STA 141A
Group Project
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Title: Ravata Solutions Experimental Data Analysis

Work Distribution:

James Hizon:
- Intro RS Dataset write-up
- Working with a single .csv file (single well)
- Classification
- Data Preprocessing
- Data Visualization
- Intro to Time-Series Exploration
- Programming Language: Python

Eric Nguyen:
- Multiple .csv files (Multiple wells in a given experiment)
- Linear Regression
- Statistical Analysis
- Data Visualization of Multiple Plots
- Programming Language: R

Introduction to Ravata Solutions Dataset:

In our dataset, we are working with data that has been collected from a Biotech device from James Hizon's internship at Ravata Solutions. The purpose of our analysis is to observe different features (wells) of our device from a given experiment. In September, there were 8 experiments performed on different devices, with a total of 80 .csv files. But in our data analysis, we will simply breakdown our data analysis. Note that we are working with time-series data. First, we will observe a single .csv file that contains our analysis on a single feature (well) of our Biotech device. We will be doing some classification, data preprocessing, data visualization using the Python programming language on the Jupyter Notebook IDE. Second, we will work with 10 different wells within the same experiment, and work with regression analysis for each well in addition to creating plots with R using RStudio.

Overall, in our project, we wanted to be exposed to data science tools within both programming languages in addition to two extremely important methods for data analysis: classification and regression.

Key Questions for Exploration:

1. What is the relationship between voltage and impedance? What is the relationship between frequency and impedance? How do both voltage and frequency together have an effect on impedance? How does this affect the speed of the embryo process?
2. Which variable seems to be more important to affecting the embryo process?
3. Given voltage and frequency values, let's say, Voltage = 90 MV and Frequency = 90KHZ, what can we predict will be the Impedance value label (Low/High)? In general, what categorical label can we expect the Impedance value to be?
4. At which "Voltage" and "Frequency" values, do we have discrepancies/outliers? What then, can we interpret about the model? How should we deal with or change these values?

Outline:

I. **Data Preprocessing for Classification**
II. **Using Data Visualization as a guide for Data Preprocessing**
III. **Linear Regression**
IV. **Introduction to Time-Series Exploration**
V. **Conclusion**
VI. **Appendix(Graphs and summary statements for the other wells)**

I. Data Preprocessing for Classification

At the end of our data preprocessing, we want to create categorical labels for Impedance values, because if we have low impedance, this will translate to faster speed of embryo reproduction.

From the internship at Ravata Solutions, a function was created that reads a ".csv" file to create a dataframe, parses the data to be ready for plotting, in addition to converting variables into numerical data.

```python
# FUNCTION TO PREPROCESS DATA (READY FOR SQL TABLE):
def preprocess_fromdf(filename):
    """
    Function:
    - Reads a .csv file.
    - Creates a dataframe as needed.
    """

    df = pd.read_csv(filename)
    # MAYBE, have to drop columns only if the values inside are NULL.
    # UPDATE: I removed Phase from dropping, b/c exists inside raw data file. ASK ABOUT IT.
    df = df.drop(['Bias Voltage','Phase','Conductance', 'Susceptance', 'Resistance','Reactance', 'Capacitance Para
    df['Frequency'] = df['Frequency'].map(lambda x: x.rstrip('KHZ'))
    df['Voltage'] = df['Voltage'].map(lambda x: x.rstrip(' MV'))
    df['Frequency'] = pd.to_numeric(df['Frequency'])
    df['Voltage'] = pd.to_numeric(df['Voltage'])

    return df

# LIST OF CSV FILES:
csvFiles_List = []
for i in range(10):
    csvFiles_List += ['Well_'+str(i+1)+'.csv']
csvFiles_List
```

First, we will observe a single ".csv" file that contains information on our device.

In [8]:
```python
# USE FOR STA 141A:

df_well_1 = preprocess_fromdf('Well_1.csv')
df_well_1.head(18)
```

Out[8]:

	Time	Voltage	Frequency	Impedance
0	2019-09-23 12:28:01.228297	10	10	60979.4
1	2019-09-23 12:28:01.650156	10	10	60443.1
2	2019-09-23 12:28:02.056392	10	10	61510.8
3	2019-09-23 12:28:02.556371	10	20	47860.5
4	2019-09-23 12:28:02.962614	10	20	49085.0
5	2019-09-23 12:28:03.368849	10	20	47314.9
6	2019-09-23 12:28:03.868838	10	30	44268.0
7	2019-09-23 12:28:04.275068	10	30	44333.0
8	2019-09-23 12:28:04.681307	10	30	45133.2

Next, we will convert our continuous variables into categorical variables based off a range of values. We look at the **mean**, **max**, **min**, and **standard deviation** to help us see what we should expect would be our range of values. Given a range of values, we will create our categorical variables (low/high) for the Impedance values.

```
In [38]: df_well_1['Impedance'].min()
Out[38]: 2769.83

In [39]: df_well_1['Impedance'].max()
Out[39]: 69248.5

In [37]: # Explore Impedance: min, max, median, mode, std
         # to try and categorize variables.
         df_well_1['Impedance'].mean()
Out[37]: 14894.940752990811

In [36]: df_well_1['Impedance'].std()
Out[36]: 14987.552044157746
```

Here, because the mean value for Impedance is 14894.94 and the standard deviation is 14987.55, we will use the mean value as the "**decision boundary**" for classification. The standard deviation helps us to point out that values above the mean + standard deviation are equal to our outliers.

```
In [15]: # Create outlier bound:

         df_outlier_bound = df_well_1['Impedance'].mean() + df_well_1['Impedance'].std()
         df_outlier_bound

         # outlier bound is 29882.5.
Out[15]: 29882.49279714856
```

So, the outlier bound value is around 30,000.

```
In [16]: # SET UP BINS:

bin = [0, 14894.940752990811, 29882.49279714856, 80000]

# Use pd.cut function to attribute values into specific bins.

# How should we categorize our variables?
# "Low, Med, High" or "Low, High, Outlier"?
category = pd.cut(df_well_1['Impedance'], bin, labels = ['Low','High', 'Outlier'])
category = category.to_frame()
category.columns = ['Impedance']

# Concatenate age and its' bin

df_new = pd.concat([df_well_1, category], axis=1)
df_new

# Change (0, 50000] to 'Low'.
```

Out[16]:

	Time	Voltage	Frequency	Impedance	Impedance
0	2019-09-23 12:28:01.228297	10	10	60979.40	Outlier
1	2019-09-23 12:28:01.650156	10	10	60443.10	Outlier
2	2019-09-23 12:28:02.056392	10	10	61510.80	Outlier
3	2019-09-23 12:28:02.556371	10	20	47860.50	Outlier
4	2019-09-23 12:28:02.962614	10	20	49085.00	Outlier
5	2019-09-23 12:28:03.368849	10	20	47314.90	Outlier
6	2019-09-23 12:28:03.868838	10	30	44268.00	Outlier
7	2019-09-23 12:28:04.275068	10	30	44333.00	Outlier
8	2019-09-23 12:28:04.681307	10	30	45133.20	Outlier

Then, we want to change our column names as follows.

```
In [17]: # TRY function:

def df_column_uniquify(df):
    df_columns = df.columns
    new_columns = []
    for item in df_columns:
        counter = 0
        newitem = item
        while newitem in new_columns:
            counter += 1
            newitem = "{}_{}".format(item, counter)
        new_columns.append(newitem)
    df.columns = new_columns
    return df
```

```
In [18]: df_new = df_column_uniquify(df_new)
df_new.columns=['Time','Voltage','Frequency','Impedance Value','Low/High/Outlier Imp. Label']
df_new.head(300)
```

Out[18]:

	Time	Voltage	Frequency	Impedance Value	Low/High/Outlier Imp. Label
0	2019-09-23 12:28:01.228297	10	10	60979.40	Outlier
1	2019-09-23 12:28:01.650156	10	10	60443.10	Outlier
2	2019-09-23 12:28:02.056392	10	10	61510.80	Outlier
3	2019-09-23 12:28:02.556371	10	20	47860.50	Outlier
4	2019-09-23 12:28:02.962614	10	20	49085.00	Outlier
5	2019-09-23 12:28:03.368849	10	20	47314.90	Outlier
6	2019-09-23 12:28:03.868838	10	30	44268.00	Outlier
7	2019-09-23 12:28:04.275068	10	30	44333.00	Outlier
8	2019-09-23 12:28:04.681307	10	30	45133.20	Outlier

287	2019-09-23 12:30:08.520921	10	960	2986.69	Low
288	2019-09-23 12:30:09.036532	10	970	2965.47	Low
289	2019-09-23 12:30:09.442761	10	970	2948.09	Low
290	2019-09-23 12:30:09.849018	10	970	2962.54	Low
291	2019-09-23 12:30:10.317737	10	980	2788.37	Low
292	2019-09-23 12:30:10.708350	10	980	2786.32	Low
293	2019-09-23 12:30:11.083336	10	980	2791.25	Low
294	2019-09-23 12:30:12.473916	20	10	64740.70	Outlier
295	2019-09-23 12:30:12.880153	20	10	65455.30	Outlier
296	2019-09-23 12:30:13.286387	20	10	64226.30	Outlier
297	2019-09-23 12:30:13.786375	20	20	49743.40	Outlier
298	2019-09-23 12:30:14.208234	20	20	49802.60	Outlier
299	2019-09-23 12:30:14.630097	20	20	50145.70	Outlier

300 rows × 5 columns

In [20]:
```
df_new[df_new['Low/High/Outlier Imp. Label']=='High']
```

Out[20]:

	Time	Voltage	Frequency	Impedance Value	Low/High/Outlier Imp. Label
66	2019-09-23 12:28:30.852307	10	230	26076.3	High
67	2019-09-23 12:28:31.274175	10	230	26466.6	High
68	2019-09-23 12:28:31.696045	10	230	26125.5	High
69	2019-09-23 12:28:32.211637	10	240	26114.4	High
70	2019-09-23 12:28:32.633497	10	240	26087.6	High
71	2019-09-23 12:28:33.055354	10	240	25993.1	High
72	2019-09-23 12:28:33.555338	10	250	24617.6	High
73	2019-09-23 12:28:33.977206	10	250	24475.2	High
74	2019-09-23 12:28:34.399061	10	250	24314.1	High

Above, we did some data exploration. We can observe that the rate of change going from **10 MV** and **980 KHZ** to **20 MV** and **10 KHZ** remains constant (we can do further exploration on this topic as our **time-series data analysis**. We also wanted to check and make sure there High Levels of Impedance actually exist.

QUESTION:

Now, let's say, we want to know if, given the Voltage is **90 MV** and Frequency is **90 KHZ**, would the value be **low** or **high**?

In [21]:
```
# Check results using index values: Voltage = 90 MV, Frequency = 90 MV.
df_new_V90F90 = df_new[df_new['Voltage']==90][df_new['Frequency']==90]
df_new_V90F90
```

```
/home/james/anaconda3/lib/python3.7/site-packages/ipykernel_launcher.py:2: UserWarning:

Boolean Series key will be reindexed to match DataFrame index.
```

Out[21]:

	Time	Voltage	Frequency	Impedance Value	Low/High/Outlier Imp. Label
2376	2019-09-23 12:45:41.411679	90	90	39949.4	Outlier
2377	2019-09-23 12:45:41.833541	90	90	39927.8	Outlier
2378	2019-09-23 12:45:42.239784	90	90	39938.5	Outlier

Actually, we found that, at Voltage = **90 MV** and Frequency = **90 KHZ**, the Impedance value is an **outlier**. Now, we should ask the following question, is it truly an outlier? We know that the max value is around 60000 and the min value is around 2700. We found the outlier bound to be around 30000.

QUESTION:

How should we change our data?

This question will be answered in the next section.

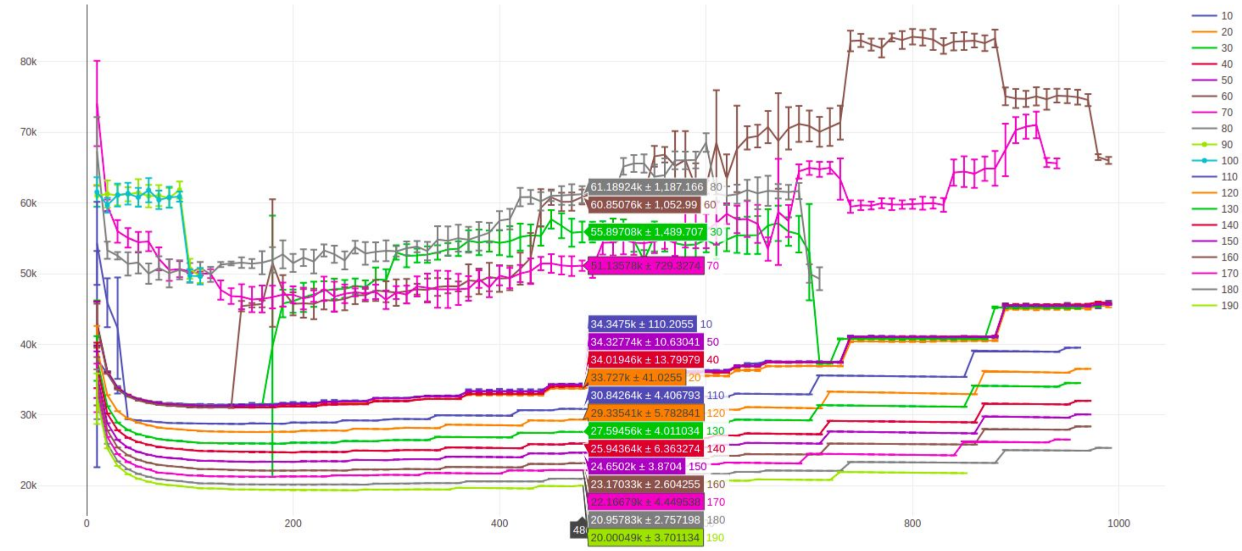
II. Using Data Visualization to guide in Data Preprocessing

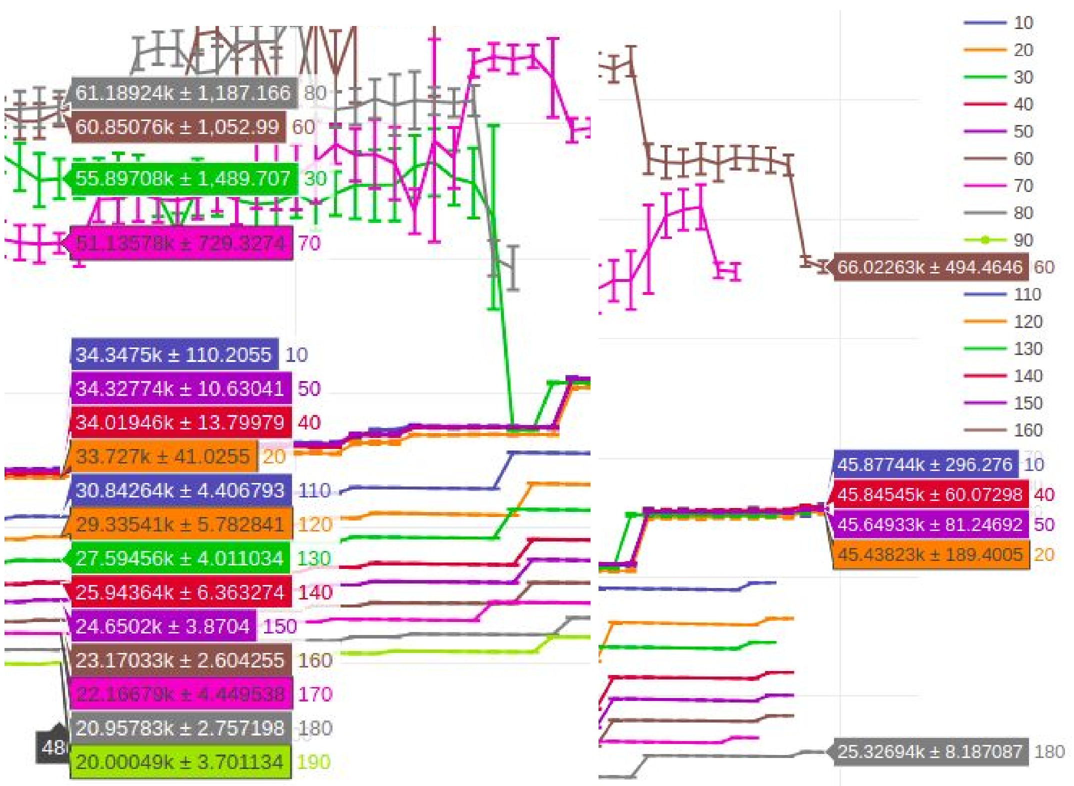
This is the code that sums up how we obtained our plot for a single ".csv" file:

```
container = []
for i in a.index:
    traces = (go.Scatter(
        x= np.arange(10,990,10), # MANUALLY CREATED A SERIES OF RANGE 1, 1869. OR # USE df['col'].value_count
        y= a1.loc[i, np.arange(10,990,10)],
        name = i))
    container.append(traces)

fig = dict(data=container)
pyo.plot(fig, validate=False) # Offline Plotting

#figure = go.Figure(data=traces)

#pyo.plot(figure)
```

```
'temp-plot.html'
```

The following is a plotted inside Jupyter Notebook using the "plotly" package:





Note that there are four Voltage values **(30, 60, 70** and **80)** by which these values are above there rest. Using the interactive plot,we can see that a majority of the values range from **19K KHZ** to **46K KHZ**. So, we should change our bins accordingly, where we would want to classify data points with voltage values of 30, 60, 70 and 80 as outliers.

```python
# ADD VALUE TO GET MEDIAN:(46-19)/2 = 13.5
# LOW: 0
# NEW MEDIAN: 19K + 13.5K = 32.5
# NEW HIGH: 46K
# OUTLIERS: ABOVE 46K

new_bin = [0, 32500, 46000, 80000]

# Use pd.cut function to attribute values into specific bins.

# How should we categorize our variables?
# "Low, Med, High" or "Low, High, Outlier"?
category = pd.cut(df_well_1['Impedance'], new_bin, labels = ['Low','High', 'Outlier'])
category = category.to_frame()
category.columns = ['Impedance']

# Concatenate age and its' bin

df_new = pd.concat([df_well_1, category], axis=1)
df_new
```

	Time	Voltage	Frequency	Impedance	Impedance
0	2019-09-23 12:28:01.228297	10	10	60979.40	Outlier
1	2019-09-23 12:28:01.650156	10	10	60443.10	Outlier
2	2019-09-23 12:28:02.056392	10	10	61510.80	Outlier
3	2019-09-23 12:28:02.556371	10	20	47860.50	Outlier
4	2019-09-23 12:28:02.962614	10	20	49085.00	Outlier
5	2019-09-23 12:28:03.368849	10	20	47314.90	Outlier
6	2019-09-23 12:28:03.868838	10	30	44268.00	High
7	2019-09-23 12:28:04.275068	10	30	44333.00	High
8	2019-09-23 12:28:04.681307	10	30	45133.20	High
9	2019-09-23 12:28:05.196902	10	40	43039.30	High
10	2019-09-23 12:28:05.618770	10	40	42246.60	High

Now, we see that some of our values have changed from possessing the "**Outlier**" categorical variable to now possessing the "**High**" categorical variable.

```python
# Check results using index values: Voltage = 90 MV, Frequency = 90 MV.
df_new_V90F90 = df_new[df_new['Voltage']==90][df_new['Frequency']==90]
df_new_V90F90
```

```
/home/james/anaconda3/lib/python3.7/site-packages/ipykernel_launcher.py:2: UserWarning:

Boolean Series key will be reindexed to match DataFrame index.
```

	Time	Voltage	Frequency	Impedance Value	Low/High/Outlier Imp. Label
2376	2019-09-23 12:45:41.411679	90	90	39949.4	High
2377	2019-09-23 12:45:41.833541	90	90	39927.8	High
2378	2019-09-23 12:45:42.239784	90	90	39938.5	High

Thus, when Voltage = 90 MV and Frequency = 90 KHZ for Well 1, we can expect "**High**" Impedance values.

Now, let's see what would we expect our categorical label to be in general.

```
In [33]: # Total # of Impedance values: 8526
         df_new.count()

Out[33]: Time                           8526
         Voltage                        8526
         Frequency                      8526
         Impedance Value                8526
         Low/High/Outlier Imp. Label    8526
         dtype: int64
```

```
In [30]: # Use .count() to find total # of "High" values.
         df_new[df_new['Low/High/Outlier Imp. Label']=='High'].count() # Total: 1457

Out[30]: Time                           1457
         Voltage                        1457
         Frequency                      1457
         Impedance Value                1457
         Low/High/Outlier Imp. Label    1457
         dtype: int64
```

```
In [31]: # Use .count() to find total # of "Low" values.
         df_new[df_new['Low/High/Outlier Imp. Label']=='Low'].count() # Total: 6861

Out[31]: Time                           6861
         Voltage                        6861
         Frequency                      6861
         Impedance Value                6861
         Low/High/Outlier Imp. Label    6861
         dtype: int64
```

```
In [32]: # Use .count() to find total number of "Outlier" values.
         df_new[df_new['Low/High/Outlier Imp. Label']=='Outlier'].count() # Total: 208

Out[32]: Time                           208
         Voltage                        208
         Frequency                      208
         Impedance Value                208
         Low/High/Outlier Imp. Label    208
         dtype: int64
```

Above, we can see the total number of Impedance values for a given ".csv" file, in addition to the total number of values having the corresponding categorical label. Afterwards we can obtain the percentage of each as follows:

```
# High Imp. Value Pct: 17.09 %
1457/8526 * 100

17.08890452732817
```

```
# Low Imp. Value Pct: 80.4%
6861/8526 * 100

80.47149894440535
```

```
# Outlier Imp. Value Pct: 2.44%
208/8526 * 100

2.439596528266479
```

Therefore, after all of the data preprocessing changes, we will assume that most values have a **low impedance value (80.4 %)**. This is what we want for our device: low impedance values will translate to faster processing for embryo reproduction for Well 1.

Note: Our outliers make up 2.44% of our data for a given ".csv" file.

We can also answer our question from the beginning.

QUESTION:
At what frequency and voltage values do we expect our outliers to range from?

```
In [62]: df_new[df_new['Low/High/Outlier Imp. Label']=='Outlier'].head(18)
```

Out[62]:

	Time	Voltage	Frequency	Impedance Value	Low/High/Outlier Imp. Label
0	2019-09-23 12:28:01.228297	10	10	60979.4	Outlier
1	2019-09-23 12:28:01.650156	10	10	60443.1	Outlier
2	2019-09-23 12:28:02.056392	10	10	61510.8	Outlier
3	2019-09-23 12:28:02.556371	10	20	47860.5	Outlier
4	2019-09-23 12:28:02.962614	10	20	49085.0	Outlier
5	2019-09-23 12:28:03.368849	10	20	47314.9	Outlier
294	2019-09-23 12:30:12.473916	20	10	64740.7	Outlier
295	2019-09-23 12:30:12.880153	20	10	65455.3	Outlier
296	2019-09-23 12:30:13.286387	20	10	64226.3	Outlier
297	2019-09-23 12:30:13.786375	20	20	49743.4	Outlier
298	2019-09-23 12:30:14.208234	20	20	49802.6	Outlier
299	2019-09-23 12:30:14.630097	20	20	50145.7	Outlier
302	2019-09-23 12:30:15.973800	20	30	46001.8	Outlier
588	2019-09-23 12:32:23.735163	30	10	65609.3	Outlier
589	2019-09-23 12:32:24.141402	30	10	66702.7	Outlier
590	2019-09-23 12:32:24.563261	30	10	67612.7	Outlier
591	2019-09-23 12:32:25.094491	30	20	50390.7	Outlier
592	2019-09-23 12:32:25.516349	30	20	50405.4	Outlier

We can use the min(), max(), mean() and std() functions in Python. For voltage, we only need max() and min().
Voltage range: 10-290 MV

```
df_new[df_new['Low/High/Outlier Imp. Label']=='Outlier']["Voltage"].max()
```

```
290
```

```
df_new[df_new['Low/High/Outlier Imp. Label']=='Outlier']["Frequency"].min()
```

```
10
```

Frequency Range: 10 KHZ - 40KHZ
Mean Frequency: 17.74 KHZ
Std. Deviation Frequency: 7.88 KHZ

```
df_new[df_new['Low/High/Outlier Imp. Label']=='Outlier']["Frequency"].max()
```

```
40
```

```
df_new[df_new['Low/High/Outlier Imp. Label']=='Outlier']["Frequency"].min()
```

```
10
```

```
df_new[df_new['Low/High/Outlier Imp. Label']=='Outlier']["Frequency"].mean()
```

```
17.740384615384617
```

```
df_new[df_new['Low/High/Outlier Imp. Label']=='Outlier']["Frequency"].std()
```

```
7.875228934401255
```

Given that the total frequency values range from 10 KHZ to 990 KHZ, we can interpret that since most of our outliers will be from 10 KHZ to 40 KHZ, the next step can be to drop values from 10 KHZ to 40 KHZ and see if there is any change within the plots we create. We won't do it in this project due to time constraints, but it is a good idea to think about.

If we want to work with **binary classification**, we can drop our outliers, and the categorical labels will be helpful to classify whether a given impedance value is low or high.

III. Linear Regression

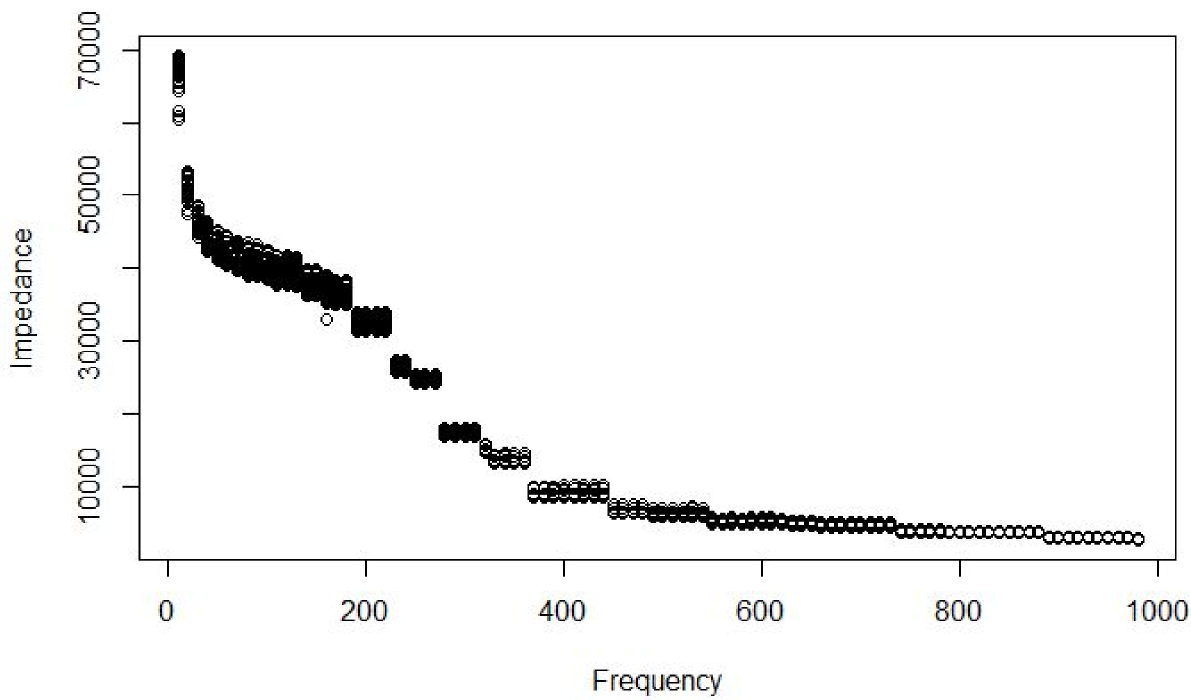
When doing linear regression for our data set since we have such a large amount of data our predictors will always be significant. We see this through the summary statements for each of the models we created. The first model was a model with just the predictor frequency and the response impedance. The second model was a model with just the predictor voltage and the response impedance. The last model we created was with 2 predictors (both voltage and frequency) and the response impedance. We made these models for each of the 10 wells, where each contained their own data of equal size. Looking at the scatter plots for each well we see that frequency seems to have a relationship with impedance, but voltage does not. We can see that, as we raise the frequency, the impedance becomes lower. Thus, frequency increases the speed of the embryo process. Also, checking the correlation between frequency and voltage in R gave us 0. Thus, we know that these values are not correlated with one another and thus do not affect each other.

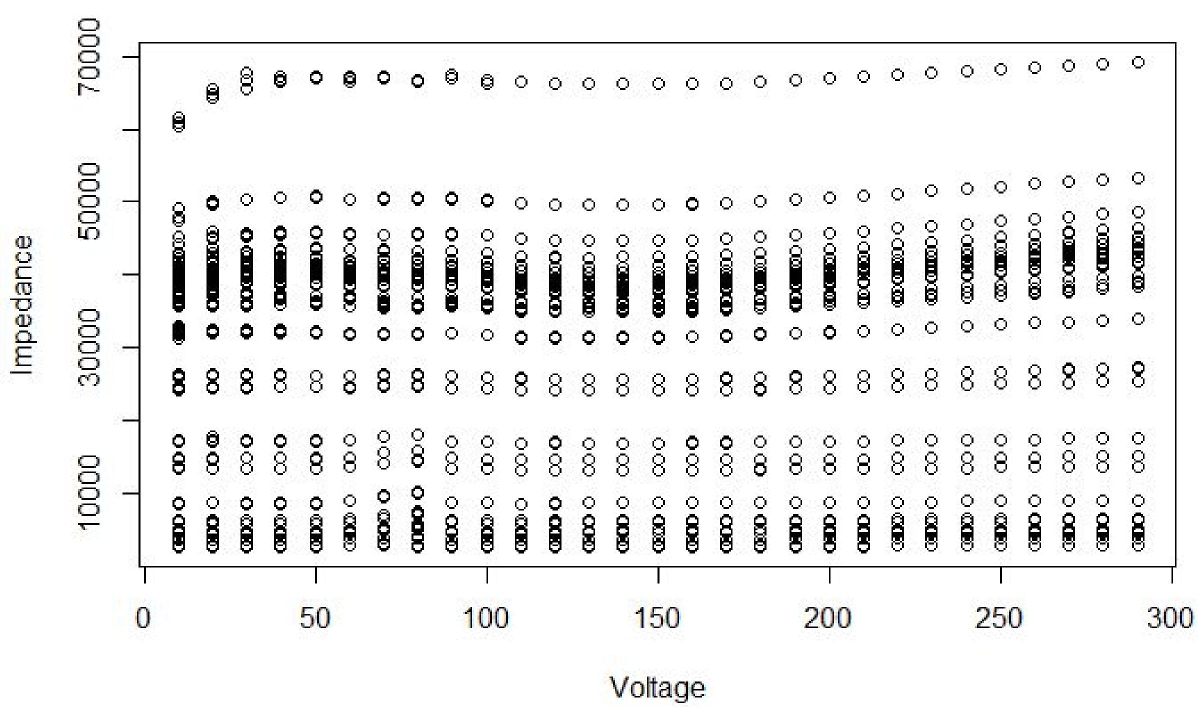
After creating the models and looking at the summary statements, I created plots for each model so we can check if the data is normal. Below are the plots for impedance vs. voltage, impedance vs. frequency, in addition to impedance vs. both voltage and frequency. We see that there is a non-linear relationship between voltage vs. impedance, frequency vs. impedance, and both voltage and frequency vs. impedance. Here, we find that our plots show a non-linear, non-normal relationship. However, we know from our summary statements that our predictors are significant. Our R-squared and adjusted R-squared stay the same for both frequency as well as frequency and voltage models. Thus, we know that our model does not change in effectiveness when we add more predictors. Yet, for voltage, our adjusted R-squared becomes lower. Thus, it seems that voltage might be a worse predictor compared to frequency. It also has a low R-squared value, thus the variability is not very well explained by this predictor.

Our data also seems to show that the wells have a factor on impedance, since the intercepts and standard errors for each well for the 3 different models are vastly different. This might change, however, when we transform the data to make it more normal.

Well 1:

Scatter plots



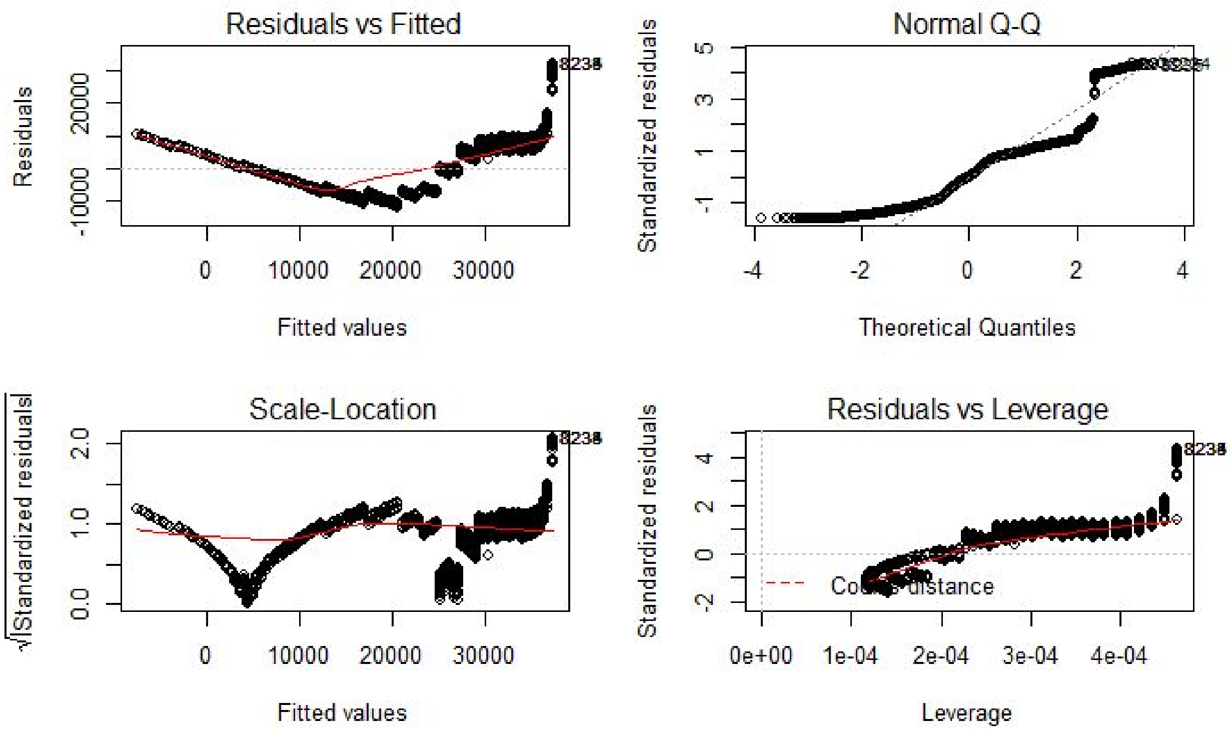


Summary Statements

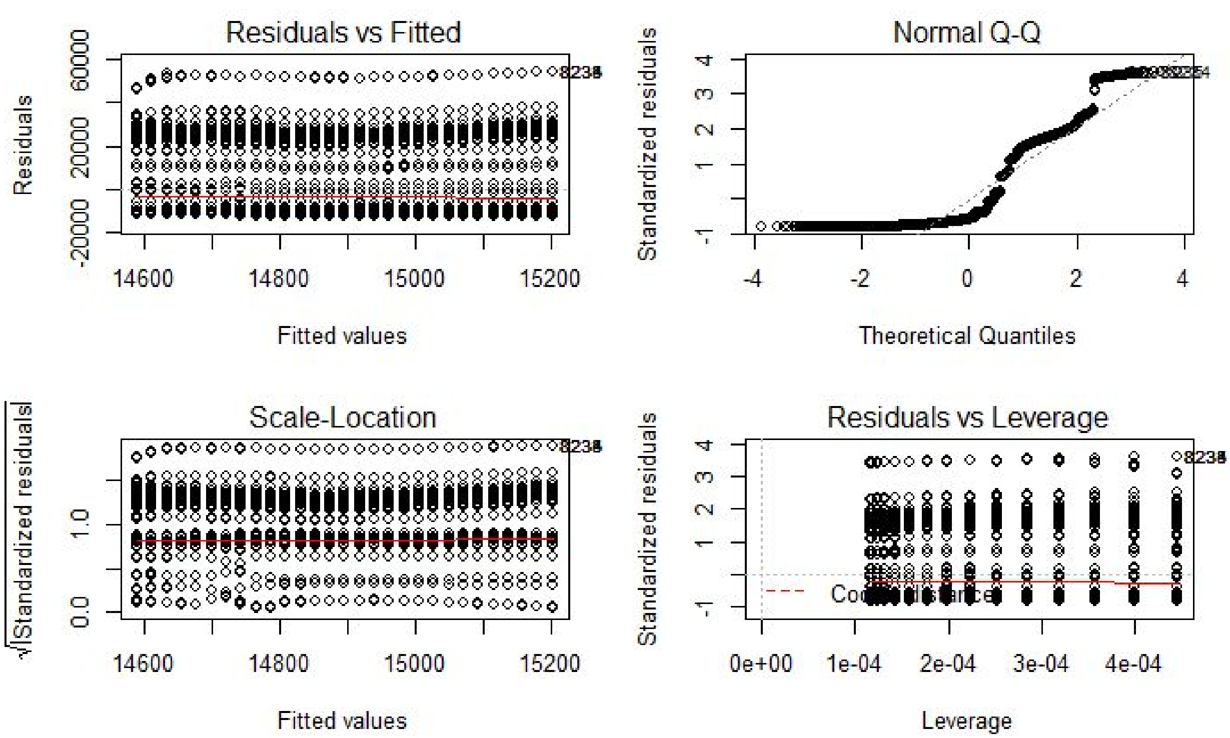
```
Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_1)

Residuals:
   Min     1Q Median     3Q    Max 
-12044  -6966     25   6125  31982 

Coefficients:
              Estimate Std. Error t value Pr(>|t|)    
(Intercept) 37727.5397   160.9092   234.5   <2e-16 ***
Frequency     -46.1265     0.2822  -163.4   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 7372 on 8524 degrees of freedom
Multiple R-squared:  0.7581,	Adjusted R-squared:  0.7581 
F-statistic: 2.671e+04 on 1 and 8524 DF,  p-value: < 2.2e-16


Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_1)

Residuals:
   Min     1Q Median     3Q    Max 
-12367 -10780  -8619  10058  54048 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)    
(Intercept) 14567.074    333.206  43.718   <2e-16 ***
Voltage         2.186      1.940   1.127     0.26    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 14990 on 8524 degrees of freedom
```

```
Multiple R-squared:  0.0001489,        Adjusted R-squared:  3.16e-05
F-statistic: 1.269 on 1 and 8524 DF,  p-value: 0.2599
Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_1)

Residuals:
   Min     1Q Median     3Q    Max
-11987  -6947    -50   6114  31676

Coefficients:
            Estimate Std. Error  t value Pr(>|t|)
(Intercept) 37399.6725   215.3084  173.703   <2e-16 ***
Frequency     -46.1265     0.2822 -163.475   <2e-16 ***
Voltage         2.1858     0.9540    2.291    0.022 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 7370 on 8523 degrees of freedom
Multiple R-squared:  0.7582,  Adjusted R-squared:  0.7582
F-statistic: 1.336e+04 on 2 and 8523 DF,  p-value: < 2.2e-16
```

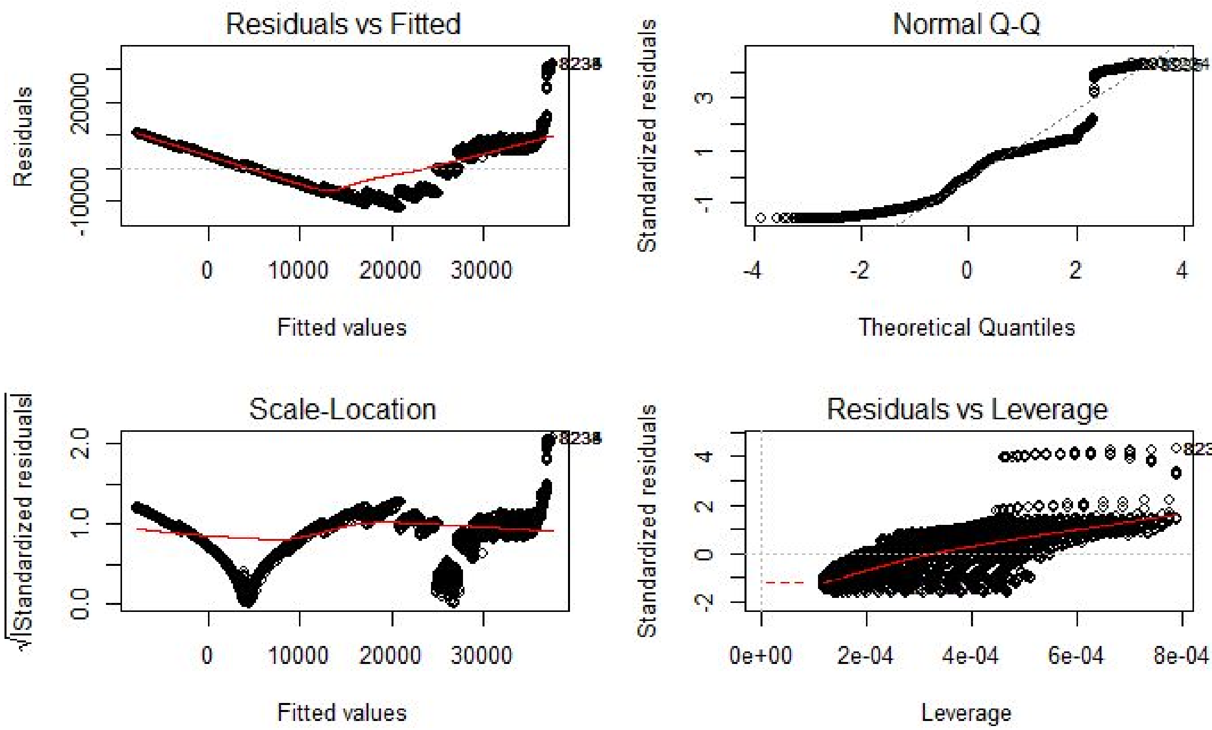
Impedance vs Frequency



Impedance vs Voltage



Impedance vs Frequency + Voltage



We see that for all 10 wells, we have similar graphs to the ones above. To see the other wells, check the appendix below.

From these graphs we can see that our data needs to be transformed since it is not normal from our qq plots, and the residuals form a pattern instead of being scattered. Also, the line for the residual plot is not straight. Thus, it also tells us it is not normal. Our other graphs such as the leverage plot and fitted values show that our data is not normal and there may be high leverage points. To be more specific, our graphs for frequency seem to be not normal at all since they have high leverage points. The qqplot does not look normal and the residuals are also not normal, since they form a pattern for all the 10 wells. For voltage, it seems like the residuals are more spread out, which seems to show that our variance is normal, but our qqplot is not normal since the line does not look linear, and we seem to have high leverage points. For the models with both voltage and frequency, we have the same problem, given that the model with just frequency, it seems that our residuals and qqplot are not normal and there are high leverage points for all 10 wells. Thus, it seems like we have to transform the graphs before we can analyze the data and try to make our data more normal.

When doing transformations, taking the **4th root** of the data seemed to have the greatest effect in making it the most normal. Thus, after transforming the graphs we get the following new graphs of our data.

Well 1 transformed

Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_1_T)

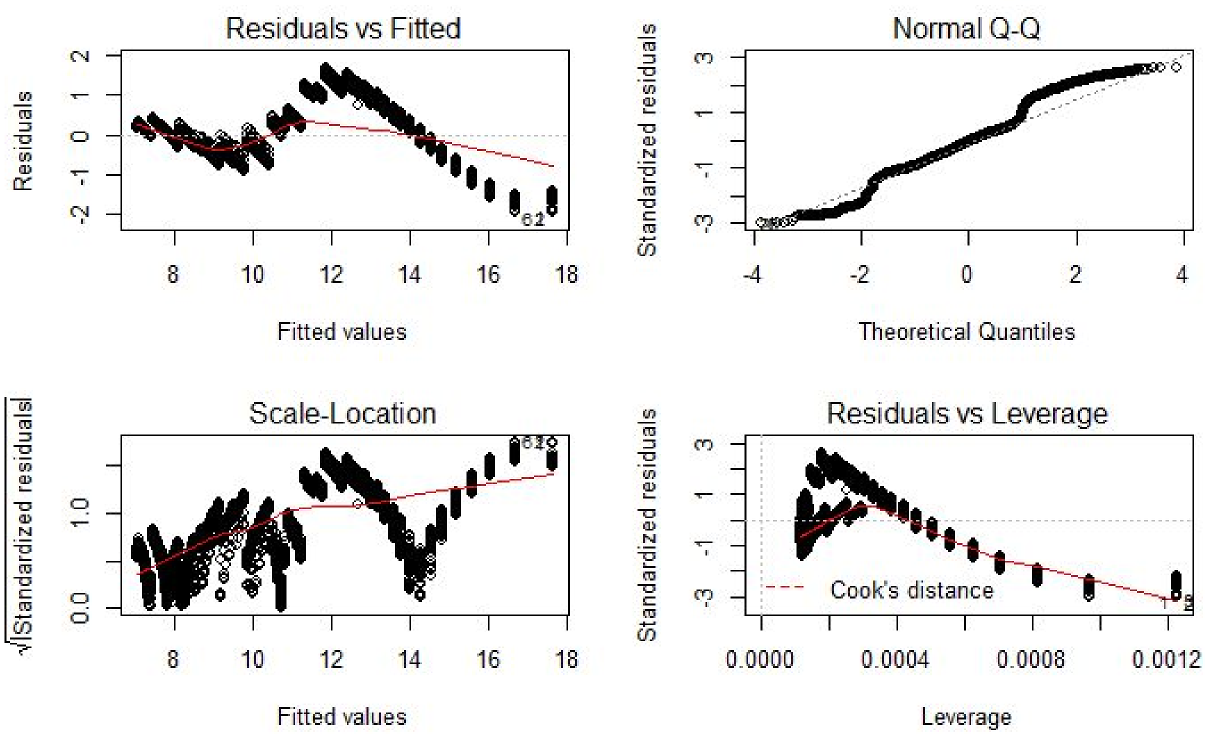
```
Residuals:
     Min       1Q   Median       3Q      Max 
-1.95121 -0.41599 -0.02442  0.27595  1.68419 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)    
(Intercept) 22.549402   0.036137     624   <2e-16 ***
Frequency   -2.766122   0.007881    -351   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.6443 on 8524 degrees of freedom
Multiple R-squared:  0.9353,  Adjusted R-squared:  0.9353 
F-statistic: 1.232e+05 on 1 and 8524 DF,  p-value: < 2.2e-16
```

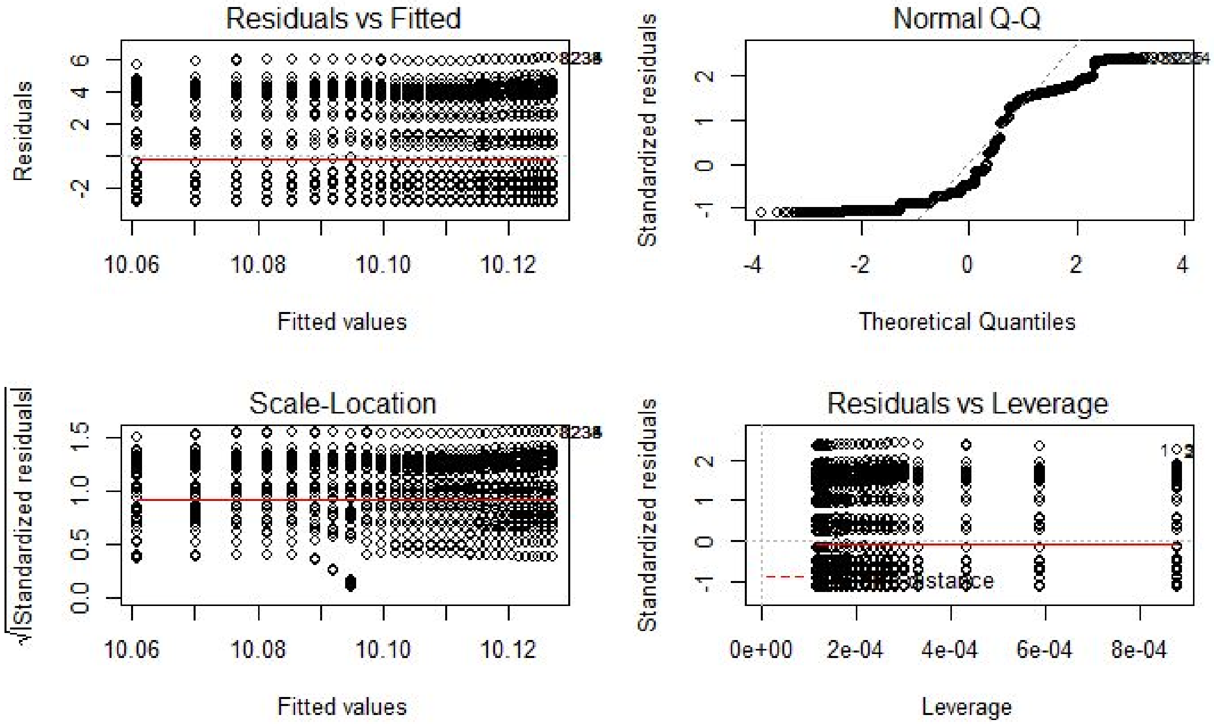
Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_1_T)

```
Residuals:
   Min     1Q Median     3Q    Max 
-2.843 -2.168 -1.230  2.461  6.095 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept) 10.01074    0.15119  66.211   <2e-16 ***
Voltage      0.02815    0.04435   0.635    0.526    
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 2.533 on 8524 degrees of freedom
Multiple R-squared:  4.729e-05,	Adjusted R-squared:  -7.002e-05 
F-statistic: 0.4031 on 1 and 8524 DF,  p-value: 0.5255
```

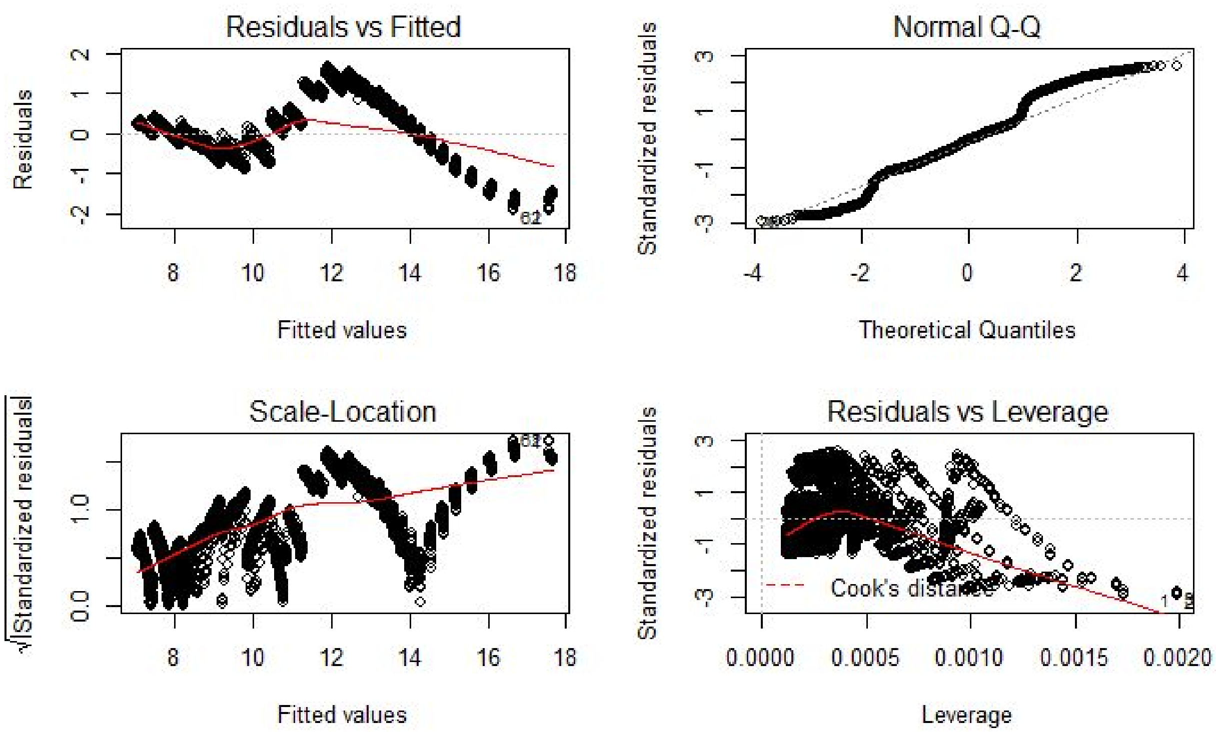
Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_1_T)

```
Residuals:
    Min      1Q   Median      3Q     Max
-1.90688 -0.41105 -0.02571  0.27788  1.66241

Coefficients:
            Estimate Std. Error  t value Pr(>|t|)
(Intercept) 22.455003   0.052298  429.363   <2e-16 ***
Frequency   -2.766122   0.007879 -351.075   <2e-16 ***
Voltage      0.028154   0.011278    2.496   0.0126 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.6441 on 8523 degrees of freedom
Multiple R-squared:  0.9353,  Adjusted R-squared:  0.9353
F-statistic: 6.163e+04 on 2 and 8523 DF,  p-value: < 2.2e-16
```





Residuals vs Fitted
Residuals
Fitted values
10.06 10.08 10.10 10.12
Normal Q-Q
Standardized residuals
Theoretical Quantiles
Scale-Location
√|Standardized residuals|
Residuals vs Leverage
Leverage
0e+00 2e-04 4e-04 6e-04 8e-04



Residuals vs Fitted
Residuals
Fitted values
8 10 12 14 16 18
Normal Q-Q
Standardized residuals
Theoretical Quantiles
Scale-Location
√|Standardized residuals|
Residuals vs Leverage
Cook's distance
Leverage
0.0000 0.0005 0.0010 0.0015 0.0020

We can see that the graphs look a lot better after transforming. The data becomes more normal, and there does not seem to be high leverage points. Our data now looks like it has a normal qqplot, but the residuals are still not normal. This may be due to the fact that we have a very large data set which is affecting it. The other graphs such as the leverage and scale location graphs seem to change but are still not normal.

We see from our summary statements, all the wells now seem to be very consistent with one another for all 3 models. The intercepts and standard errors are all close together, differing by a non-significant amount. Thus, we are able to say that the wells do not really play a role in predicting impedance and the quality of the wells are pretty high. The R-squared and adjusted R-squared values seem to be the same when frequency is involved in the model, but when it is just voltage, the adjusted R-squared becomes a lot smaller.

Overall we see that voltage has an effect on the impedance, but does not seem to be as important as the frequency. The frequency seems to be the most important predictor from our graphs and summary statistics. We see that as frequency is increased the impedance starts to decrease. Thus, it increases the overall speed of the embryo process. The voltage scatter plot does not show us a relationship between the two since multiple points of the voltage have different impedance levels. Combining both voltage and frequency seem to have the same effect as just using frequency.

IV. Introduction to Time-Series Exploration

Since we have a column labeled “Time” within our dataframe, what we want to try to do is study the rate of change of a given feature over time. The following is sample code that we can model our code to do some time-series data analysis using Python:

```
#df is your dataframe
index = pd.date_range(df['time_stamp'])
values = pd.Series(df.values, index=index) #Read above link about the different Offset Aliases, S=Seconds
resampled_values = values.resample('2.5S')
resampled_values.diff() #compute the difference between each point!
```

<u>**Q:**</u> Maybe, we can add, what between which values will we see the highest rate of change (for a time period of 2.5 sec)?

Because of time constraints, we will not be able to perform this step. But, it is a good idea to think about in terms of our data.

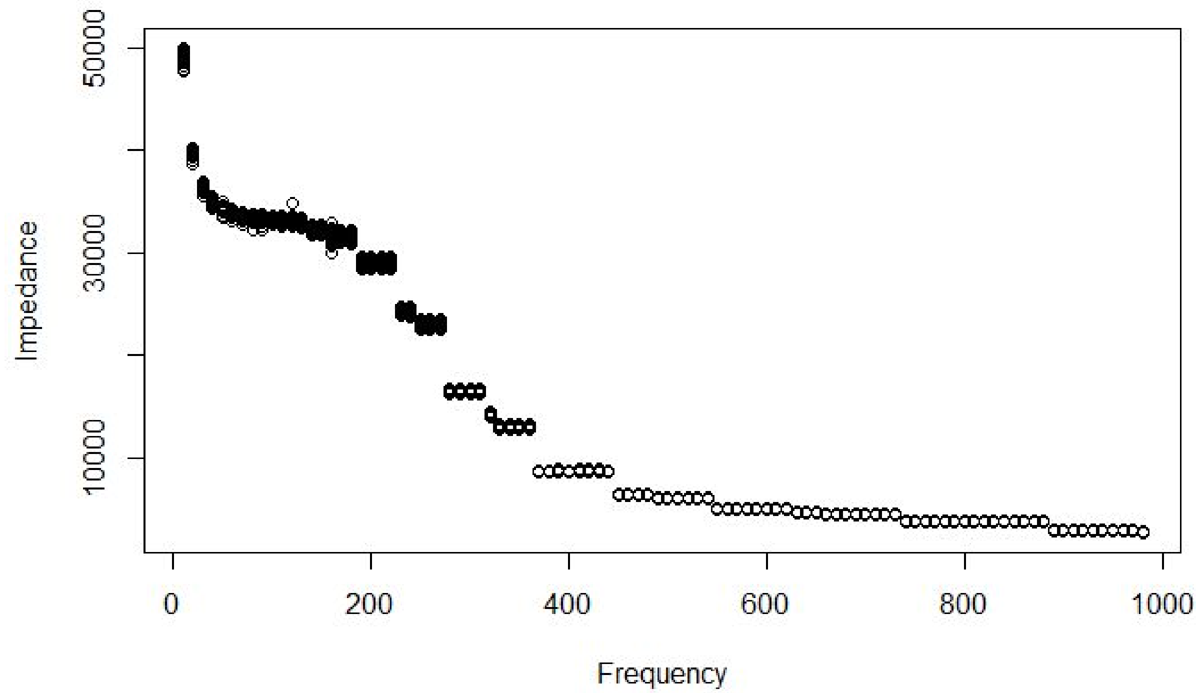
V. Conclusion

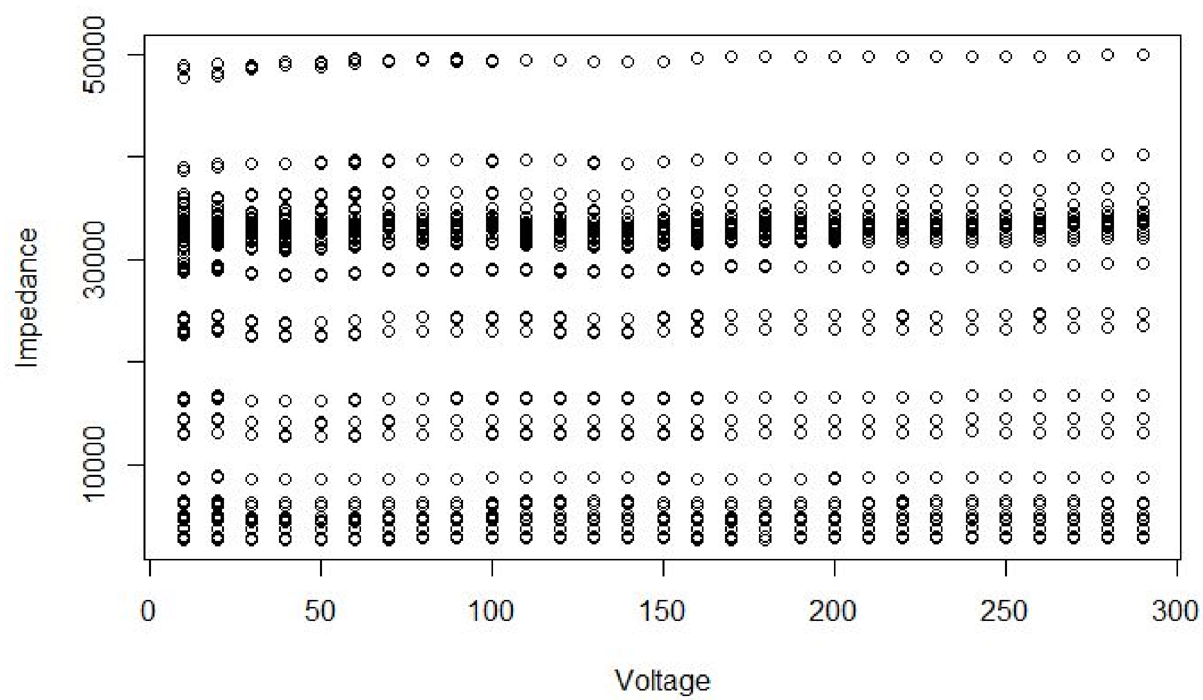
When comparing our results from both classification and regression methods, we observe similar results. When preprocessing our Well 1 data inside Python to create our categorical variables, we find that around 80% of our data is classified to have low impedance values. This translates to how, in Well 1, when we created a scatter plot in R, we saw that many of our values are categorized to have low impedance when we have low frequency. In addition, using classification, we found most of our outliers exist at low frequency (10 KHZ to 40 KHZ), which we can see in our scatter plot inside R.

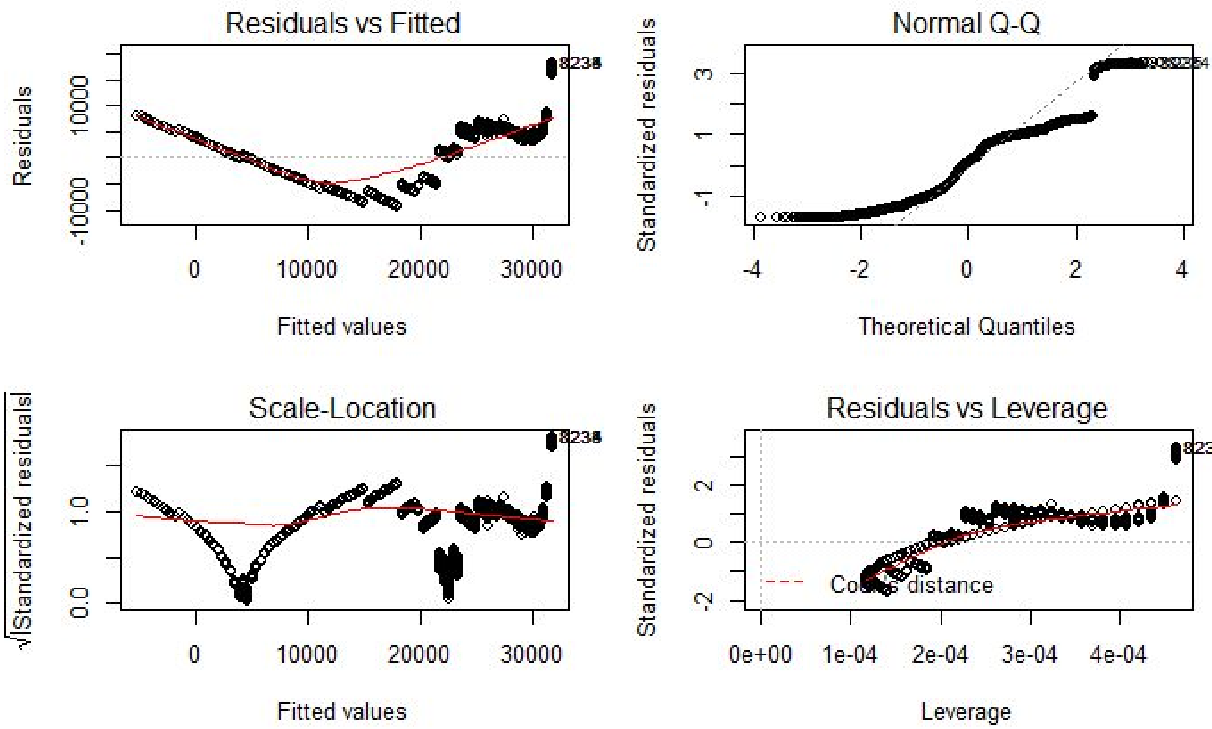
We are able to use our classification model to help predict outliers from certain ranges and find out what percentage of our data is low/high. This will allow us to help remove certain values for our linear regression model to help make it more normal, and it will allow us to predict impedance values more accurately. By doing this, we can see how certain values of frequency and voltage will affect the impedance, thus it will either raise or lower the speed of the embryo process.

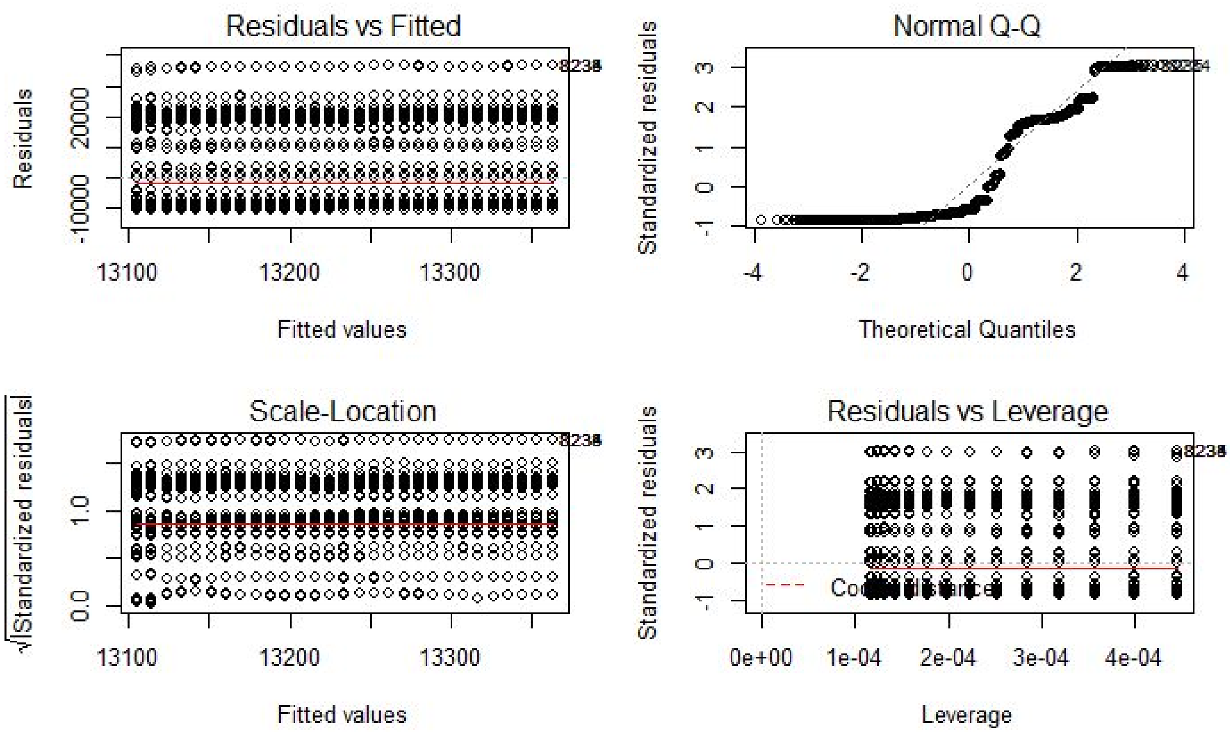
Overall, in the decision making process, when we see low impedance values consistently within a given well, we should leave the well as is. But, if we find high impedance values, we should adjust the frequency in our wells in such a way, that we will obtain lower impedance values. But because the data seems to not have much variance between wells, we do not need to make any adjustments.

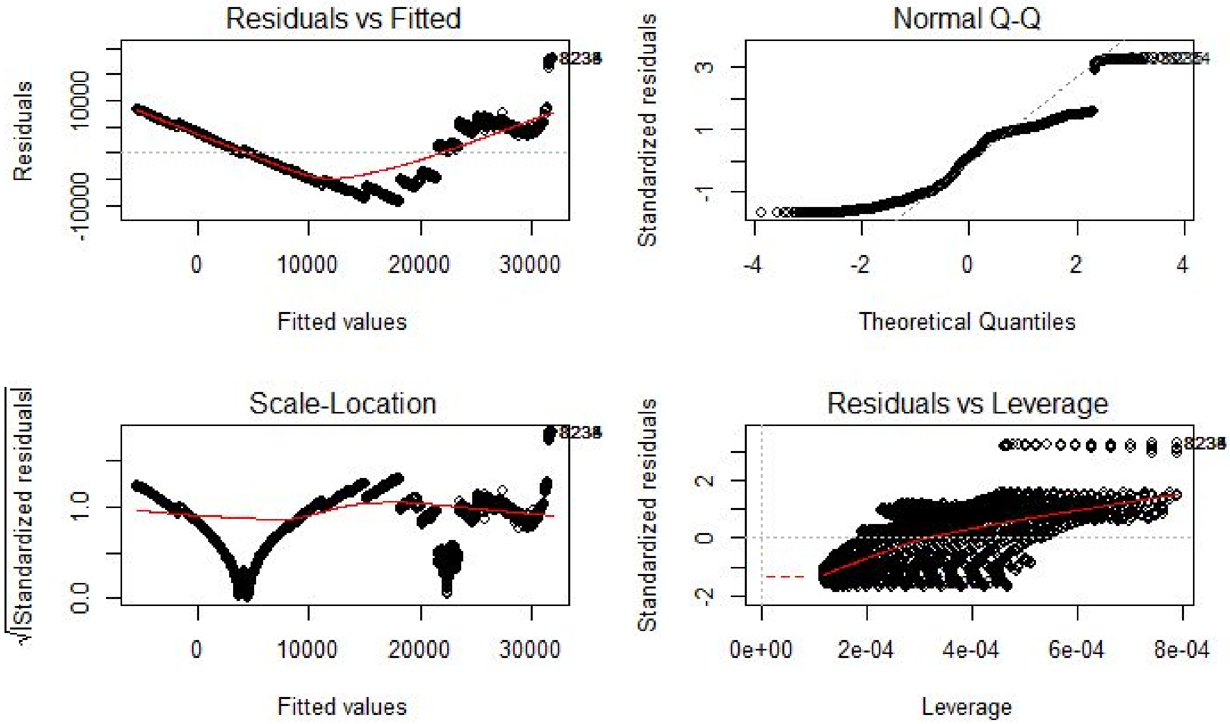
VI. Appendix
Well 2


50000
30000
10000
Impedance
0
200
400
600
800
1000
Frequency

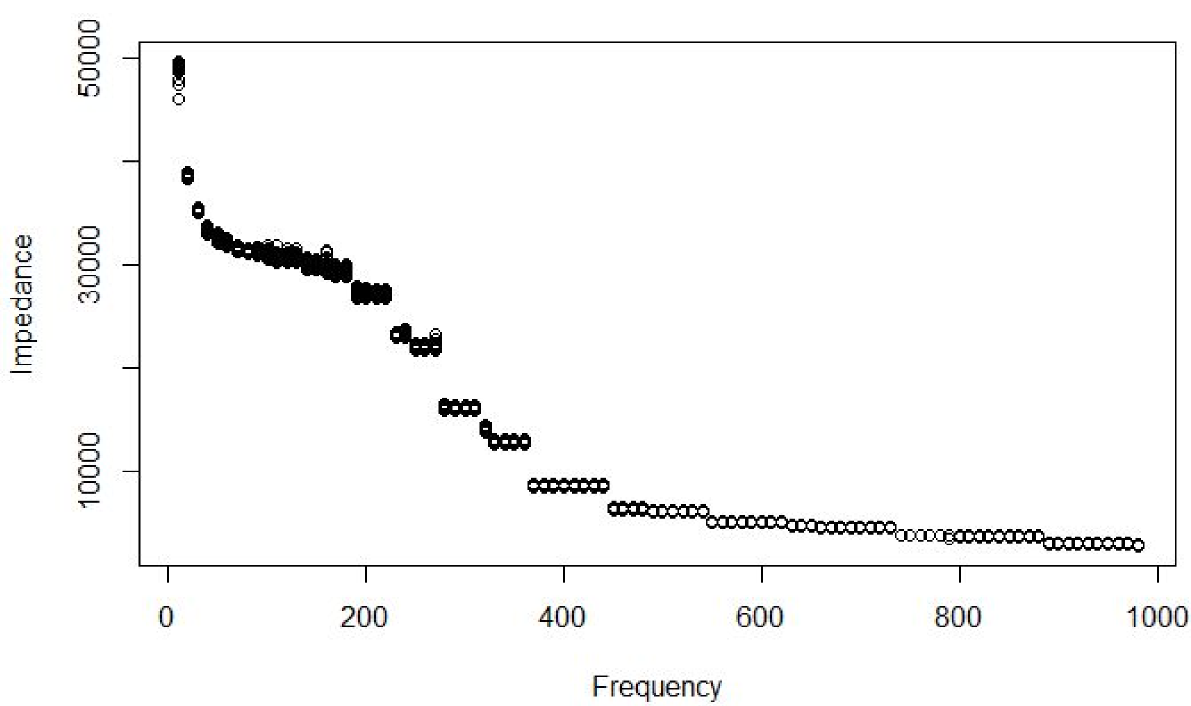

50000
30000
10000
Impedance
0
50
100
150
200
250
300
Voltage

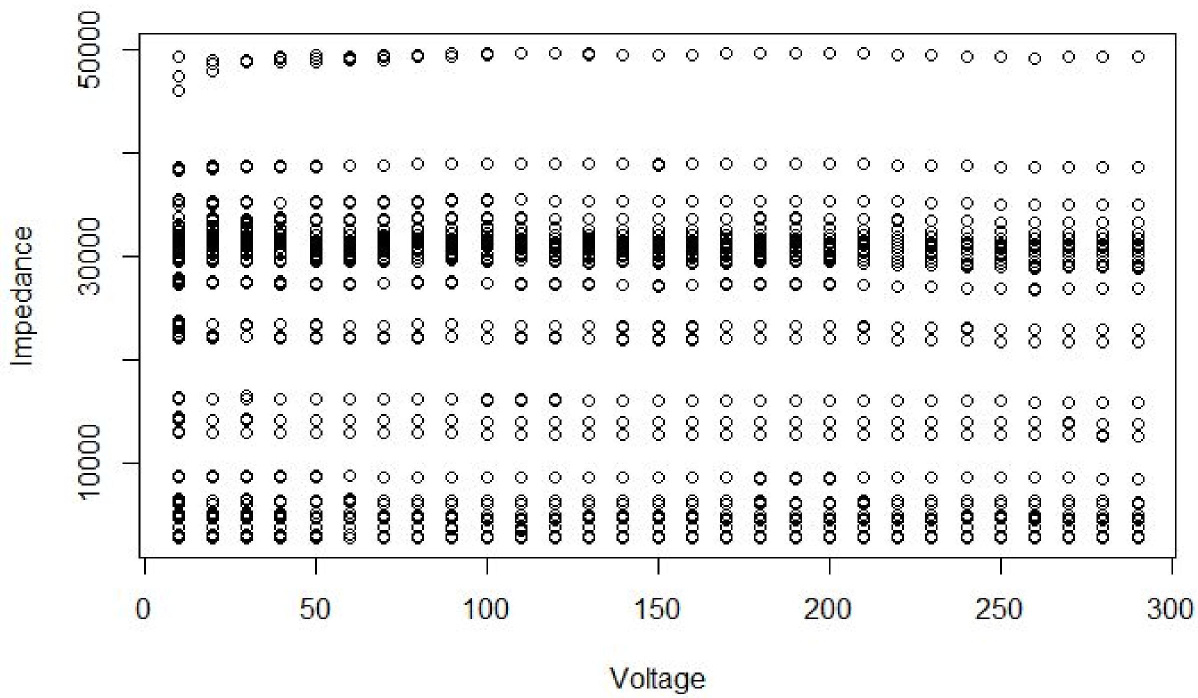

Residuals vs Fitted
Residuals
Fitted values
Normal Q-Q
Standardized residuals
Theoretical Quantiles
Scale-Location
√|Standardized residuals|
Fitted values
Residuals vs Leverage
Standardized residuals
Cook's distance
Leverage


Residuals vs Fitted
Residuals
Fitted values
Normal Q-Q
Standardized residuals
Theoretical Quantiles
Scale-Location
√|Standardized residuals|
Fitted values
Residuals vs Leverage
Standardized residuals
Cook's distance
Leverage

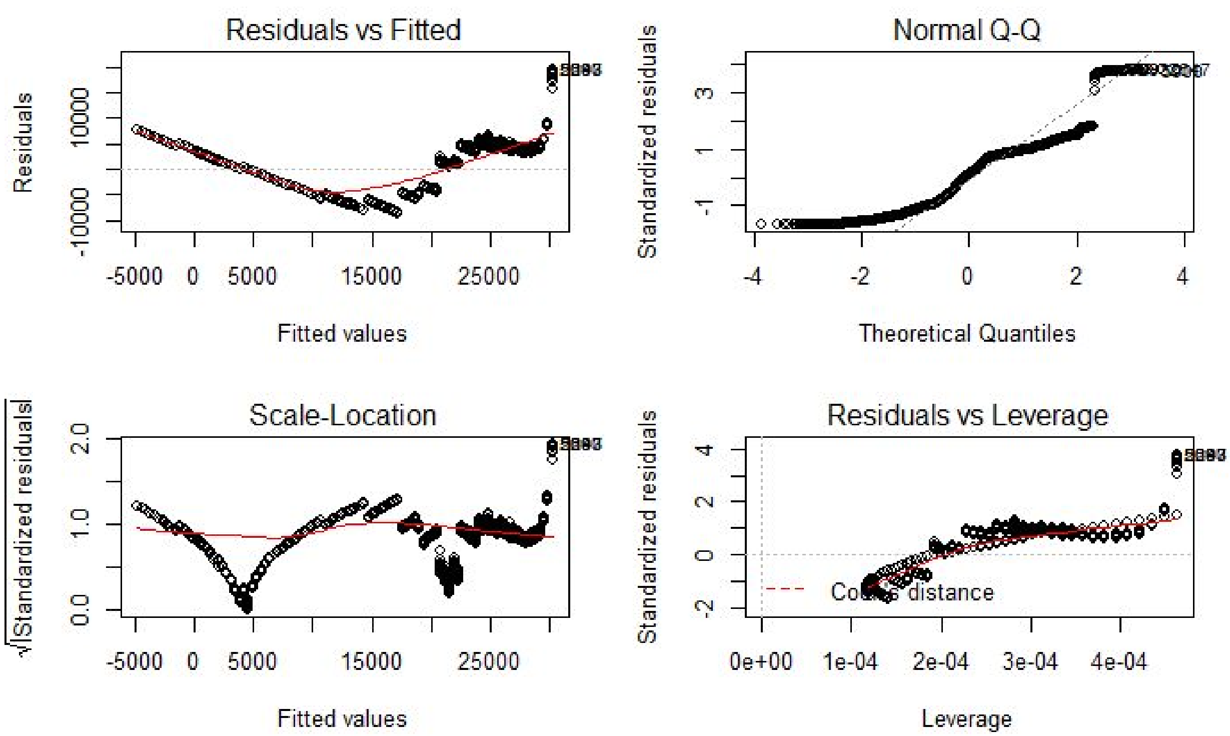

Residuals vs Fitted
Residuals
Fitted values
Normal Q-Q
Standardized residuals
Theoretical Quantiles
Scale-Location
√|Standardized residuals|
Fitted values
Residuals vs Leverage
Standardized residuals
Leverage

Well 3

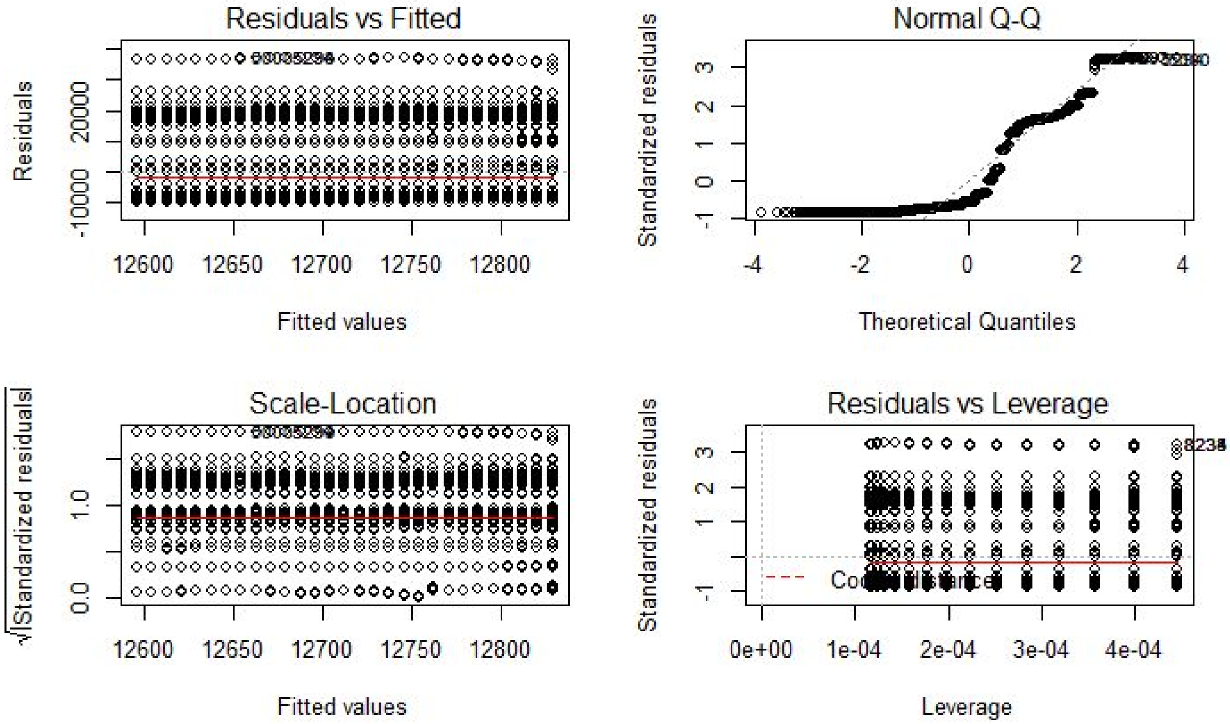

Impedance
Frequency

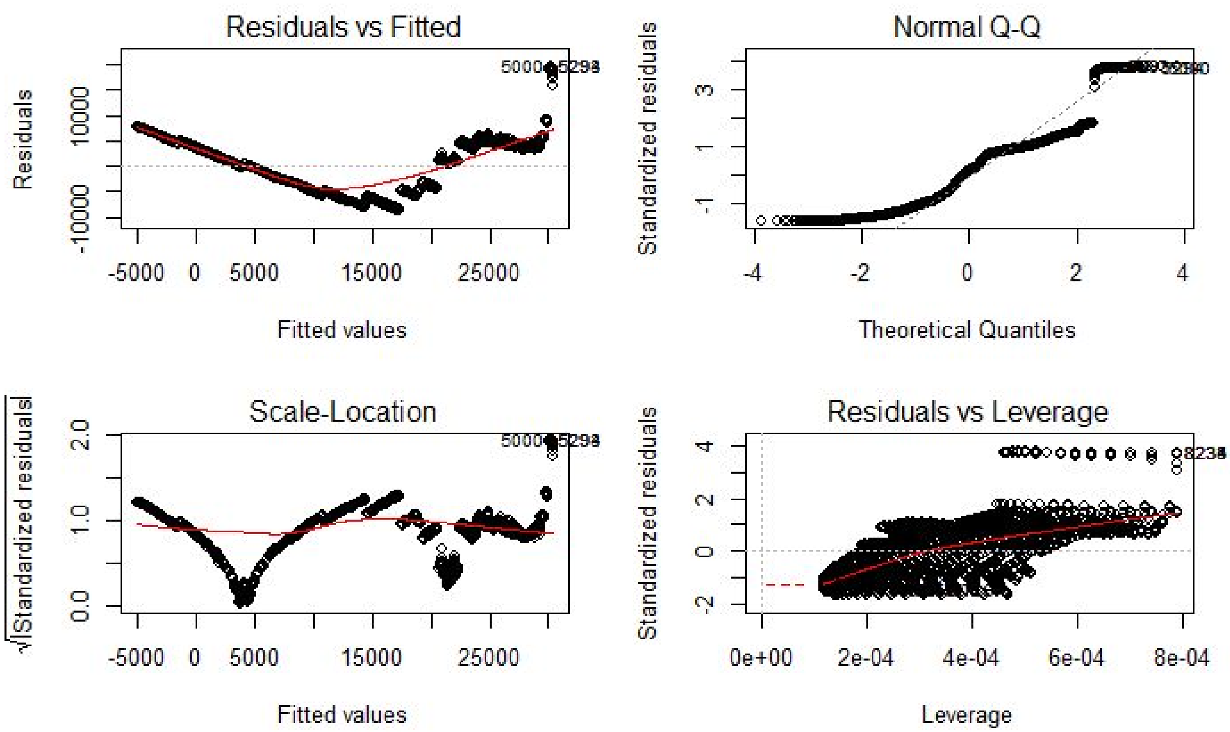


Impedance
50000
30000
10000
0
50
100
150
200
250
300
Voltage

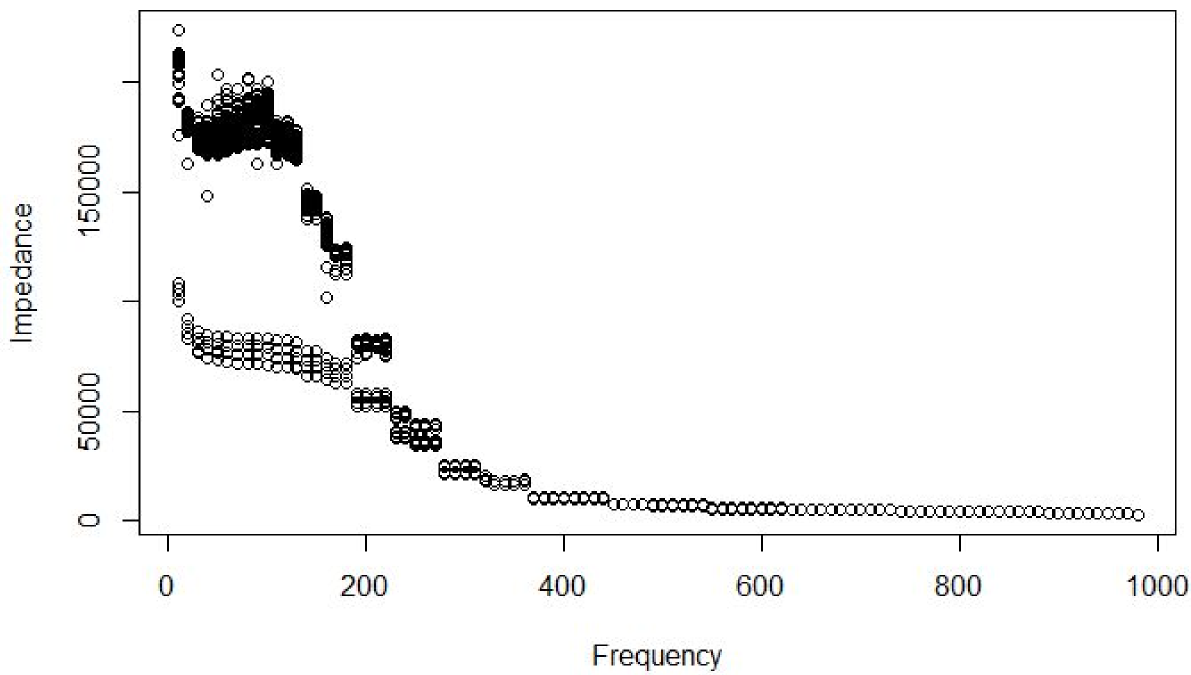


Residuals vs Fitted
Residuals
Fitted values
Normal Q-Q
Standardized residuals
Theoretical Quantiles
Scale-Location
√|Standardized residuals|
Fitted values
Residuals vs Leverage
Standardized residuals
Cook's distance
Leverage

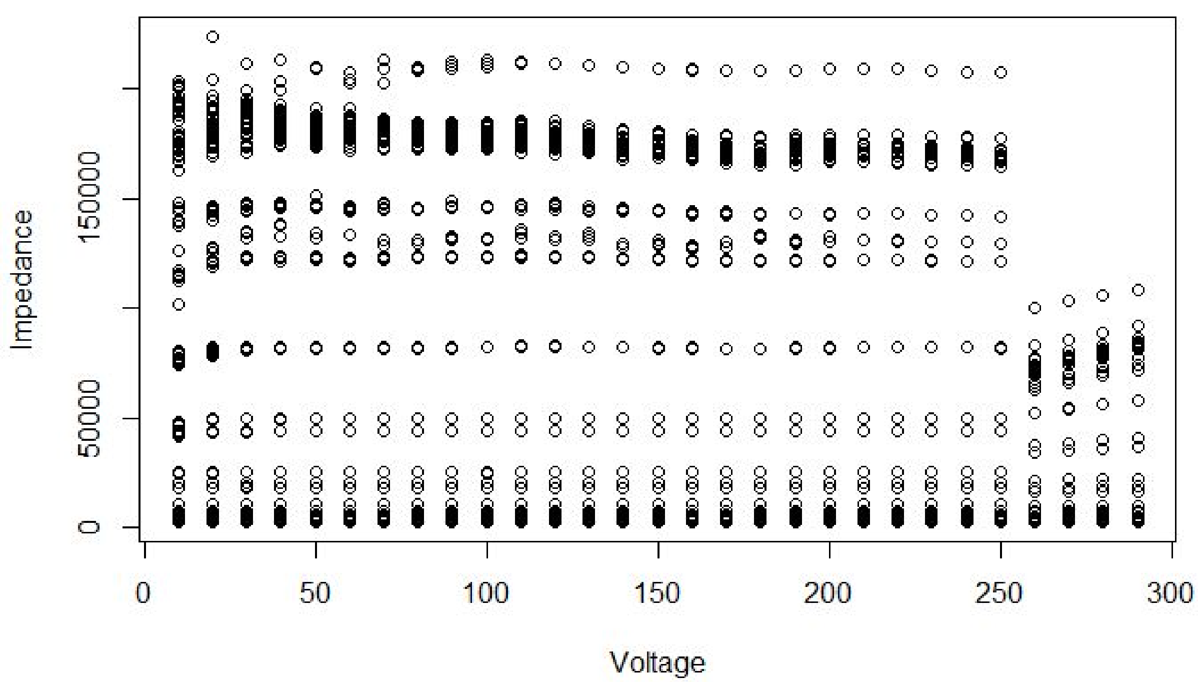

Residuals vs Fitted
Residuals
Fitted values
Normal Q-Q
Standardized residuals
Theoretical Quantiles
Scale-Location
√|Standardized residuals|
Fitted values
Residuals vs Leverage
Standardized residuals
Leverage
Cook's distance


Residuals vs Fitted
Residuals
Fitted values
Normal Q-Q
Standardized residuals
Theoretical Quantiles
Scale-Location
√|Standardized residuals|
Fitted values
Residuals vs Leverage
Standardized residuals
Leverage

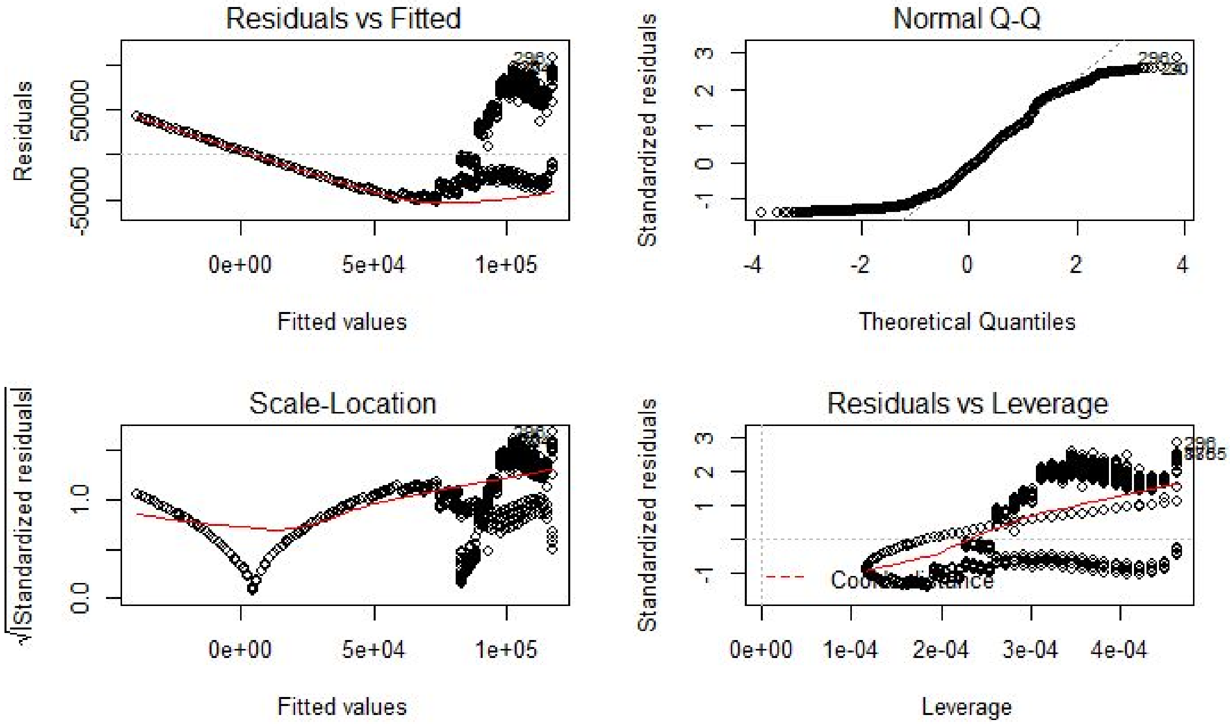
Well 4

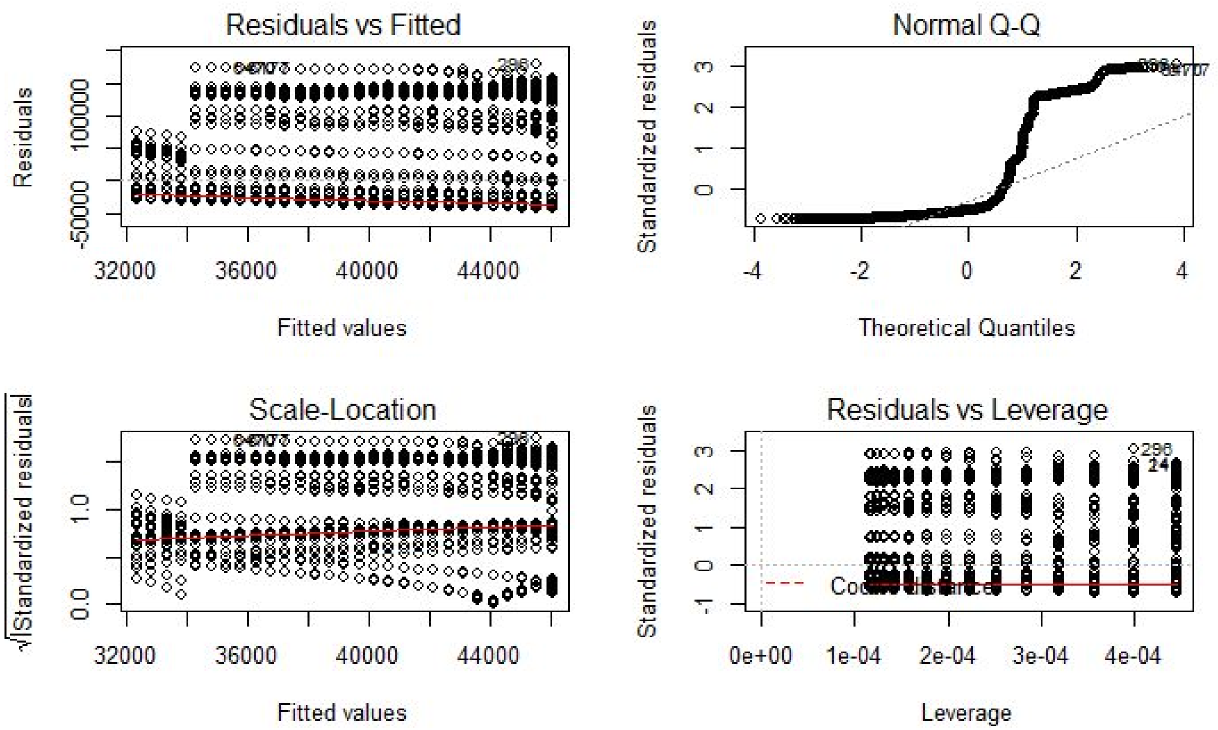


Impedance
0
50000
150000
0
200
400
600
800
1000
Frequency



Impedance
0
50000
150000
0
50
100
150
200
250
300
Voltage


Residuals vs Fitted
Residuals
Fitted values
Normal Q-Q
Standardized residuals
Theoretical Quantiles
Scale-Location
√|Standardized residuals|
Fitted values
Residuals vs Leverage
Standardized residuals
Leverage
Cook's distance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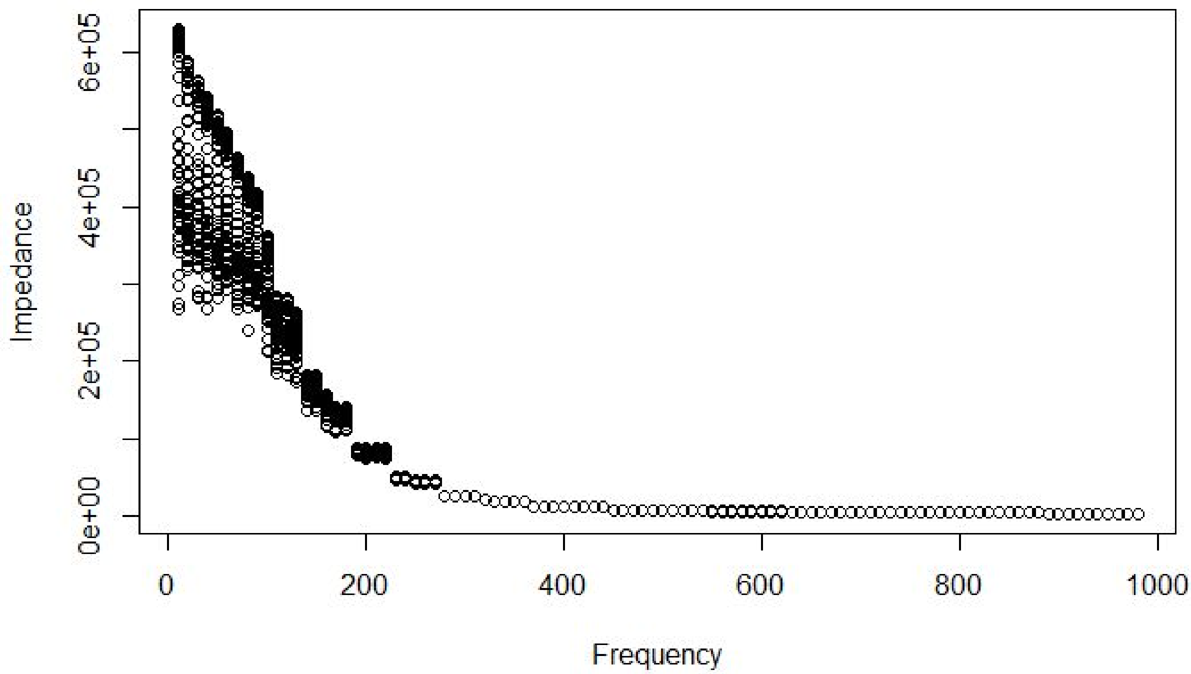
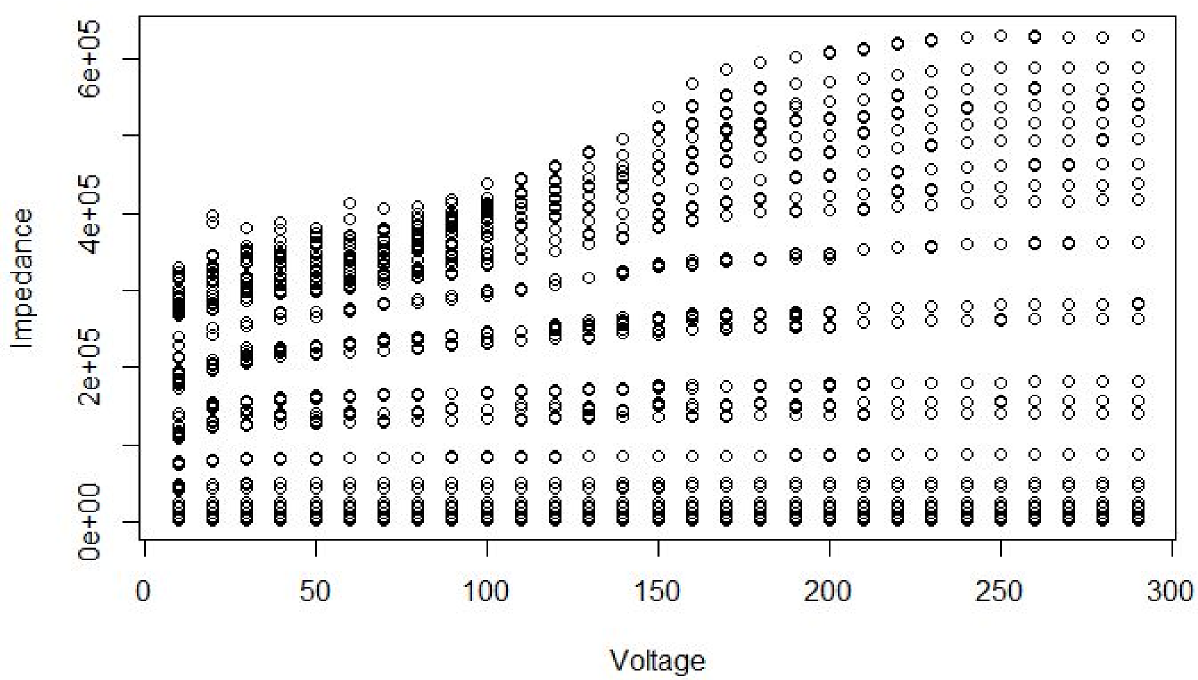
Residuals
Fitted values
Normal Q-Q
Standardized residuals
Theoretical Quantiles
Scale-Location
√|Standardized residuals|
Fitted values
Residuals vs Leverage
Standardized residuals
Leverage
Cook's distance

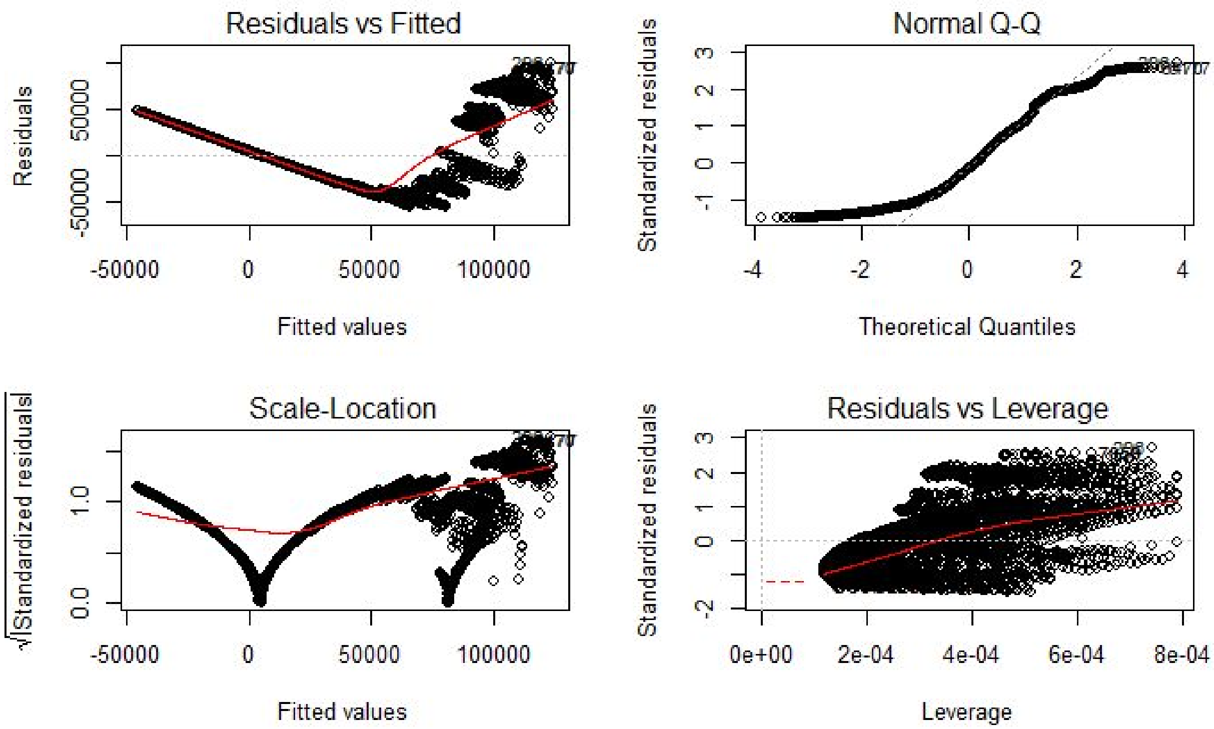
Well 5

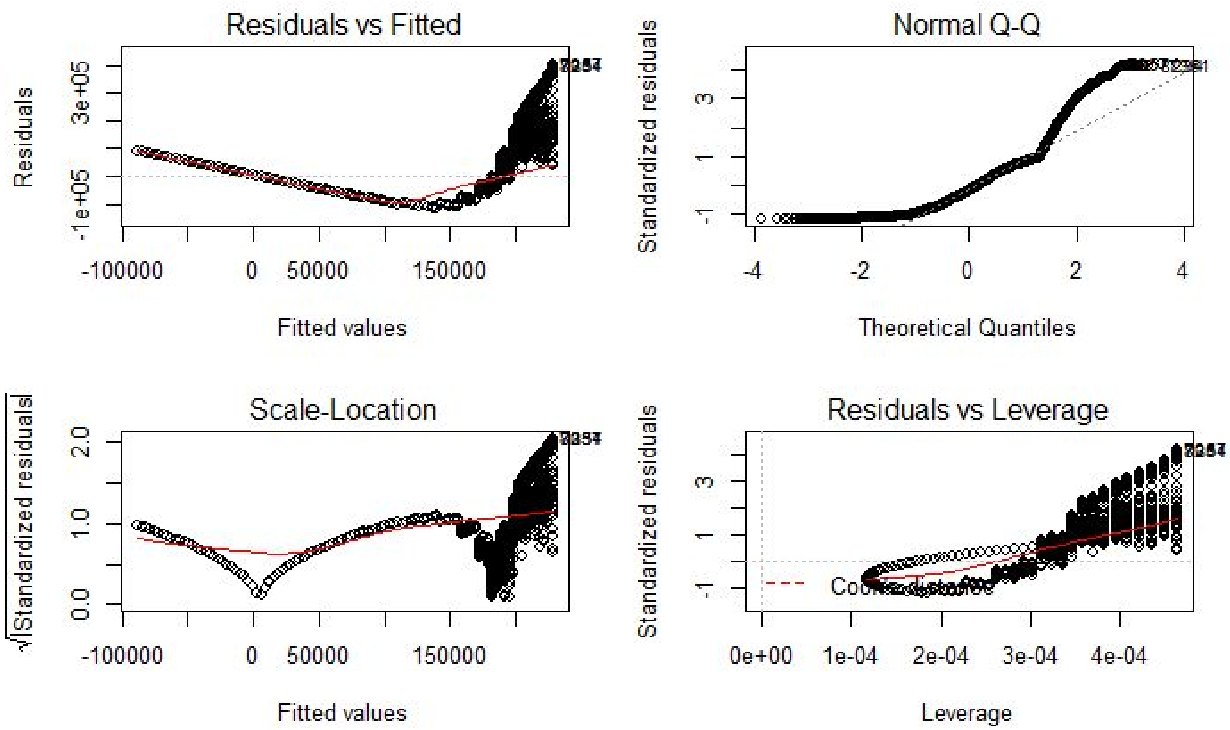


Impedance
0e+00
2e+05
4e+05
6e+05
0
200
400
600
800
1000
Frequency



Impedance
0e+00
2e+05
4e+05
6e+05
0
50
100
150
200
250
300
Voltage


Residuals vs Fitted
Residuals
Fitted values
Normal Q-Q
Standardized residuals
Theoretical Quantiles
Scale-Location
√|Standardized residuals|
Fitted values
Residuals vs Leverage
Standardized residuals
Leverage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Standardized residuals
Theoretical Quantiles
Scale-Location
√|Standardized residuals|
Fitted values
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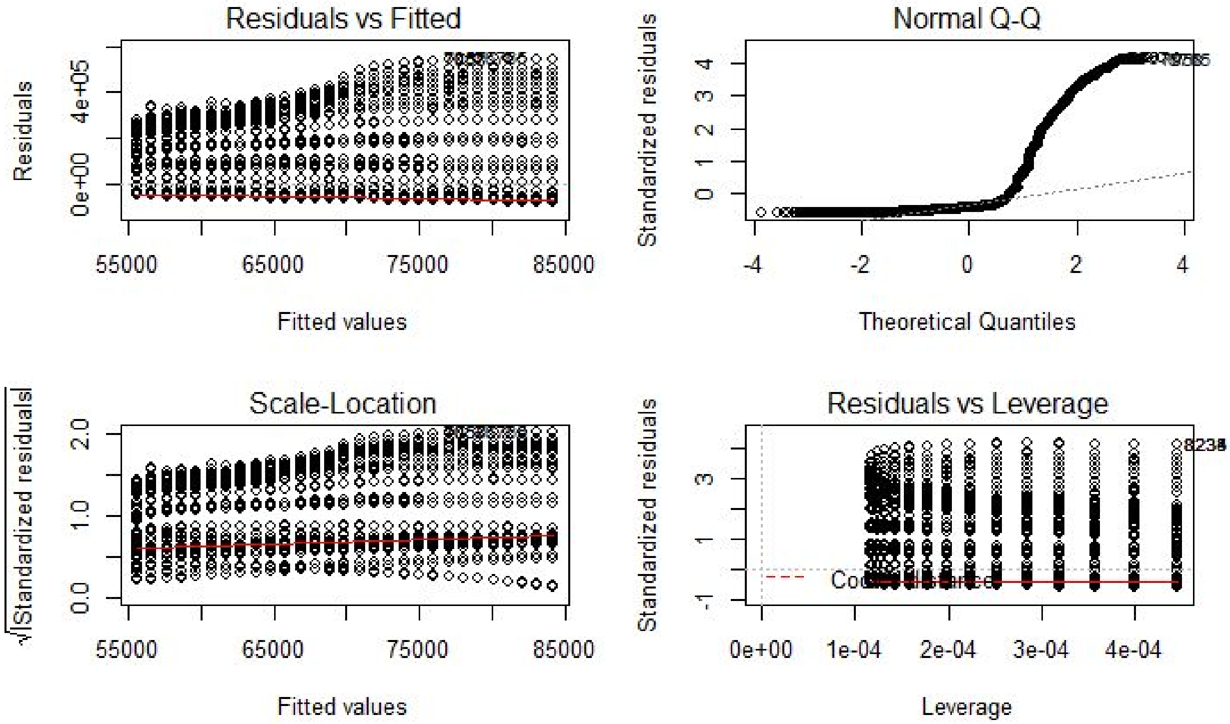
Standardized residuals
Leverage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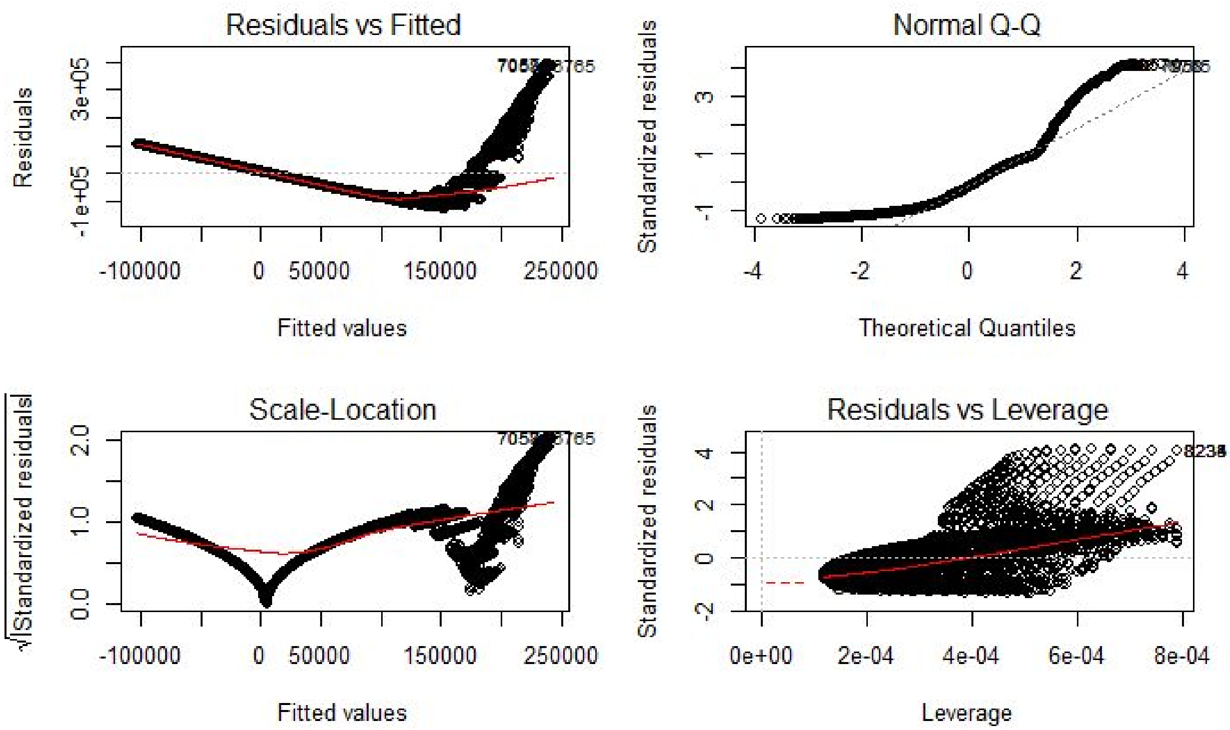
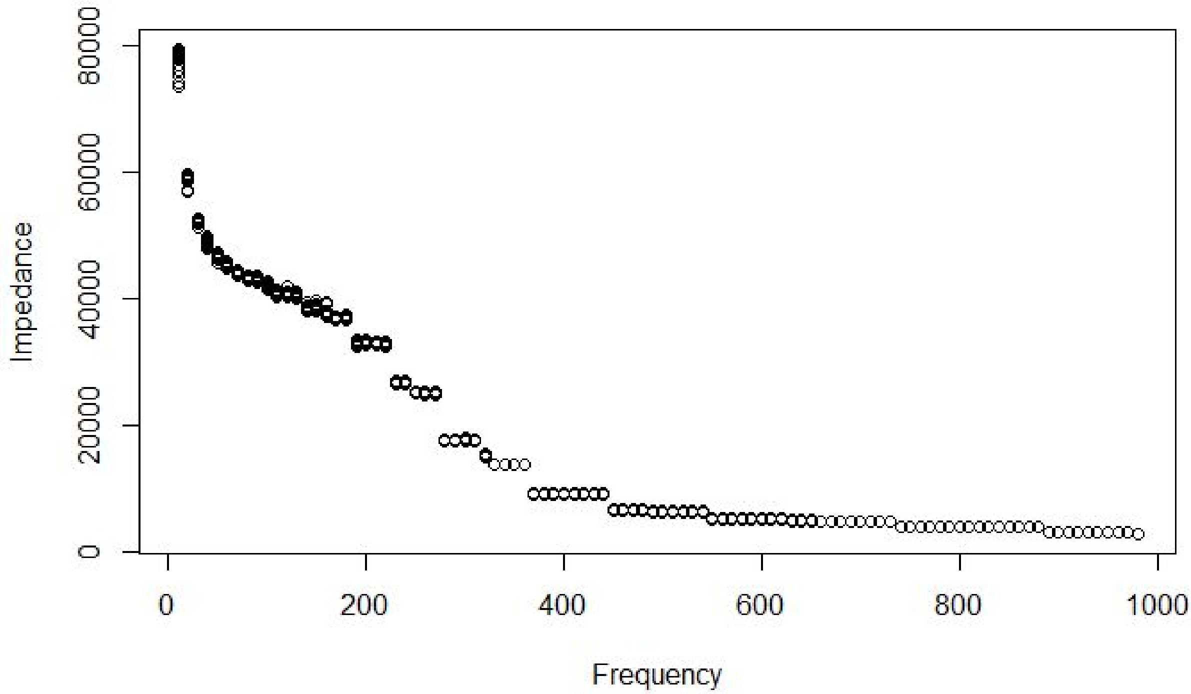
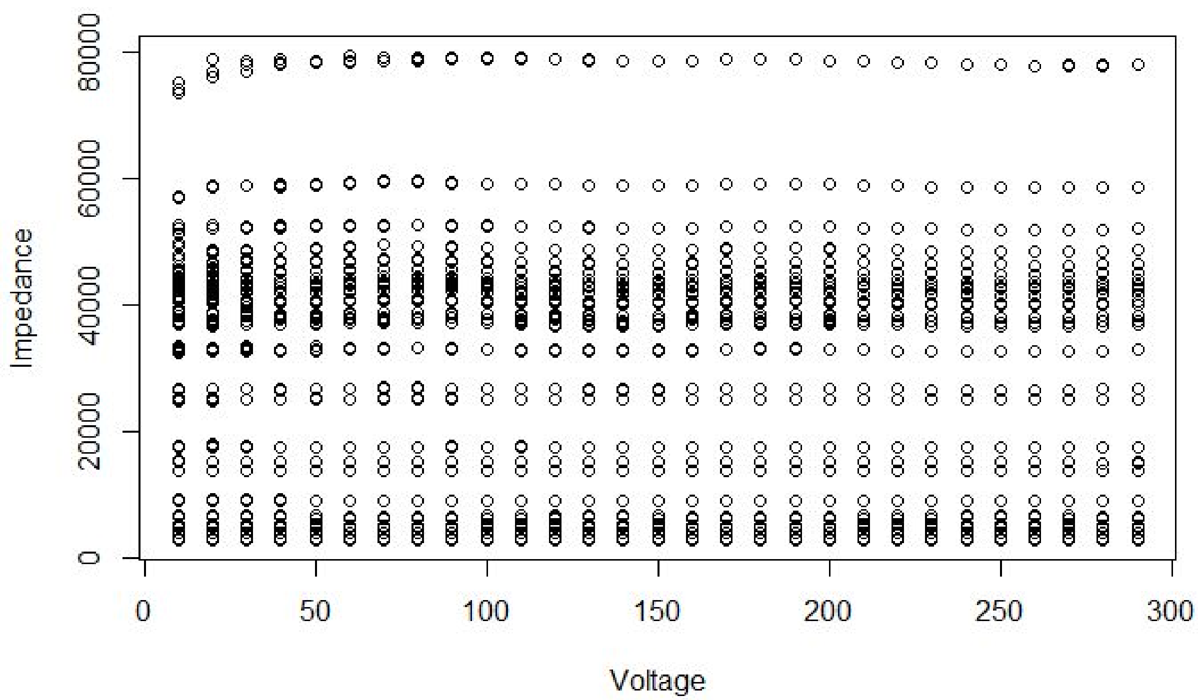
Residuals
Fitted values
Normal Q-Q
Standardized residuals
Theoretical Quantiles
Scale-Location
√|Standardized residuals|
Fitted values
Residuals vs Leverage
Standardized residuals
Leverage
8234


Residuals vs Fitted
Residuals
Fitted values
Normal Q-Q
Standardized residuals
Theoretical Quantiles
Scale-Location
√|Standardized residuals|
Fitted values
Residuals vs Leverage
Standardized residuals
Leverage
8234

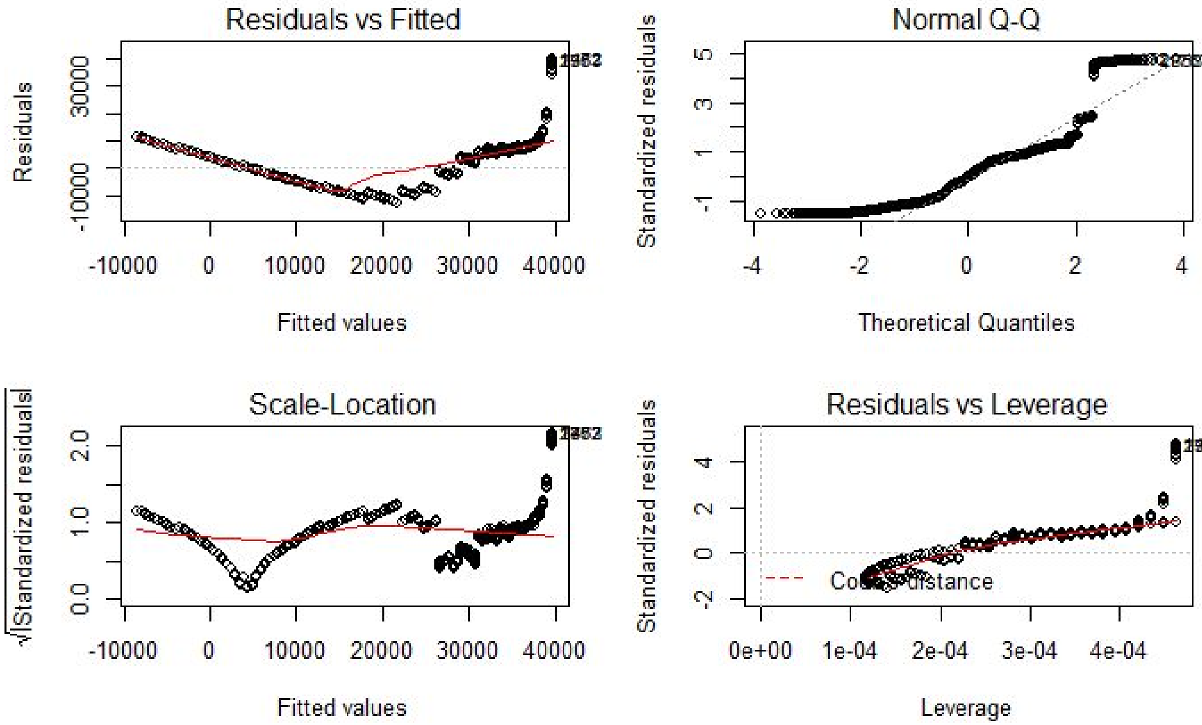
Well 6

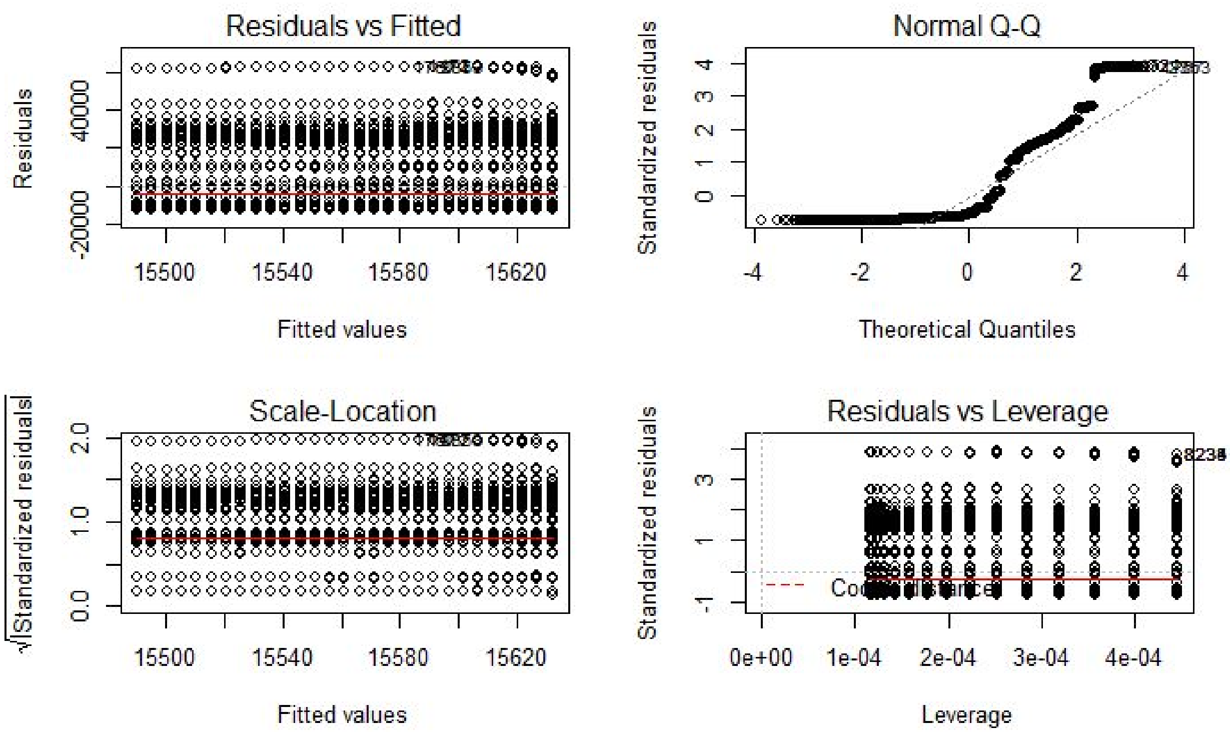


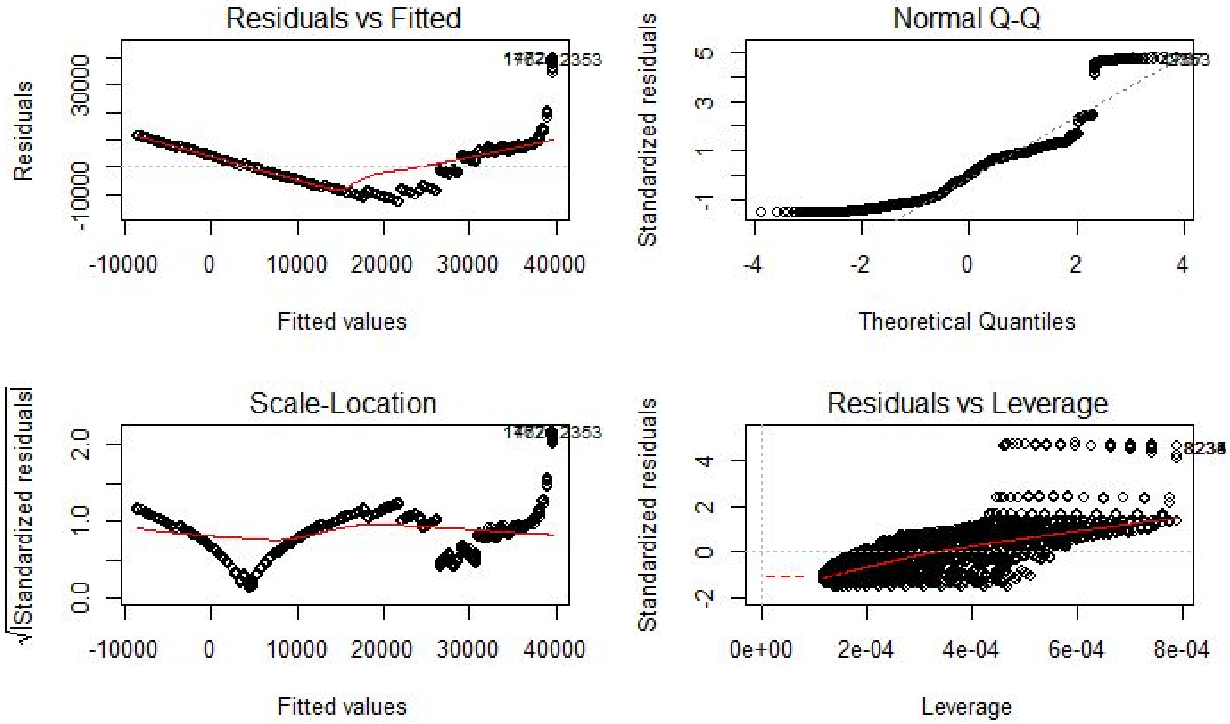
80000
60000
40000
20000
0
Impedance
0
200
400
600
800
1000
Frequency



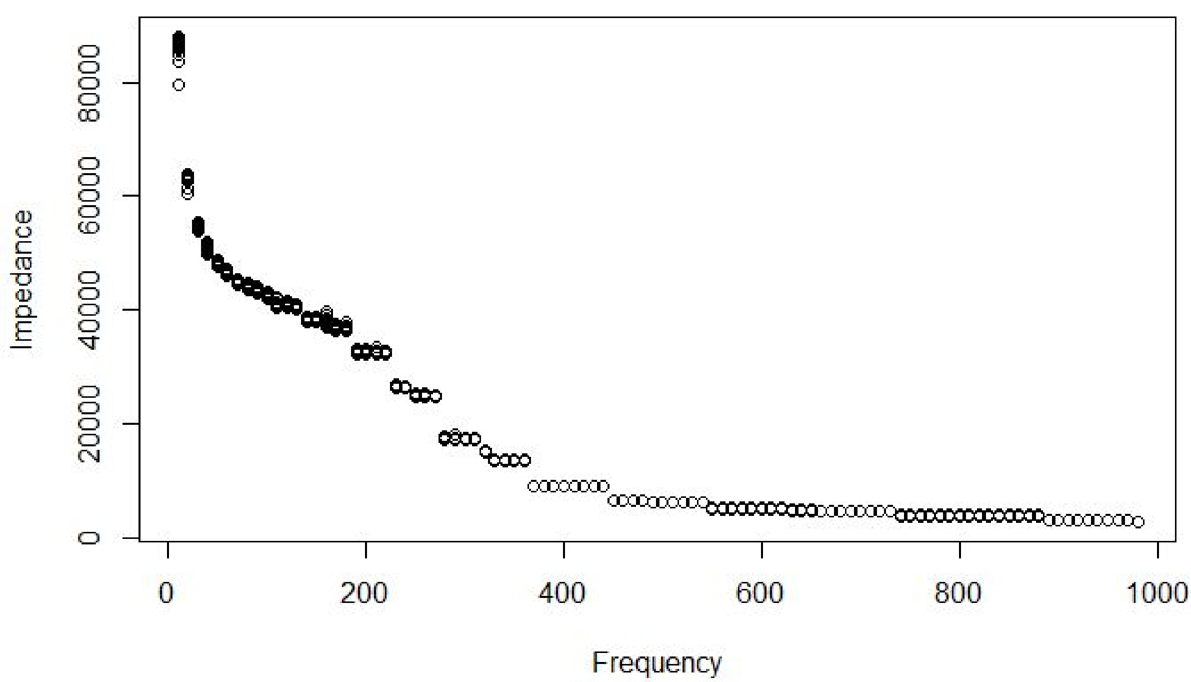
80000
60000
40000
20000
0
Impedance
0
50
100
150
200
250
300
Voltage

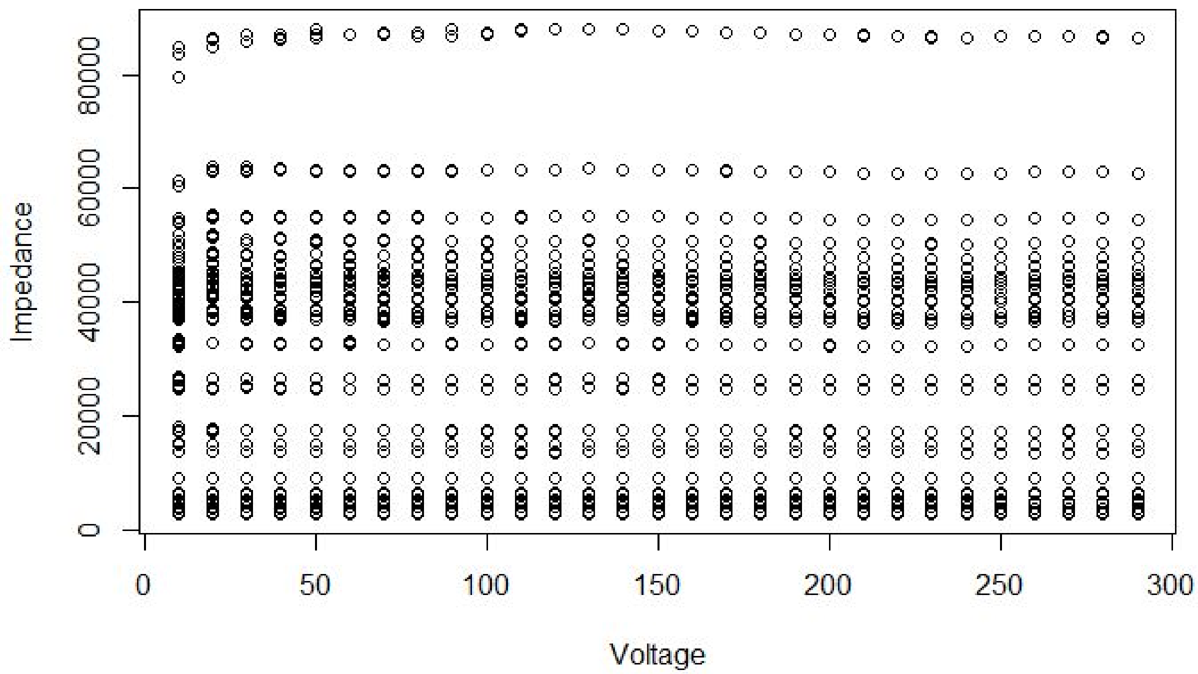

Residuals vs Fitted
Residuals
Fitted values
Normal Q-Q
Standardized residuals
Theoretical Quantiles
Scale-Location
√|Standardized residuals|
Fitted values
Residuals vs Leverage
Standardized residuals
Cook's distance
Leverage

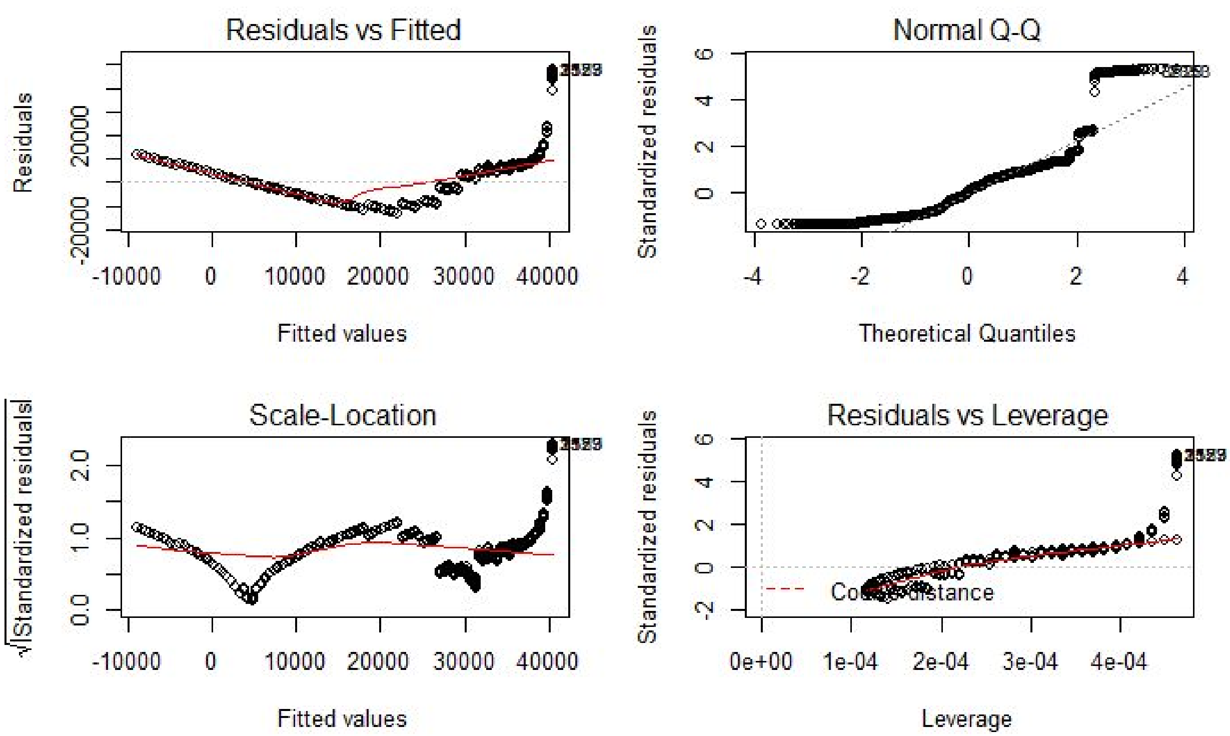

Residuals vs Fitted
Residuals
Fitted values
Normal Q-Q
Standardized residuals
Theoretical Quantiles
Scale-Location
√|Standardized residuals|
Fitted values
Residuals vs Leverage
Standardized residuals
Cook's distance
Leverage

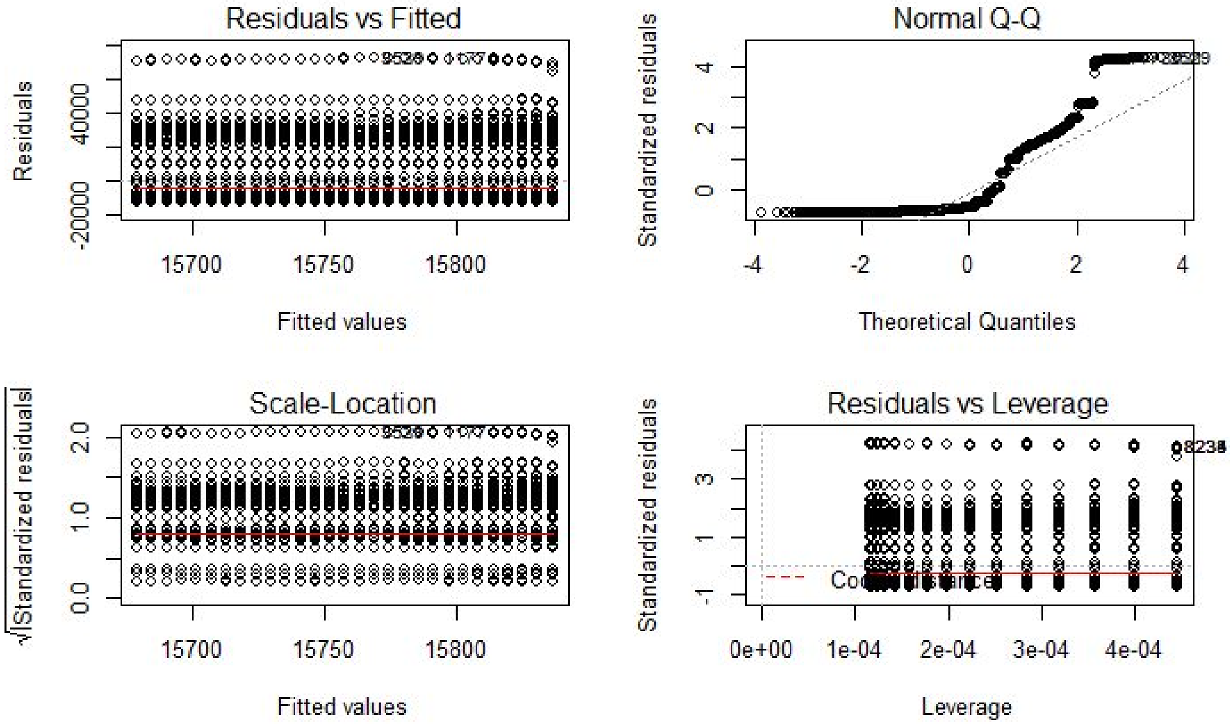

Residuals vs Fitted
Normal Q-Q
Scale-Location
Residuals vs Leverage
Fitted values
Theoretical Quantiles
Leverage
Residuals
Standardized residuals
√|Standardized residuals|

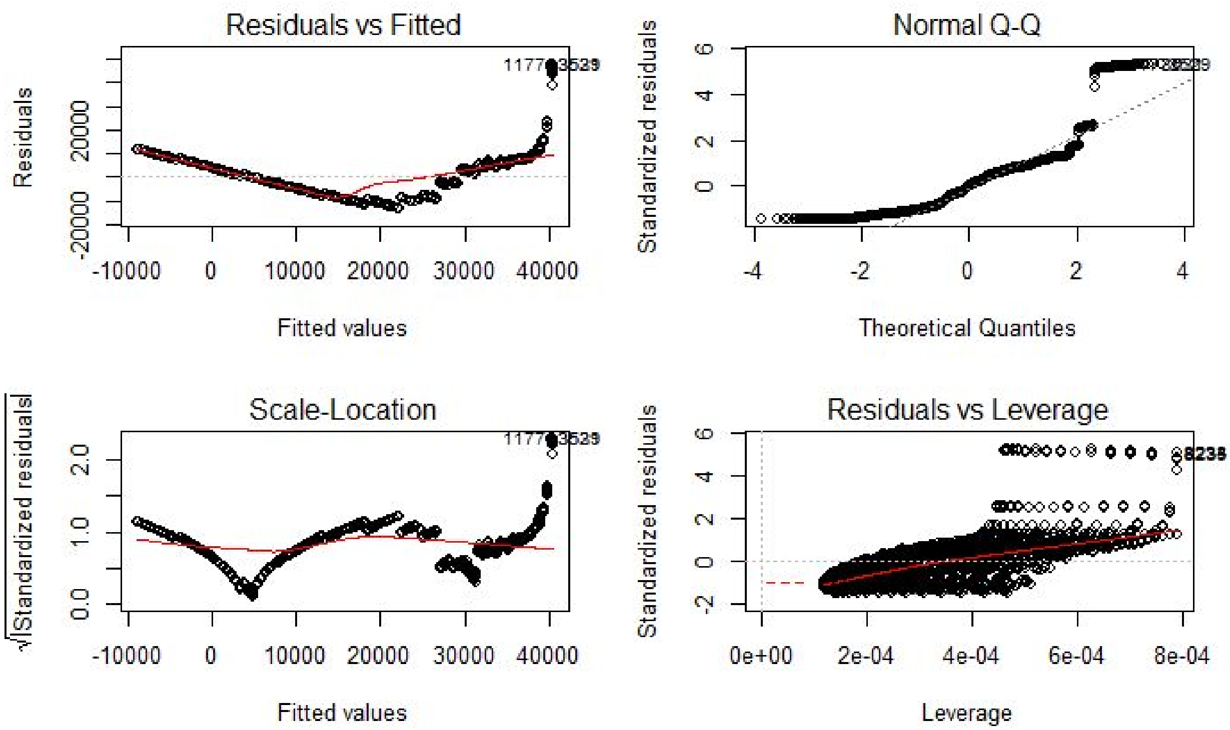
Well 7


Impedance
Frequency

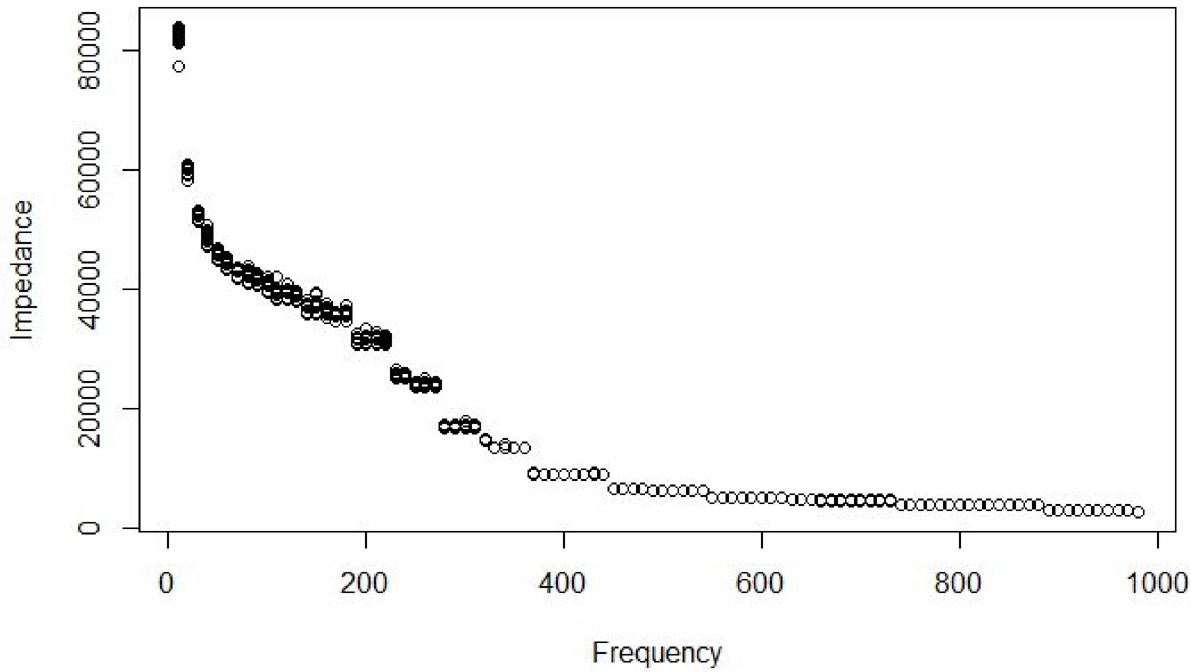

Impedance
Voltage
0
20000
40000
60000
80000
0
50
100
150
200
250
300


Residuals vs Fitted
Residuals
Fitted values
Normal Q-Q
Standardized residuals
Theoretical Quantiles
Scale-Location
√|Standardized residuals|
Fitted values
Residuals vs Leverage
Standardized residuals
Leverage
Cook's distance

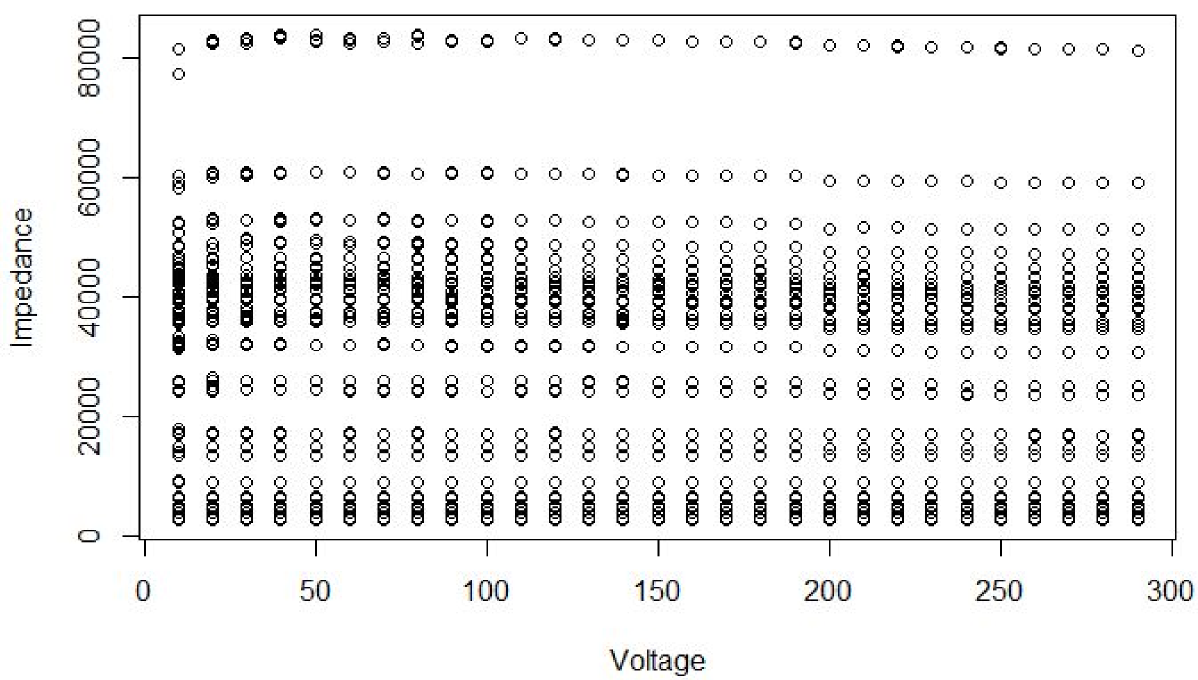

Residuals vs Fitted
Residuals
Fitted values
Normal Q-Q
Standardized residuals
Theoretical Quantiles
Scale-Location
√|Standardized residuals|
Fitted values
Residuals vs Leverage
Standardized residuals
Leverage


Residuals vs Fitted
Residuals
Fitted values
Normal Q-Q
Standardized residuals
Theoretical Quantiles
Scale-Location
√|Standardized residuals|
Fitted values
Residuals vs Leverage
Standardized residuals
Leverage

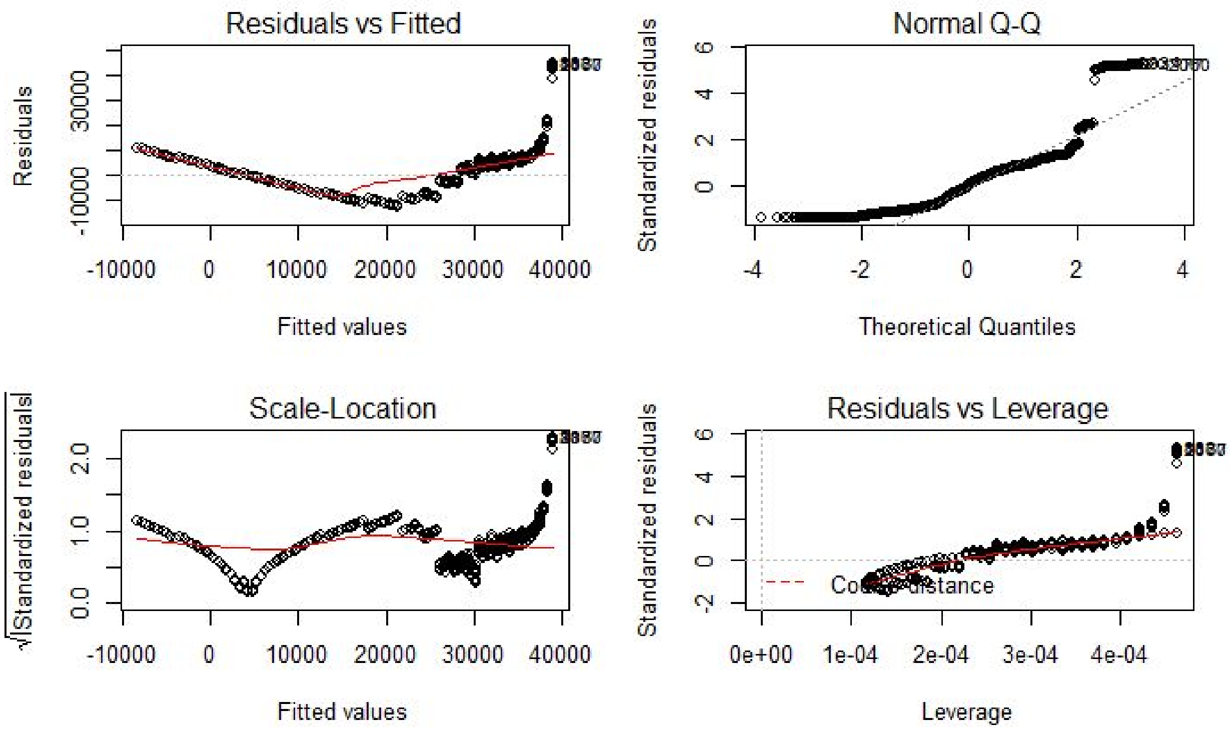
Well 8

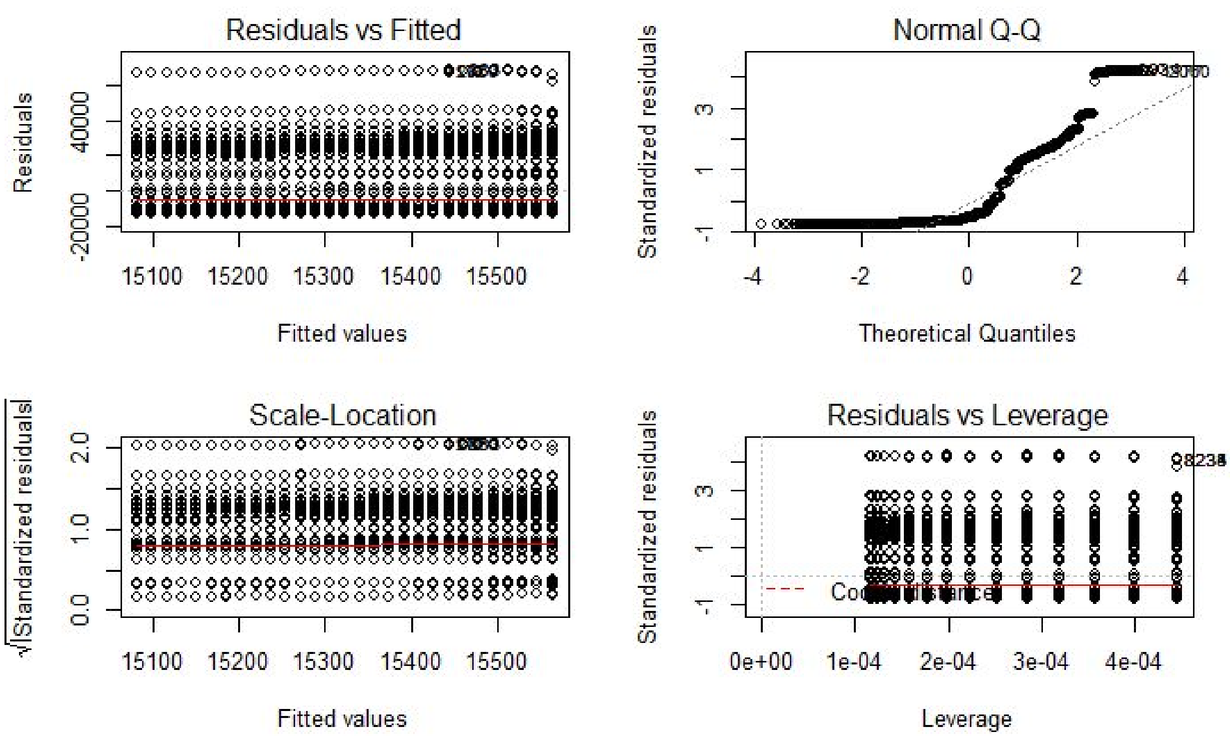


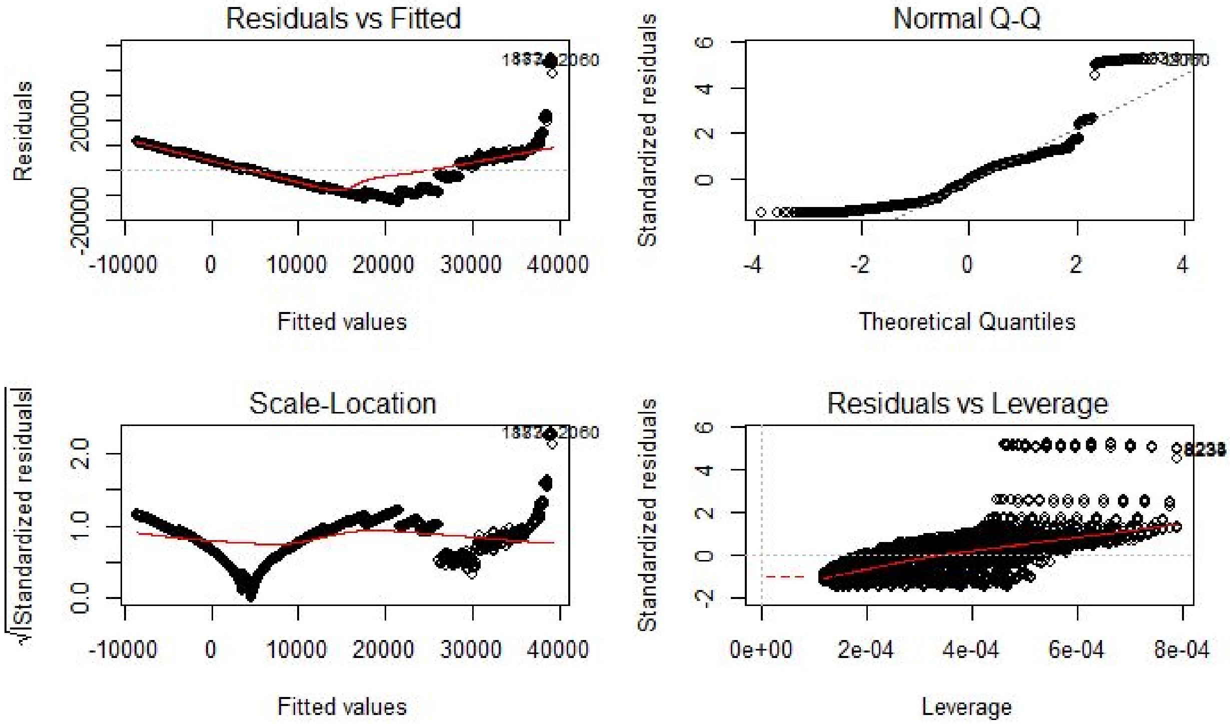
Impedance
Frequency
0
20000
40000
60000
80000
0
200
400
600
800
1000



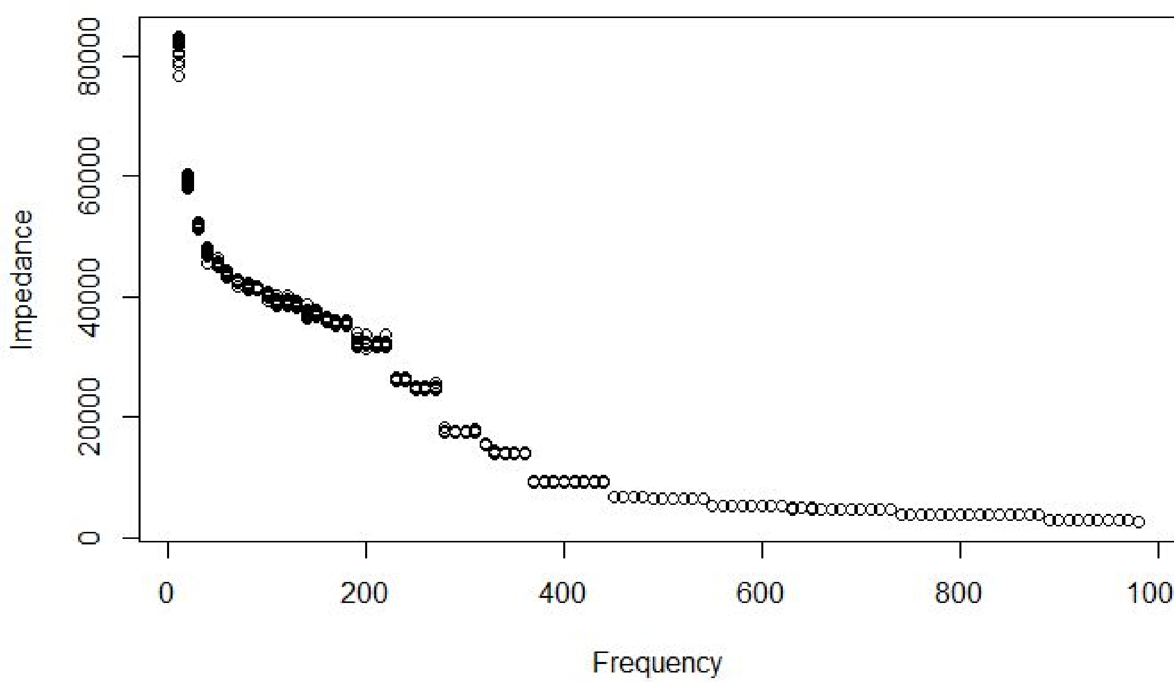
Impedance
Voltage
0
20000
40000
60000
80000
0
50
100
150
200
250
300

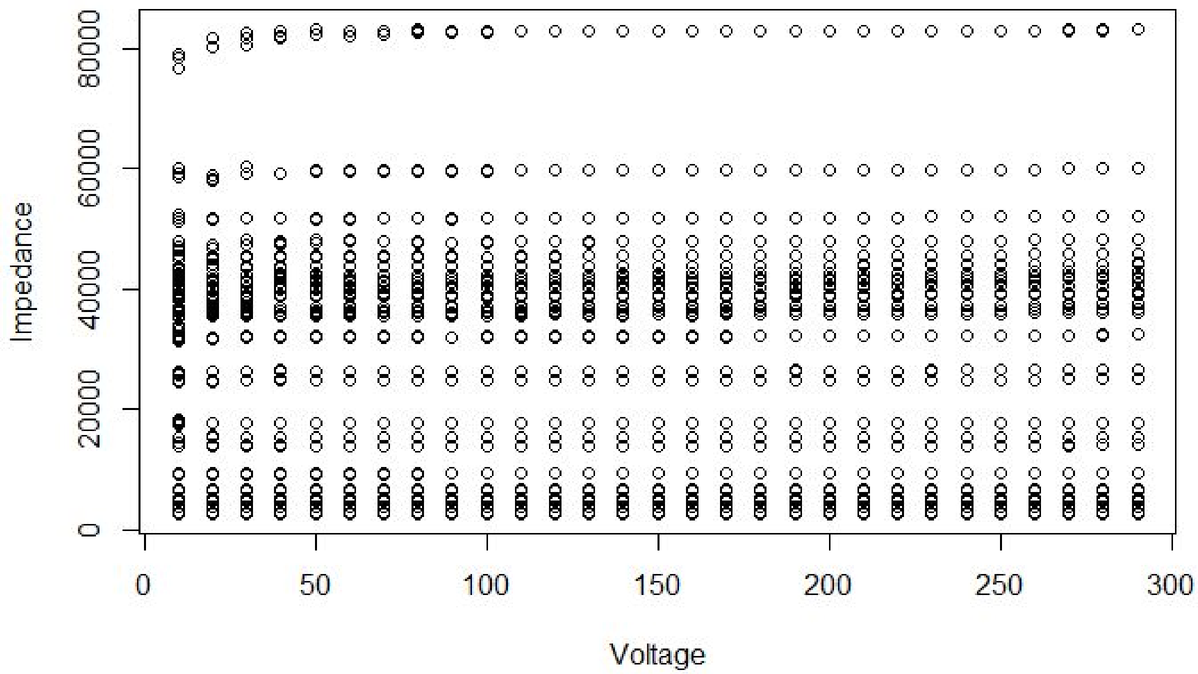

Residuals vs Fitted
Residuals
Fitted values
-10000
0
10000
20000
30000
40000
Normal Q-Q
Standardized residuals
Theoretical Quantiles
-4
-2
0
2
4
6
Scale-Location
√|Standardized residuals|
0.0
1.0
2.0
Residuals vs Leverage
Cook's distance
Leverage
0e+00
1e-04
2e-04
3e-04
4e-04

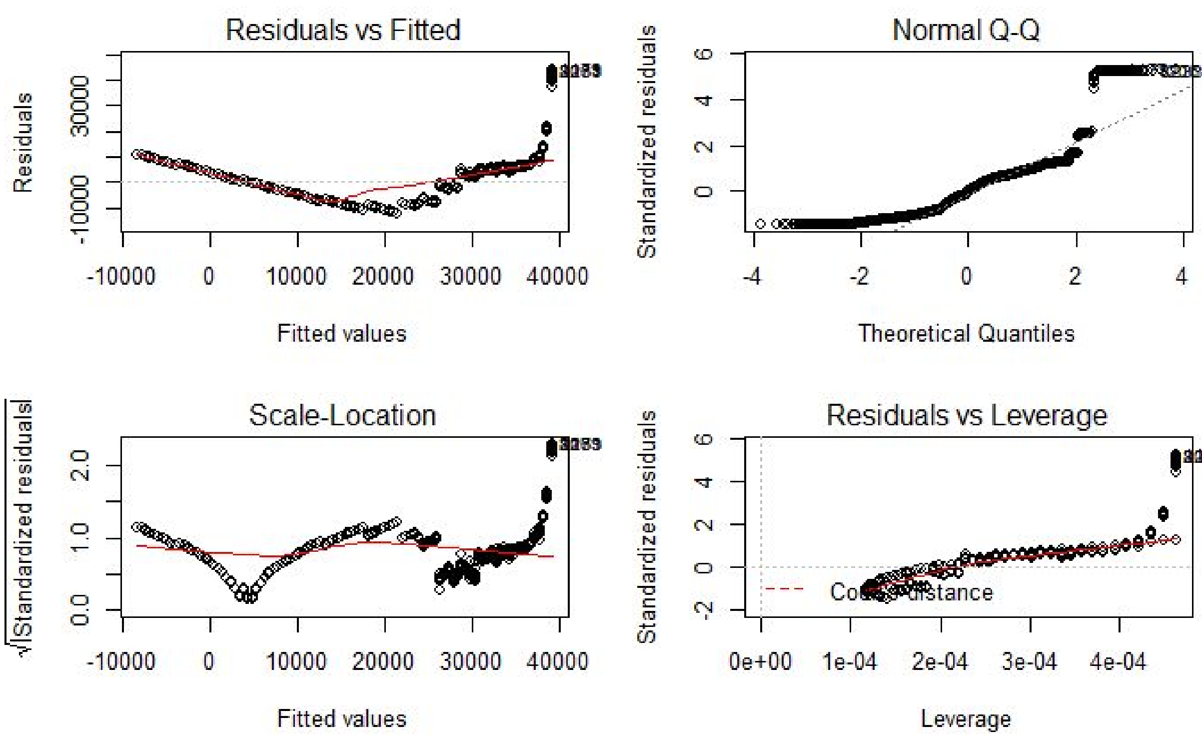

Residuals vs Fitted
Residuals
-20000
40000
Fitted values
15100
15200
15300
15400
15500
Normal Q-Q
Standardized residuals
Theoretical Quantiles
-4
-2
0
2
4
-1
1
3
Scale-Location
√|Standardized residuals|
0.0
1.0
2.0
Residuals vs Leverage
Cook's distance
Leverage
0e+00
1e-04
2e-04
3e-04
4e-04

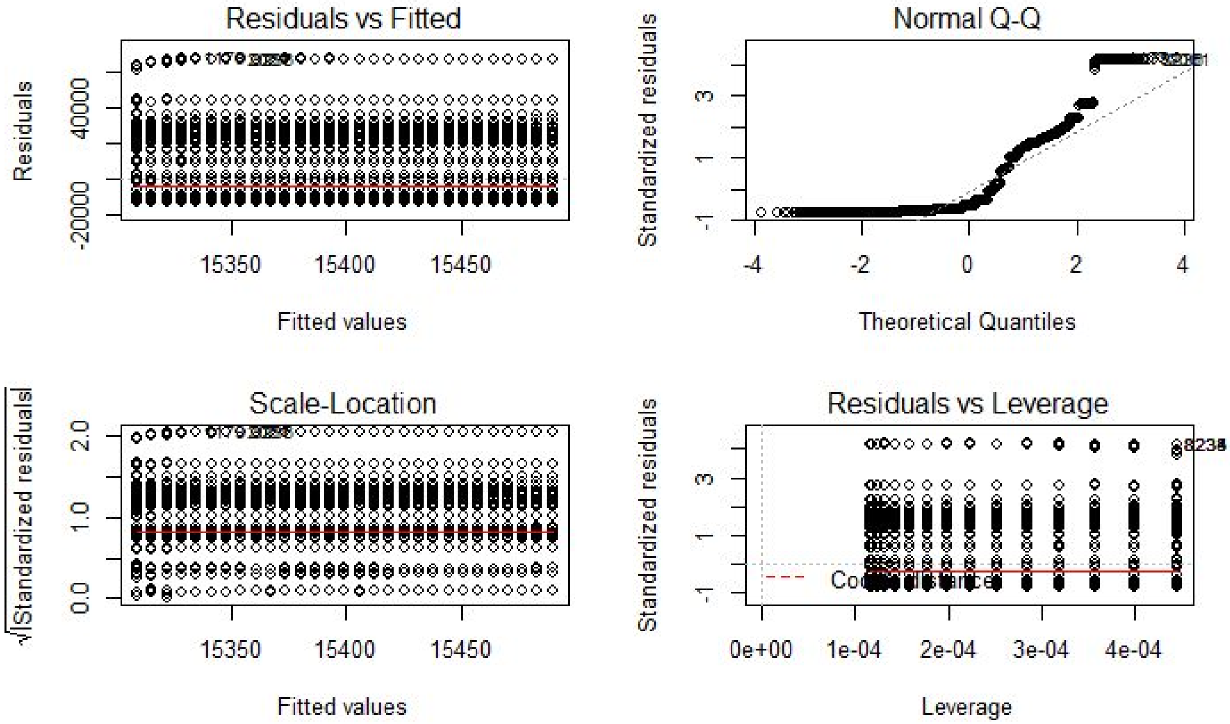

Residuals vs Fitted
Residuals
Fitted values
Normal Q-Q
Standardized residuals
Theoretical Quantiles
Scale-Location
√|Standardized residuals|
Fitted values
Residuals vs Leverage
Standardized residuals
Leverage

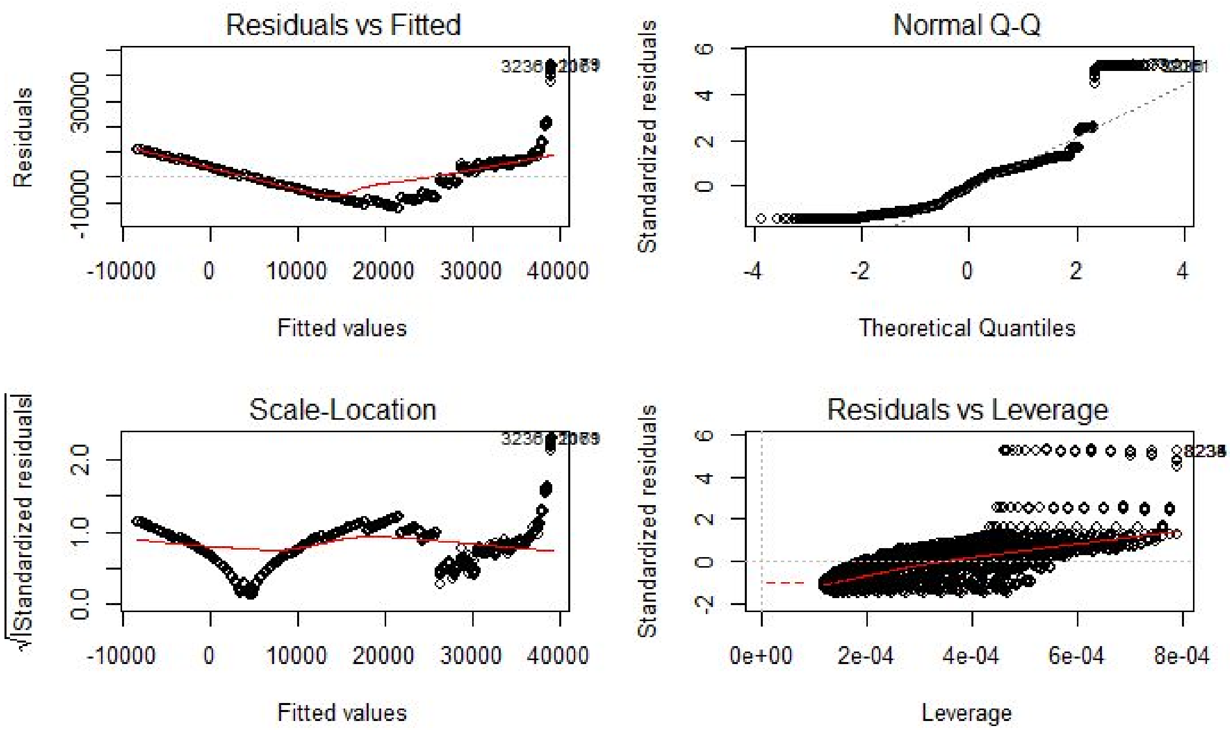
Well 9


Impedance
Frequency

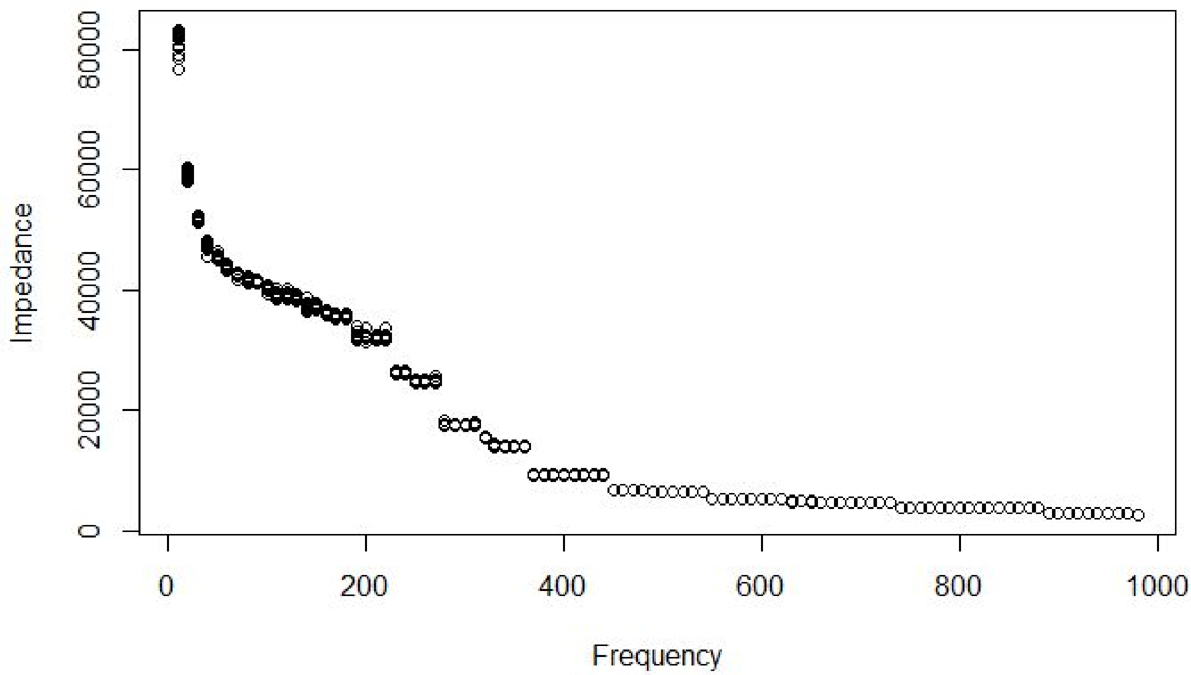

Impedance
Voltage
0
20000
40000
60000
80000
0
50
100
150
200
250
300


Residuals vs Fitted
Residuals
Fitted values
Normal Q-Q
Standardized residuals
Theoretical Quantiles
Scale-Location
√|Standardized residuals|
Fitted values
Residuals vs Leverage
Standardized residuals
Leverage
Cook's distance

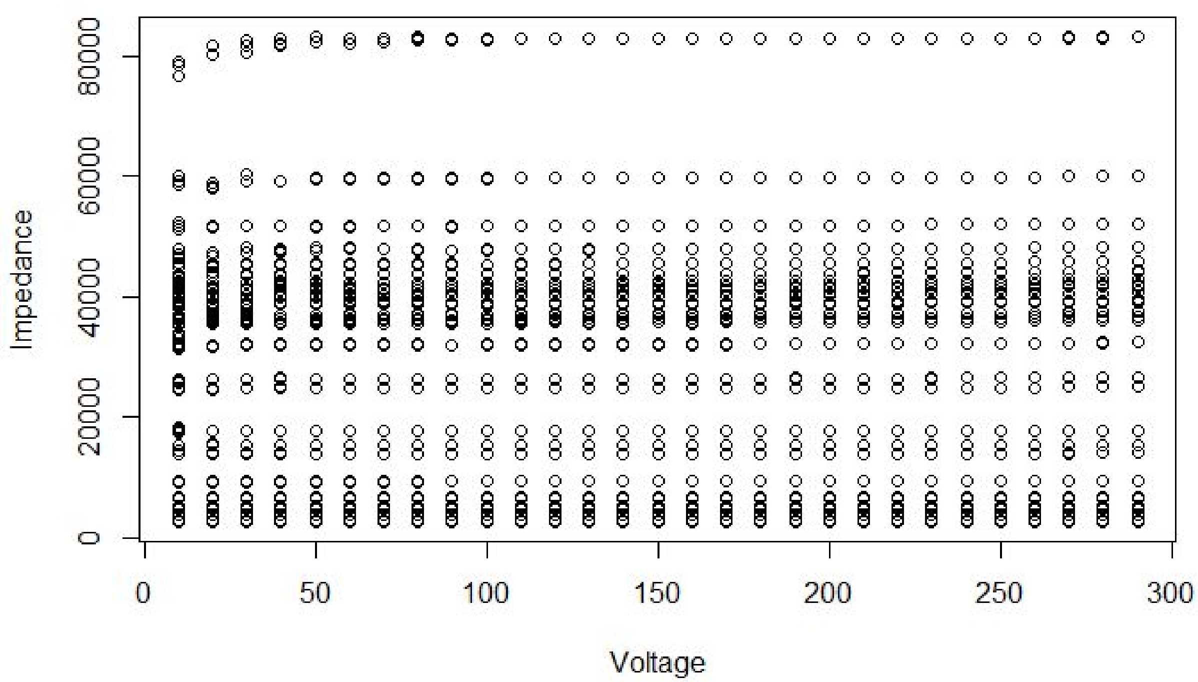

Residuals vs Fitted
Residuals
-20000
40000
15350
15400
15450
Fitted values
Normal Q-Q
Standardized residuals
-1
1
3
-4
-2
0
2
4
Theoretical Quantiles
Scale-Location
√|Standardized residuals|
0.0
1.0
2.0
15350
15400
15450
Fitted values
Residuals vs Leverage
Standardized residuals
-1
1
3
8238
0e+00
1e-04
2e-04
3e-04
4e-04
Leverage


Residuals vs Fitted
Residuals
-10000
10000
30000
-10000
0
10000
20000
30000
40000
Fitted values
Normal Q-Q
Standardized residuals
0
2
4
6
-4
-2
0
2
4
Theoretical Quantiles
Scale-Location
√|Standardized residuals|
0.0
1.0
2.0
-10000
0
10000
20000
30000
40000
Fitted values
Residuals vs Leverage
Standardized residuals
-2
0
2
4
6
8238
0e+00
2e-04
4e-04
6e-04
8e-04
Leverage

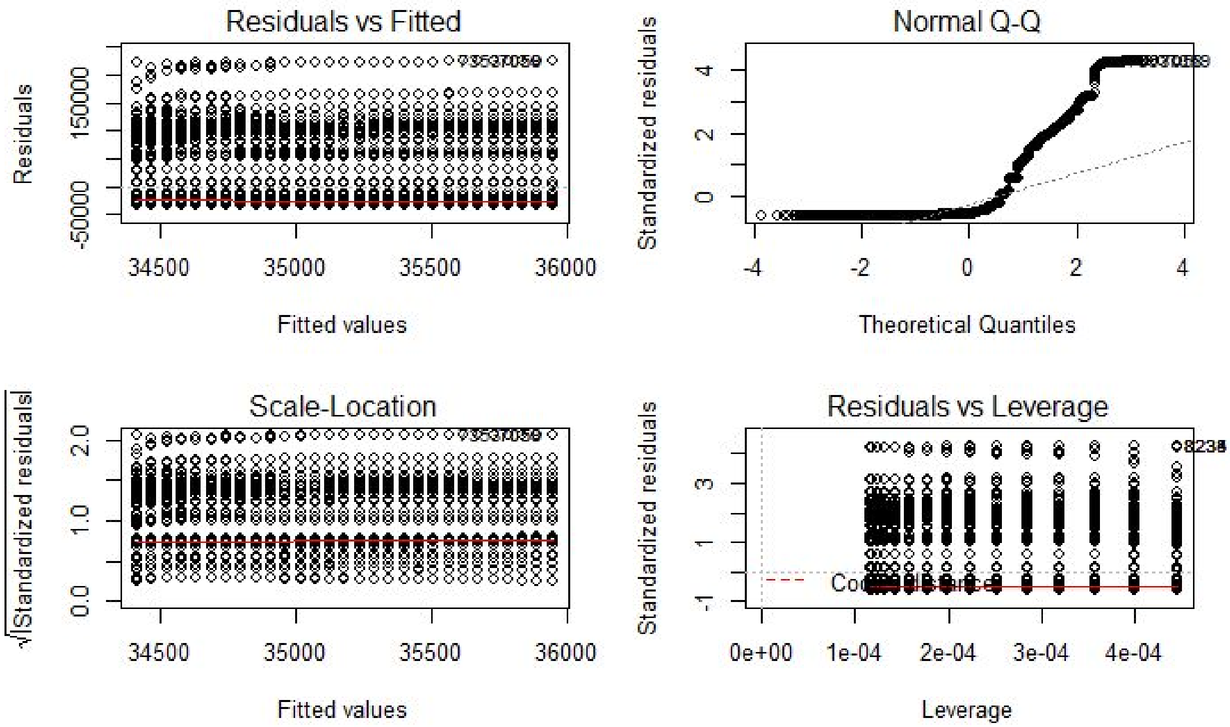
Well 10

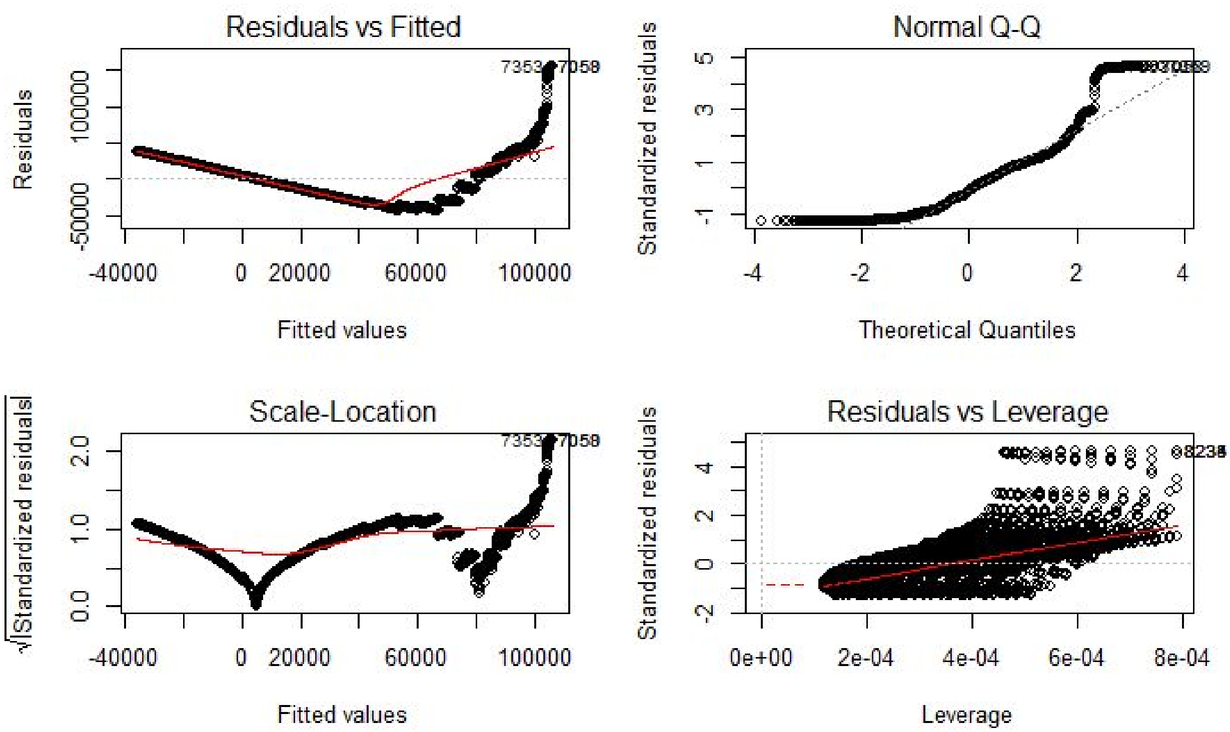


80000
60000
40000
20000
0
Impedance
0
200
400
600
800
1000
Frequency

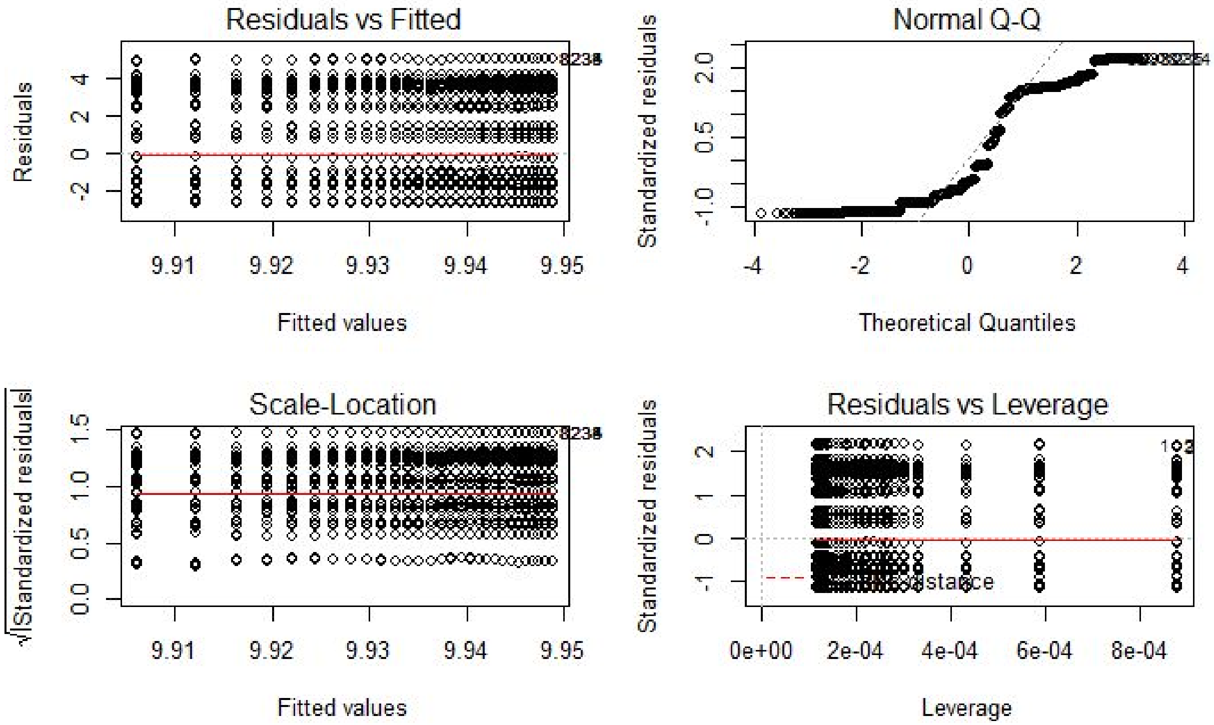


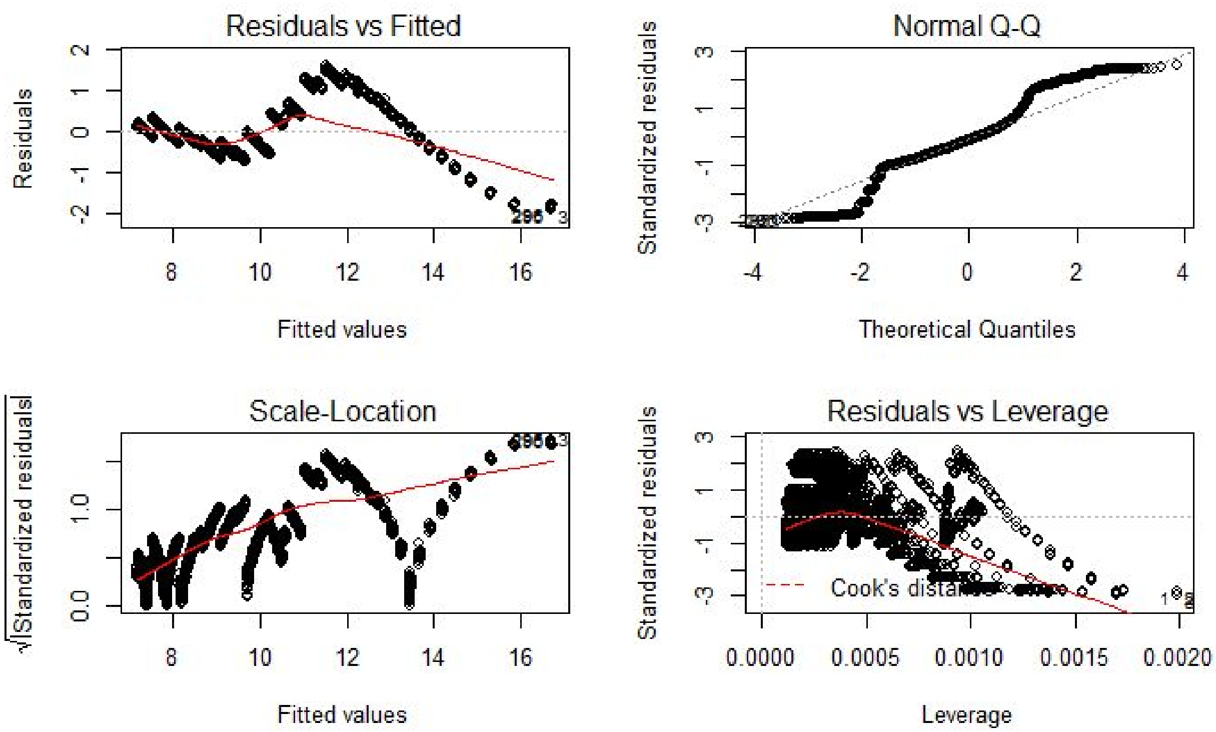
80000
60000
40000
20000
0
Impedance
0
50
100
150
200
250
300
Voltage


Residuals vs Fitted
Residuals
Fitted values
Normal Q-Q
Standardized residuals
Theoretical Quantiles
Scale-Location
√|Standardized residuals|
Fitted values
Residuals vs Leverage
Standardized residuals
Leverage

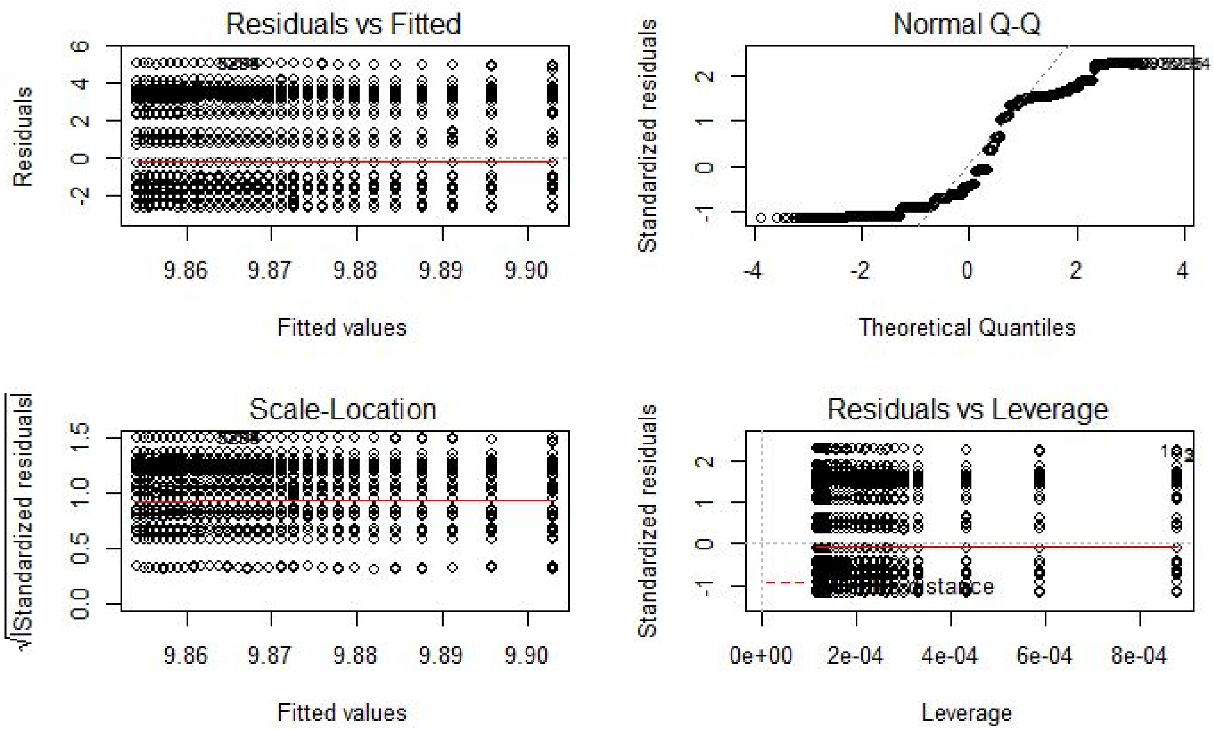

Residuals vs Fitted
Residuals
Fitted values
Normal Q-Q
Standardized residuals
Theoretical Quantiles
Scale-Location
√|Standardized residuals|
Fitted values
Residuals vs Leverage
Standardized residuals
Leverage

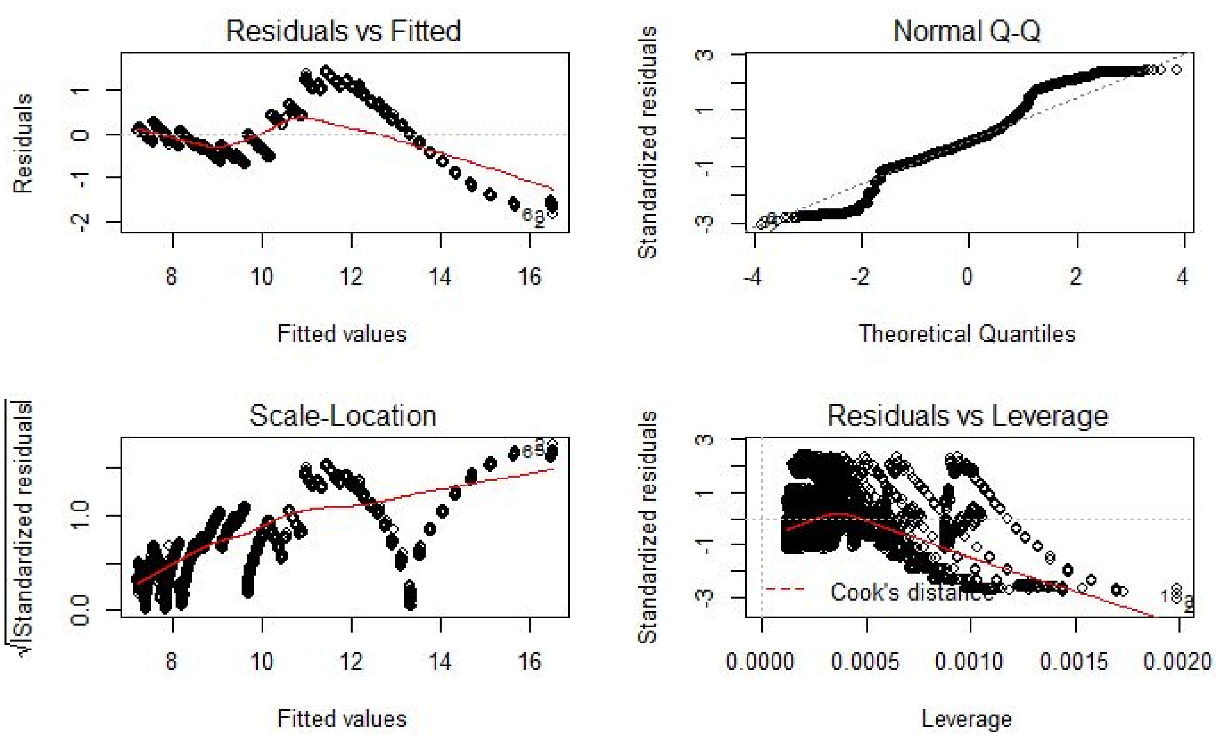
Well 2 transformed



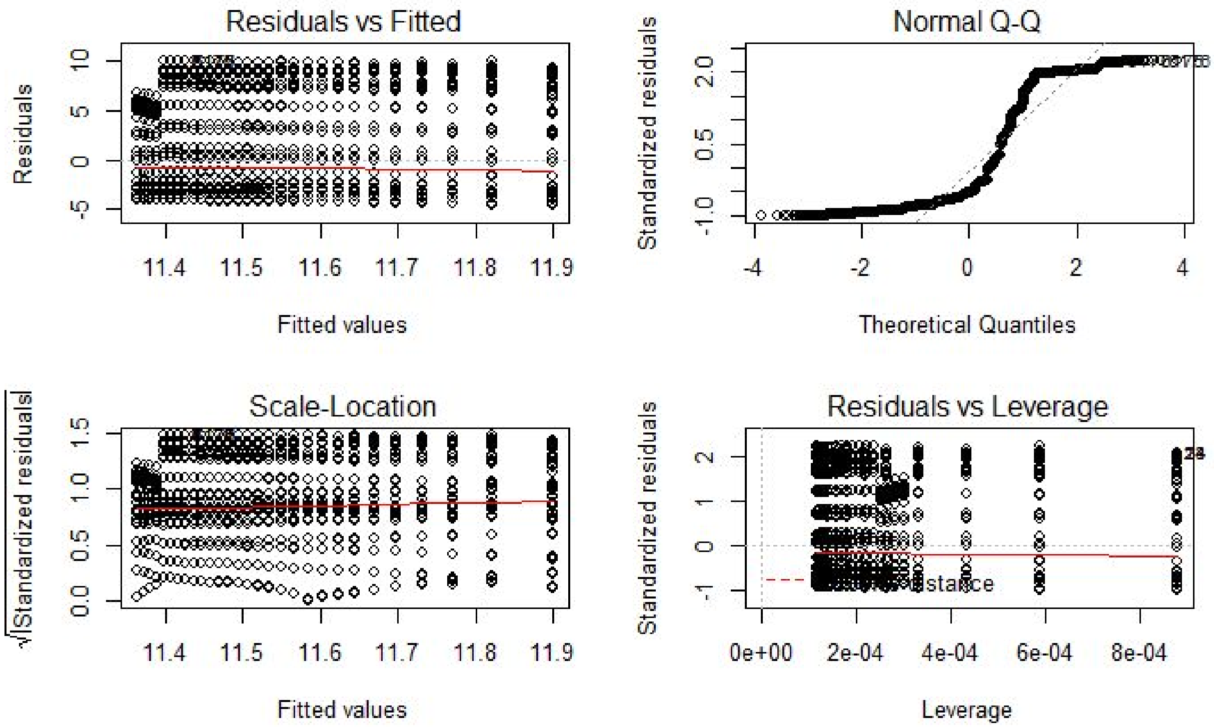


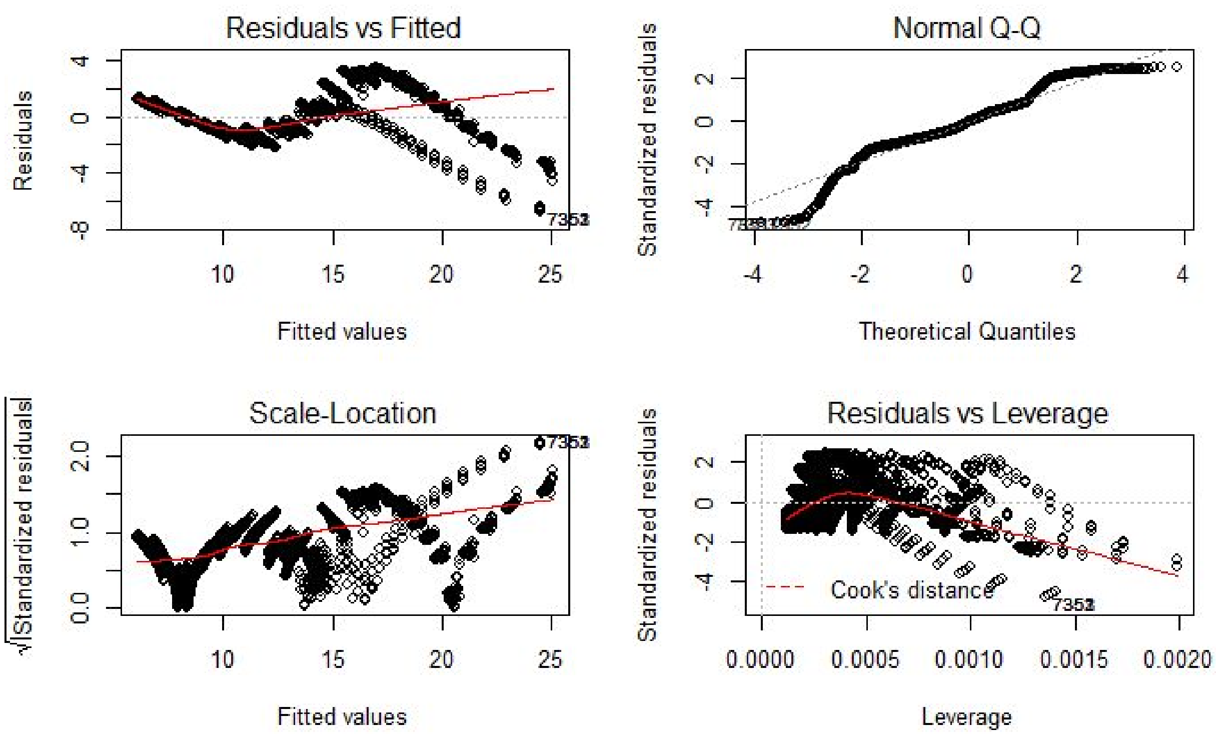
Well 3 transformed



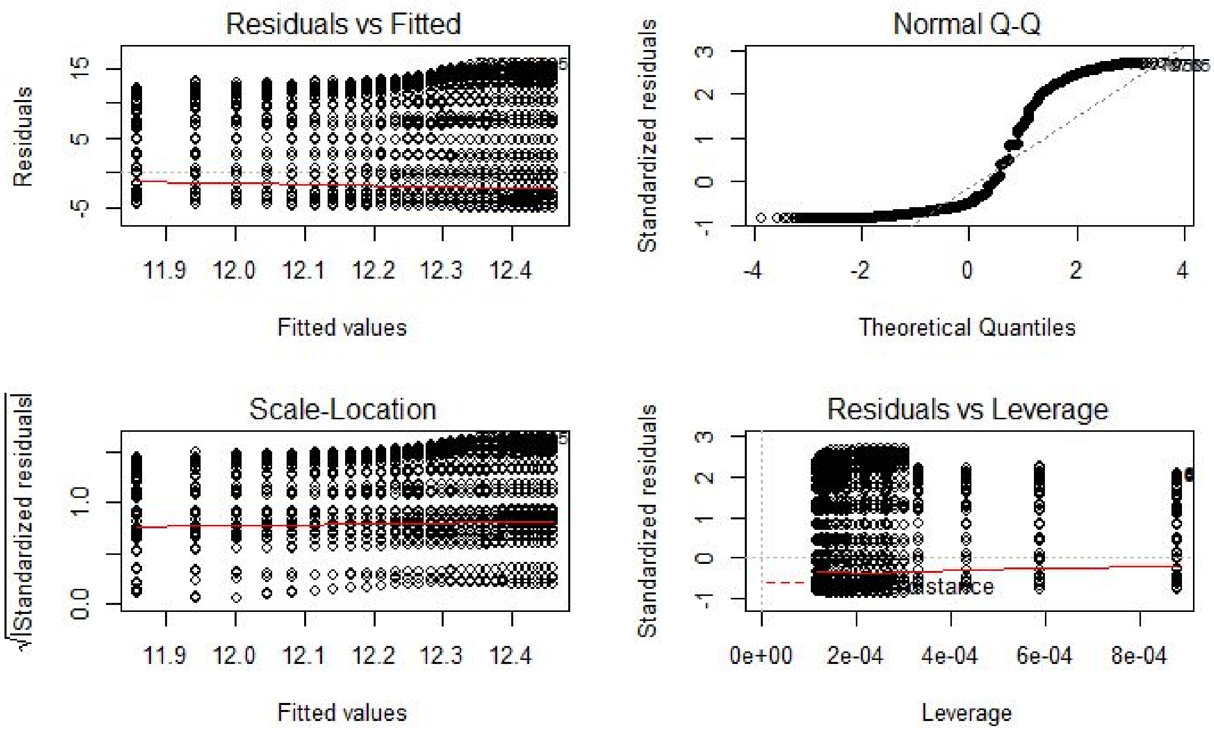


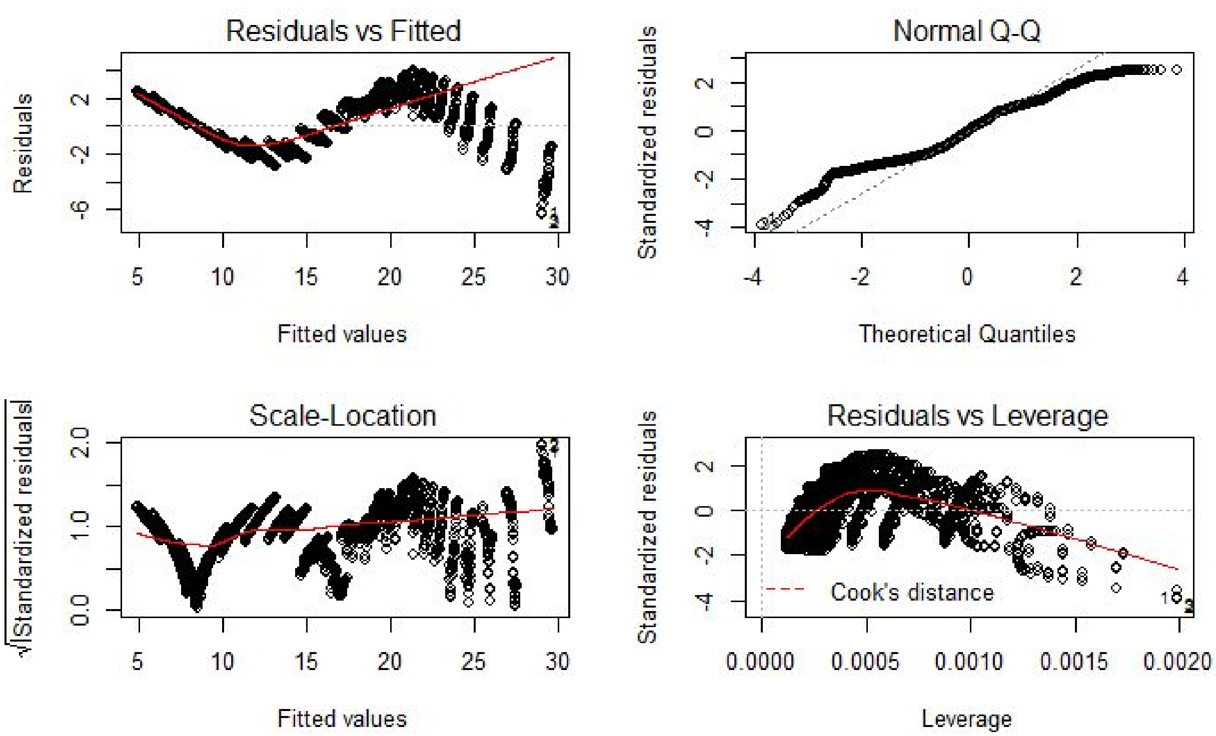
Well 4 transformed



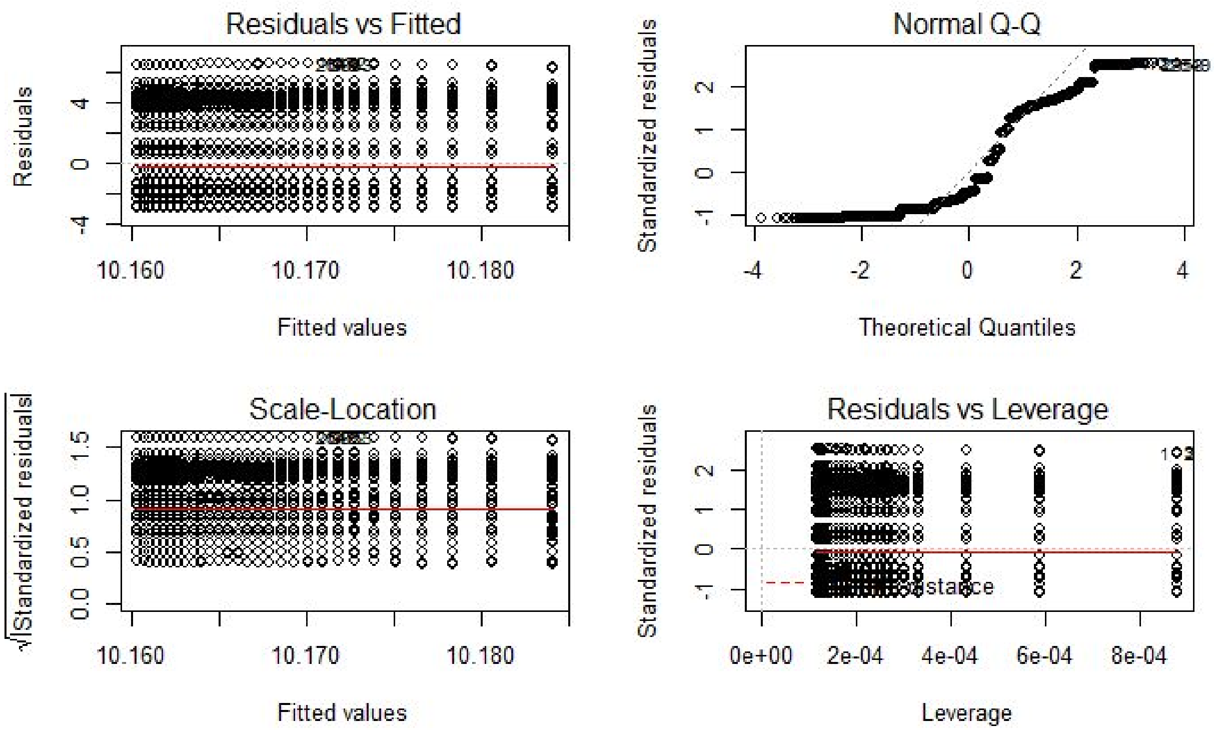


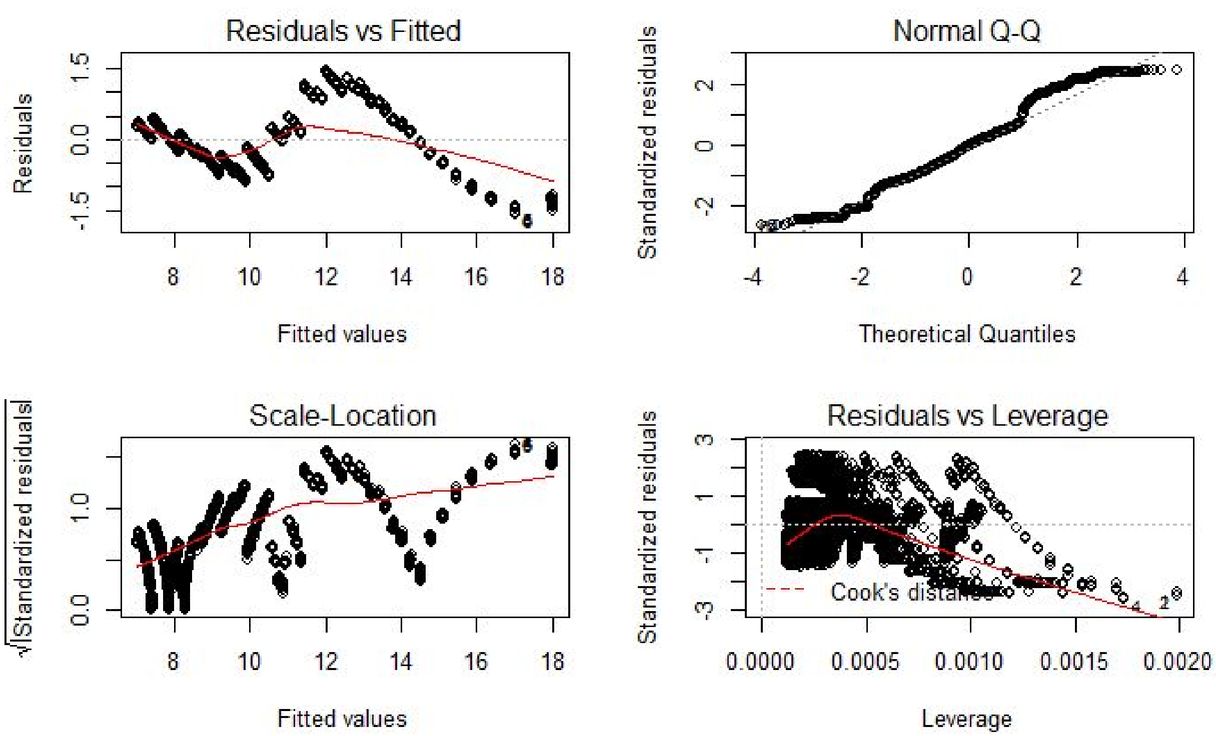
Well 5 transformed



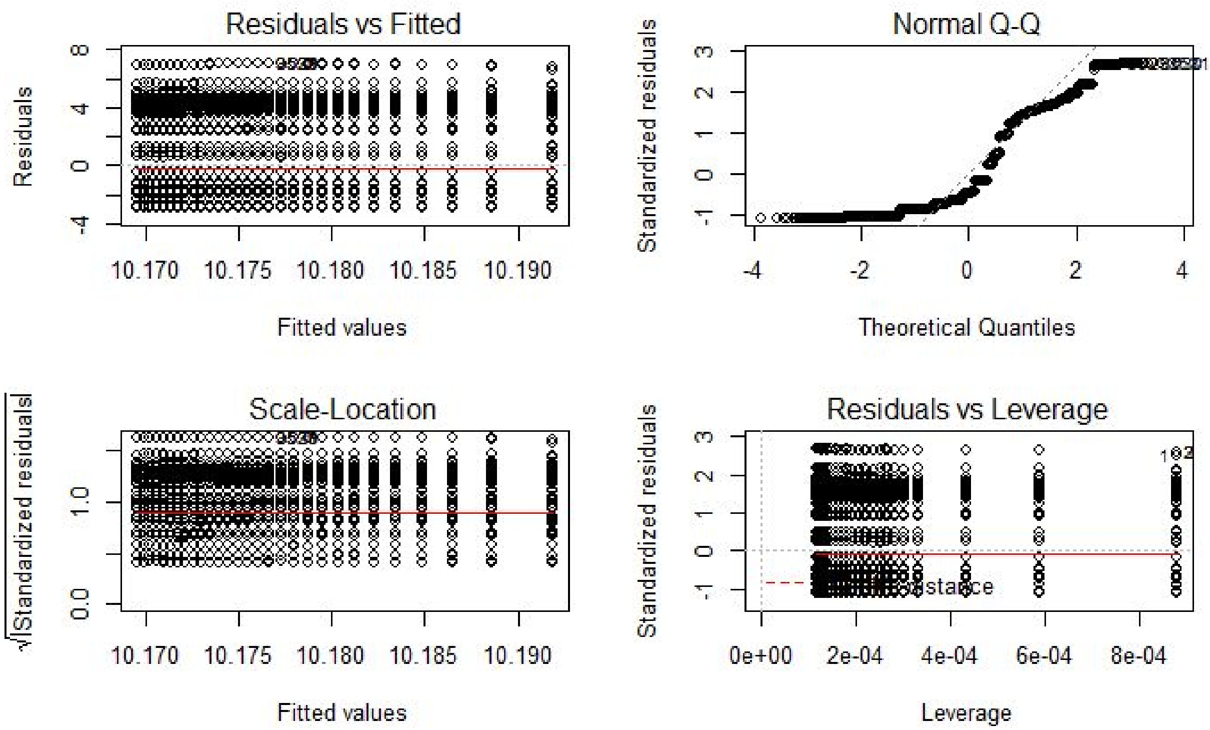


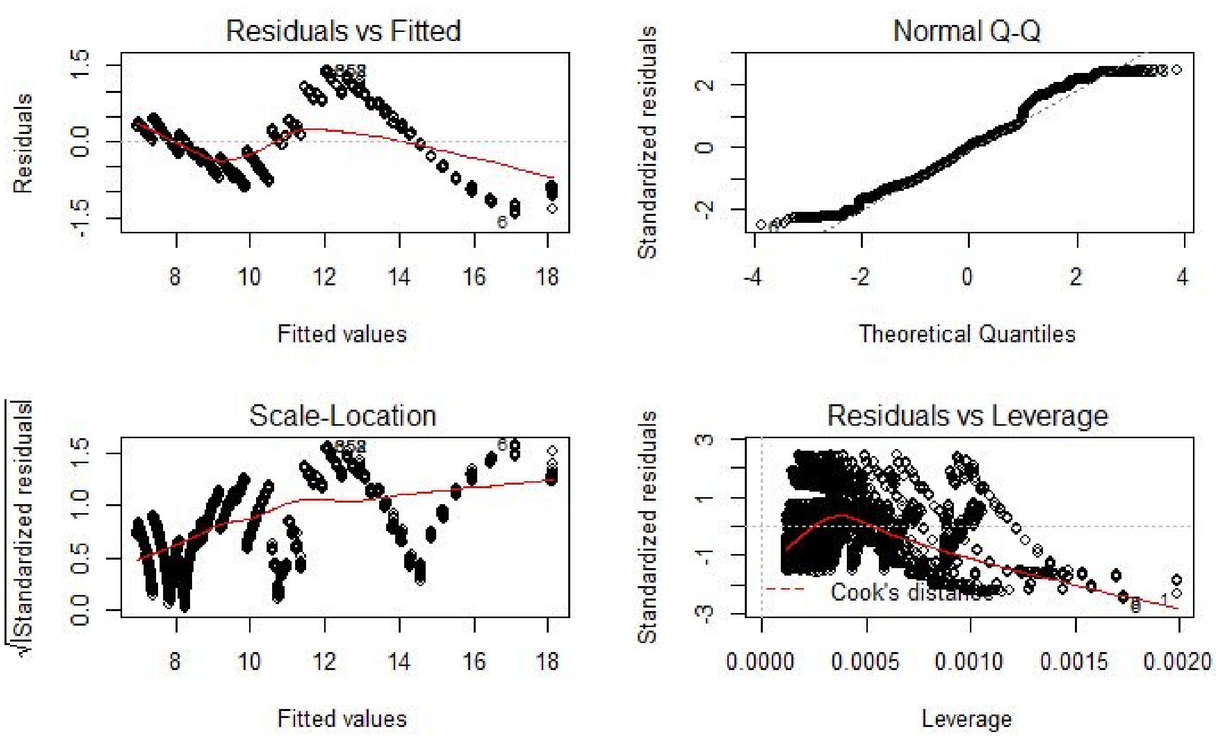
Well 6 transformed



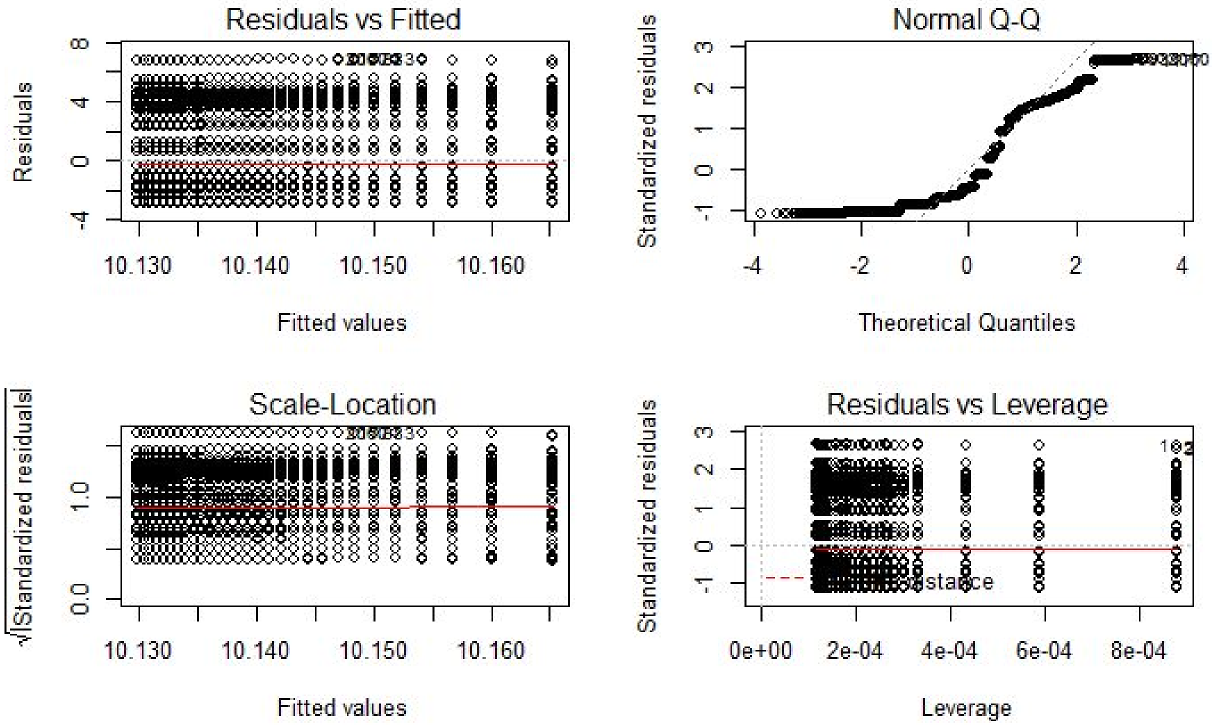


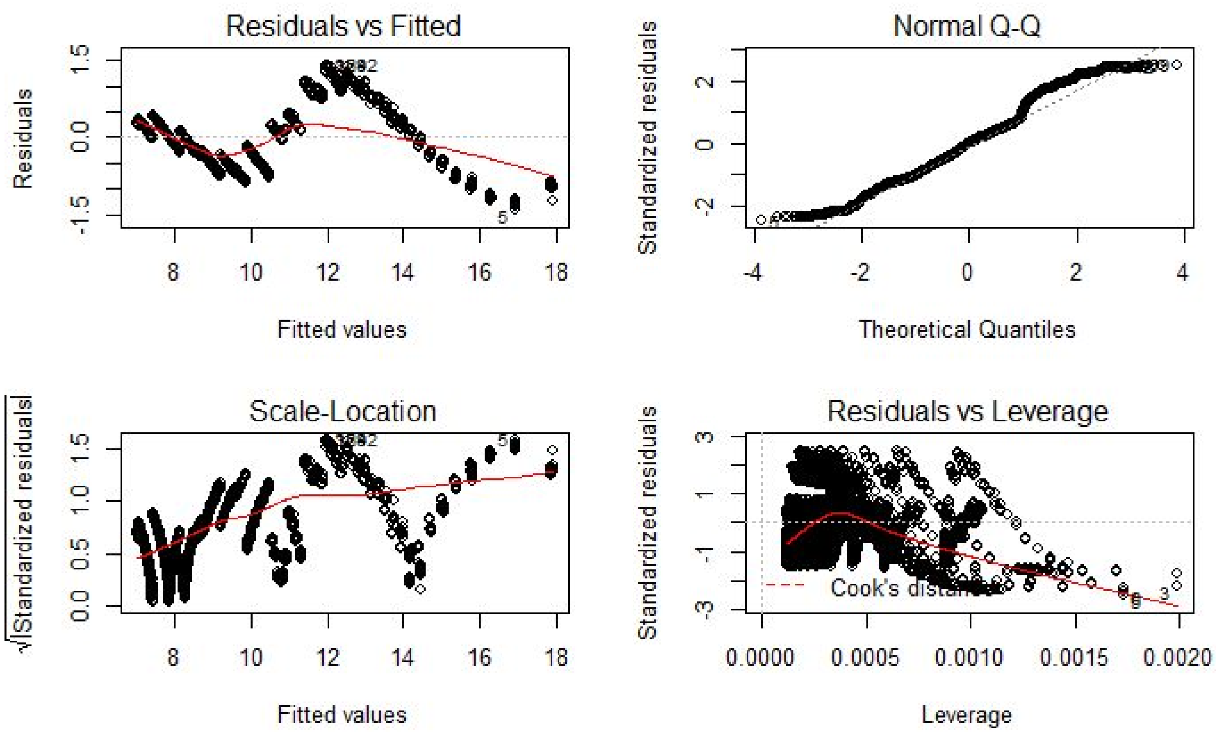
Well 7 transformed



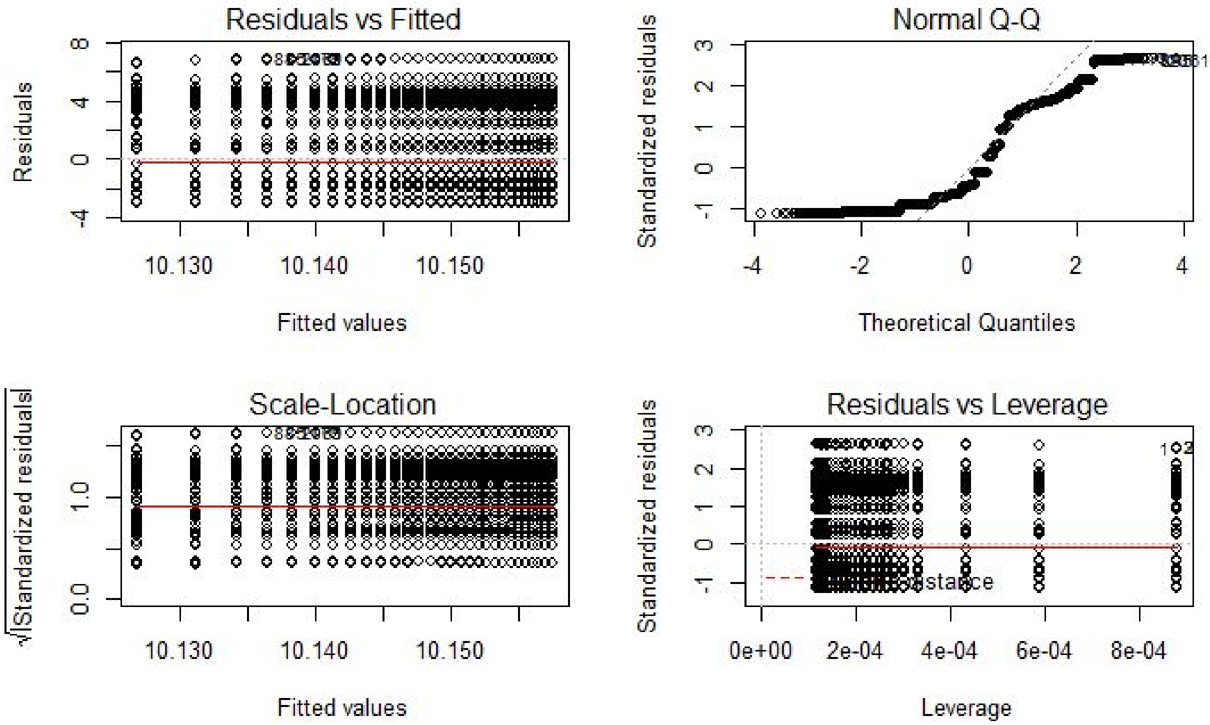


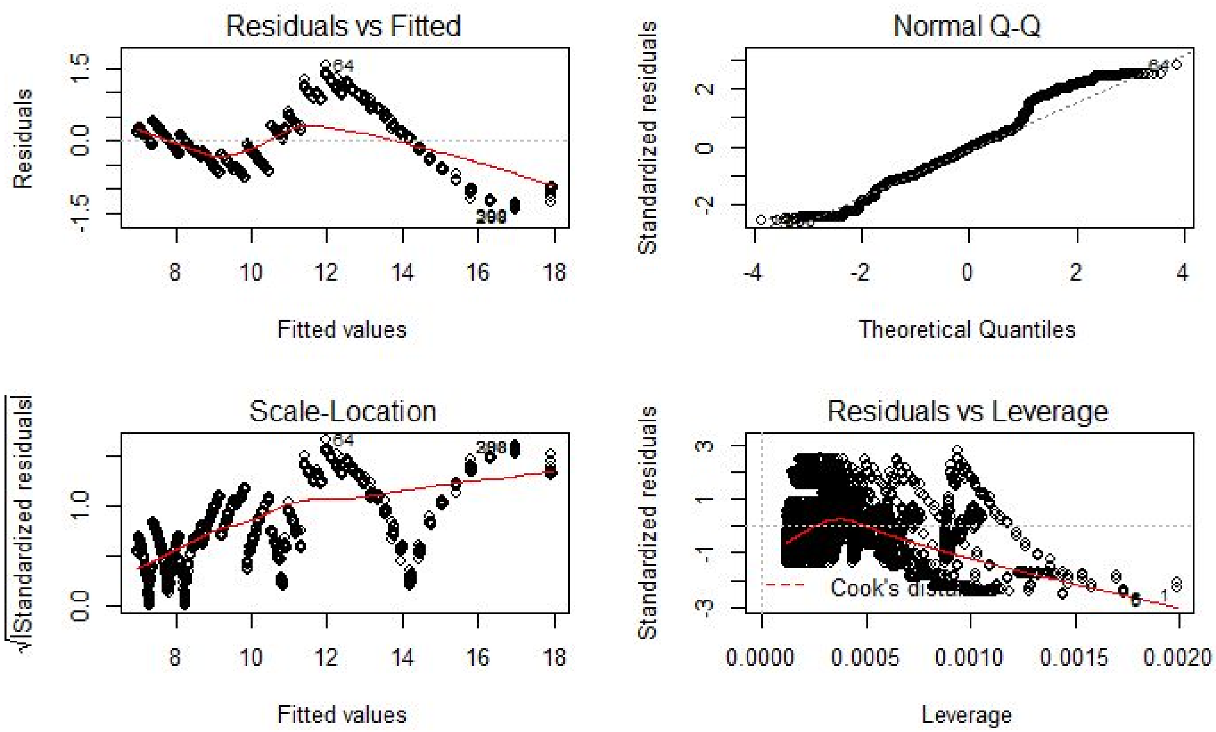
Well 8 transformed



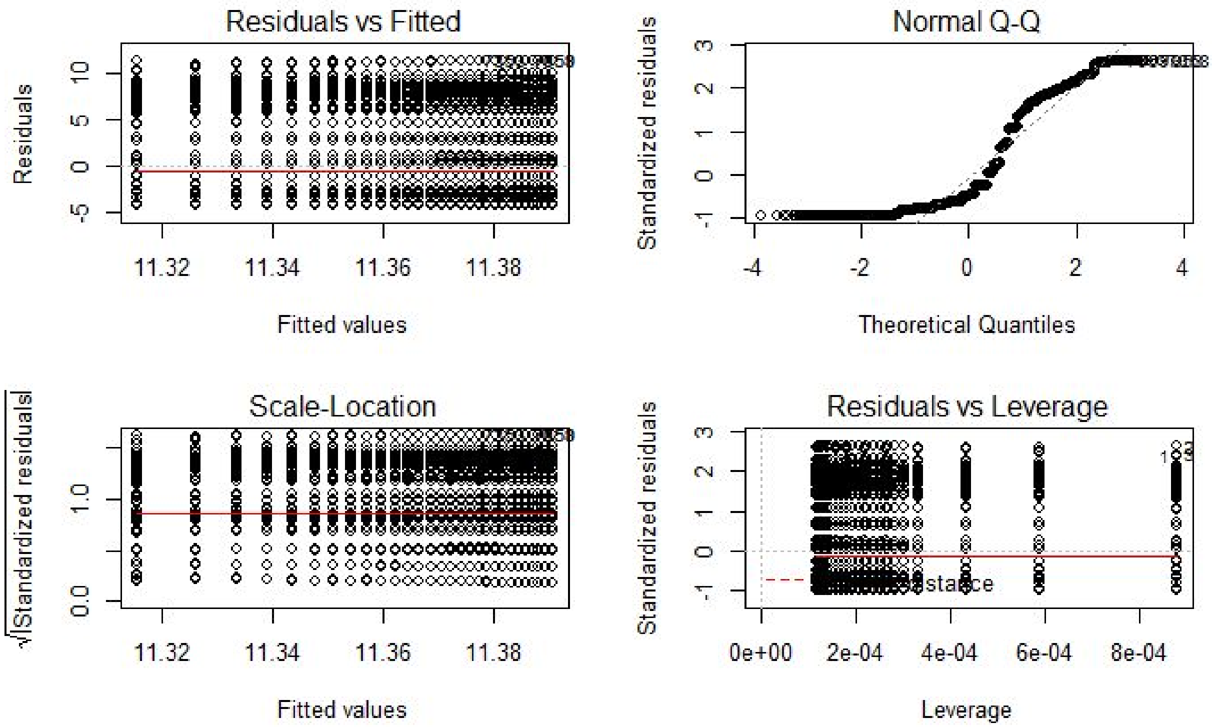


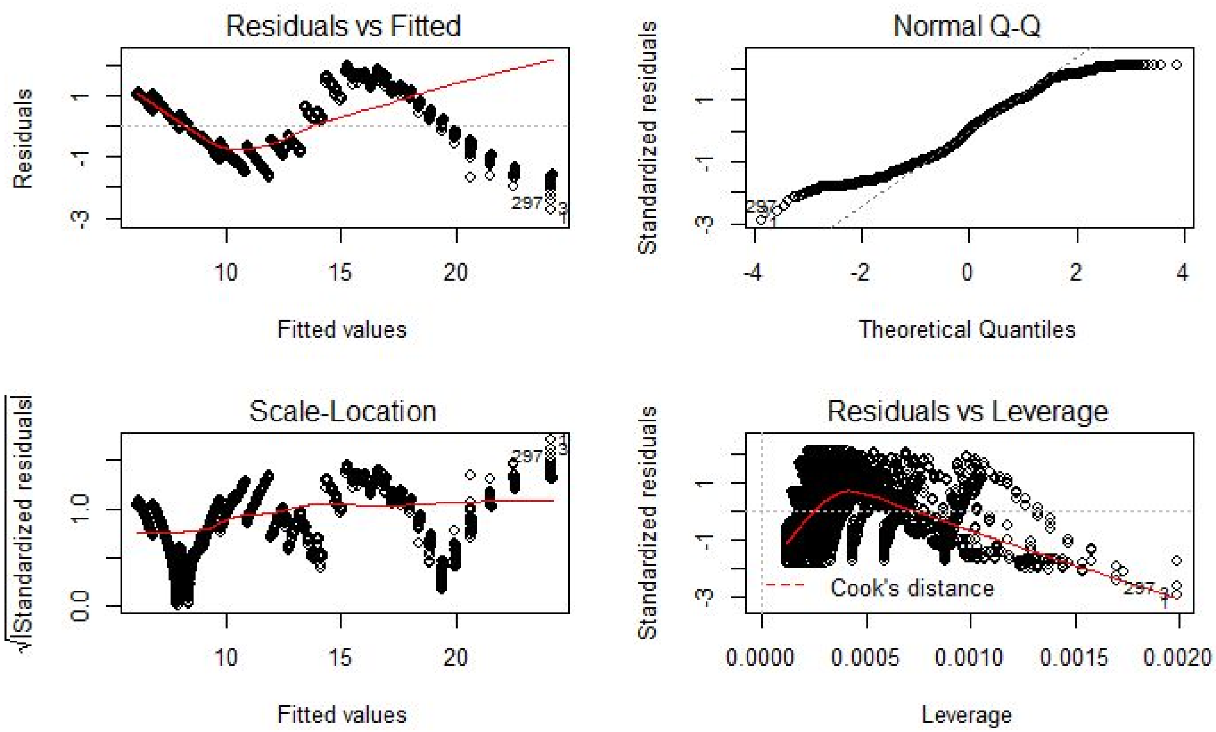
Well 9 transformed





Well 10 transformed





Summary Statements

```
Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_2)

Residuals:
   Min     1Q Median     3Q    Max 
 -9468  -5369    624   4848  18244 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)    
(Intercept) 32165.4031   120.3951   267.2   <2e-16 ***
Frequency     -38.2454     0.2112  -181.1   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 5516 on 8524 degrees of freedom
Multiple R-squared:  0.7937,  Adjusted R-squared:  0.7937 
F-statistic: 3.28e+04 on 1 and 8524 DF,  p-value: < 2.2e-16
```

```
Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_2)

Residuals:
   Min     1Q Median     3Q    Max 
-10557  -9343  -7097   9990  36664 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept) 13096.228    270.014  48.502   <2e-16 ***
Voltage         0.918      1.572   0.584    0.559    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 12140 on 8524 degrees of freedom
Multiple R-squared:  4e-05,    Adjusted R-squared:  -7.731e-05 
F-statistic: 0.341 on 1 and 8524 DF,  p-value: 0.5593
```

```
Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_2)

Residuals:
    Min      1Q  Median      3Q     Max 
-9425.5 -5365.2   597.8  4842.9 18115.3 

Coefficients:
             Estimate Std. Error  t value Pr(>|t|)    
(Intercept) 32027.7098   161.1315  198.768   <2e-16 ***
Frequency     -38.2454     0.2112 -181.118   <2e-16 ***
Voltage         0.9180     0.7140    1.286    0.199    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 5516 on 8523 degrees of freedom
Multiple R-squared:  0.7938,  Adjusted R-squared:  0.7937 
F-statistic: 1.64e+04 on 2 and 8523 DF,  p-value: < 2.2e-16

Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_2_T)

Residuals:
     Min       1Q   Median       3Q      Max 
-1.95162 -0.37199 -0.08659  0.27364  1.57353 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)    
(Intercept) 21.172347   0.036254   584.0   <2e-16 ***
Frequency   -2.497906   0.007907  -315.9   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.6464 on 8524 degrees of freedom
Multiple R-squared:  0.9213,  Adjusted R-squared:  0.9213 
F-statistic: 9.98e+04 on 1 and 8524 DF,  p-value: < 2.2e-16
```

```
Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_2_T)

Residuals:
   Min     1Q Median     3Q    Max
-2.684 -2.074 -1.090  2.411  5.007

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  9.87387    0.13757   71.78   <2e-16 ***
Voltage      0.01816    0.04035    0.45    0.653
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 2.304 on 8524 degrees of freedom
Multiple R-squared:  2.375e-05,	Adjusted R-squared:  -9.356e-05
F-statistic: 0.2025 on 1 and 8524 DF,  p-value: 0.6527


Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_2_T)

Residuals:
     Min       1Q   Median       3Q      Max
-1.92303 -0.36812 -0.08512  0.27138  1.60211

Coefficients:
             Estimate Std. Error  t value Pr(>|t|)
(Intercept) 21.111472   0.052479  402.284   <2e-16 ***
Frequency   -2.497906   0.007906 -315.942   <2e-16 ***
Voltage      0.018156   0.011317    1.604    0.109
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.6463 on 8523 degrees of freedom
Multiple R-squared:  0.9213,  Adjusted R-squared:  0.9213
F-statistic: 4.991e+04 on 2 and 8523 DF,  p-value: < 2.2e-16

Call:
```

```
lm(formula = Impedance ~ Frequency, data = Project_Well_3)

Residuals:
    Min      1Q  Median      3Q     Max
-8757.1 -4953.4   598.8  4279.1 19564.4

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) 30584.0181   113.1904   270.2   <2e-16 ***
Frequency     -36.1035     0.1985  -181.9   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 5186 on 8524 degrees of freedom
Multiple R-squared:  0.7951,  Adjusted R-squared:  0.795
F-statistic: 3.307e+04 on 1 and 8524 DF,  p-value: < 2.2e-16


Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_3)

Residuals:
   Min     1Q Median     3Q    Max
-10045  -8854  -6642   9426  37108

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) 12837.4844   254.6791  50.407   <2e-16 ***
Voltage        -0.8314     1.4828  -0.561    0.575
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 11460 on 8524 degrees of freedom
Multiple R-squared:  3.688e-05,	Adjusted R-squared:  -8.043e-05
F-statistic: 0.3144 on 1 and 8524 DF,  p-value: 0.575


Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_3)
```

```
Residuals:
    Min      1Q  Median      3Q     Max 
-8746.5 -4976.0   568.7  4296.2 19597.7 

Coefficients:
             Estimate Std. Error  t value Pr(>|t|)    
(Intercept) 30708.7274   151.4901  202.711   <2e-16 ***
Frequency     -36.1035     0.1985 -181.856   <2e-16 ***
Voltage        -0.8314     0.6713   -1.239    0.216    
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 5186 on 8523 degrees of freedom
Multiple R-squared:  0.7951,  Adjusted R-squared:  0.7951 
F-statistic: 1.654e+04 on 2 and 8523 DF,  p-value: < 2.2e-16

Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_3_T)

Residuals:
     Min       1Q   Median       3Q      Max 
-1.81798 -0.34710 -0.07988  0.27062  1.44927 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)    
(Intercept) 20.783885   0.033795   615.0   <2e-16 ***
Frequency   -2.425887   0.007371  -329.1   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.6025 on 8524 degrees of freedom
Multiple R-squared:  0.9271,  Adjusted R-squared:  0.927 
F-statistic: 1.083e+05 on 1 and 8524 DF,  p-value: < 2.2e-16


Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_3_T)
```

```
Residuals:
   Min     1Q Median     3Q    Max 
-2.639 -2.019 -1.047  2.329  5.075 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept)  9.93986    0.13319  74.632   <2e-16 ***
Voltage     -0.02075    0.03906  -0.531    0.595    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 2.231 on 8524 degrees of freedom
Multiple R-squared:  3.311e-05,	Adjusted R-squared:  -8.42e-05 
F-statistic: 0.2822 on 1 and 8524 DF,  p-value: 0.5953


Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_3_T)

Residuals:
     Min       1Q   Median       3Q      Max 
-1.85066 -0.34745 -0.08228  0.27186  1.44079 

Coefficients:
             Estimate Std. Error  t value Pr(>|t|)    
(Intercept) 20.853467   0.048915  426.321   <2e-16 ***
Frequency   -2.425887   0.007369 -329.189   <2e-16 ***
Voltage     -0.020753   0.010549   -1.967   0.0492 *  
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.6024 on 8523 degrees of freedom
Multiple R-squared:  0.9271,	Adjusted R-squared:  0.9271 
F-statistic: 5.418e+04 on 2 and 8523 DF,  p-value: < 2.2e-16

Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_4)

Residuals:
```

```
   Min     1Q Median     3Q    Max 
-52206 -32936  -5697  27527 106573 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)    
(Intercept) 118931.588    816.825   145.6   <2e-16 ***
Frequency     -161.070      1.433  -112.4   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 37420 on 8524 degrees of freedom
Multiple R-squared:  0.5972,  Adjusted R-squared:  0.5972 
F-statistic: 1.264e+04 on 1 and 8524 DF,  p-value: < 2.2e-16


Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_4)

Residuals:
   Min     1Q Median     3Q    Max 
-43175 -35103 -29371   5424 178335 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept) 46537.323   1307.827  35.584  < 2e-16 ***
Voltage       -48.903      7.614  -6.422 1.41e-10 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 58820 on 8524 degrees of freedom
Multiple R-squared:  0.004816,	Adjusted R-squared:  0.004699 
F-statistic: 41.25 on 1 and 8524 DF,  p-value: 1.413e-10


Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_4)

Residuals:
   Min     1Q Median     3Q    Max 
```

```
-56160 -32610  -5910  28014 100216

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 126267.066   1086.753  116.19   <2e-16 ***
Frequency     -161.070      1.424 -113.10   <2e-16 ***
Voltage        -48.903      4.815  -10.16   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 37200 on 8523 degrees of freedom
Multiple R-squared:  0.602,    Adjusted R-squared:  0.6019
F-statistic:  6447 on 2 and 8523 DF,  p-value: < 2.2e-16

�^� not meaningful for factors
Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_4_T)

Residuals:
    Min      1Q  Median      3Q     Max
-6.8744 -0.9526 -0.1038  0.7807  3.5817

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 33.25104    0.07879   422.0   <2e-16 ***
Frequency   -4.82596    0.01718  -280.8   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 1.405 on 8524 degrees of freedom
Multiple R-squared:  0.9025,  Adjusted R-squared:  0.9025
F-statistic: 7.887e+04 on 1 and 8524 DF,  p-value: < 2.2e-16


Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_4_T)

Residuals:
   Min     1Q Median     3Q    Max
```

```
-4.577 -3.437 -2.306  3.006  9.953

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 12.30371    0.26841  45.839  < 2e-16 ***
Voltage     -0.22778    0.07872  -2.893  0.00382 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 4.496 on 8524 degrees of freedom
Multiple R-squared:  0.0009811,	Adjusted R-squared:  0.0008639
F-statistic: 8.371 on 1 and 8524 DF,  p-value: 0.003821


Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_4_T)

Residuals:
    Min      1Q  Median      3Q     Max
-6.7235 -0.9839 -0.0746  0.7761  3.4544

Coefficients:
            Estimate Std. Error  t value Pr(>|t|)
(Intercept) 34.01476    0.11350  299.702   <2e-16 ***
Frequency   -4.82596    0.01710 -282.242   <2e-16 ***
Voltage     -0.22778    0.02448   -9.306   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 1.398 on 8523 degrees of freedom
Multiple R-squared:  0.9034,  Adjusted R-squared:  0.9034
F-statistic: 3.987e+04 on 2 and 8523 DF,  p-value: < 2.2e-16
```

Show in New WindowClear OutputExpand/Collapse Output

```
Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_1)
```

```
Residuals:
   Min     1Q Median     3Q    Max 
-12044  -6966     25   6125  31982 

Coefficients:
              Estimate Std. Error t value Pr(>|t|)    
(Intercept) 37727.5397   160.9092   234.5   <2e-16 ***
Frequency     -46.1265     0.2822  -163.4   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 7372 on 8524 degrees of freedom
Multiple R-squared:  0.7581,  Adjusted R-squared:  0.7581 
F-statistic: 2.671e+04 on 1 and 8524 DF,  p-value: < 2.2e-16


Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_1)

Residuals:
   Min     1Q Median     3Q    Max 
-12367 -10780  -8619  10058  54048 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)    
(Intercept) 14567.074    333.206  43.718   <2e-16 ***
Voltage         2.186      1.940   1.127     0.26    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 14990 on 8524 degrees of freedom
Multiple R-squared:  0.0001489,	Adjusted R-squared:  3.16e-05 
F-statistic: 1.269 on 1 and 8524 DF,  p-value: 0.2599


Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_1)

Residuals:
```

```
   Min     1Q Median     3Q    Max 
-11987  -6947    -50   6114  31676 

Coefficients:
             Estimate Std. Error  t value Pr(>|t|)    
(Intercept) 37399.6725   215.3084  173.703   <2e-16 ***
Frequency     -46.1265     0.2822 -163.475   <2e-16 ***
Voltage         2.1858     0.9540    2.291    0.022 *  
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 7370 on 8523 degrees of freedom
Multiple R-squared:  0.7582,  Adjusted R-squared:  0.7582 
F-statistic: 1.336e+04 on 2 and 8523 DF,  p-value: < 2.2e-16

�^� not meaningful for factors
Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_1_T)

Residuals:
     Min       1Q   Median       3Q      Max 
-1.95121 -0.41599 -0.02442  0.27595  1.68419 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)    
(Intercept) 22.549402   0.036137     624   <2e-16 ***
Frequency   -2.766122   0.007881    -351   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.6443 on 8524 degrees of freedom
Multiple R-squared:  0.9353,  Adjusted R-squared:  0.9353 
F-statistic: 1.232e+05 on 1 and 8524 DF,  p-value: < 2.2e-16


Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_1_T)

Residuals:
```

```
   Min     1Q Median     3Q    Max 
-2.843 -2.168 -1.230  2.461  6.095 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept) 10.01074    0.15119  66.211   <2e-16 ***
Voltage      0.02815    0.04435   0.635    0.526    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 2.533 on 8524 degrees of freedom
Multiple R-squared:  4.729e-05,	Adjusted R-squared:  -7.002e-05 
F-statistic: 0.4031 on 1 and 8524 DF,  p-value: 0.5255



Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_1_T)

Residuals:
     Min       1Q   Median       3Q      Max 
-1.90688 -0.41105 -0.02571  0.27788  1.66241 

Coefficients:
             Estimate Std. Error  t value Pr(>|t|)    
(Intercept) 22.455003   0.052298  429.363   <2e-16 ***
Frequency   -2.766122   0.007879 -351.075   <2e-16 ***
Voltage      0.028154   0.011278    2.496   0.0126 *  
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.6441 on 8523 degrees of freedom
Multiple R-squared:  0.9353,  Adjusted R-squared:  0.9353 
F-statistic: 6.163e+04 on 2 and 8523 DF,  p-value: < 2.2e-16

[1] 0
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```

```
Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_1)

Residuals:
   Min     1Q Median     3Q    Max 
-12044  -6966     25   6125  31982 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)    
(Intercept) 37727.5397   160.9092   234.5   <2e-16 ***
Frequency     -46.1265     0.2822  -163.4   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 7372 on 8524 degrees of freedom
Multiple R-squared:  0.7581,  Adjusted R-squared:  0.7581 
F-statistic: 2.671e+04 on 1 and 8524 DF,  p-value: < 2.2e-16


Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_1)

Residuals:
   Min     1Q Median     3Q    Max 
-12367 -10780  -8619  10058  54048 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)    
(Intercept) 14567.074    333.206  43.718   <2e-16 ***
Voltage         2.186      1.940   1.127     0.26    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 14990 on 8524 degrees of freedom
Multiple R-squared:  0.0001489,	Adjusted R-squared:  3.16e-05 
```

```
F-statistic: 1.269 on 1 and 8524 DF,  p-value: 0.2599


Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_1)

Residuals:
   Min     1Q Median     3Q    Max 
-11987  -6947    -50   6114  31676 

Coefficients:
              Estimate Std. Error  t value Pr(>|t|)    
(Intercept) 37399.6725   215.3084  173.703   <2e-16 ***
Frequency     -46.1265     0.2822 -163.475   <2e-16 ***
Voltage         2.1858     0.9540    2.291    0.022 *  
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 7370 on 8523 degrees of freedom
Multiple R-squared:  0.7582,  Adjusted R-squared:  0.7582 
F-statistic: 1.336e+04 on 2 and 8523 DF,  p-value: < 2.2e-16

�^� not meaningful for factors
Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_1_T)

Residuals:
     Min       1Q   Median       3Q      Max 
-1.95121 -0.41599 -0.02442  0.27595  1.68419 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)    
(Intercept) 22.549402   0.036137     624   <2e-16 ***
Frequency   -2.766122   0.007881    -351   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.6443 on 8524 degrees of freedom
Multiple R-squared:  0.9353,  Adjusted R-squared:  0.9353 
```

F-statistic: 1.232e+05 on 1 and 8524 DF, p-value: < 2.2e-16

```
Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_1_T)

Residuals:
   Min     1Q Median     3Q    Max 
-2.843 -2.168 -1.230  2.461  6.095 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept) 10.01074    0.15119  66.211   <2e-16 ***
Voltage      0.02815    0.04435   0.635    0.526    
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 2.533 on 8524 degrees of freedom
Multiple R-squared:  4.729e-05,	Adjusted R-squared:  -7.002e-05 
F-statistic: 0.4031 on 1 and 8524 DF,  p-value: 0.5255


Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_1_T)

Residuals:
     Min       1Q   Median       3Q      Max 
-1.90688 -0.41105 -0.02571  0.27788  1.66241 

Coefficients:
             Estimate Std. Error  t value Pr(>|t|)    
(Intercept) 22.455003   0.052298  429.363   <2e-16 ***
Frequency   -2.766122   0.007879 -351.075   <2e-16 ***
Voltage      0.028154   0.011278    2.496   0.0126 *  
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.6441 on 8523 degrees of freedom
Multiple R-squared:  0.9353,	Adjusted R-squared:  0.9353 
```

```
F-statistic: 6.163e+04 on 2 and 8523 DF,  p-value: < 2.2e-16

[1] 0
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Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_2)

Residuals:
   Min     1Q Median     3Q    Max 
 -9468  -5369    624   4848  18244 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)    
(Intercept) 32165.4031   120.3951   267.2   <2e-16 ***
Frequency     -38.2454     0.2112  -181.1   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 5516 on 8524 degrees of freedom
Multiple R-squared:  0.7937,  Adjusted R-squared:  0.7937 
F-statistic: 3.28e+04 on 1 and 8524 DF,  p-value: < 2.2e-16


Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_2)

Residuals:
   Min     1Q Median     3Q    Max 
-10557  -9343  -7097   9990  36664 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)    
(Intercept) 13096.228    270.014  48.502   <2e-16 ***
Voltage         0.918      1.572   0.584    0.559    
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
Residual standard error: 12140 on 8524 degrees of freedom
Multiple R-squared:  4e-05,	Adjusted R-squared:  -7.731e-05
F-statistic: 0.341 on 1 and 8524 DF,  p-value: 0.5593


Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_2)

Residuals:
    Min      1Q  Median      3Q     Max
-9425.5 -5365.2   597.8  4842.9 18115.3

Coefficients:
              Estimate Std. Error  t value Pr(>|t|)
(Intercept) 32027.7098   161.1315  198.768   <2e-16 ***
Frequency     -38.2454     0.2112 -181.118   <2e-16 ***
Voltage         0.9180     0.7140    1.286    0.199
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 5516 on 8523 degrees of freedom
Multiple R-squared:  0.7938,	Adjusted R-squared:  0.7937
F-statistic: 1.64e+04 on 2 and 8523 DF,  p-value: < 2.2e-16

�^� not meaningful for factors
Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_2_T)

Residuals:
     Min       1Q   Median       3Q      Max
-1.95162 -0.37199 -0.08659  0.27364  1.57353

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 21.172347   0.036254   584.0   <2e-16 ***
Frequency   -2.497906   0.007907  -315.9   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Residual standard error: 0.6464 on 8524 degrees of freedom
Multiple R-squared: 0.9213, Adjusted R-squared: 0.9213
F-statistic: 9.98e+04 on 1 and 8524 DF, p-value: < 2.2e-16

```
Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_2_T)

Residuals:
   Min     1Q Median     3Q    Max 
-2.684 -2.074 -1.090  2.411  5.007 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept)  9.87387    0.13757   71.78   <2e-16 ***
Voltage      0.01816    0.04035    0.45    0.653    
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 2.304 on 8524 degrees of freedom
Multiple R-squared:  2.375e-05,	Adjusted R-squared:  -9.356e-05 
F-statistic: 0.2025 on 1 and 8524 DF,  p-value: 0.6527


Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_2_T)

Residuals:
     Min       1Q   Median       3Q      Max 
-1.92303 -0.36812 -0.08512  0.27138  1.60211 

Coefficients:
             Estimate Std. Error  t value Pr(>|t|)    
(Intercept) 21.111472   0.052479  402.284   <2e-16 ***
Frequency   -2.497906   0.007906 -315.942   <2e-16 ***
Voltage      0.018156   0.011317    1.604    0.109    
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Residual standard error: 0.6463 on 8523 degrees of freedom
Multiple R-squared: 0.9213, Adjusted R-squared: 0.9213
F-statistic: 4.991e+04 on 2 and 8523 DF, p-value: < 2.2e-16

R Console

Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_2)

Residuals:
```
   Min     1Q Median     3Q    Max 
 -9468  -5369    624   4848  18244 
```

Coefficients:
```
              Estimate Std. Error t value Pr(>|t|)    
(Intercept) 32165.4031   120.3951   267.2   <2e-16 ***
Frequency     -38.2454     0.2112  -181.1   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Residual standard error: 5516 on 8524 degrees of freedom
Multiple R-squared: 0.7937, Adjusted R-squared: 0.7937
F-statistic: 3.28e+04 on 1 and 8524 DF, p-value: < 2.2e-16

Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_2)

Residuals:
```
   Min     1Q Median     3Q    Max 
-10557  -9343  -7097   9990  36664 
```

Coefficients:

```
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 13096.228    270.014  48.502   <2e-16 ***
Voltage         0.918      1.572   0.584    0.559
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 12140 on 8524 degrees of freedom
Multiple R-squared:  4e-05,    Adjusted R-squared:  -7.731e-05
F-statistic: 0.341 on 1 and 8524 DF,  p-value: 0.5593


Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_2)

Residuals:
    Min      1Q  Median      3Q     Max
-9425.5 -5365.2   597.8  4842.9 18115.3

Coefficients:
              Estimate Std. Error  t value Pr(>|t|)
(Intercept) 32027.7098   161.1315  198.768   <2e-16 ***
Frequency     -38.2454     0.2112 -181.118   <2e-16 ***
Voltage         0.9180     0.7140    1.286    0.199
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 5516 on 8523 degrees of freedom
Multiple R-squared:  0.7938,  Adjusted R-squared:  0.7937
F-statistic: 1.64e+04 on 2 and 8523 DF,  p-value: < 2.2e-16

�^� not meaningful for factors
Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_2_T)

Residuals:
     Min       1Q   Median       3Q      Max
-1.95162 -0.37199 -0.08659  0.27364  1.57353

Coefficients:
```

```
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 21.172347   0.036254   584.0   <2e-16 ***
Frequency   -2.497906   0.007907  -315.9   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.6464 on 8524 degrees of freedom
Multiple R-squared:  0.9213,  Adjusted R-squared:  0.9213
F-statistic: 9.98e+04 on 1 and 8524 DF,  p-value: < 2.2e-16
```

```
Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_2_T)

Residuals:
   Min     1Q Median     3Q    Max
-2.684 -2.074 -1.090  2.411  5.007

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  9.87387    0.13757   71.78   <2e-16 ***
Voltage      0.01816    0.04035    0.45    0.653
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 2.304 on 8524 degrees of freedom
Multiple R-squared:  2.375e-05,        Adjusted R-squared:  -9.356e-05
F-statistic: 0.2025 on 1 and 8524 DF,  p-value: 0.6527
```

```
Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_2_T)

Residuals:
     Min       1Q   Median       3Q      Max
-1.92303 -0.36812 -0.08512  0.27138  1.60211

Coefficients:
            Estimate Std. Error  t value Pr(>|t|)
```

```
(Intercept) 21.111472   0.052479  402.284   <2e-16 ***
Frequency   -2.497906   0.007906 -315.942   <2e-16 ***
Voltage      0.018156   0.011317    1.604    0.109
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.6463 on 8523 degrees of freedom
Multiple R-squared:  0.9213,  Adjusted R-squared:  0.9213
F-statistic: 4.991e+04 on 2 and 8523 DF,  p-value: < 2.2e-16
```

Show in New WindowClear OutputExpand/Collapse Output

```
Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_3)

Residuals:
    Min      1Q  Median      3Q     Max
-8757.1 -4953.4   598.8  4279.1 19564.4

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) 30584.0181   113.1904   270.2   <2e-16 ***
Frequency     -36.1035     0.1985  -181.9   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 5186 on 8524 degrees of freedom
Multiple R-squared:  0.7951,  Adjusted R-squared:  0.795
F-statistic: 3.307e+04 on 1 and 8524 DF,  p-value: < 2.2e-16


Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_3)

Residuals:
   Min     1Q Median     3Q    Max
-10045  -8854  -6642   9426  37108
```

```
Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 12837.4844   254.6791  50.407   <2e-16 ***
Voltage       -0.8314     1.4828  -0.561    0.575
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 11460 on 8524 degrees of freedom
Multiple R-squared:  3.688e-05,	Adjusted R-squared:  -8.043e-05
F-statistic: 0.3144 on 1 and 8524 DF,  p-value: 0.575


Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_3)

Residuals:
   Min      1Q  Median      3Q     Max
-8746.5 -4976.0   568.7  4296.2 19597.7

Coefficients:
            Estimate Std. Error  t value Pr(>|t|)
(Intercept) 30708.7274   151.4901  202.711   <2e-16 ***
Frequency     -36.1035     0.1985 -181.856   <2e-16 ***
Voltage       -0.8314     0.6713   -1.239    0.216
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 5186 on 8523 degrees of freedom
Multiple R-squared:  0.7951,  Adjusted R-squared:  0.7951
F-statistic: 1.654e+04 on 2 and 8523 DF,  p-value: < 2.2e-16

�^� not meaningful for factors
Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_3_T)

Residuals:
    Min       1Q   Median       3Q      Max
-1.81798 -0.34710 -0.07988  0.27062  1.44927
```

```
Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 20.783885   0.033795   615.0   <2e-16 ***
Frequency   -2.425887   0.007371  -329.1   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.6025 on 8524 degrees of freedom
Multiple R-squared:  0.9271,  Adjusted R-squared:  0.927
F-statistic: 1.083e+05 on 1 and 8524 DF,  p-value: < 2.2e-16


Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_3_T)

Residuals:
   Min     1Q Median     3Q    Max
-2.639 -2.019 -1.047  2.329  5.075

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  9.93986    0.13319  74.632   <2e-16 ***
Voltage     -0.02075    0.03906  -0.531    0.595
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 2.231 on 8524 degrees of freedom
Multiple R-squared:  3.311e-05,	Adjusted R-squared:  -8.42e-05
F-statistic: 0.2822 on 1 and 8524 DF,  p-value: 0.5953


Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_3_T)

Residuals:
     Min       1Q   Median       3Q      Max
-1.85066 -0.34745 -0.08228  0.27186  1.44079

Coefficients:
```

```
            Estimate Std. Error  t value Pr(>|t|)
(Intercept) 20.853467   0.048915  426.321   <2e-16 ***
Frequency   -2.425887   0.007369 -329.189   <2e-16 ***
Voltage     -0.020753   0.010549   -1.967   0.0492 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.6024 on 8523 degrees of freedom
Multiple R-squared:  0.9271,  Adjusted R-squared:  0.9271
F-statistic: 5.418e+04 on 2 and 8523 DF,  p-value: < 2.2e-16
```

R Console

```
Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_3)

Residuals:
    Min      1Q  Median      3Q     Max
-8757.1 -4953.4   598.8  4279.1 19564.4

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 30584.0181   113.1904   270.2   <2e-16 ***
Frequency     -36.1035     0.1985  -181.9   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 5186 on 8524 degrees of freedom
Multiple R-squared:  0.7951,  Adjusted R-squared:  0.795
F-statistic: 3.307e+04 on 1 and 8524 DF,  p-value: < 2.2e-16


Call:
```

```
lm(formula = Impedance ~ Voltage, data = Project_Well_3)

Residuals:
   Min     1Q Median     3Q    Max 
-10045  -8854  -6642   9426  37108 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)    
(Intercept) 12837.4844   254.6791  50.407   <2e-16 ***
Voltage       -0.8314     1.4828  -0.561    0.575    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 11460 on 8524 degrees of freedom
Multiple R-squared:  3.688e-05,	Adjusted R-squared:  -8.043e-05 
F-statistic: 0.3144 on 1 and 8524 DF,  p-value: 0.575


Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_3)

Residuals:
    Min      1Q  Median      3Q     Max 
-8746.5 -4976.0   568.7  4296.2 19597.7 

Coefficients:
             Estimate Std. Error  t value Pr(>|t|)    
(Intercept) 30708.7274   151.4901  202.711   <2e-16 ***
Frequency     -36.1035     0.1985 -181.856   <2e-16 ***
Voltage       -0.8314     0.6713   -1.239    0.216    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 5186 on 8523 degrees of freedom
Multiple R-squared:  0.7951,  Adjusted R-squared:  0.7951 
F-statistic: 1.654e+04 on 2 and 8523 DF,  p-value: < 2.2e-16

�^� not meaningful for factors
Call:
```

```
lm(formula = Impedance ~ Frequency, data = Project_Well_3_T)

Residuals:
     Min       1Q   Median       3Q      Max 
-1.81798 -0.34710 -0.07988  0.27062  1.44927 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)    
(Intercept) 20.783885   0.033795   615.0   <2e-16 ***
Frequency   -2.425887   0.007371  -329.1   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.6025 on 8524 degrees of freedom
Multiple R-squared:  0.9271,  Adjusted R-squared:  0.927 
F-statistic: 1.083e+05 on 1 and 8524 DF,  p-value: < 2.2e-16


Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_3_T)

Residuals:
   Min     1Q Median     3Q    Max 
-2.639 -2.019 -1.047  2.329  5.075 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept)  9.93986    0.13319  74.632   <2e-16 ***
Voltage     -0.02075    0.03906  -0.531    0.595    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 2.231 on 8524 degrees of freedom
Multiple R-squared:  3.311e-05,	Adjusted R-squared:  -8.42e-05 
F-statistic: 0.2822 on 1 and 8524 DF,  p-value: 0.5953


Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_3_T)
```

```
Residuals:
    Min       1Q   Median       3Q      Max 
-1.85066 -0.34745 -0.08228  0.27186  1.44079 

Coefficients:
             Estimate Std. Error  t value Pr(>|t|)    
(Intercept) 20.853467   0.048915  426.321   <2e-16 ***
Frequency   -2.425887   0.007369 -329.189   <2e-16 ***
Voltage     -0.020753   0.010549   -1.967   0.0492 *  
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.6024 on 8523 degrees of freedom
Multiple R-squared:  0.9271,	Adjusted R-squared:  0.9271 
F-statistic: 5.418e+04 on 2 and 8523 DF,  p-value: < 2.2e-16
```

Show in New WindowClear OutputExpand/Collapse Output

```
Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_4)

Residuals:
   Min     1Q Median     3Q    Max 
-52206 -32936  -5697  27527 106573 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)    
(Intercept) 118931.588    816.825   145.6   <2e-16 ***
Frequency     -161.070      1.433  -112.4   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 37420 on 8524 degrees of freedom
Multiple R-squared:  0.5972,	Adjusted R-squared:  0.5972 
F-statistic: 1.264e+04 on 1 and 8524 DF,  p-value: < 2.2e-16
```

```
Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_4)

Residuals:
   Min     1Q Median     3Q    Max 
-43175 -35103 -29371   5424 178335 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept) 46537.323   1307.827  35.584  < 2e-16 ***
Voltage       -48.903      7.614  -6.422 1.41e-10 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 58820 on 8524 degrees of freedom
Multiple R-squared:  0.004816,	Adjusted R-squared:  0.004699 
F-statistic: 41.25 on 1 and 8524 DF,  p-value: 1.413e-10
```

```
Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_4)

Residuals:
   Min     1Q Median     3Q    Max 
-56160 -32610  -5910  28014 100216 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)    
(Intercept) 126267.066   1086.753  116.19   <2e-16 ***
Frequency     -161.070      1.424 -113.10   <2e-16 ***
Voltage        -48.903      4.815  -10.16   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 37200 on 8523 degrees of freedom
Multiple R-squared:  0.602,	Adjusted R-squared:  0.6019 
F-statistic:  6447 on 2 and 8523 DF,  p-value: < 2.2e-16
```

�^� not meaningful for factors

```
Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_4_T)

Residuals:
    Min      1Q  Median      3Q     Max 
-6.8744 -0.9526 -0.1038  0.7807  3.5817 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept) 33.25104    0.07879   422.0   <2e-16 ***
Frequency   -4.82596    0.01718  -280.8   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 1.405 on 8524 degrees of freedom
Multiple R-squared:  0.9025,  Adjusted R-squared:  0.9025 
F-statistic: 7.887e+04 on 1 and 8524 DF,  p-value: < 2.2e-16


Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_4_T)

Residuals:
   Min     1Q Median     3Q    Max 
-4.577 -3.437 -2.306  3.006  9.953 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept) 12.30371    0.26841  45.839  < 2e-16 ***
Voltage     -0.22778    0.07872  -2.893  0.00382 ** 
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 4.496 on 8524 degrees of freedom
Multiple R-squared:  0.0009811,	Adjusted R-squared:  0.0008639 
F-statistic: 8.371 on 1 and 8524 DF,  p-value: 0.003821


Call:
```

```
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_4_T)

Residuals:
    Min      1Q  Median      3Q     Max 
-6.7235 -0.9839 -0.0746  0.7761  3.4544 

Coefficients:
            Estimate Std. Error  t value Pr(>|t|)    
(Intercept) 34.01476    0.11350  299.702   <2e-16 ***
Frequency   -4.82596    0.01710 -282.242   <2e-16 ***
Voltage     -0.22778    0.02448   -9.306   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 1.398 on 8523 degrees of freedom
Multiple R-squared:  0.9034,  Adjusted R-squared:  0.9034 
F-statistic: 3.987e+04 on 2 and 8523 DF,  p-value: < 2.2e-16
```

R Console

```
Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_4)

Residuals:
   Min     1Q Median     3Q    Max 
-52206 -32936  -5697  27527 106573 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)    
(Intercept) 118931.588    816.825   145.6   <2e-16 ***
Frequency     -161.070      1.433  -112.4   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
Residual standard error: 37420 on 8524 degrees of freedom
Multiple R-squared:  0.5972,  Adjusted R-squared:  0.5972
F-statistic: 1.264e+04 on 1 and 8524 DF,  p-value: < 2.2e-16


Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_4)

Residuals:
   Min     1Q Median     3Q    Max
-43175 -35103 -29371   5424 178335

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 46537.323   1307.827  35.584  < 2e-16 ***
Voltage       -48.903      7.614  -6.422 1.41e-10 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 58820 on 8524 degrees of freedom
Multiple R-squared:  0.004816,          Adjusted R-squared:  0.004699
F-statistic: 41.25 on 1 and 8524 DF,  p-value: 1.413e-10


Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_4)

Residuals:
   Min     1Q Median     3Q    Max
-56160 -32610  -5910  28014 100216

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) 126267.066   1086.753  116.19   <2e-16 ***
Frequency     -161.070      1.424 -113.10   <2e-16 ***
Voltage        -48.903      4.815  -10.16   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
Residual standard error: 37200 on 8523 degrees of freedom
Multiple R-squared:  0.602,	Adjusted R-squared:  0.6019
F-statistic:  6447 on 2 and 8523 DF,  p-value: < 2.2e-16

�^� not meaningful for factors
Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_4_T)

Residuals:
    Min      1Q  Median      3Q     Max
-6.8744 -0.9526 -0.1038  0.7807  3.5817

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 33.25104    0.07879   422.0   <2e-16 ***
Frequency   -4.82596    0.01718  -280.8   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 1.405 on 8524 degrees of freedom
Multiple R-squared:  0.9025,  Adjusted R-squared:  0.9025
F-statistic: 7.887e+04 on 1 and 8524 DF,  p-value: < 2.2e-16


Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_4_T)

Residuals:
   Min     1Q Median     3Q    Max
-4.577 -3.437 -2.306  3.006  9.953

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 12.30371    0.26841  45.839  < 2e-16 ***
Voltage     -0.22778    0.07872  -2.893  0.00382 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
Residual standard error: 4.496 on 8524 degrees of freedom
Multiple R-squared:  0.0009811,	Adjusted R-squared:  0.0008639
F-statistic: 8.371 on 1 and 8524 DF,  p-value: 0.003821


Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_4_T)

Residuals:
    Min      1Q  Median      3Q     Max
-6.7235 -0.9839 -0.0746  0.7761  3.4544

Coefficients:
            Estimate Std. Error  t value Pr(>|t|)
(Intercept) 34.01476    0.11350  299.702   <2e-16 ***
Frequency   -4.82596    0.01710 -282.242   <2e-16 ***
Voltage     -0.22778    0.02448   -9.306   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 1.398 on 8523 degrees of freedom
Multiple R-squared:  0.9034,  Adjusted R-squared:  0.9034
F-statistic: 3.987e+04 on 2 and 8523 DF,  p-value: < 2.2e-16
```

Show in New WindowClear OutputExpand/Collapse Output

```
Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_5)

Residuals:
    Min      1Q  Median      3Q     Max
-115348  -76892  -17305   53228  402334

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 231363.12    2098.09  110.27   <2e-16 ***
Frequency     -326.23       3.68  -88.65   <2e-16 ***
---
```

```
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 96120 on 8524 degrees of freedom
Multiple R-squared:  0.4797,  Adjusted R-squared:  0.4796
F-statistic:  7859 on 1 and 8524 DF,  p-value: < 2.2e-16


Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_5)

Residuals:
   Min     1Q Median     3Q    Max
-81196 -67206 -56599 -22866 550385

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 54624.33    2956.70  18.475  < 2e-16 ***
Voltage       101.70      17.21   5.908  3.6e-09 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 133000 on 8524 degrees of freedom
Multiple R-squared:  0.004078,	Adjusted R-squared:  0.003961
F-statistic:  34.9 on 1 and 8524 DF,  p-value: 3.596e-09


Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_5)

Residuals:
    Min      1Q  Median      3Q     Max
-128441  -76774  -16519   52916  392164

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) 216107.566   2797.241  77.257  < 2e-16 ***
Frequency     -326.229      3.666 -88.993  < 2e-16 ***
Voltage        101.704     12.395   8.206 2.63e-16 ***
---
```

```
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 95750 on 8523 degrees of freedom
Multiple R-squared:  0.4838,  Adjusted R-squared:  0.4836
F-statistic:  3994 on 2 and 8523 DF,  p-value: < 2.2e-16

�^� not meaningful for factors
Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_5_T)

Residuals:
    Min      1Q  Median      3Q     Max
-6.7443 -1.4645  0.0097  1.3986  4.1822

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 40.74518    0.09058   449.8   <2e-16 ***
Frequency   -6.33157    0.01976  -320.5   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 1.615 on 8524 degrees of freedom
Multiple R-squared:  0.9234,  Adjusted R-squared:  0.9234
F-statistic: 1.027e+05 on 1 and 8524 DF,  p-value: < 2.2e-16


Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_5_T)

Residuals:
   Min     1Q Median     3Q    Max
-5.106 -4.014 -3.028  2.405 15.758

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  11.4040     0.3482  32.753   <2e-16 ***
Voltage       0.2555     0.1021   2.502   0.0124 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Residual standard error: 5.832 on 8524 degrees of freedom
Multiple R-squared: 0.0007337,	Adjusted R-squared: 0.0006165
F-statistic: 6.259 on 1 and 8524 DF, p-value: 0.01238

```
Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_5_T)

Residuals:
    Min      1Q  Median      3Q     Max
-6.3420 -1.4491  0.0235  1.3602  3.9845

Coefficients:
            Estimate Std. Error  t value Pr(>|t|)
(Intercept) 39.88857    0.13051  305.641   <2e-16 ***
Frequency   -6.33157    0.01966 -322.026   <2e-16 ***
Voltage      0.25548    0.02814    9.077   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1.607 on 8523 degrees of freedom
Multiple R-squared:  0.9241,  Adjusted R-squared:  0.9241
F-statistic: 5.189e+04 on 2 and 8523 DF,  p-value: < 2.2e-16
```

R Console

```
Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_5)

Residuals:
    Min      1Q  Median      3Q     Max
-115348  -76892  -17305   53228  402334
```

```
Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 231363.12    2098.09  110.27   <2e-16 ***
Frequency     -326.23       3.68  -88.65   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 96120 on 8524 degrees of freedom
Multiple R-squared:  0.4797,  Adjusted R-squared:  0.4796
F-statistic:  7859 on 1 and 8524 DF,  p-value: < 2.2e-16


Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_5)

Residuals:
   Min     1Q Median     3Q    Max
-81196 -67206 -56599 -22866 550385

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 54624.33    2956.70  18.475  < 2e-16 ***
Voltage       101.70      17.21   5.908  3.6e-09 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 133000 on 8524 degrees of freedom
Multiple R-squared:  0.004078,	Adjusted R-squared:  0.003961
F-statistic:  34.9 on 1 and 8524 DF,  p-value: 3.596e-09


Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_5)

Residuals:
    Min      1Q  Median      3Q     Max
-128441  -76774  -16519   52916  392164
```

```
Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 216107.566   2797.241  77.257  < 2e-16 ***
Frequency     -326.229      3.666 -88.993  < 2e-16 ***
Voltage        101.704     12.395   8.206 2.63e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 95750 on 8523 degrees of freedom
Multiple R-squared:  0.4838,	Adjusted R-squared:  0.4836 
F-statistic:  3994 on 2 and 8523 DF,  p-value: < 2.2e-16

�^� not meaningful for factors
Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_5_T)

Residuals:
    Min      1Q  Median      3Q     Max 
-6.7443 -1.4645  0.0097  1.3986  4.1822 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept) 40.74518    0.09058   449.8   <2e-16 ***
Frequency   -6.33157    0.01976  -320.5   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 1.615 on 8524 degrees of freedom
Multiple R-squared:  0.9234,	Adjusted R-squared:  0.9234 
F-statistic: 1.027e+05 on 1 and 8524 DF,  p-value: < 2.2e-16


Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_5_T)

Residuals:
   Min     1Q Median     3Q    Max 
-5.106 -4.014 -3.028  2.405 15.758 
```

```
Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  11.4040     0.3482  32.753   <2e-16 ***
Voltage       0.2555     0.1021   2.502   0.0124 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 5.832 on 8524 degrees of freedom
Multiple R-squared:  0.0007337,	Adjusted R-squared:  0.0006165
F-statistic: 6.259 on 1 and 8524 DF,  p-value: 0.01238


Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_5_T)

Residuals:
    Min      1Q  Median      3Q     Max
-6.3420 -1.4491  0.0235  1.3602  3.9845

Coefficients:
            Estimate Std. Error  t value Pr(>|t|)
(Intercept) 39.88857    0.13051  305.641   <2e-16 ***
Frequency   -6.33157    0.01966 -322.026   <2e-16 ***
Voltage      0.25548    0.02814    9.077   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1.607 on 8523 degrees of freedom
Multiple R-squared:  0.9241,  Adjusted R-squared:  0.9241
F-statistic: 5.189e+04 on 2 and 8523 DF,  p-value: < 2.2e-16
Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_6)

Residuals:
   Min     1Q Median     3Q    Max
-12855  -7699    -27   6303  39892

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
```

```
(Intercept) 40052.2652   183.2810   218.5   <2e-16 ***
Frequency     -49.4770     0.3215  -153.9   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 8397 on 8524 degrees of freedom
Multiple R-squared:  0.7354,  Adjusted R-squared:  0.7353
F-statistic: 2.369e+04 on 1 and 8524 DF,  p-value: < 2.2e-16


Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_6)

Residuals:
   Min     1Q Median     3Q    Max
-12807 -11670  -9294   9517  63843

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 15637.3725   362.9113   43.09   <2e-16 ***
Voltage       -0.5081     2.1130   -0.24     0.81
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 16320 on 8524 degrees of freedom
Multiple R-squared:  6.784e-06,	Adjusted R-squared:  -0.0001105
F-statistic: 0.05783 on 1 and 8524 DF,  p-value: 0.81


Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_6)

Residuals:
   Min     1Q Median     3Q    Max
-12896  -7707    -44   6297  39847

Coefficients:
            Estimate Std. Error  t value Pr(>|t|)
(Intercept) 40128.4831   245.3159  163.579   <2e-16 ***
```

```
Frequency     -49.4770     0.3215 -153.901   <2e-16 ***
Voltage       -0.5081     1.0870   -0.467     0.64
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 8397 on 8523 degrees of freedom
Multiple R-squared:  0.7354,  Adjusted R-squared:  0.7353
F-statistic: 1.184e+04 on 2 and 8523 DF,  p-value: < 2.2e-16

�^� not meaningful for factors
Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_6_T)

Residuals:
     Min       1Q   Median       3Q      Max
-1.57876 -0.42173 -0.00517  0.29474  1.46620

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 23.084268   0.033804   682.9   <2e-16 ***
Frequency   -2.871013   0.007373  -389.4   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.6027 on 8524 degrees of freedom
Multiple R-squared:  0.9468,  Adjusted R-squared:  0.9468
F-statistic: 1.516e+05 on 1 and 8524 DF,  p-value: < 2.2e-16


Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_6_T)

Residuals:
   Min     1Q Median     3Q    Max
-2.893 -2.290 -1.269  2.417  6.615

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 10.20211    0.15597  65.409   <2e-16 ***
```

```
Voltage     -0.01013    0.04575  -0.222    0.825
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 2.613 on 8524 degrees of freedom
Multiple R-squared:  5.758e-06,	Adjusted R-squared:  -0.0001116
F-statistic: 0.04908 on 1 and 8524 DF,  p-value: 0.8247


Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_6_T)

Residuals:
     Min       1Q   Median       3Q      Max
-1.59472 -0.41986 -0.00611  0.29350  1.46231

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 23.118249   0.048938  472.40   <2e-16 ***
Frequency   -2.871013   0.007373 -389.41   <2e-16 ***
Voltage     -0.010135   0.010554   -0.96    0.337
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.6027 on 8523 degrees of freedom
Multiple R-squared:  0.9468,  Adjusted R-squared:  0.9468
F-statistic: 7.582e+04 on 2 and 8523 DF,  p-value: < 2.2e-16


Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_7)

Residuals:
   Min     1Q Median     3Q    Max
-13262  -7872     24   6083  47798

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 40878.7956   198.1226   206.3   <2e-16 ***
```

```
Frequency     -50.7494     0.3475  -146.0   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 9077 on 8524 degrees of freedom
Multiple R-squared:  0.7145,  Adjusted R-squared:  0.7144
F-statistic: 2.133e+04 on 1 and 8524 DF,  p-value: < 2.2e-16


Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_7)

Residuals:
   Min     1Q Median     3Q    Max
-13023 -11865  -9486   9064  72355

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 15842.1986   377.6545  41.949   <2e-16 ***
Voltage       -0.5623     2.1988  -0.256    0.798
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 16990 on 8524 degrees of freedom
Multiple R-squared:  7.671e-06,	Adjusted R-squared:  -0.0001096
F-statistic: 0.06539 on 1 and 8524 DF,  p-value: 0.7982


Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_7)

Residuals:
   Min     1Q Median     3Q    Max
-13286  -7867     34   6072  47741

Coefficients:
            Estimate Std. Error  t value Pr(>|t|)
(Intercept) 40963.1339   265.1808  154.472   <2e-16 ***
Frequency     -50.7494     0.3475 -146.033   <2e-16 ***
```

```
Voltage       -0.5623     1.1750   -0.479    0.632
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 9077 on 8523 degrees of freedom
Multiple R-squared:  0.7145,  Adjusted R-squared:  0.7144
F-statistic: 1.066e+04 on 2 and 8523 DF,  p-value: < 2.2e-16

�^� not meaningful for factors
Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_7_T)

Residuals:
     Min       1Q   Median       3Q      Max
-1.42954 -0.42937  0.01241  0.31141  1.41151

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 23.278343   0.032246   721.9   <2e-16 ***
Frequency   -2.912202   0.007033  -414.1   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.5749 on 8524 degrees of freedom
Multiple R-squared:  0.9526,  Adjusted R-squared:  0.9526
F-statistic: 1.715e+05 on 1 and 8524 DF,  p-value: < 2.2e-16


Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_7_T)

Residuals:
   Min     1Q Median     3Q    Max
-2.909 -2.294 -1.283  2.373  7.052

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 10.208698   0.157725  64.725   <2e-16 ***
Voltage     -0.009484   0.046260  -0.205    0.838
```

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 2.642 on 8524 degrees of freedom
Multiple R-squared: 4.93e-06,	Adjusted R-squared: -0.0001124
F-statistic: 0.04203 on 1 and 8524 DF, p-value: 0.8376

Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_7_T)

Residuals:
```
    Min      1Q   Median      3Q      Max
-1.44448 -0.42790  0.01247  0.31051  1.39976
```

Coefficients:
```
             Estimate Std. Error  t value Pr(>|t|)
(Intercept) 23.310141   0.046682  499.341   <2e-16 ***
Frequency   -2.912202   0.007033 -414.086   <2e-16 ***
Voltage     -0.009484   0.010067   -0.942    0.346
```

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.5749 on 8523 degrees of freedom
Multiple R-squared: 0.9526, Adjusted R-squared: 0.9526
F-statistic: 8.573e+04 on 2 and 8523 DF, p-value: < 2.2e-16

Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_8)

Residuals:
```
   Min     1Q Median     3Q    Max
-12522  -7498      5   5757  45202
```

Coefficients:
```
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 39381.5025   186.4735   211.2   <2e-16 ***
Frequency     -48.6033     0.3271  -148.6   <2e-16 ***
```

```
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 8543 on 8524 degrees of freedom
Multiple R-squared:  0.7215,  Adjusted R-squared:  0.7215
F-statistic: 2.208e+04 on 1 and 8524 DF,  p-value: < 2.2e-16


Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_8)

Residuals:
   Min     1Q Median     3Q    Max
-12761 -11249  -8956   8985  68585

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 15580.737    359.902   43.29   <2e-16 ***
Voltage       -1.719      2.095   -0.82    0.412
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 16190 on 8524 degrees of freedom
Multiple R-squared:  7.894e-05,	Adjusted R-squared:  -3.836e-05
F-statistic: 0.673 on 1 and 8524 DF,  p-value: 0.412


Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_8)

Residuals:
   Min     1Q Median     3Q    Max
-12763  -7580      0   5784  45013

Coefficients:
            Estimate Std. Error  t value Pr(>|t|)
(Intercept) 39639.351    249.557  158.839   <2e-16 ***
Frequency     -48.603      0.327 -148.614   <2e-16 ***
Voltage        -1.719      1.106   -1.555     0.12
---
```

```
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 8543 on 8523 degrees of freedom
Multiple R-squared:  0.7216,  Adjusted R-squared:  0.7215
F-statistic: 1.104e+04 on 2 and 8523 DF,  p-value: < 2.2e-16

�^� not meaningful for factors
Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_8_T)

Residuals:
     Min       1Q   Median       3Q      Max
-1.38257 -0.40144  0.00351  0.29170  1.41145

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 22.944122   0.031461   729.3   <2e-16 ***
Frequency   -2.845774   0.006862  -414.7   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.5609 on 8524 degrees of freedom
Multiple R-squared:  0.9528,  Adjusted R-squared:  0.9528
F-statistic: 1.72e+05 on 1 and 8524 DF,  p-value: < 2.2e-16


Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_8_T)

Residuals:
   Min     1Q Median     3Q    Max
-2.889 -2.259 -1.241  2.350  6.875

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 10.19192    0.15412  66.132   <2e-16 ***
Voltage     -0.01503    0.04520  -0.333    0.739
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
Residual standard error: 2.581 on 8524 degrees of freedom
Multiple R-squared:  1.297e-05,	Adjusted R-squared:  -0.0001043
F-statistic: 0.1106 on 1 and 8524 DF,  p-value: 0.7395


Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_8_T)

Residuals:
    Min      1Q  Median      3Q     Max
-1.4062 -0.3972  0.0022  0.2857  1.3928

Coefficients:
             Estimate Std. Error  t value Pr(>|t|)
(Intercept) 22.994522   0.045542  504.912   <2e-16 ***
Frequency   -2.845774   0.006861 -414.771   <2e-16 ***
Voltage     -0.015032   0.009821   -1.531    0.126
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.5609 on 8523 degrees of freedom
Multiple R-squared:  0.9528,  Adjusted R-squared:  0.9528
F-statistic: 8.602e+04 on 2 and 8523 DF,  p-value: < 2.2e-16

Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_9)

Residuals:
   Min     1Q Median     3Q    Max
-12368  -7343    -16   5479  44172

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) 39594.9576   182.8297   216.6   <2e-16 ***
Frequency     -48.8801     0.3207  -152.4   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
Residual standard error: 8376 on 8524 degrees of freedom
Multiple R-squared:  0.7316,  Adjusted R-squared:  0.7316
F-statistic: 2.323e+04 on 1 and 8524 DF,  p-value: < 2.2e-16


Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_9)

Residuals:
   Min     1Q Median     3Q    Max
-12844 -11594  -8992   9452  67944

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 1.530e+04  3.595e+02  42.571   <2e-16 ***
Voltage     6.446e-01  2.093e+00   0.308    0.758
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 16170 on 8524 degrees of freedom
Multiple R-squared:  1.113e-05,	Adjusted R-squared:  -0.0001062
F-statistic: 0.09488 on 1 and 8524 DF,  p-value: 0.7581


Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_9)

Residuals:
   Min     1Q Median     3Q    Max
-12309  -7323      5   5489  44237

Coefficients:
             Estimate Std. Error  t value Pr(>|t|)
(Intercept) 39498.2616   244.7098  161.409   <2e-16 ***
Frequency     -48.8801     0.3207 -152.421   <2e-16 ***
Voltage         0.6446     1.0843    0.595    0.552
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
Residual standard error: 8377 on 8523 degrees of freedom
Multiple R-squared:  0.7316,  Adjusted R-squared:  0.7315
F-statistic: 1.162e+04 on 2 and 8523 DF,  p-value: < 2.2e-16

�^� not meaningful for factors
Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_9_T)

Residuals:
     Min       1Q   Median       3Q      Max
-1.45880 -0.36816 -0.03685  0.25838  1.54425

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 23.052672   0.031658   728.2   <2e-16 ***
Frequency   -2.868608   0.006905  -415.5   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.5644 on 8524 degrees of freedom
Multiple R-squared:  0.9529,  Adjusted R-squared:  0.9529
F-statistic: 1.726e+05 on 1 and 8524 DF,  p-value: < 2.2e-16


Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_9_T)

Residuals:
   Min     1Q Median     3Q    Max
-2.986 -2.321 -1.205  2.409  6.849

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 10.10383    0.15534  65.044   <2e-16 ***
Voltage      0.01298    0.04556   0.285    0.776
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 2.602 on 8524 degrees of freedom
```

```
Multiple R-squared:  9.52e-06,	Adjusted R-squared:  -0.0001078
F-statistic: 0.08115 on 1 and 8524 DF,  p-value: 0.7758


Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_9_T)

Residuals:
     Min       1Q   Median       3Q      Max 
-1.44273 -0.36853 -0.03248  0.25468  1.56469 

Coefficients:
             Estimate Std. Error  t value Pr(>|t|)    
(Intercept) 23.009156   0.045828  502.074   <2e-16 ***
Frequency   -2.868608   0.006904 -415.484   <2e-16 ***
Voltage      0.012978   0.009883    1.313    0.189    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.5644 on 8523 degrees of freedom
Multiple R-squared:  0.953,	Adjusted R-squared:  0.9529 
F-statistic: 8.631e+04 on 2 and 8523 DF,  p-value: < 2.2e-16



Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_10)

Residuals:
   Min     1Q Median     3Q    Max 
-42910 -28750  -4150  23031 155418 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)    
(Intercept) 106891.732    729.406   146.5   <2e-16 ***
Frequency     -144.869      1.279  -113.2   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
Residual standard error: 33420 on 8524 degrees of freedom
Multiple R-squared:  0.6007,  Adjusted R-squared:  0.6006
F-statistic: 1.282e+04 on 1 and 8524 DF,  p-value: < 2.2e-16


Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_10)

Residuals:
   Min     1Q Median     3Q    Max
-33248 -30713 -27824   4488 225039

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 34362.305   1175.687  29.227   <2e-16 ***
Voltage         5.461      6.845   0.798    0.425
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 52880 on 8524 degrees of freedom
Multiple R-squared:  7.467e-05,	Adjusted R-squared:  -4.264e-05
F-statistic: 0.6365 on 1 and 8524 DF,  p-value: 0.425


Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_10)

Residuals:
   Min     1Q Median     3Q    Max
-43199 -28982  -4147  22852 154778

Coefficients:
             Estimate Std. Error  t value Pr(>|t|)
(Intercept) 106072.551    976.209  108.658   <2e-16 ***
Frequency     -144.869      1.279 -113.239   <2e-16 ***
Voltage          5.461      4.326    1.263    0.207
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Residual standard error: 33420 on 8523 degrees of freedom
Multiple R-squared: 0.6008, Adjusted R-squared: 0.6007
F-statistic: 6412 on 2 and 8523 DF, p-value: < 2.2e-16

�^� not meaningful for factors
Call:
lm(formula = Impedance ~ Frequency, data = Project_Well_10_T)

Residuals:
```
     Min       1Q   Median       3Q      Max 
-2.78384 -0.78343 -0.01138  0.75904  1.98451 
```

Coefficients:
```
            Estimate Std. Error t value Pr(>|t|)    
(Intercept) 32.49901    0.05233   621.1   <2e-16 ***
Frequency   -4.69751    0.01141  -411.6   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Residual standard error: 0.9329 on 8524 degrees of freedom
Multiple R-squared: 0.9521, Adjusted R-squared: 0.9521
F-statistic: 1.694e+05 on 1 and 8524 DF, p-value: < 2.2e-16

Call:
lm(formula = Impedance ~ Voltage, data = Project_Well_10_T)

Residuals:
```
   Min     1Q Median     3Q    Max 
-4.184 -3.427 -2.148  2.724 11.212 
```

Coefficients:
```
            Estimate Std. Error t value Pr(>|t|)    
(Intercept) 11.25862    0.25449  44.240   <2e-16 ***
Voltage      0.03196    0.07464   0.428    0.669    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Residual standard error: 4.263 on 8524 degrees of freedom

```
Multiple R-squared:  2.151e-05,	Adjusted R-squared:  -9.58e-05
F-statistic: 0.1834 on 1 and 8524 DF,  p-value: 0.6685


Call:
lm(formula = Impedance ~ Frequency + Voltage, data = Project_Well_10_T)

Residuals:
     Min       1Q   Median       3Q      Max
-2.73351 -0.78169  0.02178  0.74735  1.97046

Coefficients:
            Estimate Std. Error  t value Pr(>|t|)
(Intercept) 32.39185    0.07574  427.686   <2e-16 ***
Frequency   -4.69751    0.01141 -411.694   <2e-16 ***
Voltage      0.03196    0.01633    1.957   0.0504 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.9328 on 8523 degrees of freedom
Multiple R-squared:  0.9521,  Adjusted R-squared:  0.9521
F-statistic: 8.475e+04 on 2 and 8523 DF,  p-value: < 2.2e-16
```