.5504
min	1.000000	4135001.0	0.000000	0.000000	0.000000	6.183645e+06	20.398505	18.140415	0.000000	-0.000000	-7111.3494
25%	17194.250000	4135001.0	0.000000	0.000000	0.000000	6.512007e+06	22.724491	21.123944	0.000000	-0.000000	-31.3461
50%	34387.500000	4135001.0	428.571429	41.450000	2658.473214	7.146685e+06	24.670178	24.818984	0.031620	427.415207	-0.0000
75%	51580.750000	4135001.0	6365.468750	623.561161	6274.000000	7.268751e+06	27.960429	41.693659	0.454880	6386.950755	3.9972
max	68774.000000	4135001.0	14471.125000	1410.950000	9163.000000	7.846821e+06	35.252486	65.545714	1.221652	14891.731663	14891.7316

Running Non Linear Fit on Each Day

In [18]:
```
p0 = [1.,0.,-1.e4,-1.e-1] # starting values
paramdf = pd.DataFrame()

for d in df.DATES.unique():
    ddf = df[df.DATES == d]
    popt, pcov = curve_fit(func, (ddf.IRRADIATION, ddf.MODULE_TEMPERATURE), ddf.DC_POWER, p0, maxfev=100000)

    dfa = pd.DataFrame({'a':[popt[0]], 'b': [popt[1]], 'c':[popt[2]], 'd':[popt[3]]})
    paramdf = paramdf.append(dfa)
```

In [19]:
```
paramdf.to_csv('Data/nonlinearparamsestimates.csv', index = False)
```

In [ ]: